New physics searches with highly charged ions: Nonlinear calcium King plot constrains new bosons and nuclear properties

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Highly charged ions (HCI) are promising candidates for novel optical clocks and tests of fundamental physics [1]. Typically, the megakelvin-temperature environment in which HCI are produced hinders high-precision spectroscopy. To overcome this, we extract HCI from an electron beam ion trap and transfer them to a cryogenic linear Paul trap. There, single HCI are sympathetically cooled by Be^+ ions down to millikelvin temperatures, thus enabling quantum logic state readout [2]. In this way, we developed an optical clock based on Ar^{13+} and determined its absolute frequency with sub-Hz uncertainty by comparison with the Yb^+ octupole ion clock at PTB [3]. We recently applied these techniques to determine the isotope shift of a narrow magnetic-dipole transition in Ca^{14+} with 150 mHz accuracy for all five even and stable isotopes $^{40,42,44,46,48}Ca$. We combine these results with recently improved measurements of isotope shifts in Ca^+ conducted at ETH Zürich and more precise measurements of nuclear mass ratios performed at MPIK Heidelberg in a so-called King plot. To first order, the standard model predicts a linear King plot. However, nonlinearities can arise from higher-order effects or a new force that would couple electrons and neutrons. For the first time, we observe a $\sim 900\sigma$ nonlinearity in the King plot of Ca and identify two standard model effects as its potential sources: the second-order recoil shift and the nuclear polarization effect. Despite the observed nonlinearity, we derive improved constraints on a new force using the King plot method and argue that more precise calculations and additional isotope shift measurements could further tighten these constraints in the future [4].

References

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