A 15: Precision spectroscopy of atoms and ions II

Time: Wednesday 11:00–13:15 Location: f107

Invited Talk A 15.1 Wed 11:00 f107

The ALPHATRAP *g*-factor experiment — •TIM SAILER[1], IOANNA ARAPOGLOU[1], ALEXANDER EGL[1], FELIX HAHNE[1,2], MARTIN HÖCKER[1], PETER MICKE[1,3], BINGSHENG TU[1], ANDREAS WEIGEL[1], JOSÉ R. CRESPO LÓPEZ-URRUTIA[1], SVEN STURM[1], and KLAUS BLAUM[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fakultät für Physik und Astronomie, Universität Heidelberg — [3]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig

The Penning-trap experiment ALPHATRAP, located at the Max-Planck-Institut für Kernphysik, aims to measure the g-factor of bound electrons in highly charged ions (HCI) up to hydrogen-like $^{208}Pb^{81+}$. In the electrical field of the nucleus with a strength of the order of 10^{16} V/cm, bound-state quantum electrodynamics can be tested with highest precision in extreme conditions.

We recently performed the first measurements at the ALPHATRAP setup, measuring the g-factor of boron-like $^{40}Ar^{13+}$. Additionally, a novel measurement technique that enables laser spectroscopy on single ions has been developed and was used to measure the $2p^2P_{1/2}$ – $^2P_{3/2}$ fine-structure transition on the same ion. Furthermore, the ALPHATRAP setup has recently been connected via a UHV beamline to the Heidelberg electron-beam-ion-trap (HD-EBIT), which gives access to heavy highly-charged ions. First ions produced in that EBIT have been successfully loaded and stored in ALPHATRAP with corresponding measurements being set up. The results of these measurements and prospects of upcoming studies will be discussed.

A 15.2 Wed 11:30 f107

A New Experiment for the Measurements of the Nuclear Magnetic Moment of $^3He^{2+}$ and the Ground-State Hyperfine Splitting of $^3He^+$ — •MARIUS MÜLLER[1,2], STEFAN DICKOPF[1,2], ANDREAS MOOSER[1], ANTONIA SCHNEIDER[1], TOM SEGAL[1], STEFAN ULMER[3], JOCHEN WALZ[4,5], and KLAUS BLAUM[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Ruprecht-Karls-Universität, Heidelberg, Germany — [3]RIKEN, Ulmer Fundamental Symmetries Laboratory, Wako, Japan — [4]Johannes Gutenberg-Universität, Mainz, Germany — [5]Helmholtz-Institut Mainz, Germany

The Heidelberg ^{3}He-experiment is aiming at the first direct high-precision measurement of the nuclear magnetic moment of $^3He^{2+}$ with a relative uncertainty on the 10^{-9} level and an improved measurement of the ground-state hyperfine splitting of $^3He^+$ by at least one order of magnitude. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized ^{3}He-NMR-probes for absolute magnetometry. The HFS measurement of $^3He^+$ is sensitive to nuclear structure effects and would give information about such effects in a three-nucleon system. For both measurements a four Penning trap setup was designed and similar techniques as already demonstrated in proton and antiproton magnetic moment measurements [1,2] are going to be applied. The current status of the experiment is presented.

[1] Schneider et al., Science Vol 358, 1081 (2017)
[2] Smorra et al., Nature, Vol 550, 371 (2017)

A 15.3 Wed 11:45 f107

A robust clock transition on $^{40}Ca^+$ with a continuous dynamical decoupling scheme — •KAI DIETZE[1,2], LENNART PELZER[1,2], NATI AHARON[3], LUDWIG KRINNER[1,2], NICOLAS SPETHMANN[1], ALEX RETZKER[3], and PIET SCHMIDT[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig,D — [2]Leibniz-Universität-Hannover,30167 Hannover,D — [3]The Hebrew University of Jerusalem, 91904 Jerusalem, IL

The statistical uncertainty of optical atomic clocks based on single trapped ions is limited by long averaging times. Referencing the clock laser simultaneously on large ensembles of ions can improve the laser frequency noise and thus allow longer probe times. However, trapping a larger number of ions introduces several systematic frequency shifts, resulting in inhomogeneous broadening of the clock transition. In our experiment, we couple the clock transition between the $4S_{1/2}$ and $5D_{5/2}$ Zeeman-substates of $^{40}Ca^+$ with radiofrequency fields, to engineer dressed states with significantly reduced systematic shifts. The scheme is based on up to four driving fields to suppress the linear Zeeman-, quadrupole-, and tensor ac-Stark shifts by orders of magnitude [1]. We present predictions on the performance of these strongly coupled systems as a reference transition for laser stabilization and experimental results implementing this scheme in our segmented Paul-trap as a multi-ion approach.

[1] Aharon *et al.*, New Journal of Physics **21** (2019) 083040.

A 15.4 Wed 12:00 f107

Collinear Laser Spectroscopy of Ca^+: Solving the field shift puzzle of the $4s \to 4p$ transitions — •PATRICK MÜLLER[1], PHILLIP IMGRAM[1], KRISTIAN KÖNIG[2], JÖRG KRÄMER[1], BERNHARD MAASS[1], and WILFRIED NÖRTERSHÄUSER[1] — [1]Institut für Kernphysik, Technische Universität Darmstadt — [2]NSCL, Michigan State University

The ratio of the isotopic field shifts can be accessed well from theory as well as from experiment and hence, serves as a profound benchmark for atomic structure calculations. Experimentally, it can be determined solely from optical frequency measurements of two different transitions over the isotopic chain. Previous ion trap measurements of the $4s\,^2S_{1/2} \to 4p\,^2P_{1/2}$ (D1) and $4s\,^2S_{1/2} \to 4p\,^2P_{3/2}$ (D2) transition resulted in a field shift ratio of $F_{D2}/F_{D1} = 1.0085(12)$ which exceeds all theoretical predictions and even the boundaries set by the hydrogenic model [1].
We report on collinear laser spectroscopy measurements of the $4s \to 4p$ as well as the $3d \to 4p$ transition frequencies in naturally abundant Ca^+ isotopes at the 100-kHz precision level. The $4s \to 4p$ transitions were used to determine the field shift ratio F_{D2}/F_{D1} in a King plot analysis. The new experimental value agrees well with preceding atomic structure calculations and was successfully checked for self-consistency by combining the results of the $4s \to 4p$ and $3d \to 4p$ transitions to form ring closures across the contributing states.
Acknowledgement This work has been supported by BMBF under contract # 05P19RDFN1.
[1] Shi et al., Applied Physics B **123**, 2 (2016)

A 15.5 Wed 12:15 f107

Non-perturbative calculation of the two-loop self-energy contribution to the bound-electron *g*-factor — •BASTIAN SIKORA[1], VLADIMIR A. YEROKHIN[2], NATALIA S. ORESHKINA[1], HALIL CAKIR[1], CHRISOPH H. KEITEL[1], and ZOLTÁN HARMAN[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

We present the status of our ongoing calculation of the two-loop self-energy contribution to the bound-electron *g*-factor, which currently gives rise to the largest uncertainty of theoretical *g*-factor predictions. In our approach, the interaction between electron and nucleus is taken into account exactly. We have obtained full results for the loop-after-loop diagrams, and partial results for the nested and overlapping loop diagrams.

Our results will be highly relevant for *g*-factor measurements with high-*Z* ions as well as for an independent determination of the fine-structure constant α from the bound-electron *g*-factor in the near future.– [1] B. Sikora, V. A. Yerokhin, N. S. Oreshkina *et al.*, in press, arXiv:1804.05733v1 [physics.atom-ph] (2018).

A 15.6 Wed 12:30 f107

Two-loop radiative corrections to the bound-electron *g* factor involving the magnetic loop — •VINCENT DEBIERRE, BASTIAN SIKORA, HALIL CAKIR, NATALIA S. ORESHKINA, ZOLTÁN HARMAN, and CHRISTOPH H. KEITEL — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg

The *g* factor of bound electrons in light and medium-light hydrogen-like ions (e.g. C, Si) has been measured with an accuracy of a few parts in 10^{11} [S. Sturm *et al.*, Nature **506**, 467 (2014)]. Experiments such as ALPHATRAP and HITRAP aim at reaching this accuracy with heavy, few-electron ions, motivating the evaluation of two-loop radiative corrections.

We calculate a specific set of two-loop corrections to the bound-electron *g* factor in the hydrogen-like ground state. Diagrams belonging to this set include the magnetic loop as a subprocess and vanish in the free-loop approximation [V.A. Yerokhin and Z. Harman, Phys. Rev. A **88**, 042502 (2013)]. At the lowest nonvanishing order, they involve the scattering of the external magnetic field in the Coulomb field of the ionic nucleus. We computed the electric-loop-magnetic-loop diagram, the magnetic-loop-after-loop diagram, and the self-energy-magnetic-loop diagrams. Our approach treats the binding of the electron to the nucleus nonperturbatively.

The computed corrections to the g factor are of order up to 10^{-8} in the case of ^{82}Pb. These corrections will be relevant to the projected determination of the fine-structure constant from g-factor measurements.

A 15.7 Wed 12:45 f107

The g factor of bound electrons as a probe for physics beyond the Standard Model — •Vincent Debierre, Christoph H. Keitel, and Zoltán Harman — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg

We demonstrate the relevance of the g factor of bound electrons in few-electron ions to the search for physics beyond the Standard Model (SM). The contribution to the g factor from hypothetical forces beyond the SM can be computed and, when compared to existing and projected experimental data, used to derive competitive bounds on the parameters of these forces.

A first method to implement this program consists in comparing the best available theoretical and experimental results on the g factor. We also use data on the difference of g factors of different electronic levels [V.A. Yerokhin *et al.*, Phys. Rev. Lett. **116**, 100801 (2016)]. Stringent bounds can be obtained in the future with this method, through the furtherance of bound state QED calculations at the two-loop level.

Another method makes use of the isotope shift. Inspired by a recent proposal concerning optical frequencies in ions [J.C. Berengut *et al.*, Phys. Rev. Lett. **120**, 091801 (2018)], we propose to use precision spectroscopy of the isotope shifts in the g factor of few-electron ions, in order to obtain bounds on proposed new forces. By carefully considering subleading nuclear corrections to the g factor, our treatment allows for the precise interpretation of isotope shift data. We also combine the isotope shift with the above-mentioned weighted difference, which yields competitive bounds [V. Debierre *et al.*, arXiv:1901.06959].

A 15.8 Wed 13:00 f107

Laser photodetachment spectroscopy in a MR-ToF device — •D. Leimbach[1,2,3], V. Lagaki[1,4], for the GANDALPH[1,2], and MIRACLS collaboration[1,4] — [1]CERN, Geneva, Switzerland — [2]Dep. of Physics, University of Gothenburg, Sweden — [3]Inst. für Physik, Johannes Gutenberg-Universität, Germany — [4]Universität Greifswald, Germany

The electron affinity (EA) is the energy released when an additional electron is bound to a neutral atom, creating a negative ion. Due to the lack of a long-range Coulomb attraction, the EA is dominated by electron-correlation effects. Hence, EAs are strong experimental benchmarks on theoretical atomic-structure models which go beyond the independent particle approximation. Although the isotope shift (IS) in the EA of stable chlorine (Cl) isotopes has been measured, recent calculations improve the theoretical precision beyond the experimental one. For this reason, we plan to perform laser photodetachment spectroscopy to determine this IS more precisely. This will be achieved by reusing the ion beam when trapped in an MR-ToF device. Thereby, the measurement efficiency is increased which allows us to employ a narrow band cw laser compared to the previously used high-power and broad-band pulsed laser. Once successful, we will extend this type of studies for the first time to long-lived radionuclides by determining the IS of 36Cl(vs 35Cl). This novel approach can be applied to EA-IS measurements of short-lived radionuclides as well as EA determination of sparsely produced and eventually superheavy elements. We will present the technique and status of the experimental campaign.