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Making a solid-state nuclear optical clock (25+5)

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The first nuclear excited state or isomer of Th-229 has an extremely low energy (8.4 eV/148 nm) and long lived (~10^3 s) excited state, therefore termed an isomer (Th-229m). Owing to its narrow resonance, Th-229m is a platform for a future extremely precise nuclear optical clock. In a crystal such as CaF2 the ultimate precision is estimated to be on the 10^-17 level. Owing to its nuclear nature, it would be a new sensitive probe for fundamental physics. Recently, the very first laser spectroscopy of a nucleus, Th-229 doped in crystalline CaF2, has been achieved. Immediately the nuclear spectroscopy was reproduced for Th-229 doped in LiSAF. Afterwards, the first clock comparison was performed between the nuclear excited state of Th-229 in CaF2 and the electronic excited state in Sr-87 with a resolution of 300 kHz. This string of recent successes hinges on the development of a highly doped VUV transparent CaF2 crystal, doped with the radioactive Th-229. In previous attempts, the nuclear excitation seemed less efficient than is now known.

In this talk I will elaborate on the nuclear hyperfine spectroscopy measurements and how the crystal platform was originally developed and characterized: Crystal growth [12] and crystal healing [13]. More recently, an indication appeared why previous attempts of excitation in a crystal were unsuccessful: The nuclear excitation quenches through an interaction with the solid-state environment. I will further report a diverse array of new measurements and calculations characterizing the interaction and the solid-state environment of Th-229:CaF2 crystals. These measurements and calculations show we can control the interaction of the nucleus with its environment, shine light on its electronic environment and indicate exciting new ways to improve clock operation. With every characterization, and every simulation, the solid-state nuclear clock comes a step closer.

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