

A 3: Precision spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 14:00–15:30

Location: A-H2

A 3.1 Mon 14:00 A-H2

Sympathetic cooling of macroscopically separated ions via image-current coupling — ●CHRISTIAN WILL¹, MATTHEW BOHMAN^{1,2}, MARKUS WIESINGER^{1,2}, FATMA ABBASS⁴, JACK DEVLIN^{2,7}, STEFAN ERLEWEIN^{2,7}, MARKUS FLECK^{2,8}, JULIA JÄGER^{1,7}, BARBARA LATA CZ², PETER MICKE⁷, ANDREAS MOOSER¹, DANIEL POPPER⁴, ELISE WURSTEN^{1,2,7}, KLAUS BLAUM¹, YASUYUKI MATSUDA⁸, CHRISTIAN OSPELKAUS^{5,6}, WOLFGANG QUINT⁹, JOCHEN WALZ^{3,4}, CHRISTIAN SMORRA^{2,4}, and STEFAN ULMER² — ¹Max-Planck-Institut für Kernphysik — ²RIKEN — ³Helmholtz-Institut Mainz — ⁴Johannes Gutenberg-Universität Mainz — ⁵Leibniz Universität Hannover — ⁶Physikalisch-Technische Bundesanstalt — ⁷CERN — ⁸University of Tokyo — ⁹GSF 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 technique 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.

A 3.2 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 ${}^3\text{He}^{2+}$ — ●ANNABELLE KAISER¹, ANTONIA SCHNEIDER¹, ANDREAS MOOSER¹, STEFAN DICKOPF¹, MARIUS MÜLLER¹, ALEXANDER RISCHKA¹, STEFAN ULMER², JOCHEN WALZ³, and KLAUS BLAUM¹ — ¹Max-Planck Institute for Nuclear Physics, Heidelberg, Germany — ²RIKEN, Wako, Japan — ³Johannes 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 ${}^3\text{He}^{2+}$, 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 ${}^3\text{He}^{2+}$ ion will be prepared at temperatures of a few mK via sympathetic laser cooling with ${}^9\text{Be}^+$. 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)

A 3.3 Mon 14:30 A-H2

High-precision measurement of the hyperfine structure of ${}^3\text{He}^+$ in a Penning trap — ●ANTONIA SCHNEIDER¹, BASTIAN SIKORA¹, STEFAN DICKOPF¹, MARIUS MÜLLER¹, NATALIA S. ORESHKINA¹, ALEXANDER RISCHKA¹, IGOR VALUEV¹, STEFAN ULMER², JOCHEN WALZ^{3,4}, ZOLTAN HARMAN¹, CHRISTOPH H. KEITEL¹, ANDREAS MOOSER¹, and KLAUS BLAUM¹ — ¹Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117, Heidelberg, Germany — ²RIKEN, Ulmer Fundamental Symmetries Laboratory, 2-1 Hiroosawa, Wako, Saitama, 351-0198, Japan — ³Institute for Physics, Johannes Gutenberg-University Mainz, Staudinger Weg 7, D-55099 Mainz, Germany — ⁴Helmholtz Institute Mainz, Staudingerweg 18, D-55128 Mainz, Germany

We investigated the ground-state hyperfine structure of a single ${}^3\text{He}^+$ 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 ${}^3\text{He}$ 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.

A 3.4 Mon 14:45 A-H2

Optimal laser cooling of a single ion in a radiofrequency trap — ●DANIEL VADLEJCH¹, ANDRÉ KULOSA¹, HENNING FÜRST^{1,2}, OLEG PRUDNIKOV³, and TANJA MEHLSTÄUBLER^{1,2} — ¹Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — ²Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — ³Institute 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 ${}^{172}\text{Yb}^+$ 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).

A 3.5 Mon 15:00 A-H2

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at ALPHATRAP — ●C. M. KÖNIG¹, F. HEISSE¹, J. MORGNER¹, T. SAILER¹, B. TU^{1,2}, K. BLAUM¹, S. SCHILLER³, and S. STURM¹ — ¹Max-Planck-Institut für Kernphysik, 69117 Heidelberg — ²Institute of Modern Physics, Fudan University, Shanghai 200433 — ³Institut 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_p/m_e [3]. The development of the required techniques will be an important step towards spectroscopy of an antimatter $\bar{\text{H}}_2^-$ 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)

A 3.6 Mon 15:15 A-H2

Enhanced Dipolar Interactions — ●ARTUR SKLJAROW¹, BENYAMIN SHNIRMAN¹, XIAOYU CHENG¹, CHARLES S. ADAMS², TILMAN PFAU¹, ROBERT LÖW¹, and HADISEH ALAEIAN³ — ¹5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, Germany — ²JQC Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, United Kingdom — ³Department 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.