Physicists set new record for quantum teleportation with matter qubits

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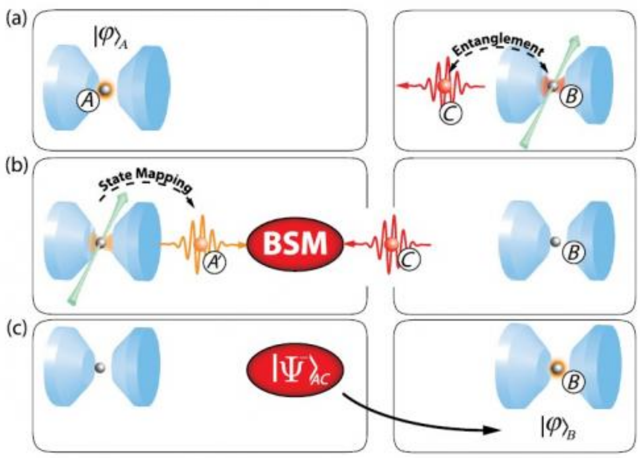

Experimental setup for teleportation between single-atom quantum memories. Single atoms (gray spheres A and B) are trapped in optical cavities (blue cones) separated by a distance of 21 m. (a) Entanglement is generated between atom B and an ancilla photon C. (b) The atomic qubit at node A is mapped onto a photonic qubit A' and a Bell-state measurement between the two photons is performed. (c) Detection of an event heralds the successful teleportation of the atomic qubit from node A to node B. Credit: Christian Nölleke, et al. ©2013 American Physical Society

(Phys.org) —In most demonstrations of quantum teleportation between remote atomic qubits, the atoms exist in free space. In a new study, scientists have discovered that trapping the atoms in optical cavities can overcome some of the previous obstacles facing matter teleportation, which enables an improvement in efficiency of almost 5 orders of magnitude and teleportation across a record-breaking distance of 21 m. These improvements in quantum teleportation could open the doors to realizing quantum networks with many nodes for teleporting qubits to various destinations.

The researchers, Christian Nölleke, et al., at the Max Planck Institute for Quantum Optics at Garching, Germany, have published their study on the new teleportation scheme in a recent issue of *Physical Review Letters*.

"The greatest significance of our work is the dramatic increase in efficiency compared to previous realizations of matter-matter teleportation," Nölleke said. "Besides, it is the first demonstration of matter-matter teleportation between truly independent systems and constitutes the current record in distance of 21 m. The previous record was 1 m."

In quantum teleportation, quantum information can be transmitted from one node to another in a quantum network without physically traversing the space in between. The technique could be used to transmit information in a secure way over very large distances, and can ultimately lead to worldwide quantum internet.

Teleportation can be realized with either photonic qubits or matter qubits. In 2012, physicists teleported photonic qubits a record distance of 143 km. Teleporting matter qubits over long distances is more difficult than teleporting photonic qubits because it requires quantum memories and a strong interaction between light and matter. In a previous experiment, scientists have performed material teleportation without a strong light-matter interaction, and achieved a distance of 1 m. However, the low photon-collection efficiency in free space prevents scaling of that approach to larger distances.

In the new study, the physicists have eliminated this obstacle by trapping two remote single atoms in their own optical cavity. The optical cavity increases the photon collection efficiency and the interaction strength between atom and photon. Both effects lead to an increase in the number of "usable" photons. In the absence of a cavity, atom-photon entanglement can also be generated with high efficiency; however, the emission direction of the photons is random, so most of the photons will be lost.

During the teleportation process, the spin state of the atomic qubit at one node is mapped onto the polarization of a photonic qubit. At the second node, entanglement is simultaneously generated between a second atom and a second photon. Then the researchers performed a Bell-state measurement between the two photons, which destroys the two photons and projects the second atom onto the state of the first atom. This projection teleports the qubit between the atoms.

One of the important achievements of this scheme is that is has a success probability of 0.1%. Although this may not seem like a very high efficiency, it's nearly 100,000 times higher than that achieved in previous experiments. The main reason for the improvement is that, in contrast to previous demonstrations, the efficiency is not predominantly limited by single-photon collection efficiency. Instead, the limiting factor is the requirement to transmit and detect two photons simultaneously, which is inherent in the Bell-state measurement.

The performance of the special type of Bell-state measurement (purely photonic) is already close to the edge of what is possible with current technology (mainly limited by fiber losses and efficiencies of the detectors). To increase the efficiency of this stage, the scientists would have to use a different type of Bell-state measurement based on deterministic quantum gates. Fortunately, the current cavity system has the potential to straightforwardly implement such a Bell-state measurement.

"Future plans include to increase the light-matter interaction by using cavities that provide us with a higher atom-photon coupling strength," Nölleke said. "This would increase the efficiency of our protocol even further. Another prospect is to implement a different type of Bell-state measurement to increase the efficiency."

Since the atoms trapped in optical cavities act as non-identical quantum memories, the scheme could have applications for building quantum networks where identical network nodes are hard to realize. For larger network consisting of more than two nodes, the time is takes to teleport a quantum state must be shorter than the coherence time. In the current experiment, this time is 0.1 s and therefore smaller than coherence times in atoms (~1 s).

"Applications are the realization of quantum networks and the secure transmission of information using quantum key distribution at a global scale," Nölleke said. "Both applications require the transfer of quantum states over long distances. As we explain in the first paragraph of our paper, there is no classical technique to achieve this. There is, however, a clear strategy based on so-called 'quantum repeaters' (the quantum version of a classical repeater) and the utilization of teleportation to transfer quantum states over very long distances."

More information: Christian Nölleke, et al. "Efficient Teleportation Between Remote Single-Atom Quantum Memories." *PRL* 110, 140403 (2013). DOI: 10.1103/PhysRevLett.110.140403
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