This Changes Everything

Professor Dai's Group Joins the Race to Characterize a Brand New Class of Superconductors

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The number 43 might not seem all that impressive on its own, but it was enough to galvanize Professor Pengcheng Dai's research group into a Friday night run to Maryland and a marathon weekend of work—culminating in a *Nature* paper just four days later.

In fact, "Magnetic Order Close to Superconductivity in the Iron-Based Layered La(O_{1-x},F_x)FeAs Systems," is already online at www.nature.com, as the Dai group joins the worldwide frenzy to create and characterize the first new class of high-temperature superconductors in two decades.

Superconductivity is just shy of its 100 birthday. First discovered in 1911, it's the phenomenon where, at a point called the transition temperature (Tc), electrons overcome their natural repulsion to one another and pair up to carry current with no resistance. But a newer generation of materials—the high-temperature superconductors—are only 22 years old and still present a challenge to researchers. Their transition temperature is much higher than that of conventional superconductors, which have a Tc barrier of about 39 Kelvin found in MgB_2, but their electron pairing doesn't fit traditional models.

Dai explained that for 20 years, only the cuprates—compounds comprising copper and oxygen—have exceeded a Tc of 40 Kelvin. All that changed February 23rd. Scientists in Japan had been working with compounds made of iron and phosphorus to see if they could elicit superconductivity, typically getting only very low transition temperatures (less than 7 K). But when they moved just one box down the periodic table, substituting arsenic for phosphorus, the Tc suddenly jumped to 26K. A chain reaction followed as researchers in China began working with these new iron-arsenic compounds and transition temperatures climbed rapidly to 43K on March 25th. Dai was already in line for some samples from a colleague at Beijing National Laboratory for Condensed Matter Physics but did not know this would be a breakthrough.

"When I saw Tc hit 43K," he said, "I called and said, 'Send them over in the fastest way.' The sample arrived at UT that Friday morning, March 25. Clarina went to NIST that night."

Clarina de la Cruz, a postdoc in the Dai group, took off for the National Institute of Standards and Technology Center for Neutron Research in Gaithersburg, Maryland. The excitement these superconductors generated was such that NIST actually took other samples off the spectrometer to work in these new iron-arsenic compounds.

There is no conclusive answer as to why cuprates become superconductors, but the Dai group is among many camps that suspect magnetism plays a key factor. Some researchers, however, propose that magnetism is tied to copper, so finding a superconductor derived of other elements would be a significant step forward.

"In our view, it is extremely important to find another example," Dai said.

His research group studied the structure and magnetic order of a non-superconducting parent compound made from lanthanum, oxygen, iron, and arsenic. Then they doped the compound with fluorine. What they found is that, as in the cuprates, the parent compound is antiferromagnetic—meaning it has magnetic atoms that line up so that each atom has a magnetic field in the opposite direction of the atom next to it. When fluorine is added to the compound, static magnetism vanishes and superconductivity appears—the same as in cuprates.

"That, in essence, is the key message of this paper," Dai said. "That doesn't mean that it's exactly the same, because it's not. One thing that's different between this stuff and cuprates is that the parent compound in this stuff is a semi-metal, whereas in the cuprates the parent compound is actually an insulator."

The group also noticed that at 150K, there was a drop in resistivity accompanied by a phase transition—a slight shift in the sample's crystalline structure. The magnetic transition occurred at a slightly lower temperature (137K); fluorine doping suppressed both transitions. The experiments were carried out both at NIST and at the Oak Ridge National Laboratory High-Flux

Isotope Reactor using neutron scattering—bombarding a sample with a beam of neutrons and then following their pattern to learn something about the target's atomic and magnetic structures.

The next step, Dai said, is to figure out what causes electrons to pair up in these materials. While in conventional superconductors it's universally accepted that this exchange coupling is caused by the way electrons interact with vibrations in a material's lattice, there is no such settled-on explanation for high Tc superconductors.

"If you can prove using experiments and theory that there's another way of pairing electrons, then you can potentially engineer materials with very large exchange coupling that can potentially have even higher Tc than what is available now," he said.

Such potential has prompted Dai and his group to shift gears. While they previously studied cuprates, they are now looking at iron-arsenic compounds, and hosted a mini-workshop on this new class of materials at UT on May 12. These superconductors have generated a flurry of online publishing activity from scientists all over the world; Dai said papers are now posted at the rate of two per day. Their own paper has been already been cited more than 20 times, even before being published in *Nature*. Dai was also quoted in the May 16 issue of *Science* in Adrian Cho's article on this new class of superconductors.

Along with de la Cruz and Dai, other authors are Qing Huang, Jeff Lynn, Jiying Li, William Ratcliff II, Jerel Zarestky, Herb Mook, Guofeng Chen, J. L. Luo, and N. L. Wang. They represent UT, Knoxville; ORNL; the NIST Center for Neutron Research; the University of Maryland; Iowa State University; and the Beijing National Laboratory for Condensed Matter Physics, part of the Chinese Academy of Sciences. The work is supported by the US Department of Energy, the National Science Foundation of China, the Chinese Academy of Sciences, and the Ministry of Science and Technology in China.