A 22: Highly Charged Ions and their Applications I

Time: Wednesday 14:30–16:30 Location: HS 1098

A 22.1 Wed 14:30 HS 1098

Quantum-logic based search techniques for highly forbidden transitions in highly charged ions — •Shuying Chen[1], Lukas J. Spiess[1], Alexander Wilzewski[1], Malte Wehrheim[1], Kai Dietze[1], Ivan Vybornyi[2], Klemens Hammerer[2], José R. Crespo López-Urrutia[3], and Piet O. Schmidt[1,4] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institute of Theoretical Physics, Leibniz Universität Hannover, Hannover, Germany — [3]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

Optical clocks are the most precise measurement devices, finding application in frequency metrology and fundamental physics. Highly charged ions (HCI) are promising candidates as a reference in optical clocks. To establish a next-generation HCI optical clock at the state-of-the-art precision, an HCI possessing a sub-Hz natural linewidth transition is required. Numerous candidate systems have been explored theoretically but experimental challenges remain due to the considerable uncertainty of the transition frequencies. In this work, we perform experimental and theoretical analysis of search techniques based on a two-ion crystal system confined within a linear Paul trap, with the goal of identifying ultra-narrow transitions in HCI. These techniques include Rabi excitation, the optical dipole force (ODF), and linear continuous sweeping (LCS).

A 22.2 Wed 14:45 HS 1098

Towards optical spectroscopy of highly charged californium ions in preparation for a Cf15+/17+ ion clock — •Lakshmi Priya Kozhiparambil Sajith[1,4], Nils Holger Rehbehn[2], Michael Karl Rosner[2], Kostas Georgiou[3], Leo Prokhorov[3], Aaron Smith[3], Luis Hellmich[4], Ullrich Schwanke[4], Giovanni Barontini[3], José Ramon Crespo López-Urrutia[2], and Steven Worm[1,4] — [1]Deutsches Elektronen Synchrotron (DESY), Platanenallee 6, 15738 Zeuthen , Germany — [2]Max Planck Institut für Kernphysik, Saupfercheckweg 1, Heidelberg, Germany — [3]School of Physics and Astronomy, University of Birmingham, Edgbaston Park Rd, Birmingham B15 2TT, United Kingdom — [4]Humbolt Universität zu Berlin, Unter den Linden 6, 10117 Berlin , Germany

Highly charged Cf ions are a very good candidate for investigating possible variations in fundamental constants owing to its high sensitivity coefficient, in particular, of the fine structure constant. For the construction of a Cf15+ or Cf17+ optical clock, Cf atoms, ablated from a source with a laser, are fed into an electron beam ion trap (EBIT) where highly charged Cf ions are produced, which are then transported through a beam line where they are bunched and pre-cooled and finally trapped in a Coulomb crystal of Ca ions in a cryogenic Paul trap. For the determination of the clock transition for the highly charged Cf ion clock, optical spectroscopy will be performed in an electron beam ion trap. The experimental set-up, including the complexities of the injection of californium atoms, and some preliminary results will be presented.

A 22.3 Wed 15:00 HS 1098

Resistive cooling of ions' center-of-momentum energy in a Penning trap on milli-second time scales — •Markus Kiffer[1], Stefan Ringleb[1], Manuel Vogel[3], and Thomas Stöhlker[1,2,3] — [1]Friedrich Schiller-Universität Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt, Germany

Resistive cooling is a well-established technique to cool the axial motion of ions in a Penning trap. It is especially efficient for large ensembles as the cooling rate scales linearly with the number of ions. Such a fast rate is necessary to quickly create a dense ion cloud for laser experiments at the HILITE experiment. However, this fast rate is only expected for the collective motion of the ion cloud, which decays quickly due to trap anharmonicities.

In our setup the ion bunches are produced by a dedicated ion source and trapped directly in a harmonic potential. This means the ions have a significant collective motion and are immediately in resonance with the cooling circuit, which allows the prompt measurement after trapping. We present measured cooling curves of the collective cloud motion for a controlled ion number and verify that the measured rate is proportional to the number of trapped ions. Using an effective energy model we model the measured curve and extract both the resistive cooling rate and the dephasing rate. Currently, we trap several thousand Ne^{8+} ions, which results in a collective cooling time on the order of 10 ms.

A 22.4 Wed 15:15 HS 1098

Laser spectroscopy of hydrogen-like $^{208}Bi^{82+}$ — •Rodolfo Sánchez for the LIBELLE-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany

We report the first successful measurement of the 1s hyperfine splitting of the high-Z radioactive ion $^{208}Bi^{82+}$. The experiment was performed at GSI, the facility for heavy ion research, where these exotic ions were produced in flight and stored in the experimental storage ring (ESR) at a velocity of 72% of the speed of light. At this speed, the Doppler shift transforms the visible laser light into the far ultraviolet range required to drive the hyperfine-transition in $^{208}Bi^{82+}$.

The observation of this hyperfine line is a very important step towards the determination of the so-called "specific difference", a weighted difference between the hyperfine transition energies in hydrogen-like and lithium-like ions that eliminates uncertainties due to the nuclear magnetic moment distribution [1]. At this point, only the specific difference provides the means to test QED in the strongest magnetic fields available in the laboratory and has been determined so far exclusively for the stable isotope ^{209}Bi [2,3].

[1] V. M. Shabaev, et al., Phys. Rev. Lett. 86, 3959 (2001).
[2] J. Ullmann, et al., Nature Comm. 8, 15484 (2017).
[3] L. V. Skripnikov, et al. Phys. Rev. Lett. 120, 093001 (2018).

A 22.5 Wed 15:30 HS 1098

S-EBIT II, first commissioning results — •Tino Morgenroth[1,2,3], Sonja Bernitt[1,2,3], Rex Simon[1,2,3], Sergiy Trotsenko[2], Reinhold Schuch[1,4], and Thomas Stöhlker[1,2,3] — [1]Helmholtz Institute Jena, 07743 Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [3]IOQ, Friedrich-Schiller-University Jena, 07743 Jena, Germany — [4]Department of Physics, Stockholm University, 106 91 Stockholm, Sweden

The demand for beamtime at GSI facilities like ESR, CRYRING or HITRAP has increased over the last years and can not be fully covered by the GSI accelerator infrastructure. Local ion sources play an important role in closing this gap and allowing for *offline operation* of experiments at GSI.

Electron Beam Ion Traps (EBITs) are widely known as a versatile tool for spectroscopic studies of partially ionized atomic systems. Furthermore, they can be used as small stand-alone ion sources, capable of producing beams of heavy highly-charged ions of a certain charge state at reasonable intensities.

The S-EBIT II is currently under commissioning for operation as a facility for x-ray spectroscopy and as a standalone ion source for HITRAP. This will provide new opportunities for local experiments independently from the GSI accelerator infrastructure. Examples are the ARTEMIS experiment and the upcoming cryogenic paul trap for quantum logic spectroscopy. As a first step towards completing commissioning, we carried out DR measurements with argon.

A 22.6 Wed 15:45 HS 1098

Precision spectroscopy of highly charged ions in the ARTEMIS Penning trap for electron g-factor measurements at HITRAP — •Arya Krishnan[1,2], Bianca Reich[1,3], Johannes Krempel-Hesse[4], Kanika Kanika[1,3], Jeffrey W. Klimes[1], Khwaish K. Anjum[1,5], Patrick Baus[2], Gerhard Birkl[2], Manuel Vogel[1], and Wolfgang Quint[1,3] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Germany — [2]Technical University of Darmstadt, Germany — [3]University of Heidelberg, Germany — [4]University of Giessen, Germany — [5]University of Jena, Germany

The ARTEMIS experiment at the HITRAP facility situated at GSI focuses on precision measurements of electron magnetic moments in highly charged ions. Ions are currently produced inside the cryogenic Penning trap of the experiment [Kanika et al., J. Phys. B 56, 175001 (2023)] and are prepared and cooled using non-destructive techniques

[Ebrahimi et al., Phys. Rev. A 98, 023423 (2018)]. Electron magnetic moments (g-factor) will be measured using the laser-microwave double-resonance spectroscopy on the desired few-electron ions stored in the trap. The connection to the HITRAP beamline and upgrades for dynamic capture and storage of ions from external sources enables this method to be applied to hydrogen-like heavy species such as Bi82+ and other lighter species such as S11+. The half-open design of the trap allows optical access which in turn facilitates microwave probing of the Larmor frequency through laser spectroscopy of fine/hyperfine structure of the ions. We present the current status of the experiment.

A 22.7 Wed 16:00 HS 1098

Analyzing heavy elemental polyatomic molecular ions for tests of fundamental physics — •Carsten Zülch, Konstantin Gaul, Steffen M. Giesen, and Robert Berger — Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Straße 4, 35032 Marburg, Germany

Recently, we proposed diatomic highly charged molecular ions for precision tests of fundamental physics [1]. These provide unique, compressed electronic spectra — an effect which can be exploited in the search for a spatio-temporal variation of fundamental constants —, long trapping times and sympathetical coolability [2]. Polyatomic molecules possess more internal degrees of freedom and can exhibit internal comagnetometer states as well as internally broken symmetries [3,4]. Thus, polyatomic molecular ions promise to advance quantum information sciences, cold chemistry and collisions, high precision spectroscopy and therewith the search for symmetry violation beyond the Standard Model. In this contribution we investigate a multitude of polyatomic molecular ions in respect of their electronic structure, spectroscopic constants and enhancement factors of symmetry violating properties in a broken-symmetry quasirelativistic mean-field ansatz such as $PaNC^{3+}$ or $PaNCS^{3+}$. We subsequently account for electron correlation using two-component many-body perturbation theory.

[1] Zülch, Gaul, Giesen, Garcia Ruiz, Berger, *arXiv* 2203.10333.
[2] Zülch, Gaul, Berger, *Isr. J. Chem.* 2023, 63, e202300035.
[3] Isaev, Berger, *PRL* 2016, 116; Kozyryev et al., *JPB* 2016, 49.
[4] Isaev et al., *JPB* 2017, 50; Kozyryev et al., *PRL* 2017, 119.

A 22.8 Wed 16:15 HS 1098

Cooling of heavy highly charged ions: The HITRAP-Penning Trap — •Dimitrios Zisis for the Hitrap-Collaboration — GSI Helmholtzzentrum für Schwerionenforschung, Germany — Technical University of Darmstadt, Germany

For conducting high-precision experiments at low energies and small energy distributions, heavy and highly charged ions (HCI) need to be decelerated and cooled, which is the aim of the HITRAP facility. It is situated at the GSI Helmholtzzentrum für Schwerionenforschung, where a wide range of HCI can be provided. Its unique capability to decelerate and cool HCI, not only enables easier ion storage and manipulation but also further transport towards attached experiments.

At HITRAP, HCI are decelerated in a two-step process from 4 MeV/u to 6 keV/u before being captured in a Penning trap for electron cooling. This cooling process precedes the subsequent ejection of ions, facilitating their transport to various precision experiments.

We present the latest successful outcomes in electron cooling of HCI. Despite the observed reduction in ion energy, a detailed investigation of systematic effects has yet to be carried out. Future steps involve the optimization of the cooling process including more advanced detection methods and further systematic studies.