Q 13: Precision Measurements and Metrology: Optical Clocks

Time: Monday 17:00–19:00 Location: P 104

Q 13.1 Mon 17:00 P 104

Decay channels of the ^{229}Th nuclear isomeric state involving atomic electrons — •Pavlo Bilous and Adriana Pálffy — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany

The thorium isotope ^{229}Th is unique due to its nuclear isomeric (*i.e.* long living) excited state with the energy of $E_{\mathrm{iso}} = 7.8$ eV typical for optical atomic transitions. Being a bridge between atomic and nuclear physics, this nuclear transition has very narrow width and high stability to external perturbations, so it can be a key to metrology applications such as a nuclear frequency standard. The excitation and decay channels of this transition may well involve the electronic shell due to the very low value of E_{iso}.

For the neutral atom ^{229}Th, the isomeric state may decay via internal conversion (IC). For ^{229}Th ions this is not the case as the energy E_{iso} is lower than the corresponding ionization thresholds. However, IC from excited electronic states remains energetically allowed. On the other hand, the energy can be transferred to the electronic shell with excitation of an electron to another bound state accompanied by the absorption or emission of a photon (so called electron bridge). This channel can be strongly enhanced if the electronic and the nuclear transitions are on resonance. Here we consider several channels of decay of the nuclear isomeric state involving the atomic electrons and carry out *ab initio* calculations of corresponding rates using multiconfigurational Dirac-Fock wave functions for the bound atomic electrons.

Q 13.2 Mon 17:15 P 104

Entwicklung und Aufbau einer kompakten und hochstabilen optischen Frequenzreferenz für den Einsatz auf einer Höhenforschungsrakete — •Markus Oswald[1], Thilo Schuldt[1,2], Klaus Döringshoff[3], Markus Krutzik[3], Vladimir Schkolnik[3], Franz B. Gutsch[3], Achim Peters[3] und Claus Braxmaier[1,2] — [1]Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM), Universität Bremen — [2]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Bremen — [3]Humboldt-Universität zu Berlin

Hochstabile optische Frequenzreferenzen spielen bei einer Vielzahl von Weltraumanwendungen eine entscheidende Rolle, wie beispielsweise bei der Detektion von Gravitationswellen, der Navigation oder der Erdbeobachtung. Hierbei stellen Frequenzreferenzen auf Basis von molekularem Jod unter Nutzung der dopplerfreien Sättigungs-Spektroskopie eine vielversprechende Technologie für zukünftige Missionen dar, insbesondere hinsichtlich ihrer Stabilität über lange Zeiträume. Im Rahmen des JoKARUS-Projekts (Jod-Kammresonator unter Schwerelosigkeit) soll erstmals ein Jod-Spektroskopiemodul auf einer Höhenforschungsrakete zum Einsatz kommen und so den Weg bereiten für zukünftige Weltraumeinsätze (z.B. NGGM, eLISA). Ausgehend von vorangegangenen Laboraufbauten wurde ein Instrumentendesign entwickelt und hinsichtlich der Anforderungen der Mission an Kompaktheit, Leistungsfähigkeit und Robustheit optimiert und unter Einbeziehung qualifizierter Klebeverfahren auf einer 246 mm x 145 mm Quarzglasplatte integriert. Finanziert durch das DLR aus Mitteln des BMWi (Förderkennzeichen 50WM1646).

Q 13.3 Mon 17:30 P 104

Relative field sensitivities in ^{171}Yb$^+$ transitions — •Richard Lange, Nils Huntemann, Christian Sanner, Christian Tamm, Burghard Lipphardt, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The ^{171}Yb$^+$ ion exhibits two transitions that are employed in our setup of a single-ion optical frequency standard, the ^{2}S$_{1/2}$ → ^{2}D$_{3/2}$ electric quadrupole (E2) [PRA **89**, 023820] and the ^{2}S$_{1/2}$ → ^{2}F$_{7/2}$ electric octupole (E3) [PRL **108**, 090801] transition. In order to provide a frequency standard with highest accuracy, deviations from the unperturbed transition frequencies due to external perturbations have to be taken into account and corrected for. In particular, the effects related to external magnetic and electric fields as well as field gradients need to be investigated. The significantly higher sensitivity of the E2 transition frequency to these perturbations allows for an examination of the E3 transition frequency shifts on a magnified scale.

With precise information about the relative field sensitivities, uncertainties in the E3 transition frequency due to field perturbations can be reduced: Shifts of the E3 transition frequency can be corrected more accurately analyzing changes in the E2 transition frequency than measuring the fields and field gradients directly. In this talk we present improved measurement results of the relative field sensitivities of the E2 and E3 transition frequencies and discuss the effects of these results on the uncertainty budgets of our frequency standards.

Q 13.4 Mon 17:45 P 104

First campaigns with PTB transportable optical lattice clock — •J. Grotti[1], S. Koller[1], S. Vogt[1], A. Al-Masoudi[1], S. Dörscher[1], S. Herbers[1], S. Häfner[1], U. Sterr[1], C. Lisdat[1], H. Denker[2], M. Pizzocaro[3], P. Thoumany[3], B. Rauf[3], C. Clivati[3], M. Zucco[3], F. Levi[3], D. Calonico[3], A. Rolland[4], F. Baynes[4], and H. Margolis[4] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Erdmessung - Leibniz Universität Hannover, Schneiderberg 50, 30167 Hannover, Germany — [3]Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91 , 10135 Torino, Italy — [4]National Physical Laboratory, Teddington, Middlesex TW11 0LW, UK

A transportable lattice clock based on ^{87}Sr atoms has been built at PTB and successfully tested in the laboratory. The clock showed a stability of $1.3 \cdot 10^{-15}/\sqrt{\tau}$ and a systematic uncertainty of $7.4 \cdot 10^{-17}$. Furthermore, its frequency is in agreement with the stationary system of PTB. The system has been placed inside a car trailer and used for two measurement campaigns: A proof of principle experiment of relativistic geodesy in the Frejus tunnel, at the Italy-France boarder, and a local measurement of the ^{171}Yb/^{87}Sr clock frequency ratio at Torino. These campaigns were performed in collaboration with INRIM, NPL and the Institut für Erdmessung (IfE), Leibniz University Hannover. Results will be shown in the talk. This work is supported by QUEST, DFG (RTG 1729, CRC 1128), EU-FP7 (FACT) and EMRP (ITOC). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 13.5 Mon 18:00 P 104

A Sr lattice clock with $6 \cdot 10^{-17}/\sqrt{\tau/\mathrm{s}}$ frequency instability — •Roman Schwarz[1], Sören Dörscher[1], Ali Al-Masoudi[1], Sofia Herbers[1], Dan-Gheorghita Matei[1], Thomas Legero[1], Sebastian Häfner[1], Christian Grebing[1], Erik Benkler[1], Wei Zhang[2], Lindsay Sonderhouse[2], John M. Robinson[2], Jun Ye[2], Fritz Riehle[1], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309, USA

Optical clocks represent the forefront of frequency metrology enabling applications in relativistic geodesy, tests of fundamental physics, and the search for dark matter. As their systematic uncertainty reaches the low 10^{-18} regime, reducing their frequency instability becomes even more important in order to exploit their potential. Here, we report on recent improvements of the Sr lattice clocks at PTB by phase-locking the interrogation laser to cryogenic Si resonators at 194 THz. Frequency instabilities of $6 \cdot 10^{-17}(\tau/\mathrm{s})^{-1/2}$ are inferred from clock self-comparisons.

This work is supported by QUEST, the DFG within CRC 1128 (geo-Q), CRC 1227 (DQ-*mat*) and RTG 1729, EMPIR within OC18. The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation program and the EMPIR Participating States.

Q 13.6 Mon 18:15 P 104

Evaluation of a magnesium frequency standard and progress towards a frequency measurement — •Klaus Zipfel, Dominika Fim, Nandan Jha, Steffen Rühmann, Steffen Sauer, Waldemar Friesen, Pia Koopmann, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

State-of-the-art optical atomic lattice clocks with fermionic strontium already reached uncertainties in the low 10^{-18} regime [1,2]. In order to operate on that level, a high Q factor and hence a narrow observable linewidth of the clock transition is key for the evaluation of the systematics.

In this presentation, we report on spectroscopy with an observable linewidth of 100 Hz for the ^{1}S$_0$ - ^{3}P$_0$ clock transition in bosonic magnesium, which corresponds to the highest Q factor for an optical transition in that species so far. As a consequence, the resolution for evaluating the uncertainties like 2nd order Zeeman and lattice AC-Stark shift increases. We will show the latest results for our systematics and as well present the progress towards an absolute frequency measurement.

[1] B. J. Bloom et al., Nature **506**, 71 - 75 (2014)
[2] T.L. Nicholson et al., Nature Communications **6**, 6896 (2015)

Q 13.7 Mon 18:30 P 104

Ion dynamics and systematic shifts in a multi-ion atomic clock — •Dimitri Kalincev, Jonas Keller, Tobias Burgermeister, Alexandre Didier, Jan Kiethe, André Kulosa, Tabea Nordmann, Thorben Schmirander, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Single ion optical clocks have an estimated systematic fractional frequency uncertainty at the 10^{-18} level. The main limitation in measuring atomic frequencies is their statistical uncertainty due to the fundamental limit of quantum projection noise. In order to exploit the high accuracy, very long averaging times are required. We show that the statistical uncertainty of single-ion-clocks can be overcome with a multi-ion-approach while keeping excellent control of systematics. For mixed crystals, we analyze effects relevant at the 10^{-19} level and below. We identify crystal configurations that can be cooled efficiently while having low heating rates.

With a new chip-based linear Paul-trap, designed for low axial micromotion, we measure heating rates as a function of the ion secular frequency. We simultaneously measure micromotion across an ion Coulomb crystal. Based on experimental results on trap induced shifts and on our calculations, we present an estimated error budget for a multi-ion-clock.

Q 13.8 Mon 18:45 P 104

High precision and high frequency sensing with a continuous drive utilizing the Nitrogen Vacancy center — •Daniel Louzon[1,2], Alexander Stark[1,3], Thomas Undnen[1], Nati Aharon[2], Alexander Huck[3], Ulrik L. Andersen[3], Alex Retzker[2], and Fedor Jelzko[1] — [1]Ulm University, Ulm, Germany — [2]Hebrew University, Jerusalem — [3]Technical University of Denmark, Kongens Lyngby, Denmark

Single defect centers in diamond and especially the nitrogen-vacancy (NV) show remarkable physical properties such as long spin coherence time and the emission of single photons. These properties make them ideal candidates for qubits and nano-scale magnetic field sensors [1].

High frequency sensing, using a two level system, is considered T_2^* limited, given dynamical decoupling techniques cannot be applied on a time scale shorter than the on-resonance signal being measured.

We present the implementation of a novel technique to measure a weak high frequency signal using a detuned two level system and a series of continuous driving fields prolonging the coherence time of the two level system in principle close to its T_1 time [2].

The technique is demonstrated on a single NV center in diamond as the two level system, measuring a weak high frequency signal, with a coherence time over an order of magnitude longer than its T_2^*.

[1] M. Doherty et al., Physics Reports 528, 1 (2013) [2] N. Aharon et al., arXiv: 1609.07812 (2016).