Department of Physics & Astronomy
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Microscopic Magnetism

UT physics professors provide an overview of magnetism in iron-based superconductors for *Nature Physics*

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Four years is a common benchmark whereby cultures tend to recalibrate: new Olympic champions are crowned, new political representatives are elected, and an extra day is added to the calendar. Following their debut in 2008, iron-based high-temperature superconductors have provided plenty of interest to merit a review of their properties and potential, and two UT physics professors are co-authors of that assessment.

Professors Elbio Dagotto and Pengcheng Dai, along with their colleague Professor Jiangping Hu of the Chinese Academy of Sciences and Purdue University, provide an overview of these still-young materials in *Nature Physics* with the review article, "**Magnetism and its Microscopic Origin in Iron-Based High-Temperature Superconductors (http://www.nature.com/nphys/journal/v8/n10/full/nphys2438.html)**," published October 3. They focus on recent theoretical and experimental results, comparing iron-based superconductors both with their predecessors and with one another.

A century ago scientists discovered that the structure and properties of certain metalsaluminum, for example, or mercurycould render them superconducting. Because electric current that moves with no resistance would have practical applications for transportation, communications, and a myriad of other industries, much research has been dedicated to understanding how superconductivity originates. The key, scientists found, was in the pairing of electrons, which normally repel one another. Finding out exactly *why* electrons overcome their natural aversion to form pairs became the next logical question. In the earliest examples, (the so-called *conventional superconductors*), researchers learned that this phenomenon results from interactions between metal atoms within a material's crystal lattice structure and itinerant electrons, via vibrations called phonons. The drawback was that the transition temperaturethe temperature below which a material becomes a superconductor (*Tc*)was far too low to be practical. The next breakthrough came in the mid-1980s when studies showed that many copper-based compounds were not only superconducting, but also had higher transition temperatures than their conventional forerunners. Though they still functioned well below room temperature, the advent of high-temperature superconductors was yet another step forward. They also gave researchers another mystery to solve. Lattice vibrations could not account for electron pairing in these materials, but magnetism seemed to play a key role.

Why Magnetism?

Dai, Hu, and Dagotto point out in the introduction of their *Nature Physics* review that the past 25 years have seen tremendous effort dedicated to understanding the interplay between magnetism and superconductivity. Experimental studies have shown that the parent compounds of superconducting copper oxides (called cuprates) have an anti-ferromagnetic (AF) order, meaning they comprise the spins of neighboring ions that line up in opposite directions, alternating between up and down. As spin fluctuations within this framework may be responsible for electron pairing in cuprates, scientists logically considered the role of magnetism in the iron-based superconductors when they emerged in 2008. Since then, researchers the world over have conducted numerous experiments and theoretical calculations to narrow down the microscopic origin of magnetism in these materials. In their review, the authors examine those findings and note that at first glance, the results suggest that anti-ferromagnetism in iron-based superconductors is driven by Fermi surface nesting of itinerant, or roaming, electrons. Named for physicist Enrico Fermi, a Fermi surface is an abstract concept, deeply rooted in quantum mechanics, that helps define and predict the properties of metals with a crystalline structure. Its shape is dependent on the arrangement of a material's atoms and the number of electrons available to conduct electricity, and the behavior of those electrons at or near the Fermi surface plays a key role in determining many properties of a solid, such as its electrical resistance and the thermal conductivity. Surface nesting results when segments of one Fermi surface are connected to those of another via a unique lattice vector. Yet upon further analysis of four years' worth of investigations, Dai, Hu, and Dagotto clarify that Fermi surface nesting isn't quite a one-size-fits-all explanation for the magnetic origins of the newest class of superconductors.

A Growing, and Complex Family Tree

In the *Nature Physics* article, the authors consider several parameters to provide a current picture of magnetism in iron-based high-*Tc* superconductors. They discuss the magnetic order of these materials in a non-superconducting state and go on to examine doping effects, deviations from Fermi surface nesting, and the role of electron correlations. Citing 129 references, they offer in-depth insight into the fascinating and complex properties of this new class of materials. Since their initial discovery four years ago, iron-based superconductors have branched into three families, with their respective structures presenting differing possibilities about their magnetic origins. While the anti-ferromagnetic structure in iron pnictides suggests consistency with Fermi surface nesting, the AF order in the iron chalcogenides and iron selenides indicates that this is not the case. And although the copper oxides all have parent compounds that are insulators, the iron-based superconductors can have either metallic or insulating parent ground states, providing further indication that simple Fermi surface nesting isn't responsible for the microscopic origin of their AF order. Dopingthe addition of an electron or a space for one (*i.e.* a hole, that effectively behaves as a particle) can induce superconductivity in iron-based materials, yet also reveals some interesting and contradictory results. A review of neutron scattering and neutron diffraction experiments shows that in some cases superconductivity emerges when static AF order is suppressed, while in other samples superconductivity and anti-ferromagnetism coexist. The strength of electronic correlations also differs between family members in iron-based superconductors, with theory models and experiments indicating that coupling in pnictides is neither weak nor strong, but somewhere in the more intermediate region, while superconductivity in the recently-discovered selenides may potentially prove to be more dependent on electron correlations. Ultimately, this review illuminates the rich and complex nature of iron-based high-temperature superconductors, which will require further and more sophisticated theoretical and experimental studies to reveal their properties.

Both Dagotto and Dai have conducted numerous investigations on these and other materials as part of the condensed matter research group at UT. Dagotto is a Distinguished Professor with a joint appointment as a Distinguished Scientist with the Materials Science and Technology Division at Oak Ridge National Laboratory. He is a co-editor of the recently-published text Multifunctional Oxide Heterostructures and co-wrote the book's first chapter, which is dedicated to strongly-correlated electronic materials. Dai holds a Chair of Excellence with the Joint Institute for Advanced Materials (JIAM) and his group discovered the anti-ferromagnetic order in the parent compound of iron pnictide superconductors in a *Nature* paper, "Magnetic order close to superconductivity in the iron-based layered $LaO_{1-x}F_xFeAs$ systems" (*Nature* 453, 899-902 (2008)). This seminal paper on iron-based superconductivity appeared in May 2008 and has been cited more than 900 times.

- Read the ***Nature Physics* Article** **(http://www.nature.com/nphys/journal/v8/n10/full/nphys2438.html)**