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

Time: Monday 17:00–18:45 Location: F107

Invited Talk Q 12.1 Mon 17:00 F107

Nonperturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1], Siegbert Hagmann[2], Alexandre Gumberidze[2], Yury Litvinov[2,3], and Thomas Stöhlker[2,4,5] — [1]Justus-Liebig-Univ., Giessen — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Ruprecht-Karls-Univ., Heidelberg — [4]Helmholtzinstitut Jena — [5]Friedrich-Schiller-Univ., Jena

Experimental data for atomic collisions of highly-charged ions are essential for benchmarking the theoretical description of dynamical processes in atomic physics. Of particular challenge is the accurate description of those processes that exceed the applicability of relativistic first-order perturbation theories. Recently, we have investigated two characteristic cases of such collision systems at the GSI heavy-ion accelerator. For collisions of U^{89+} projectiles with N_2 and Xe targets at 76 MeV/u, we studied the electron-loss-to-continuum cusp both experimentally and theoretically. We compared the continuum electron spectra of the two collision systems, which originate from the ionization of the projectile, and were able to identify a clear signature for the non-perturbative character of the collision systems [1]. Furthermore, we performed an x-ray spectroscopy experiment for slow collisions of Xe^{54+} and Xe^{53+} projectiles with a Xe target at 30 and 15 MeV/u. We analyzed the target $K\alpha$ satellite and hypersatellite lines to derive cross section ratios for double-to-single target K-shell vacancy production and compared the results to relativistic two-center calculations [2].

[1] Phys. Rev. A **104**, 012809 (2021)
[2] Phys. Rev. A **105**, 022810 (2022)

Q 12.2 Mon 17:30 F107

High-precision hyperfine structure measurement of $^9Be^{3+}$ for tests of nuclear shielding theory — •Stefan Dickopf, Annabelle Kaiser, Marius Müller, Bastian Sikora, Zoltan Harman, Christoph Keitel, Stefan Ulmer, Andreas Mooser, and Klaus Blaum — Max-Planck Institute for Nuclear Physics, Heidelberg, Germany

Hyperfine structure (HFS) measurements on $^3He^{1+}$ in our Penning-trap setup have recently been used to determine the magnetic moment of its nucleus [1]. To use this value for high accuracy magnetic field measurements with ^{3}He-NMR-probes it has to be corrected for by a diamagnetic shielding due to the orbiting electrons. By measuring the HFS of $^9Be^{3+}$ and comparing it to measurements on $^9Be^{1+}$ we can test the theory of the diamagnetic shielding factor [2,3].

A determination of the g-factor of the nucleus with a precision of about 10^{-9} is planned, making a test of the diamagnetic shielding on the same level possible. Recent improvements to our setup and a high precision mass measurement carried out at the PENTATRAP experiment will further allow us to determine the bound electron g-factor of $^9Be^{3+}$ to a few parts in 10^{-11}, yielding an additional high-precision test of QED g-factor calculations [1].

[1] A. Schneider et al, Nature 606, 878-883 (2022)
[2] D. J. Wineland, J. J. Bollinger, and Wayne M. Itano, Phys. Rev. Lett. 50, 628-631 (1983)
[3] K. Pachucki and M. Puchalski, Optics Communication 283, 641-643 (2010)

Q 12.3 Mon 17:45 F107

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •C. M. König[1], F. Heisse[1], I. V. Kortunov[2], J. Morgner[1], T. Sailer[1], B. Tu[1,3], V. Vogt[2], K. Blaum[1], S. Schiller[2], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf — [3]Institute of Modern Physics, Fudan University, Shanghai 200433

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. In the Penning-trap setup Alphatrap [1] we can perform high-precision spectroscopy on single MHI using non-destructive quantum state detection. Measurements on the hyperfine structure (HFS) of HD^+, allow us to extract the bound g factors of the constituent particles, as well as coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision *ab-initio* theory and are important for a better understanding of rovibrational spectroscopy performed on this ion, from which fundamental constants, such as m_p/m_e are determined to high precision [2].

We are currently extending our methods to single-ion rovibrational laser spectroscopy of MHI. The development of these techniques is one of the required steps towards spectroscopy of an antimatter $\overline{H}_2^-$ ion [3]. I will present an overview of our setup, measurement results of the HFS of HD^+ and first steps towards rovibrational laser spectroscopy.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] I. V. Kortunov, *et al.*, Nature Physics vol **17**, 569-573 (2021)
[3] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

Q 12.4 Mon 18:00 F107

Probing a beyond standard model force via isotope shift spectroscopy in ultracold mercury — •Thorsten Groh, Felix Affeld, and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

High precision spectroscopy of atomic isotope shifts could probe for a new beyond standard model (SM) force carrier that directly couples electrons and neutrons [Delaunay, PRD 96, 093001; Berengut, PRL 120, 091801], where signatures of such new particles would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

While latest spectroscopy of Ytterbium [Hur, PRL 128, 163201; Figueroa, PRL 128, 073001; Ono, PRX 12, 021033] down to the Hz-level already show strong deviations from linearity, it is hard to distinguish new physics from many SM effects like quadratic field shift and nuclear deformations.

Mercury is one of the heaviest laser-coolable elements with a core close to the lead nuclear shell closure, which suppresses nuclear deformations. It is an ideal platform for isotope spectroscopy possessing five naturally occurring bosonic isotopes, all of which we spectroscopically address in a magneto-optical trap. Our precision isotope shift spectroscopy in ultracold mercury on a total of five optical transitions combined with multidimensional King plot analysis show strong nonlinearities. We report on our latest improvements in the measurements and on new analysis of the nonlinearity origins.

Q 12.5 Mon 18:15 F107

1s Hyperfine splitting in Muonic Hydrogen — •Siddharth Rajamohanan[1], Ahmed Ouf[1], and Randolf Pohl[2] — [1]QUANTUM, Institut für Physik & Exzellenzcluster PRISMA,Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany — [2]Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+, Johannes Gutenberg-Universität Mainz,55099 Mainz, Germany

Precision measurements on atoms and ions are a powerful tool for testing bound-state QED theory and the Standard Model [1]. Experiments done in the last decade by the CREMA collaboration on muonic Hydrogen and Helium have given a more accurate understanding of the lightest nuclei charge radius [2,3]. Our present experiment aims at a measurement of ground state Hyperfine Splitting in muonic hydrogen up to a relative accuracy of 1 ppm using pulsed laser spectroscopy. This allows us to determine the Zemach radius, which encodes the magnetic properties of the proton. A unique laser system, multi-pass cavity, and scintillation detection system are necessary for the experiment. We report the current status of our experiment and the recent developments.

[1] M. S. Safronova, D. Budker, D. DeMille, Derek F. Jackson Kimball, A. Derevianko, and Charles W. Clark, Rev. Mod. Phys. 90, 025008 (2018)
[2] R. Pohl et al., Nature 466, 213 (2010)
[3] A. Antognini, et al., Science, Vol. 339, 2013, pp. 417-420

Q 12.6 Mon 18:30 F107

Ground-state hyperfine spectroscopy of $^3He^+$ in a Penning trap — •Marius Müller[1], Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Annabelle Kaiser[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor A. Valuev[1], Stefan Ulmer[2], Jochen Walz[3,4], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [3]Helmholtz-Institut, Mainz, Germany — [4]Johannes Gutenberg Universität, Mainz, Germany

Hyperpolarized ^3He NMR magnetometers have intrinsically smaller systematic corrections than standard water NMR probes [1]. Therefore, they are an excellent candidate for high-precision absolute magnetometry in several experiments such as the muon g-2 experiments.

We measured the four ground-state hyperfine transition frequencies of a single $^3He^+$ ion, stored in the 5.7 T magnetic field of our cryogenic double Penning trap setup. From the spin-flip resonances the electronic and nuclear g-factors g_e and g_I, the zero-field hyperfine splitting E_{hfs}, as well as the Zemach radius r_Z were extracted with a relative precision of 220 ppt, 810 ppt, 30 ppt and 0.9 %, respectively [2]. This constitutes a direct calibration of ^3He NMR probes and an improvement of the precision by one order of magnitude compared to previous indirect measurements of the nuclear magnetic moment.

[1] Farooq et al., Phys. Rev. Lett. 124, 223001 (2020)
[2] Schneider et al., Nature 606, 878-883 (2022)