Systematic uncertainty analyses of $^{171}Yb^+$ single-ion atomic clocks

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Extended Abstract

$^{171}Yb^+$ provides two reference transitions that are suitable for the realization of an optical frequency standard: the $^2S_{1/2}(F=0)\rightarrow{}^2D_{3/2}(F=2)$ electric quadrupole (E2) transition at 436 nm and the $^2S_{1/2}(F=0)\rightarrow{}^2F_{7/2}(F=3)$ electric octupole (E3) transition at 467 nm. For the realization of a frequency standard with very small systematic uncertainty the E3 transition is advantageous due to its significantly lower sensitivity to electric and magnetic fields [1]. With a natural linewidth in the nHz-range it provides the potential for very high stability. Because of its extremely small oscillator strength the excitation requires very high intensity which in turn introduces a significant light shift. To avoid this frequency shift, we have implemented the Hyper-Ramsey excitation scheme [2]. Cancellation of the shift is controlled by interleaved single-pulse Rabi excitations, which reduces the related relative frequency uncertainty to 1.1×10^{-18}. To determine the frequency shift due to thermal radiation emitted by the ion's environment, we have measured the static scalar differential polarizability of the E3 transition based on light shift measurements with near-infrared lasers as $0.888(16) \times 10^{-40}$ Jm^2/V^2. Together with the results of an analysis of the thermal field emitted by the ion trap structure, this reduces the uncertainty due to thermal radiation to 1.8×10^{-18}. The residual motion of the ion yields the largest contribution (2.1×10^{-18}) to the present total systematic relative uncertainty of the clock of 3.2×10^{-18} [3].

For the evaluation of frequency shifts related to external magnetic and electric fields as well as field gradients, the significantly higher sensitivity of the E2 transition frequency to these perturbations allows for an examination of the E3 transition frequency shifts on a magnified scale. With precise information about the relative field sensitivities, uncertainties in the E3 transition frequency due to field perturbations can be reduced: Shifts of the E3 transition frequency can be corrected accurately based on measurements of shifts in the E2 transition frequency in the same ion. We present improved measurement results of the relative field sensitivities of the E2 and E3 transition frequencies and discuss the effects of these results on the uncertainty budgets of our frequency standards.

To address various interrogation-induced clock errors (e.g., light shifts, phase chirps, phase asymmetries, pulse-synchronous intensity variations) we have developed a balanced version of Ramsey's method of separated oscillatory fields that is well suited for measuring unperturbed transition frequencies of atomic reference transitions that suffer from significant clock shifts in the presence of the oscillatory drive fields. We have experimentally demonstrated the feasibility of this specialized common-mode suppression concept on the E3 transition and could show that no systematic clock shifts are incurred for arbitrarily detuned drive pulses. Unlike the composite pulse Hyper-Ramsey excitation, auto-balanced Ramsey spectroscopy can provide universal immunity to a wide variety of pulse aberrations and drive pulse induced shifts. In this context we have also devised an experimental method addressing issues related to motional heating of the confined ion.

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References

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