New Superconductor Uses Electrons

A recently discovered superconductor with an unusual property may offer new clues about how high-temperature superconductivity works. Japanese researchers Y. Tokura, H. Takagi, and S. Uchida at the University of Tokyo have fabricated a copper-oxide superconductor in which the electric current is carried by electrons. Although this may not seem like an unusual property since electrons are the current carriers in such familiar conductors as copper or silver, none of the previously known high-temperature superconductors uses electrons to transport its supercurrent. Instead, the family of copper-oxide superconductors, first discovered in 1986, normally relies on electron holes—the absence of electrons—to pass current.

"This is very important to basic research," said Victor Emery, a theoretical physicist at Brookhaven National Laboratory. "I'd rather have this than a new 150 K superconductor." Emery was referring to the fact that the superconductor discoveries that get the most attention are materials with record-setting critical temperatures. The current record holder is a thallium-based material that loses its resistance to electrical current at 125 K, so a new 150 K substance would create a lot of excitement, but Emery expects to learn more from the less glamorous material.

The Japanese researchers, who reported in the 26 January *Nature*, actually discovered a family of closely related superconductors. The materials have chemical composition $Ln_{2-x}Ce_xCuO_{4-y}$, where Ln is one of the lanthanides Pr, Nd, or Sm. The critical temperatures for these copper-oxide superconductors are nowhere near the record. The best performance mentioned in the report was in a sample of $Nd_{1.85}Ce_{0.15}CuO_{3.93}$, which showed an onset of superconductivity—a sharp drop in resistance—at 24 K.

The value of the new cerium compounds, Emery said, is that they seem to produce superconductivity in an entirely different way from the other known copper-oxide superconductors, which should offer new insights into the mechanisms of superconductivity. So far, although physicists have a well-accepted theory that explains superconductivity in certain materials with critical temperatures up to about 30 K, no one has been able to explain how the recently discovered families of higher temperature materials work.

Like several earlier copper-oxide superconductors, the new compounds achieve superconductivity by starting with an insulator—in this case, Ln_2CuO_4—and doping it with another material—in this case, cerium. An insulator can be thought of as a material in which all of the electrons are bound tightly to atoms, so the electrons cannot easily move around the material and carry a current. Adding a dopant to the insulator can leave it with either more electrons, in which case the extra electrons can move around the material; or fewer electrons, in which case there are electron vacancies, or holes, which can move from atom to atom. Either the leftover electrons or the holes can then carry a current.

The superconductor $La_{2-x}Sr_xCuO_4$, discovered in 1986, is produced by substituting strontium for some of the lanthanum in La_2CuO_4, which removes electrons, thus adding holes which carry the supercurrent. In the newly discovered material, replacing some of the lanthanide with cerium does the opposite—it adds electrons. The Japanese scientists believe it is these electrons that allow the superconductivity.

Just having spare electrons or holes is not enough to produce superconductivity; something else must happen to allow the electrons or holes to move around the material without resistance. Various theories have been proposed as to what this is, but testing them demands very delicate measurements on the superconductors, and no one theory has emerged as the best explanation. Because the new materials seem to produce superconductivity in a different way from the earlier ones, they could be important.

Paul Grant, a physicist at IBM's Almaden Research Center, cautioned that cerium superconductors might not work much differently from the others. The materials might have both holes and electrons, he said, and "more work needs to be done to determine whether the electrons are actually carrying the supercurrent."

Emery disagreed. "I think that is not so much the issue," he said, since the electron/hole distinction is mostly a matter of semantics. (The movement of an electron from point A to point B is equivalent to the movement of an electron hole from B to A.) More important, Emery said, is the fact that the new superconductors have been created by electron doping rather than hole doping, and this new mechanism may be different enough from the other that it gives theorists something more to work with.

■ Robert Pool

Superconductivity in a Nickel Oxide

Purdue University researchers say they have convincing evidence of superconductivity in a material that substitutes nickel for copper in the formula for a previously known high-temperature superconductor. Jurgen Honig, along with Zbigniew Kąkol and Józef Spałek, both visiting from the Institute of Mining and Metallurgy in Kraków, Poland, report that $La_{2-x}Sr_xNiO_4$ becomes superconducting at temperatures as high as 70 K. If this finding is verified by other researchers, the material will become the first copperless superconductor with a critical temperature greater than about 30 K, and it will be the first example of a superconductor produced by replacing copper with nickel.

Because copper and nickel have very similar electronic properties, a number of scientists have speculated that superconductivity might be found in nickel-oxide materials similar to the copper-oxide materials discovered over the past 3 years, but no one had managed to do it. The copper-oxide counterpart to the Purdue material, $La_{2-x}Sr_xCuO_4$, has been recognized as a superconductor with critical temperature up to about 40 K for more than 2 years.

The new material has not yet been isolated, its crystalline structure has not been determined, and its superconductivity is somewhat erratic, depending on the thermal treatment of the samples. "It is unfortunately not a clean effect right now," Honig said. He speculates that the samples consist of two phases, one of them superconducting and the other not, and the percentage of a sample that is superconducting depends on how it is processed. The team has done magnetic and resistance tests on the samples, Honig said, and has seen superconductivity appear anywhere from 4 K to 70 K, but usually around 20 K. Sometimes the superconductivity disappears, but Honig said it can be reclaimed by putting the sample through another heating process. "We've seen the effect about 25 times in four samples," he said. "If it's not superconductivity, it's a very good imitation."

The researchers have sent samples of the material to other labs for testing and verification, Honig said, and he has received word that C. N. R. Rao in Bangalore, India, has repeated the work and seen the same signs of superconductivity. A paper detailing the work has been accepted for publication in the *Journal of Solid State Chemistry*, Honig said.

■ Robert Pool