

Experiments with single trapped ytterbium ions at JPL

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Single trapped ions have applications not only in frequency standards and metrology but also in studying fundamental physics and implementing quantum computation. In this proceeding, we report our initial experimental results with single trapped Yb^+ ions. We have observed resolved micromotion-sideband spectra in an allowed transition and demonstrated that it can be conveniently used in micromotion reduction. In addition, we have made lifetime measurements in the two metastable D states.

The energy level scheme of Yb^+ is given in Fig. 1. Yb^+ ions are confined in a Paul-Straubel trap.¹ The ions are cooled by a 369 nm laser. To prevent from optical pumping to the $D_{3/2}$ state, a clearing laser at 609 nm is used. This transition has about 4 MHz linewidth, smaller than the trapping rf frequency(11 MHz). Therefore, by scanning the clearing laser frequency while keeping the cooling laser frequency fixed, we can quickly obtain a resolved-sideband spectrum showing the enhanced micromotion modulations(Fig. 2). By adjusting external compensation with repeated scans, we were able to suppress the micromotion modulations(Fig. 2 insert).

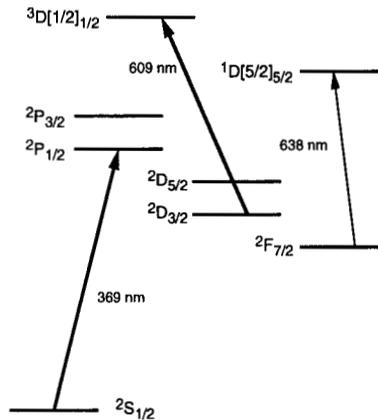


Fig. 1 Yb^+ energy level scheme(not to scale).

The $D_{5/2}$ lifetime was obtained by measuring the dwell time in the usual quantum jump experiment.² The ions were first prepared in $D_{5/2}$ through $P_{3/2}$ using the 329 nm light from a Yb discharge lamp. Upon spontaneously decaying to the ground state, the ion fluorescence resumes and the dwell time is recorded. However, there exists a long-lived F state below the $D_{5/2}$ state. About 4 out of 5 decays from the $D_{5/2}$ state end in the F state.³ Therefore, an additional 638 nm laser was used to depopulate the F state. The dwell time in the F state was made much longer than that in the $D_{5/2}$ state so as to distinguish the two. The measured lifetime is 7.0(0.4) ms, in good agreement with a previously published value.³

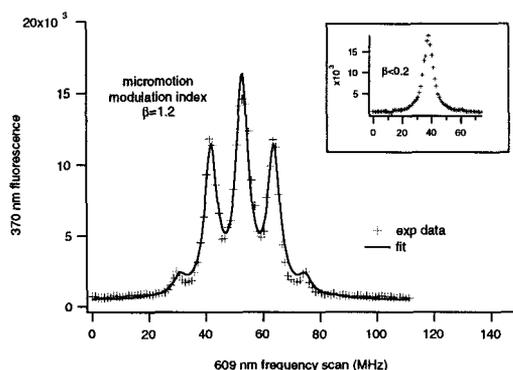


Fig. 2 Resolved micromotion sideband spectrum of a single Yb^+ ion. The sidebands disappeared after compensation in the insert.

To measure the $D_{3/2}$ state lifetime, we relied on the large branching ratio of $P_{1/2}$ to the ground and $D_{3/2}$ states. The measurement process essentially consists of two short 369 nm laser pulses separated by a given waiting time T . The first prepares the ion in $D_{3/2}$ while the second probes the final state. Without the clearing laser on, the ion emits an average of 200 photons if in the ground state, 0.03% of which can be counted. The pulse sequence was repeated many times and the photon counts were accumulated on a MCA. The ratio of the photon counts in the two pulses is $1 - \exp(-T/\tau)$. In the actual experiment, laser pulse sequences were generated by a specially designed laser chopper and additional laser pulses were used for cooling and background light elimination. Fig. 3 plots the ratio vs. waiting times. A weighted least-squares fitting gives the lifetime of 52.7(2.4) ms. This is the first $D_{3/2}$ lifetime measurement in Yb^+ with single ions and the obtained value agrees reasonably well with the published values.⁴

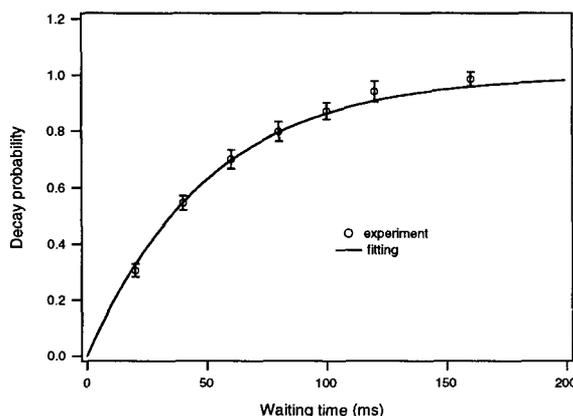


Fig. 3 Graph of the photon count ratio vs. waiting time. A least-squares fitting to $1 - \exp(-T/\tau)$ gives the lifetime of 52.7 ms.

It should be pointed out that the above quoted errors are statistic uncertainties. The systematic errors due to timing and collisions are much smaller.

This work is carried out at JPL under contracts from NASA. Authors thank Wei Wo for his contribution in the initial experiment setup.

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² W. Nagourney, J. Sandberg, and H. Dehmelt, *Phys. Rev. Lett.* **56**, 2797 (1986).

³ P. Taylor *et al.*, *Phys. Rev. A* **56**, 2699 (1997).

⁴ C. Gerz, F. Roths, F. Vedel, and G. Werth, *Z. Phys. D* **8**, 235 (1988).