Abstract for an Invited Paper
for the DAMOP07 Meeting of
The American Physical Society

Real-time Manipulation of Entanglement between Remote Atomic Ensembles for a Scalable Quantum Network

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Entanglement, a uniquely quantum mechanical property of correlations among various components of a physical system, has been recognized as a critical resource in quantum information science. Besides deterministic approaches, entanglement can be created probabilistically by way of quantum interference. It is essential that the success of entanglement creation is heralded unambiguously (by a "trigger") so that the resulting entangled state is available for subsequent operations. In addition, quantum memory is required to store the entangled states until they are needed for the protocol at hand. Combined, the "trigger" and quantum memory can lead to exponential speedup for protocols exploiting multiple components. We report the initial observation of measurement-induced entanglement between excitations stored in remote cold atomic ensembles. The resulting entangled state is heralded and stored in quantum memories. The heralded nature and quantum memory for certain quantum states are exploited to implement real-time control of the states of atomic ensembles and significantly improve the success rates of two quantum information protocols for scalable quantum networks. In one protocol, we observe the interference of two single photons from two ensembles and characterize their indistinguishability. In the other, we first prepare two pairs of entangled ensembles shared between two remote sites. The ensembles are then exploited to generate polarization-entangled photon pairs at the two remote sites, with the entanglement verified by the violation of a Bell's inequality. The photon pairs have potential applications for entanglement-based long-distance quantum communication protocols, such as quantum key distribution and quantum teleportation.