Conducting-Insulating Materials Reveal Their Secrets

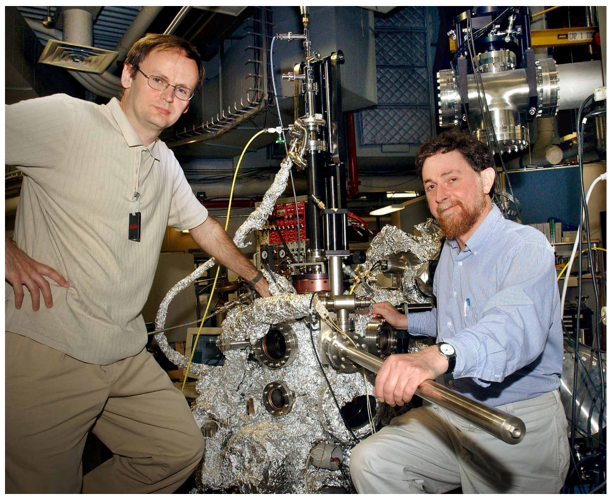
Research by physicists at the NSLS provides new insight into why some materials made of stacks of metallic planes are conductors in the direction of the planes and are insulators in the direction perpendicular to the planes. Such behavior is in marked contradiction with scientists' traditional understanding of metallic conductivity, where the electrical current is carried by electrons in every direction. Understanding how materials that are both conducting and insulating will help scientists gain new insight into superconductors – materials that conduct electricity with no energy loss.

Scientists have suspected that the dual conducting-insulating property is due to electrons interacting so strongly with each other that they do not move individually, but collectively, to carry the current within the planes. But there has been no evidence of such interactions – until now.

"A material that is both conducting and insulating is quite intriguing," says Brookhaven physicist Tonica Valla, the lead author of the study, which appears in the June 6, 2002 issue of *Nature*. "Such a dual behavior has puzzled physicists for several years. And though theoretical explanations have been suggested, we now show for the first time that the strength of the interactions between excited electrons influences their behavior."

Valla and his collaborators from Brookhaven, the University of Connecticut in Storrs, Princeton University, and Osaka University in Japan studied two different conducting-insulating materials, and showed that electrons that were confined in the planes at high temperatures are able to move between the planes at lower temperatures, allowing the material to behave more like a metal.

The "critical" temperature at which the change occurs ranges between -100 and -300 degrees Fahrenheit, depending on the material.



Physicists Tonica Valla (left) and Peter Johnson at the NSLS beamline U13, where they study the properties of conducting/insulating materials.

"These planes act like trains and electrons like passengers in the trains," says study coauthor Peter Johnson, a Brookhaven physicist. "At high temperatures, the electrons are bound together in the planes like passengers inside moving trains. Then, below the critical temperature, the electrons are not bound anymore and start moving around in the same way as passengers leave a stopped train."

To examine the interactions between the electrons, the scientists used extremely intense ultraviolet light generated by the NSLS. They looked at how the light excites the electrons in each of the three materials, and used a method called angle-resolved photoemission spectroscopy (ARPES) to accurately measure the intensity of the light emitted by the electrons as a function of their energy. The resulting ARPES spectrum was determined for various temperatures.

Below the critical temperature, a signal started to appear in the spectrum. Weak at first, the signal became more apparent as the temperature decreased. "This signal is the telltale evidence of individual electrons," Valla says. "Theorists had predicted the existence of such a signal, but nobody had observed it before."

The results of this study promise to provide further insight into how superconductors conduct electricity without heat dissipation when they are cooled below a certain temperature. In particular, the cause of high-temperature superconductors, with critical temperatures ranging from -396 to -216 degrees Fahrenheit, remains mysterious, but is assumed to be due to strong interactions between electrons.

The new study also gives insight into materials with new electrical and magnetic properties, expected to arise from strong interactions between electrons. "We expect to see dramatic new results and applications stemming from the study of materials with strongly-interacting electrons," Johnson says.

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