Measurement of the Static Scalar Polarizability of the $^{88}Sr^+$ Clock Transition

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Whether based on neutral atoms in optical lattices or trapped single ions, the blackbody radiation (BBR) shift is often the dominant source of uncertainty for optical frequency standards.[1] The 445 THz electric-quadrupole allowed $5s\,^2S_{1/2}-4d\,^2D_{5/2}$ transition of the $^{88}Sr^+$ ion is no exception. Recently, we have reported a BBR shift contribution with an uncertainty of 2.2×10^{-17}, yielding a total estimated uncertainty of 2.3×10^{-17}. The BBR contribution is an order of magnitude larger than that of any of the other known shifts that perturb the $^{88}Sr^+$ clock transition frequency.[2] In our current system, the BBR shift is primarily determined by the uncertainty of the differential static scalar polarizability $\Delta\alpha_0$.

We will present a method used to measure $\Delta\alpha_0$. The method is based on the relation between $\Delta\alpha_0$ and the trap rf drive frequency Ω_0 at which the micromotion shifts, caused by the time-dilation and the scalar Stark effects, cancel each other. To observe the cancellation effect, we compared two $^{88}Sr^+$ ion systems: one using an endcap trap, the other a Paul trap. The endcap trap, which has well-controlled systematic shifts, is used as reference. The Paul trap with large residual micromotion is used to study the changes in the clock transition frequency as a function of trap frequency and to determine Ω_0 with good accuracy. Figure 1 shows a preliminary result of this trap comparison. It illustrates clearly the cancellation effect obtained when the Paul trap is operated at the frequency of $\Omega_0 \approx 14.4$ MHz.

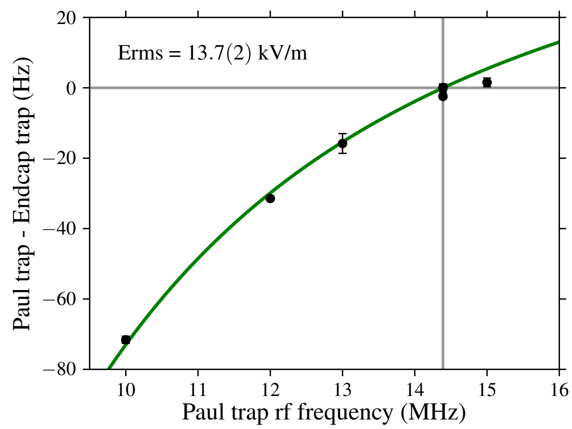

Fig. 1: Observed frequency difference between two $^{88}Sr^+$ ion optical frequency standards as a function of the operating frequency of the Paul trap with large residual micromotion. The trap frequency at which the micromotion shifts cancel each other is shown by a vertical line at ≈ 14.4 MHz. E_{rms} is a fitting parameter that gives the rms electric field at the ion due to displacement from trap center.

Preliminary analysis of the data indicates that the uncertainty of $\Delta\alpha_0$ can be reduced by at least a factor of five when compared to the current best value.[3] As a consequence, the uncertainty evaluation of the ion is reduced to 1.2×10^{-17}, limited by the BBR field estimate in the endcap trap. The improved value of $\Delta\alpha_0$ will also allow operation at Ω_0 where the net micromotion shift will be reduced by more than two orders of magnitude.[2]

[1]M. Safronova, M. Kozlov, and C. Clark, "Blackbody radiation shifts in optical atomic clocks," IEEE Transactions on Ultrasonics, Ferro-electrics and Frequency Control, **59**, pp. 439–447, 2012.

[2]P. Dubé, A.A. Madej, Z. Zhou, and J.E. Bernard, "Evaluation of systematic shifts of the $^{88}Sr^+$ single-ion optical frequency standard at the 10^{-17} level," Phys. Rev. A, **87**, 023806, 2013.

[3]D. Jiang, B. Arora, M.S. Safronova, and C.W. Clark, "Blackbody-radiation shift in a $^{88}Sr^+$ ion optical frequency standard," J. Phys. B: At. Mol. Opt. Phys. **42**, 154020, 2009.