A 20: Precision spectroscopy of atoms and ions III

Time: Wednesday 14:00–16:00 Location: f303

Invited Talk A 20.1 Wed 14:00 f303

Coherent laser spectroscopy of highly charged ions using quantum logic — •Peter Micke[1,2], Tobias Leopold[1], Steven A. King[1], Erik Benkler[1], Lukas J. Spiess[1], Lisa Schmöger[1,2], Maria Schwarz[1,2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Max-Planck-Institut für Kernphysik, Heidelberg — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Highly charged ions (HCI) are an extreme form of matter with favorable properties for novel high-accuracy atomic clocks and sensitive tests for physics beyond the Standard Model. We demonstrate the first coherent laser spectroscopy of HCI and improve the precision of the previous state-of-the-art spectroscopy by many orders of magnitude, thus unlocking the potential of HCI for applications in frequency metrology and the search for a time variation of fundamental constants [1].

We isolate a single Ar^{13+} HCI, produced in a hot plasma at a million kelvins, and confine it together with one Be^{+} ion in a Paul trap. This two-ion crystal is then cooled to its quantum-mechanical ground state of motion. Using an ultra-stable clock laser and the quantum logic technique, we resolve the electric-dipole forbidden fine-structure transition of Ar^{13+} at 441 nm with a fractional frequency uncertainty of 3×10^{-15}. Furthermore we measure the lifetime and g-factor of the excited state. The latter one resolves a discrepancy between previous theoretical predictions.

[1] P. Micke, T. Leopold, S. A. King et al., *Nature* (accepted).

A 20.2 Wed 14:30 f303

Identification of clock transitions in highly charged ions by Penning-trap mass spectrometry — •R. X. Schüssler[1], H. Bekker[1], M. Brass[2], H. Cakir[1], J. R. Crespo López-Urrutia[1], M. Door[1], P. Filianin[1], Z. Harman[1], M. Haverkort[1], W. Huang[1], P. Indelicato[3], C. H. Keitel[1], C. M. König[1], K. Kromer[1], Yu. N. Novikov[4], A. Rischka[1], Ch. Schweiger[1], S. Sturm[1], S. Ulmer[5], S. Eliseev[1], and K. Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Intitute for Theoretical Physics, Heidelberg University, Germany — [3]Laboratoire Kastler Brossel, Sorbonne Université, Paris, France — [4]Petersburg Nuclear Physics Institute, Gatchina, Russia — [5]RIKEN, Fundamental Symmetries Laboratory, Saitama, Japan

Promising candidates for a new generation of clocks are transitions in highly charged ions (HCIs), as, due to their compact size, they are less sensitive to external perturbations. Insufficiently accurate atomic structure calculations often hinder the identification of suitable transitions in HCIs. High-precision Penning-trap mass spectrometry can be used to identify transitions of long-lived metastable states by determining the mass difference of the excited and ground state. Reaching uncertainties of mass-ratio measurements on the level of $\delta m/m \leq 10^{-11}$ or better, the Pentatrap experiment, synchronously operating five Penning traps, is able to identify long-lived metastable states in HCIs with a few eV uncertainty. The talk will cover the first such transition found in $^{187}Re^{29+}$ and plans for future measurements at Pentatrap.

A 20.3 Wed 14:45 f303

Electronic Bridge in ^{229}Th doped CaF_2 — •Brenden Nickerson[1], Martin Pimon[2], Pavlo Bilous[1], Thorsten Schumm[2], and Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Technical University of Vienna, Austria

The lowest known nuclear transition of only 8 eV in ^{229}Th could serve as basis for a novel nuclear clock. However, direct photoexcitation of this nuclear state has so far remained elusive. One promising approach is to use thorium-doped VUV-transparent crystals which can host a large number of ^{229}Th nuclei [1,2].

Here an alternative method of excitation using for the first time the concept of electronic bridge (EB) in the crystal is investigated theoretically. EB makes use of the electronic shell as an intermediate stepping stone for the transfer of energy between laser photons and nuclei [3]. In VUV-transparent crystals this process is facilitated by defects, i.e., states appearing in the band gap, caused by the Th doping. In the context of current crystal experiments the EB process promises excitation rates far above direct photoexcitation with current technology. Such results contribute to the development of a nuclear frequency standard based on ^{229m}Th.

[1] Stellmer, Schreitl, & Schumm, Sci. Rep. 5, 15580 (2015)
[2] Dessovic *et al.*, J. Phys.:Condens. Matter 26, 105402 (2014)
[3] Porsev & Flambaum, Phys. Rev. A 81, 032504 (2010)

A 20.4 Wed 15:00 f303

Electronic bridge excitation in highly charged ^{229}Th ions — •Pavlo Bilous, Hendrik Bekker, José R. Crespo López-Urrutia, and Adriana Pálffy — Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

Of all nuclei, the ^{229}Th isotope possesses an extremely low-lying nuclear isomer at approx. 8 eV. This nuclear transition has the potential to provide a first nuclear frequency standard at an unprecedented accuracy, a laser operating between nuclear sublevels, and the coherent control of a nuclear excitation with a VUV laser. The practical implementation of these applications requires however a way to directly drive the isomer with a narrow band VUV laser, and in turn the precise knowledge of its energy which according to the most recent experimental results is $E_m = 8.28 \pm 0.17$ eV [1].

In this theoretical work we investigate a method to populate the Th isomer in highly charged ions produced in an electron beam ion trap using a tunable UV laser. The employed excitation mechanism, the so-called electronic bridge, occurs via the electronic shell, which is first promoted by a laser photon to a virtual state with subsequent energy transfer to the nucleus. With the absorbed laser photon energy directly related to the isomer energy E_m, this mechanism promises the determination of E_m with an accuracy of 10^{-4} eV which is limited by the Doppler broadening of the ions in the trap. Our theoretical results show that this scheme is feasible under presently available experimental parameters.

[1] B. Seiferle *et al.*, Nature 573, 243–246 (2019).

A 20.5 Wed 15:15 f303

Setup and characterization of a source of highly charged ions with reduced momentum spread — •Michael Karl Rosner[1], Peter Micke[1,2], Sandra Bogen[1], Steffen Kühn[1], Julian Stark[1], Moto Togawa[1], Christian Warnecke[1], Sungnam Park[3], Keisuke Fujii[4], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [3]Ulsan National Institute of Science and Technology, Ulsan, Korea — [4]Department of Mechanical Engineering and Science, Kyoto University, Kyoto, Japan

Highly charged ions (HCI) exhibit strongly enhanced quantum-electrodynamic and nuclear size effects. In some HCI, the frequency of forbidden optical transitions is very sensitive to a possible variation of the fine-structure constant α. Electron beam ion traps (EBIT) can reliably produce HCI [1], but at temperatures too high for such frequency-metrology studies. For this, sympathetic cooling is applied to HCI in a radio-frequency trap [2], requiring also a beamline for HCI transfer, bunching, pre-cooling and deceleration. A new setup based on our earlier HC-EBIT [1] and beamline designs [3] has been built at MPIK. We characterize it with time-of-flight measurements of the HCI charge-state distribution, kinetic energy and momentum spread; the latter has been much reduced in our pre-cooling deceleration unit.

[1] P. Micke, et al., Rev. Sci. Instrum. **89**, 063109 (2018)
[2] L. Schmöger, et al., Science **347**, 1233 (2015)
[3] P. Micke, et. el., in preparation

A 20.6 Wed 15:30 f303

Higher order isotope shifts in highly charged ions — •Robert A. Müller[1,2], Vladimir A. Yerokhin[3], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]Peter the Great St. Petersburg Polytechnic University, Russia

A common way to search for physics beyond the standard model, is the investigation of quantities that can be both measured and calculated to a very high precision. One of these quantities is the isotope shift ratio of two transitions. As a function of the number of nucleons A this ratio results in the so-called King Plot. In first order of the electron-nucleus mass ratio (m_e/M_A) the King Plot is strictly linear. Modern spectroscopy, however, is able to measure isotope shifts up to a precision, where higher order effects need consideration [1]. These effects manifest as nonlinearities in the King Plot. In this contribution we will discuss the quadratic mass shift that yields the dominating second-order isotope shift in light atoms and ions. Our calculations show that this shift can cause deviations from a linear King Plot up to several kHz. Moreover we use our theory to investigate King Plot nonlinearities introduced by a speculated new light boson and use existing measurements to restrict the properties of this particle [2].

[1] Miyake *et al.*, Phys. Rev. Res. **1**, 033113 (2019)
[2] Yerokhin *et al.*, arXiv:1910.05524 (2019)

A 20.7 Wed 15:45 f303

Towards efficient sympathetic laser cooling of highly charged ions in a Penning trap — •Felix Hahne, Bingsheng Tu, Alexander Egl, Tim Sailer, Ioanna Arapoglou, Andreas Weigel, Fabian Heisse, Sven Sturm, and Klaus Blaum — Max-Planck-Insitut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

The electric fields of highly charged ions (HCI) enable stringent tests of bound-state quantum electrodynamics under extreme conditions. The Penning-trap based Alphatrap experiment at the Max-Planck-Institut für Kernphysik in Heidelberg aims for g-factor measurements of HCI's as well as laser spectroscopy of fine or hyperfine structure transitions. The achievable accuracy in those measurements depend strongly on the motional temperature of the ion.
However, direct laser cooling of the HCI is generally hindered by the absence of suitable optical transitions and co-trapping ions for sympathetic cooling would disturb the HCI's trap eigenmotion. To this end we propose the coupling of two ions in different traps via a common tank circuit. We discuss the electronic avoided crossing coupling scheme and present the first experimentally recorded energy transfer between Kr^{23+} and Ar^{11+} coupled by a common tank circuit, which lays the basis for a novel sympathetic cooling technique.