Nano-sandwich Triggers Novel Electron Behavior

May 4 2009

(PhysOrg.com) -- A material just six atoms thick in which electrons appear to be guided by conflicting laws of physics depending on their direction of travel has been discovered by a team of physicists at the University of California, Davis. Working with computational models, the team has found that the electrons in a thin layer of vanadium dioxide sandwiched between insulating sheets of titanium dioxide exhibit one set of properties when moving in forward-backward directions, and another set when moving left to right.

With its unique properties, the material could open up a new world of possibilities in the emerging field of spintronics technology, which takes advantage of the magnetic as well as the electric properties of electrons in the design of novel electronic devices.

A paper describing the material and its properties appears in the April 22 issue of *Physical Review Letters.*

“Our model is demonstrating a new kind of band structure [dynamics of electrons], which no one has been aware of before,” said Warren Pickett, professor and chair of the physics department at UC Davis. “We think that some of the transport properties we’re seeing in the material — electrical conduction and conduction in a magnetic field — will be different than anything seen before.”

The discovery comes five years after a group at the University of Manchester in England first isolated graphene, a single-layer lattice of carbon atoms. That material, too, had unique electronic properties, and it sparked a huge surge of interest among physicists and materials scientists, who have published hundreds of papers on it. The team termed the behavior of electrons in graphene "Dirac-like" because of its similarity to the behavior of massless particles as described in an equation formulated by the illustrious theoretical physicist Paul Dirac.

Now Pickett and co-author Victor Pardo, a professor at the University of Santiago de Compostela in Spain who was a visiting professor at UC Davis when he did the work, have coined the term "semi-Dirac" to characterize the behavior of electrons in their multilayered vanadium dioxide lattice.

In this nanomaterial, Pickett explained, the sandwiching layers of the insulating titanium dioxide confine the vanadium, enforcing two-dimensional motion on its electrons. When the electrons move in one direction, they behave in the usual fashion, as particles with mass, but movement in the other direction produces behavior characteristic of particles without mass.

"It's important that we use precisely three layers of vanadium dioxide," Pickett said. "Using one or two layers only produces a magnetic insulator, while anything more than three layers produces a fairly normal magnetic metal that exhibits conducting behavior. The semi-Dirac system is neither conducting nor insulating."

A big advantage that the vanadium lattice has over the one-layer thick graphene is greater rigidity, which will make it easier to etch into experimental or functional shapes, Pickett said.

For the time being, the material exists only as a computational model. Yet many of the basic, underlying processes and principles of physics are first established theoretically, with or without computational analysis, Pickett said.

Pickett and Pardo have teamed with UC Davis physics professor Rajiv Singh and graduate student Swapnonil Banerjee to investigate the material's properties. The team has constructed a classical mathematical model called a "tight-binding" model that they expect will promote a theoretical understanding of the material at the most basic level. "We're pretty confident that this nanostructure can be made, and made clean enough to demonstrate the properties the model has demonstrated," Pickett said.

The group has already achieved a basic understanding of the low energy behavior of semi-Dirac systems and has submitted a second paper for publication describing the peculiar behavior.

Provided by UC Davis (news : web)