A 18: Precision Spectroscopy of atoms and ions V (Th 229)

Time: Wednesday 14:00–16:00 Location: S HS 2 Physik

A 18.1 Wed 14:00 S HS 2 Physik

Excitation of $^{229}Th^{2+}$ with a two-photon electron transition — •Robert A. Müller[1,2], Andrey V. Volotka[3], Stephan Fritzsche[2,4], and Andrey Surzhykov[1,2] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]Helmholtz-Institute Jena, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

About one decade ago a clock based on the optical nuclear transition in ^{229}Th has been proposed [1]. For this purpose many mechanisms to excite the ^{229}Th nucleus have been discussed. In particular such processes involving an energy transfer from electronic transitions to the nucleus are expected to be very efficient. There is, however, a major drawback that comes with these so-called *electron bridge* processes: The electronic transition has to be in resonance with the nuclear one. To overcome this problem we propose the process of nuclear excitation by a two-photon transition (NETP) to excite the ^{229}Th nucleus. In this process the electron shell deexcites via the emission of two photons, where one of them is emitted and the other one excites the nucleus. We employ a combination of configuration interaction and many-body perturbation theory to calculate the NETP probability in resonance approximation. With these calculations we propose a circular process consisting of a pumping stage and subsequent NETP. In particular we make recommendations wich electron level to pump to achieve the highest NETP probability.

[1] E. Peik and C. Tamm, Europhys. Lett. **6**1, 181 (2003)

A 18.2 Wed 14:15 S HS 2 Physik

Excitation of ^{229}Th in VUV-transparent crystals — •Brenden Nickerson and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The isomeric state of ^{229}Th near 7.8 eV holds the interest of the scientific community as a candidate for the first nuclear clock. Laser excitation of thorium-doped vacuum-ultraviolet (VUV) transparent crystals could be used a means to study this interesting transition. Thorium can be doped into VUV-transparent crystals at higher densities than can be realized in an ion trap. Furthermore, this environment enforces the Mössbauer regime, allowing for recoil-free emission, absorption and collective behavior [1].

Here, we investigate collective effects in the nuclear forward scattering (NFS) regime using narrowband pulsed lasers, coincident pulses, varying pulse phases and magnetic fields to generate unique intensity spectrum [2].

Before the exact energy of the isomeric state is found, broadband excitation must be used in its search in the crystal environment. To this end, and as a prequel to NFS, we look at the opportunity to excite the nuclear transition via the initial driving of a defect state, a color center in the crystal, which then can efficiently transfer its energy to the isomer in a process reminiscent of electron bridge [3].

[1] W.-T. Liao *et al.*, Phys. Rev. Lett. 109, 262502 (2012).
[2] B.S. Nickerson *et al.*, Accepted to PRA, arXiv:1809.01857
[3] S.G. Porsev and V.V. Flambaum, Phys. Rev. A 81, 032504 (2010)

A 18.3 Wed 14:30 S HS 2 Physik

Electronic level structure investigations in Th^+ for the excitation of the nuclear isomer — •David-Marcel Meier, Johannes Thielking, Gregor Zitzer, Maksim Okhapkin, Robert Müller, Andrey Surzhykov, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Among all known isotopes ^{229}Th possesses a uniquely low-lying nuclear excitation state at 7.8(5) eV with a lifetime of about ≈1000 s. Since this energy corresponds to a wavelength in the VUV region of about ≈160 nm, it makes direct laser excitation of the isomer challenging.

For the search of the transition's frequency we attempt to excite the nucleus via the NEET [1] or electronic bridge [2] mechanisms by two-photon laser excitation which rely on the hyperfine coupling between electron shell and nucleus. Since the Th^+ ion is a three valence electron system, it possesses a dense electronic level structure which leads to an enhanced hyperfine coupling and therefore to a higher excitation probability and strong decrease of the lifetime of the isomeric state.

For this reason, an extensive knowledge about the electronic level structure of Th^+ in the range of the isomer energy is required. In our experiment we investigate two-photon laser excitation of high-lying levels in $^{232}Th^+$ ions and we will present the latest results of the level search in the energy range from 7.8 to 9.8 eV. We found 177 previously unknown energy levels and we will furthermore report on ab-initio calculations of electronic levels in the same energy range.

[1] F.F. Karpeshin, et al., Nucl. Phys. A, 654, 579 (1999).
[2] S. G. Porsev et al., Phys. Rev. Lett. 105, 185501 (2010).

A 18.4 Wed 14:45 S HS 2 Physik

Towards a ^{229m}Th energy determination with 40 μeV accuracy — •L. von der Wense[1], B. Seiferle[1], Ch. Schneider[2], J. Jeet[2], I. Amersdorffer[1], N. Arlt[1], F. Zacherl[1], R. Haas[3,4,5], D. Renisch[3,4], Pa. Mosel[6], Ph. Mosel[6], M. Kovacev[6], U. Morgner[6], Ch.E. Düllmann[3,4,5], E.R. Hudson[2], and P.G. Thirolf[1] — [1]Ludwig-Maximilians-Universität München — [2]University of California, Los Angeles — [3]Johannes Gutenberg-Universität Mainz — [4]Helmholtz-Institut Mainz — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH — [6]Leibniz Universität Hannover

The development of a nuclear clock has been a long-standing objective [1]. There is only one nuclear excitation known which could allow for the development of a nuclear clock due to its exceptionally low energy of only a few eV above the ground state. This is the metastable first excited state in ^{229}Th [1, 2]. The development of a ^{229}Th-based nuclear clock is so far hindered by an insufficient knowledge of the excited state's energy. A new scheme of experimental search will be presented, which could allow to pin down the isomeric energy value to 40 μeV accuracy, thereby paving the way to the development of a nuclear clock [3]. The concept makes use of a direct nuclear laser excitation scheme.

[1] L. v.d.Wense et al., Nature 533, 47-51 (2016).
[2] B. Seiferle et al., PRL 118, 042501 (2017).
[3] L. v.d.Wense et al., PRL 119, 132503 (2017).

Supported by DFG grant TH956/3-2 and Horizon 2020 research and innovation programme under grant agreement 664732 “nuClock".

A 18.5 Wed 15:00 S HS 2 Physik

Gamma spectroscopy to measure the ^{229}Th isomer energy using a 2-dimensional array of metallic magnetic microcalorimeters — •Jeschua Geist[1], Daniel Hengstler[1], Christian Schötz[1], Sebastian Kempf[1], Loredana Gastaldo[1], Andreas Fleischmann[1], Christian Enss[1], Georgy A. Kazakov[2], Simon Stellmer[2], and Thorsten Schumm[2] — [1]Heidelberg University — [2]Vienna University of Technology

The isotope ^{229}Th has a nuclear isomer state with the lowest presently known excitation energy, which possibly allows to connect the fields of nuclear and atomic physic with a potential application in a nuclear clock. In order to verify and improve the accuracy of the currently most accepted energy value for this isomere energy, (7.8 ± 0.5) eV, we plan to resolve the 29.18 keV doublet in the γ-spectrum following the α-decay of ^{233}U, corresponding to the decay into the ground and isomer state, to measure the isomer transition energy without additional theoretical input parameters.

We developed the detector array maXs-30 consisting of 8x8 metallic magnetic calorimeters with an expected energy resolution below 6 eV, providing a large detection area of 16 mm^2 to face the low rate of the 29.18 keV transitions. We present a new value for the isomere energy with a detector performance of 11 eV FWHM for photons up to 60 keV, show latest recorded ^{229}Th spectra and discuss different ways to derive the isomer energy from these spectra.

A 18.6 Wed 15:15 S HS 2 Physik

Measurement of Fundamental Constants by Spectroscopy of the Molecular Hydrogen Ion — Soroosh Alighanbari[1], Gouri Giri[1], Michael Hansen[1], Florin Constantin[1,2], Vladimir Korobov[3], and •Stephan Schiller[1] — [1]Heinrich-Heine-Univ. Düsseldorf — [2]PhLAM, Univ. Lille, Villeneuve d'Ascq — [3]Joint Inst. for Nuclear Research, Dubna

Bound three-body quantum systems are important systems for fundamental physics. They allow for tests of quantum electrodynamics theory, and provide access to fundamental constants of atomic physics and to nuclear properties. Molecular hydrogen ions, the simplest molecules, are representatives of this class. They provide an independent access

to the Rydberg constant, to the ratios of electron mass to proton and to deuteron mass, and to the radiative energy contributions arising from quantum electrodynamics.

By using trapped and sympathetically laser-cooled HD^+ molecules together with a newly developed rotational spectroscopy technique and highly accurate ab initio theory, we determine $R_\infty m_e(m_p^{-1} + m_d^{-1})$ with an uncertainty of 1×10^{-10}, comparable to CODATA2014.

Invited Talk A 18.7 Wed 15:30 S HS 2 Physik

Towards a precise energy determination of the ^{229}Th nuclear isomer — •Benedict Seiferle, Lars v.d. Wense, Ines Amersorffer, and Peter G. Thirolf — LMU Munich, 85748 Garching, Germany.

The nuclear first excited state in ^{229}Th (^{229m}Th) offers the unique possibility of a direct optical control of a nucleus with today's laser technology. The energy of 7.8(5) eV and it's lifetime make it a promising candidate for a nuclear optical clock. The large uncertainty of the excitation energy, however, impedes progress towards a nuclear clock. Therefore the objective of our experiment is a precise determination of the excitation energy of ^{229m}Th via the measurement of electrons emitted during the internal conversion decay of the excited state [1,2]. The experimental setup as well as first measured spectra will be presented.

This work was supported by DFG (Th956/3-2) and by the European Union's Horizon 2020 research and innovation programme under grant agreement 6674732 "nuClock".

[1] L.v.d. Wense et al., Nature 553, 47 (2016). [2] B. Seiferle et al., PRL 118, 042501 (2017).