Q 7: Precision spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 14:00–15:30 Location: A-H2

Q 7.1 Mon 14:00 A-H2

Sympathetic cooling of macroscopically separated ions via image-current coupling — •Christian Will[1], Matthew Bohman[1,2], Markus Wiesinger[1,2], Fatma Abbass[4], Jack Devlin[2,7], Stefan Erlewein[2,7], Markus Fleck[2,8], Julia Jäger[1,7], Barbara Latacz[2], Peter Micke[7], Andreas Mooser[1], Daniel Popper[4], Elise Wursten[1,2,7], Klaus Blaum[1], Yasuyuki Matsuda[8], Christian Ospelkaus[5,6], Wolfgang Quint[9], Jochen Walz[3,4], Christian Smorra[2,4], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernphysik — [2]RIKEN — [3]Helmholtz-Institut Mainz — [4]Johannes Gutenberg-Universität Mainz — [5]Leibniz Universität Hannover — [6]Physikalisch-Technische Bundesanstalt — [7]CERN — [8]University of Tokyo — [9]GSI Helmholtzzentrum für Schwerionenforschung GmbH

A general-purpose cooling technique that achieves mK-temperatures for species without suitable laser transitions is of interest for a wide range of AMO experiments with trapped charged particles. We present recently published results on sympathetically cooling a single proton in a Penning trap with laser-cooled beryllium ions located in a different trap (Bohman et al., Nature, 2021). Coupling is achieved via image currents induced in adjacent trap electrodes, allowing a macroscopic separation between the two species. This techniques allows cooling of any trapped charged particle, with a particular focus on exotic species such as antimatter or highly-charged ions.

This talk will cover the most recent experimental results as well as future prospects based on simulation work.

Q 7.2 Mon 14:15 A-H2

Implementing Sympathetic Laser Cooling and a Josephson Junctions based Voltage Source for the Measurement of the Nuclear Magnetic Moment of ^{3}He^{2+} — •Annabelle Kaiser[1], Antonia Schneider[1], Andreas Mooser[1], Stefan Dickopf[1], Marius Müller[1], Alexander Rischka[1], Stefan Ulmer[2], Jochen Walz[3], and Klaus Blaum[1] — [1]Max-Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]RIKEN, Wako, Japan — [3]Johannes Gutenberg-University and Helmholtz-Institute, Mainz, Germany

The Heidelberg 3He-experiment is aiming at the first direct high-precision measurement of the nuclear magnetic moment of ^{3}He^{2+}, with a relative uncertainty on the 10^{-9} level. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized 3He-NMR-probes for absolute magnetometry.

The measurement is performed using a cryogenic four Penning-trap setup, with techniques presented in [1]. To achieve the mandatory frequency stability for spin-state detection, a single ^{3}He^{2+} ion will be prepared at temperatures of a few mK via sympathetic laser cooling with ^{9}Be$^+$. To further improve the stability, the noise generated by the voltage sources applied to the trap electrodes can be reduced by implementing Josephson junctions as a voltage source. The tuning will be achieved by switching a low-noise DAC in series to the Josephson junctions, aiming at an absolute voltage stability better than 70nV over two minutes. The setup and status of the project will be presented.

[1] Mooser et al, J. Phys.: Conf. Ser. 1138 012004 (2018)

Q 7.3 Mon 14:30 A-H2

High-precision measurement of the hyperfine structure of ^{3}He$^+$ in a Penning trap — •Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Marius Müller[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor Valuev[1], Stefan Ulmer[2], Jochen Walz[3,4], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan — [3]Institute for Physics, Johannes Gutenberg-University Mainz, Staudinger Weg 7, D-55099 Mainz, Germany — [4]Helmholtz Institute Mainz, Staudingerweg 18, D-55128 Mainz, Germany

We investigated the ground-state hyperfine structure of a single ^{3}He$^+$ ion in a Penning trap to directly measure the zero-field hyperfine splitting, the bound electron g-factor and the nuclear g-factor with a relative precision of $3 \cdot 10^{-11}$, $2 \cdot 10^{-10}$ and $8 \cdot 10^{-10}$, respectively. The latter allows for the determination of the g-factor of the bare nucleus with a relative precision of $8 \cdot 10^{-10}$ via our accurate calculation of the diamagnetic shielding constant. This constitutes the first direct calibration for ^{3}He nuclear magnetic resonance (NMR) probes and an improvement of the precision by one order of magnitude compared to previous indirect results [1]. The measured zero-field hyperfine splitting allows us to determine the Zemach radius, which characterizes the electric and magnetic form factors, with a relative precision of $7 \cdot 10^{-3}$.

[1] Y. I. Neronov and N. N. Seregin, Metrologia, **51** (2014) 54.

Q 7.4 Mon 14:45 A-H2

Optimal laser cooling of a single ion in a radiofrequency trap — •Daniel Vadlejch[1], André Kulosa[1], Henning Fürst[1,2], Oleg Prudnikov[3], and Tanja Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Institute of Laser Physics, 630090, Novosibirsk, Russia

We present a systematic study of quench cooling of a single ion trapped in a linear radiofrequency (RF) Paul trap. In our experiments, a narrow electronic quadrupole transition near 411 nm in ^{172}Yb$^+$ is used for resolved sideband cooling [1]. The cooling transition is effectively quench-broadened by means of a laser at 1650 nm, coupling the excited state of the transition to a higher-lying, fastly decaying state. We control the broadening via the intensity of the quenching field and distinguish different regimes of laser cooling. We show optimum cooling parameters for rapid cooling towards the motional ground state of the trap and discuss their impact on the population distribution of Fock states during the cooling process. The presented work builds the fundament for further multi-ion experiments, e.g, using large mixed-species crystals with different cooling properties for optical clocks [2].

[1] D. Kalincev et al., *Quantum Sci. Technol.* **6**, 034033 (2021).
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019).

Q 7.5 Mon 15:00 A-H2

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •C. M. König[1], F. Heisse[1], J. Morgner[1], T. Sailer[1], B. Tu[1,2], K. Blaum[1], S. Schiller[3], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institute of Modern Physics, Fudan University, Shanghai 200433 — [3]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. We plan to perform high-precision spectroscopy on single MHI in the Penning-trap setup of Alphatrap [1], initially focusing on the hyperfine structure of HD$^+$. This will allow extracting the bound g factors of the constituent particles and coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision ab initio theory [2] and are important for a better understanding of rovibrational spectroscopy performed on this ion.
In the future, we aim to extend our methods to single-ion rovibrational laser spectroscopy of H_2^+ enabling the ultra precise determination of fundamental constants, such as $m_{\mathrm{p}}/m_{\mathrm{e}}$ [3]. The development of the required techniques will be an important step towards spectroscopy of an antimatter $\overline{H}_2^-$ ion [4]. In this contribution, I will present an overview of the experimental setup and first measurement results of the hyperfine structure of HD$^+$.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] J.-Ph. Karr, *et al.* Phys. Rev. A **102**, 052827 (2020)
[3] J.-Ph. Karr, *et al.*, Phys. Rev. A **94**, 050501(R) (2016)
[4] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

Q 7.6 Mon 15:15 A-H2

Enhanced Dipolar Interactions — •Artur Skljarow[1], Benyamin Shnirman[1], Xiaoyu Cheng[1], Charles S. Adams[2], Tilman Pfau[1], Robert Löw[1], and Hadiseh Alaeian[3] — [1]5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, Germany — [2]JQC Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, United Kingdom — [3]Department of Physics & Astronomy, Purdue Quantum Science & Engineering Institute, Purdue University, West Lafayette, IN, USA

The interest in nonlinear quantum optics based on strong photon-photon interactions continuously grows with time as it might lead to an all-optical quantum network.

Atoms aligned in a 1D chain or 2D lattice show stronger interactions than in an arbitrary 3D arrangement as they exchange photons in a favored direction. A wide variety of ultracold experiments makes use of this fact by trapping individual atoms in 1D or 2D optical traps or tweezers and probing their interaction with a free-space laser beam. In contrast to the ultracold experiments, here we create confined 1D light fields, well below the diffraction limit, with engineered nanophotonic devices and immerse them in a thermal cloud of atoms. As a result, we observe the first realization of repulsive blue-shifted dipole-dipole interactions in a thermal vapor. Additionally, we demonstrate the power of nanophotonics by boosting those interactions by almost one order of magnitude via a Purcell modification hence, creating a highly nonlinear medium.