Superconductivity seen in a new light

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Artist's impression of a high critical temperature superconductor immersed in a magnetic field. The magnetic field generates whirls of current called vortices. These allow to better perceive an ordered electronic structure that coexists with the superconducting state. Credit: © UNIGE - Xavier Ravinet

Superconducting materials have the characteristic of letting an electric current flow without resistance. The study of superconductors with a high critical temperature discovered in the 1980s remains a very attractive research subject for physicists. Indeed, many experimental observations still lack an adequate theoretical description. Researchers from the University of Geneva (UNIGE) in Switzerland and the

Technical University Munich in Germany have lifted the veil on the electronic characteristics of high-temperature superconductors. Their research, published in *Nature Communications*, shows that the electronic densities measured in these superconductors are a combination of two separate effects. As a result, they propose a new model that suggests the existence of two coexisting states rather than competing ones postulated for the past thirty years, a small revolution in the world of superconductivity.

Below a certain temperature, a superconducting material loses all electrical resistance (equal to zero). When immersed in a magnetic field, high-temperature superconductors (high-Tc) allow this field to penetrate in the form of filamentary regions, called vortices, a condition in which the material is no longer superconducting. Each vortex is a whirl of electronic currents generating their own magnetic fields and in which the electronic structure is different from the rest of the material.

Coexistence rather than competition

Some theoretical models describe high-Tc superconductors as a competition between two fundamental states, each developing its own spectral signature. The first is characterized by an ordered spatial arrangement of electrons. The second, corresponding to the superconducting phase, is characterized by electrons assembled in pairs.

"However, by measuring the density of electronic states with local tunneling spectroscopy, we discovered that the spectra that were attributed solely to the core of a vortex, where the material is not in the superconducting state, are also present elsewhere—that is to say, in areas where the superconducting state exists. This implies that these spectroscopic signatures do not originate in the vortex cores and cannot be in competition with the superconducting state," explains Christoph Renner, professor in the Department of Quantum Matter Physics of the

Faculty of Science at UNIGE. "This study therefore questions the view that these two states are in competition, as largely assumed until now. Instead, they turn out to be two coexisting states that together contribute to the measured spectra," professor Renner says. Indeed, physicists from UNIGE using theoretical simulation tools have shown that the experimental spectra can be reproduced perfectly by considering the superposition of the spectroscopic signature of a superconductor and this other electronic signature, brought to light through this new research.

This discovery is a breakthrough toward understanding the nature of the high-temperature superconducting state. It challenges some theoretical models based on the competition of the two states mentioned above. It also sheds new light on the electronic nature of the vortex cores, which potentially has an impact on their dynamics. Mastery of these dynamics, and particularly of the anchoring of vortices that depend on their electronic nature, is critical for many applications such as high-field electromagnets.

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