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SYNTHESIS AND PROPERTIES OF THE HEAVIEST ELEMENTS[1]

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The improvements of experimental technique in last years give a new possibility for a production of heaviest elements. Experimental limit for α - γ spectroscopy study was decreased to the order of several 100 pb which allows detailed spectroscopy experiments for the superheavy elements up to the Seaborgium. Several α and α - γ spectroscopy experiments were recently performed at the velocity filter SHIP in GSI Darmstadt (Germany). As example, the decay properties of ^{246,247,251}Md, ^{255}Lr and ^{261}Sg are presented.

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1 Introduction

Most of the known information about the structure of neutron deficient nuclei in the region above Z = 100 was obtained so far by means of α spectroscopy. To obtain more detailed information the application of the method of α - γ and/or α-conversion electron (CE) coincidence spectroscopy is necessary. The enhanced sensitivity and use of the γ detectors allows more precise studies of the mentioned isotopes compared to previous measurements. The obtained data deliver valuable information about nuclear structure of the isotopes in the region of elements with Z > 100. This gives the possibility for further development of theoretical models and improves their prediction power.

The study of complete fusion is also a very useful method to obtain information about thermodynamics and dynamical characteristics of nuclear matter. Presently used computer codes and theoretical models like HIVAP, JULIAN/PACE or ALICE are unable to provide reliable results for the synthesis of the heaviest systems. Therefore new reaction cross-section data are important ingredients to improve these codes and "tune" the input parameters.

Some results of recent spectroscopy studies and excitation function measurements are presented below.

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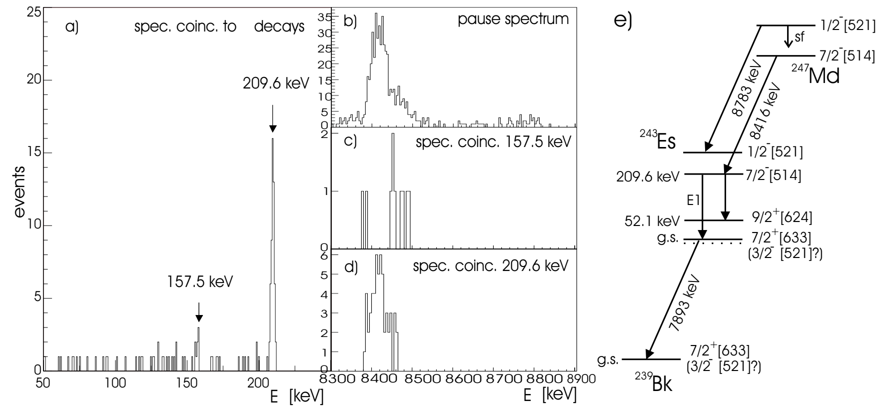

Fig. 1. Results for the reaction ^{40}Ar(4.67AMeV)+^{209}Bi. a) γ spectrum in coincidence to α decays of 8380 - 8900 keV. b) α spectrum taken in beam pause c) and d) α spectra in coincidence with 157.5 keV and 209.6 keV γ transition, respectively, e) Proposed decay schemes for ^{247}Md and ^{243}Es.

2 Experimental Setup

Information about nuclear structure can be obtained by means of decay spectroscopy or in-beam spectroscopy methods. Using in-beam spectroscopy information about the de-excitation process of the compound nucleus immediately after particle evaporation is obtained. The detectors for measuring γ-rays and CEs are placed around the target position. The disadvantage of the in-beam spectroscopy method is the present limitation for reaction cross section of few 100 nb due to limited beam intensity caused by maximum counting rate around 10000 /s in a single Ge detector that can be processed.

Decay spectroscopy is a powerful tool for a study of low lying excited levels. Most of the presently known nuclear structure information in the region of heavy neutron deficient isotopes was obtained in decay spectroscopy measurements. In most of the present experimental setups a sensitive detection system is combined with an in-flight separator to dissever the reaction products from primary beam. Our experiments were performed at the velocity filter SHIP at GSI Darmstadt. The detector setup and calibrations are discussed elsewhere [1].

3 Results

3.1 Decay of ^{247,246}Md and their daughter products

The isotopes ^{247,246}Md were produced in the reaction ^{40}Ar+^{209}Bi. Known decay data of ^{247}Md were confirmed in our experiment by α decay of E_α = 8416$\pm$10 keV and half-life of 1.3 $\pm$ 0.1 s. The hindrance factor (HF) $\approx$1 indicates equal spin and parity for the ground-state of ^{247}Md and corresponding state populated in ^{243}Es. Isomeric spontaneous fission (SF) activity tentatively reported before [2] was confirmed by observation of 24 SF events in beam pause with the half-

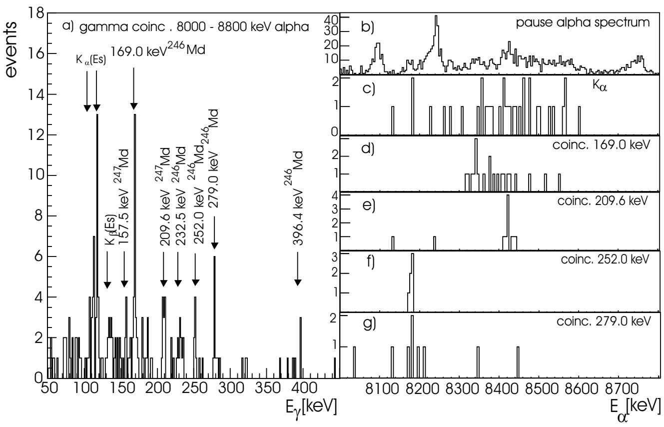

Fig. 2. Results for the reaction ^{40}Ar(4.95 AMeV)+^{209}Bi. a) γ transitions in coincidence to α decays of 8000-8800 keV b) α spectrum taken in the beam pause. Further are shown the alpha spectra in coincidence with c) K$_\alpha$ X rays and d) 169.0 keV, e) 209.6 keV, f) 252.0 keV and g) 279.0 keV γ lines.

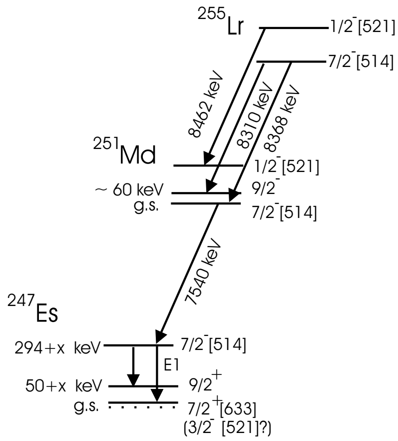

Fig. 3. Proposed decay scheme of ^{255}Lr and ^{251}Md. Given level energies are in keV.

life of 0.3±0.1 s. Beside this, previously unknown α activity with energy of 8783±40 keV and a half-life 0.26±0.03 s was observed and - according to similar half-lives - both activities were attributed to the decay of the same isomeric state for witch SF branching ratio of b$_{SF}$ = 23 % was obtained. An indication of g.s.-g.s. decay at the energy of 8660±20 keV (not shown in the figure) was found. Using the method of delayed α-α coincidences the decay of ^{243}Es was studied. The strong α decay line of 7893±10 keV and half-life 23±2 s confirm the results of previous measurements. The presence of 7939 keV line reported before [3] was not confirmed. Weak line of 7860±20 keV indicates the α-decay into excited level with the energy around 40 keV. By comparing the number of ^{247}Md and ^{243}Es decays the α-branch for ^{243}Es can be estimated to be b$_\alpha$ = 59.7 ± 2.5 %. Two γ-lines with energies of E$_\gamma$ = 209.6±0.5 keV and E$_\gamma$ = 157.5±0.5 keV were identified in coincidence with α - decay of ^{247}Md (see fig. 1a)). The ground-state assignment for ^{243}Es is uncertain and the existence of two low lying levels 3/2$^-$[521] and 7/2$^+$[633] seems to be possible (see [4] for more details).

Figure 2 b) shows strong influence of ^{246}Md α-decay energy summing with CE. The α-decays of 8250-8690 keV with the half-life of 1.3±0.4 s are in coincidence with γ transitions of 169.0 keV, 232.5 keV, and 396.4 keV. The activity of 8744±10 keV has half-life of 0.75±0.18 s. Additionally in coincidence with γ transitions of 252.0 keV and 279.0 keV weak line of 8178±10 keV was observed and assigned - due to its different lifetime of 4.4±0.8 s - to the decay from isomeric state ^{246m}Md. It had been already realized in previous experiments that the number of SF events exceeded the value expected from known SF branch of ^{246}Fm produced by EC decay of ^{246}Md. This was previously explained by EC delayed fission branch [5]. Our results gave reasons to explain this excess by SF branch of this isomeric state. For ^{242}Es we observed γ rays of 86.6 keV, 107.0 keV and 122.4 keV in coincidence with its α decays of 7780 - 7960 keV. The α decay of E$_\alpha$ = 8025±20 keV was tentatively assigned as g.s.-g.s. transition.

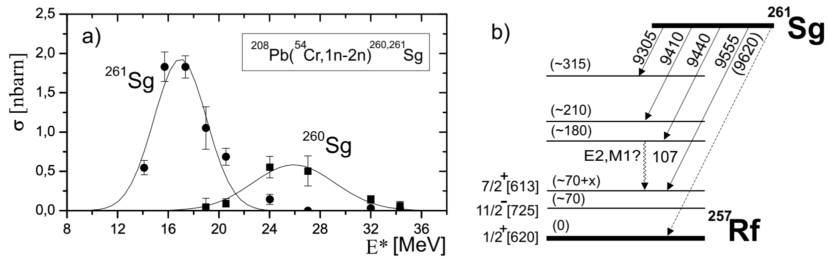

Fig. 4. a) Excitation function measurement for reaction ^{54}Cr+^{208}Pb b) Tentative proposal for decay scheme of ^{261}Sg. All energies in decay scheme are given in keV.

3.2 Decay of ^{255}Lr and its daughter products ^{251}Md

The isotope ^{255}Lr was produced in reaction of ^{48}Ca+^{209}Bi. Besides the α-decay of 8369±10 keV with the half-life of 19.9 ± 5.3 s weak line of 8310±10 keV was observed and interpreted as the decay into the 9/2$^-$ excited level of the rotational band build on the 7/2$^-$[514] ground state of ^{251}Md. Additionally also the α-decay of 8462 ± 10 keV and half-life of 2.56 ± 0.25 s was identified and assigned to the decay from the isomeric 1/2$^-$[521] state. For its daughter product ^{251}Md two γ transitions were detected. The transition with the energy of E_γ = 294 keV and E1 character was explained as a de-excitation from the 7/2$^-$[514] Nilsson level - populated by the α-decay - into the 7/2$^+$[633] level. The E_γ = 244 keV transition was explained as the de-excitation feeding 9/2$^+$ level of the 7/2$^+$[633] rotational band (see fig. 3).

3.3 Decay of ^{261}Sg

The isotopes ^{261}Sg and ^{260}Sg were produced in excitation function measurement of ^{54}Cr+^{208}Pb (see fig. 4 a). The maximum value of 1.9 nb for the 1n channel at E* = 16 MeV exceeds more than 3 times the maximum value of 0.6 nb for 2n channel at E* = 26 MeV of excitation energy.

The decay of ^{261}Sg shows a fine structure influenced by energy summing with CE. In coincidence with α-decay besides K-X-rays we observed 107 keV γ-transition and ascribed it as an E2 or M1 transition. The analysis reveals an existence of the isomer 7/2$^+$[613] populated by 9555 keV α-decay. Another isomer of 11/2$^-$[725] is expected from the knowledge of ^{257}Rf decay. In addition, an indication of g.s.-g.s. transition of 9620 keV was observed. The ground state and isomeric J^π values are attributed according to the predictions of [6] and systematics of N = 153 isotones. A tentative decay scheme for ^{261}Sg as shown in fig. 4 b) may be proposed.

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