Physicists Propose New Ultracold Scheme for Scalable Quantum Information Processing

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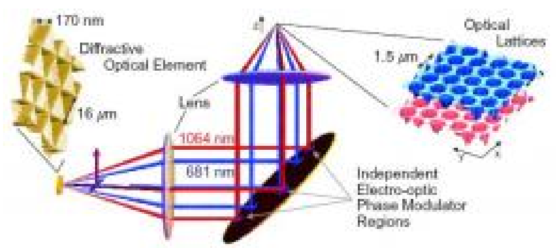

In the new system, lithium and cesium atoms are held in separate optical lattices, and (far right) the atoms can be overlapped by translating the lattices with respect to each other. When the messenger and qubit atoms are overlapped, entangling operations can be performed. Credit: New J. Phys. 11 055022, Kathy-Anne Brickman Soderberg, Nathan Gemelke and Cheng Chin, James Franck Institute and Physics Department, University of Chicago, Chicago, IL 60637, USA.

(PhysOrg.com) -- Since 1994, when Peter Shor famously showed that a quantum computer could factor large numbers exponentially faster than any current classical algorithm, physicists have been investigating a variety of quantum computing schemes. However, truly scalable, controlled entanglement between many particles remains an elusive goal. In a recent study, physicists have proposed a new system that uses ultracold atoms trapped in an optical lattice to generate entanglement, which may be a promising method for realizing a scalable quantum computer due to the high degree of control it offers.

Physicists Kathy-Anne Brickman Soderberg, Nathan Gemelke, and Cheng Chin of the University of Chicago have presented their novel system in a recent issue of the *New Journal of Physics*.

As the scientists explain, the scheme uses two different species of atoms: lithium atoms act as quantum bits to store information, and cesium atoms act as messenger bits that mediate entanglement between distant lithium qubit atoms. Each atomic species is trapped in its own optical lattice, which is an intensity pattern made by several overlapping laser beams. By shifting the relative alignment of the lattices through optical phases, each cesium atom can, in principle, be transported to any distant lithium atom in a controlled way. During this shifting, the cesium atoms can swap entanglement between any two lithium qubit atoms. In the end, the qubit atoms are entangled with each other and the messenger atom is disentangled from the qubits.

While previous schemes have also used atoms in optical lattices to implement entanglement, the new proposal is unique in that it introduces the auxiliary messenger atoms. As the scientists explain, independent control of the qubit and messenger atoms provides the key to achieve a large-scale quantum computation. The fact that lithium and cesium atoms have very different dominant atomic transition lines makes it possible to independently confine and control the two species.

Atoms trapped in optical lattices have several advantages as a quantum information processing system. As the physicists explain, this kind of system easily lends itself to scalability because thousands of atoms can be isolated in a regular array, and can be transported simply by controlling the optical phases of the lattice beams. Also, since many cesium atoms can be held in the optical lattice, multiple copies of the same computation can proceed in parallel.

“Our scheme is scalable in the sense that we do not need to carry out pairwise operations over the lattice to entangle two distant qubits," Brickman Soderberg told *PhysOrg.com*. "Instead we can use the messenger atoms to directly carry the entanglement between the qubits. Another strength of our system is that we can individually address our qubit atoms by overlapping the target qubit with a messenger atom, thus eliminating the need for tightly focused laser beams. This will allow us to perform targeted single qubit operations, which may be a necessary step in a large-scale quantum computer."

In their study, the scientists also show that the system can perform some simple quantum logic gate operations, such as targeted qubit operations, based on the translatable optical lattices at two wavelengths. In addition, the messenger atoms can be used for reading out the quantum information from the qubits. Also, in analyzing the accuracy and uncertainties of the system, the physicists found that fidelities greater than 97% should be possible when entangling distant qubits. The scientists plan to fully demonstrate the system in future work.

"Currently we have both atomic species cooled and trapped in a magneto-optical trap and are preparing to further cool the atoms in a second optical trap," Brickman Soderberg said. "Once the atoms are cold, our immediate goal is to study the interactions between lithium and cesium to identify the best strategy to perform quantum logic operations. Since this is the first time that lithium and cesium have been combined for this purpose, not much work has been done to study the dynamics between the atoms. After that, we will load each atom into its own optical lattice to carry out the qubit operations discussed in the paper."

More information: Kathy-Anne Brickman Soderberg, Nathan Gemelke, and Cheng Chin. "Ultracold molecules: vehicles to scalable quantum information processing." New Journal of Physics 11 (2009) 055022.