Precision measurement and control of Stark shifts in a Yb optical lattice clock

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In an optical lattice clock, the measured transition frequency must be corrected for systematic frequency shifts, including Stark shifts attributed to blackbody radiation (BBR), stray static charge in the system, and the lattice trapping light. Here we describe in detail our strategies to control these Stark shifts and present their resulting contributions to the clock uncertainty budget.

To control the BBR shift, we have constructed a "shield" that furnishes the lattice-trapped atoms with a highly-uniform, room temperature environment. Several precision sensors on the shield monitor its temperature in real-time, allowing an accurate determination of the BBR shift. By activating heaters on the shield, we were able to experimentally demonstrate consistency between our evaluated BBR environment and the expected atomic response over a range of temperatures. We further discuss improvements in the shield design to achieve BBR environmental uncertainty at the low 10^{-19} level.

To mitigate the build-up of stray static charge, we were careful to employ conductive materials on our aforementioned shield, resulting in an effective Faraday cage surrounding the atoms. Nevertheless, the absence of stray fields must be verified. To this end, we introduced a static field at the atoms by applying high voltage to isolated portions of the shield, while keeping the remainder electrically grounded. Reversing polarity of the applied voltage results in a clock signal that is sensitive to a stray field in the direction of the applied field. Using this method, we probed for stray fields along three mutually orthogonal axes, leading to an uncertainty at the 10^{-19} level for the electrically grounded configuration.

In a lowest order approximation, operation of the lattice at the "magic" wavelength yields identical trapping potentials for both clock states, resulting in zero net lattice-light shift. However, higher order interactions with the lattice light—including hyperpolarizability, magnetic dipole, and electric quadrupole interactions—have non-negligible effects on the trapping potentials. We have constructed a build-up cavity for our lattice laser, which allows us to operate with lattice trap depths beyond $1000E_R$ (E_R = photon recoil energy). Exploiting this flexibility, we have measured clock frequencies over a large range of trap depths using a number of different lattice wavelengths. By simultaneously accounting for other important effects using both experimental data and theoretical modeling, including axial and transverse motional state distributions, we have found an optimal operational condition (lattice depth and wavelength) so as to minimize uncertainty in the lattice-light shift. We also discuss theoretical calculations of the lattice-light shift parameters for different optical lattice clock species.