2 PhD Positions

In the ERC Synergy Grant Project "ThoriumNuclearClock" at LMU Munich/Germany

ThoriumNuclearClock is an ERC Synergy Grant project that started on February 1st 2020, for a duration of 6 years. 4 international research teams (3 experimental: LMU Munich/Germany, PI: P.G. Thirolf, TU Vienna/Austria, PI: T. Schumm, PTB Braunschweig/Germany, PI: E. Peik; 1 theoretical: U Delaware/USA, PI: M. Safronova) will join forces to build world's first optical nuclear clock and apply it to fundamental physics studies.

Project background:

Today's most precise time and frequency measurements are performed with optical atomic clocks. However, it has been proposed that they could potentially be outperformed by a nuclear clock, which employs a nuclear transition instead of an atomic shell transition. There is only one known nuclear state that could serve as a nuclear clock using currently available technology, namely, the isomeric first excited state of ^{229}Th. Since more than 40 years nuclear physicists have targeted the identification and characterization of the elusive isomeric ground state transition of ^{229m}Th. Evidence for its existence until recently could only be inferred from indirect measurements, suggesting since 2009 an excitation energy of 7.8(5) eV. Thus the first excited state in ^{229}Th represents the lowest nuclear excitation so far reported in the whole landscape of known isotopes. In 2016, the first direct detection of this nuclear state could be realized via its internal conversion decay branch, laying the foundation for precise studies of its decay parameters [1]. Subsequently, a measurement of the half-life of the neutral isomer was achieved, confirming the expected reduction of 9 orders of magnitude compared to the one of charged ^{229m}Th [2]. Recently, collinear laser spectroscopy was applied to resolve the hyperfine structure of the thorium isomer, providing information on nuclear moments and the charge radius [3]. Most recently, also the cornerstone on the road towards the nuclear clock, which is a precise and direct determination of the excitation energy of the isomer, could be achieved [4, 5]. Thus major progress on the properties of this elusive nuclear state could be achieved in the last three years, opening the door towards an all-optical control and thus the development of an ultra-precise nuclear frequency standard. Such a nuclear clock promises intriguing applications in applied as well as fundamental physics, ranging from geodesy and seismology to the investigation of possible time variations of fundamental constants.

[1] L. v.d. Wense et al., Nature 533, 47-51 (2016).
[2] B. Seiferle, L. v.d. Wense, P.G. Thirolf, Phys. Rev. Lett. 118, 042501 (2017).
[3] J. Thielking et al., Nature 556, 321 (2018).
[4] B. Seiferle, L. v.d. Wense, P.G. Thirolf, Eur. Phys. Jour. A 53, 108, (2017).
[5] B. Seiferle et al., Nature 573, 243 (2019).

1. PhD Thesis Project description:

Understanding surface effects on the lifetime of ^{229m}Th and characterization of a new experimental setup comprising a recoil ion source and a cryogenic Paul trap for laser-based ^{229m}Th manipulation

The objective of this thesis project will be twofold:

(i) in previous measurements a dependence of the lifetime of ^{229m}Th on the properties of the surface that was used for neutralization was observed. Proper understanding of the involved mechanisms is of great interest to the community, especially for the development of a solid state nuclear optical clock. To perform these measurements an existing high-flux (^{233}U activity: 290 kBq) gas cell-based isomer beam (ca. 10000 ^{229}Th ions extracted/second, providing ca. 200 thorium isomers/second [1]) will be used. In order to properly study surface effects, this setup needs to be extended by a detection chamber enabling the characterization and high cleanliness of surfaces.

(ii) a compact, low-activity (10 kBq) recoil source for $^{229m}Th^{q+}$ (q=1-3) has already been developed and is ready for commissioning, based on our longterm experience with ^{229m}Th ion beams. ^{233}U α-recoils will be thermalized in a buffer gas cell, extracted into and phase-space-cooled in a radiofrequency ion guide (RFQ) and purified from α-decay daughter products in a quadrupole mass separator (QMS). The backbone of the new experimental setup to study ^{229m}Th will be a cryogenic Paul trap, coupled to the new recoil ion source. It will enable long (several hours) storage of $^{229}Th^{q+}$ ions (q=1-3), thus, allowing for a first experimental campaign targeting the (yet unknown) ionic lifetime of ^{229m}Th, expected as $t_{1/2}= 10^3$-10^4 s. The setup will be built "VUV-ready", i.e. allowing for laser manipulation (sympathetic laser cooling and direct VUV laser excitation) of stored thorium isomers. (Mass selective) extraction of ions will be possible, e.g. for subsequent IC electron detection and spectroscopy. The cryogenic linear Paul trap will be operated at temperatures below 10 K, primarily to provide ultra-high-vacuum conditions of $\leq 10^{-14}$ mbar H_2 partial pressure. Thus ion trapping times of up to several hours can be realized.

We seek candidates with a background in the following fields:

- ion manipulation/trapping with electromagnetic fields
- electron spectroscopy

[1] L. v.d. Wense, B. Seiferle, M. Laatiaoui, P.G. Thirolf, Determination of the extraction efficiency for ^{233}U source recoil ions from the MLL buffer-gas stopping cell, Eur. Phys. Jour. A 51, 29 (2015)

2. PhD Thesis Project description:

Preparation of Sr/Th sympathetic laser cooling and measurement of the ionic ^{229m}Th lifetime

The objective of the thesis project will be the setup and commissioning of a laser system and electronics for sympathetic (laser) cooling of Th^{3+} with $^{88}Sr^{+}$ (based on an established design) as a prerequisite of laser manipulation of ^{229m}Th ions. $^{88}Sr^{+}$ is free from hyperfine structure and can be conveniently laser cooled with two diode lasers at wavelengths of 422 nm and 1092 nm.

A first experimental application of the laser cooling system will be to measure the isomer's ionic lifetime in a cryogenic Paul trap (allowing for the required long storage times of several hours) for different charge states (Th^{+}, Th^{2+}, Th^{3+}), using a newly developed recoil ion source. The lifetime of the charged thorium isomer is its last key property that has not yet been experimentally determined (expectations range between 10^3 – 10^4 seconds) due to the lack of an experimental trapping facility that provides long enough ion storage times. Diagnostics will be based either on the detection of the IC electrons behind the trap or, more sensitively, via a fluorescence measurement of scattered photons from a hyperfine resonance of the isomer in $^{229m}Th^{3+}$. These measurements will be performed in close collaboration with an experimental team from the German metrology institute PTB.

We seek candidates with a background in the following fields(s):

- laser cooling of ions
- Ion detection techniques
- Ion trapping in a linear Paul trap

If you are highly motivated to work at the forefront of physics and technology in a dynamic and internationally highly visible project and in close collaboration with other leading experimentalists and theorists, then you are encouraged to apply to join our team for one of the described PhD thesis projects.

Applications including a list of professional and educational history, transcripts of grades, publication list and possible recommendations should be sent to:

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