Q 3: Precision spectroscopy of atoms and ions I (with A)

Time: Monday 10:30–12:30 Location: BEBEL E42

Q 3.1 Mon 10:30 BEBEL E42

Messung der Zyklotronfrequenz eines einzelnen Protons in einer Penningfalle — •Peter Koss[1], Klaus Blaum[2,3], Sascha Bräuninger[2,3], Holger Kracke[1,4], Clemens Leiteritz[1,4], Andreas Mooser[1,4], Wolfgang Quint[3,5], Stefan Ulmer[6] und Jochen Walz[1,4] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [3]Ruprecht-Karls-Universität, 69047 Heidelberg — [4]Helmholtz Institut Mainz, 55099 Mainz — [5]GSI, 64291 Darmstadt — [6]RIKEN, Wako, Saitama 351-0198, Japan

Ziel des Experiments ist die Bestimmung des g-Faktors eines einzelnen Protons in einem Doppel-Penningfallen-Aufbau. Der g-Faktor kann aus der Messung der freien Zyklotronfrequenz $\nu_c = \frac{q}{m}B$ und der Larmorfrequenz $\nu_L = g\frac{q}{2m}B$ über die Relation $\frac{g}{2} = \frac{\nu_L}{\nu_c}$ bestimmt werden. Die freie Zyklotronfrequenz wird aus den Bewegungsfrequenzen der drei unabhängigen Eigenbewegungen des Protons in der Falle über das Invarianztheorem $\nu_c^2 = \nu_+^2 + \nu_-^2 + \nu_z^2$ bestimmt. Der limitierende Faktor bei der Bestimmung der freien Zyklotronfrequenz ist die Unsicherheit der modifizierten Zyklotronfrequenz, da diese die größte der drei Eigenfrequenzen ist. Die modifizifierte Zyklotronfrequenz muss somit möglichst genau bestimmt werden. Dazu wurden drei Messmethoden zur Bestimmung von ν_+, die kohärente Detektion, die sequentielle Doppel-Dip-Messung und die verzahnte Doppel-Dip-Messung, systematisch untersucht. In diesem Vortrag werden die Methoden zunächst vorgestellt und anschließend verglichen.

Q 3.2 Mon 10:45 BEBEL E42

Nachweis von einzelnen Spin-Quantensprüngen eines in einer Penningfalle gespeicherten Protons — •Clemens Leiteritz[1], Andreas Mooser[1,2], Peter Koss[1], Holger Kracke[1,2], Klaus Blaum[3], Wolfgang Quint[4,5], Stefan Ulmer[6] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [3]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [4]Ruprecht-Karls-Universität, 69047 Heidelberg — [5]GSI Darmstadt, 64291 Darmstadt — [6]RIKEN, Wako, Saitama 351-0198, Japan

Wir berichten über ein Experiment zur Bestimmung des g-Faktors eines einzelnen, in einer Penningfalle gespeicherten Protons. Es wird eine relative Genauigkeit von 10^{-9} angestrebt. Der g-Faktor $g = 2\frac{\omega_L}{\omega_c}$ kann aus der Messung der freien Zyklotronfrequenz $\omega_c = \frac{q}{m}B$ sowie der Larmorfrequenz ω_L im Magnetfeld B bestimmt werden. Hierzu verwenden wir ein Doppel-Penningfallensystem. In der Präzisionsfalle wird die freie Zyklotronfrequenz bestimmt und durch ein angelegtes Hochfrequenz-Feld ein Umklappen des Spins induziert. Durch eine magnetische Inhomogenität im Zentrum der Analysefalle wird der Spin des Protons an die axiale Bewegung entlang des Magnetfelds gekoppelt. Spin-Quantensprünge lassen sich anhand kleiner Änderungen der Axialfrequenz des Teilchens identifizieren. Diese Technik ermöglicht die Messung der Spin-Flip Rate als Funktion der angelegten Hochfrequenz, und somit eine Bestimmung der Larmorfrequenz. Im Vortrag wird der aktuelle Stand des Experiments vorgestellt.

Q 3.3 Mon 11:00 BEBEL E42

Theoretical calculations for the determination of the electron mass via measurement of the g-factor of $^{12}C^{5+}$ — •Jacek Zatorski[1], Zoltán Harman[1,2], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Planckstraße 1, 64291 Darmstadt, Germany

We present theoretical results of a recent determination of the electron mass (Ref. [1]) via measurement of the bound electron g-factor in $^{12}C^{5+}$. The electron mass was determined with a relative uncertainty approximately 13 times lower than the established CODATA value (Ref. [2]) by means of comparison of theoretical prediction for $g\left(^{12}C^{5+}\right)$ and the experimental value. In order to reduce an error bar on the theory's side, we, first of all, estimated the unknown two-loop higher-order correction to $g\left(^{12}C^{5+}\right)$, which is the main source of the uncertainty, by extracting this effect from experimental results for $g\left(^{28}Si^{13+}\right)$. In addition, we have improved on the accuracy of certain other physical terms contributing to the g-factor.

[1] S. Sturm, F. Köhler, J. Zatorski, A. Wagner, Z. Harman, G. Werth, W. Quint, C. H. Keitel, and K. Blaum, manuscript submitted.
[2] P. J. Mohr, B. N. Taylor and D. B. Newell, Rev. Mod. Phys. 84, 1527 (2012).

Q 3.4 Mon 11:15 BEBEL E42

High-precision QED calculations of the g factor of Li-like ions — •Andrey Volotka[1], Dmitry Glazov[2], Vladimir Shabaev[2], Ilya Tupitsyn[2], and Günter Plunien[1] — [1]Institut für Theoretische Physik, TU Dresden — [2]St. Petersburg State University, Russia

Recent progress in *ab initio* QED calculations of the g factor of Li-like ions will be reported. The one- and two-photon exchange as well as the screened radiative corrections have been rigorously evaluated within an extended Furry picture, which includes a local screening potential in the unperturbed Hamiltonian. In addition, a special scheme, which considerably accelerates the partial-wave expansion convergence, has been employed for the evaluation of the screened radiative corrections. As a result, the theoretical accuracy for the g factor of Li-like ions has been significantly increased for all values of Z.

Q 3.5 Mon 11:30 BEBEL E42

Doppler-free broadband two-photon excitation spectroscopy with two optical frequency combs — •Arthur Hipke[1,2], Samuel A. Meek[1], Nathalie Picqué[1,2,3], and Theodor W. Hänsch[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstrasse 4/III, 80799 München, Germany — [3]Institut des Sciences Moléculaires d'Orsay, CNRS, Bâtiment 350, Université Paris-Sud, 91405 Orsay, France

Doppler-free precision measurements of atomic samples are traditionally performed using either a cw laser, or an optical frequency comb for sample interrogation. The limited spectral span where powerful cw lasers are available, however, puts a limit on the optical transitions it can be used for. Using a comb instead considerably complicates data analysis, since multiple transitions can potentially be driven simultaneously, resulting in highly intricate spectra. The limitations of both of these techniques can be overcome by simultaneously interrogating the sample with two combs having slightly detuned repetition rates. We demonstrate this technique's capability for high-resolution (up to 2 MHz) broadband precision spectroscopy by exciting the $5S_{1/2} \rightarrow 5D_{3/2}$ and $5S_{1/2} \rightarrow 5D_{5/2}$ two-photon transitions of atomic Rb vapor at 385 THz (778 nm). Broad two-photon excitation spectra showing well-resolved excited-states Rb hyperfine structure will be presented, clearly paving the way for precision spectroscopy of complex, molecular spectra in any spectral region where optical frequency combs are available.

Q 3.6 Mon 11:45 BEBEL E42

Ra^+ ion trapping -Atomic Parity Violation measurement and an optical clock — •Amita Mohanty, Elwin A. Dijck, Mayerlin Nunez Portela, Nivedya Valappol, Oliver Boell, Klaus Jungmann, Cornelis G. G Onderwater, Sophie Schlesser, Rob G. E. Timmermans, Lorenz Wilmann, and Hans W. Wilschut — University of Groningen, FWN, Zernikelaan 25, NL-9747AA Groningen

A single trapped Ra^+ ion has an excellent potential for a precision measurement of the Weinberg mixing angle at low momentum transfer and testing thereby the electroweak running. The absolute frequencies of the transition 7s $^2S_{1/2}$-7d$^2D_{3/2}$ at wavelength 828 nm have been determined in $^{212*214}Ra^+$ to better than 19 MHz with laser spectroscopy on small samples of ions trapped in a linear Paul trap at the online facility TRIμP of KVI. The measurement of the Weinberg angle requires the localization of the ion within a fraction of an optical wavelength. The current experiments are focused on trapping and laser spectroscopy on a single Ba+ as a precursor for Ra^+. Work towards single ion trapping of Ra^+, including the preparation of an offline ^{223}Ra source is in progress. Most elements of the setup for single Ra+ ion parity measurement are also well suited for realizing a most stable optical clock.

Q 3.7 Mon 12:00 BEBEL E42

Determination of the level structure of Ir^{17+} featuring transitions extremely sensitive to a variation of the fine-structure

constant — •Alexander Windberger[1], Oscar O. Versolato[2], Hendrik Bekker[1], Victor Bock[1], Sebastian Kaul[1], Ruben Schupp[1], Julian Stark[1], Joachim Ullrich[2], Zoltan Harman[1], Natalia Oreshkina[1], Christoph Keitel[1], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Leibniz Universität, Hannover

The Ir^{17+} ion is an ideal system to detect a possible variation of the fine-structure constant and test it in the laboratory, such as the one claimed by Webb and coworkers based on their analysis of quasar absorption spectra at high redshifts. The required sensitivity at the level of 10^{-19} /year can be attained by comparing highly forbidden optical transitions in the Ir^{17+} ion in a clock setup. Since theory reaches only an accuracy of 10^{-1} for those frequencies, an exploration of its electronic structure is needed. We perform electron excitation spectroscopy on Ir^{17+} inside the Heidelberg electron beam ion trap (EBIT) in the optical and vacuum-ultraviolet (VUV) range with an accuracy of 5 ppm and 200 ppm, respectively. To assign transitions to their corresponding levels, different approaches are considered, such as Rydberg-Ritz combinations, determination of g-factors, and use of the characteristic energy scaling of M1 transitions as a function of the atomic number. VUV fluorescence spectroscopy with FLASH-EBIT at BESSY II will be used for improved investigations of key ground state transitions.

Q 3.8 Mon 12:15 BEBEL E42

The mass of the electron — •Florian Köhler[1,2,3], Sven Sturm[3], Anke Wagner[3], Günter Werth[4], Wolfgang Quint[1,2], and Klaus Blaum[3] — [1]Fakultät für Physik, Universität Heidelberg — [2]GSI Darmstadt — [3]Max-Planck-Institut für Kernphysik, Heidelberg — [4]Institut für Physik, Johannes Gutenberg-Universität, Mainz

Recently the g-factor experiment for highly charged ions located in Mainz has provided the most stringent bound-state quantum electrodynamics (BS-QED) test [1]. Here, the bound electron g-factor of $^{28}Si^{13+}$ has been determined by the Larmor-to-cyclotron frequency ratio and the ion-to-electron mass ratio. For hydrogenlike ions with small nuclear charge, e.g. Z=6, the g-factor can be calculated with parts-per-trillion precision. Experimental improvements [2] enabled the measurement of the Larmor-to-cyclotron frequency ratio with a relative precision of $3 \cdot 10^{-11}$ for $^{12}C^{5+}$. In combination with theoretical predictions, the atomic mass of the electron has been improved by a factor of 13 with respect to the current CODATA value. This result will directly contribute to ultra-high precision tests of the Standard Model, e.g. the determination of the fine structure constant [3] and future BS-QED tests. In this talk the measurement of the electron mass will be presented and the current status on BS-QED tests will be summarised.

[1] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 023002 (2011)
[2] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 143003 (2011)
[3] R. Bouchendira *et al.*, Phys. Rev. Lett. **106**, 080801 (2011)