Quantum Optics with Trapped Ions*

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The ability to localize a small number of atoms, with each one moving much less than an optical wavelength (the Lamb-Dicke regime) is a prerequisite for a wide range of fundamental atom-field experiments. Recent developments in ion trapping technology, relevant to this goal, are discussed and some possible experimental directions are outlined.

The confinement of motion to the Lamb-Dicke regime (for an optical transition) was demonstrated with a single laser-cooled ion in a quadrupole rf Paul trap [1]. However, two or more ions in the trap are pushed by their mutual coulomb repulsion from the center of the trap, which leads to relatively large "micromotion" associated with the non-zero rf field, and limits the achievable confinement. These problems can be overcome in a linear trap, in which the rf field vanishes along a line instead of just a single point. The development of the linear trap in recent years has been stimulated by the potential for high accuracy spectroscopy of stored ions. In one version of this idea, a linear trap for frequency standards achieved confinement of an elongated cloud of ions [2]. In a "racetrack" version of the trap, a crystallized string of laser-cooled ions was observed, with weak confinement along the axis of the trap [3]. A small linear trap was recently developed which can attain tight confinement in both the radial and axial directions. In this trap, crystallized strings of up to 33 ions and down to a single ion were observed [4]. The axial well depth can be adjusted by applying a static electric potential, and the radial pseudopotential well depth can be controlled by varying the rf drive amplitude. The secular frequencies of the trap are measured directly, and the observed ion positions are in close agreement with a static calculation for different numbers of ions.

These new developments in ion trapping technology open the way for a wide range of interesting experiments in fundamental Physics which require tight confinement of a small number of atoms. One example of such experiments is interference in the fluorescence of two radiating atoms which can give a measure of the coherence of that radiation and can demonstrate non-classical effects [5]. Another area of interest is the study of collective behavior of atoms coupled to an optical cavity. The last example is the study of optical bistability with a small number of atoms in a cavity, and ultimately with a single atom [6].

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