BCS standard theory of superconductivity collapses

One of the first victims of the new high-temperature superconductors has been the existing standard theory of superconductivity, which was known as BCS theory. This theory was developed by John Bardeen, Leon N. Cooper, and J. Robert Schrieffer—thus BCS—in 1957. It says that an electron moving through a crystal lattice, as in a metal, tends to transiently distort or "pucker" the "elastic" chemical bonds of the lattice slightly. This is due to the negatively charged electron attracting the positively charged ion nuclei of the lattice atoms.

A second passing electron will be attracted to the excess positive charge created by the higher density of ions in the "pucker" region. Thus, according to BCS, the first electron in effect "attracts" the second electron via the pucker.

This weak attraction is then said to bind the two electrons into a so-called "Cooper pair." And because electrons, like people, generally like to cohabitate in pairs with opposite spins, the Cooper pair of "free" electrons in the superconductor act in unison with matched and opposite spins and momenta like those stable pairs found in atomic orbits.

According to the BCS theory the transition from electricity conduction within the crystal lattice based on "single" free electrons to that based on Cooper pairs is quite dramatic. The general reason given for this dramatic change in electrical conductivity is that uncoupled, free electrons strongly resist increases in electron population density—that is, the single electrons resist compression to higher electric current densities. This is said to be the case because the electrons follow Fermion-like behavior. According to E. Fermi, single, free electrons have a fundamental "quantum" behavior which only allows one electron to populate any given quantum energy state. This is supposedly the source of the "single" free electron's resistance to condensation.

But when the electrons form Cooper pairs, the two coupled electrons act like a single particle with a totally different behavior than that of Fermions. In fact the Cooper pair acts like a photon—the quantum cell of electromagnetic radiation, light. Photons are theoretically capable of being relatively easily compressed to very high population densities. In this case the elementary particle—the photon or Cooper electron pair—are said to act as Bosons. And in theory, an infinite number of Bosons can populate a single quantum energy state as opposed to only one for the Fermion.

BCS describes this overall transition as the formation of Cooper pairs which can condense into a single macroscopic quantum state with long-range order throughout the lattice. But recent experiments with the new high-temperature superconductors prove that the BCS theory of "linear" sums of Cooper pairs is totally inadequate.

At first, the lanthanum-based copper oxide superconductors appeared to be following the BCS model at temperatures up to 50°K. But at 90°K the new superconductors exhibited behavior which was contrary to the BCS model and operates according to a supposedly unknown mechanism.

This problem came to a boil when two research groups announced that they had conducted an essential test of lattice puckering, one of the axiomatic characteristics of the BCS theory. The lattice puckering, which supposedly leads to the formation of the Cooper pair in the BCS theory, is really nothing more than lattice vibrations. And if the weight of the lattice atoms is changed, such as by utilizing a heavier chemical isotope (that is, the same chemical element with more neutrons in its nucleus), then the superconducting behavior, Tc for example, should significantly change.

At the April Materials Research Society meeting in Anaheim, California, the AT&T Bell Lab and the University of California, Berkeley groups announced that they had independently performed such an experiment with different oxygen isotopes. The experiment utilized two samples of the superconducting copper oxide ceramic which were identical except for the oxygen atoms. In one sample the more prevalent oxygen-16 isotope was utilized. In the other sample, the heavier oxygen-18, which has two more neutrons in its nucleus, but otherwise has the same chemical properties as oxygen-16, was used. The researchers cooled the samples and measured the temperature at which each one became superconductive.

According to the BCS theory, the superconducting transition temperature, Tc, depends on the frequency of the lattice vibrations. And it is well known that a lattice with heavier atoms will vibrate at a different frequency than one with lighter atoms. But the two experiments show quite convincingly that Tc does not change at all. Theorists are quite perplexed. The experiments indicate that the number and arrangement of the oxygens in the lattice is key to the superconducting behavior—that is, instead of the "elementary" quantum processes, such as Cooper pair formation, macroscopic lattice geometry and composition is primary.