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Towards quantum logic spectroscopy of heavy few-electron ions

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Highly charged ions (HCI) feature an enhanced sensitivity to fundamental physics while many systematic effects from external perturbations are highly suppressed [1]. They are therefore excellent systems to test our understanding of nature and to realize novel high-accuracy optical atomic clocks.

Recently, quantum logic spectroscopy (QLS) of a fine-structure transition in a medium-light HCI of intermediate charge state [2] and the operation of an optical clock based on this transition [3] have been demonstrated. Even more extreme systems are heavy HCI in their highest charge-states (e.g. hydrogen-like or lithium-like ions) which offer narrow, laser-accessible transitions in their hyperfine structure (e.g. 1019.7 nm in $^{207}Pb^{81+}$) and the strongest electromagnetic fields that are accessible in a lab. On top of that, the small number of bound electrons allows for an accurate calculation of their atomic structure. However, they are not yet available for QLS due to the missing combination of a source for heavy HCI and a suitable experiment. State of the art is collinear laser spectroscopy at a heavy-ion storage ring, reaching an uncertainty level of 10^{-5} [4].

This contribution will report on a unique and versatile spectroscopy platform being set up at the HITRAP facility of the GSI Helmholtz Center for Heavy Ion Research to establish QLS for frequency metrology of heavy and simple ions. This will allow to improve the state-of-the-art uncertainty by many orders of magnitude, ultimately enabling unprecedented tests of fundamental physics and searches for physics beyond the Standard Model. The major challenges concerning the production and preparation of these ions as well as establishing a sufficiently low background pressure to prevent charge exchange reactions will be discussed.

[1] M. G. Kozlov et al., Rev. Mod. Phys. 90, 045005 (2018)
[2] P. Micke et al., Nature 578, 60–65 (2020)
[3] S. A. King et al., Nature 611, 43–47 (2022)
[4] J. Ullmann et al., Nat. Commun. 8, 15484 (2017)

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