Scientists in China and US chart latest discoveries of iron-based superconductors

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Superconductivity is a remarkable macroscopic quantum phenomenon, discovered just over a century ago. As temperature decreases to below a critical value, the electric resistance of a superconductor vanishes and the magnetic field is repelled. Superconductors have many applications, and can be used to transport electricity without loss of energy. Conventional superconductivity is explained by the Bardeen-Cooper-Schrieffer theory, posited more than five decades ago. In a superconducting state, two electrons with opposite momenta attract each other to form a bound pair. The pairing mechanism in a conventional superconductor is due to couplings between electrons and phonons, which are a quantum version of lattice vibrations.

The transition temperature (Tc) is very low - usually well below 40 K. The low transition temperature has greatly limited practical applications of superconductors. In a paper published in the Beijing-based journal *National Science Review*, a team of scientists based in the United States and China review recent discoveries of iron-based superconductors featuring the highest superconducting transition temperature next to copper oxides.

In an article titled, "Iron-based high transition temperature superconductors," co-authors Xianhui Chen, Pengcheng Dai, Donglai Feng, Tao Xiang and Fu-Chun Zhang present an overview of material aspects and physical properties of iron-based superconductors. They outline the transition temperature's dependence on the crystal structure, the interplay between antiferromagnetism and superconductivity, and the electronic properties of compounds obtained by angle-resolved photoemission spectroscopy.

"It has been a dream to realize high-Tc or room temperature superconductors, which may revolutionarily change power transmission in the world," they explain in sketching out the latest advances in this search for more practical superconductors. One impetus to accelerate this search was triggered by the discovery nearly two decades ago of a high-Tc superconducting cuprate. A worldwide search since then has uncovered the highest transition temperature at ambient pressure of 135 K in an Hg-based cuprate. The second class of high-Tc materials covers iron-based superconductors, initially discovered in 2008. The highest Tc in bulk iron-based superconductors discovered to date is 55 K in SmO1?x FxFeAs.

So far many families of iron-based superconductors have been discovered. "Study of iron-based superconductors and their physical properties has been one of the major activities in condensed matter physics in the past several years," state the authors of the study.

Several powerful new techniques, including angle-resolved photoemission spectroscope and scanning tunneling microscopy, have been developed while studying high-Tc superconductors. These techniques, together with neutron scattering, nuclear magnetic resonance, and optical conducting measurements, have been applied to examine the properties of the new compounds.

Iron-based superconductivity shares many common features with the high-Tc cuprates. Both are unconventional superconductors in the sense that phonons are unlikely to play any dominant role in their superconductivity. Both are quasi-2D, and their superconductivity is in the proximity of antiferromagnetism. In the cuprates, the low-energy physics is described by a single band, while in the iron-based compounds, there are multi-orbitals involved. Yet some of the physics in the cuprates remain controversial. Deeper investigation of iron-based superconductors might broaden understanding of their unconventional superconductivity and provide a new route for finding higher temperature superconductors.

In mapping out recent breakthroughs, the co-authors outline superconducting crystal structures, the interplay between magnetism and superconductivity, and the electronic structure of iron-based as revealed through angle resolved photoemission spectroscopy and scanning tunneling spectroscopy experiments. They also review current theories regarding superconductivity. Over the past decade, they state in the study, "Tremendous progress has been achieved in the synthesis of materials, growth of single crystals, characterization of crystal structures, measurements of thermodynamics, and transport and various spectroscopic quantities for iron-based superconductors." "This has given us a comprehensive understanding on the chemical and crystal structures, band structures, spin and orbital orderings, pairing symmetry, and other physical properties of iron-based superconductors," they explain. Iron-based superconductors are proximate to antiferromagnetism, which suggests that AF fluctuations are responsible for the observed superconductivity. Investigating the superconductivity mechanism should focus in part on the cause of the pairing of electrons. Meanwhile, a theory should be developed to explain existing experimental data and to predict new experimental effects.

Like cuprate superconductivity, iron-based superconductivity is generally believed to originate predominantly from the electron-electron repulsive interaction, which induces antiferromagnetic fluctuations. A solid theoretical description of high-Tc superconductivity in both cuprate and iron-based materials remains a great challenge. Iron-based superconductors are multi-band materials. All five 3d orbitals of Fe hybridize strongly with As or Se 4p orbitals. They also couple strongly with each other and have contribution to both itinerant conducting electrons and localized magnetic moments.

Scientists in the field are still trying to develop a clear physical picture with reliable theoretical tools to treat an electronic system with strong coupling between itinerant and localized electrons. It is likewise important to design experimental measurements that could solve a number of key problems, which in turn could test theories on iron-based superconductivity. "While we are still far from the stage to predict high-Tc materials, there is good progress along this development," state the paper's coauthors. "It is possible in the future that theory may guide the search or synthesis of the high-Tc superconductors."

Co-authors Tao Xiang, based at the Institute of Physics, Chinese Academy of Sciences in Beijing, and Fu-Chun Zhang, a professor at Zhejiang University in the eastern Chinese city of Hangzhou, said: "Progress achieved in studies of the mechanism of iron-based superconductivity could have a strong impact on the study of theory of strongly correlated quantum systems."

Co-author Xianhui Chen, a professor at the University of Science and Technology of China, said that the recent discovery of superconductivity at 190 K in H2S under pressure up to 200 GPa, reported in December of 2014 by three scientists based at Germany's Max Planck Institute for Chemistry, "suggests that room temperature superconductivity could be achieved."

More information: Xianhui Chen, Pengcheng Dai, Donglai Feng, Tao Xiang, Fu-Chun Zhang. "Iron-based high transition temperature superconductors". *National Science Review*, nsr.oxfordjournals.org/content … 014/07/03/nsr.nwu007

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