The surface knows what lies beneath: Physicists show how to detect higher-order topological insulators

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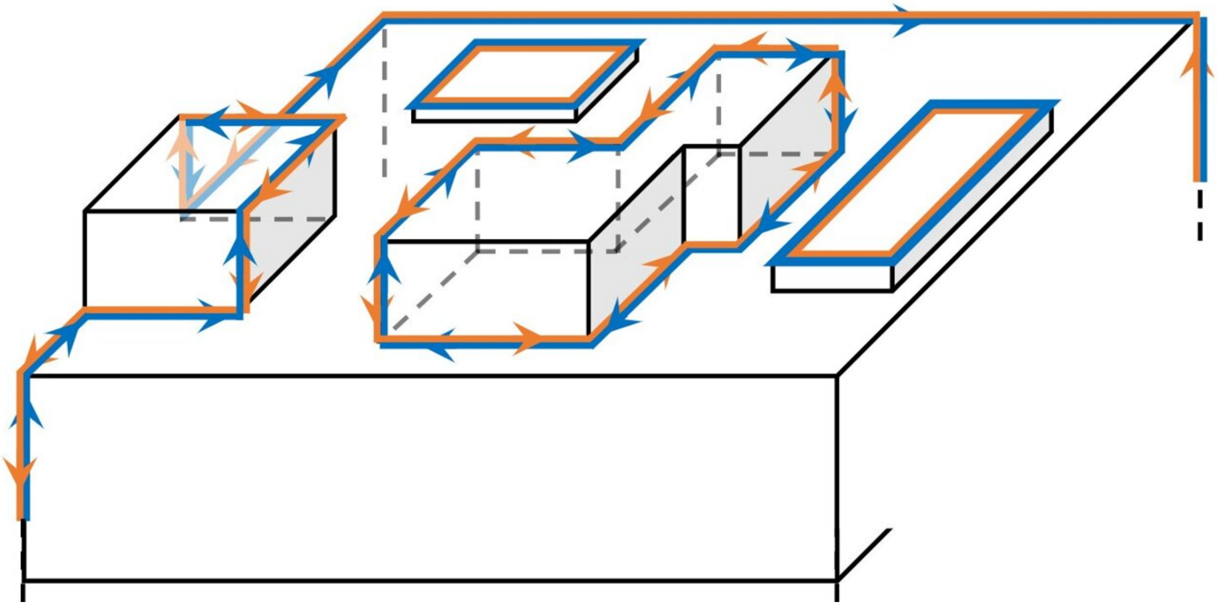

One-dimensional surface hinge states characteristic of HOTIs. Researchers have shown how to detect HOTIs without observing such hinge states. Credit: The Grainger College of Engineering at University of Illinois Urbana-Champaign

Just like a book can't be judged by its cover, a material can't always be judged by its surface. But, for an elusive conjectured class of materials, physicists have now shown that the surface previously thought to be "featureless" holds an unmistakable signature that could lead to the first definitive observation.

Higher-order topological insulators, or HOTIs, have attracted attention for their ability to conduct electricity along one-dimensional lines on their surfaces, but this property is quite difficult to experimentally distinguish from other effects. By instead studying the interiors of these materials from a different perspective, a team of physicists has identified a surface signature that is unique to HOTIs that can determine how light reflects from their surfaces.

As the team reports in the journal *Nature Communications,* this property could be used to experimentally confirm the existence of such topological states in real materials.

"The bulk or interior properties of HOTIs and other topological insulators have been discounted for a long time, but it turns out that a lot of interesting things are going on there as well," said Barry Bradlyn, a physics professor at the University of Illinois Urbana-Champaign and a project co-lead. "When we looked at the surfaces through a more careful lens, they immediately stood out as far from trivial or featureless."

For a long time, topological insulators have been noted for their ability to carry electrical currents on their surfaces while having insulating interiors. HOTIs, though, would restrict electrical conduction to a one-dimensional edge, or "hinge," rather than the entire two-dimensional surface.

"Charles Kane, who discovered topological insulators, introduced a good analogy," said Benjamin Wieder, a faculty member at the Institut de Physique Théorique, Université Paris-Saclay and project co-lead. "We can think of standard topological insulators as Hershey's Kisses. A conducting metal foil wrapped around an insulator that doesn't conduct electricity, the chocolate in this case, is a pretty good way to understand them. With HOTIs, though, it's as though someone took the foil and crumpled it into a thin ring encircling the chocolate."

While surface conducting states have been observed in standard topological insulators, resolving the hinge in HOTIs has proven to be exceptionally difficult. Bradlyn explained that this property can only exist in material samples that have an unusually high degree of symmetry, meaning that their crystal structures must be unrealistically perfect.

Instead, Bradlyn and his collaborators turned their attention from the hinge state to the interior, where the electrons tend to "delocalize" from individual atoms and spread through the entire material. Unlike past studies that treat all electrons the same, the researchers considered differences in spin—a property of electrons that allows them to behave as miniature magnets.

"When we divided the interior electrons into their two possible spin states, up and down, we saw that each state leaves a unique surface signature," said Kuan-Sen Lin, a physics graduate student at the U. of I. and the study's lead author. "Even though the surface of a HOTI seems uninteresting, when you look at what each spin is separately doing on the surface, an unmistakable new behavior emerges that we hope will soon be measured in experiment."

Because electrons with different spins behave as magnets, they respond differently when electric voltage is applied to the material, causing the two spin states to accumulate on opposite sides. This accumulation can be detected by taking advantage of the magneto-optic Kerr effect, in which the polarization, or orientation of the light, changes when it reflects from the surface of a magnet. In the case of HOTIs, the researchers calculated the polarization change from each spin state, and they found it to be exactly half the change that would result from an ordinary insulator.

"In the Kiss analogy, we might expect that because the foil has been crumpled, the chocolate is in direct contact with the air," said Gregory Fiete, a physics professor at Northeastern University and a corresponding author on the study. "With the spin-dependent surface behaviors we found, we can say that there is in fact a transparent layer that keeps the chocolate separate from the rest of the supermarket."

By building on first-principles calculations with the specialized theoretical toolkit the researchers developed for this study, they identified the metal bismuth bromide as a very strong candidate for observing this effect. They are currently working with U. of I. physics professor Fahad Mahmood and U. of I. materials science & engineering professor Daniel Shoemaker to design and perform the experiments proposed in this study.

"The properties of HOTIs that we identified here would be very useful in quantum computing and spintronic devices, but we need to see them in experiment first," Bradlyn said. Wieder added, "We hope that our work shows that the insides and surfaces of topological materials still host many mysterious and advantageous features if you know how to look for them."

The first principles calculations on bismuth bromide were performed by Zhaopeng Guo and Zhijun Wang of the Chinese Academy of Sciences. Additional computational support was provided by Jeremey Blackburn of Binghamton University. Giandomenico Palumbo of the Dublin Institute for Advanced Studies and Yoonseok Hwang of the U. of I. also contributed to this work.

More information: Kuan-Sen Lin et al, Spin-resolved topology and partial axion angles in three-dimensional insulators, *Nature*

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