Superconductors get a boost from pressure

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Superconductors can convey more than 150 times more electricity than copper wires because they don't restrict electron movement, the essence of electricity. But to do this, the materials have to be cooled below a very low, so-called, transition temperature, which often makes them impractical for widespread use.

Now for the first time, scientists have found that in addition to chemical manipulation, the superconducting state can be induced by high pressure in so-called high-temperature superconductors. The discovery, published in the May 30, 2008, issue of *Physical Review Letters*, opens a new window on understanding and harnessing these miracle materials.

The early superconductors had to be cooled to extremely low (below 20 K or -423° F) temperatures. But in the 1980s scientists discovered a class of what they call high-temperature superconductors made of ceramic copper oxides, called cuprates. They found that at temperatures as high as about 135 K, or -216º F, these materials transition into superconductors. Understanding how they work and thus how they can be manipulated to operate at even higher temperatures is currently one of the most important unsolved problems in physics—a holy grail for many.

"In cuprate superconductors the atoms are arranged in a layered structure," explained co-author of the study, Viktor Struzhkin at the Carnegie Institution's Geophysical Laboratory. "When the material goes into the superconducting state, changes occur in the copper-oxide planes, the electron spins behave differently, the vibrational energy is altered, the charges move differently, and more."

Another co-author of the study, Alexander Goncharov, elaborated: "Over the years scientists have found that the transition temperature can be increased with a specific amount of 'doping,' which is the addition of charged particles—either negatively charged electrons or positively charged holes. We wanted to see the effects of high pressure on one bismuth-based high-temperature cuprate ($\mathrm{Bi1.98.Sr2.06Y0.68Cu2O8}+\delta$). Pressure has the added bonus that it can be applied gradually, like tuning a radio. We gradually tuned in to the superconductivity and could watch what happened over a broad range of pressures."

The scientists observed the subatomic effects on the material of pressures close to 350,000 times the atmospheric pressure at sea level (35 GPa) using a diamond anvil cell to squeeze the sample and specialized techniques, Raman spectroscopy and X-ray diffraction, to measure the changes.

"21 GPa was the magic number, or critical pressure," remarked Tanja Cuk, the lead author and a student at Stanford University, who carried out this work as part of her Ph.D. thesis research. "By compressing the structure, we were able to observe changes in six different physical properties. But even more exciting, the changes were similar to those observed when the material has been doped to its optimal level. This means that the critical pressure is likely related to doping. Plus, by finding that pressure can be used instead of temperature and doping, we've found an entirely new approach to studying what's behind superconducting properties of high-Tc superconductors."

According to Struzhkin: "This study brings us one step closer to understanding the mechanism of high-temperature superconductivity by giving a completely new perspective of the superconducting state driven by a continuous variable—pressure. It appears that superconductivity is favored on the borderline between insulating and metallic states. By applying these high pressures, we may be able to discover the missing clues to the mechanism of the high-temperature superconductivity and move a few steps closer to using superconductors in daily life. This could change our whole energy system."

Source: Carnegie Institution

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