Physicists Achieve Quantum Entanglement Between Remote Ensembles of Atoms

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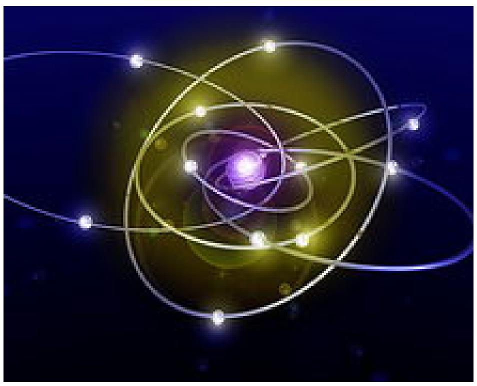

Physicists have managed to "entangle" the physical state of a group of atoms with that of another group of atoms across the room. This research represents an important advance relevant to the foundations of quantum mechanics and to quantum information science, including the possibility of scalable quantum networks (i.e., a quantum Internet) in the future.

Reporting in the December 8 issue of the journal *Nature*, California Institute of Technology physicist H. Jeff Kimble and his colleagues announce the first realization of entanglement for one "spin excitation" stored jointly between two samples of atoms. In the Caltech experiment, the atomic ensembles are located in a pair of apparatuses 2.8 meters apart, with each ensemble composed of about 100,000 individual atoms.

The entanglement generated by the Caltech researchers consisted of a quantum state for which, when one quantum spin (i.e., one quantum bit) flipped for the atoms at the site L of one ensemble, invariably none flipped at the site R of the other ensemble, and when one spin flipped at R, invariably none flipped at L. Yet, remarkably, because of the entanglement, both possibilities existed simultaneously.

According to Kimble, who is the Valentine Professor and professor of physics at Caltech, this research significantly extends laboratory capabilities for entanglement generation, with now-entangled "quantum bits" of matter stored with separation several thousand times greater than was heretofore possible.

Moreover the experiment provides the first example of an entangled state stored in a quantum memory that can be transferred from the memory to another physical system (in this case, from matter to light). Since the work of Schrödinger and Einstein in the 1930s, entanglement has remained one of the most profound aspects and persistent mysteries of quantum theory. Entanglement leads to strong correlations between the various components of a physical system, even if those components are very far apart. Such correlations cannot be explained by classical physics and have been the subject of active experimental investigation for more than 40 years, including pioneering demonstrations that used entangled states of photons, carried out by John Clauser (son of Caltech's Millikan Professor of Engineering, Emeritus, Francis Clauser).

In more recent times, entangled quantum states have emerged as a critical resource for enabling tasks in information science that are otherwise impossible in the classical realm of conventional information processing and distribution. Some tasks in quantum information science (for instance, the implementation of scalable quantum networks) require that entangled states be stored in massive particles, which was first accomplished for trapped ions separated by a few hundred micrometers in experiments at the National Institute of Standards and Technology in Boulder, Colorado, in 1998.

In the Caltech experiment, the entanglement involves "collective atomic spin excitations." To generate such excitations, an ensemble of cold atoms initially all in level "a" of two possible ground levels is addressed with a suitable "writing" laser pulse. For weak excitation with the write laser, one atom in the sample is sometimes transferred to ground level "b," thereby emitting a photon.

Because of the impossibility of determining which particular atom emitted the photon, detection of this first write photon projects the ensemble of atoms into a state with a single collective spin excitation distributed over all the atoms. The presence (one atom in state b) or absence (all atoms in state a) of this symmetrized spin excitation behaves as a single quantum bit.

To generate entanglement between spatially separated ensembles at sites L and R, the write fields emitted at both locations are combined together in a fashion that erases any information about their origin. Under this condition, if a photon is detected, it is impossible in principle to determine from which ensemble's L or R it came, so that both possibilities must be included in the subsequent description of the quantum state of the ensembles.

The resulting quantum state is an entangled state with "1" stored in the L ensemble and "0" in the R ensemble, and vice versa. That is, there exist simultaneously the complimentary possibilities for one spin excitation to be present in level b at site L ("1") and all atoms in the ground level a at site R ("0"), as well as for no spin excitations to be present in level b at site L ("0") and one excitation to be present at site R ("1").

This entangled state can be stored in the atoms for a programmable time, and then transferred into propagating light fields, which had not been possible before now. The Caltech researchers devised a method to determine unambiguously the presence of entanglement for the propagating light fields, and hence for the atomic ensembles.

The Caltech experiment confirms for the first time experimentally that entanglement between two independent, remote, massive quantum objects can be created by quantum interference in the detection of a photon emitted by one of the objects.

In addition to Kimble, the other authors are Chin-Wen Chou, a graduate student in physics; Hugues de Riedmatten, Daniel Felinto, and Sergey Polyakov, all postdoctoral scholars in Kimble's group; and Steven J. van Enk of Bell Labs, Lucent Technologies.

Source: Caltech