Higher-order shifts of a clock frequency in Sr, Yb and Hg atoms trapped in an optical lattice

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The recent progress in designing optical frequency standards with an uncertainty at a level 10^{-17} – 10^{-18} requires unprecedented accuracy in estimating the role of higher-order uncertainties of optical clocks[1]. In this paper, we systematically evaluate the multipole, nonlinear and other higher-order contributions to uncertainty for the alkaline-earth-like-atoms Sr, Yb and Hg.

In agreement with our general approach[2] the dependence of the lattice-induced shift of the clock frequency on the lattice-laser intensity may be written as

$$\Delta \nu_{cl}^{latt}(n,\xi,I) = c_{1/2}(n)I^{1/2} + c_1(n,\xi)I + c_{3/2}(n,\xi)I^{3/2} + c_2(\xi)I^2 \tag{1}$$

The coefficients $c_i(n,\xi)$ depend on the quantum number n of the vibrations of atoms in the lattice potential wells and on the circular polarization degree ξ of the lattice radiation ($-1\leq\xi\leq 1$), therefore they may be reduced significantly by the sideband cooling down oscillations of atoms to $n=0$, together with tuning the lattice laser to the magic frequency and magic ellipticity. The coefficient $c_{1/2}(n)$ is determined by the difference between the combined polarizabilities $\alpha_{g(e)}^{dqm}(\omega) = \alpha_{g(e)}^{E1}(\omega) - \alpha_{g(e)}^{qm}(\omega)$ of the ground-state (g) and excited (e) atom[2]. The linear in I term is mainly determined by the difference of the electric dipole polarizabilities $\alpha_{g(e)}^{E1}(\omega)$ and an additional, significantly smaller hyperpolarizability-dependent contribution from the anharmonic term[2]. The coefficients $c_{3/2}$ and c_2 depend on the hyperpolarizabilities.

For determining the magic wavelength there exist several experimentally realizable strategies, which may eliminate the most contributing terms of equation (1):

1. Equalization of the clock-level shifts in a traveling wave;
2. Equalization of the clock-level shifts in a standing wave;
3. Equalization of E1 polarizabilities of the clock states.

These and other aspects of experimentally realizable strategies will be reported in detail.

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[1]. B. J. Bloom, et al., "An optical lattice clock with accuracy and stability at the 10^{-18}", Nature, 2014, in press.
[2]V.D.Ovsiannikov, et al., "Multipole, nonlinear, and anharmonic uncertainties of clocks of Sr atoms in an optical lattice," Phys.Rev.A., vol. 88, p.013405(2013).