Complex order parameter in ruthenate superconductors confirmed

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Since it was discovered to be superconducting over a decade ago, the pairing symmetry of strontium ruthenium oxide has been widely explored and debated. Now, a team of researchers led by Dale Van Harlingen at the University of Illinois at Urbana-Champaign say the debate is over.

"We have pretty unambiguous evidence for 'p-wave' symmetry with a complex order parameter that breaks time-reversal symmetry in this ruthenate superconductor," said Van Harlingen, a Willett Professor and head of the department of physics at Illinois.

Until now, this complex odd symmetry state had been predicted by theoreticians, but never fully confirmed. Van Harlingen and colleagues report their latest findings in the Nov. 24 issue of the journal *Science*.

The order parameter of a superconductor characterizes the nature of the pairing interaction that forms Cooper pairs. It controls many of the superconductor's properties, and provides a crucial clue to the microscopic mechanism responsible for the superconductivity.

Conventional superconductors that form Cooper pairs through phonon interactions have an "s-wave" symmetry with an isotropic order parameter. Unconventional superconductors, however, have anisotropy in either or both the phase and magnitude of the order parameter.

Ten years ago, Van Harlingen's group pioneered the Josephson interferometer technique that showed the high-temperature superconducting cuprates had “d-wave” symmetry. They are now applying the technique to a wide range of superconducting materials suspected of having unconventional symmetry.

“Our technique can directly measure phase differences in the superconducting order parameter,” said Van Harlingen, who is also a researcher at the university’s Micro and Nanotechnology Laboratory, and a professor in the university’s Center for Advanced Study, one of the highest forms of campus recognition. “This allows us to make an unambiguous determination of the pairing symmetry in unconventional superconductors,” he said.

To use their interferometer technique, the researchers begin by constructing a corner Josephson junction that straddles different faces of a single crystal of the ruthenate superconductor. They then measure the magnetic field modulation of the supercurrent that reveals the phase shift between different tunneling directions.

If all areas of a Josephson junction have the same order parameter phase, the critical current (measured as a function of applied magnetic field) will create a Fraunhofer diffraction pattern, analogous to a single-slit optical diffraction pattern. However, phase differences in the order parameter on adjacent crystal faces of a corner junction, or the presence of chiral domains (characterized by the direction of phase winding) along a single junction face, will result in modulated diffraction patterns.

“We observed highly modulated diffraction patterns across single edge junctions, which implies the existence of chiral domains,” Van Harlingen said. Abrupt changes seen in the diffraction patterns as a function of magnetic field or time indicate these domains are dynamical, changing their size or orientation.

“The presence of these domains and the distinctly different diffraction patterns observed on orthogonal faces of the same single crystal confirms the ‘p-wave’ triplet spin pairing state and the complex nature of the superconducting order parameter in the ruthenate superconductors,” Van Harlingen said.

Source: University of Illinois at Urbana-Champaign

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