Progress towards a single ytterbium ion optical clock

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A single laser-cooled ion held in an electrodynamic trap is a near ideal atomic sample for a frequency standard. The quantum jump technique is used to observe a high-Q forbidden transition in the ion. It has been suggested that the ultimate limit to the reproducibility of a standard of this type will lie in the region of one part in 10^{18} [1].

For most ion trap systems being currently pursued, the forbidden reference transition has a linewidth in the region of 1 Hz. This gives a limit of the order $\sigma_y(\tau) \sim 10^{-15}$ $\mathrm{Hz}^{-1/2}$ to the stability of such a single ion standard. To study the ion at the 10^{-18} level would therefore require an averaging time of $\sigma_y(\tau) \sim 1$ month. A reduction in the natural linewidth of only a factor of 10, would reduce this averaging time 100-fold to just a few hours. This underlines the need for forbidden transitions of sub-hertz natural linewidth.

Such a transition occurs in the singly charged ytterbium system. The $^2F_{7/2}$ state in Yb^+ can only spontaneously decay via an extremely forbidden electric octupole (E3) transition to the $^2S_{1/2}$ ground state. The resulting octupole transition at 467 nm has a natural linewidth in the nanohertz region due to the 10 year radiative lifetime of the $^2F_{7/2}$ state [2]. The effective removal of the natural linewidth barrier to the stability of the standard means that in practice its stability will most likely be limited by the probe laser linewidth.

Past work has concentrated on simply observing the $^2S_{1/2}$-$^2F_{7/2}$ octupole reference transition at 467 nm. The difficulty in observing such a weak transition, led to first observing it in the technically straightforward $^{172}Yb^+$ isotope [2]. The 172-isotope is, however, unsuitable as a frequency standard as the reference frequency is susceptible to the linear Zeeman effect. This has necessitated a switch to the $^{171}Yb^+$ isotope, which has m_F=0 – m_F=0 transitions that are free from the linear Zeeman effect. This reduces the effect of perturbing magnetic fields to an almost negligible level.

Work will be presented on recent spectroscopy in the $^{171}Yb^+$ isotope [3, 4, 5] and development in narrowing the linewidth of the 467 nm probe laser. A Ti-Sapphire laser is locked to an ultra-high finesse cavity using the Pound, Drever, Hall technique [6], with an external double-pass AOM as the actuator. The cavity, made from ultra-low expansivity (ULE) glass, is situated in a vacuum chamber and is temperature controlled and isolated from vibrations. Linewidths ~ 1 kHz are achieved and work is underway to reduce this further. The stabilised beam is frequency doubled to 467 nm using $KNbO_3$ in an angle tuning arrangement.

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