BCS theory

Before the discovery of superconductivity, it was thought that all materials should have some nonzero resistance due to lattice vibrations and lattice imperfections, much like the behavior of the silver in **Figure 1.**

The first complete microscopic theory of superconductivity was not developed until 1957. This theory is called *BCS theory* after the three scientists who first developed it: John Bardeen, Leon Cooper, and Robert Schrieffer. The crucial breakthrough of BCS theory is a new understanding of the special way that electrons traveling in pairs move through the lattice of a superconductor. According to BCS theory, electrons do suffer collisions in a superconductor, just as they do in any other material. However, the collisions do not alter the total momentum of a pair of electrons. The net effect is as if the electrons moved unimpeded through the lattice.

Cooper pairs

Imagine an electron moving through a lattice, such as electron 1 in **Figure 2.** There is an attractive force between the electron and the nearby positively charged atoms in the lattice. As the electron passes by, the attractive force causes the lattice atoms to be pulled toward the electron. The result is a concentration of positive charge near the electron. If a second electron is nearby, it can be attracted to this excess positive charge in the lattice before the lattice has had a chance to return to its equilibrium position.

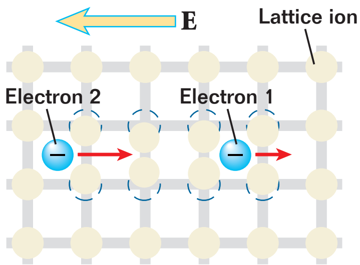

Figure 2
The first electron deforms the lattice, and the deformation affects the second electron. The net result is as if the two electrons were loosely bound together. Such a two-electron bound state is called a *Cooper pair.*

Through the process of deforming the lattice, the first electron gives up some of its momentum. The deformed region of the lattice attracts the second electron, transferring excess momentum to the second electron. The net effect of this two-step process is a weak, delayed attractive force between the two electrons, resulting from the motion of the lattice as it is deformed by the first electron. The two electrons travel through the lattice acting as if they were a single particle. This particle is called a *Cooper pair.* In BCS theory, Cooper pairs are responsible for superconductivity.

The reason superconductivity has been found at only low temperatures so far is that Cooper pairs are weakly bound. Random thermal motions in the lattice tend to destroy the bonds between Cooper pairs. Even at very low temperatures, Cooper pairs are constantly being formed, destroyed, and reformed in a superconducting material, usually with different pairings of electrons.

Calculations of the properties of a Cooper pair have shown that this peculiar bound state of two electrons has zero total momentum in the absence of an applied electric field. When an external electric field is applied, the Cooper pairs move through the lattice under the influence of the field. However, the center of mass for every Cooper pair has exactly the same momentum. This crucial feature of Cooper pairs explains superconductivity. If one electron scatters, the other electron in a pair also scatters in a way that keeps the total momentum constant. The net result is that scattering due to lattice imperfections and lattice vibrations has no net effect on Cooper pairs.