Physicists Demonstrate Qubit-Qutrit Entanglement

February 26 2008, By Lisa Zyga

For the first time, physicists have entangled a qubit with a “qutrit” – the 3D version of the 2D qubit. Qubit-qutrit entanglement could lead to advantages in quantum computing, such as increased security and more efficient quantum gates, as well as enable novel tests of quantum mechanics.

The research team, composed of physicists from the University of Queensland, the University of Bristol, and the University of Waterloo, has published its results in a recent issue of *Physical Review Letters*. The researchers made qutrits with biphotons (two correlated photons), resulting in “biphotonic qutrits.” Then, they entangled these qutrits with photonic qubits (made with one photon) using a combination of linear optic elements and measurements.

A qutrit, just as it sounds, is the quantum information analogue of the classical trit. Due to its quantum mechanical nature, a qutrit can exist in superpositions of its three basis states. This is similar to how a qubit can exist in superpositions of its two states. Because of the qutrit’s 3D nature, though, it can carry much more information than the qubit. (A string of n classical bits holds 1^n states, a string of n qubits holds 2^n states, and a string of n qutrits holds 3^n states.)

Many researchers have investigated the possibilities of entangling a qubit and qutrit, hoping to develop a valuable tool for improving quantum computing and exploring novel quantum phenomena, among other things. The authors’ result now makes such theoretical proposals experimentally testable.

“For me, the significance our paper is about how entangling systems to a qubit can be a great way to manipulate that system,” co-author Benjamin Lanyon of the University of Queensland told *PhysOrg.com*. “In our example, we use this technique to dramatically extend the range of possible transforms on qutrits – these higher dimensional quantum information carriers, which offer loads of advantages, but are otherwise really difficult to handle.”

In their study, the researchers show that qubit-qutrit entanglement can be a useful resource to manipulate the difficult-to-handle qutrits. The scientists built a non-linear qutrit polarizer, which involves creation of the entanglement and destructive measurement of the qubit. The result is to temporarily remove a single qutrit state from the qutrit’s superposition.

Lanyon explains that this is an example of a measurement-induced nonlinearity (MINL), which is known to be an extremely powerful tool to manipulate qubits and realize an optical quantum computer.

“Measurements on the output of optical circuits built from only linear elements (such as beamsplitters, phase shifters and mirrors) can give rise to a non-linear evolution of the input optical field, i.e. for all intents and proposes, the photons seem to have interacted,” said Lanyon. “This is surprising, since photons do not naturally interact in these systems, and the effect is called a measurement-induced nonlinearity. In the context of our study, the MINL gives rise to the non-linear evolution required to generate entanglement and remove a single logical state from a qutrit superposition.”

He also gave a visual description.

"Consider that there are a number of different paths that the photons could take through the optical circuit," he said. "As in the double-slit experiment with electrons, the photons take all these paths at once, and, at the output, we end up with a large superposition. Now let's make a measurement of the whole (or part) of the output state. Certain results mean that certain paths were not taken – and therefore we can get rid of paths this way, conditional on getting certain measurement outcomes. Very clever measurements can leave you with a path history that results in entanglement."

The researchers also propose a number of extensions to their work. For example, a pair of entangled qubit-qutrit states could be used to create qutrit-qutrit entanglement, which would first require entangling the two qubits. High-brightness single-photon sources currently in development will help with these kinds of future experiments. The researchers also propose that using MINLs as a manipulation technique is not limited to photons, but can be applied to any type of bosonic quantum information carrier.

The scientists predict that higher dimensional entanglement will have applications including optimizing security in quantum information systems, and increasing channel capacity for quantum communication, among other uses.

More information: Lanyon, B. P., Weinhold, T. J., Langford, N. K., O'Brien, J. L., Resch, K. J., Gilchrist, A., and White, A. G. "Manipulating Biphotonic Qutrits." *Physical Review Letters* 100, 060504 (2008).