Physicists describe a new mechanism for metallic magnetism

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Predicting the magnetic behavior of metallic compounds is a surprisingly difficult problem for theoretical physicists. While the properties of a common refrigerator magnet are not a great mystery, certain materials exhibit magnetic properties that do not fit within existing theories of magnetism. One such material inspired a recent theoretical breakthrough by physicists at the University of California, Santa Cruz.

In a paper scheduled for publication in the August 26 issue of the journal *Physical Review Letters*, Sriram Shastry, a professor of physics at UCSC, and graduate student Jan Haerter describe "kinetic antiferromagnetism," a new mechanism for metallic magnetism in materials with a particular type of atomic lattice structure. The paper solves a problem that has stumped theoretical physicists for decades.

"New materials tend to drive theoretical advances," Shastry said. "Metallic magnetism is a real frontier field in theoretical physics, and it has practical applications in materials science."

Superconductors, magnetic storage devices (such as computer hard drives), and other applications are among the areas in which theoretical advances in metallic magnetism could play an important role.

Shastry and Haerter were interested in the unusual magnetic behavior of sodium cobalt oxide, a material first described in 1997 and intensively studied in recent years. The material can be made with variable amounts of sodium ions sandwiched between layers of cobalt oxide. The cobalt atoms form a triangular lattice structure that gives rise to "electronic frustration," which refers to the inability of the electrons in the system to achieve a single state that minimizes their total energy.

A landmark in the theoretical understanding of why certain metals are ferromagnetic--known as the Nagaoka-Thouless theorem--was achieved in the mid-1960s, but only applies to materials with an unfrustrated lattice structure. The frustrated case has remained unsolved for the past 40 years.

"This problem has been a tough nut to crack. We were able to make some progress and came up with a surprising result," Shastry said.

The magnetic properties of metals result from the configuration of the spins of electrons. Electron spin is a quantum mechanical property that can be either "up" or "down." In a ferromagnetic metal the electron spins tend to spontaneously align in the same direction. Ferromagnetism accounts for refrigerator magnets and most other magnetic behavior encountered in daily life.

In antiferromagnetism, the spins align in a regular pattern with neighboring spins pointing in opposite directions, or antiparallel. For electrons living on a triangular lattice, however, this configuration is frustrated, because two of the three electrons in each triangle must have the same spin.

"In physics, frustration is a good thing because it results in interesting properties. There are many kinds of frustrated systems in nature," Shastry said.

The kinetic antiferromagnetism in a triangular lattice described by Haerter and Shastry results from the movement of electrons when there is a single "electron hole," or unoccupied site for an electron, in the lattice. They used a theoretical model that enabled them to study the spin configuration around the electron hole, and found that the hole is surrounded by an unfrustrated hexagon in which the electron spins alternate in an antiferromagnetic pattern.

"The hole can be seen as a moving impurity around which spins tend to line up antiferromagnetically," the authors wrote in the paper.

Physicists use the concept of a moving electron hole to simplify the analysis of the motions of large numbers of electrons. The Nagaoka-Thouless theorem shows how the motion of a single hole on an unfrustrated lattice leads to ferromagnetism. Haerter and Shastry showed that the motion of a single hole on a frustrated lattice results in weak antiferromagnetism.

"It is surprising because the kinetic motion of electrons usually leads to ferromagnetism," Shastry said.

Sodium cobalt oxide is one of the first known metallic compounds with a triangular lattice structure. The density of electron holes in the lattice varies depending on the sodium content, and this has dramatic effects on the material's magnetic behavior. Haerter and Shastry's theory provides new insights into the physics of this unusual system.

Source: University of California - Santa Cruz

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