Highly Charged Ion Optical Clocks to Test Fundamental Physics

Piet O. Schmidt[1,2]

[1]*QUEST Institute, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany*
[2]*Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany*

Highly charged ions (HCI) have many favorable properties for tests of fundamental physics and as potential next-generation optical atomic frequency standards [1]. For example, narrow optical fine-structure transitions have smaller polarizabilities and electric quadrupole moments, but much stronger relativistic, QED and nuclear size contributions to their binding energy compared to their (near) neutral counterparts. Therefore, HCI have been found to be among the most sensitive atomic species to probe for a possible variation of the fine-structure constant or dark matter coupling.
HCI can readily be produced and stored in an electron beam ion trap (EBIT). There, the most accurate laser spectroscopy on any HCI was performed on the 17 Hz wide fine-structure transition in Ar^{13+} with 400 MHz resolution, lagging almost twelve orders of magnitude behind state-of-the-art optical clocks. This was primarily limited by Doppler broadening of the megakelvin hot ion plasma in the EBIT [2]. The lack of a suitable optical transition for laser cooling and detection can be overcome through sympathetic cooling with a co-trapped Be^+ ion [3]. Techniques developed for quantum information processing with trapped ions can be used to perform quantum logic spectroscopy [4]: A series of laser pulses transfers the internal state information of the Ar^{13+} ion after spectroscopy onto the Be^+ ion for efficient readout.
We present the first coherent laser spectroscopy of an HCI. Ar^{13+} are extracted from a compact EBIT [5], charge-to-mass selected and injected into a cryogenic Paul trap containing a crystal of laser-cooled Be^+ ions [6]. By removing excess Be^+ ions, a crystal composed of a Be^+/Ar^{13+} ion pair is obtained. Results on sympathetic ground state cooling and quantum logic spectroscopy of the Ar^{13+} $P_{1/2}$-$P_{3/2}$ fine-structure transition at 441 nm will be presented, improving the precision of the observed line center by more than eight orders of magnitude. Furthermore, excited state lifetimes and the first high-accuracy measurement of excited state g-factor demonstrate the versatility of the technique to access all relevant atomic parameters [7]. Finally, we have started to perform frequency measurements of this transition, including first estimates of systematic uncertainties.

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