Int. Workshop “Shapes and Dynamics of Atomic Nuclei: Contemporary Aspects”
ed. Nikolay Minkov, Heron Press, Sofia 2026

Dawn of the ^{229m}Th nuclear clock: Achievements and Perspectives

P.G. Thirolf

Ludwig-Maximilians-Universität München, 85748 Garching, Germany

Abstract

The quest for an optical nuclear frequency standard, the ’nuclear clock’ based on the uniquely low-energetic ’thorium isomer’ ^{229m}Th, has increasingly triggered research activities worldwide in the last decade. Today’s most precise timekeeping by optical atomic clocks could potentially be outperformed by a nuclear clock, based on a nuclear instead of an electronic transition. Presently, only the ’Thorium Isomer ^{229m}Th’, i.e. the isomeric first excited state of ^{229}Th, qualifies for such a nuclear frequency standard. A nuclear clock promises intriguing applications in applied as well as fundamental physics, like potential variations of fundamental constants or the search for Dark Matter [1]. After years of nuclear-spectroscopy driven identification and characterization activities of ^{229m}Th, recently seminal breakthroughs with first laser-driven excitations of the isomeric nuclear resonance in ^{229}Th could be achieved, both using intense broad-band [2, 3] and VUV frequency-comb based narrow-band lasers [4]. The expectation of a nuclear clock prototype to appear soon was indeed realized recently, when almost simultaneously 2 groups reported on the realization of first working nuclear clocks based on optical excitation of ^{229m}Th and fluorescence detection in a solid-state approach using doped large-bandgap crystals [5,6]. Alternative approaches based on thin films [7] and laser-driven conversion-electron Mössbauer spectroscopy [8] also succeeded in isomer excitation, while the complementary approach using individual laser-cooled trapped ions in vacuum is still under study. The talk will review the status and perspectives of ongoing activities on realizing a high-precision nuclear frequency ^{229m}Th based standard both in the solid-state and trapped ^{229m}Th^{3+} ion approach.

References

[1] E. Peik et al., *Quantum Sci. Technol.* **6** (2021) 034002
[2] J. Tiedau et al., *Phys. Rev. Lett.*, **132** (2024) 182501
[3] R. Elwell et al., *Phys. Rev. Lett.*, **133** (2024) 013201
[4] Ch. Zhang et al., *Nature* **633** (2024) 63-70
[5] L. Toscani De Col et al., *arXiv:2606.04997v1* (2026)
[6] B. Huang et al., *arXiv:2606.08870* (2026)
[7] Ch. Zhang et al., *Nature* **636** (2024) 603-608
[8] R. Elwell et al., *Nature* **648** (2025) 300–305