SECTION 1–3 REVIEW

1. How are covalent bonds formed?
2. What is meant by the term *intrinsic*?
3. What is a crystal?
4. Effectively, how many valence electrons are there in each atom within a silicon crystal?

1–4 CONDUCTION IN SEMICONDUCTORS

The way a material conducts electrical current is important in understanding how electronic devices operate. You can't really understand the operation of a device such as a diode or transistor without knowing something about the basic current mechanisms. In this section, you will see how conduction occurs in semiconductive material.

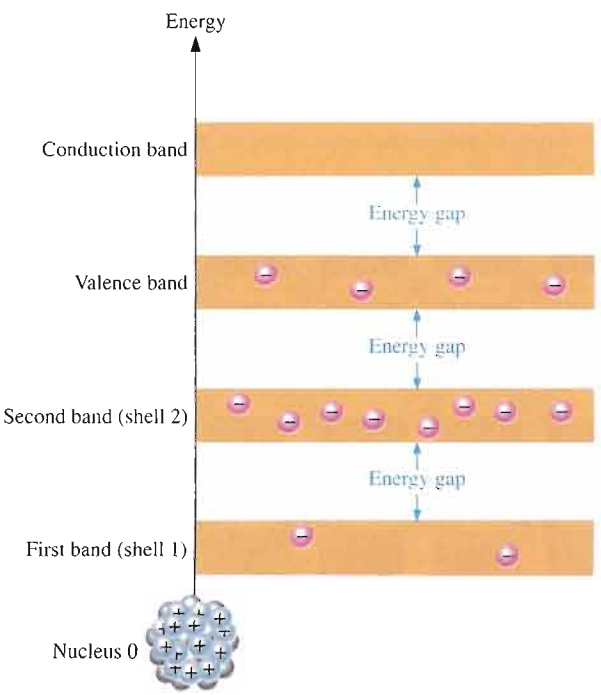
After completing this section, you should be able to

- **Describe how current is produced in a semiconductor**
- Describe a conduction electron
- Define *hole*
- Explain what an electron-hole pair is
- Discuss recombination
- Explain the difference between electron current and hole current

As you have learned, the electrons of an atom can exist only within prescribed energy bands. Each shell around the nucleus corresponds to a certain energy band and is separated from adjacent shells by energy gaps, in which no electrons can exist. Figure 1–10 shows the energy band diagram for an unexcited (no external energy such as heat) atom in a pure silicon crystal. This condition occurs *only* at a temperature of absolute 0 Kelvin.

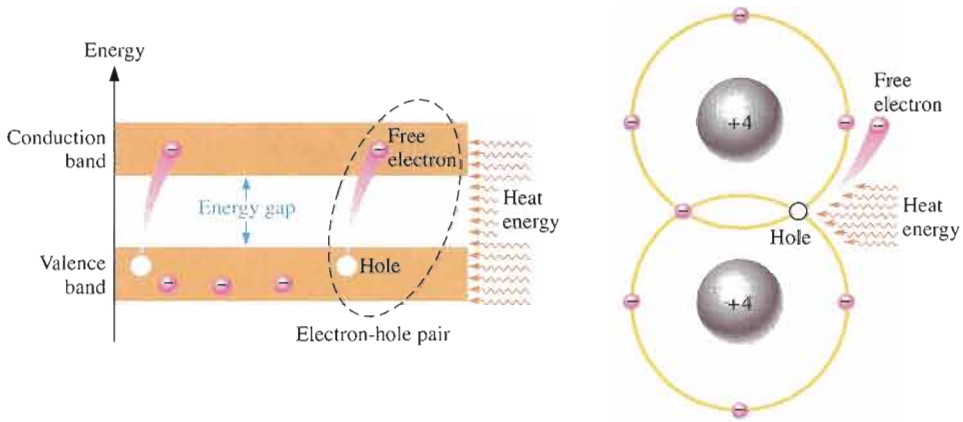
FIGURE 1–10

Energy band diagram for an unexcited atom in a pure (intrinsic) silicon crystal. There are no electrons in the conduction band.



Conduction Electrons and Holes

An intrinsic (pure) silicon crystal at room temperature has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electrons. Free electrons are also called **conduction electrons**. This is illustrated in the energy diagram of Figure 1–11(a) and in the bonding diagram of Figure 1–11(b).



(a) Energy diagram

(b) Bonding diagram

FIGURE 1–11

Creation of electron-hole pairs in a silicon crystal. Electrons in the conduction band are free electrons.

When an electron jumps to the conduction band, a vacancy is left in the valence band within the crystal. This vacancy is called a **hole**. For every electron raised to the conduction band by external energy, there is one hole left in the valence band, creating what is called an **electron-hole pair**. **Recombination** occurs when a conduction-band electron loses energy and falls back into a hole in the valence band.

To summarize, a piece of intrinsic silicon at room temperature has, at any instant, a number of conduction-band (free) electrons that are unattached to any atom and are essentially drifting randomly throughout the material. There is also an equal number of holes in the valence band created when these electrons jump into the conduction band. This is illustrated in Figure 1–12.

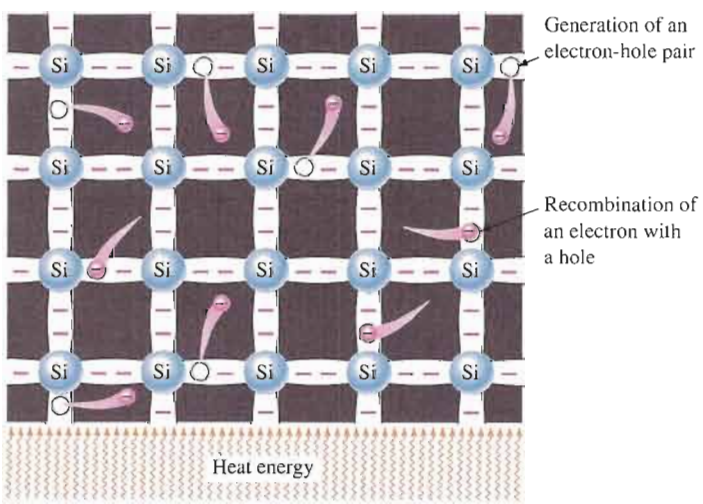


FIGURE 1–12

Electron-hole pairs in a silicon crystal. Free electrons are being generated continuously while some recombine with holes.

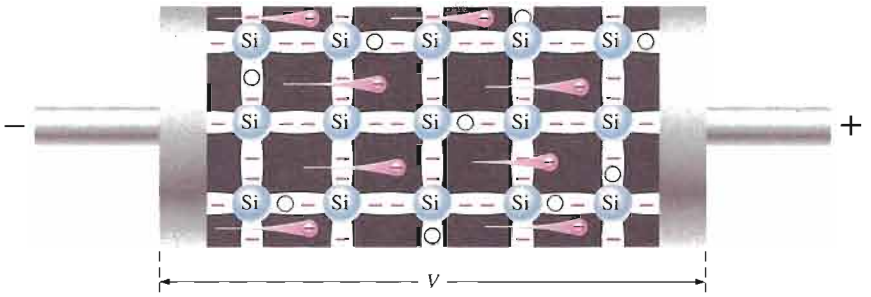
Electron and Hole Current

When a voltage is applied across a piece of intrinsic silicon, as shown in Figure 1–13, the thermally generated free electrons in the conduction band, which are free to move

randomly in the crystal structure, are now easily attracted toward the positive end. This movement of free electrons is one type of current in a semiconductive material and is called *electron current*.

FIGURE 1–13

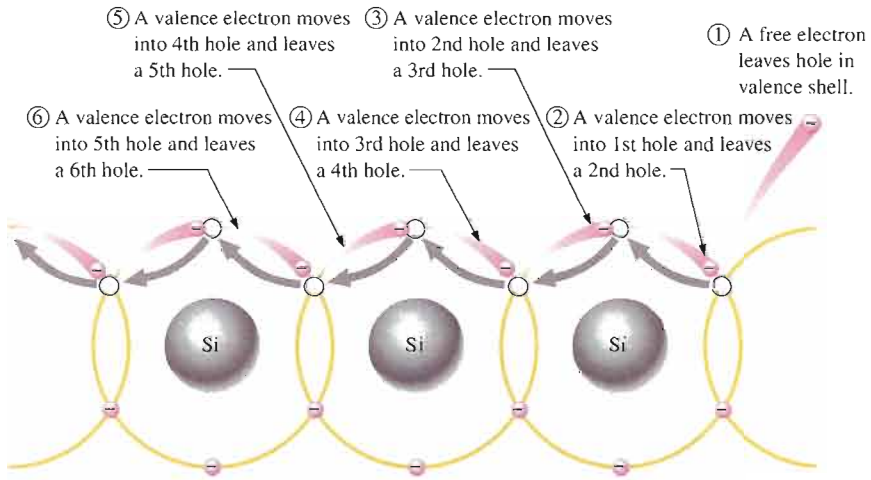
Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons.



Another type of current occurs in the valence band, where the holes created by the free electrons exist. Electrons remaining in the valence band are still attached to their atoms and are not free to move randomly in the crystal structure as are the free electrons. However, a valence electron can move into a nearby hole with little change in its energy level, thus leaving another hole where it came from. Effectively the hole has moved from one place to another in the crystal structure, as illustrated in Figure 1–14. This is called *hole current*.

FIGURE 1–14

Hole current in intrinsic silicon.



When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.

SECTION 1–4 REVIEW

1. Are free electrons in the valence band or in the conduction band?
2. Which electrons are responsible for current in a material?
3. What is a hole?
4. At what energy level does hole current occur?