A 33: Precision Spectroscopy of Atoms and Ions V (joint session A/Q)

Time: Thursday 14:30–16:30 Location: N 3

A 33.1 Thu 14:30 N 3

Indium multi-ion clock operation and investigations of ground state cooling — •Shobhit Saheb Dey[1], Ingrid Maria Richter[1], Mouhamed-Omar Manai[1], Hartmut Nimrod Hausser[1], Dongliang Cong[1], Jonas Keller[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Institut für Quantenoptik, Leibniz Universität Hannover

Optical clocks based on trapped ions are pushing forward the limits of time and frequency metrology with systematic uncertainties approaching the low 10^{-19} range, while their stability stays fundamentally limited by the Quantum Projection Noise(QPN). Uncorrelated parallel interrogation of N ions is expected to scale down the QPN limited instability by $1/\sqrt{N}$. We establish this scaling up to 8 ions in a $^{115}In^{+}$–$^{172}Yb^{+}$ Coulomb crystal clock interrogating the $^1S_0$–$^3P_0$ clock transition of $^{115}In^{+}$ and Doppler cooling via $^{172}Yb^{+}$ ions. Thermal motion of ions at Doppler temperature causes a time-dilation (TD) shift, which is among the largest contributors to the systematic-uncertainty budget in the ion based clocks today.

Thus, we are currently investigating ground state cooling of Coulomb crystal with tens of ions using the 360 kHz wide $^1S_0$–$^3P_1$ intercombination line in $^{115}In^{+}$. This is expected to reduce relative shifts due to the TD to low-10^{-19} regime and we can spectroscopically measure the TD shift via interleaved clock operation.

A 33.2 Thu 14:45 N 3

Hyperfine-induced state-dependent lifetime quenching on the $^2S_{1/2} \rightarrow {}^2F_{7/2}$ elctric octupole transition in $^{173}Yb^{+}$ — •Ikbal A. Biswas[1], Jialiang Yu[1], Anand Prakash[2], Clara Zyskind[1], Rattakorn Kaewuam[3], Piyaphat Phoonthong[3], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [3]National Institute of Metrology (Thailand), 3/4-5 Moo 3, Klong 5, Klong Luang, 12120 Pathumthani, Thailand

We report the coherent excitation of the highly forbidden $^2S_{1/2} \rightarrow {}^2F_{7/2}$ clock transition in the odd isotope $^{173}Yb^{+}$ with nuclear spin $I = 5/2$. The measured lifetimes of the $F_e = 2, 3, 4$ hyperfine states are shorter than the unperturbed $^2F_{7/2}$ clock state of $^{171}Yb^{+}$ due to hyperfine-induced electric dipole decay channel. This reduced lifetime lowers the required optical power for coherent excitation of the clock transition, thereby reducing the AC Stark shift caused by the clock laser. Using a 3-ion Coulomb crystal, we experimentally demonstrate suppression of the AC Stark shift, a critical improvement for the scalability of future multi-ion Yb^{+} clocks. Furthermore, we report the the measured hyperfine splitting and calculated quadratic Zeeman sensitivities of the $^2F_{7/2}$ clock state. Our results pave the way toward multi-ion optical clocks based on $^{173}Yb^{+}$.

A 33.3 Thu 15:00 N 3

Shelving Spectroscopy of ground state ultraviolet transitions in dysprosium — •Kevin Ng[1], Paul Uerlings[1], Fiona Hellstern[1], Jens Hertkorn[1], Luis Weiss[1], Stephan Welte[1,2], Tilman Pfau[1], and Ralf Klemt[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]CZS Center QPhoton

The open inner-shell electronic structure of lanthanides with large magnetic moments gives rise to a rich spectrum of transitions available for laser cooling, trapping and coherent control of dipolar atoms. Despite this, the large number of ultraviolet (UV) transitions that exist below 400 nm in these atoms have so far been rarely utilized. Here, we investigate multiple ground state UV transitions in dysprosium. Many of these transitions have decay strengths to the ultralong-lived, low-lying first excited state that are comparable to the strongest transitions commonly used in dipolar gas experiments. Using shelving spectroscopy which improves detection sensitivity and provides a straightforward way to distinguish the numerous isotope and hyperfine transitions, we measure isotope shifts, hyperfine coefficients and create King plots to determine their electronic nature. Such knowledge of these UV transitions, which analogously exist in other magnetic atoms is important for optically populating the first excited state and can be used for creating an optical clock, high resolution imaging in quantum gas microscopy and probing lanthanide nuclei with enhanced Schiff moments in searches for physics beyond the standard model.

A 33.4 Thu 15:15 N 3

MMC Array to Study X-ray Transitions in Muonic Atoms — •Hendrik Hadenfeldt for the QUARTET-Collaboration — Kirchhoff-Institute for Physics, Heidelberg University, Germany

The QUARTET collaboration aims to improve the accuracy of absolute nuclear charge radii of light nuclei from Li to Ne using high-precision X-ray spectroscopy of muonic atoms. A measurement with isotopically pure oxygen and copper has recently been performed at the Paul-Scherrer-Institute (PSI). Conventional solid-state detectors do not provide sufficient accuracy in the relevant energy range around 120 keV. Therefore, we use a low-temperature Metallic Magnetic Calorimeter (MMC). MMCs are characterized by a high resolving power of several thousand and a high quantum efficiency for the energy range of interest using 100 μm thick absorbers. In this talk, we present a newly developed MMC detector. First preliminary spectra and systematic effects observed in the measurement are discussed. The acquired data, together with the achieved energy resolution of better than 50 eV FWHM at 120 keV, enable a more precise characterization of muonic X-ray lines. In addition, we present the world's first compositional study of a prehistoric human tooth using high-precision X-ray spectroscopy of muonic atoms.

A 33.5 Thu 15:30 N 3

High-Precision Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at ALPHATRAP — •P. Justus[1], M. Bohman[1], A. Gramberg[1], F. Heisse[1], I. Kortunov[2], V. Vogt[2], C. König[1], K. Blaum[1], S. Schiller[2], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Institut für Experimentalphysik, Universität Düsseldorf, Düsseldorf

Molecular hydrogen ions are the simplest molecules and thus ideal systems for testing QED through comparison of high-precision measurements with theoretical predictions [1]. At ALPHATRAP we measured for the ro-vibrational ground state of HD^{+} the bound-electron g-factor to 0.20 ppb precision and the spin-interaction coefficients with 44 ppb and 151 ppb uncertainty [2], which can be compared to *ab initio* theory [3]. In a next step, we carried out high-precision laser spectroscopy of ro-vibrational levels via driving the $0 \rightarrow 5$ vibrational transition in HD^{+}.

We will present conclusions drawn from our measurements and planned refinements that will, in the future, provide a versatile platform for ultra-high precision laser spectroscopy - particularly of molecular hydrogen ions, including H_2^{+} and the antimatter equivalent $\bar{H}_2^{-}$ - in a cryogenic Penning trap [4].

[1] Karr, J.-Ph. et al., Phys. Rev. A **94**, 050501 (2016)
[2] König, C. M. et al., Phys. Rev. Lett., **134**, 163001 (2025)
[3] Karr, J.-Ph. et al., Phys. Rev. A **102**, 052827 (2020)
[4] Myers, E. G., Phys. Rev. A, **98**, 010101 (2018)

A 33.6 Thu 15:45 N 3

Tungsten Emissivity Modeling and Temperature Diagnostics for the Project 8 Atomic Beam Source — •Brunilda Mucogllava[1], Martin Fertl[1], and Marco Röllig[2] for the KAMATE-Collaboration — [1]Johannes Gutenberg University Mainz — [2]Tritium Laboratory Karlsruhe

To achieve a neutrino-mass sensitivity of 40 meV/c2, the Project 8 experiment aims to employ cyclotron radiation emission spectroscopy to measure the energies of beta-decay electrons from an atomic tritium source. The JGU Mainz atomic test stand uses a Hydrogen Atom Beam Source (HABS) in which molecular hydrogen flows through a 1-mm-diameter tungsten capillary radiatively heated to ˜2200 K. The dissociation efficiency of the source depends on the hydrogen flow rate and on the capillary surface temperature. Because the source operates under ultra-high-vacuum conditions, where access is limited and direct-contact sensors risk damaging the capillary, minimally invasive diagnostics, such as optical analysis of its thermal radiation, are preferred. Accurate temperature determination requires reliable knowledge of the tungsten surface emissivity, its evolution over repeated thermal cycles, and the consequent impact on the achievable maximum temperatures. To address these challenges, a dedicated calibration setup was

developed at the Tritium Laboratory Karlsruhe to measure tungsten emissivity using a near-infrared spectrometer and a single-wavelength pyrometer. This talk will present new results on tungsten-emissivity modeling and HABS temperature diagnostics, addressing challenges in calibration, temperature stability, and source aging.

A 33.7 Thu 16:00 N 3

Towards electron and Ca^+ ion cotrapping in a dual-frequency Paul trap — •Vladimir Mikhailovskii[1,2,3], Natalija Sheth[1,2,3], Mohammadreza Nematollahi[1,2,3], Guofeng Qu[4], Michal Hejduk[5], Niklas Vilhelm Lausti[5], K. T. Satyajith[6], Christian Smorra[7], Gunther Werth[3], Neha Yadav[8], Qian Yu[8], Clemens Matthiesen[8], Hartmut Haffner[8], Ferdinand Schmidt-Kaler[3], Hendrik Bekker[1,2,3], and Dmitry Budker[1,2,3,8] — [1]Helmholtz-Institut Mainz, 55128 Mainz, Germany — [2]GSI Helmholtzzentrum fur Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [3]QUANTUM, Institut fur Physik, Johannes Gutenberg-Universitat, 55128, Mainz, Germany — [4]Institute of Nuclear Science and Technology, Sichuan University, 610065, Chengdu, China — [5]Faculty of Mathematics and Physics, Charles University, Prague 8, Czech Republic — [6]Delta Q, MITK, 576217, Moodlakatte, India — [7]Heinrich Heine University Dusseldorf, 40225 Dusseldorf, Germany — [8]Department of Physics, University of California, 94720-7300, Berkeley, USA

Achieving simultaneous cotrapping of oppositely charged particles in the same Paul trap volume is an important milestone in the AntiMatter On a Chip project [1]. In our recent research we studied trapping of either electrons or Ca^+ ions in a dual-frequency field [2]. Here we overview the achieved results, discuss current shortcomings, and propose strategies towards simultaneous trapping of oppositely charged particles, aiming at cotrapping matter and antimatter.

1.N. Leefer, et al. Hyperfine Interact 238, 12 (2017)
2.V. Mikhailovskii, et al. arXiv:2508.16407 (2025)

A 33.8 Thu 16:15 N 3

Sympathetic cooling and spectroscopy of Ca-Th ion crystal — •Valerii Andriushkov[1,2,3], Ke Zhang[3], Yumiao Wang[3], Darius Fenner[3], Keerthan Subramanian[3], Florian Zacherl[3], Srinivasa Pradeep Arasada[3], Jonas Stricker[1,2,3], Christoph E. Düllmann[1,2,3], Lars von der Wense[3], Ferdinand Schmidt-Kaler[3], and Dmitry Budker[1,2,3,4] — [1]Helmholtz Institute Mainz, Mainz — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Johannes Gutenberg Universität Mainz, Mainz — [4]Department of Physics, University of California, Berkeley, USA

The TACTICa (Trapping and Cooling of Thorium Ions via Calcium) and NuQuant experiments aim to use ion-trapping techniques to investigate thorium ions for fundamental research, as well as to study ^{229}Th for the development of a nuclear clock. Thorium ions are produced using a laser-ablation ion source and loaded into a linear Paul trap, where they form a mixed-species Coulomb crystal with Ca^+. The thorium ions are efficiently cooled by the co-trapped Ca^+ ions. Our goal is to perform high-precision spectroscopy of thorium ions, which will be achieved with quantum logic spectroscopy. This project is supported by the DFG Project TACTICa (grant agreement no. 495729045) and the BMFTR Quantum Futur II Grant Project NuQuant (FKZ 13N16295A).