Key advance made toward understanding "pseudogap" phase in HTS

Researchers have been trying for some 20 years to understand why the low temperature at which copper-oxide high-temperature superconductors (HTS) carry current with no resistance cannot be increased to be closer to room temperature. Recently, researchers have focused on trying to understand and control an electronic phase called the "pseudogap" phase, which is non-superconducting and is observed at a temperature above the superconducting phase. But what form of electronic order (if any) characterizes the pseudogap phase has remained a challenging mystery.

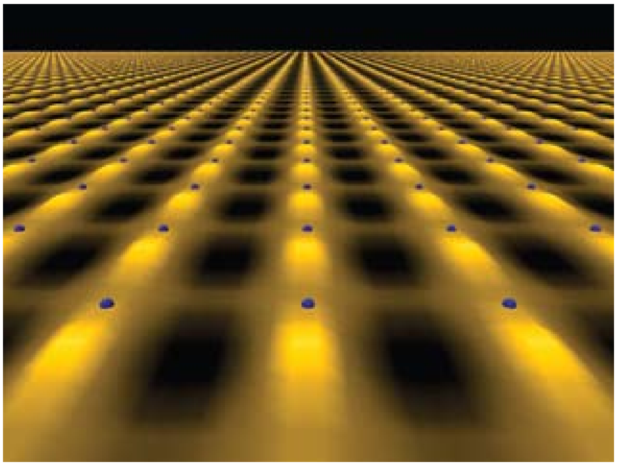
Now an international group of researchers have discovered a fundamental difference in how electrons behave at the two distinct oxygen-atom sites within each copper-oxide unit, which appears to be a specific property of the non-superconducting pseudogap phase. The research—described in the July 15th issue of *Nature* (DOI 10.1038/nature09169; p. 347)—may lead to new approaches to understanding the pseudogap phase, which has been hypothesized as a key hurdle to achieving room-temperature superconductivity.

To identify the change in electronic behavior, the research team from Binghamton University, Cornell University, Brookhaven National Laboratory, the University of Tokyo, the Korea Advanced Institute of Science and Technology, the RIKEN laboratory in Japan, Japan's Institute of Advanced Industrial Science and Technology, and the University of St. Andrews in Scotland used a technique known as spectroscopic imaging scanning tunneling microscopy to measure the relative ease with which electrons could jump from the surface at each individual copper and oxygen site to the tip of the microscope needle. New theoretical approaches pioneered by Michael Lawler of Binghamton and Eun-Ah Kim of Cornell helped the group understand the electron behavior.

Across the entire copper-oxide crystal, the researchers found a difference in the electronic states associated with the mysterious pseudogap phase: The number of electrons able to "tunnel" to the microscope tip differed depending on the position of the oxygen atom relative to the copper atom.

"Picture the copper atom at the center of the unit, with one oxygen to the 'north' and one to the 'east,' and this whole unit repeating itself over and over across the copper-oxide layer," said study leader Séamus Davis, director of the Center for Emergent Superconductivity at the U.S. Department of Energy's Brookhaven National Laboratory and the J.D. White Distinguished Professor of Physical Sciences at Cornell University. "In every single copper-oxide unit, the tunneling ability of electrons from the northern oxygen atom was different from that of the eastern oxygen."

The discovery of this asymmetrical behavior could be a breakthrough in understanding and controlling high-temperature superconductors because, historically, uncovering the reductions in symmetry responsible for other states of matter has led to significant advances in understanding and achieving control over those states. For example, discovery of the symmetries broken in liquid crystals eventually led to their control and everyday use in liquid crystal displays (LCDs).



This pattern shows the tunneling potential of electrons on oxygen atoms "north" and "east" of each copper atom (shown embedded in the pattern) in the copper-oxide layer of a superconductor in the pseudogap phase. On oxygen atoms *north* of each copper, the tunneling potential is strong, as indicated by the brightness of the yellow patches forming lines in the north-south direction. On oxygen atoms *east* of each copper, the tunneling potential is weaker, indicated by less intense yellow lines in the east-west direction. This apparent broken symmetry may help scientists understand the pseudogap phase of copper-oxide superconductors.

The researchers next plan to look for a similar broken symmetry in other copper-oxide superconductors. They will also try to determine how the directional asymmetry in electronic behavior affects the ability of electrons to flow through the system; how that directional dependence might inhibit superconductivity; and eventually, how this might be overcome at temperatures warm enough to make high-temperature superconducting (HTS) technologies practical.

"The ultimate goal is to discover or create materials that can act as superconductors, to carry electric current with no energy loss, at room temperature," Davis said.

Other members of the research team are K. Fujita, J. Lee, A.R. Schmidt, Y. Kohsaka, C.K. Kim, H. Eisaki, S. Uchida, and J.P. Sethna. □

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