Background gases collisional shift in a Sr optical lattice clock

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Optical lattice clocks are one of the best atomic clocks, with an unprecedented frequency estimation uncertainty of 18 digits. This remarkable performance enables a range of applications, especially the redefinition of the SI unit second. Further improvement of the frequency estimation by reducing the uncertainty stemming from various sources is a long-standing goal.

Among the factors degrading the clock performance, two-body collisions between the cold atoms trapped in the optical lattice and the background gas molecules, induce a frequency shift on the clock transition that is proportional to the loss rate of the trapped atoms. This shift, typically in the 10^{-17} range for a 1s lifetime of atoms, can be estimated from a theoretical model[1,2] or experimental measurements[3,4]. In the case of collisions between cold Sr atoms and hot H_2 molecules, which are eventually the dominant background gases in the vacuum chamber, we observed a 2-fold discrepancy between the experiment and the theoretical semi-classical solution of the C_6 molecular potential. To investigate this discrepancy, and to allow for the model to be extended to evaluate the correction for other gases, we modified the model by adding short-range C_{12} interactions. Because C_{12} coefficients are not well documented in the literature, we calculated the frequency shift on the clock levels for C_{12} values spanning several orders of magnitude (Fig. 1). From this simulation, we first conclude that it is possible to explain the experimentally observed value, but also observe that extreme values of C_{12} coefficients always yield constrained values for the frequency shift. We will also present simulation results for other gases (e.g. Ar, He, and N_2). The

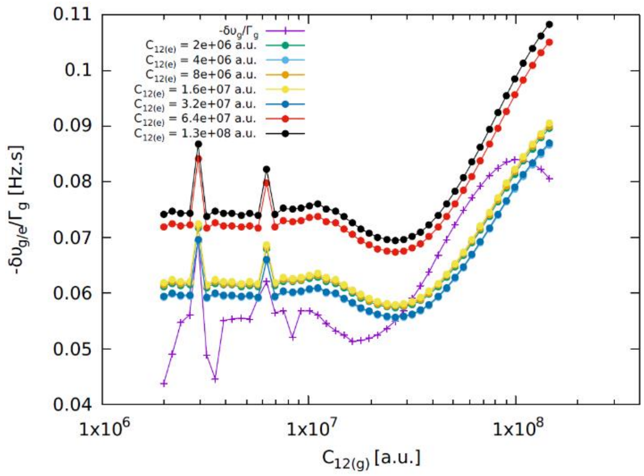

Fig. 1: Simulation of the excited state (circles) and ground state (cross) frequency shifts, scaled to a 1 s lifetime, for Sr-H_2 collisions, at different values of C_{12} coefficients. The experimental value[4] is $(\delta\nu_e-\delta\nu_g)/\Gamma_g = 0.0129\ (13)$ Hz.s.

[1] K. Gibble "Scattering of cold-atom coherences by hot atoms: frequency shifts from background-gas collisions", Phys. Rev. Lett. 110, 180802, 2013.

[2] M. Abdel-Hafiz, *et al* "Guidelines for developing optical clocks with 10^{-18} fractional frequency uncertainty", arXiv:1906.11495, 2019.

[3] W. F. McGrew, *et al* "Atomic clock performance enabling geodesy below the centimetre level", Nature 564, 87-90, 2018.

[4] B. X. R. Alves, *et al* "Background gas collision frequency shift on lattice-trapped strontium atoms", In proceedings of IEEE IFCS and EFTF, 1-2, 2019.

experimental measurements of the loss rate ratio Γ_e/Γ_g and collisional shift for the interaction between Sr and different background gases (including He, Ar, N_2) injected into the vacuum chamber and calibrated with a residual gas analyzer will also be demonstrated. These measurements help to constrain the theoretical model, especially when compared to the measured frequency shift induced on the clock transition, but also can be used as an indication of the residual gas actually present in a clock vacuum system.

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