Zeroing in on quantum effects: New materials yield clues about high-temperature superconductors

May 28 2010

(PhysOrg.com) -- A team of U.S. and Chinese physicists are zeroing in on critical effects at the heart of the latest high-temperature superconductors -- but they're using other materials to do it.

In new research appearing online today in the journal Physical Review Letters, the Rice University-led team offers new evidence about the quantum features of the latest class of high-temperature superconductors, a family of iron-based compounds called "pnictides" (pronounced: NICK-tides).

"In correlated electron systems like the pnictides and their parent compounds, the electrons are caught in a competition between forces," said Rice physicist Qimiao Si, a co-author of the study. "On the one hand, they are compelled to move around, and on the other, they are forced to arrange themselves in a particular way because of their desire to repel one another. In this study, we varied the ratio between these competing forces in an effort to find the tipping point where one takes over from the other."

The aim of the research is to better understand the processes that lead to high-temperature superconductivity. If better understood and developed, high-temperature superconductors could revolutionize electric generators, MRI scanners, high-speed trains and other devices. In today's wiring, electricity is lost due to resistance and heating. This happens because electrons bump and ricochet from atom to atom as they pass down wires, and they lose a bit of energy in the form of heat each time they bounce around.

Almost a century ago, physicists discovered materials that could conduct electrons without losing energy to resistance. These "superconductors" had to be very cold, and it took physicists nearly 50 years to come up with an explanation for them: The electron-electron repulsion in these low-temperature superconductors was so weak that with the mediation of lattice vibrations, electrons overcame it, paired up and glided freely without the bumping and heating.

That explanation sufficed until 1986, when physicists discovered new materials that became superconductors at temperatures above 100 kelvins. These "high-temperature superconductors" were made of layers of copper alloys sandwiched between layers of nonconducting material that were laced, or "doped," with trace amounts of material that could contribute a few extra electrons to the mix.

Physicists quickly realized their existing theories of superconductivity could not explain what was happening in the new materials. For one thing, the undoped versions of the compounds didn't conduct electricity at all. Their electrons -- due to their desire to repel one another -- tended to lock themselves a comfortable distance away from their neighbors. This locked pattern was dubbed "Mott localization," which gives rise to an insulating state.

In 2008, the search for answers took another turn when a second class of high-temperature superconductors was discovered. Dubbed the pnictides, these new iron-based superconductors were also layered and also needed to be doped. But unlike their copper cousins, undoped pnictides were not Mott insulators.

"Mott localization doesn't occur in the undoped pnictides, but there is considerable evidence that the electrons in these materials are near the point where Mott localization occurs," Si said. "This proximity to Mott localization endows the system with strong quantum magnetic fluctuations, which we believe underlie the high-temperature superconductivity in the pnictides."

In all high-temperature superconductors, the iron or copper atoms in the conducting layers form a grid-like, checkerboard pattern.

In work published earlier this year, Si and colleagues replaced arsenic atoms in one of the intervening layers of a pnictide with slightly smaller phosphorous atoms. This subtle change brought the iron atoms in the checkerboard a tad closer together, and that changed the amount of energy that was compelling electrons to move between the iron atoms. The experiments confirmed a 2008 prediction of Si and, University of California, Los Angeles (UCLA) theorist Elihu Abrahams, who had predicted that boosting the electrons' kinetic energy would drive the pnictides further away from the Mott tipping point.

In the latest tests, Si and colleagues at Rice, China's Zhejiang University, UCLA, Los Alamos National Laboratory and the State University of New York at Buffalo (SUNY-Buffalo) sought to move the system in the other direction, toward Mott localization.

"We wanted to decrease the kinetic energy by expanding the distance between iron atoms in the lattice," said study co-author Jian-Xin Zhu, a theorist from Los Alamos. "Unfortunately, there is no pnictide material with those properties."

So the team's experimentalists, Rice's Emilia Morosan and Zhejiang's Minghu Fang, hit upon the idea of substituting a similarly patterned material called an iron oxychalcogenide (pronounced: OXY-cal-cah-genyde). Like the iron pnictides, iron oxychalcogenides are layered materials. But compared with the pnictides, the distance between iron atoms is expanded in the oxychalcogenides.

Tests on the new materials confirmed the theoretical predictions of the team; a slight expansion of the iron lattice pushed the system into a Mott insulating state.

"Our results provide further evidence that the undoped iron pnictide parent compounds are on the verge of Mott localization," Abrahams said.

Provided by Rice University

Citation: Zeroing in on quantum effects: New materials yield clues about high-temperature superconductors (2010, May 28) retrieved 29 April 2024 from https://phys.org/news/2010-05-zeroing-quantum-effects-materials-yield.html

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.