

Physicists find a new state of matter in a 'transistor'

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McGill University researchers have discovered a new state of matter, a quasi-three- dimensional electron crystal, in a material very much like those used in the fabrication of modern transistors. This discovery could have momentous implications for the development of new electronic devices. Currently, the number of transistors that can be inexpensively crammed onto a single computer chip increases exponentially, doubling approximately every two years, a trend known as Moore's Law. But there are limits, experts say. As chips get smaller and smaller, scientists expect that the bizarre laws and behaviours of quantum physics will take over, making ever-smaller chips impossible.

This discovery, and other similar efforts, could help the electronics industry once traditional manufacturing techniques approach these quantum limits over the next decade or so, the researchers said. Working with one of the purest semiconductor materials ever made, they discovered the quasi-three-dimensional electron crystal in a device cooled at ultra-low temperatures roughly 100 times colder than intergalactic space. The material was then exposed to the most powerful continuous magnetic fields generated on Earth. Their results were published in the October issue of the journal *Nature Physics*.

Two-dimensional electron crystals were discovered in the laboratory in the 1990s, and were predicted as far back as 1934 by renowned Hungarian physicist Eugene Wigner.

"Picture a sandwich, and the ham in the middle is your electrons,"

explained Dr. Guillaume Gervais, director of McGill's Ultra-Low Temperature Condensed Matter Experiment Lab. "In a 2D electron crystal, the electrons are squeezed between two materials and they're very two dimensional. They can move on a plane, like billiard balls on a pool table, but there's no up and down motion. There's a thickness, but they're stuck."

Until an accidental discovery during one of Gervais's earliest ultra-low temperature experiments in 2005, however, no one predicted the existence of quasi-three-dimensional electron crystals.

"We decided to tweak the two-dimensionality by applying a very large magnetic field, using the largest magnet in the world at the Magnet Lab in Florida," he said. "You only have access to it for about five days a year, and on the third day, something totally unexpected popped."

Gervais's "pop" was the startling transformation of a two-dimensional electron system inside the semiconducting material into a quasi-three-dimensional system, something existing theory did not predict.

"It's actually not quite 3-D, it's an in-between state, a totally new phenomenon," he said. "This is the kind of thing the theoreticians love. Now they're scratching their heads and trying to fine-tune their models."

The importance of this discovery to micro-electronics and computing could be profound. Since the invention of the integrated circuit in 1958, Moore's Law has powered the ever-accelerating home electronics, personal computer and Internet revolutions which have changed the world. But, Gervais explained, Moore's Law is not an irresistible force, and some time in the next decade, it will inevitably collide with the immovable object of the laws of physics.

"In a standard transistor, you have a gate and the electron flow is

controlled by it like a faucet would control a gas flow," he said. "You can understand the particles as independent units, which lets us treat them as ones and zeroes or on and off switches in digital computing.

"However, once you get down to the nano scale, quantum forces kick in and the electrons may condense into a collective state and lose their individual nature. Then all sorts of bizarre phenomena pop up. In some cases, the electrons may even split. Concepts of 'on' and 'off' lose all meaning under these conditions."

"This issue is academic, but it's not just academic. The same semiconductor materials we're working with are currently used in cellphones and other electronic devices. We need to understand quantum effects so we can use them to our own advantage and perhaps reinvent the transistor altogether. That way, progress in electronics will keep happening ."

Article: [www.nature.com/nphys/journal/v ... t/abs/nphys1094.html](http://www.nature.com/nphys/journal/v...t/abs/nphys1094.html)

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