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# Physicists Discover Novel Quantum Effect in Bilayer Graphene

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Theorists at The University of Texas at Dallas, along with colleagues in Germany, have for the first time observed a rare phenomenon called the quantum anomalous Hall effect in a very simple material. Previous experiments have detected it only in complex or delicate materials.

Dr. Fan Zhang, associate professor of physics in the School of Natural Sciences and Mathematics, is an author of a study published on Oct. 6 in the journal Nature that demonstrates the exotic behavior in bilayer graphene, which is a naturally occurring, two-atom thin layer of carbon atoms arranged in two honeycomb lattices stacked together.

The quantum Hall effect is a macroscopic phenomenon in which the transverse resistance in a material changes by quantized values in a stepwise fashion. It occurs in two-dimensional electron systems at low temperatures and under strong magnetic fields. In the absence of an external magnetic field, however, a 2D system may spontaneously generate its own magnetic field, for example, through an orbital ferromagnetism that is produced by interactions among electrons. This behavior is called the quantum anomalous Hall effect.

“When the rare quantum anomalous Hall effect was investigated previously, the materials studied were complex,” Zhang said. “By contrast, our material is comparably simple, since it just consists of two layers of graphene and occurs naturally.”

Dr. Thomas Weitz, an author of the study and a professor at the University of Göttingen, said: “Additionally, we found quite counterintuitively that even though carbon is not supposed to be magnetic or ferroelectric, we observed experimental signatures consistent with both.”

In research published in 2011, Zhang, a theoretical physicist, predicted that bilayer graphene would have five competing ground states, the most stable states of the material that occur at a temperature near absolute zero (minus 273.15 degrees Celsius or minus 459.67 degrees Fahrenheit). Such states are driven by the mutual interaction of electrons whose behavior is governed by quantum mechanics and quantum statistics.

“We predicted that there would be five families of states in bilayer graphene that compete with each other to be the ground state. Four have been observed in the past. This is the last one and the most challenging to observe,” Zhang said.

In experiments described in the Nature article, the researchers found eight different ground states in this fifth family that exhibit the quantum anomalous Hall effect, ferromagnetism and ferroelectricity simultaneously.

“We also showed that we could choose among this octet of ground states by applying small external electric and magnetic fields as well as controlling the sign of charge carriers,” Weitz said.

“We predicted, observed, elucidated and controlled a quantum anomalous Hall octet, where three striking quantum phenomena — ferromagnetism, ferroelectricity and zero-field quantum Hall effect — can coexist and even cooperate in bilayer graphene.”
Dr. Fan Zhang, associate professor of physics in the School of Natural Sciences and Mathematics

The ability to control the electronic properties of bilayer graphene to such a high degree might make it a potential candidate for future low-dissipation quantum information applications, although Zhang and Weitz said they are primarily interested in revealing the “beauty of fundamental physics.”

“We predicted, observed, elucidated and controlled a quantum anomalous Hall octet, where three striking quantum phenomena — ferromagnetism, ferroelectricity and zero-field quantum Hall effect — can coexist and even cooperate in bilayer graphene,” Zhang said. “Now we know we can unify ferromagnetism, ferroelectricity and the quantum anomalous Hall effect in this simple material, which is amazing and unprecedented.”

Read the original article on The University of Texas at Dallas.