Quantum teleportation between atomic ensembles demonstrated for first time

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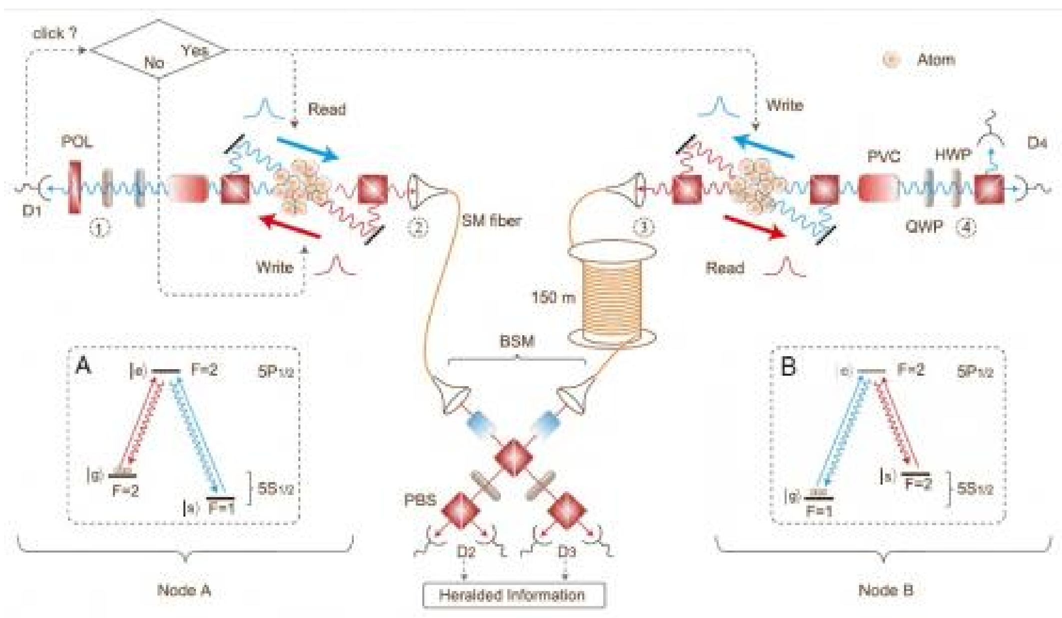

The experimental setup for quantum teleportation between two remote atomic ensembles. Credit: Bao, et al. ©2012 PNAS Early Edition

(Phys.org)—One of the key components of quantum communication is quantum teleportation, a technique used to transfer quantum states to distant locations without actual transmission of the physical carriers. Quantum teleportation relies on entanglement, and it has so far been demonstrated between single photons, between a photon and matter, and between single ions. Now for the first time, physicists have demonstrated quantum teleportation by entangling two remote macroscopic atomic ensembles, each with a radius of about 1 mm.

The researchers, led by Jian-Wei Pan of the Hefei National Laboratory for Physical Sciences at the Microscale, the University of Science and Technology of China in Hefei, and the University of Heidelberg in Germany, have published their paper on "Quantum teleportation between remote atomic-ensemble quantum memories" in a recent issue of the Proceedings of the National Academy of Sciences.

As the physicists explained, quantum teleportation between two atomic ensembles has certain advantages over the previous kinds of teleportation demonstrated.

"Teleportation between two photons has been demonstrated earlier (first in 1997)," coauthor Chao-Yang Lu, of the Hefei National Laboratory for Physical Sciences at the Microscale and the Department of Modern Physics at the University of Science and Technology of China, told *Phys.org*. "The problem with the photon is that it always keeps traveling. You have to keep it to do useful quantum information processing tasks (in which case we call it a 'keeper'). Compared to the trapped ion experiment, an advantage of the atomic ensembles is that they have a much higher success rate."

In the quantum teleportation experiment performed here, the two atomic ensembles each consist of about 100 million rubidium atoms and are connected by a 150-m optical fiber, but physically separated by about half a meter in the lab. The atomic ensembles act as quantum memories due to their ability to store photonic qubits within their stationary matter system. Along with quantum teleportation, quantum memories are another key component of quantum communication.

In experiments, the scientists demonstrated that they could teleport a collective atomic excitation, or spin wave state, from one ensemble to the other. To do this, they first mapped the spin wave state of the first atomic ensemble to a propagating photon, and then performed Bell state measurements on that photon and a second photon that was already entangled with the spin wave state of the second atomic ensemble. Once the two photons were projected into an (entangled) Bell state, the quantum information was teleported to the second atomic ensemble.

To verify that the spin wave state of the first atomic ensemble was indeed teleported via the photons due to the entangled atomic ensembles, the researchers read out the atomic state using photons and used detectors to measure the quantum information embedded in the photons. The results showed that teleportation was successful 88% of the time, with imperfections mainly limited by interfering high-order excitations and background excitations.

"We think that our work is interesting from two perspectives," said Lu. "The first is that it is the first quantum teleportation involving two macroscopic objects. Quantum teleportation of increasingly complex objects is obvious a long sought-after dream, especially for big fans of, say, Star Trek. Of course, we note that in our current experiment, although about 100 million atoms are involved, the actual quantum information teleported is their collective excitation (spin wave), which is just a single qubit.

"Secondly, from a more practical point of view, teleportation among quantum memory nodes may also be a functioning module in the future quantum networks to exchange and transfer information. A similar experiment was performed with single trapped ions as well. Our experiment, however, features a much higher (four orders of magnitude) success rate."

The researchers explained that many advanced techniques were involved in achieving teleportation between the two atomic ensembles.

"The present experiment combines state-of-the-art techniques developed in atomic physics experiments, including preparation of cold atomic ensembles with magneto-optical trap, controlled interaction between light and atoms, single-photon manipulation, filtering and detection, with new developed methods of heralded state preparation with feedback control and quantum state teleportation," Lu said.

In order to extend quantum teleportation to multiple atomic ensembles, the storage lifetime of the spin wave states in the atomic ensembles must be increased from its current lifetime of about 129 microseconds. The researchers hope to increase the lifetime to up to 100 milliseconds by using optical lattices to confine atomic motion. Such improvements would pave the way toward large-scale quantum networks that rely on quantum teleportation to exchange quantum information.

More information: Xiao-Hui Bao, et al. "Quantum teleportation between remote atomic-ensemble quantum memories." *PNAS Early Edition*. DOI: 10.1073/pnas.1207329109