Quantum Control of the Collective Motion of Two Ions*

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The motion of a collection of trapped ions about its equilibrium configuration is strongly coupled by the Coulomb force. When the ions are sufficiently cold, this collective motion takes the form of a set of harmonic oscillator normal modes, each of which can be coupled to a given ion's internal states with appropriate laser fields. Following the scheme of Cirac and Zoller [1], the collective motion of trapped ions thus forms a "data bus" for quantum logic operations and allows the generation of arbitrary entanglements of the internal states of the ions. Quantum control of the ions' collective motion - including the cooling of a collective motional mode to the ground state and the preservation of its coherence - is a key ingredient in this scheme.

We report the first steps toward implementing quantum logic operations on more than one ion. Beryllium ions are stored in an elliptical rf (Paul) ion trap whose geometry allows the confinement of several ions along a line. We report the cooling of all six collective motional modes of two Be ions to the ground state [2]. We have also found that the heating out of the ground state of the three center-of-mass (COM) modes occurs at an anomalously high rate of 5-20 quanta/ms, while the heating of the remaining three non-COM modes is not detectable (<< 1 quantum/ms). This clearly points to the superiority of non-COM modes for quantum logic applications. However, the heating of the COM modes may still indirectly affect the fidelity of logic operations, since thermal motion in spectator modes of motion will suppress the coupling between the laser field and the ions.

"Micromotion" of an ion in a rf trap will also suppress the laser-ion interaction, or Rabi frequency. In the presence of an external uniform electric field, a collection of ions will not lie symmetrically about the nominal center of the trap where the rf fields vanish. This leads to a different amount of micromotion for each ion, and suggests a simple way to achieve differential addressing of two ions without using tightly focussed laser beams. We have realized almost arbitrary ratios of Rabi frequencies of two ions by simply introducing a static electric field with compensation electrodes. This scheme for differential addressing permits the creation of EPR-like entangled states of two ions.

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1. J.I. Cirac and P. Zoller, Phys. Rev. Lett. 74, 491 (1995).
2. B.E. King, C.S. Wood, C.J. Myatt, Q.A. Turchette, D. Leibfried, W.M. Itano, C. Monroe, and D.J. Wineland (LANL e-print quantum-ph/9803023).