Quantum logic spectroscopy of highly charged ions

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Synopsis We demonstrate the first coherent laser spectroscopy of highly charged ions (HCI). Produced in an electron beam ion trap, we transfer Ar^{13+} into a Paul trap, prepare a two-ion crystal with an auxiliary Be^{+} ion and cool the system to its motional ground state. Using the quantum logic technique for state preparation and detection, we improve the spectroscopic resolution of the most accurately measured optical HCI transition by about 9 orders of magnitude and bring it down to the Hz-level. This proves the feasibility of an optical atomic clock based on HCI.

Highly charged ions (HCI) offer extreme properties which make them particularly sensitive to new physics, e. g. the variation of fundamental constants. Next-generation clocks based on HCI were proposed more than one decade ago as a consequence of their insensitivity to external fields. However, optical spectroscopy was so far limited to the 10^{-7} fractional accuracy level due to the MK temperatures at which HCI are produced.

Recently, the successful extraction of boron-like Ar^{13+} from an electron beam ion trap, transfer, and recapture in a laser-cooled Coulomb crystal of Be^{+} ions was demonstrated at the Cryogenic Paul Trap Experiment (CryPTEx) at the Max-Planck-Insitut fr Kernphysik [1]. Following this approach, we have set up an evolved version of the experiment at the Physikalisch-Technische Bundesanstalt [2, 3, 4] and prepared Ar^{13+}-Be^{+} two-ion crystals in their quantum-mechanical ground state of motion. A sub-Hz stable, narrow-linewidth clock laser is used to probe the forbidden 441 nm $^2P_{1/2} - {}^2P_{3/2}$ M1 transition by using the quantum logic technique for state preparation and detection [5]. This first demonstration of coherent laser spectroscopy of an HCI improves the resolution of the most accurately measured HCI transition by 9 orders of magnitude. The splitting of the six Zeeman components allows us to observe relativistic, interelectronic-interaction, and QED effects as well as improve the experimental accuracy of the excited-state g-factor.

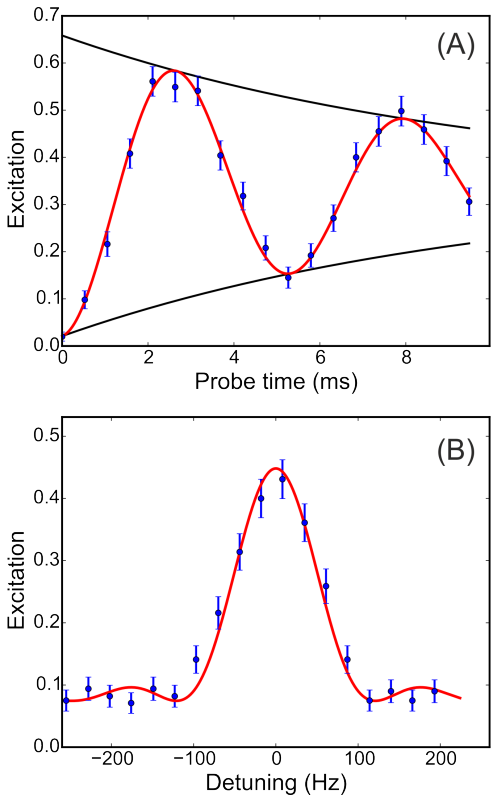

Figure 1. Rabi spectroscopy of an HCI. (A) Coherent excitation of the Ar^{13+} M1 transition. The coherence decay is consistent with the excited-state lifetime of 9.6 ms. (B) Frequency scan with a probe time of 8 ms yielding a FWHM of about 110 Hz.

References

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