Frequency reference validation with $^{176}Lu^+$

K. J. Arnold[1,2], S. Bustabad[3], Zhao Qi[1], Qin Qichen[1], Zhiqiang Zhang[1], Zhang Zhao[1], M. D. Barrett[1,2,3]

1. Center for Quantum Technologies, National University of Singapore, Singapore
2. Temasek Laboratories, National University of Singapore, Singapore
3. National Metrology Center, Agency for Science, Technology and Research (A*STAR), Singapore

email: phybmd@nus.edu.sg

Singly ionized lutetium ($^{176}Lu^+$) has a unique level structure that provides multiple clock transitions [1]. In combination with hyperfine averaging [1], two of these transitions ($^1S_0 - {}^3D_1$ & $^1S_0 - {}^3D_2$) present both a long lifetime and low sensitivity to the electromagnetic environment, which allows high performance clock operation on both transitions [2]. Recently we have demonstrated clock comparison on the $^1S_0 - {}^3D_1$ at the low 10^{-18} level limited by clock stability, with an error budget that supports the capability to go well beyond 10^{-18} [3].

Clock assessment is nothing more than the measurement of atomic properties that define the sensitivity of the atomic reference to its electromagnetic environment, an assessment of that environment, and an account of relativistic shifts. When a frequency ratio is measured within the one apparatus, relativistic shifts drop out and both transitions experience the same electromagnetic environment. Consequently, the error budget for the frequency ratio is practically identical to the individual error budgets for the two transitions. Since motional effects are easily quantifiable and typically very small for a heavy ion, the frequency ratio measured in situ provides a well-defined metric to compare the performance of remotely located systems. If the frequency ratios disagree, we can be certain at least one of the clock assessments is incorrect. If they agree, clock comparison on the $^1S_0 - {}^3D_1$ (primary) transition would only differ by the gravitational red shift between them, which may be confirmed by comparison on the $^1S_0 - {}^3D_2$ (secondary) transition.

Provided the zero-temperature frequency ratio is established, the above idea can be extended to include temperature assessment for room temperature systems. The frequency ratio would provide a measurement of the system temperature, and a comparison on the primary would provide the gravitational red-shift with a minor correction for temperature. Subsequent comparison on the secondary must give a frequency difference consistent with the inferred temperature and redshift.

References

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