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One Mystery of High-Tc Superconductivity Resolved

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Research published online in the journal Science this week by Tonica Valla, a physicist at the U.S. Department of Energy’s Brookhaven National Laboratory, appears to resolve one mystery in the 20-year study of high-temperature (high T_c) superconductors — materials that lose their resistance to the flow of electricity at relatively high temperatures.

The research shows that a “pseudogap” in the energy level of the material’s electronic spectrum is the result of the electrons being bound into pairs above the so-called transition temperature to the superconducting state, but unable to superconduct because the pairs move incoherently.

In conventional superconductors, which operate at much lower temperatures (near absolute zero), superconductivity occurs as soon as electron pairs are formed. But in the case of the high-T_c materials, the electrons, though paired, “do not ‘see’ each other,” Valla says, “so they cannot establish ‘phase coherence,’ with all the pairs behaving as a ‘collective.’”

The origin of this pseudogap, along with the mechanism for forming the pairs necessary for superconductivity, has been one of the biggest mysteries scientists have been trying to understand about high-T_c superconductors since their discovery some 20 years ago. Because of their higher operating temperatures (up to 134 kelvins at ambient pressure and up to 164 K under high pressure), high-T_c superconductors have much greater potential for real world applications, such as zero-loss power transmission lines, than do conventional superconductors.

The material studied by Valla’s group — a special form of a compound made of lanthanum, barium, copper, and oxygen, where there is exactly one barium atom for every eight copper atoms — is actually not a superconductor. With less or more barium, the material acts as a high-T_c superconductor (in fact, this was the very first high-T_c superconductor discovered). But at the 1:8 ratio, the material momentarily loses its superconductivity.

Yet despite the fact that this material, at this ratio, is not a superconductor, it has a very similar energy signature — including the energy gap in the electronic spectrum (pseudogap) — as other high-T_c superconductors in their superconducting states.

Valla’s group interprets the finding as evidence that the electron pairs are formed first (as “preformed pairs”) and phase coherence occurs later, at some lower temperature (the transition temperature, or T_c), when thermal fluctuations of the phase are suppressed enough to cause superconductivity.

"Our research shows that the pseudogap is caused by the same interactions that are responsible for superconductivity — interactions that bind two electrons into a pair," Valla says.

"In high-Tc superconductors, however, this pairing is only the first step," he continues. "The superconducting transition is delayed, possibly — and ironically — because the pairing might be too strong. Figuratively speaking, a strong pairing produces "small" pairs with strongly fluctuating phases. Only by cooling the material to much lower temperatures do the phase fluctuations become suppressed. At that point, the phase becomes locked so the electron pairs can act coherently — and the system becomes a superconductor."

Source: Brookhaven National Laboratory