

## A 40: Precision spectroscopy of atoms and ions III (with Q)

Time: Friday 11:00–12:45

Location: f428

A 40.1 Fri 11:00 f428

**Spectroscopy of hyperfine structures and isotope shifts in the sequence of 97-99 technetium** — ●TOBIAS KRON<sup>1</sup>, REINHARD HEINKE<sup>1</sup>, SEBASTIAN RAEDER<sup>2</sup>, TOBIAS REICH<sup>3</sup>, PASCAL SCHÖNBERG<sup>3</sup>, and KLAUS WENDT<sup>1</sup> — <sup>1</sup>Institute of Physics, Mainz University — <sup>2</sup>GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — <sup>3</sup>Institute of Nuclear Chemistry, Mainz University

One of the dominant fission products of uranium is technetium-99, which is generally extremely rare in nature, due to the fact that all isotopes are unstable. With a long half-life and its strong  $\beta^-$ -radioactivity, <sup>99</sup>Tc is one of the major radiotoxic long-term remnants of nuclear reactors and atomic bombs. On the other hand, knowledge on atomic and nuclear properties of technetium isotopes is rather scarce due to their rare occurrence. Both, ultra-trace determination as well as investigations of nuclear structure are of relevance and require extensive atomic spectroscopy as input.

This talk presents first results of high resolution resonance ionization spectroscopy on the isotopes <sup>97–99</sup>Tc. Measurements were carried out on smallest samples in the order of  $10^{12}$  atoms or less, using a high repetition rate laser system. The hyperfine structures and isotope shifts of several transitions were investigated, giving new information on nuclear structure and deriving the so-far unclear nuclear spin of <sup>98</sup>Tc. Experimental linewidths around 100 MHz were achieved by using a frequency-doubled pulsed injection-locked titanium:sapphire laser in combination with a newly developed ion source with a perpendicular laser-atom beam geometry in a radiofrequency quadrupole structure.

A 40.2 Fri 11:15 f428

**Identification of the splitting and sequence of closely-spaced energy levels by analyzing the angle-resolved fluorescence light** — ●ZHONGWEN WU<sup>1,2</sup>, ANDREY SURZHYKOV<sup>1</sup>, ANDREY VOLOTKA<sup>1</sup>, and STEPHAN FRITZSCHE<sup>1,3</sup> — <sup>1</sup>Helmholtz Institute Jena, Germany — <sup>2</sup>Northwest Normal University, China — <sup>3</sup>University of Jena, Germany

The energy-dependent photoexcitation and subsequent fluorescence radiation of atoms have been investigated within the framework of second-order perturbation theory and the density matrix theory. Special attention has been paid to the angular distribution of the characteristic x-rays from (partial) overlapping resonances and how they are affected by the level splitting and the sequence of these resonances, if analyzed as a function of the photon energy of the exciting light. Detailed computations within the multiconfiguration Dirac-Fock method were carried out for the  $1s^2 2s^2 2p^6 3s$   $J_0 = 1/2 + \gamma_1(\hbar\omega) \rightarrow (1s^2 2s 2p^6 3s)_{13p_{3/2}}$   $J = 1/2, 3/2 \rightarrow 1s^2 2s^2 2p^6 3s$   $J_f = 1/2 + \gamma_2$  excitation and decay of neutral sodium atoms. A remarkably strong dependence of the angular distribution of these x-rays upon the level splitting and even the sequence was found by crossing the resonances. This dependence arises from the finite lifetime of the overlapping resonances. We therefore suggest that accurate measurements of x-ray angular distribution could be used to identify the level splitting and sequence of closely-spaced atomic resonances following inner-shell excitations.

A 40.3 Fri 11:30 f428

**Precision isotope shift measurements of calcium ions using photon recoil spectroscopy** — FLORIAN GEBERT<sup>1</sup>, YONG WAN<sup>1</sup>, FABIAN WOLF<sup>1</sup>, JAN-CHRISTOPHE HEIP<sup>1</sup>, ●CHUNYAN SHI<sup>1</sup>, CHRISTIAN GORGES<sup>2</sup>, SIMON KAUFMANN<sup>2</sup>, WILFRIED NÖRTERSCHÄUSER<sup>2</sup>, and PIET O. SCHMIDT<sup>1,3</sup> — <sup>1</sup>QUEST Institut, PTB, Braunschweig, Germany — <sup>2</sup>Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany — <sup>3</sup>Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

In photon recoil spectroscopy (PRS), recoil kicks from photon absorption near a dipole-allowed transition in a single trapped ion are detected via motional coupling to a co-trapped cooling ion [1].

We present isotope shift measurements of the  $^2S_{1/2} \rightarrow ^2P_{1/2}$  (D1 line),  $^2D_{3/2} \rightarrow ^2P_{1/2}$  (non-closed transition) [2] and  $^2S_{1/2} \rightarrow ^2P_{3/2}$  (D2 line) transitions in the calcium isotopes  $^{40}\text{Ca}^+$ ,  $^{42}\text{Ca}^+$ ,  $^{44}\text{Ca}^+$  and  $^{48}\text{Ca}^+$  with an accuracy better than 100 kHz by employing the PRS technique. Furthermore, the isotope shift difference between the D1 and D2 line of calcium ions has been resolved for the first time. As a result from the precision isotope shift measurements, the uncer-

tainties of the relative field and mass shift constants in the respective transitions as well as the mean square nuclear charge radii of these calcium isotopes have been improved.

[1] Y. Wan et al. Nat. Commun **5**, 4096 (2014)[2] F. Gebert et al. Phys. Rev. Lett. **115**, 053003(2015)

A 40.4 Fri 11:45 f428

**A tunable laser with a drift <100 kHz through stabilization to the Rb D2 line** — ●TOBIAS LEOPOLD<sup>1</sup>, LISA SCHMÖGER<sup>1,2</sup>, STEFANIE FEUCHTENBEINER<sup>2</sup>, NILS SCHARNHORST<sup>1</sup>, IAN D. LEROUX<sup>1</sup>, JOSÉ R. CRESPO LÓPEZ-URRUTIA<sup>2</sup>, and PIET O. SCHMIDT<sup>1,3</sup> — <sup>1</sup>Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — <sup>2</sup>Max-Planck-Institut für Kernphysik, 69117 Heidelberg — <sup>3</sup>Institut für Quantenoptik, Universität Hannover

Stable lasers with a narrow linewidth are an important tool for precision spectroscopy. Here, we present a simple and versatile laser system for spectroscopy of trapped highly charged ions at sub-Kelvin temperatures. While covering the wavelength range from 780 - 890 nm we reach a linewidth and long-term frequency drift on the 50 kHz level, corresponding to a fractional instability of  $< 1 \times 10^{-10}$ .

As frequency reference we use a low-cost 780 nm DFB-laser stabilized to a hyperfine transition of the rubidium D2 line by modulation transfer spectroscopy. The stability of this laser is transferred to the spectroscopy laser by use of an optical reference cavity. Tunability over 1.5 GHz in closed-loop operation is possible by means of the off-set sideband locking technique. We measure the instability of both reference and spectroscopy laser against a Maser-stabilized frequency comb.

The laser system presented here will be used for spectroscopy of the  $1s^2 2s^2 2p^2 P_{1/2} - ^2P_{3/2}$  transition in trapped Ar<sup>13+</sup> ions at 441 nm. Sympathetically cooled in a laser cooled cloud of beryllium ions the 100 Hz natural linewidth is expected to be Doppler broadened to several 100 kHz.

A 40.5 Fri 12:00 f428

**The ALPHATRAP double Penning-trap experiment** — ●IOANNA ARAPOGLOU<sup>1,2</sup>, ALEXANDER EGL<sup>1,2</sup>, HENRIK HIRZLER<sup>1,2</sup>, SANDRO KRAEMER<sup>1,2</sup>, TIM SAILER<sup>1,2</sup>, ANDREAS WEIGEL<sup>1,2</sup>, ROBERT WOLF<sup>1</sup>, SVEN STURM<sup>1</sup>, and KLAUS BLAUM<sup>1</sup> — <sup>1</sup>Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — <sup>2</sup>Fakultät für Physik und Astronomie, Universität Heidelberg

The ALPHATRAP experiment, being a follow-up of the  $g$ -factor experiment at Mainz, aims for high-precision tests of bound-state quantum electrodynamics in electric fields with strengths in the order of  $10^{16}$  V/cm. These fields are provided by heavy highly charged ions, such as hydrogen-like  $^{208}\text{Pb}^{81+}$ . Furthermore, via the high-precision determination of the bound electron  $g$ -factor, fundamental constants such as the fine-structure constant  $\alpha$  can be determined. The Heidelberg Electron-Beam Ion Trap delivers the desired heavy highly charged ions, which are injected into and manipulated by means of the ALPHATRAP cryogenic double Penning-trap system. The latter is optimised for heavy highly charged ions and consists of a 7-pole and a 5-pole cylindrical Penning trap that are used for high-precision measurements and spin orientation detection, respectively. This configuration together with the measurement principle and the current status of the experiment will be presented.

A 40.6 Fri 12:15 f428

**Towards Electron Affinity Measurements of Radioactive Elements: Laser Photodetachment of Negative Ions at CERN/ISOLDE** — SEBASTIAN ROTHE<sup>2,3,5</sup>, ●REINHARD HEINKE<sup>1</sup>, VALENTIN FEDOSSEEV<sup>2</sup>, THOMAS DAY GOODACRE<sup>2,5</sup>, DAG HANSTORP<sup>3</sup>, TOBIAS KRON<sup>1</sup>, YUAN LIU<sup>4</sup>, BRUCE MARSH<sup>2</sup>, ANNIE RINGWALL-MOBERG<sup>3</sup>, RALF ERIK ROSSEL<sup>2</sup>, JULIA SUNDBERG<sup>3</sup>, JAKOB WELANDER<sup>3</sup>, and KLAUS WENDT<sup>1</sup> — <sup>1</sup>JGU Mainz — <sup>2</sup>EN Department, CERN — <sup>3</sup>University of Gothenburg — <sup>4</sup>Oak Ridge National Laboratory — <sup>5</sup>University of Manchester

Modern on-line isotope separators such as ISOLDE at CERN yield access to a wide variety of exotic nuclei. Besides investigations on nuclear properties of rare isotopes, these facilities allow for detailed studies on the fundamental atomic structures of the few all-radioactive elements across the Periodic Table. In this respect, two values are of elementary

importance: (a) The first ionization potential (IP), i.e. the required energy to remove an electron from the neutral atom and produce a positively charged ion, and (b) the electron affinity (EA), i.e. the binding energy of an extra electron to form a negatively charged ion. For all-radioactive elements, their knowledge is even more relevant, as they are required as input for quantum chemical calculations on the behaviour within chemical compounds. Whereas the IPs of the all-radioactive elements Polonium and Astatine were precisely measured at ISOLDE via Rydberg spectroscopy recently, the EAs of these elements are still under investigation.

The talk will give an overview of the experimental setup as well as on the measurement technique, applying laser photodetachment spectroscopy with a high performance, high repetition rate tuneable laser system. First results on iodine carried out on a negative ion beam at ISOLDE are discussed together with alternatives for negative ion production at ISOLDE and an outlook on the envisaged experiments.

A 40.7 Fri 12:30 f428

**Resonance ionization studies in holmium and a redetermination of its ionization potential** — •PASCAL NAUBEREIT<sup>1</sup>, YUAN LIU<sup>2</sup>, TINA GOTTWALD<sup>1</sup>, and KLAUS WENDT<sup>1</sup> — <sup>1</sup>Institute of Physics, Mainz University, D-55128 Mainz, Germany — <sup>2</sup>Physics

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The first ionization potential of Holmium as well as many other lanthanides was measured around 1978 with rather big uncertainties in the order of  $5 \text{ cm}^{-1}$  using early methods of laser spectroscopy. Values that are much more precise are obtained by using two or three step resonance ionization spectroscopy via high lying Rydberg states and applying detailed analyses of convergence limits of different Rydberg series.

Here we report on three step resonance ionization measurements into  $6snp$  levels with principal quantum numbers  $17 < n < 59$  converging towards the two lowest members of the ionic ground state configuration. Strong interactions with interloper states, well known for most of the lanthanides, perturb the Rydberg series below the first IP for Ho. In contrary the auto-ionizing Rydberg series, observed just above the first ionization potential, exhibits a smooth behavior in the studied range from  $33 < n < 57$ . Correspondingly, the latter was used to reevaluate the first ionization potential of Holmium with an uncertainty of better than  $0.1 \text{ cm}^{-1}$ . The spectroscopic measurements, which also led to the identification of a new efficient resonant excitation scheme for holmium isotope implantation within the ECHO project, as well as the Rydberg analysis are discussed.