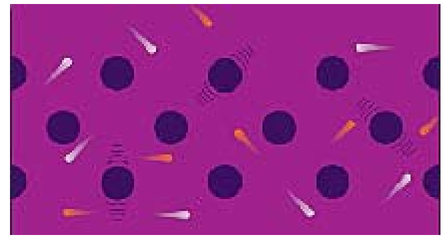
SIMES Physicists Demystify Electron Behavior in High-temperature Superconductors



(Image: *Symmetry* magazine.)

Researchers at the Stanford Institute for Materials and Energy Science, a joint institute of SLAC and Stanford University, have found encouraging evidence to help explain the mysterious behavior of electrons in "unconventional" high-temperature superconductors. In an article published last week in *Nature Physics*, SIMES researcher and Stanford Professor Martin Greven and his team show a simple relationship that may help explain some key properties of unconventional superconductors. Research on such materials could impact further studies for practical uses in superconducting magnets and wires that transmit electricity without energy loss.

"The article shows a leap of insight gained based on our prior experimental work and seeing how it fits in with everything else we already know about other unconventional superconductors," said Greven, who together with co-author Guichuan Yu is now transitioning to a new post at the University of Minnesota. The paper is the culmination of research projects led by then Stanford graduate student Yu, investigating the properties of two unconventional superconductors, which operate at higher temperatures than their supercold conventional counterparts.

Superconductivity is a low-temperature phenomenon in certain materials that is characterized by zero electrical resistance. It relies on unusual collective behavior of electrons, which pair together to move freely without energy-sapping interactions. In conventional low-temperature superconductors, electrons pair as a result of their interaction with the vibrations of a crystal lattice, the ordered arrangement of atoms in many superconducting materials. An electron moving in one direction causes a vibration in the lattice, like an insect walking across a spider web. An electron moving in the opposite direction detects these vibrations and combines with the first electron, forming what physicists call a Cooper pair.

In unconventional superconductors, however, significant electronic and magnetic interactions, rather than lattice vibrations, seem to cause electron pairing. "What glues electrons into Cooper pairs in these materials has been an open question, but one promising answer is magnetic effects," Greven said.

Greven and his team set to work identifying the connection between magnetism and superconductivity in unconventional superconductors. After growing complex copper-oxides in the form of crystals, the team bombarded their samples with neutrons. They then analyzed the scattering of the neutrons off the crystal to determine the magnetic phenomena associated with electrons in the material.

The studies inspired the new insight that a key magnetic feature found in unconventional superconductors, called magnetic resonance, exhibits a universal linear relationship with the superconducting energy scale in these materials, called the superconducting gap.

"This suggests a more profound relation between magnetism and superconductivity than we had previously thought," Greven said. "It seems to provide further evidence that magnetic excitations may play an important role in the Cooper-pair formation in a wide range of unconventional superconductors."

"You can't really predict what this discovery will lead to in half a century," Greven said. "Insights into how quantum mechanics plays out in more conventional materials have lead to the knowledge of conventional superconductors, semiconductors and transistors, and effectively to Silicon Valley. The materials that we study now are exotic and complex. Determining how quantum mechanics works in these materials will potentially lead to new technology that could be very useful to society."

—*Lauren Knoche*

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