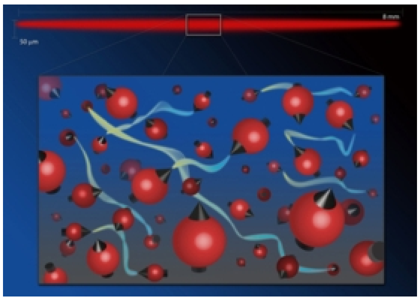
Quantum Entanglement Creates New State of Matter

Half a million ultracold atoms were linked together in the first-ever "macroscopic spin singlet" state

Sep 22, 2014 | By Clara Moskowitz

Physicists have used a quantum connection Albert Einstein called "spooky action at a distance" to link 500,000 atoms together so that their fates were entwined. The atoms were connected via "entanglement," which means an action performed on one atom will reverberate on any atom entangled with it, even if the particles are far apart. The huge cloud of entangled atoms is the first "macroscopic spin singlet," a new state of matter that was predicted but never before realized.



Atoms' spins (shown here as black arrows) were connected through quantum entanglement (ribbons), so that if one atom's spin was altered, the spin of its entangled partner would also change.

Credit: Alina Hirschmann/Nerea Grisaleña

Entanglement is a consequence of the strange probabilistic rules of quantum mechanics and seems to permit an eerie instantaneous connection over long distances that defies the laws of our macroscopic world (hence Einstein's "spooky" remark). A spin singlet is one form of entanglement where multiple particles' spins—their intrinsic angular momentum—add up to 0, meaning the system has zero total angular mo

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Entangling such a large group of atoms in this way was no easy feat. First, the researchers cooled the atoms to 20 millionths of a kelvin—a frigid temperature necessary to keep the atoms almost perfectly still; any collisions between them would disturb their spins. Then, to determine the atoms' total spin, the researchers performed what is called a quantum nondemolition measurement—a passive means of learning about a quantum system that avoids altering its state. (This is necessary because active measurements of quantum systems tend to disturb their subjects, irrevocably changing the very thing being measured.)

To make the nondemolition measurement, the scientists sent a pulse of about 100 million photons (particles of light) through the cloud of atoms. These photons had energies that were precisely calculated so that they would not excite the atoms but rather would pass through. The photons themselves, however, were affected by the encounter. The atoms' spins acted as magnets to rotate the polarization, or orientation, of the light. By measuring how much the photons' polarization had changed after passing through the cloud, the researchers could determine the total spin of the cloud's atoms.

Although the measurement didn't change the spin state of the particles, it did have the effect of entangling many of them with one another. The researchers assume the atoms started out with spins pointing in random directions. In some cases, however, the measurement showed that their total added up to zero. When that happened, the measurement "locked in" that net zero result, in a way, ensuring that subsequent measurements would continue to find that the total spin equaled zero. "The measurement itself has somehow created the singlet state," says Naeimeh Behbood of The Institute of Photonic Sciences in Barcelona. "It has created an entangled state from a state without entanglement. How it does this is a deep mystery of quantum mechanics."

The total experiment involved a cloud of about one million rubidium atoms, but the passive measurements could not quantify exactly how many of these atoms became entangled. For the system's total spin to equal zero, however, the quantum limits of the measurement guarantee that at least half of them—500,000 atoms—were entangled. That is still a record number for a spin singlet, and the first time that whole atoms have been entangled into one macroscopic system with net zero spin. (Previous experiments have done this to photons.) The study was published August 25 in *Physical Review Letters*. "I find it a remarkable result both for fundamental and applied research," says physicist Marco Koschorreck of the University of Bonn, who was not involved in the study. Because the entangled atoms' spins are very sensitive to magnetic manipulation, he says, the macroscopic spin singlet could be used to sense magnetic fields.

In the near future the researchers would like to better understand the new state of matter they created. For example, because they only know the total spin of their cloud, they do not know how individual atoms contribute to it. "For example, which atoms are entangled?" Behbood asks. "Is it nearest neighbors [pairs of atoms right next to one another] or the most distant atoms—or is it random? Do the atoms form singlets in pairs or in larger groups?" Such questions could help the scientists better understand how quantum nondemolition produces entanglement and how to manipulate it for practical purposes. The more we understand entanglement, the less "spooky" it becomes.

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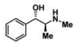

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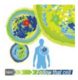

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