Unusual electrons go with the flow

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Courtesy of Princeton University
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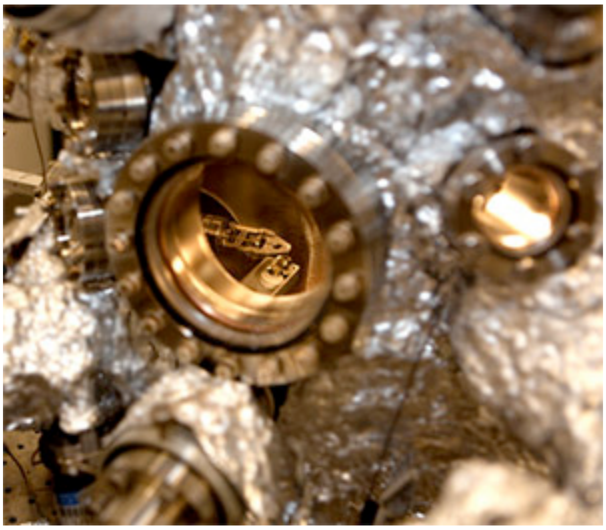
Scientists on a quest to discover new states of matter have found that on the surfaces of certain materials, charged subatomic particles known as electrons act like miniature superheroes: they relentlessly dodge cliff-like obstacles, sometimes moving straight through barriers.

The findings represent the first time such behavior by electrons has been tracked and recorded, scientists said, and hints at the possibilities of speeding up integrated circuits that process information by flow of electrons between different devices.



This view provides a look into the heart of a scanning tunneling microscope in the specially designed Princeton Nanoscale Microscopy Laboratory, where precise measurements are possible because sounds and vibrations, through many technologies, are kept to a minimum. (Photo: Brian Wilson)

The new materials might break the bottleneck that occurs when metallic interconnects get so small that even the tiniest atomic imperfection hinders their performance, the researchers said.

Princeton University physicist Ali Yazdani and colleagues noted the odd behavior in a “topological surface state” on a microscopic wedge of the metal antimony. The work is reported in the July 15 issue of the research journal *Nature*.

Normally, electron flow in materials is hindered by imperfections—seemingly slight edges and rifts act like cliffs and crevasses in this microscopic world. Recent theories, however, predict that electrons on the surface of some compounds, containing elements such as antimony, can be immune to such disruptions.

Electrons, like other subatomic particles, have both particle-like and wavelike properties, in a duality that has never been satisfactorily explained, yet shows itself persistently in experiments. The electrons that defy blockages in their flow, Yazdani said, do so because of a special form of electron wave that seemingly alters the pattern of flow around any imperfection.

Many of the “topological” materials, such as antimony, have been important in the world economy, but their unusual surface conduction hadn't previously been examined. Part of

the challenge had been the difficulty in measuring the flow of electrons at the surface.

“Material imperfections just cannot trap these surface electrons,” said Yazdani. “This demonstration suggests that surface conduction in these compounds may be useful for high-current transmission even in the presence of atomic-scale irregularities.”

An electron is a subatomic particle that carries a negative electric charge. It typically orbits an atom's nucleus, but electrons can also hop between atoms in some materials, such as crystals, and move freely in their interiors or surfaces.

These free electrons are responsible for electric current, playing central roles in many industrial, scientific and medical applications. For most metals, electrons in the interior carry most of the current, with the surface electrons not moving much.

The intensity of electric current depend on a given material's “conductivity” at a given temperature. Metals such as copper and gold are good conductors, allowing for rapid flow of electrons. Materials such as glass and Teflon, with structures that hinder electron flow, are poor conductors. The atoms of metals have a structure allowing their electrons to behave as if they were free, or not bound to the atom.

The Princeton work is part of an inquiry into materials called topological insulators, which act as insulators in their interior while letting charges move on their boundary. In a phenomenon known as the quantum Hall effect, this behavior occurs when a magnetic field is applied to the material at a right angle. A type of topological insulator has also been found in which this behavior occurs without a magnetic field.

The antimony crystal used in the new experiment is a metal but shares the unusual surface electron characteristics with related insulating compounds.

Because the electrons move freely on its surface regardless of its shape, the material has a “topological surface state,” Yazdani said. Topology is a mathematical field concerned with spatial properties preserved despite deformation, like stretching, of objects. Accordingly, a doughnut and a coffee cup can be seen as topologically the same because they both are basically areas with holes in the middle.

Yazdani's team was able to measure how long electrons stay in a region of the material and how many of them flow through to other areas. The results showed a surprising efficiency by which surface electrons on antimony go through barriers that typically stop other surface electrons on the surface of most conducting materials, such as copper, said the researchers. They worked in the specially designed Princeton Nanoscale Microscopy Laboratory, where precise atomic-scale measurements are possible because sounds and vibrations are minimized.

The team used a powerful scanning tunneling microscope to view electrons on the surface of the antimony sample. In such a microscope, an image is produced by pointing a finely focused electron beam, as in a TV set, across a sample. Researchers gently scan the microscope's single-atom sharp metal tip just above the surface of the material being studied. By monitoring how electrons flow from the needle into the sample, the instrument can produce precise images of atoms, as well as the flow of electron waves.

The experiment, Cava said, “shows for the first time that the theoretically predicted immunity of topological surface states to death at the hands of the ever-present defects in the atomic arrangements on crystal surfaces is really true.”