Q 21: Precision Spectroscopy of Atoms and Ions II (with A)

Time: Tuesday 11:00–13:15 Location: M/HS1

Invited Talk Q 21.1 Tue 11:00 M/HS1

Observation of wave function collapse and four-electron Auger process in inner-shell photoionization of atomic ions — •Stefan Schippers — IAMP, Justus-Liebig-Universität Gießen, Germany

Inner-shell ionization of atomic ions is an important process in astrophysical and man-made plasmas. The creation of an inner-shell vacancy leads to the formation of multiply excited states which de-excite via many competing channels, some of which are quite exotic. Recently, the study of inner-shell photoionization of ions has become feasible at the PETRA III synchrotron radiation facility at DESY in Hamburg, Germany. There, the Photon-Ion spectrometer at PETRA III (PIPE) [1] was set up at the beam line P04 [2] which provides photons in the 250–3000 eV energy range. First results were obtained on the $3d$ ionization of multiply charged xenon ions where the formation of resonances via the collapse of nf wave functions was studied as a function of the primary ion charge [3]. Further experiments with singly charged carbon ions gave a compelling evidence of the new experimental capabilities of the PIPE setup. For the first time, multiple ionization by K-shell excitation of an atomic ion could be studied. As one of the de-excitation channels, the long sought-after triple Auger process — mediated by a four-body interaction — could be unambiguously identified [4].

[1] S. Schippers et al., J. Phys. B 47, 115602 (2014).
[2] J. Viefhaus et al., Nucl. Instrum. Methods A 710 (2013) 151.
[3] S. Schippers et al., J. Phys. B (in print).
[4] A. Müller et al., Phys. Rev. Lett. (in print).

Q 21.2 Tue 11:30 M/HS1

Laser spectroscopy of the heaviest elements at GSI — •Premaditya Chhetri[1], MIchael Block[2,3], Harmut Backe[4], Peter Kunz[5], Fritz-Peter Hessberger[2,3], Mustapha Laatiaoui[2], Werner Lauth[4], Felix Lautenschläger[1], Sebastian Raeder[7], Thomas Walther[1], and Calvin Wraith[6] — [1]TU Darmstadt, Darmstadt — [2]Helmholtzinstitut Mainz, Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [4]JGU Mainz, Mainz — [5]TRIUMF, Vancouver, Canada — [6]University of Liverpool, Liverpool, United Kindom — [7]KU Leuven, Leuven, Belgium

Laser spectroscopy of the heaviest elements allows the study of the evolution of relativistic effects on their atomic structure. In addition, nuclear properties such as spins and nuclear moments can be obtained. In our experiments at the GSI we exploit the Radiation Detected Resonance Ionization Spectroscopy in a buffer-gas filled stopping cell and use a two step photoionization process to search for the $^1P_1$ level in ^{254}No. Yb, a chemical homolog of No, can be produced at a higher rate and is used for optimizing the system. In this talk a general overview of our experimental setup and some results from a recent online experiment on ^{155}Yb will be presented.

Q 21.3 Tue 11:45 M/HS1

The g-factor of the proton and progress towards the antiproton — •Andreas Mooser for the BASE-Collaboration — RIKEN Advanced Science Institute, Japan

By measuring the ratio of the Larmor and the cyclotron frequency of a single trapped proton with a fractional precision of 3.3 ppb we succeeded to perform the most precise and first direct high-precision measurement of the g-factor of the proton [1]. This was possible by recent advances in the quantum control of a single proton in a Penning trap [2]. As a next step, we currently pursue the application of our techniques towards a measurement of the g-factor of the antiproton [3], which will result in one of the most precise tests of CPT invariance on the baryionic sector. Pushing our limits even further, we are exploring experimental techniques, which will allow significantly accelerated measurement cycles using sophisticated Penning traps, detection systems and sympathetic laser cooling of single protons/antiprotons. This shall open up the possibility for a search of diurnal variations of the Larmor frequency caused by CPT- and Lorentz violating contributions beyond the Standard Model. In the talk our recent results on the measurement of the g-factor of the proton and an outlook regarding our future developments are given.

[1] A. Mooser *et al.*, Nature **509**, 596 (2014).
[2] A. Mooser *et al.*, Phys. Rev. Lett. **110**, 140405 (2013).
[3] C. Smorra *et al.*, Hyperfine Interact. **228**, 31 (2014).

Q 21.4 Tue 12:00 M/HS1

Microwave Electrometry with Rydberg Atoms in a Vapor Cell — •Harald Kübler[1,2], Jonathan A. Sedlacek[1], Haoquan Fan[1], Santosh Kumar[1], Renate Daschner[2], Robert Löw[2], Tilman Pfau[2], and James p. Shaffer[1] — [1]Homer L. Dodge Department of Physics and Astronomy, The University of Oklahoma, 440 W. Brooks St. Norman, Oklahoma 73019, USA — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Quantum based standards of length and time as well as measurements of other useful physical quantities, ex. magnetic fields, are important because quantum systems, like atoms, show clear advantages for providing stable and uniform measurements. We demonstrate a new method for measuring microwave electric fields based on quantum interference in a Rubidium atom. Using a bright resonance prepared within an electromagnetically induced transparency window we are able to achieve a sensitivity of $30\,\mu\mathrm{V\,cm^{-1}}\sqrt{\mathrm{Hz}}^{-1}$ with a modest setup [1]. This method can be used for vector electrometry with a precision below 1° [2] and microwave field imaging with a sub-wavelength resolution [3]. Furthermore we show first results on exploiting the dispersive features of the system.

[1] J.A. Sedlacek, et al. *Nature Physics* **8**, 819 (2012)
[2] J.A. Sedlacek, et al. *Phys. Rev. Lett.* **111**, 063001 (2013)
[3] H. Q. Fan, et al. *Opt. Lett.* **39**, 3030-3033 (2014)

Q 21.5 Tue 12:15 M/HS1

A high-precision measurement of the isotope effect in the magnetic moment of highly charged ^{40,48}Ca^{17+} ions — •Jiamin Hou[1], Florian Köhler[1,2], Sven Sturm[1], Anke Wagner[1], Wolfgang Quint[2], Günter Werth[3], and Klaus Blaum[1] — [1]MPIK, Heidelberg, Germany — [2]GSI, Darmstadt, Germany — [3]JGU, Mainz, Germany

To achieve a comprehensive understanding of the fundamental properties of nature, high-precision experiments with trapped charged particles are one of the most promising methods. In this experiment, the magnetic moments, i.e. g-factors, of the bound electrons for lithium-like ^{40}Ca and ^{48}Ca ions in the medium Z region (Z=20) have been measured for the first time with a relative uncertainty of $7 \cdot 10^{-10}$, giving rise to a stringent test of the isotope effect. We determine the bound-state electron magnetic moment by measuring the ratio of the electron spin-precession frequency and the ion's cyclotron frequency[1,2] in a cryogenic Penning-trap apparatus. The final result is obtained by combining our results with state-of-the-art QED calculations and an independent Penning-trap mass measurement. In the next step, hydrogen-like ^{40,48}Ca^{19+} will be studied. The comparison with the lithium-like system allows us to separate nuclear and inter-electronic effects. Furthermore, a novel trap system is under development which will push the achievable precision into the 10^{-12} regime and thus will open new possibilities for the determination of fundamental constants.

[1] A.Wagner et al. Phys. Rev. Lett. 110, 033003 (2013)
[2] S. Sturm et al. Phys. Rev. Lett. 107, 023002(2011)

Q 21.6 Tue 12:30 M/HS1

Spin noise spectroscopy beyond thermal equilibrium and linear response — •Dibyendu Roy[1,2,3], Philipp Glasenapp[4], Luyi Yang[5], Dwight G. Rickel[5], Alex Greilich[4], Manfred Bayer[4], Nikolai A. Sinitsyn[2], and Scott A. Crooker[5] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — [3]Center for Nonlinear Studies, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — [4]Experimentelle Physik 2, Technische Universitat Dortmund, D-44221 Dortmund, Germany — [5]National High Magnetic Field Lab, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Per the fluctuation-dissipation theorem, the information obtained from spin fluctuation studies in thermal equilibrium is necessarily constrained by the system's linear response functions. However, by including weak radiofrequency magnetic fields, we demonstrate that intrinsic and random spin fluctuations even in strictly unpolarized ensembles can reveal underlying patterns of correlation and coupling beyond linear response, and can be used to study non-equilibrium and even multiphoton coherent spin phenomena [arXiv:1407.2895]. We demonstrate this capability in a classical vapor of 41K alkali atoms, where spin fluctuations alone directly reveal Rabi splittings, the formation of Mollow triplets and Autler-Townes doublets, ac Zeeman shifts, and even nonlinear multiphoton coherences.

Q 21.7 Tue 12:45 M/HS1

Frequency metrology of ultracold ^{3}He and ^{4}He in the framework of the proton radius puzzle — •Robert J. Rengelink, Remy P.M.J.W. Notermans, and Wim Vassen — LaserLaB, Department of Physics and Astronomy, VU University, Amsterdam, the Netherlands

Ultracold gases can be probed with long interrogation times which allows very weak optical transitions to be made. In helium narrow transitions involving S-states are of interest from the perspective of testing QED and as a sensitive probe of the nuclear charge radius. At VU university we study the doubly forbidden $2\ ^3S \rightarrow 2\ ^1S$ transition at 1557 nm, which allows an accurate determination of the ^{3}He-4He differential nuclear charge radius. Previously, this transition was measured to kHz accuracy in our group (van Rooij *et. al*, Science **333**,196 (2011)). To achieve a level of accuracy comparable to the projected accuracy of muonic helium experiments currently being performed at the Paul Scherrer Institute (Nebel *et. al*, Hyperfine Interact. **212**, 195-201(2012)) we intend to push the accuracy to the 0.1 kHz level.

In this contribution, I will discuss the improvements currently being implemented in our experiment. These include an improved laser frequency stabilization scheme, a better determination of the Zeeman shift and, most importantly, the implementation of a magic wavelength dipole trap at 320 nm (Notermans *et. al*, Phys. Rev. A **90**, 052508 (2014)) to eliminate the AC-stark shift. For this purpose a laser system has been built with a continuous output power of 2W at this challenging UV wavelength.

Q 21.8 Tue 13:00 M/HS1

A novel permanent magnetic EBIT — •Peter Micke[1,2], Sven Bernitt[1,3], James Harries[4], Lisa F. Buchauer[1], Thore M. Bücking[1], Steffen Kühn[1], Piet O. Schmidt[2,5], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Friedrich-Schiller-Universität Jena, Germany — [4]SPring-8, Hyogo, Japan — [5]Leibniz Universität Hannover, Germany

Research on moderately and highly charged ions (HCIs) is of great interest not only for atomic physics but also fundamental studies. Electron beam ion traps (EBITs) have proven to be versatile and indispensable tools for the production and study of such ions. In an EBIT, an electron beam is compressed by a strong, inhomogeneous magnetic field to breed the ions efficiently. Usually the field is generated by superconducting magnet coils. To ease operation we introduce a novel magnetic design based on permanent magnets for a 0.74 tesla EBIT. It allows operation at room temperature, resulting in a low-cost and low-maintenance apparatus. An open trap design offers a large solid angle access to the trap center. Our EBIT is intended to serve as a reliable source for HCIs. Additionally a new off-axis gun is under construction, to be used at synchrotron and free-electron laser light sources for energy calibration by spectroscopy on HCIs. By using this off-axis gun the photon beam can pass through the EBIT and is available for beamline users. Currently, first experiments with a prototype are carried out regarding trapping and extraction of HCIs.