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Feasible protocol for teleportation between atomic ensembles

We devised and analyzed an experimentally feasible scheme for the deterministic teleportation of an atomic state between two ensembles at room temperature. Deterministic teleportation between two matter systems over a macroscopic distance is an essential prerequisite for quantum networks, but has not yet been implemented in experiment. In atomic vapors at room temperature, teleportation between light and matter has been realized, however, the teleportation of quantum states between two atomic ensembles could not be realized so far, due to the lack of a protocol that was feasible with the experimentally available interaction and in the presence of a realistic amount of noise. The scheme we proposed overcomes these problems, hopefully setting the stage for an experimental implementation of teleportation between two ensembles in the coming year.

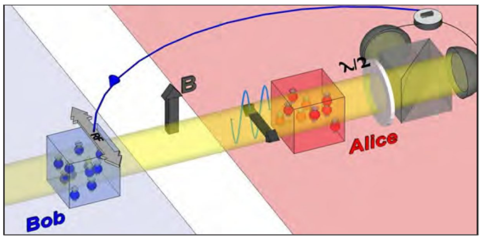

Figure 1: Teleportation of the quantum state of one Cesium ensemble at room temperature to another.

Specifically, we proposed and analyzed a teleportation scheme for the collective spin of two atomic ensembles that can take advantage of any nontrivial quadratic interaction between the optical and atomic modes, which makes use of the temporal mode structure in the ensembles to improve the fidelity, and performs better than standard teleportation schemes both for realistic interaction and in the presence of noise. The teleportation protocol is formulated for two spin-polarized Cesium-133 atomic ensembles at room temperature. The macroscopic spins of both ensembles are oriented in the same direction along the magnetic field B. This is achieved via optically pumping into F=4,m=4. The atomic ensemble at Bob's site is entangled with a light beam which is detuned by Δ from the D2 line F=4 to F'=5 transition. Alice conducts a joined measurement on the light beam and the atomic ensemble bearing the input state by performing a polarization measurement on the light after it has also interacted with the second ensemble. To complete the teleportation, the measurement results are fed back to Bob's ensemble via a magnetic RF pulse.

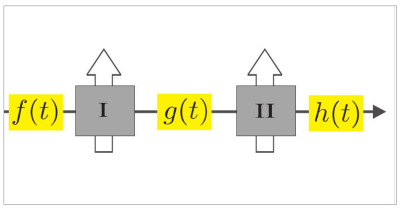

Figure 2: Sketch of the teleportation scheme between ensembles I and II. Both spins are aligned, the coupling strengths are modulated [f(t),g(t)] and an optimized read-out mode h(t) is chosen.

The interaction of light with atomic ensembles in a magnetic field involves an infinite hierarchy of back-action modes. Choosing (in contrast to the standard scheme) a parallel orientation of the spins in the two atomic ensembles yields a richer temporal mode structure in the ensembles. This can be taken advantage of if the coupling strengths of light with both ensembles are suitably modulated (functions f(t) and g(t) in Fig. 2). Solving the equations of motion, we obtain input-output relations for the system and from them a closed expression for the average teleportation fidelity. Our treatment takes into account the dominant noise process, namely decay of the atomic variables at a constant rate. By judicious choice of the temporal form of the modulation and of the read-out mode (function h(t) in Fig. 2) the average teleportation fidelity can be improved significantly to above 95% in the noise-free case (i.e., by an order of magnitude compared to the standard scheme, see Fig. 3). Moreover, we show that teleportation with a fidelity beating the classical limit is possible in the presence of realistic losses and also with any non-trivial quadratic coupling between light and matter (not necessarily QND). Further improvements of the scheme are under investigation.

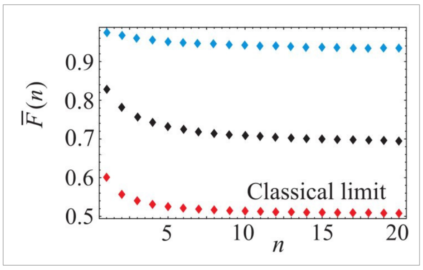

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figure 3: Average teleportation fidelity for the proposed scheme with (blue) and without (black) pulse shaping.