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

Time: Tuesday 11:00–13:00 Location: HS 1098

Q 14.1 Tue 11:00 HS 1098

Implementing a Josephson Voltage Standard on a Penning Trap for the Nuclear Magnetic Moment Measurements of ^{2}D, ^{3}He and ^{7}Li — •Annabelle Kaiser[1], Stefan Dickopf[1], Marius Müller[1], Ralf Behr[2], Ute Beutel[1], Ankush Kaushik[1], Luis Palafox[2], Stefan Ulmer[3,4], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch Technische Bundesanstalt, Braunschweig, Germany — [3]RIKEN, Wako, Japan — [4]HHU Düsseldorf, Germany

Penning traps are versatile tools for high-precision measurements of e.g. the hyperfine structure from which atomic masses, binding energies and electron as well as nuclear magnetic moments can be extracted. For the latter, a spin-flip needs to be resolved with a change in signal that is barely detectable before the background noise, using methods described in [1]. This requires an ultra-stable trapping environment and extremely cold ion temperatures. A new technique will be presented, which reduces the noise originating from the voltage sources generating the electrostatic trapping potential: By implementing a tunable 10 V Josephson voltage standard, the stability of the ion's axial frequency was measured to be twice as stable (10 ppb over 8 minutes, at 800 kHz absolute frequency) as with the typical low-noise voltage sources UM1-14. An environment this stable enables the direct high-precision measurements of the nuclear magnetic moment of ^{2}D, ^{3}He and ^{7}Li. First results of the frequency stability improvement will be presented, along with the status of the project.

[1] Mooser et al., J. Phys.: Conf. Ser. 1138 012004 (2018)

Q 14.2 Tue 11:15 HS 1098

Measurement of the bound-electron *g*-factor in ^{4}He$^+$ for the determination of the electron mass — •Marius Müller[1], Stefan Dickopf[1], Annabelle Kaiser[1], Ute Beutel[1], Ankush Kaushik[1], Stefan Ulmer[2,3], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland — [2]RIKEN, Wako, Japan — [3]Heinrich-Heine-Universität, Düsseldorf, Deutschland

The determination of fundamental constants is of great importance for many fields of science and technology. One of these fundamental constants is the atomic mass of the electron, which was previously determined to a fractional uncertainty of 30 ppt by a collaborative effort of high-precision Penning-trap *g*-factor measurements of hydrogen-like carbon-12 and state-of-the-art bound-state QED calculations [1]. Recent measurements of the helium-4 mass at LIONTRAP with a relative precision of 12 ppt [2] allow for an independent cross-check of the electron mass in a different ionic system and further enable an improvement in precision by a factor of 2.5.

At our experimental Penning-trap setup at the MPIK in Heidelberg [3], we are currently conducting high-precision bound-electron *g*-factor measurements of ^{4}He$^+$ in order to improve the precision of the atomic mass of the electron. The current status and first experimental results of the helium-4 measurement campaign will be presented.

[1] S. Sturm *et al.*, Nature 506, 467 (2014)
[2] S. Sasidharan *et al.*, Phys. Rev. Lett. 131, 093201 (2023)
[3] A. Schneider *et al.*, Nature 606, 878 (2022)

Q 14.3 Tue 11:30 HS 1098

Precision ground-state hyperfine and Zeeman spectroscopy on ^{9}Be ions — •Stefan Dickopf[1], Bastian Sikora[1], Annabelle Kaiser[1], Marius Müller[1], Stefan Ulmer[2], Vladimir Yerokhin[1], Zoltan Harman[1], Christoph Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institut für Experimentalphysik, Heinrich-Heine-Universität, Düsseldorf, Germany

Measurements of the Zeeman splitting in systems with nuclear magnetic moments can be used to infer the shielded nuclear and the bound electron *g*-factors, as well as the zero-field hyperfine splitting [1]. We measured the Zeeman splitting of ^{9}Be^{3+} and compare it to measurements on ^{9}Be^{1+} [2] to test the theory of the diamagnetic shielding factor [3] on the parts per billion level. Additionally, we compare our measured zero-field splitting with the value obtained in ^{9}Be^{1+} via the so-called hyperfine specific difference to cancel theoretically intractable nuclear structure contributions. Recent progress and the latest results will be presented.

[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 14.4 Tue 11:45 HS 1098

Isotope shift spectroscopy in ultracold atomic mercury — •Thorsten Groh, Sascha Heider, and Simon Stellmer — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn

Low energy beyond standard model theories predict a new boson, that would act as a new force carrier coupling neutrons and leptons via a Yukawa like interaction [Delaunay, PRD 96, 093001; Berengut, PRL 120, 091801]. Precision spectroscopy of atomic isotope shifts could resolve this coupling as an energy shift of electronic levels. New physics signatures would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

We cool mercury in a magneto-optical trap. Our results on high resolution deep UV laser spectroscopy show strong deviations from linearity. Our multidimensional King plot analysis indicates that these are dominated by standard model contributions, quadratic field shifts and nuclear deformations. With recent improvements on the machine and spectroscopy results on additional lines we investigate the nonlinearity origins further.

Q 14.5 Tue 12:00 HS 1098

Spectroscopy of calcium on an atomic vapor — •Lukas Möller, David Röser, Frederik Wenger, Andreas Reuss, Anica Hamer, and Simon Stellmer — Physikalisches Institut, Universität Bonn

Calcium is an element that posseses multiple desireable qualities that make it suitable for a multitude of applications, including atomic clocks and the search for beyond standard model physics. All of these applications are based on high precision spectroscopy. Spectroscopy on thermal atomic vapor is a straightforward and well-estabished method. By applying a lock-in detection scheme that uses both frequency and amplitude modulation to saturated absorption spectroscopy, we measure the isotope shifts of the 423-nm 1S0 -> 1P1 transition for all stable calcium isotopes.

Q 14.6 Tue 12:15 HS 1098

Developments towards quantum logic spectroscopy for high-precision CPT symmetry tests in a cryogenic Penning trap — •Jan Schaper[1], Julia Coenders[1], Moritz von Boehn[1], Nima Hashemi[1], Juan Manuel Cornejo[1], Stefan Ulmer[3,4], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Ulmer Fundamental Symmetries Laboratory, Riken, Japan — [4]Heinrich-Heine-Universität Düsseldorf, Germany

High-precision matter-antimatter comparisons allow to test CPT symmetry and to search for new physics beyond the standard model. The BASE collaboration contributes to these tests by measuring the charge-to-mass ratio and *g*-factor of protons and antiprotons in cryogenic Penning traps [1-3]. The BASE experiment at the Leibniz University Hannover is developing measurement schemes based on sympathetic cooling and quantum logic spectroscopy to further increase sampling rates, using ^{9}Be$^+$ both as cooling and logic ion [4].

This talk will present recent advances, including adiabatic transport in the ms-regime [5] and ground-state cooling of a single ^{9}Be$^+$ ion [6]. Furthermore, upcoming changes to the experimental apparatus, including a redesigned Penning trap stack, will be shown.

[1] G. Schneider et al., Science 358, 1081 (2017) [2] C. Smorra et al., Nature 550, 371 (2017) [3] M.J. Borchert et al., Nature 601, 53 (2022) [4] Juan M Cornejo et al 2021 New J. Phys. 23 073045 [5] Meiners et al., arXiv:2309.06776 (2023) [6] Cornejo et at., arXiv:2310.18262 (2023)

Q 14.7 Tue 12:30 HS 1098

X-Ray Spectroscopy of the Kα transitions in He-like Uranium — •Philip Pfäfflein[1,2,3], Steffen Allgeier[4], Sonja Bernitt[1,2,3], Andreas Fleischmann[4], Marvin Friedrich[4], Alexandre Gumberidze[2], Christoph Hahn[1,2], Daniel

Hengstler[4], Marc O. Herdrich[1,2,3], Felix Kröger[1,2,3], Patricia Kuntz[4], Michael Lestinsky[2], Bastian Löher[2], Esther B. Menz[1,2,3], Uwe Spillmann[2], Sergiy Trotsenko[1,2], Günter Weber[1,2], Binghui Zhu[1,2,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Germany — [2]GSI, Darmstadt, Germany — [3]Jena University, Germany — [4]Heidelberg University, Germany

Helium-like ions are the simplest atomic multi-body systems. Their study along the isoelectronic sequence allows for precision tests of the interplay of the effects of electron–electron correlation, relativity and quantum electrodynamics (QED) within a wide range of electromagnetic field strengths. Heavy highly charged ions are ideal for probing higher order QED terms. For the 1s state in uranium, e.g. their contributions are on the 1 eV level at binding energies of above 100 keV.

In spring 2021 an X-ray spectroscopy study of helium-like uranium ions has been performed at the electron cooler of the low-energy storage ring CRYRING@ESR at GSI, Darmstadt using metallic magnetic calorimeter detectors. The achieved spectral resolution reveals the substructure of the Kα_1 and Kα_2 lines for the first time. Using two detectors the Doppler shift was deduced from the recorded spectra. This breakthrough in X-ray spectroscopy enables future precision tests of bound-state QED and many-body effects in extreme field strengths.

Q 14.8 Tue 12:45 HS 1098

Towards high precision quantum logic spectroscopy of single molecular ions —

•Maximilian Jasin Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesanstalt, Braunschweig — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy. In addition to the single molecular ion, one well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state is used as a bus to transfer information about the internal state of the molecular ion to the atomic ion. Using calcium as a logic ion, we have implemented a quantum logic scheme to detect population transfer on a co-trapped spectroscopy ion. The interaction is driven by a far detuned Raman laser setup. We present the latest progress of our experiment, aiming at high precision spectroscopy of molecular and complex atomic ions.