Q 14: Precision Spectroscopy of Atoms and Ions I (joint session A/Q)

Time: Monday 17:00–19:00 Location: N 3

Invited Talk Q 14.1 Mon 17:00 N 3

Isotope shifts and population dynamics in neutron-rich Mg^+ measured with MIRACLS — •Konstantin Mohr for the MIRACLS-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung

The **M**ulti **I**on **R**eflection **A**pparatus for **C**ollinear **L**aser **S**pectroscopy (MIRACLS) combines a multi-reflection time-of-flight (MR-ToF) device and collinear laser spectroscopy (CLS) to overcome the current sensitivity limits of fluorescence-based collinear laser spetroscopy. By multiple ion-photon interactions in the MR-ToF device, the MIRACLS setup at the ISOLDE facility at CERN enables CLS studies of short-lived radioactive isotopes far from stability with very low yields, such as ^{34}Mg.

Simultaneous collinear and anticollinear spectroscopy of the D_1 and D_2 transitions in $^{24-34}Mg^+$ ions has been performed, with particular interest on ^{33,34}Mg at the island of inversion. To extract isotope shifts – and thus probe shape coexistence driven by intruder states around the N=20 shell – a detailed understanding of the population dynamics within the hyperfine structure of the odd isotopes is essential. The resulting complex line shapes were disentangled and the effects of population redistribution quantified through rate-equation based simulations.

In this contribution, we discuss the distinctive features of the MIRACLS approach and experimental challenges associated with multiple photon-ion interactions. Furthermore, first results of the isotope shifts of the Mg isotopic chain will be presented.

Q 14.2 Mon 17:30 N 3

Precision calculation of the bound-electron g factor in molecular hydrogen ions — •Ossama Kullie[1], Hugo Nogueira[2], and Jean-Philippe Karr[2,3] — [1]Theoretical Physics at Institute for Physics, University of Kassel, Germany — [2]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, 4 place Jussieu, F-75005 Paris, France — [3]Université Evry Paris-Saclay, Boulevard François Mitterrand, F-91000 Evry, France

In this work [1], we present calculations of the bound-electron g-factor for a wide range of rovibrational states in the ground electronic state ($1s\sigma$) of the molecular hydrogen ions H_2^+ and HD^+. Relativistic and QED corrections of orders up to α^5 are taken into account. All contributions are calculated in a nonrelativistic QED framework, except for relativistic corrections of order $(Z\alpha)^4$ and above, which are obtained by calculating the relativistic g-factor using a precise solution of the two-center Dirac equation with FEM [2]. A relative accuracy of $\sim 10^{-11}$ is achieved for the scalar g-factor component, with an improvement by more than three orders of magnitude over previous calculations. These results are useful for internal state identification and rovibraional spectroscopy of single molecular hydrogen ions in Penning traps, and open a new avenue towards precision tests of QED. Finally, a comparison with experimental result of high-precision Penning-trap spectroscopy of the ground-state spin structure of HD^+ [2] is given. [1] Ossama Kullie, Hugo D. Nogueira and Jean-Philippe Karr, Phys. Rev. A **112**, 052813 (2025). O. Kullie et. al., Phys. Rev. A 105, 052801 (2022). [3] Charlotte M. König et. al., Phys. Rev. Lett. (2025) under review.

Q 14.3 Mon 17:45 N 3

Hyper-EBIT: The development of a source for very highly charged ions — •Luca Yannik Geissler, Matthew Bohman, Fabian Heisse, Philipp Justus, Anton Gramberg, Jonathan Morgner, Charlotte Maria König, Jialin Liu, José Ramon Crespo López-Urrutia, Sven Sturm, and Klaus Blaum — Max-Planck-Institut für Kernphysik, 69117 Heidelberg

Quantum electrodynamics (QED) is considered to be the most successful quantum field theory in the Standard Model. Its most precise test follows from the comparison of the measured g-factor of the free electron and its prediction by QED. While this comparison tests QED at small electromagnetic field strengths, highly charged ions (HCI) allow performing a similar test at much stronger fields. In HCI, only the innermost electron(s) remain, which experience strong electric fields of up to $10^{16}\ \frac{\mathrm{V}}{\mathrm{cm}}$ due to the vicinity of the electrons and the nucleus. An experiment that enables such precision studies is ALPHATRAP[Sturm et al., EPJST 227, 1425 (2019)], a cryogenic Penning-trap setup dedicated to measuring the bound-electron magnetic moments of HCIs with high precision. The most stringent test of the bound-electron g-factor performed by ALPHATRAP to date was conducted with hydrogen-like tin[Morgner et al., Nature 622, 53 (2023)]. To extend these high-field tests to heavier HCIs, such as $g_j(^{208}Pb^{81+})$, an electron-beam ion trap (EBIT), the Hyper-EBIT, was built at MPIK to produce such ions. It is designed to provide electron-beam energies of up to 300 keV and beam currents of up to 500 mA. This contribution presents the latest developments and current status of the Hyper-EBIT.

Q 14.4 Mon 18:00 N 3

Magneto-optical trapping of Zinc — •Lukas Möller, Felix Waldherr, and Simon Stellmer — Universität Bonn, Germany

Laser-cooling and trapping of neutral atoms is a widely used technique in contemporary atomic physics. The element zinc, an alkaline-earth-like metal, is a promising candidate for a new optical clock. Work on zinc also motivates the development of new cw-laser sources in the UV range, since its strong cooling transition lies at 213.9 nm. We report magneto-optical trapping of all 5 stable isotopes of Zinc, as the first step towards spectroscopy of the clock transition.

Q 14.5 Mon 18:15 N 3

Isotope shifts of the $^1S_0 \to {}^3P_1$ intercombination line in zinc — •Felix Waldherr, Lukas Möller, and Simon Stellmer — Universität Bonn, Germany

Zinc is a promising element for optical precision measurements due to its low black-body radiation sensitivity. We study the intercombination line at 308 nm using Doppler-free spectroscopy in a thermal zinc vapor. A narrow-linewidth, frequency-stabilized laser system enables the determination of resonance frequencies for all stable isotopes. The resulting isotope shifts offer a basis for future work in nuclear structure. In addition, the 308 nm transition is of direct relevance for laser-cooling schemes, where it can serve as a narrow second-stage cooling transition following the strong 214 nm cooling line.

Q 14.6 Mon 18:30 N 3

Towards the first 1S-2S Measurement in Atomic Tritium — •Hendrik Schürg and Randolf Pohl — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Exzellenzcluster PRISMA$^+$, Mainz, Germany

Laser spectroscopy is an effective method for obtaining high-precision results for the root-mean-square charge radii of nuclei. Here, we outline a route towards the first measurement of the 1S-2S interval in atomic tritium – giving access to the triton charge radius through the hydrogen-tritium 1S-2S isotope shift. Our approach relies on a compact radio-frequency discharge cell that will safely confine the radioactive tritium gas and enables optogalvanic detection of the resonant excitation to the 2S state via the laser-induced perturbation of the plasma's impedance. So far, we have demonstrated Doppler-free intermodulated optogalvanic spectroscopy of the hydrogen Balmer-β fine structure components near 486 nm. For the two-photon 1S-2S transition at 243 nm, we analyze expected line shifts and broadenings, and estimate an optogalvanic signal strength based on a collisional-radiative plasma model. Achieving the required laser intensity will involve the integration of the discharge cell into a deep-uv enhancement cavity.

Q 14.7 Mon 18:45 N 3

Continuation of Laser-Based HV Measurements at COALA — •Hendrik Bodnar, Kristian König, and Wilfried Nörtershäuser — Institute for nuclear physics, TU Darmstadt

The ALIVE experiment at the Collinear Apparatus for Laser spectroscopy and Applied sciences (COALA) at TU Darmstadt aims to measure high voltages in the tens-of-kilovolts range with ppm precision. Conventional techniques rely on voltage dividers that reduce the high-voltage to about 10 V. A drawback of these dividers, however, is the time-dependent drift of their division ratio. In contrast, the ALIVE experiment determines the high-voltage via the Doppler-shift of a transition line in an ion, which has been accelerated using the high-voltage under investigation. Therefore, the ion beam is superimposed with a laser beam and the laser frequency is adjusted to excite the ions. When the rest-frame transition frequency and the laboratory laser frequency are known and measured with sufficient accuracy, respectively, the voltage experienced by the ions can be calculated.

The best precision achieved so far with this approach was 5 ppm [1]. This limitation originated mainly from the design of the acceleration region and its influence on the ion beam. The new design of the acccel-eration region and first measurements will be presented. Funding from the DFG under project number 461079926 and support under project ID 279384907-SFB 1245 is acknowledged.

[1] Krämer et al., Metrologia 55 268, (2018)