A 25: Posters: Precision spectroscopy of atoms and ions

Zeit: Donnerstag 16:30–18:30 Raum: Poster C3

A 25.1 Do 16:30 Poster C3

Präzise Messung der Hyperfeinstruktur in hochgeladenen Ionen — •Manuel Vogel, Danyal Winters, Zoran Andjelkovic, Wilfried Nörtershäuser und die SPECTRAP- Kollaboration — Gesellschaft für Schwerionenforschung GSI, Planckstrasse 1, 64291 Darmstadt

In hochgeladenen Ionen wie etwa $^{208}Pb^{81+}$ liegen Übergänge zwischen Niveaus der Hyperfeinstruktur im optischen Bereich oder nahe daran und sind mit Methoden der Laserspektroskopie zugänglich. Wir stellen ein Experiment vor, solche Ionen in einer Penningfalle zu speichern, ihre thermische Bewegung auf 4 Kelvin zu kühlen und ihre Hyperfeinstruktur mit einer relativen Auflösung $\Delta\lambda/\lambda$ von etwa 10^{-7} zu vermessen. Dies stellt eine Verbesserung früherer Experimente um 3 Größenordnungen dar und erlaubt stringente Tests entsprechender QED-Rechnungen. Das Projekt trägt den Namen SPECTRAP und findet statt im Rahmen des HITRAP-Projektes an der GSI Darmstadt. Wir präsentieren die zugrunde liegenden Methoden und den Status des experimentellen Aufbaus.

A 25.2 Do 16:30 Poster C3

Polarization studies on the two–photon decay of hydrogen–like ions — •Andrey Surzhykov[1,2], Thomas Radtke[3], Thomas Stöhlker[4,5], and Stephan Fritzsche[1,4] — [1]Max–Planck–Institut für Kernphysik, Heidelberg — [2]École Normale Supérieure, Paris — [3]Universität Kassel — [4]Gesellschaft für Schwerionenforschung (GSI), Darmstadt — [5]Universität Heidelberg

Since the early days of quantum mechanics, the two–photon decay of hydrogen–like ions has been the subject of intense experimental and theoretical studies. While, however, most investigations in the past dealt with the total transition probabilities, much of today's interest is focused on the energy as well as angular distributions [1] and even on the polarization properties of emitted photons [2]. In the nearest future, for example, the two–photon polarization measurements are likely to be carried out at the GSI facility in Darmstadt. In order to provide theoretical support for these experiments, we present a density matrix formalism for the description of the (linear) polarization of one of the photons measured *in coincidence* with the second one. Based on this formalism and on the relativistic Dirac's equation, detailed polarization calculations are performed for the $2s_{1/2} \to 1s_{1/2}$ and $3d_{5/2} \to 1s_{1/2}$ transitions in neutral hydrogen as well as in hydrogen–like xenon and uranium ions. The results of these computations show a strong dependence on the two–photon decay geometry as well as on the magnetic sublevel population of the excited ionic states.

[1] A. Surzhykov *et al.*, Phys. Rev. A **71** (2005) 022509.
[2] H. Kleinpoppen *et al.*, Phys. Scr. **T72** (1997) 7.

A 25.3 Do 16:30 Poster C3

Relativistic photon polarization studies in the two-photon decay of hydrogenlike systems — •Thomas Radtke[1], Stephan Fritzsche[2], and Andrey Surzhykov[3] — [1]Institut für Physik, Universität Kassel, D-34132 Kassel, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Gesellschaft für Schwerionenforschung (GSI), 64291 Darmstadt, Germany

The two-photon decay of metastable hydrogen and hydrogen-like systems has attracted renewed interest from the early days of quantum mechanics. Since then, many theoretical and experimental studies have been carried out to investigate the total decay rates and angular correlation functions of the emitted photons [1].

In this contribution, we analyze the (linear) polarization correlation of the two simultaneously emitted photons in the $2s_{1/2} \to 1s_{1/2}$ and $3d_{5/2} \to 1s_{1/2}$ decay of hydrogenlike atoms and ions. Our description is based on Dirac's equation and, hence, enables us to explore the relativistic and multipole effects upon the photon polarization. For the decay of hydrogen and hydrogen-like U^{91+} ions, results are shown for the angular dependence of the polarization correlation and are compared to the nonrelativistic dipole approximation.

[1] A. Surzhykov, P. Koval, S. Fritzsche, Phys. Rev. A 71, 022509 (2005)

A 25.4 Do 16:30 Poster C3

One single trapped and laser cooled radium ion: Towards an all-optical atomic clock — •Oscar Versolato, Lotje Wansbeek, Lorenz Willmann, Rob Timmermans, and Klaus Jungmann — KVI, University of Groningen

One single trapped Radium ion is an ideal candidate for an all-optical frequency standard (*clock*). This system provides a long coherence time and tractable systematics. If the ion is laser cooled to the Lamb-Dicke regime, first order Doppler shifts are eliminated. Ultra-narrow transitions in radium ions provide an excellent basis for such a high stability clock, using commercially available semiconductor lasers in the visible regime. In certain odd isotopes of radium, the nuclear electric quadrupole shift is absent [1]. Further, the radium ion is an excellent candidate for a high sensitivity experiment to search for a time variation of the finestructure constant [2].

[1] B.K. Sahoo et al., (to be published) [2] V.A. Dzuba, V.V. Flambaum, Phys. Rev. A 61, 034502 (2000)

A 25.5 Do 16:30 Poster C3

Atomic parity violation in one single trapped radium ion as a probe of electroweak running — •Lotje Wansbeek, Oscar Versolato, Lorenz Willmann, Rob Timmermans, and Klaus Jungmann — KVI, University of Groningen

In a single trapped and laser cooled radium ion we investigate atomic parity violation by probing the differential splitting (*light shifts*) of the 7S and 6D Zeeman levels, which is caused by the interaction of the ion with an off-resonant laser light field. This experiment serves as a low-energy test of the electroweak Standard Model of particle physics. With precision RF spectroscopy and subsequent monitoring of quantum jumps, this splitting can be determined to sub-Hertz accuracy. A proof-of-principle has recently been given for the barium ion, and crucial ideas are being extended to Ra+ which is a superior candidate [1].

[1] J. Sherman et al., Phys. Rev. Lett. 94, 243001 (2005)

A 25.6 Do 16:30 Poster C3

Absolute determination of x-ray transition energies in hydrogen- and heliumlike ions at the Heidelberg EBIT — •Katharina Kubiček[1], Johannes Braun[1], Hjalmar Bruhns[2], José R. Crespo López-Urrutia[1], and Joachim Ullrich[1] — [1]Max-Planck-Institut for Nuclear Physics, Heidelberg, Germany — [2]Columbia Astrophysics Laboratory, New York, USA

Absolute and relative high-precision wavelength measurements on highly charged ions (HCI) using an improved Bond method were carried out at the Heidelberg electron beam ion trap (EBIT). Measuring the Lyman-α_1 transition in Ar^{17+} and "w" ($1s2p\ ^1P_1 \to 1s^2\ ^1S_0$) resonance line in Ar^{16+} resulted in transition energies of 3322.993(16) eV and 3139.588(12) eV. These results are the most precise absolute measurements on transition energies in highly charged ions up to now, with total errors of 5 ppm and 4 ppm. The Lyman-α_1 in S^{15+} and "w"transition energy in S^{14+} yielded 2622.692(27) eV and 2460.629(31) eV . The "w"transition energies were also measured relatively to the Lyman-α_1 transitions. A new method for determination of the Bragg angle making use of two light fiducial beams to determine the incoming direction of the x-rays implemented at the flat crystal spectrometer at our laboratory was applied to increase the precision to the present level.

A 25.7 Do 16:30 Poster C3

Towards Direct Frequency Comb Spectroscopy using Quantum Logic — •Börge Hemmerling, Lukas An der Lan, and Piet O. Schmidt — Institut für Experimentalphysik, Universität Innsbruck, Austria

A possible change of the fine-structure constant over cosmological time scales derived from quasar absorption lines is currently strongly debated. One of the difficulties turns out to be the lack of precise laboratory data on transition lines of elements with a complex level structure such as Ti^+ and Fe^+ [1].

We challenge this problem by developing a versatile experimental setup in which spectroscopy ions are sympathetically cooled by magnesium ions in a linear Paul trap. Using quantum logic techniques, initial state preparation and state detection of the spectroscopy ion can be very efficient. Owing to the complex level structure of these spectroscopy ions, repumping from unwanted states is required. We

plan to implement this by applying an appropriately tailored optical frequency comb.

We will present the latest status of our experimental setup and simulation results on the expected fluorescence signal from a Ca^+ test candidate. We furthermore present schemes based on quantum logic techniques to interrogate single ions in order to further improve the accuracy of the spectroscopic data.

[1] J. C. Berengut, V. A. Dzuba, V. V. Flambaum, M. V. Marchenko and J. K. Webb, arXiv:physics/0408017 (2006)

A 25.8 Do 16:30 Poster C3

Two–photon decay rates for highly–excited ionic states — •Andrey Surzhykov[1,2] and Ulrich D. Jentschura[1] — [1]Max–Planck–Institut für Kernphysik, Heidelberg — [2]École Normale Supérieure, Paris

Even though the two–photon decay of hydrogen–like ions has been under intense investigations for more than a half century, the analysis of this process still raises a number of unresolved problems. The problems concern, for example, the two–photon transition from the excited into the ground state which passes the real intermediate state [1]. Such a transition leads to the narrow *resonances* in the energy spectrum of emitted photons. The proper treatment of these resonances is required for computing the total decay rates obtained after an integration over the energy of one of the emitted photons. In our contribution, therefore, we present a quantum electrodynamical approach based on on a careful mathematical handling of the resonances infinitesimally displaced from the photon integration contour [2]. By making use of this approach, we obtain the finite, physically sensible results for the decay rates of the two–photon $3s \to 1s$ and $4s \to 1s$ transitions in neutral hydrogen as well as in hydrogen–like xenon Xe^{53+} and uranium U^{91+} ions.

[1] J. D. Cresser *et al.*, Phys. Rev. A **33** (1986) 1677.
[2] U. D. Jentschura, J. Phys. A **40** (2007) F223.

A 25.9 Do 16:30 Poster C3

Soft X-ray spectroscopy on highly charged ions — •Thomas Baumann, Sascha Epp, Martin Simon, José R. Crespo López-Urrutia, and Joachim Ullrich — Max-Planck Institut für Kernphysik, Heidelberg, Germany

A flat-field grazing incidence grating spectrometer has been used to study the emission spectra of highly charged ions (HCI) in the soft X-ray region, covering a spectral range from 5 to 40 nm. HCIs were produced and confined at the FLASH-EBIT (Electron Beam Ion Trap), which is capable of preparing ions of essentially any element up to charge states with ionisation energies from 100 eV to 50 keV. In order to improve the spectral resolution beyond our current limits, a new soft X-ray spectrometer has been designed and assembled. It enhances the linear dispersion (and thus the resolution) by a factor of three. These two instruments are ideal not only for spectroscopic diagnostics requiring wide spectral coverage but also for precision wavelength measurements. As an example, measurements at excitation energies between 100 eV and 400 eV covering Xe and Fe in low charge states (XeIX to XeXV, FeVII to FeXV) are presented. The Xe data are particularly relevant for the next generation of semiconductor microlithography devices.

A 25.10 Do 16:30 Poster C3

Two-electron QED contributions to the ground state binding energy in He-like Kr ions — •Paul H. Mokler[1], José R. Crespo López-Urrutia[1], Fred J. Currell[2,3], Nobuyuki Nakamura[3], Shunsuke Ohtani[3], Hiro Tawara[1], Joachim Ullrich[1], and Hiroyuki Watanabe[3] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Queen's University, Belfast BT7 1NN, Northern Ireland, U.K. — [3]University of Electro-Communications, Chofu, Tokyo 182-0021, Japan

The two-electron QED contributions to the ground state binding energy of He-like Kr(34+) ions has been determined in two independent experiments performed with electron beam ion traps (EBIT) in Heidelberg (HD) and Tokyo (BT, Belfast-Tokyo collaboration). X-rays arising from radiative recombination (RR) of free electrons to the ground state of initially bare Kr(36+) and hydrogen-like Kr(35+) ions were observed as a function of the interacting electron energy. The K edge absorption by thin Eu and W foils provided fixed photon energy references used to measure the difference in binding energy, ΔE-2e, between the H- and He-like Kr ions (35+ and 34+, respectively). The two independent measurements agree well, yielding a final result of ΔE-2e = 641.8 (+/-1.7) eV. This value confirms recent theoretical results totally based on rigorous QED calculations. Its accuracy is just of the order required to access screened radiative QED contributions.

A 25.11 Do 16:30 Poster C3

Messung der Polarisation für den radiativen Elektroneneinfang in U^{91+} — •S. Hess, H. Bräuning, C. Brandau, S. Geyer, A. Kumar, R. Märtin, R. Reuschl, U. Spillmann, Th. Stöhlker, M. Trassinelli, S. Trotsenko und G. Weber — GSI, Darmstadt, Germany

Die lineare Polarisation der Röntgenstrahlung beim radiativen Elektroneneinfang (REC) in hochgeladene Schwerionen entzog sich bis vor kurzem experimentellen Studien [1]. Theoretische Untersuchungen zeigen jedoch eine starke Empfindlichkeit der Polarisation auf die Details des Prozesses, so z.B. auf die Spin-Polarisation der beteiligten Teilchen [2]. Wir präsentieren neue Messungen zur Polarisation für den Einfang in die K-Schale und erstmals auch für die j-Unterzustände der L-Schale von U^{91+} Ionen (Energie: 43 MeV/u). Zum Nachweis der Polarisation kam erstmals ein speziell für diesen Zweck entwickeltes Si(Li) Compton-Polarimeter mit einer Ortsauflösung von ca. 2 mm und einer aktiven Fläche von 64×64 mm^2 zum Einsatz. Durch die Kombination von Orts-, Zeit- und Energieauflösung und Multihit-Fähigkeit entspricht das Verhalten dieses Detektors dem eines idealen Compton-Polarimeters. Dies wird durch eine erste Auswertung der Polarisation für den K-REC, die charakteristische K_α-Strahlung sowie durch entsprechende Monte-Carlo Simulationen bestätigt.

[1] S. Tashenov et al., Phys. Rev. Lett. 97 (2006) 223202
[2] J. Eichler und Th. Stöhlker, Pys. Rep. 439 (2007) 1

A 25.12 Do 16:30 Poster C3

Spectroscopy of neutral Radium — •Aran Mol, Subhadeep De, Klaus Jungmann, Hans Wilschut, and Lorenz Willmann — KVI, University of Groningen, Groningen, The Netherlands

The heavy alkaline earth atoms radium is uniquely sensitive towards parity and time reversal symmetry violations due to a large enhancement of an intrinsic permanent electric dipole moment of the nucleous or the electron. Furthermore, radium is sensitive to atomic parity violation and the nuclear anapole moment. To prepare such experiments spectroscopy of relevant atomic states need to be done. At a later stage we will build a neutral atom trap for radium. We have built an atomic beam of the short lived isotope ^{225}Ra with a flux of several 10^4 atoms/sec. We are preparing the laser spectroscopy using this beam setup. In the preparation for efficient laser cooling and trapping we have successfully trapped barium, which is similar in it's requirements for laser cooling. The techniques which we have developed with barium can be used to trap rare radium isotopes. We report on the progress of the experiments.

A 25.13 Do 16:30 Poster C3

Neue Methoden zur Bestimmung der Lamb-Verschiebung in schweren H-artigen Ionen — •Regina Reuschl für die FOCAL-Kollaboration — GSI, Darmstadt, Deutschland — IKF, Universität Frankfurt, Deutschland

Um die Effekte der Quantenelektrodynamik (QED) auf die Grundzustandsbindungsenergie in schweren H-artigen Ionen, sehr genau bestimmen zu können [1], ist ein neuartiges hochpräzises Transmission-Kristallspektrometer, aufgebaut in einer FOcusing Compensated Asymmetric Laue (FOCAL) Geometrie [2], am Experimentierspeicherring (ESR) der GSI in Darmstadt getestet worden. In diesem Beitrag präsentieren wir die Ergebnisse dieses Experimentes. Ziel des Experimentes ist die hochpräzise Bestimmung der Ly-α-Übergänge in H-artigem Pb^{81+}, die durch Stöße mit einem Krypton Gastarget erzeugt werden. Aufgrund der sehr geringen Photoneneffizienz des Spektrometers, lediglich 10^{-8}, sind die Orts- und Energieauflösung eines segmentierten Germanium-Detektors eine notwendige Voraussetzung für eine erfolgreiche Durchführung des Experiments. Durch eine Kollaboration mit dem Forschungszentrum Jülich [3] haben wir ein Detektorsystem mit den gewünschten Eigenschaften erhalten. Die Kombination aus Detektor und Spektrometer erlaubt uns, alle Energien eines interessanten Energiebereiches simultan zu messen.

[1] S. Fritzsche, P. Indelicato, and Th. Stöhlker, J. Phys. B: At. Mol. Opt. Phys. **38**, S707 (2005)
[2] H.F. Beyer et al., Spectrochimica Acta Part B **59**, 1535 (2004)
[3] D. Protić et al., IEEE Trans. Nucl. Sci. **52**, 3194 (2005)

A 25.14 Do 16:30 Poster C3

Bragg-Kristallspektrometrie der $K_{\alpha 1}$- und $K_{\alpha 2}$-

Emissionslinien von Zink — •Renate Märtin[1,2], Martino Trassinelli[1,3,4], Heinrich F. Beyer[1], Ajay Kumar[1], Pierre Planchette[5] und Thomas Stöhlker[1,4] — [1]Gesellschaft für Schwerionenforschung, Darmstadt, Germany — [2]IKF, Universität Frankfurt, Germany — [3]Institut des Nanosciences de Paris, France — [4]Physikalisches Institut, Universität Heidelberg, Germany — [5]École Normale Supérieure de Cachan, Paris, France

Mit einem Bragg-Kristallspektrometer wurden die $K_{\alpha 1}$- und $K_{\alpha 2}$-Linien im Emissionspektrum von Zink mit einer Auflösung von ca. 1 eV bestimmt. $K_{\alpha 1}$- und $K_{\alpha 2}$-Emissionslinien verschiedener Elemente dienen in der Präzisionsspektroskopie als Kalibrierstandards. Eine solch hohe Auflösung erlaubt es, eine Linienanalyse auf dem Niveau einzelner beitragender Komponenten (Satellitenlinien, Linien des entsprechenden Ions nach Auger-Emissionen etc.) durchzuführen. Hochpräzise Daten liegen bereits für benachbarte Atome wie z.B. Kupfer vor [1]. Für Zink und den dazugehörigen Energiebereich von 8,6 keV gibt es bisher keine Messung mit äquivalenter Genauigkeit.

Mit Hilfe einer Röntgenröhre wurde ein Zinkblock bestrahlt ($E = 30$ keV), und das entstandene Fluoreszensspektrum mit einem zylindrisch gekrümmten Germaniumkristall (220) unter einem Winkel von 46° auf eine ortsempfindliche Röntgen-CCD-Kamera abgebildet. Die Daten für Zink werden mit den Referenzmessungen für Kupfer von Deutsch et al. [1] und eigenen Kupfermessungen verglichen.

[1] M. Deutsch *et al.*, Physical Review A **51**, 283 (1995).

A 25.15 Do 16:30 Poster C3

Röntgenspektroskopie an hochgeladenen Schwerionen an der GSI, Darmstadt — •Alexander Mayr[1,2], Bernd Sicherl[1,2], Joachim Jacoby[1,2], Thomas Kühl[2], Olga Rosmej[2], Daniel Zimmer[2], Bernhard Zielbauer[2], Paul Neumayer[2] und Rustam Berezov[1,2] — [1]Institut für Angewandte Physik, Uni Frankfurt — [2]GSI, Darmstadt

Im Rahmen des PHELIX Laser Projekts an der GSI, Darmstadt, wird zur Zeit 7,3 nm Röntgenlaser betrieben, der vom 1kJ-Verstärker des PHELIX-Lasers optisch gepumpt wird. Mit Hilfe des Röntgenlasers soll Spektroskopie an extrem hoch geladenen (Li-ähnlichen) Schwerionen durchgeführt werden. An der GSI stehen hoch geladene Schwerionen bis hin zu Uran zur Verfügung. Diese Kombination aus Schwerionenstrahl und Röntgenlaser erlaubt eine genaue spektroskopische Bestimmung der quantenmechanischen Zustände von Atomkernen. Für Li-ähnliche Ionen liefert die Theorie ausreichend genaue quantenelektrodynamische Modelle, deren Vorhersagen durch Vergleich mit den Ergebnissen des Experimentes überprüft werden können. Der Beitrag beschäftigt sich mit dem experimentellen Konzept und der geplanten Strahlzeit am Experimentierspeicherring ESR. Vorgestellt werden die Ergebnisse der Versuche mit dem 7,3 nm Samarium-Röntgenlaser und der aktuelle Stand der zugehörigen Detektorentwicklung.

A 25.16 Do 16:30 Poster C3

Program package for semi-empirical analysis of the fine- and hyperfine structure of complex atoms — •Jerzy Dembczyński, Jaroslaw Ruczkowski, and Magdalena Elantkowska for the Dembczynski-Collaboration — Chair of Quantum Engineering and Metrology, Poznan University of Technology, Nieszawska 13B, 60-965 Poznan, Poland

The experimental work combined with semi-empirical calculations is a very efficient tool for the investigations of the fine- and hyperfine structure of the complex atoms.

We present a set of programs for the analysis of the fine- and hyperfine structure. The input data for the calculations are : the fine structure energy levels, the g_J-factors and the hyperfine structure (hfs) A and B constants of experimentally observed levels.

The programs are used for the analysis of electron systems containing any number of configurations up to four open shells. In the energy matrix generated, all kinds of electrostatic, magnetic and correlated electrostatic and magnetic interaction, up to second order perturbation theory, were included.

As a result, we obtain predicted energy values for all the levels of the system considered, their exact spectroscopic description and also g_J-factors and hfs A and B constants.

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