TECHNOLOGY UPDATE

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Supercritically charged vacancy in graphene is like an artificial atom

A team of physicists in the US, Japan and Belgium say they have discovered a new way to control and guide electrons in graphene by removing a single carbon atom from its perfect honeycombed lattice. The vacancy produced can host a local charge and this charge can be built up gradually by applying voltage pulses with the tip of a scanning tunnelling microscope (STM). This is the first observation ever of a stable and tuneable charged vacancy in graphene and could allow researchers to fabricate artificial atom arrays for performing the electronic equivalent of optical operations.

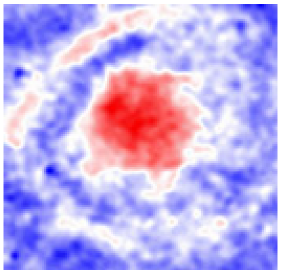

Figure 1

Graphene, a 2D honeycomb lattice of carbon, first isolated in 2004, boasts a wealth of fascinating electronic properties, many of which come from the fact that electrons in the material travel through it at extremely high speeds for relatively long distances without hitting anything. This means that electronic devices, like transistors, made from graphene could be faster and lighter than any that exist today. One of the challenges in graphene research today, however, is to find out ways to tailor its electronic properties and control how electrons move through it.

A team led by Eva Andrei of Rutgers University in the US has now found that the vacancies formed by removing a single carbon atom from graphene can stably host a local charge and that this charge can be built up gradually by applying voltage pulses with the tip of an STM. When the charge exceeds a certain critical value, the electrons in graphene fall towards the vacancy where they become trapped in satellite orbits, resembling those of an artificial atom.

"In fact, the transition from a sub-critical to the supercritical regime and the concomitant trapping of electrons is the condensed matter analogue of the long-sought-after phenomenon of atomic collapse at super-heavy nuclei, whereby electrons are expected to fall into the nucleus, emitting positrons," explains Andrei. "In real atoms, this collapse has never been observed because it would require us to study super-heavy nuclei, which do not exist in nature."

Bound states at vacancy sites can be tuned by a gate voltage

Remarkably, we find that the bound states at the vacancy sites can be tuned by a gate voltage, and that the charge trapping mechanism can be turned on and off, so providing a new mechanism to control and guide electrons in graphene, Andrei tells *nanotechweb.org*.

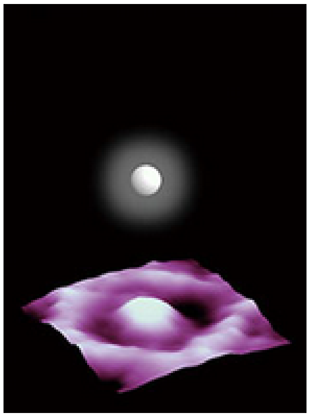

Figure 2

As with many discoveries in science, this one was rather serendipitous too, she adds. "After identifying a single atom vacancy using atomic resolution STM, Yuhang Jiang, a post-doctoral researcher in our group, found that if she used the STM tip to apply gentle voltage pulses at the centre of the vacancy, it became charged. She further observed that the amount of charge hosted by the vacancy increases with each additional voltage pulse. Most surprisingly, she saw that this charge was absolutely stable."

The team used a technique called Landau level spectroscopy together with numerical simulations to measure the amount of charge deposited.

"The discovery that vacancies in graphene can stably host a charge that is tuneable and controllable, and which traps or releases electrons in response to an applied gate voltage, has important implications," adds Andrei. "It provides a completely new 'knob' to control and guide electrons in graphene that could potentially allow us to fabricate artificial atom arrays for performing the electronic equivalent of optical operations."

The researchers say they are now busy studying other phenomena associated with vacancies in graphene, including electrostatic switching of the material's magnetic moment through the use of the so-called Kondo effect.

The present work is detailed in *Nature Physics*
doi:10.1038/nphys3665.