A 12: Precision Spectroscopy of Atoms and Ions II (joint session A/Q)

Time: Tuesday 11:00–13:00 Location: N 3

Invited Talk A 12.1 Tue 11:00 N 3

Stringent Tests of the Standard Model via High-Precision Measurements at ALPHATRAP — •Fabian Heisse[1], Matthew Bohman[1], Luca Geissler[1], Anton Gramberg[1], Philipp Justus[1], Charlotte König[1], Ivan Kortunov[2], Jialin Liu[1], Jonathan Morgner[1], Jacob Schrader[1], Victor Vogt[2], Stephan Schiller[2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Institut für Experimentalphysik, Univ. Düsseldorf, Düsseldorf

The Standard Model describes a broad range of physical phenomena but remains incomplete. Therefore, it is of utmost importance to verify its foundational theories in all their facets. The ALPHATRAP experiment is a dedicated cryogenic Penning-trap apparatus, designed for this exact purpose [1]. It enables measurements of bound electron g-factors ranging from light molecular hydrogen ions to heavy highly charged ions using non-destructive single ion spectroscopy techniques.

I will present the measurements of the bound electron g-factor in H-like, Li-like, and B-like tin ions ($Z = 50$) with 0.5 parts-per-billion precision. There, extreme electric field strength up to 10^{15} V/cm act on the electron, magnifying QED effects and allowing to test them via the comparison with theory [2]. Finally, I will show the results of the hyperfine microwave and rovibrational laser spectroscopy of the HD$^+$ ion [3]. These are essential for future matter-antimatter comparisons.

[1] Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425 (2019).
[2] Morgner *et al.*, Nature **622**, 5357 (2023).
[3] König *et al.*, Phys. Rev. Lett. **134**, 163001 (2025).

A 12.2 Tue 11:30 N 3

Doppler-free two-photon spectroscopy of xenon — •Björn-Benny Bauer[2,1], Felix Waldherr[1], Thorsten Groh[1], Skyler Degenkolb[2], and Simon Stellmer[1] — [1]University Bonn, Germany — [2]University Heidelberg, Germany

High-precision spectroscopy of xenon is essential for a range of applications, including electric dipole moment (EDM) searches and isotope-shift studies, but suitable high-power deep-UV laser sources remain difficult to access. Here, we present high-resolution, Doppler-free two-photon spectroscopy of xenon using fluorescence detection. From these measurements, we determine the isotope shifts and extract the hyperfine structure parameters of the targeted transition. We further perform a King-plot analysis incorporating electronically similar transitions. The results exhibit clear linearity among the bosonic isotopes, while pronounced non-linearities arise when fermionic isotopes are included.

A 12.3 Tue 11:45 N 3

Precision X-Ray Spectroscopy of Kα transitions in He-like Uranium using Metallic Magnetic Calorimeter Detectors — •Daniel A. Schnauss-Müller[1,2,3], Johanna H. Walch[1,2,3], Philip Pfäfflein[1,2,3], Marc O. Herdrich[1,2], Michael Lestinsky[2], Daniel Hengstler[4], Andreas Fleischmann[4], Christian Enss[4], Günter Weber[1,2], and Thomas Stöhlker[1,2] — [1]Helmholtz Institut, Jena — [2]GSI, Darmstadt — [3]Friedrich-Schiller-Universität, Jena — [4]Kirchhoff Institut, Heidelberg

He-like ions, as the simplest atomic multibody system, provide a unique testing ground for the interplay of the effects of electron-electron correlations and quantum electrodynamics (QED). Of particular interest are heavy highly charged systems, where inner shell electrons are exposed to extremely high field strengths. For L to K-transitions, experiments with ions at nuclear charge states Z > 54 where not available until now. Two X-ray spectroscopy studies of He-like uranium ions have been performed at the electron cooler of the storage ring CRYRING@ESR at GSI Darmstadt, using novel detectors of the maXs series, developed within the SPARC collaboration. Those detectors are able to measure photons from a few keV up to over 100 keV allowing the simultaneous investigation of Balmer-like and Kα transitions. The achieved spectral resolution of better than 90 eV at X-ray energies close to 100 keV reveals the substructure of the Kα1 and Kα2 lines for the first time. The result of this experiment and the first insights of a rerun this year are presented in the talk.

A 12.4 Tue 12:00 N 3

Advances in the investigation of atomic transitions in Lr — •Elisabeth Rickert for the Lawrencium Collaboration-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — Hemholtz-Institut, Mainz, Germany — Johannes Gutenberg-Universität, Mainz,Germany

The investigation of the atomic level structure of the heaviest elements is experimentally and theoretically challenging. The electric shell structure of transfermium elements is strongly influenced by relativistic effects, which significantly complicates theoretical predictions. Experimentally, atomic levels are largely unknown for $Z > 100$, whereby low production cross sections and short half-lives demand a tailored approach for laser spectroscopy on single-atom-at-a-time quantities. The RAdiation Detection Resonance Ionization Spectroscopy (RADRIS) technique has been successfully applied for the atomic level search in nobelium (No, $Z = 102$). In recent years, the RADRIS setup has been adapted to investigate the atomic structure of lawrencium (Lr, $Z = 103$). The two strongest ground-state transitions have been theoretically predicted in the regions around 20420 cm^{-1} ($^2S_{1/2}$) and 28500 cm^{-1} ($^2D_{3/2}$ state). In 2020 and 2022, over 800 cm^{-1} and 700 cm^{-1} have been scanned around the predicted transition wavenumber in the visible and uv range, respectively. So far, no transition could be detected, but 35% of the anticipated uncertainty of the theoretical predictions is still to be investigated. In the contribution, the status of the experiment and the data analysis will be presented.

A 12.5 Tue 12:15 N 3

Measurement of the hyperfine structure of the $4f^{14}5d$: $^2D_{5/2}$ state in trapped ^{173}Yb$^+$ ions — •Rohan Chakravarthy[1], Jialiang Yu[1], Ikbal A. Biswas[1], Anand Prakash[2], Clara Zyskind[1], and Tanja E. Mehlstäubler[1,2] — [1]PTB, Germany — [2]LUH, Germany

We report a measurement of the hyperfine structure of the $4f^{14}5d$: $^2D_{5/2}$ state in ^{173}Yb$^+$ using the $4f^{14}6s$: $^2S_{1/2} \rightarrow 4f^{14}5d$: $^2D_{5/2}$ electric quadrupole (E2) transition at 411 nm in trapped ^{173}Yb$^+$ ions and the resolution of the higher order hyperfine structure C coefficient. The measurement involves coherent excitation of the atom with an ultrastable laser to the excited hyperfine states and the measurement of the absolute frequency of the transitions with a frequency comb referenced to an ultrastable silicon cavity and a hydrogen maser. This measurement, along with the planned measurement of the hyperfine structure of the $4f^{13}6s^2$: $^2F_{7/2}$ state will lead to the resolution of the higher order nuclear moments predicted in Yb.

A 12.6 Tue 12:30 N 3

Two-Dimensional Magneto-Optical Trap as a Cold Atomic Beam Source for High-Precision Spectroscopy on Lithium — •Gregor Schwendler, Tim Redelbach, Hannah Jost, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany.

Lithium is of great interest in atomic and nuclear physics studies. The determination of the isotope shift from spectroscopy of the D-lines has shown inconsistencies, which could be partially explained by quantum interference effects.[1] We aim to further reduce systematic uncertainties in the spectroscopy by using a cold atomic beam extracted from a high-flux two-dimensional magneto-optical trap[2], which drastically reduces the first-order Doppler shift. Additionally, the use of an active fiber-based retroreflector[3] further suppresses systematics by producing retracing wavefronts in the spectroscopy beam. Our cold atomic beam provides an atomic flux on the order of 10^9 atoms/s, sufficient for high-precision spectroscopy, and a tunable mean velocity in the range of 50 to 100 m/s. I will report on the current results and the status of the experiment.

[1] Brown et al., *Physical Review A* 87.3 (2013), p. 032504.
[2] Tiecke et al., *Physical Review A* 80.1 (2009), p. 013409.
[3] Beyer et al., *Optics Express* 24.15 (2016), p. 17470.

A 12.7 Tue 12:45 N 3

Cold Hydrogen Beam Source for Magnetic Trapping of Atomic Hydrogen — •Merten Heppener and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA++ , Mainz, Germany

We are currently setting up an experiment to determine the root-meansquare triton charge radius via two-photon 1S-2S laser spectroscopy at 243 nm on magnetically trapped tritium atoms [1]. For preparation of trapping, a cold atomic hydrogen source consisting of a microwave discharge and a cryogenic nozzle was set up. The atom beam was characterized using time-of-flight techniques, the results of which we will present here. A velocity filter in form of a magnetic quadrupole guide will be installed shortly to further reduce the beam velocity. After achieving a stable atomic hydrogen beam, the 243 nm laser system and enhancement cavity will be integrated into the vacuum apparatus to probe the 1S-2S two-photon transition. In the future, it is planned to load the slow hydrogen atoms into a magnetic minimum trap using a cold lithium buffer gas.

[1] S. Schmidt et al. J. Phys.: Conf. Ser. 1138, 012010 (2018)