An Optical Clock Based on a Single Trapped Ra^+ Ion

Elwin A. Dijck[1], A. Mohanty, M. Nuñez Portela, O. Böll, S. Hoekstra, K. Jungmann, C.J.G. Onderwater, R.G.E. Timmermans, L. Willmann, H.W. Wilschut

KVI, University of Groningen, Zernikelaan 25, 9747 AA Groningen, The Netherlands
[1]dijck@kvi.nl

Single-ion based optical clocks currently provide the highest accuracy for time and frequency standards. The estimated stability of ion clocks such as those based on Al^+, Hg^+ and Yb^+ already exceeds that of the latest ^{133}Cs fountain clock standards. Each ion species has its benefits as well as drawbacks. We investigate the properties of a radium single-ion optical clock [1]. An important advantage of Ra^+ is that all required optical wavelengths are available from semiconductor diode lasers. This promises a low-cost and compact setup. The system is furthermore of interest for a high-precision measurement of atomic parity violation [2].

The ultra-narrow optical transition from the ground state to the metastable D-state of Ra^+ is an excellent candidate for a stable and accurate clock. The electric quadrupole transitions $7s\,^2S_{1/2} - 6d\,^2D_{3/2}$ at 828 nm and $7s\,^2S_{1/2} - 6d\,^2D_{5/2}$ at 728 nm offer clock candidates in several radium isotopes. In particular, the $7s\,^2S_{1/2}$ ($F = 2$, $m_F = 0$) $- 6d\,^2D_{3/2}$ ($F = 0$, $m_F = 0$) transition in $^{223}Ra^+$ can be exploited as a robust clock operating at a projected fractional frequency uncertainty of 10^{-17}, since it exhibits no linear Zeeman and electric quadrupole shifts. With more experimental effort, clocks exploiting $^{223,225,226}Ra^+$ can reach uncertainties at or beyond the 10^{-18} level [1].

In our experimental program we have performed laser spectroscopy of trapped $^{209–214}Ra^+$ at the KVI AGOR/TRIμP facility. This yielded the hyperfine structure of the $6d\,^2D_{3/2}$ level, the isotope shift of the $6d\,^2D_{3/2} - 7p\,^2P_{1/2,3/2}$ transitions and the lifetime of the $6d\,^2D_{5/2}$ level [2], providing input for the design of the Ra^+ clock and further refinement of the theoretical work.

Applications of the Ra^+ clock include the direct comparison of clock frequencies using optical fiber networks and optical frequency combs. The comparison of different ion species is of fundamental interest due to their specific dependence on possible changes of the physical constants, e.g. the fine structure constant. The Ra^+ clock transition is much more sensitive to $d\alpha/dt$ than the Al^+ clock transition, and its shift is opposite in sign to that of Hg^+ [1]. The clock would also allow the determination of frequency shifts in the gravitational field of the Earth, with possible applications in geodesy.

An optical fiber link has been established between KVI and the LaserLaB at VU University Amsterdam [3] via a 317 km commercial communication fiber provided by SURFnet. This enables the comparison of the Ra^+ clock to an Al^+ clock in development at the LaserLaB and to investigate the implementation of an improved Earth-bound positioning system.

References:
[1] O.O. Versolato et al., Phys. Rev. A **83**, 043829 (2011); B.K. Sahoo et al., Phys. Rev. A **76**, 040504(R) (2007).
[2] G.S. Giri et al., Phys. Rev. A **84**, 020503(R) (2011); O.O. Versolato et al., Phys. Rev. A **82**, 010501(R) (2010); L.W. Wansbeek et al., Phys. Rev. A **78**, 050501(R) (2008).
[3] J.C.J. Koelemeij et al., at TNC 2012 conference, http://tnc2012.terena.org/core/presentation/43