Update on Electron Superconductors

A flurry of work on a recently discovered class of superconductors has verified that the current in these materials is carried by electrons instead of electron holes, with major implications for theories that try to explain high-temperature superconductivity. "It's the biggest news since the original Bednorz-Müller discovery [of the first high-temperature superconductor]," said physicist Arthur Sleight of Du Pont. "It throws almost all of the existing theories out the window."

Six weeks ago, Japanese researchers Y. Tokura, H. Takagi, and S. Uchida announced the discovery of a class of superconductors in which the supercurrent apparently was carried by electrons. This was unlike all other known high-temperature superconductors, in which electron holes, or the absence of electrons, carry the current. A superconductor is a material that loses all resistance to the passage of an electrical current when it is cooled to below a certain critical temperature. High-temperature superconductors, which were first discovered about 3 years ago, have critical temperatures anywhere from about 20 K to 125 K.

The new compounds are of the form $Ln_{2-x}Ce_xCuO_{4-y}$, where Ln is one of the lanthanides Pr, Nd, or Sm. The highest reported critical temperature is 24 K, much lower than the 90 K to 125 K of the best copper-oxide superconductors. Despite the relatively low critical temperatures, however, the electron-based superconductors have been attention getters because if the new mechanism for superconductivity were verified, it would place severe restraints on superconductivity theories.

Final verification is quickly getting nearer. For instance, researchers are beginning to get new electron superconductors by replacing the elements of the original compound with closely related elements. A team of researchers at the University of California at San Diego led by Brian Maple said it has found three new electron-based superconductors in this way. In one, Ln is replaced by Eu, a lanthanide with properties similar to Pr, Nd and Sm; in the other two, Th is used in place of Ce. The compounds are: $Eu_{1.85}Ce_{0.15}CuO_{4-y}$, with a critical temperature of 13 K; $Pr_{1.85}Th_{0.15}CuO_{4-y}$, 23 K; and $Nd_{1.85}Th_{0.15}CuO_{4-y}$, 20 K.

In other news, a team of researchers led by John Tranquada at Brookhaven National Laboratory reported 2 weeks ago that x-ray absorption measurements show electrons are indeed the charge carriers in the materials discovered by the Japanese. In an article in the 23 February *Nature*, they wrote that the nature of the charge carriers in the electron superconductors is quite different from that in the hole materials. "These observations should put a significant constraint on theories of electron pairing that attempt to describe simultaneously all of the copper-oxide superconductors."

In the 6 March *Physical Review Letters*, the three Japanese scientists from the University of Tokyo announced tests that confirmed electrons to be the charge carriers. In addition, they took a close look at how the superconductivity appears in their compounds by varying x in $Nd_{2-x}Ce_xCuO_{4-y}$. As x increases from 0, an increasing amount of Nd in Nd_2CuO_{4-y} is replaced with Ce, which has the effect of adding extra electrons that can move around the material freely. This electron doping turns the semiconductor Nd_2CuO_4 into a metallic conductor when $x = 0.14$. This semiconductor-metal transition appears to be connected with the superconductivity, the Japanese researchers report, because the material suddenly becomes superconducting with a critical temperature of about 20 K once x reaches 0.14. When x exceeds 0.18, the superconductivity disappears. Similar results hold for the $Pr_{2-x}Ce_xCuO_{4-y}$ material.

In the 2 March *Nature*, a group including the three Japanese plus researchers from Columbia University, the University of British Columbia, and Du Pont studied the magnetic ordering of the atoms in $Nd_{2-x}Ce_xCuO_{4-y}$ for x between 0 and 0.16. The magnetic order found in the samples when x was low vanished as x increased and superconductivity appeared.

Sleight pointed out that this route to superconductivity via electron doping is quite similar to the way other superconductors are formed by adding electron holes. "You can get superconductivity either by reducing [adding electrons] or by oxidizing [subtracting electrons, or adding holes]," Sleight said. "The same doping level gives you optimum superconductivity on both sides." This symmetry between adding and subtracting electrons will have to be reflected in any theory that explains high-temperature superconductivity, he said, and existing theories based on the supposition that there is something unique about hole carriers are "out the window." ■ ROBERT POOL

Diary of a Solar Flare

At approximately 8:52 a.m. EST on the morning of Monday, 6 March, a fierce bloom of light erupted from the center of an exceptionally large group of sunspots just as the sun's rotation was bringing the spots into view along its eastern limb. Presumably the outburst was caused by a sudden release of magnetic energy, although no one can really claim to understand these things. But whatever the cause, it was by far the biggest solar flare since the event of 24 April 1984, during the decline of the last sunspot cycle. And it is the first really big eruption of the current cycle, which is rapidly rising toward a near-record peak sometime in 1990 or 1991. Estimates put the 6 March flare at about X-15 on the standard scale, corresponding to a total energy release of some 10^{32} ergs—or about as much energy as we humans have consumed in our entire history.

Eight minutes and 20 seconds after the initial outburst, the first pulse of x-rays and other electromagnetic radiation swept past the earth at the speed of light. Solar radiation detectors on both the Solar Maximum Mission satellite and on the GOES weather satellites were quickly overwhelmed, although all have since recovered.

Only slightly behind the first wave of radiation came the second: high-energy charged particles accelerated by the flare to just under the speed of light. Most of the particles from this particular flare seem to have bypassed us entirely, since it was essentially aiming off to the side. But in general, flare particles act like an intense swarm of cosmic rays. If and when astronauts ever venture beyond the protection of the earth's magnetic field, which deflects the particles, they will have to carry special shielding: the particle radiation from a flare as strong as this one could be lethal.

Finally, at about 1:30 p.m. EST on Wednesday, 8 March, the earth was engulfed by a flare-induced shock wave in solar wind—the steady, outgoing stream of particles and magnetic fields that the sun emits in even its calmest moments. The ensuing geomagnetic storm triggered northern lights as far south as Chicago and upstate New York. At the same time, the storm heated and expanded the upper atmosphere enough to increase the drag on the low-flying Solar Max satellite. Solar Max promptly dropped by nearly a kilometer.

Meanwhile, the 6 March flare itself had faded only a few hours after it started. But its parent sunspot group, roughly 50 times as wide as the earth, continued to bring forth lesser flares for several days thereafter.

■ M. MITCHELL WALDROP