Development of an Ion Trap Quantum Information Processor

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We are currently constructing a linear ion trap for use as a quantum information processor, with the particular goal of investigating experimentally quantum error correction. Our scheme is based on the original proposals of Cirac and Zoller [1], and Monroe *et al.* [2], using a linear "crystal" of trapped ions to implement quantum bits and quantum gates, but will use a new method for reading out the state of the trapped ions [3].

The ion in our experiments is $^{40}\mathrm{Ca}^+$. A quantum bit will be represented by the two internal Zeeman states of the ground $^4S_{1/2}$ level of each ion, where the degeneracy is lifted by a small (~1G) magnetic field; hence the lifetime of the qubit states is essentially infinite. Superposition states may be created by means of a Raman transition linking the two states; the small radiofrequency energy splitting between the two states will allow accurate control of this transition. Quantum gates between different ions in the linear crystal are effected using the external, motional, degree of freedom of the whole crystal, where laser beams focused onto individual ions control which qubits are coupled to form the gate. Read-out of the state of the ions will be achieved by transferring (shelving) one of the qubit states to the $^3D_{5/2}$ metastable level and then testing which ions were shelved.

Since the first operation of our ion trap one year ago, we have achieved laser cooling of ions to temperatures of a few mK; imaged linear crystals of several ions; made the most precise determination of the lifetime of the $^3D_{5/2}$ metastable level by measuring the duration of many quantum jumps of a single cold ion [4]; demonstrated definitively that unexplained correlated quantum jumps between several cooled ions (as observed elsewhere [5, 6]) do not occur in our trap [7]; and made preliminary investigations of dark resonances in transitions in the ($^4S_{1/2}$, $^4P_{1/2}$, $^3D_{3/2}$) level system. Recently we have used a violet semiconductor diode laser [8] (at 397 nm) to trap and Doppler-cool ions; this offers considerable simplification over the frequency-doubling techniques usually employed.

Our new result for the $^3D_{5/2}$ lifetime, $\tau = 1168 \pm 7\,\mathrm{ms}$, is significantly longer than previous measurements (see figure 1). We believe this may be due to a previously unrecognised source of systematic error, *viz.* de-excitation from the metastable level by background radiation emitted by the infra-red diode laser used to drive the $^3D_{3/2} \rightarrow {}^4P_{1/2}$ repumping transition. In our experiment, if not eliminated this radiation shortened the apparent $^3D_{5/2}$ lifetime by as much as a factor of 3 at high laser intensities ($80\,\mathrm{mW/mm^2}$). This type of systematic effect may also explain the correlated quantum jumps observed elsewhere in crystals of several ions.

Apparatus details, the above results, and recent progress will be presented at the conference.

Reference	τ (ms)
Arbes *et al.* 1994	1054(61)
Knoop *et al.* 1995	994(38)
Gudjons *et al.* 1996	1064(17)
Ritter *et al.* 1997	969(21)
Lidberg *et al.* 1999	1090(50)
Block *et al.* 1999	1100(18)
This work [4]	1168(7)
Ali & Kim 1988	950
Zeippen 1990	1053
Guet & Johnson 1991	1236
Vaeck *et al.* 1992	1140
Brage *et al.* 1993	1163
Liaw 1995	1045
Biémont & Zeippen 1996	1070

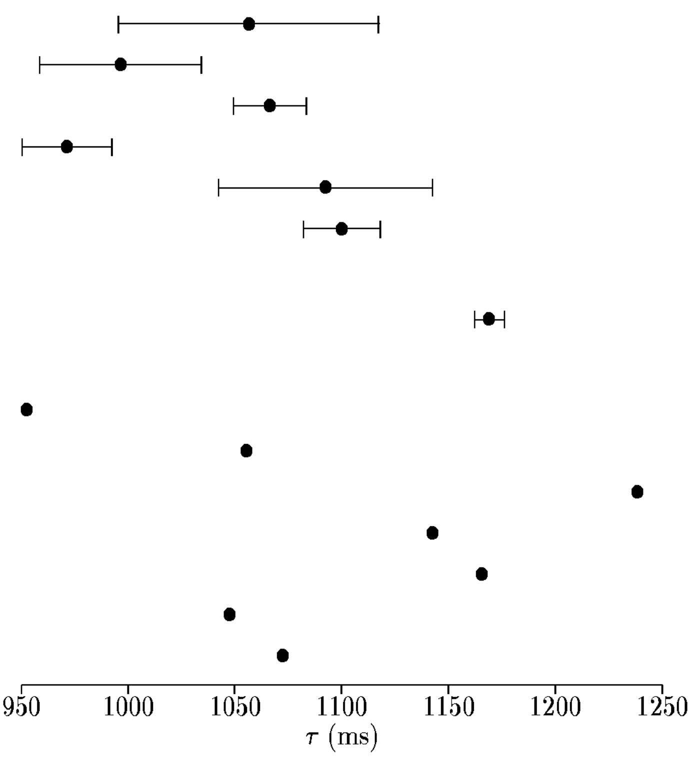

Figure 1: Values of the lifetime τ of the ${}^3D_{5/2}$ level of ${}^{40}\mathrm{Ca}^+$, experimentally measured (points with error bars) and theoretically calculated *ab initio* (circles). For full references see [4]. Earlier measured values are not shown since they have considerably larger experimental uncertainty.

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