Towards a thorium-229 isomer based nuclear clock: recent progress

Piet Van Duppen

KU Leuven, Instituut voor Kern- en Stralingsfysica, 3001 Leuven, Belgium

The low-excitation energy of the Th-229 nuclear isomer around 8.3 eV is an ideal candidate for the development of a nuclear clock which could be particularly suited for fundamental physics studies [1, 2]. The presence of such a low-energy isomer was evidenced from indirect measurements decades ago, however, the experimental proof for its existence was only reported in 2016 [3]. Using VUV spectroscopy and an alternative way to populate the isomer via the beta decay of Ac-229 produced at ISOLDE-CERN, the radiative decay of the Th-229 isomer embedded in large bandgap crystals (like CaF2 and MgF2) was observed [4]. This measurement reduced the uncertainty of the energy value to a level that allowed a search for laser excitation of the nuclear isomer and prepared the route towards the development of a nuclear clock. Indeed soon after, laser excitation of the isomer was observed [5,6,7]. The uncertainty of the excitation energy was reduced by several orders of magnitude even resolving the nuclear quadrupolar splitting resulting from the interaction of the quadrupole moment of the Th-229 nucleus with the crystal's electric field gradient. Meanwhile other large band crystal materials are being tested to identify the best suited crystal material for a nuclear clock [8].

In this presentation, the recent developments for and the route towards a nuclear clock will be highlighted

[1] E. Peik and C. Tamm, Europhysics Letters **61**, 181 (2003).
[2] E. Peik et al., Quantum Science and Technology, **6(3)** 034002 (2021)
[3] L. von der Wense et al. Nature **533**, 47–51 (2016).
[4] S. Kraemer et al. Nature **617**, 706–710 (2023)
[5] J. Tiedau et al. Phys. Rev. Lett. **132**, 182501 (2024).
[6] C. Zhang et al. Nature **633**, 63–70 (2024).
[7] R. Elwell et al. Phys. Rev. Lett. **133**, 013201 (2024).
[8] S.V. Pineda et al. Phys. Rev. Res. **7**, 013052 (2025).