Researchers explore magnetic properties of iron-based superconductors

March 16 2009

These are BCS superconductors. Credit: Naval Research Laboratory

Scientists at the Naval Research Laboratory (NRL) have proposed theoretical models to explain the normal magnetic properties in iron-based superconductors. This research was published in the December 21, 2008 issue of *Nature Physics*. Their research builds on earlier research they conducted proposing a theoretical model for superconductivity in newly discovered iron-based superconductors. That earlier research was published in *Physical Review Letters*.

To set the stage for the NRL researchers' recent accomplishments, looking back over the last 50 years, the following are three very important discoveries in terms of superconducting materials:

• high-Tc cuprates in 1988, with critical temperature up to 160 K,
• Magnesium diboride (MgB_2) (2001, 39 K) and
• iron-based superconductors (2008, up to 57 K).

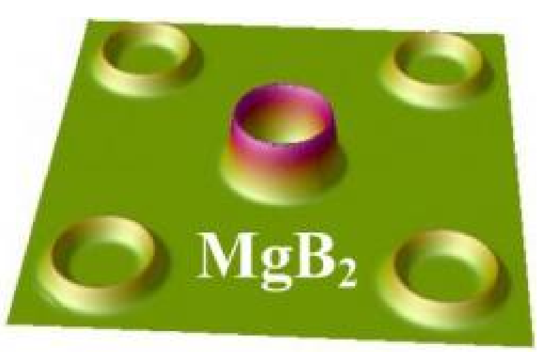
This figure illustrates superconductivity in cuprates. Credit: Naval Research Laboratory

Superconductivity in cuprates (chemical compounds containing copper oxide) is believed to originate from electron-electron interaction, magnetic or Coulomb, and is understood as so-called d-wave symmetry superconductivity.

While in conventional BCS superconductors, the superconducting order parameter is the same for all electrons, as illustrated in the first panel, for d-wave it actually changes sign depending on the direction in which an electron moves (roughly, like $\cos 2\alpha$). It is worth noting that in 20 years more than 100,000 papers have been published studying the high-Tc cuprates.

Many believe that MgB_2 was the next milestone in the area of superconducting materials for the reason that the mechanism there is conventional, yet critical temperature is much higher that in any other conventional superconductor, and, at that time, was second only to cuprates. It appeared that MgB_2 was the first example of a multigap superconductor, where the order parameter never changes sign, but is rather different for different groups of electrons. This fact was theoretically predicted at NRL and soon confirmed through experiments. While not elevating exactly to the level of excitement that cuprates produced, MgB_2 resulted in 4,000 publications in seven years.

The most recent breakthrough in superconductivity was discovery of high-temperature superconductivity in iron-based material such as LaFeAsO, $BaFe_2As_2$, and others. With iron being a strongly magnetic species, these materials immediately promised a new paradigm in search of new superconductors. Indeed, it became increasingly clear that superconductivity here is very dissimilar to either cuprates or MgB_2, and that string magnetism of iron likely plays a crucial role. Within a few months after the initial discovery, two NRL scientists, Dr. Igor Mazin and Dr. Michelle Johannes from the Materials Science and Technology Division, in collaboration with two researchers at Oak Ridge (both NRL alumni), proposed that a totally new superconducting state is realized in FeAs superconductors, which they dubbed "s±", where two groups of electrons sport not only different order parameters, but also different signs.



The compound MgB2. Credit: Naval Research Laboratory

Soon experimental evidence began to accumulate in favor of the NRL researchers' proposal, and currently is generally considered as the most likely scenario. Their paper was posted on March 19, 2008, and published in Physical Review Letters on August 1, 2008, and by December 2008 had been cited in other articles and preprints more than a hundred times. These novel materials remain one of the hottest issues in physics; since their discovery, papers on this subject have been appearing at a steady rate of 2.5 per day. Should this rate remain active, the number of publications will surpass that on MgB_2 in four years.

It appears though that superconductivity is not the only mystery of these so-called ferropnictides. In the undoped state, they demonstrate highly unusual magnetic properties with a very rare magnetic ordering pattern and highly unstable measurable magnitude of the magnetic moment. In fact, by small modifications of the materials they can be driven from practically nonmagnetic state to a strong magnetism comparable to that in pure iron. Most shockingly, the transition temperature barely changes. Some of the systems feature two transitions: a magnetic one, and a magnetically driven structural one. But, these occur counterintuitively; the structural transition occurs first and the magnetic one next. These and many other properties can hardly be explained by existing theories.

In the December 2008 Nature Physics article, Drs. Mazin and Johannes propose a highly unusual ground state. They suggest that the Fe ions are always magnetic in ferropnictides, but the observable magnetic moment is strongly reduced or entirely suppressed because of formation of antiferromagnetic domains whose boundaries are dynamic and strongly fluctuation. Observable long-range order appears when domains are large and their walls are pinned. Structural transition without observable long-range magnetism occurs when domain boundaries are predominantly antiphase ones so that the x/y symmetry is broken even though there is no long-range order. Superconducting composition where neither long-range magnetism nor structural distortions are observed corresponds to twin domains, which are small and their boundaries are dynamic. Should this conjecture be corroborated by the experiment, researchers will be entering an entirely new world of magnetic excitations (topological excitations of domain boundaries) that will most likely be very important, if not instrumental for the high-Tc superconductivity in ferropnictides.

Source: Naval Research Laboratory (news : web)

Citation: Researchers explore magnetic properties of iron-based superconductors (2009, March 16) retrieved 10 April 2024 from https://phys.org/news/2009-03-explore-magnetic-properties-iron-based-superconductors.html