Superconductors with electrons in charge

The discovery of a new family of ceramic superconductors that lose all resistance to the flow of electrical current at a lowly 24 kelvins (-416°F) seems a much less glamorous result than achieving a record-high superconducting transition temperature. Nevertheless, these new compounds, in which electrons carry the superconducting current, may provide important clues about how high-temperature superconductors work. In all previously known examples, "holes" (the absence of electrons) in the electronic structure of the material's crystal lattice are responsible for the superconducting current.

Discovered by Yoshi Tokura and his colleagues at the University of Tokyo, the new compounds contain copper, oxygen, the rare-earth element cerium and any one of three lanthanides: lanthanum, praseodymium or samarium. The researchers describe their compounds in the Jan. 26 NATURE.

All high-temperature superconductors made to date contain layers of copper and oxygen atoms. Normally, each copper atom is surrounded by five or six oxygen atoms. Four oxygen atoms lie in the same plane as the copper atom, and the remaining oxygen atoms sit above and/or below the copper atom. In the new compounds, the top and bottom oxygen atoms are absent, leaving only the copper-oxygen planes. The introduction of cerium in place of the elements used in previously discovered superconductors provides extra electrons. For superconductivity to occur, theorists believe these electrons must pair up despite the fact that electrons have like charges and naturally tend to repel each other. Although scientists have proposed a number of theories to account for how electrons (or holes) pair up, the matter remains a mystery.

Because of differences in the way superconductors with holes and those with electrons may behave, researchers now have a new way to test their theories. Many proposed mechanisms, especially those relying on such details as the presence of oxygen atoms above and below a copper atom, are likely to require rethinking. In the end, the results of these tests may help scientists zero in on the proper description for superconductivity in high-temperature superconductors. Furthermore, the Japanese discovery suggests a new direction for synthesizing superconductors.

The Japanese results are now fully confirmed. Experiments carried out at the Brookhaven National Laboratory in Upton, N.Y., and reported in the Feb. 23 NATURE give clear evidence for the presence of singly charged copper ions, a sure sign the material contains extra electrons. "It is clear that the nature of the charge carriers in the electron-doped superconductors is different from that in hole-doped materials," the researchers say. "These observations should put a significant constraint on theories of electron-pairing that attempt to describe simultaneously all of the copper oxide superconductors."

Troubling connections

Making an electrical connection between a high-temperature superconductor and a metal wire may be trickier than many researchers had hoped or expected. A series of careful studies conducted by John H. Weaver of the University of Minnesota in Minneapolis and his collaborators reveals that metals such as titanium, iron, copper and aluminum react with a ceramic superconductor. The reaction often disrupts the superconductor's surface to create a layer that is no longer superconducting. "These are fragile surfaces," Weaver says.

The only metals that appear to be safe for making electrical contact with a copper-oxide-based superconductor are gold and silver. The researchers have also found that depositing layers of compounds such as aluminum oxide or calcium fluoride can protect a superconducting surface without disrupting and changing the surface's properties.

What you see isn't always what you get

If you have to judge a book by its cover, make sure you look at the correct cover. That's the metaphoric message from a collaborative study by investigators at four national laboratories who took a new look at surface electrons of the so-called "1-2-3" high-temperature ceramic superconductors.

By now, scientists have gotten over the initial shock of finding the celebrity ceramics behave like superconducting metals. "They're supposed to be rocks," observes Aloysius J. Arko, a physicist at Los Alamos (N.M.) National Laboratory and a principal investigator on the project. Recent observations that the electronic structure of these materials appears nonmetallic have added to the head-scratching. Instead of having many conduction electrons as in a metal, the ceramics appear to have very few — a meaty paradox for superconductor theorists to demystify.

But Arko and more than a dozen colleagues say the paradox may be more apparent than real. They argue that their refined observations of the ceramics' electronic structure once again portray the materials as metals. In earlier studies, scientists assumed the surface properties of a superconductor crystal represent its bulk properties. Also, many scientists tacitly assumed the surfaces wouldn't change in the time it takes to determine an electronic structure. Arko and company see it differently. They discovered that surfaces of some superconductor crystals rapidly transform (by losing oxygen) from a metallic superconducting form into a nonmetallic one, especially at the relatively high temperatures at which most prior studies had been done (77 kelvins and up). This transformation has led to wrong inferences about the superconductor's bulk properties, Arko says.

The scientists did their electronic structure measurements at colder temperatures (20 kelvins) and only on freshly exposed crystal surfaces. Other researchers looking at different classes of the new superconductors now are finding similar metal-like electronic structures, Arko says. "We are quite sure they are metals," he adds. "But we still don't understand why they are superconductors."

Adding to the technological wish list

Thread one conductor through the hollow of another cylindrical conductor, separate them with an insulator (dielectric) such as Teflon and you'll have a coaxial cable. They're great for transmitting telephone and television signals because they neither produce, nor are influenced much by, external electromagnetic fields. Electrical engineers Christopher Rose and Mike J. Gans at AT&T Bell Laboratories in Holmdel, N.J., report theoretical calculations suggesting that a future superconducting coaxial cable made with a magnetically levitated core could transmit data at a rate of 100 billion bits per second over a distance of 600 kilometers, or about 375 miles. Today's optical fibers can reliably transmit data at this rate but only one-tenth as far. Cut the data rate by a tenth, and the future cable's reliable transmission distance stretches to 37,500 miles, or 1½ times around the planet.

Passing resistance-free current through the cable would create magnetic forces between the cable's two concentric superconductors. When the core conductor is placed slightly lower than the cable's geometric center, the net magnetic force is upward and will levitate the conductor, the researchers argue in a paper submitted to IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES. The cable would be free of the transmission losses associated with the insulating support that otherwise would have to be inserted between the conductors, Rose points out. For practical application, superconductors that work at room temperatures or above and that form into long cables will have to come along.