UW-Madison physicists build basic quantum computing circuit

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by Jill Sakai

Exerting delicate control over a pair of atoms within a mere seven-millionths-of-a-second window of opportunity, physicists at the University of Wisconsin-Madison created an atomic circuit that may help quantum computing become a reality.

Quantum computing represents a new paradigm in information processing that may complement classical computers. Much of the dizzying rate of increase in traditional computing power has come as transistors shrink and pack more tightly onto chips — a trend that cannot continue indefinitely.

"At some point in time you get to the limit where a single transistor that makes up an electronic circuit is one atom, and then you can no longer predict how the transistor will work with classical methods," explains UW-Madison physics professor Mark Saffman. "You have to use the physics that describes atoms — quantum mechanics."

At that point, he says, "you open up completely new possibilities for processing information. There are certain calculational problems... that can be solved exponentially faster on a quantum computer than on any foreseeable classical computer."

With fellow physics professor Thad Walker, Saffman successfully used neutral atoms to create what is known as a controlled-NOT (CNOT) gate, a basic type of circuit that will be an essential element of any quantum computer. As described in the Jan. 8 issue of the journal Physical Review Letters, the work is the first demonstration of a quantum gate between two uncharged atoms.

The use of neutral atoms rather than charged ions or other materials distinguishes the achievement from previous work. "The current gold standard in experimental quantum computing has been set by trapped ions... People can run small programs now with up to eight ions in traps," says Saffman.

However, to be useful for computing applications, systems must contain enough quantum bits, or qubits, to be capable of running long programs and handling more complex calculations. An ion-based system presents challenges for scaling up because ions are highly interactive with each other and their environment, making them difficult to control.

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"Neutral atoms have the advantage that in their ground state they don't talk to each other, so you can put more of them in a small region without having them interact with each other and cause problems," Saffman says. "This is a step forward toward creating larger systems."

The team used a combination of lasers, extreme cold (a fraction of a degree above absolute zero), and a powerful vacuum to immobilize two rubidium atoms within "optical traps." They used another laser to excite the atoms to a high-energy state to create the CNOT quantum gate between the two atoms, also achieving a property called entanglement in which the states of the two atoms are linked such that measuring one provides information about the other.

Writing in the same journal issue, another team also entangled neutral atoms but without the CNOT gate. Creating the gate is advantageous because it allows more control over the states of the atoms, Saffman says, as well as demonstrating a fundamental aspect of an eventual quantum computer.

The Wisconsin group is now working toward arrays of up to 50 atoms to test the feasibility of scaling up their methods. They are also looking for ways to link qubits stored in atoms with qubits stored in light with an eye toward future communication applications, such as "quantum internets."

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