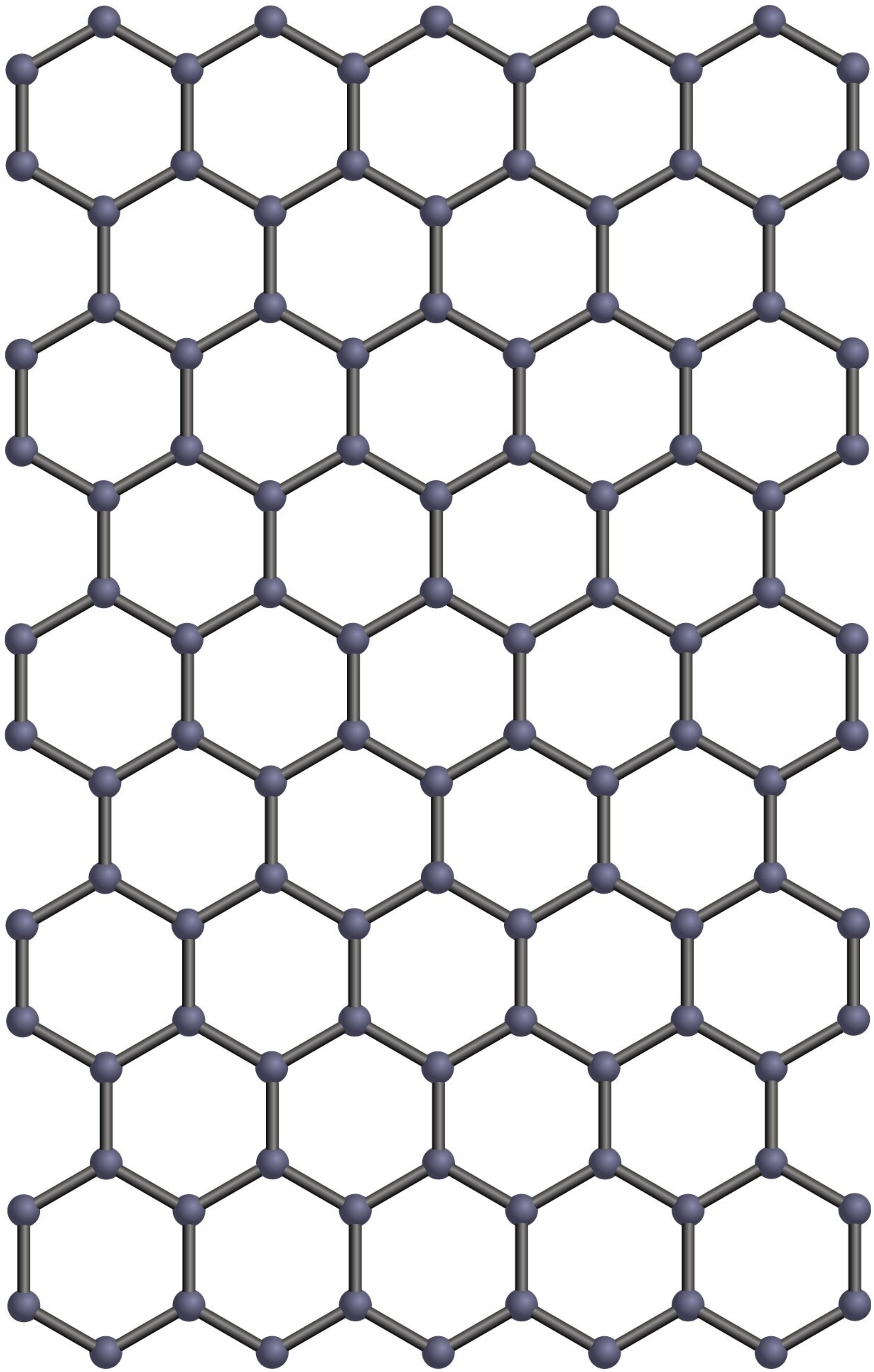
Graphite offers up new quantum surprise

February 25 2019



Credit: CC0 Public Domain

Researchers at The University of Manchester in the UK, led by Dr. Artem Mishchenko, Prof Volodya Fal'ko and Prof Andre Geim, have discovered the quantum Hall effect in bulk graphite—a layered crystal consisting of stacked graphene layers. This is an unexpected result because the quantum Hall effect is possible only in so-called two-dimensional (2-D) systems where electrons' motion is restricted to a plane and must be disallowed in the perpendicular direction. They have also found that the material behaves differently depending on whether it contains odd or even number of graphene layers—even when the number of layers in the crystal exceeds hundreds. The work is an important step to the understanding of the fundamental properties of graphite, which have often been misunderstood, especially in recent years.

In their work, published in *Nature Physics*, Mishchenko and colleagues studied devices made from cleaved graphite crystals, which essentially contain no defects. The researchers preserved the high quality of the material also by encapsulating it in another high-quality layered material—hexagonal boron nitride. They shaped their devices in a Hall bar geometry, which allowed them to measure electron transport in the thin graphite.

"The measurements were quite simple." explains Dr. Jun Yin, the first author of the paper. "We passed a small current along the Hall bar, applied strong magnetic field perpendicular to the Hall bar plane and then measured voltages generated along and across the device to extract longitudinal resistivity and Hall resistance.

Dimensional reduction

Fal'ko who led the theory part said: "We were quite surprised when we saw the quantum Hall effect (QHE) - a sequence of quantized plateaux in the Hall resistance—accompanied by zero longitudinal resistivity in our samples. These are thick enough to behave just as a normal bulk semimetal in which QHE should be forbidden."

The researchers say that the QHE comes from the fact that the applied magnetic field forces the electrons in graphite to move in a reduced dimension, with conductivity only allowed in the direction parallel to the field. In thin enough samples, however, this one-dimensional motion can become quantized thanks to the formation of standing electron waves. The material thus goes from being a 3-D electron system to a 2-D one with discrete energy levels.

Even/odd number of graphene layers is important

Another big surprise is that this QHE is very sensitive to even/odd number of graphene layers. The electrons in graphite are similar to those in graphene and come in two "flavours" (called valleys). The standing waves formed from electrons of two different flavours sit on either even—or odd—numbered layers in graphite. In films with even number of layers, the number of even and odd layers is the same, so the energies of the standing waves of different flavours coincide.

The situation is different in films with odd numbers of layers, however, because the number of even and odd layers is different, that is, there is always an extra odd layer. This results in the energy levels of the standing waves of different flavours shifting with respect to each other and means that these samples have reduced QHE energy gaps. The phenomenon even persists for graphite hundreds of layers thick.

Observations of the fractional QHE

The unexpected discoveries did not end there: the researchers say they also observed the fractional QHE in thin graphite below 0.5 K. The FQHE is different from normal QHE and is a result of strong interactions between electrons. These interactions, which can often lead to important collective phenomena such as superconductivity, magnetism and superfluidity, make the charge carriers in a FQHE material behave as quasiparticles with charge that is a fraction of that of an electron.

"Most of the results we have observed can be explained using a simple single-electron model but seeing the FQHE tells us that the picture is not so simple," says Mishchenko. "There are plenty of electron-electron interactions in our graphite samples at high magnetic fields and low temperatures, which shows that many-body physics is important in this material."

Coming back to graphite

Graphene has been in the limelight these last 15 years, and with reason, and graphite was pushed back a little by its one-layer-thick offspring, Mishchenko adds. "We have now come back to this old material. Knowledge gained from graphene research, improved experimental techniques (such as van der Waals assembly technology) and a better theoretical understanding (again from graphene physics), has already allowed us to discover this novel type of the QHE in graphite devices we made.

"Our work is a new stepping stone to further studies on this material, including many-body physics, like density waves, excitonic condensation or Wigner crystallization."

The graphite studied here has natural (Bernal) stacking, but there is another stable allotrope of graphite—rhombohedral. There are no reported transport measurements on this material so far, only lots of theoretical predictions, including high-temperature superconductivity and ferromagnetism. The Manchester researchers say they thus now plan to explore this allotrope too.

"For decades graphite was used by researchers as a kind of 'philosopher's stone' that can deliver all probable and improbable phenomena including room-temperature superconductivity," Geim adds with a smile. "Our work shows what is, in principle, possible in this material, at least when it is in its purest form."

More information: Dimensional reduction, quantum Hall effect and layer parity in graphite films, *Nature Physics* (2019). DOI: 10.1038/s41567-019-0427-6 , www.nature.com/articles/s41567-019-0427-6

Provided by University of Manchester

Citation: Graphite offers up new quantum surprise (2019, February 25) retrieved 9 April 2024 from https://phys.org/news/2019-02-graphite-quantum.html