Department of Physics & Astronomy

PHYSICS NEWS FLASH

Superconductors and Crystal Wizards

UT Physicists Have Two Articles in *Nature Physics* for September 2006

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UT's physicists contributed two articles to the September 2006 issue of *Nature Physics*. Professor Pengcheng Dai's group looks at the role of magnetism in superonductors; Adjunct Professor David Mandrus and his colleagues write up their work on crystals and how their structure can influence their properties.

It's All About Magnetism

Physics Professor Pengcheng Dai knows that understanding superconductivity means asking the right questions, using the right tools, and appreciating the finer points of matchmaking. That's because high-temperature (high-T_c) superconductors—the materials he studies—derive their superconducting properties from the way their electrons pair up to carry current with no resistance. Yet since this category of materials was discovered 20 years ago, scientists have been challenged to figure out exactly why the electrons form pairs in the first place. Dr. Dai and colleagues have recently discovered that magnetism might be one answer. Their findings are published in "Magnetic energy change available to superconducting condensation in optimally doped $YBa_2Cu_3O_{6.95}$."

Dr. Dai explained that, essentially, this is the first experiment to completely map out magnetic excitations in $YBa_2Cu_3O_{6.95}$, a superconducting material made from yttrium, barium, copper, and oxygen.

"We have used the measured magnetic excitation to calculate the magnetic contribution to the superconducting condensation energy," he said. The group found that the change in magnetic exchange energy between the normal and superconducting states was about 15 times larger than the superconducting condensation energy—more than enough to provide the driving force for high-T_c superconductivity in the material. Although these calculations do not yet prove that magnetism is the driving force for superconductivity, they show that magnetic energy changes are big enough to cause electron-pairing and superconductivity.

The article's first author, Hyungje Woo, is a post-doc in Dr. Dai's research group. Both also work with the Center for Neutron Scattering at Oak Ridge National Laboratory. Co-authors include Stephen Hayden of the University of Bristol (UK), Herb Mook of ORNL, Thomas Dahm of the Universität Tübingen, Douglas Scalapino of the University of California-Santa Barbara, Toby Perring of the Rutherford Appleton Laboratory (UK), and Fatih Dogan of the University of Missouri-Rolla.

The Crystal Wizards

Search for "crystals" on Google and you'll get more than 55 million hits. Some are devoted to jewelry, others to cell phone covers, and some to the 1960s girl group of the same name. But refine the search a little and you just might come across David Mandrus, whose specialty is growing crystals with novel and interesting characteristics.

Dr. Mandrus was a co-author of the *Nature Physics* paper "Nonlinear optical signatures of the tensor order in $Cd_2Re_20_7$." Other authors with UT connections are post-doc Ivan Sergienko, Ph.D. alumnus Jian He, and Rongying Jin, who is part of the new Joint Institute for Joint Materials. All are with the Materials Science and Technology Division at Oak Ridge National Laboratory.

Intrigued by the possibilities of fabricating materials with all kinds of properties—superconductivity, for example—these UT-ORNL scientists focus on crystals, structures with a basic pattern repeated in an orderly fashion. Once they've carefully grown and characterized the materials, they determine which measurements need to be made. Then they call on colleagues with the tools and know-how to complete that step.

For this project, they fabricated crystals made from cadmium, rhenium, and oxygen ($Cd_2Re_20_7$). Cadmium and rhenium are from the element class known as the transition metals. The resulting crystal is thus called a transition metal oxide (TMO), a type of structure highly susceptible to influences from light, heat, or an electric or magnetic field. Understanding how electrons move about in a TMO has been challenging because their interactions are so complex.

In the *Nature Physics* article, scientists from Simon Fraser University in Burnaby, Canada, took $Cd_2Re_20_7$ crystals from the Mandrus group to investigate their structure and consequently find a window into the properties of such complex systems.

Crystals are categorized based on their symmetry—how they remain unchanged even if they're flipped (reflection), spun a full 360 degrees (rotation), or moved up and down (translation). In inversion symmetry, however, everything is inverted about a point. By nature, Cd2Re207 crystals are continuously changing their structure, and as they do so, they break inversion symmetry. Post-doc Ivan Sergienko played a significant role in the work by sorting out the physical consequences when this occurs, particularly the observation of the Goldstone phonon mode.

Using nonlinear optics—the effects laser light can cause as it passes through an object—Jesse Petersen, Michael Caswell and Steven Dodge of SFU found that the crystals revealed symmetries they do not show in other experimental setups. The optical approach revealed properties of the $Cd_2Re_20_7$crystals' tensor order—a mathematical framework describing objects whose components transform according to certain rules. This work, which builds on two earlier papers in Physical Review Letters, is another step forward in understanding how a material's structure influences its behavior.

And all of that begins with the scientists who create the materials in the first place.

"There is a famous quote from Shelley: 'Poets are the unacknowledged legislators of the world,'" Dr. Mandrus said. "I like to think that the people who make materials are the 'unacknowledged legislators' of the world of condensed matter physics."