Teleportation of Quantum Information between Distant Atomic Qubits

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Abstract: We teleport quantum information between two distant ytterbium ions trapped in different vacuum chambers separated by one meter. Full state tomography shows that the heralded probabilistic process employed has a fidelity of 90%.

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Quantum teleportation is the disembodied transfer of an unknown quantum state between systems. Using only classical communication during the transmission, the process relies on the prior establishment of entanglement between the systems [1].

Here we demonstrate the teleportation of a quantum bit stored in a single trapped ytterbium ion over the distance of one meter to a second ytterbium ion stored in a completely independent trap with an average fidelity of 90% [2].

Source and target qubits are encoded in the ground state hyperfine “clock” states of trapped ytterbium ions. First, the source qubit is uploaded to one ion, while the target ion is prepared in an equal superposition of the two qubit states. Each ion is then promoted to its excited electronic state with synchronized picosecond optical π-pulses, while preserving the hyperfine coherence in each ion. The frequency of a subsequently emitted π-polarized $369.5\mathrm{nm}$ photon from each ion is then entangled with the qubit state of each respective ion. The two photons are directed to interfere on a 50% beamsplitter. As a consequence of the two photon interference, a coincidence detection of one photon at each output port of the beamsplitter is only possible if the photons are in the antisymmetric superposition of the two distinguishable frequency modes. This in turn projects the ions onto the antisymmetric superposition state. If now the result of a measurement of the source ion is relayed to the target ion, the original quantum state can be recovered at the target ion by a conditional rotation.

The teleportation protocol realized here differs from the original proposal [1] in that we use four qubits —two ions and two photons— rather than three. Moreover, our implementation is probabilistic, with a success probability per attempt of only about 10^{-8}. Nevertheless, the heralding event of the two-photon coincidence detection still allows our teleportation protocol to succeed without postselection, and there are promising methods for dramatically improving the success probability and scaling to complex distributed quantum networks.

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References

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