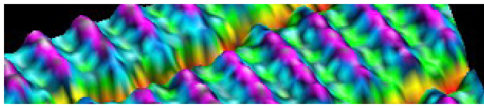

Electron Spin and Superconductivity

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Professor Pengcheng Dai's latest research into the marvel of superconductivity shares many elements of a family drama. There's competition and coexistence, not unlike a sibling rivalry. There's the "glue" holding things together, like a steady matriarch. But most importantly this latest work, published online in the May 22 issue of *Nature Physics*, is another step closer to understanding how and why electric current can move without inhibition—superconductivity—which could have significant implications for travel, medicine, energy, and computing.

First discovered 100 years ago, superconducting materials are of keen interest to researchers because they can carry electrical current free from any resistance that would otherwise slow it down. The bigger question lies in how this happens. Research has shown that in all cases, electrons (which by nature repel one another) for some reason pair up in superconductors, ushering the current along. In conventional superconductors, this electron-pairing is brought about by lattice vibrations, or phonons. The materials have a crystal-like structure, and when electrons interact with metal atoms within that structure, the vibrations result in electron pairs. With the discovery of high-temperature superconductors in the mid-1980s, however, scientists had to go back to the drawing board. Phonons could not explain this phenomenon in materials with ever-climbing transition temperatures (*Tc*), the temperature below which a substance becomes superconducting. And given that the higher the transition temperature, the more applications become possible in fields like transportation and energy, decoding how high-temperature superconductivity works could offer tremendous economic benefits.

In this most recent work, titled "Electron-spin excitation coupling in an electron-doped copper oxide superconductor," Dai and his colleagues tested two nominally identical superconducting samples. By removing a tiny amount of excess oxygen from one of the samples through the annealing process, they were able to slightly change its transition temperature, which does not change phonon spectra but may change spin and electronic structure of the system. They used both neutron scattering (a technique that bounces a neutron off a target nucleus to reveal a material's properties), and scanning tunneling spectroscopy, where they used a scanning tunneling microscope to probe the compound's surface and glean information about its topography, as well its electronic states and structure.

The same way the sun rotates on its axis and orbits the sun, electrons spin on an axis and orbit nuclei. An electron's spin can have one of two orientations—up or down—depending on how it responds to an external magnetic field. When a material is antiferromagnetic, the adjacent ions are aligned in arrays that alternate between up and down. These materials show almost no response to an external magnetic field at low temperatures and only a weak attraction at higher ones.

In the experiments outlined in the *Nature Physics* paper, researchers studied a pure superconductor compound comprising praseodymium, lanthanum, cerium, copper, and oxygen (PLCCO) with a transition temperature of 24 kelvin. They compared it with an almost identical PLCCO compound with a transition temperature of 21 kelvin, which exhibits antiferromagnetic order coexisting with superconductivity. Neutron scattering detected spin excitations with two distinct modes that evolve with the transition temperature, while the scanning tunneling spectroscopy experiments detected low-energy electron tunneling modes that evolve in a remarkably similar fashion. The results showed that antiferromagnetism and superconductivity compete locally and coexist spatially on nanometer length scales. The data also indicated that the electron coupling at low energies originates from the electron-spin excitations, not electron-phonon interactions. As the paper explains, "these results suggest that spin excitations are the mediating glue for the electron pairing and superconductivity in PLCCO."

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