Topological materials become switchable
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A donut is not a breakfast roll. Those are two very clearly distinguishable objects: One has a hole, the other does not. In mathematics, the two shapes are said to be topologically different—you cannot transform one into the other by small, continuous deformations. Therefore, the difference between them is robust to perturbations: Even if you knead and bend the bun it still doesn’t look like a donut.

Such topological properties also play an important role in material science, albeit in a somewhat more abstract way. If a material property can be explained topologically, then it is also robust to disturbances: A change in the environmental conditions does not make it disappear. Now, for the first time, a research team has succeeded in specifically switching such a topological property: Certain material states are stable against disturbances in a wide range of parameters, but at a certain magnetic field they can be switched off completely. This makes topological material properties manipulatable for the first time.

Geometry in abstract spaces

In physics, "topological properties" of a material have nothing to do with its geometric shape—it is not about crystal samples that are donut-shaped or spherical. Rather, the term "topological properties" refers to the complex interaction of the many electrons in the material.

This interaction can be represented mathematically in very specific ways. It is often useful not to think about the position of the electrons, but rather about their momentum—or in other words: about their position in an abstract "momentum space." In such mathematical spaces, certain properties of the material can be studied, which can be distinguished from each other according to topological criteria—similar to donut and bun.

"Finding such topological properties is an exciting thing in itself; in 2016, the Nobel Prize in Physics was awarded for the discoveries of such states," says Prof. Silke Bühler-Paschen from the Institute of Solid State Physics at TU Wien. "But we have now been able to show something completely new: we have succeeded for the first time in manipulating and even switching off such topological states."

Extreme topological effects on slow charge carriers

A special material made of cerium, bismuth and palladium was used for this purpose. Bühler-Paschen’s research group had already made several spectacular discoveries in previous years using this material. For example, they were able to demonstrate exotic topological behavior in this material by precisely measuring its electrical or thermal properties.

This behavior results from the fact that the electric charge in this material moves in a peculiar way. In an ordinary electrically conductive material, current flows simply by individual electrons moving through the material. In this special material, however, it is different.

The interaction of many charge carriers creates
very special "quasiparticles" here—a collective excitation of the charge carriers that can propagate through the material, similar to how sound can propagate through air as a density wave without individual air particles having to move from the sound source to the sound receiver.

These excitations move very slowly in this material. In a sense, they do not get past each other very well. And this leads to the fact that the topological properties of the material in momentum space have particularly strong consequences in this case.

Switching off topological properties

"Our measurements show that these electrical and thermal properties are indeed robust, as one would expect from topological material properties," says Bühler-Paschen. Small impurities or external disturbances do not bring about a dramatic change. "But surprisingly, we found out: with an external magnetic field, you can control these topological properties. You can even make them disappear completely at a certain point. So we have stable, robust properties that you can selectively turn on and off."

This control is made possible by the internal structure of the excitations, which are responsible for charge transport: They carry not only electric charge, but also a magnetic moment—and this makes it possible to switch them through a magnetic field.

"If you apply an ever stronger external magnetic field, you can imagine these charge carriers to be pushed closer and closer together until they meet and annihilate each other—similar to a matter particle and an antimatter particle if you let them collide," says Silke Bühler-Paschen.

Worldwide search for exciting applications

The experiments were conducted at TU Wien (Vienna), but for some additional measurements the team was able to use high-field laboratories in Nijmegen (Netherlands) and at Los Alamos National Laboratory (U.S.). Theoretical support was provided by Rice University (U.S.).