Physicists Transcribe Entanglement into and out of a Quantum Memory

6 March 2008

Scientists at the California Institute of Technology have laid the groundwork for a crucial step in quantum information science. They show how entanglement, an essential property of quantum mechanics, can be generated between beams of light, stored in a quantum memory, and mapped back into light with the push of a button.

In the March 6 issue of the journal *Nature*, Caltech Valentine Professor of Physics H. Jeff Kimble and his colleagues demonstrate for the first time an important capability required for the control of quantum information and quantum networks, namely the coherent conversion of photonic entanglement into and out of separated quantum memories.

Entanglement lies at the heart of quantum physics, and is a state where parts of a composite system are more strongly correlated than is possible for any classical counterparts regardless of the distance separating them. Entanglement is a critical resource for diverse applications in quantum information science, such as for quantum metrology, computation, and communication. Quantum networks rely on entanglement for the teleportation of quantum states from place to place.

In a quest to turn these abstract ideas into real laboratory systems and to distribute entanglement to remote locations (even on a continental scale), Kimble explains that quantum physicists have studied ways to propagate photonic information into and out of quantum memory using a system called a quantum repeater, invented in 1998 by H. Briegel, J.I. Cirac, and P. Zoller at the University of Innsbruck. Until now, work in Kimble's group on the realization of a quantum repeater with atomic ensembles relied upon the probabilistic creation of entanglement. In this setting entanglement between two clouds of atoms was generated probabilistically but with an unambiguous heralding event.

While such systems hold the potential for scalable quantum networks, it has been difficult for Kimble's Quantum Optics Group to apply such schemes to certain protocols necessary for quantum networks, such as entanglement connection. Now, with the new protocol and future improvements, "We can push a button and generate entanglement," says physics graduate student Kyung Soo Choi, one of four authors of the Caltech experiment.

While entanglement has been traditionally carried out with photons in attempt to connect two distant systems, these particles of light are difficult to store because of their small interactions with matter when taken one by one. A quantum memory for light is an essential ingredient for achieving scalable quantum networks with photons. Choi says. "The question is now, 'How do you change the entangled state of light into an entanglement of matter and back into light?'" This was not possible for any physical system until now.

The new work, Choi says, "is a proof-of-principle demonstration that entanglement between material systems can be generated deterministically by mapping the entanglement of light to and from two spatially separated quantum memories." The Caltech team separated the processes for generating and storing the entanglement, thereby breaking a previous inherent link between the quality and probability of state preparation. "In a general context, our work represents an important step in laboratory capabilities for the creation and manipulation of entangled states of light and matter. We hope that our results will be useful as a tool in the effort to realize quantum repeaters and thereby scalable quantum networks over long distances," remarks Kimble.

In the Caltech experiment, a single photon is first split, generating an entangled state of light with quantum amplitudes for the photon to propagate two distinct paths, taking both at once. The Caltech team in turn transcribed, or mapped, the entanglement onto distinct atomic ensembles separated by one millimeter. To create the interface between the light and matter, the team employed laser-cooled cesium atoms whose atomic states interact with a control laser to create destructive quantum interference, making the atomic ensembles either invisible or highly opaque to the input light. Called Electromagnetically Induced Transparency and pioneered by S. Harris at Stanford University, the mechanism manipulates the speed of the light for the incoming entangled photon and that kicks off the entire procedure.

"We can reduce the speed of light to the speed of a train, and then in fact stop the light inside the matter by slowly turning off the control laser, where now the quantum information--the entangled state of light--is stored inside the atomic ensembles," Choi describes. "By turning on the control laser again, we can reversibly accelerate the 'stopped' light back to the speed of light and restore the quantum entanglement as propagating beams of light."

In this experiment, the photonic entanglement was mapped into the atomic ensembles in a time ~ 20 nanoseconds and then stored in the atomic ensembles for one microsecond, with storage times extendable up to 10 microseconds. The photonic entanglements of the input and output of the quantum interface were explicitly quantified with a conversion efficiency of 20 percent. However, the researchers emphasize, real-world realization of a quantum network remains far out of reach even with these parameters and the state-of-the-art of quantum controls. Choi comments, "Further improvements in quantum control and storage capabilities in matter-light interfaces will lead to fruitful and exciting discoveries in Quantum Information Science, including for the realization of quantum networks."

Source: Caltech

APA citation: Physicists Transcribe Entanglement into and out of a Quantum Memory (2008, March 6) retrieved 30 October 2020 from https://phys.org/news/2008-03-physicists-entanglement-quantum-memory.html