PHYS.ORG

Physicists Investigate Unusual Four-Qubit Entanglement

September 30 2009, By Lisa Zyga

Four-qubit bound entanglement may have applications in secret sharing protocols, such as the secret code used to protect the launch sequence of a nuclear missile. Credit: DOD Defense Visual Information Center.

(PhysOrg.com) -- For the first time, physicists have experimentally demonstrated a four-qubit bound-entangled state - a peculiar form of entanglement that cannot be distilled (optimized) by the usual means. However, the scientists have found a novel method for distilling the entanglement by working with two qubits at a time. As the researchers explain, the special properties of bound entanglement could make it a useful quantum resource for new multiparty communication and secret sharing schemes, and the results could also contribute to a deeper understanding of the foundations of quantum mechanics.

In their study, physicists Elias Amselem and Mohamed Bourennane of

Stockholm University have investigated the counterintuitive puzzles of bound entanglement. While entanglement of two pure states is fairly well understood by physicists, the entanglement of mixed and multipartite (more than two) states, such as bound entanglement, is still under intense research.

"Quantum entanglement leads to the most counterintuitive effects in quantum mechanics, and it is of great relevance in advanced quantum information methods and also opens a number of questions about the nature of entanglement itself," Bourennane told *PhysOrg.com*. "Until now, there is, in general, no known measure for entanglement for a system of more than two particles; therefore, no one is able to say that a state is more or less entangled than the other. At the same time, it is still quite difficult to observe multi-particle entanglement."

As Bourennane explained, inevitable interactions with the environment can cause quantum entanglement to become noisy during the information processing. An important and crucial question is to know which of the noisy states can be distilled to maximally entangled states, with the help of local operations and classical communication, and then be useful again for further information processing. For this reason, the theoretical discovery of bound entanglement (by Ryszard Horodecki, Michal Horodecki and Pawel Horodecki) is very important, being a class of quantum entangled states where no entanglement can be distilled.

"Our paper reports for the first time on the experimental evidence of the existence of the bound entangled state, the so-called Smolin state, and fully characterizes it using quantum state tomography," Bourennane said. "We also study its entanglement properties, using the separability criterion, the Bell inequality, and the witness method. As can be seen, the paper contains new achievements and new insight regarding the general understanding of entanglement."

To create the Smolin state in the laboratory, the scientists used polarized photons as qubits. Using a laser, they pumped two ultraviolet pulses into a nonlinear crystal to create four photons, entangled in pairs. Then, by applying single-polarization-qubit flip and phase gates between one photon from each pair, the scientists created a bound-entangled state that is an equal mixture of all four Bell states of the four photons. The researchers fully characterized the entanglement properties of the Smolin state, including constructing its density matrix using quantum-state tomography.

After creating the four-qubit bound-entangled state, the scientists investigated distillation. In general, entanglement distillation is a way to maximize entanglement by overcoming noisy channels. Although a bound-entangled state cannot be distilled by local operators and classical communication, it can be distilled in a different way.

"We have experimentally demonstrated the unlocking entanglement protocol where two of the four parties sharing the bound entangled state join and perform a Bell measurement, and then broadcast their measurement results to the other two parties, which will then share a maximally entangled state," Bourennane said.

As the physicists explain, these unusual properties make the Smolin bound-entangled state useful for novel multiparty quantum communication schemes, such as secret sharing, communication complexity reduction, and remote information concentration.

"For example, in the secret sharing protocol, the splitting of a secret in a way that a single person is not able to reconstruct it is a common task in information processing and especially high security applications," Bourennane said. "Suppose, for example, that the launch sequence of a nuclear missile is protected by a secret code. Yet, it should be ensured that a single lunatic alone is not able to activate it, but at least two lunatics are required. Solutions for this problem, and its generalization and variations, are studied in classical cryptography. Such problems are called secret sharing. The aim is to split information, using some mathematical algorithms, and to distribute the resulting pieces to two or more legitimate parties. However, classical communication is susceptible to eavesdropping attacks. As the usage of quantum resources can lead to unconditionally secure communication, protocols introducing quantum cryptography to secret sharing have been proposed. The distribution of the four-qubit bound-entangled Smolin state among four communicating parties allows the information splitting and the eavesdropper protection simultaneously."

More information: Elias Amselem and Mohamed Bourennane. "Experimental four-qubit bound entanglement." *Nature Physics.* Published online 23 August 2009. DOI: 10.1038/NPHYS1372