Superconductors and BCS Theory

The resistance of many solids (other than semiconductors) increases with increasing temperature. The reason is that at a nonzero temperature, the atoms in a solid are always vibrating, and the higher the temperature, the larger the amplitude of the vibrations. It is more difficult for electrons to move through the solid when the atoms are moving with large amplitudes. This situation is somewhat similar to walking through a crowded room. It is much harder to do so when the people are in motion than when they are standing still.

If the resistance depended only on atomic vibrations, we would expect the resistance of the material that is cooled to absolute zero to go gradually to zero. Experiments have shown, however, that this does not happen. In fact, the resistances of very cold solids behave in two very different ways—either the substance suddenly begins superconducting at temperatures above absolute zero or it never superconducts, no matter how cold it gets.

Resistance from lattice imperfections

The graph in **Figure 1** shows the temperature dependence of the resistance of two similar objects, one made of silver and the other made of tin. The temperature dependence of the resistance of the silver object is similar to that of a typical metal. At higher temperatures, the resistance decreases as the metal is cooled. This decrease in resistance suggests that the amplitude of the lattice vibrations is decreasing, as expected. But at a temperature of about 10 K, the curve levels off and the resistance becomes constant. Cooling the metal further does not appreciably lower the resistance, even though the vibrations of the metal's atoms have been lessened.

Part of the cause of this nonzero resistance, even at absolute zero, is *lattice imperfection*. The regular, geometric pattern of the crystal, or lattice, in a solid is often flawed. A lattice imperfection occurs when some of the atoms do not line up perfectly.

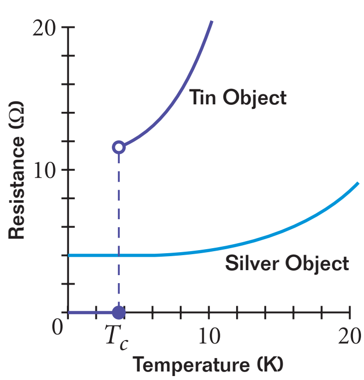

Figure 1
The resistance of silver exhibits the behavior of a normal metal. The resistance of tin goes to zero at temperature T_c, the temperature at which tin becomes a superconductor.

Imagine you are walking through a crowded room in which the people are standing in perfect rows. It would be easy to walk through the room between two rows. Now imagine that occasionally one person stands in the middle of the aisle instead of in the row, making it harder for you to pass. This is similar to the effect of a lattice imperfection. Even in the absence of thermal vibrations, many materials exhibit a *residual resistance* due to the imperfect geometric arrangement of their atoms.

Figure 1 shows that the resistance of tin jumps to zero below a certain temperature that is well above absolute zero. A solid whose resistance is zero below a certain nonzero temperature is called a **superconductor.** The temperature at which the resistance goes to zero is the critical temperature of the superconductor, as described in the chapter "Electrical Energy and Current."