Stride toward quantum computer reported

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Courtesy
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Researchers are reporting that they have passed a major hurdle in the quest to create a radically new kind of computer, the quantum computer.

Quantum computers would exploit the sometimes apparently nonsensical laws of quantum physics, or nature at the subatomic scale, to achieve unprecedented power and speed.

A major challenge been finding a way to manipulate individual electrons, electrically charged components of atoms. Electrons are seen as the most likely candidates to constitute the new machines' processing components, or "qubits."

Princeton physicist Jason Petta said he and some colleagues have demonstrated a method that alters the properties of a lone electron without disturbing the trillions of electrons in its immediate surroundings. The feat is considered essential to the development of quantum computers.

Petta has fashioned a new method of trapping one or two electrons in microscopic corrals created by applying to minuscule electrodes voltages, or electric fields that move electrons. Writing in the Feb. 5 edition of the research journal *Science*, Petta and colleagues describe how electrons trapped in these corrals form "spin qubits," quantum versions of classic computer information units known as bits.

Previous experiments used a technique in which electrons were exposed to microwave radiation. However, because it affected all the electrons uniformly, the technique could not be used to manipulate single electrons in spin qubits. It also was slow. Petta's method not only achieves control of single electrons, but it does so extremely rapidly, he said—in a billionth of a second.

Subatomic particles are found to follow the laws of quantum physics—in which, for example, they can be in two places at once—as long as these particles stay alone or in very small groups. When they come into contact with a greater mass, the quantum effects normally appear to vanish.

"If you can take a small enough object like a single electron and isolate it well enough from external perturbations, then it will behave quantum mechanically for a long period of time," said Petta. "All we want is for the electron to just sit there and do what we tell it to do. But the outside world is sort of poking at it, and that process of the outside world poking at it causes it to lose its quantum mechanical nature."

When the electrons in Petta's experiment are in what he calls their quantum state, they

are “coherent,” following rules that are radically different from the world seen by the naked eye. Living for fractions of a second in the realm of quantum physics before they are rattled by external forces, the electrons obey a unique set of physical laws that govern the behavior of ultra-small objects. Quantum computers would be designed to take advantage of these characteristics.

In addition to electrical charge, electrons possess something akin to rotation. In the quantum world, objects can turn in ways that are at odds with common experience. The Austrian theoretical physicist Wolfgang Pauli, who won the Nobel Prize in Physics in 1945, proposed that an electron in a quantum state can assume one of two states, “spin-up” or “spin-down.” It can be imagined as behaving like a tiny bar magnet with spin-up corresponding to the north pole pointing up and spin-down corresponding to the north pole pointing down.

An electron in a quantum state can simultaneously be partially in the spin-up state and partially in the spin-down state or anywhere in between, a quantum mechanical property called “superposition of states.” A qubit based on the spin of an electron could have nearly limitless potential because it can be neither strictly on nor strictly off.

New designs could take advantage of a rich set of possibilities offered by harnessing this property to enhance computing power. In the past decade, theorists and mathematicians have designed formulas that exploit this mysterious superposition to perform intricate calculations at speeds unmatched by supercomputers today.

Petta’s work is aimed at exploiting electron spin.

“In the quest to build a quantum computer with electron spin qubits, nuclear spins are typically a nuisance,” said Guido Burkard, a theoretical physicist at the University of Konstanz in Germany. “Petta and coworkers demonstrate a new method that utilizes the nuclear spins for performing fast quantum operations. For solid-state quantum computing, their result is a big step forward.”

Petta’s spin qubits, which he envisions as the core of future quantum logic elements, are cooled to ultra-cold temperatures and trapped in two tiny corrals known as quantum wells on the surface of a chip made of high-purity gallium arsenide. The depth of each well is controlled by varying the voltage on tiny electrodes or gates. Like a juggler tossing two balls between his hands, Petta can move the electrons from one well to the other by selectively switching the gate voltages.

Before this experiment, it wasn’t clear how experimenters could manipulate the spin of one electron without disturbing the spin of another in a closely packed space, according to physicist Phuan Ong, director of the Princeton Center for Complex Materials.

Petta’s research also is part of the fledgling field of “spintronics” in which scientists are studying how to use an electron’s spin to create new types of electronic devices. Most electrical devices today operate on the basis of another key property of the electron, its charge.

There are many more challenges to face, Petta said. “Our approach is really to look at the building blocks of the system, to think deeply about what the limitations are and what we can do to overcome them,” he added. “But we are still at the level of just manipulating one or two quantum bits, and you really need hundreds to do something useful.” As excited as he is about present progress, long-term applications are still years away, he added; “it’s a one-day-at-a-time approach.”