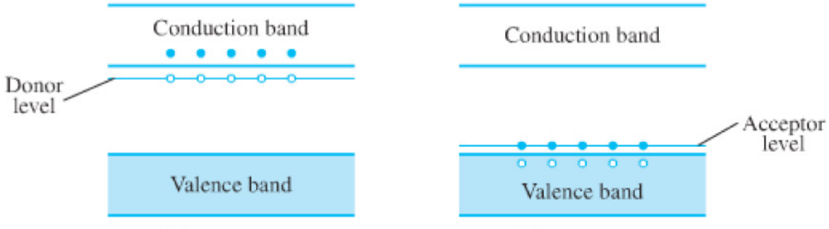
According to the band theory (Section 29–6), in a doped semiconductor the impurity provides additional energy states between the bands as shown in Fig. 29–26. In an n-type semiconductor, the impurity energy level lies just below the conduction band, Fig. 29–26a. Electrons in this energy level need only about 0.05 eV in Si (even less in Ge) to reach the conduction band; this is on the order of the thermal energy, $\frac{3}{2}kT$ (= 0.04 eV at 300 K), so transitions occur readily at room temperature. This energy level can thus supply electrons to the conduction band, so it is called a **donor** level. In p-type semiconductors, the impurity energy level is just above the valence band (Fig. 29–26b). It is called an **acceptor** level because electrons from the valence band can easily jump into it. Positive holes are left behind in the valence band, and as other electrons move into these holes, the holes move about as discussed earlier.



(a) n-type (b) p-type

FIGURE 29–26 Impurity energy levels in doped semiconductors.

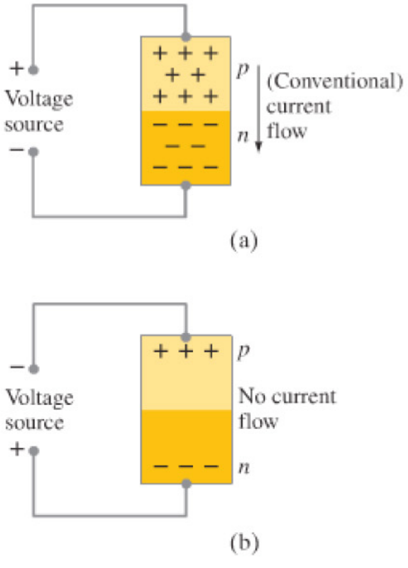
* 29–8 Semiconductor Diodes

Semiconductor diodes and transistors are essential components of modern electronic devices. The miniaturization achieved today allows many thousands of diodes, transistors, resistors, and so on, to be placed on a single *chip* less than a millimeter on a side. We now discuss, briefly and qualitatively, the operation of diodes and transistors.

pn *junction diode*

When an n-type semiconductor is joined to a p-type, a ***pn* junction diode** is formed. Separately, the two semiconductors are electrically neutral. When joined, a few electrons near the junction diffuse from the n-type into the p-type semiconductor, where they fill a few of the holes. The n-type is left with a positive charge, and the p-type acquires a net negative charge. Thus a potential difference is established, with the n side positive relative to the p side, and this prevents further diffusion of electrons.

FIGURE 29–27 Schematic diagram showing how a semiconductor diode operates. Current flows when the voltage is connected in forward bias, as in (a), but not when connected in reverse bias, as in (b).



If a battery is connected to a diode with the positive terminal to the p side and the negative terminal to the n side as in Fig. 29–27a, the externally applied voltage opposes the internal potential difference and the diode is said to be **forward biased**. If the voltage is great enough (about 0.3 V for Ge, 0.6 V for Si at room temperature), a current will flow. The positive holes in the p-type semiconductor are repelled by the positive terminal of the battery, and the electrons in the n-type are repelled by the negative terminal of the battery. The holes and electrons meet at the junction, and the electrons cross over and fill the holes. A current is flowing. Meanwhile, the positive terminal of the battery is continually pulling electrons off the p end, forming new holes, and electrons are being supplied by the negative terminal at the n end. Consequently, a large current flows through the diode.

When the diode is **reverse biased**, as in Fig. 29–27b, the holes in the p end are attracted to the battery's negative terminal and the electrons in the n end are attracted to the positive terminal. The current carriers do not meet near the junction and, ideally, no current flows.

A graph of current versus voltage for a typical diode is shown in Fig. 29–28. As can be seen, a real diode does allow a small amount of reverse current to flow.[†] For most practical purposes, this is negligible.

[†] At room temperature it is a few μA in Ge, and a few pA in Si. The reverse current increases rapidly with temperature, however, and may render a diode ineffective above 200°C.