Developments towards high resolution laser spectroscopy of ^{235m}U

A. Raggio[1], L. E. Reed[2], J. Warbinek[2,3], I. Pohjalainen[1], R.P. de Groote[4], I. D. Moore[1], Ch. E. Düllmann[2,3,5] , M. Block[2,3,5] and the IGISOL group[1]

[1]Accelerator Laboratory, Department of Physics, University of Jyväskylä, Finland
[2]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, Germany
[3]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[4]KU Leuven, Instituut voor Kern-en Stralingsfysica, Leuven, Belgium
[5]Helmholtz Institute Mainz, Mainz, Germany

LISA
LASER IONISATION AND SPECTROSCOPY OF ACTINIDES

MOTIVATION

The measurement of hyperfine structures and isotope shifts with high-resolution laser spectroscopy offers access to fundamental nuclear structure properties including spins, mean-square charge radii and electromagnetic moments. Within the LISA framework [1], a new measurement campaign has been started on uranium by means of collinear laser spectroscopy at the IGISOL facility. The final aim is the study of the second lowest-lying isomeric state in the nuclear landscape, the 76-eV isomer in ^{235}U.

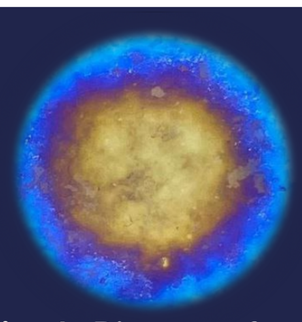


Fig. 1: Picture of a 22 mm diameter ^{240}Pu source.

GAS-CELL STUDIES

To generate an isomeric beam, a set of 27 molecular plated [2] ^{239}Pu alpha-recoil sources have been produced at Mainz University (JGU) with an average activity of 200 kBq/source. The ^{235m}U isomer is populated directly with a 71% branching ratio by the alpha decay of ^{239}Pu and has a halflife of 26 minutes.

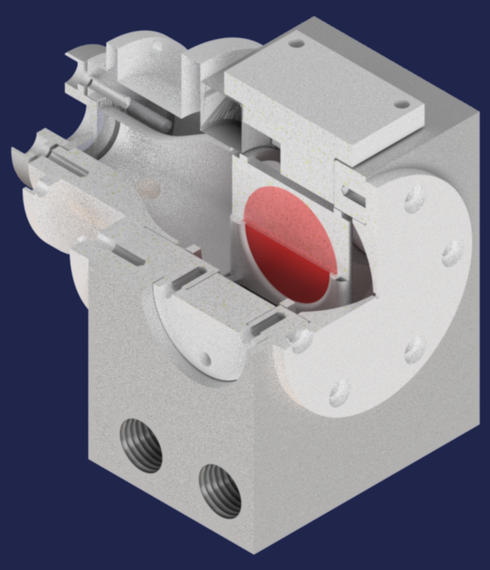


Fig. 2: Cross-sectional view of the actinide gas-cell with two sources mounted inside.

The sources have been initially tested in the actinide gas cell [3] where the alpha-recoils are stopped in a buffer gas (He) and extracted towards the IGISOL beamline.

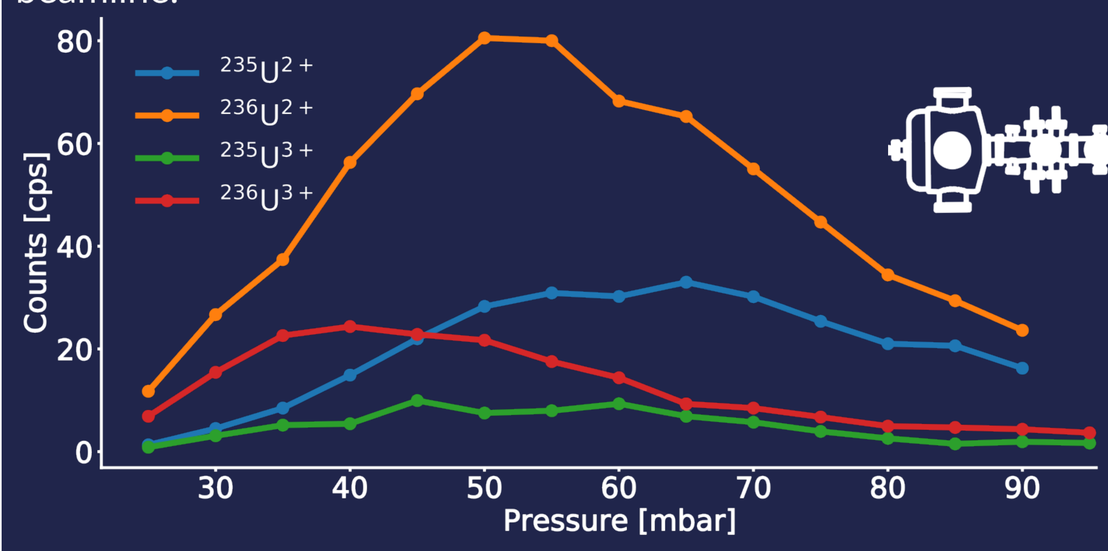


Fig. 3: Uranium recoil yields measured using an MCP detector at IGISOL switchyard after gas-cell extraction and mass separation.

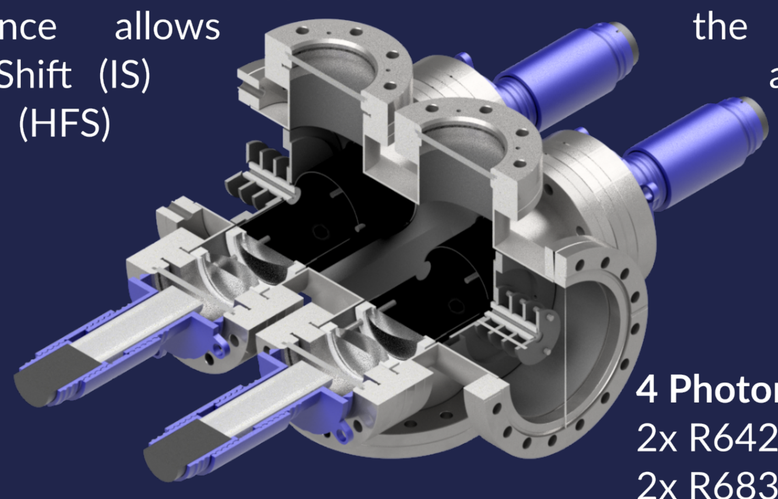
In addition to the ^{239}Pu source, a reference ^{240}Pu source was additionally installed providing ^{236}U alpha recoils. The charge distribution of the recoils reflects the purity of the He buffer gas in the gas cell. For the final measurement, manipulation of the charge state will be needed to produce singly-charged ions.

REFERENCES

[1] LISA – Laser Ionization and Spectroscopy of Actinides, <https://lisa-itn.web.cern.ch/>
[2] Vascon, A., et al., NIM A, 696 (2012): 180–191.
[3] Pohjalainen, I. et al., Nucl. Instr. Meth. Phys. Res. Sect. B, 376 (2016) 233-239.
[4] Koszorus A. et al. submitted to Spectrochimica Acta Part B: Atomic Spectroscopy.

COLLINEAR LASER SPECTROSCOPY (CLS)

After mass separation, ions are cooled and bunched in a radiofrequency cooler-buncher, before being reaccelerated to 30 keV and delivered to the collinear beamline. There, ions are overlapped in a counter-propagating geometry with a CW laser beam which excites them from either the ground state or low-lying metastable state. Detection of laser-induced fluorescence allows the measurement of Isotope Shift (IS) and Hyperfine structure (HFS) from the frequency pattern.



4 Photomultiplier Tubes:
2x R6427 300nm to 650nm
2x R6834 160nm to 330nm

Fig. 4: Cross-sectional view of the upgraded IGISOL collinear line light collection region [4].

GROUND STATE TEMPLATE

Using an electric discharge source placed in the IGISOL target chamber more than 10 ionic transitions have been studied in the three natural uranium isotopes : 234 (0.0054%), 235 (0.72%) and 238 (99.27%). A detection efficiency of 1 photon per 3000 ions was measured on ^{238}U resonance.

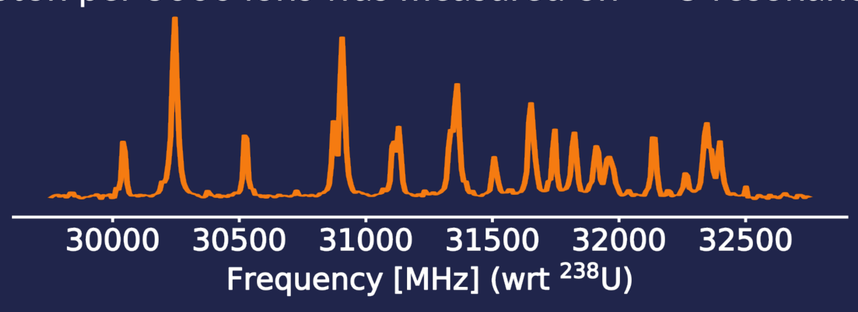


Fig. 5: ^{235gs}U hyperfine structure of the 305.02 nm transition from J=4.5 to J=4.5. The nuclear angular momentum of the ground state is 7/2, producing therefore 22 HFS peaks.

HYPERFINE SPLITTING

$$\Delta E_{\mathrm{hfs}} = \frac{1}{2} A_{\mathrm{hfs}} C + B_{\mathrm{hfs}} \frac{\frac{3}{2} C(C+1) - 2I(I+1)J(J+1)}{2I(2I-1)2J(2J-1)}$$

$$C = F(F+1) - I(I+1) - J(J+1)$$

A_{hfs} and B_{hfs} are the dipole and quadrupole coupling constants

ISOTOPE SHIFT

$$\delta\nu_i^{A,A'} = M_i \frac{A' - A}{A,A} + F_i \delta\langle r^2 \rangle^{A,A'}$$

M_i and F_i are the mass and the field shift constants

OUTLOOK

CLS of ^{235m}U isomer planned for 2023

- Extraction and transmission efficiency need to be improved, test with different gas cells planned in the fall.
- Manipulation of recoils charge state needs to be investigated

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