Reducing the uncertainty of Yb^+ ion clocks to below 10^{-18}

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Optical clocks based on the $^2S_{1/2}$-$^2D_{3/2}$ electric quadrupole (E2) and $^2S_{1/2}$-$^2F_{7/2}$ electric octupole (E3) transitions in $^{171}Yb^+$ have been accepted as secondary representations of the second and were demonstrated to enable 10^{-17} and 10^{-18} uncertainty, respectively [1, 2]. For these clocks, the leading contribution to the uncertainties resulted from their sensitivity to thermal radiation, causing black-body radiation (BBR) shifts of about -5×10^{-16} and -7×10^{-17} at room temperature. So far, the corresponding differential polarizabilities for both transitions have been determined using near-infrared and infrared laser fields together with theoretical modelling to extrapolate to the wavelength range relevant for room temperature BBR [2, 3]. In these works, the intensity of the laser radiation perturbing the ion has been inferred from measured intensity profiles and measurements of the optical power outside the vacuum chamber. Both quantities cause limitations: Optical power measurements are typically limited to an uncertainty of about 1 %, losses from vacuum windows need to be considered and imperfections of the beam profiles can easily lead to an even larger uncertainty.

For transitions of ion-based clocks with positive BBR shifts, the differential polarizability can also be inferred from the magic trap drive frequency at which the Stark shift and second-order Doppler shift of excess micromotion cancel. Following this approach, the differential polarizability of the $^{88}Sr^+$ clock transition has been measured with only 1.5×10^{-3} uncertainty [4]. Calculation of the BBR shift at room temperature also requires a dynamic correction of about -1% at 300 K to account for changes in the differential polarizability over the spectral composition of BBR [4]. We have verified the corresponding theoretical description by measuring the longest wavelength for which the dynamic polarizability crosses zero close to 1.5 μm. With this knowledge, the $^{88}Sr^+$ ion can serve as in-situ intensity sensor for infrared radiation by measuring the offset from the unperturbed transition frequency [5]. We induced frequency shifts with radiation produced by a 10 W CO_2 laser. Its wavelength of 10.6 μm is very close to that of the peak spectral radiance of BBR at room temperature. From interleaved measurements of the $^{88}Sr^+$, $^{171}Yb^+$ E2, and $^{171}Yb^+$ E3 clock transition frequencies with the same perturbing laser field, we find the dynamic polarizabilities of the $^{171}Yb^+$ transitions with uncertainties predominantly limited by that of $^{88}Sr^+$. We also find the relative magnitude of scalar and tensorial parts of the differential polarizabilities which can be particularly helpful for future theoretical investigations. Our measurements now enable the correction of the BBR shifts with 10^{-18} and 10^{-19} uncertainty for the E2 and E3 transitions of $^{171}Yb^+$, respectively.

In addition to this determination, we will summarize how high-performance laboratory clocks and transportable clocks will profit from these measurements. For this, we will also discuss our recent progress on employing the clock transitions of the $^{173}Yb^+$ isotope.

References

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