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Press Release

Matter-matter entanglement at a distance

Scientists at the Max Planck Institute of Quantum Optics prepare quantum mechanical entanglement of two remote quantum systems.

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Because of its strange consequences the quantum mechanical phenomenon of entanglement has been called "spooky action at a distance" by Albert Einstein. For several years physicists have been developing concepts how to use this phenomenon for practical applications such as absolutely safe data transmission. For this purpose, the entanglement which is generated in a local process has to be distributed among remote quantum systems. A team of scientists around Prof. Gerhard Rempe, Director at the Max Planck Institute of Quantum Optics and head of the Quantum Dynamics Division, has now demonstrated that two remote atomic quantum systems can be prepared in a shared "entangled" state (Physical Review Letters, Advance Online Publication, 26 May 2011): one system is a single atom trapped in an optical resonator, the other one a Bose-Einstein condensate consisting of hundreds of thousands of ultracold atoms. With the hybrid system thus generated, the researchers have realized a fundamental building block of a quantum network.

In the quantum mechanical phenomenon of "entanglement" two quantum systems are coupled in such a way that their properties become strictly correlated. This requires the particles to be in close contact. For many applications in a quantum network, however, it is necessary that entanglement is shared between two remote nodes ("stationary" quantum bits). One way to achieve this is to use photons ("flying" quantum bits) for transporting the entanglement. This is somewhat analogous to classical telecommunication, were light is used to transmit information between computers or telephones. In the case of a quantum network, however, this task is much more difficult as entangled quantum states are extremely fragile and can only survive if the particles are well isolated from their environment.

The team of Professor Rempe has now taken this hurdle by preparing two atomic quantum systems located in two different laboratories in an entangled state: on the one hand a single rubidium atom trapped inside an optical resonator formed by two highly reflective mirrors, on the other hand an ensemble of hundreds of thousands of ultracold rubidium atoms which form a Bose Einstein condensate (BEC). In a BEC, all particles have the same quantum properties so that they all act as a single "superatom".

First, a laser pulse stimulates the single atom to emit a single photon. In this process, internal degrees of freedom of the atom are coupled to the polarisation of the photon, so that both particles become entangled. The photon is transported through a 30 m long optical fibre into a neighbouring laboratory where it is directed to the BEC. There, it is absorbed by the whole ensemble. This process converts the photon into a collective excitation of the BEC. "The exchange of quantum information between photons and atomic quantum systems requires a strong light-matter interaction", explains Matthias Lettner, a doctoral student working on the experiment. "For the single atom, we achieve this by multiple reflections between the two resonator mirrors, whereas for the BEC the light-matter interaction is enhanced by the large number of atoms." In a subsequent step, the

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physicists prove that the single atom and the BEC are really entangled. To this end, the photon absorbed in the BEC is retrieved with the help of a laser pulse and the state of the single atom is read out by generating a second photon. The entanglement of the two photons reaches 95 % of the maximally possible value, thus showing that the entanglement of the two atomic quantum systems must have been equally good, or even better. Moreover, the entanglement is detectable for approximately 100 microseconds.

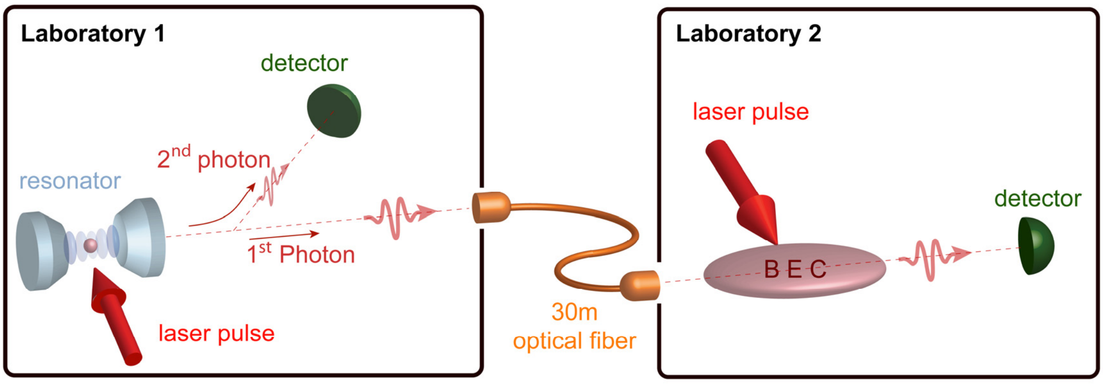

Figure: A single atom and a BEC in two separate laboratories serve as nodes in a basic quantum network. To prepare entanglement between these systems, a laser pulse is used to stimulate the atom to emit a single photon which is entangled with the single atom. The photon is used to transport the entanglement through an optical fibre into a neighbouring laboratory. Here, the photon is stored in the BEC. This procedure establishes entanglement between the single atom and the BEC. After some delay, the photon is retrieved from the BEC and the state of the single atom is mapped onto a second photon. The observation of entanglement between these two photons proves that all steps of the experiment were performed successfully.

“A BEC is very well suited as a quantum memory because this exotic state does not suffer from any disturbances caused by thermal motion”, says Matthias Lettner. “This makes it possible to store and retrieve quantum information with high efficiency and to conserve this state for a long time.”

In this experiment, the team of Professor Rempe has realized a building block for a quantum network consisting of two remote, entangled, stationary nodes. This is a milestone on the way to large-scale quantum networks in which, for example, quantum information can be transmitted absolutely safe. In addition, such networks might help realizing a universal quantum computer in which quantum bits can be exchanged with photons between nodes designed for information storage and processing.
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