When more atoms are brought close together, each energy level splits into more levels. If there are many atoms, the energy level splits so many times and the new energy levels are so closely spaced that they may be regarded as a continuous band of energies, as in **Figure 1(c).** The highest band containing occupied energy levels is called the *valence band,* as shown in **Figure 2.** The band immediately above the valence band is called the *conduction band.*

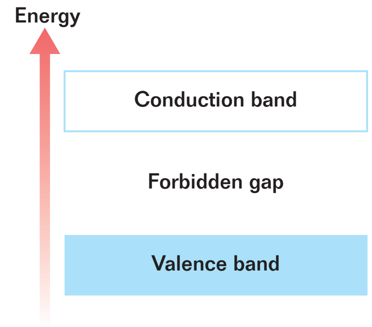

Figure 2
Energy levels of atoms become energy bands in solids. The valence band is the highest occupied band.

Electron-hole pairs and intrinsic semiconductors

Imagine that a few electrons are excited from the valence band to the conduction band by an electric field, as in **Figure 3.** The electrons in the conduction band are free to move through the material. Normally, electrons in the valence band are unable to move because all nearby energy levels are occupied. But when an electron moves from the valence band into the conduction band, it leaves a vacancy, or **hole,** in an otherwise filled valence band. The hole is positively charged because it results from the removal of an electron from a neutral atom. Whenever another valence electron from this or a nearby atom moves into the hole, a new hole is created at its former location. So, the net effect can be viewed as a positive hole migrating through the material in a direction opposite the motion of the electrons in the conduction band.

In a material containing only one element or compound, there are an equal number of conduction electrons and holes. Such combinations of charges are called *electron-hole pairs,* and a semiconductor that contains such pairs is called an *intrinsic semiconductor.* In the presence of an electric field, the holes move in the direction of the field and the conduction electrons move opposite the field.

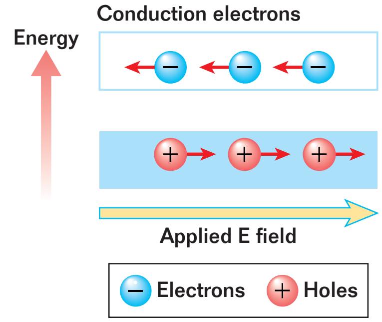

Figure 3
An electric field can excite valence electrons into the conduction band, where they are free to move through the material. Holes in the valence band can then move in the opposite direction.

Adding impurities to enhance conduction

One way to change the concentration of charge carriers is to add *impurities,* atoms that are different from those of an intrinsic semiconductor. This process is called **doping.** Even a few added impurity atoms (about one part in a million) can have a large effect on a semiconductor's resistance. The semiconductor's conductivity increases as the doping level increases. When impurities dominate conduction, the material is called an *extrinsic semiconductor.*

There are two methods for doping a semiconductor: either add impurities that have extra valence electrons or add impurities that have fewer valence electrons compared with the atoms in the intrinsic semiconductor.

Semiconductors used in commercial devices are usually doped silicon or germanium. These elements have four valence electrons. Semiconductors are doped by replacing an atom of silicon or germanium with one containing either three valence electrons or five valence electrons. Note that a doped semiconductor is electrically neutral because it is made of neutral atoms. The balance of positive and negative charges has not changed, but the number of charges that are free and able to move has. These charges are therefore able to participate in electrical conduction.

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