New insights into high-temperature superconductors

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Scientists at the Carnegie Institution's Geophysical Laboratory in collaboration with a physicist at the Chinese University of Hong Kong have discovered that two different physical parameters —pressure and the substitution of different isotopes of oxygen (isotopes are different forms of an element) —have a similar effect on electronic properties of mysterious materials called high-temperature superconductors.

The results also suggest that vibrations (called phonons), within the lattice structure of these materials, are essential to their superconductivity by binding electrons in pairs. The research is published in the February 26 - March 2 on-line edition of the *Proceedings of the National Academy of Sciences*.

Superconductors are substances that conduct electricity — the flow of electrons — without any resistance. Electrical resistance disappears in superconductors at specific, so-called, transition temperatures, T_c's. The early conventional superconductors had to be cooled to extremely low (below 20 K or –253ºC) temperatures for electricity to flow freely. In 1986 scientists discovered a class of high-temperature superconductors made of ceramic copper oxides that have much higher transition temperatures. But understanding how they work and thus how they can be manipulated has been surprisingly hard.

As Carnegie's Xiao-Jia Chen, lead author of the study explains: "High-temperature superconductors consist of copper and oxygen atoms in a layered structure. Scientists have been trying hard to determine the properties that affect their transition temperatures since 1987. In this study, we found that by substituting oxygen-16 with its heavier sibling oxygen-18, the transition temperature changes; such a substitution is known as the isotope effect. The different masses of the isotopes cause a change in lattice vibrations and hence the binding force that enables pairs of electrons to travel through the material without resistance. Even more exciting is our discovery that manipulating the compression of the crystalline lattice of the high-Tc material has a similar effect on the superconducting transition temperature. Our study revealed that pressure and the isotope effect have equivalent roles on the transition temperature in cuprate superconductors."

Superconducting materials can achieve their maximum transition temperatures at a specific amount of "doping," which is simply the addition of charged particles (negatively charged electrons or positively charged holes). Both the transition temperature and isotope effect critically depend on the doping level. For optimally doped materials, the higher the maximum transition temperature is, the smaller the isotope effect is.

Understanding this behavior is very challenging. The Carnegie / Hong Kong collaboration found that if phonons are at work, they would account both for the magnitude of the isotope effect, as a function of the doping level, and the variation among different types of cuprate superconductors. The study also revealed what might be happening to modify the electronic structures among various optimally doped materials to cause the variation of the superconducting properties. The suite of results presents a unified picture for the oxygen isotope effect in cuprates at ambient condition and under high pressure.

"Although we've known for some time that vibrations of the atoms, or phonons, propel electrons through conventional superconductors, they have just recently been suspected to be at work in high-temperature superconductors," commented coauthor Viktor Struzhkin. "This research suggests that lattice vibrations are important to the way the high-T_c materials function as well. We are very excited by the possibilities arising from these findings."

Source: Carnegie Institution

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