# Neutron Scattering Continues as a Vital Tool in Superconductivity Studies

**Neutron scattering shows magnetic excitation mechanism at work in new materials.**

**IN 2008, THE TOTALLY UNEXPECTED** DISCOVERY OF A NEW CLASS OF SUPERCONDUCTORS, THE IRON PNICTIDES, SET OFF A FEVERISH international effort to understand them. The instruments and scientists at HFIR and SNS are leaders in exploring these exotic materials, scanning the subatomic details of their structures and magnetic properties.

Several key discoveries about the iron-based superconductors (Fe SCs) have emerged from research conducted at ORNL's neutron science facilities. Mark Lumsden and Andy Christianson of ORNL and Pengcheng Dai of ORNL and the University of Tennessee led early neutron scattering studies of the pnictides. Their work has revealed important details about the magnetic order of the parent compounds and its correlation with the emergence of superconductivity.

The Fe SCs are likely to have a broad range of practical uses, but their fascination for researchers is their fundamental physics. What they offer is a research platform more amenable to tinkering and more accessible to theory than the copper-based cuprate superconductors. The pnictides are structurally simpler and more chemically flexible than the cuprates, and a greater variety of Fe SCs can be synthesized, note Lumsden and Christianson. In addition, “theorists have more of a handle on the iron pnictides than the copper oxides,” Dai says. “Our hope for the iron-based superconductors is that, long-term, by understanding them, we will understand the cuprates and all the unconventional superconductors.”

Experimental tools available now—time-of-flight chopper spectrometers, position-sensitive detectors—were unknown when the cuprates were discovered, Dai notes. Measuring spin waves of up to 300 meV, routine now on instruments such as SNS's ARCS and SEQUOIA, was impossible only a few years ago, he says. Determining the exchange coupling of the cuprates took 15 years; doing the same for the iron pnictides took only a year or so because of the availability of powerful inelastic spectrometers.

*Pengcheng Dai (left) and instrument scientist Doug Abernathy at ARCS.*

Dai ticks off four main things neutron scattering has revealed about superconducting iron compounds since 2008: The parent iron compounds exhibit antiferromagnetic order, as in the cuprates. The effective exchange coupling is about 50 meV, less than in the cuprates. The nearest-neighbor exchange coupling is strongly anisotropic. And the next-nearest neighbor coupling is similar among the pnictides and the chalcogenides, two different classes of Fe SCs.

Also well established is that long-range magnetic order and superconductivity tend not to coexist. “It's clear that you need to get rid of long-range magnetic order, or at least suppress it, before superconductivity evolves," Lumsden says.

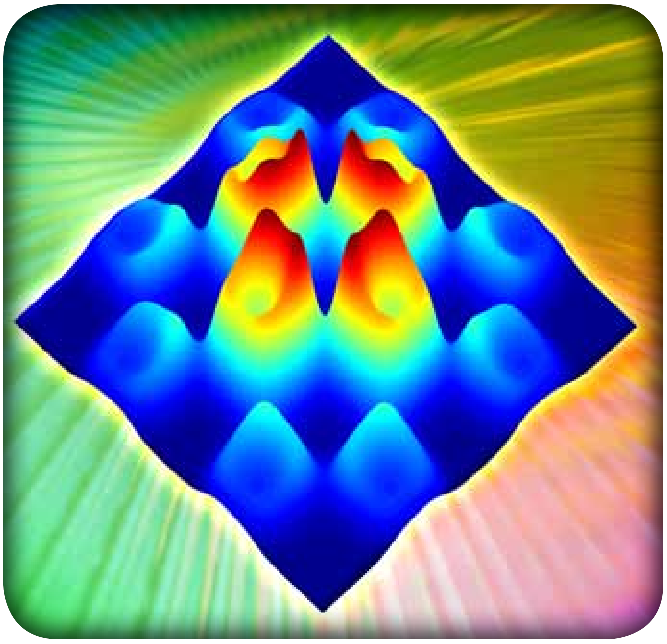
The lessons learned are mostly the basics, Christianson says. "We now know a lot about crystal structures. We know which materials we can make in this family that are superconducting and which are not. We know the basic magnetic properties, how these materials magnetically order, what the spin excitations look like. We know what the wave vector is in almost all cases where interesting magnetic behavior is occurring."

What are experiments on the Fe SCs contributing to the understanding of unconventional superconductivity? "Essentially, what we have learned about high-temperature superconductivity is that regardless of the material, the superconductivity always seems to be near an antiferromagnetic phase," says Dai. "We've learned that in the cuprates, in the case of heavy fermion superconductors, and now we've seen it in the case of iron-based superconductors."

Dai also notes the correlation between exchange coupling and the highest temperature at which superconductivity emerges in a material. That holds true for cuprate, pnictide, and heavy fermion superconductors. "So you have a whole span of materials. You can say this is all accident, but it may reveal some intrinsic features of the materials."

Big questions remain. Chief among them are the nature of the electron pairing symmetry and whether the magnetism is itinerant or local, say Lumsden and Christianson. Also, the entire magnetic spectrum, from zero energy to 300 meV, needs to be mapped for an Fe SC to see when it becomes superconducting and how the spin excitations evolve, Dai says. "From that, one can potentially calculate whether magnetic excitations have sufficient energy to drive superconductivity."

The recent discovery that iron selenide doped with potassium becomes superconducting is highly significant in the exploration of unconventional superconductivity, Dai notes. A key difference between cuprates and Fe SCs is that the parent compounds of the latter are metals. However, iron selenides doped with potassium or rubidium are insulators, like the cuprates. "This new class of materials could throw the thinking of the last three years into a tailspin. They hold the key to addressing some of the key debates."



*This image depicts part of a spectrum of magnetic fluctuations in an iron-based superconductor measured using neutron scattering. Their form suggests a universal mechanism for the origin of superconductivity in both copper oxide and iron-based superconductors.*

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