

Breakthrough offers new route to large-scale quantum computing

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(Phys.org)—In a key step toward building a machine that promises to revolutionize computing, Princeton researchers have developed a method that could quickly and reliably transmit information through a computer using the power of subatomic particles.

The finding, by a team led by Princeton's Associate Professor of Physics Jason Petta, could eventually allow engineers to build a working quantum computer. By using principles radically different from [classical physics](#), quantum computers would allow mathematicians to solve problems impossible to approach with standard computers: factoring immense numbers, cracking codes or simulating [molecular behavior](#).

Quantum computers take advantage of the strange behaviors of [subatomic particles](#) like electrons. By harnessing electrons as they spin, scientists could use the particles to form the basis for a new type of computing. The problem, though, is that these incredibly tiny electrons are hard to control. So far, scientists have only been able to harness extremely small numbers of them.

But in a recent series of experiments, Petta's team has demonstrated a new approach that could eventually allow engineers to build quantum computers consisting of millions of [quantum bits](#), or qubits.

"The whole game at this point in [quantum computing](#) is trying to build a larger system," said Andrew Houck, an associate professor of electrical engineering at Princeton who is part of the research team.

To transfer information Petta's team used a stream of [microwave photons](#) to analyze a pair of electrons trapped in a tiny cage called a quantum dot. The "[spin state](#)" of the electrons—information about how they are spinning—serves as the qubit, a basic unit of information. The microwave stream allows the scientists to read that information.

"We create a cavity with mirrors on both ends—but they don't reflect visible light, they reflect [microwave radiation](#)," Petta said. "Then we send microwaves in one end, and we look at the microwaves as they come out the other end. The microwaves are affected by the spin states of the electrons in the cavity, and we can read that change."

In an ordinary sense, the distances involved are very small; the entire apparatus operates over a little more than a centimeter. But on the subatomic scale, they are vast. It is like coordinating the motion of a top spinning on the moon with another on the surface of the Earth.

"It's the most amazing thing," said Jake Taylor, a physicist at the National Institute of Standards and Technology, who worked on the project with the Princeton team. "You have a single electron almost completely changing the properties of an inch-long electrical system."

For years, teams of scientists have pursued the idea of using quantum mechanics to build a new machine that would revolutionize computing. The goal is not to build a faster or more powerful computer, but to build one that approaches problems in a completely different fashion.

Standard computers store information as classical "bits," which can take on a value of either 0 or 1. These bits allow programmers to create the complex instructions that are the basis for modern computing power. Since Alan Turing took the first steps toward creating a computer at Princeton and the University of Cambridge in the 1930's, engineers have created vastly more powerful and complex machines, but this basic

binary system has remained unchanged.

The power of a quantum computer comes from the rules of quantum mechanics, which describe the universe of subatomic particles. Quantum mechanics says that an electron can spin in one direction, representing a 1, or in another direction, a 0. But it can also be in something called "superposition" representing all states between 1 and 0. If scientists and engineers could build a working machine that takes advantage of this, they would open up entirely new fields of computing.

"The point of a quantum computers is not that they can do what a normal computer can do but faster; that's not what they are," Houck said. "The quantum computer would allow us to approach problems differently. It would allow us to solve problems that cannot be solved with a normal computer."

Mathematicians are still working on possible uses for a quantum system, but the machines could allow the accomplishment of tasks such as predicting the behavior of molecules.

One challenge facing scientists is that the spins of electrons, or any other quantum particles, are incredibly delicate. Any outside influences, whether a wisp of magnetism or glimpse of light, destabilizes the electrons' spins and introduces errors.

Over the years, scientists have developed techniques to observe spin states without disturbing them. (This year's Nobel Prize in physics honored two scientists, Serge Haroche and David Wineland, who first demonstrated the direct observation of quantum particles.) But analyzing small numbers of spins is not enough; millions will be required to make a real quantum processor.

To make the quantum dots, the team isolated a pair of electrons on a

small section of material called a "semiconductor nanowire." Basically, that means a wire that is so thin that it can hold electrons like soda bubbles in a straw. They then created small "cages" along the wire. The cages are set up so that electrons will settle into a particular cage depending on their energy level.

This is how the Princeton team reads the spin state: electrons of similar spin will repel, while those of different spins will attract. So the team manipulates the [electrons](#) to a certain energy level and then reads their position. If they are in the same cage, they are spinning differently; if they are in different cages, the spins are the same.

The second step is to place this quantum dot inside the microwave channel, allowing the team to transfer the information about the pair's spin state—the [qubit](#).

Petta said the next step is to increase the reliability of the setup for a single electron pair. After that, the team plans to add more quantum dots to create more qubits. Team members are cautiously optimistic. There appear to be no insurmountable problems at this point but, as with any system, increasing complexity could lead to unforeseen difficulties.

"The methods we are using here are scalable, and we would like to use them in a larger system," Petta said. "But to make use of the scaling, it needs to work a little better. The first step is to make better mirrors for the microwave cavity."

The research was reported in the journal *Nature* on Oct. 18.

Provided by Princeton University

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