High-Accuracy Yb^+-Ion Clocks for Tests of Fundamental Principles and Robust Long-Term Operation

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The $^{171}Yb^+$ ion is widely used in ion-based optical clocks and quantum technology. Long trapping lifetimes exceeding months have been observed and reliable laser sources for Doppler cooling and interrogation of the clock transitions are readily available. We employ transitions from the $^2S_{1/2}$ (F=0) ground state to the first excited states for the realization of optical clocks: an electric octupole (E3) transition to $^2F_{7/2}$ (F=3) state and an electric quadrupole (E2) transition to $^2D_{3/2}$ (F=2) state. Interrogating both transitions in an alternating fashion allows us to employ the E2 transition to characterize residual fields on a magnified scale and correct the corresponding shifts for the E3 transition with low uncertainty because the relative sensitivities have been determined.

In this work, we report on results from long-term operation of the Yb1 optical clock of PTB, where we have obtained uptimes exceeding 80% over typical TAI reporting intervals of 30 days. The measurement instability of the E3/E2 frequency ratio obtained over the last two years is compatible with pure white frequency noise as expected from the quantum projection noise on the E2 transition, reaching the mid 10^{-18} level for averaging periods of 5×10^6 s. This result is consistent with the expected reproducibility of the E2 transition frequency of 4×10^{18}. Using these data and the special electronic structure of Yb^+ allows us to improve searches for a coupling of ultra-light dark matter (UDM) to photons as well as temporal drifts of the fine structure constant and its potential dependence on the gravitational field [1]. Interestingly, the same optical clock comparison data can also be used to probe UDM-nuclear couplings and provides competitive sensitivity [2].

To further improve systematic uncertainties and increase the coherent interrogation time of the Yb^+ E3 clock transition which features an excited state lifetime of 1.6 years, we have started to investigate the use of $^{88}Sr^+$ as co-trapped ancillary ion. Its well-characterized differential polarizability has enabled a direct measurement of the thermal field perturbing the ion during clock operation and a small uncertainty for the ratio of the $^{171}Yb^+$ E3 and $^{88}Sr^+$ clock transition frequencies [3]. Our measurement provides vital information for resolving the tension found between other $^{88}Sr^+$ clock frequency measurements [4,5]. Further investigation of both species in one trap will enable us to improve the performance of $^{171}Yb^+$ clocks by reducing the so-far limiting uncertainty in the sensitivity to thermal radiation and increasing the frequency stability by extending the coherent interrogation time via sympathetic cooling.

Finally, we will shortly report on our efforts to employ a transportable optical clock based on the E2 transition for contributions to TAI and frequency measurements at other institutes in Europe.

References

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