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STUDY OF K-ISOMERS IN ODD-MASS NUCLEI AT SHIP*

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This contribution reviews the recent results of the experiments performed at SHIP in the field of K-isomer studies, where we aimed at a study of high K-structures in odd-mass nuclei. In particular the results from the study of multi-quasi-particle isomeric states in ^{253}No and ^{255}Lr will be presented in detail. The high K-isomer in ^{253}No gives also the possibility to observe a rotational band, which was not observed in previous in-beam studies

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1. Introduction

Until a decade ago the structure of neutron deficient nuclei in the region of heavy nuclei with $Z \geq 100$ was obtained mainly by α spectroscopy. Recent developments of experimental techniques opened a door for detailed γ-ray spectroscopy studies in the region of trans-fermium nuclei. A review of recent achievements is presented in [1]. Indeed, more detailed results can

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be obtained using α–γ and α-conversion electron (CE) coincidence measurements but these investigations are difficult due to low production rates of the isotopes. Increased sensitivity of experimental setups and higher beam intensities available now have overcome these restrictions to a great extent.

One of the most interesting cases is the possibility to study K-isomers in the heaviest nuclei. K-isomers are a special kind of spin-traps whose existence depends not only on the spin value but also on its orientation. Experiments aimed to investigate such phenomena provide important information on the nuclear structure of the heaviest elements and are stringent tests for the quality of nuclear models. One can obtain *e.g.* information on the nucleon pairing, single particle levels, or one can study properties of levels and collective excitations not observable in in-beam measurements.

2. Experimental setup

The isotopes ^{255}Lr and ^{253}No were produced in the fusion–evaporation reactions ^{48}Ca + ^{209}Bi and ^{48}Ca + ^{207}Pb, respectively. For both reactions we used beam energy of 218 MeV. The experiments were performed at the velocity filter SHIP at GSI, Darmstadt. The pulsed ^{48}Ca beam (5 ms on/15 ms off) was delivered by the UNILAC accelerator with a typical beam intensity 1.3 $p\mu$A (particle μA). The targets were produced by evaporating layers of 450 μg/cm^2 chemical compound Bi_2O_3 or PbS onto a 40 μg/cm^2 carbon backing (mounted upstream). The targets were covered by a 10 μg/cm^2 carbon layer. Experimental setup, data acquisition system and calibrations are described elsewhere [2].

3. Decay of ^{255}Lr

The isotope ^{255}Lr was studied recently at the separators RITU in Jyväskylä and LISE in Caen, both published in [3]. Two intense α transitions with energies of (8365 ± 2) keV and (8457 ± 2) keV and half-lives of (31.1 ± 1.3) s and (2.53 ± 0.13) s, respectively were reported. An additional weak transition with an energy and half-life of (8290 ± 5) keV ≈ 35 s and two α transitions with overlapping lines at (8420 ± 5) keV and half-lives of (30 ± 4) s and (2.1 ± 0.5) s were also observed. The data were interpreted as α decays from the ground-state (assigned as 1/2-[521]) and a previously unknown isomeric level (assigned as 7/2-[513]) [3].

The decay properties of the isomeric state were confirmed in the measurements performed at SHIP. An α-decay energy and a half-life of (8467 ± 5) keV, (2.53 ± 0.05) s were obtained for the short-lived state and an α-decay energy of (8373 ± 5) keV for the longer living state.

A second isomeric state decaying by γ-emission was identified recently in an experiment performed at the VASSILISSA separator in Dubna [4]. A half-life of (1.4 ± 0.1) ms was measured, and from coincidences between CEs and γ-rays a lower limit of the excitation energy of 720 keV was estimated.

In the experiment at SHIP the method of searching for prompt CE–γ coincidences in delayed coincidence with evaporation residues (ER) implantation was applied. We measured decay properties of this isomer in more detail. The spectrum of detected γ transitions is shown in Fig. 1. The inset shows the decay time of the CE–γ coincidences following ER implantations. A half-life of the isomer of (1.81 ± 0.02) ms was determined, which is slightly longer than the value given in [4]. Based on the observed CE–γ and γ–γ coincidences we evaluated lower limits of 1.6 MeV for the excitation energy and $17/2\,\hbar$ for the angular momentum of this isomeric state.

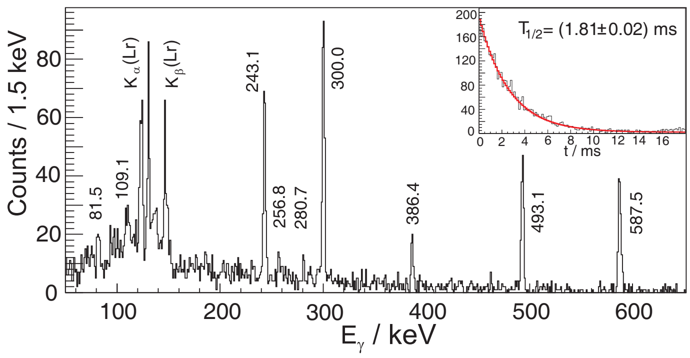

Fig. 1. Energy spectrum of γ transitions detected in the reaction of ^{48}Ca + ^{209}Bi in coincidence with CEs of energy up to the 900 keV within a time interval 20 ms after implantation of ERs. The inset shows the time distribution of the registered CE–γ coincidences after ER implantations.

Since in ^{255}Lr both, a short-lived 'high' spin state $(7/2^-)$ and a long-lived 'low' spin state $(1/2^-)$ are close in excitation energy, one expects that decay of high-K state rather populates the short lived 'high' spin state. Since we observed the feeding of 2.53 s isomeric state, its configuration rather should be assigned as $7/2^-$ than as $1/2^-$, in agreement with [3].

4. Decay of ^{253}No

In search of γ transitions delayed by ≈ 100 μs after ER implantations we observed a γ line of 167 keV having a half-life of $(23 \pm 3)\,\mu$s which we assigned to $5/2^+[622] \to 9/2^-$ [734] transition. This result was confirmed in the measurement with production of ^{253}No in the α decay of ^{257}Rf [5]. Based on this result we located the $5/2^+$ [622] level at the excitation energy of 167 keV thus extending the systematics in $N = 151$ isotones up to $Z = 102$.

Furthermore we observed a second isomeric state in ^{253}No using the previously mentioned experimental technique. The obtained half-life of this isomeric state was (668 ± 7) μs. The lower limits for the angular momentum and the excitation energy of this multi-quasi-particle isomeric state were tentatively evaluated to be $21/2\,\hbar$ and 1.6 MeV, respectively. The unique result obtained in this measurement is the observation of a rotational band populated in the de-excitation of the multi-quasi-particle isomer [6]. The analysis shows differences between the gamma transitions of the band populated by decay of the observed multi-quasi-particle isomer and the band observed in previous in-beam studies [7, 8]. We did not observe any indication for the feeding of the low lying $5/2^{+}[622]$ isomeric level in de-excitation of the multi-quasi-particle state. More details will be published elsewhere [9].

5. Conclusions

Besides the direct production of superheavy elements nuclear spectroscopy is a very important tool to investigate the nuclear structure of heaviest elements. Detailed spectroscopy measurements indicate a new island of isomerism in the neutron deficient region around $N = 152$, $Z = 100$. Besides the even-even nuclei also multi-quasi-particle isomeric states were studied in odd-mass nuclei by means of CE–γ coincidence measurements in delayed coincidence with implanted ERs. More detailed experiments are necessary to clarify their structure.

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REFERENCES

[1] R.-D. Herzberg, P.T. Greenlees, *Prog. Part. Nucl. Phys.* **61**, 674 (2008).
[2] S. Antalic *et al.*, *Eur. Phys. J.* **A38**, 219 (2008).
[3] A. Chatillon *et al.*, *Eur. Phys. J.* **A30**, 397 (2006).
[4] K. Hauschild *et al.*, *Phys. Rev.* **C78**, 021302 (2008).
[5] B. Streicher, Ph.D. Thesis, Comenius University, Bratislava 2006.
[6] F.P.Heßberger, *Phys. At. Nucl.* **70**, 1445 (2007).
[7] P. Reiter *et al.*, *Phys. Rev. Lett.* **95**, 032501 (2005).
[8] S. Eeckhaudt, Ph.D. Thesis, University of Jyväskylä, 2006.
[9] S. Antalic *et al.*, to be published.