Measuring quantum information without destroying it

January 15 2009, By Miranda Marquit

(PhysOrg.com) -- One of the Holy Grails - so to speak - of science involves building quantum computers that can perform, with accuracy, the computations too advanced and too large for classical computers. While we remain years from this goal, breakthroughs are made regularly that make the reality of quantum computing a little more tangible. One such advancement is a recent demonstration of a quantum non-demolition sum gate, at the University of Tokyo.

The gate demonstrated in Tokyo is for use in quantum optics, but it is analogous to the C-not gate used for qubits. One of the prominent features of this gate, Peter van Loock, a scientist associated with the Max Planck Institute For The Science of Light and with the University Erlangen-Nürnberg in Germany, tells *PhysOrg.com*, is that it is meant for infinite dimensions described by continuous quantum variables. “In quantum optics, there are nice techniques in the lab that can be done with continuous variables,” he says. “This gate can be seen as part of a universal set to transform a multi-mode, infinite-dimensional, optical state by an arbitrary unitary transformation, as required for universal processing and computation.”

Work on the quantum non-demolition (QND) sum gate, and interpretation of the results, was done by Jun-ichi Yoshikawa, Yoshichika Miwa, Alexander Huch, Ulrik L. Anderson and Akira Furusawa, as well as van Loock. Their findings can be found in *Physical Review Letters*: “Demonstration of a Quantum Nondemolition Sum Gate.”

“There are two main significances of this QND gate,” van Loock explains. “The first is that it is an entangling gate that does not require you to prepare the states. Second, this gate has the properties of quantum non-demolition.”

Most of the time, when one wants to entangle quantum optical modes, van Loock says, it is necessary to prepare their states beforehand. “These cannot be classical, or near-classical, states when you entangle them, for instance, using a simple beam splitter. However, with this particular gate, you do not have to prepare the states in order to get an entangled output. You can use coherent states as input and get entanglement. This gate would entangle even two fairly classical states directly coming out of a laser source.”

The other item of significance has to do with the curious non-demolition quality of the gate. Normally, when quantum states are measured, the act of observing them destroys the state. The point of QND, then, is to measure a quantum observable without disturbing it. “The necessary back action of the measurement process must then be confined onto the conjugate quantum observable,” van Loock points out. “Qualities of quantum non-demolition include information gain, signal preservation and quantum state preparation. This sum gate reveals QND features, even with regard to two non-commuting observables. Either of these could be measured after the gate in a QND fashion, with the two output modes of the gate palying the roles of signal and probe.”

Possible applications for a QND sum gate are being explored, reports van Loock. He mentions that right now, this gate is more of a technical tool - contributing to experimental knowledge of fundamental quantum physics. However, van Loock sees the possibilities for the future. He points out that the QND sum gate, though initially intended for continuous variables, could be applied to discrete superposition states such as photonic qubits. “In particular,” van Look continues, “with the current indirect implementation where the experimentally hardest part of the gate need not be directly applied to the fragile input states."

Van Loock seems rather interested in the idea of cluster-state computation and merging Gaussian and non-Gaussian states. "It would be exciting to merge continuous cluster-state computation and discrete qubit encoding using this QND sum gate. It might be applied to merge Gaussian and non-Gaussian worlds, obtaining the highest efficiency possible," van Loock says. "We would not have to focus only on continuous variables or only on discrete qubit approaches. This gate has the potential to combine the two. It's a hybrid feature."

More information: Yoshikawa, et. al. "Demonstration of a Quantum Nondemolition Sum Gate." *Physical Review Letters* (2008). Available online: link.aps.org/doi/10.1103/PhysRevLett.101.250501.