Effects of Wavefront Curvature in Optical Atomic Beam Clocks

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We rely on atomic clocks to provide a reproducible basis for our understanding of time and frequency. The accuracy of these devices is outstanding, and state-of-the-art systems achieve systematic uncertainties on the order of 10^{-18}. A careful understanding of the sources of uncertainties and shifts in the laser frequency is vital to development of future clocks. In optical atomic clocks lasers are often modeled as plane waves but in reality the wavefronts are curved, leading to deviations in the behaviour of the clock signal predicted using plane wave models [1]. Here we develop an analytic theory for atoms interacting with Gaussian lasers with curved wavefronts, allowing us to elucidate the effects of wavefront curvature on the operation of Ramsey-Borde interferometric atomic clocks. We simulate the Olson *et al.* ^{40}Ca beam clock experiment [1] and find that a realistic model for the laser that includes wavefront curvature is essential to accurately reproduce the results. In particular our model confirms the nonintuitive observation that the contrast of the Ramsey fringes is optimised when the laser is focused away from atomic beam. We also find that the observed few-hundred Hz frequency shifts away from the recoil shifted clock transition frequency can be accounted for by a combination of the optical Guoy phase and atomic time-of-flight shifts induced by curved wavefronts. Finally, we use our model to explore how the optical setup can be optimised to give stable and predictable frequency corrections to the clock transition as well as high contrast Ramsey fringes.

[1] J. Olson *et al*., *Phys. Rev. Lett.*, **123**, 073202 (2019).