Cold highly charged ions for highest precision spectroscopy

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Synopsis Cold, strongly localized highly charged ions (HCIs) are of particular interest for frequency metrology (development of novel optical clocks) and the search for physics beyond the Standard Model. We have successfully Coulomb crystallized highly-charged Ar^{13+} ions in a cryogenic Paul trap through sympathetic cooling with co-trapped, continuously laser-cooled Be^{+} ions. This constitutes a significant step forward for high-precision spectroscopy of HCIs.

With the ability to simultaneously control both the excitation and the motional degrees of freedom of individual quantum objects, atomic physics has reached a degree of accuracy without peer among the experimental sciences. In principle, the binding energy of atomic electrons in their ground state is sensitive to all levels of Standard Model physics. Their wavefunction adapts to all small contributions arising from all known interactions. This universal pattern of sensitivity is expected to appear again if forces beyond the Standard Model were to exist. In highly charged ions (HCIs), the wavefunction of the optically active electron has an enhanced sensitivity to electron-nucleus interactions and QED terms in general, and an extremely suppressed sensitivity to external field perturbations. Further, E1 forbidden optical transitions near level crossings in HCIs are extremely sensitive to possible drifts in the finestructure constant α. These favorable properties have been widely recognized as an advantage for precision tests of fundamental physics and the development of HCI based clocks in many recent theoretical works. However, all known sources of HCIs produce them at high temperatures - typically in the MK regime - which severely limits the achievable spectral resolution of photonic studies.

We have developed an experiment for retrapping, cooling and high-precision laser spectroscopy of HCIs [1]. It is based on continuously laser-cooled Be^{+} Coulomb crystals in a linear cryogenic Paul trap [2] for stopping the motion of externally produced HCIs and sympathetically cooling them below 250 mK. This cooling induces the formation of stable mixed crystals – down to a single HCI cooled by a single co-trapped Be^{+} ion [3]. The strongly suppressed thermal motion of the embedded HCIs offers novel possibilities for investigation of questions regarding the time variation of fundamental constants, parity non-conservation effects, and quantum electrodynamics.

We will give a status report on our current work aiming at high-precision spectroscopy of the $^2P_{1/2}$ - $^2P_{3/2}$ M1 transition at 441 nm in cold Ar^{13+} ions using two different spectroscopical approaches.

Adding HCIs to the quantum toolbox is one important goal within the scope of next-generation experiments, which are currently being set up. One aims at applying quantum logic schemes to HCIs and developing an HCI optical clock, the other one at direct VUV frequency comb spectroscopy of electronic transitions in HCIs.

References

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