γ SPECTROSCOPY OF NEUTRON-RICH NUCLEI WITH $A \approx 100$ PRODUCED BY CLUSTER TRANSFER REACTIONS AT REX-ISOLDE*

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In this work, we present an exploratory experiment performed at REX-ISOLDE to investigate neutron-rich Sr, Y and Zr nuclei around mass $A = 100$ by cluster transfer reactions of radioactive ^{98}Rb/^{98}Sr beams on a ^{7}Li target. The goal of the experiment is to test the potential of cluster-transfer mechanism to study the low-lying structure of neutron-rich nuclei, performing, as a first case, a γ-spectroscopy study of the structure in deformed nuclei beyond $N = 60$ populated, so far, only via β decay and spontaneous fission experiments.

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1. Introduction

Neutron-rich nuclei play an important role in the study of nuclear structure and shell evolution towards the neutron drip line. During the last decade, the employment of radioactive ion beams made it possible to investigate new isotopes, not accessible by stable beam-target combinations. To study even more exotic regions of the nuclide chart, new experimental techniques must be developed to face the new challenges of modern nuclear physics and take advantage of the new generation of radioactive ion beams facilities, such as HIE-ISOLDE, SPIRAL2, SPES, *etc.* It has been shown that multi-nucleon transfer reactions represent a powerful tool to study neutron-rich nuclei and, in particular, cluster-transfer reaction can be used to populate exotic nuclei at medium-high spin and excitation energy [1]. ^{7}Li is especially suitable for this purpose since it has a pronounced cluster structure, with an α and a t as components. Owing to a separation energy of 2.5 MeV, it easily breaks up and one of the two fragments has a sizeable probability to be captured. In this work, for the first time, the combination of a radioactive beam with cluster transfer reactions is presented. This technique may turn out to be very useful in future and the present experiment is meant as a first step of a research program aiming at γ-spectroscopy studies of the low-lying structures of neutron-rich nuclei produced employing cluster-transfer reactions.

2. Experiment

The experiment has been performed at REX-ISOLDE [2] accelerating a radioactive ^{98}Rb beam at 2.85 MeV/A, with an average intensity of 2×10^4 pps, on a 1.5 mg/cm^2 thick LiF target. Due to the short ^{98}Rb lifetime ($\approx$ 100 ms), a strong component of ^{98}Sr, the β-daughter of ^{98}Rb, has been observed in the beam. The experimental set-up was made by the HpGe array MINIBALL [3] coupled to the Si detector set-up T-REX [4] to measure γ-particle coincidences. The MINIBALL spectrometer is a high-resolution HpGe detector consisting of 24 six-fold segmented crystals, characterized by good spatial resolution. In the present experiment, it had an efficiency of 5% at 1 MeV. T-REX is a Si detector set-up optimized for transfer reactions in inverse kinematics and designed to be used in combination with the MINIBALL array. It is made by two CD detectors [5] placed at forward and backward angles plus eight lateral square detectors forming a barrel. In the present experiment, only the forward CD detector has been used in the new configuration at 22 mm from the target. This resulted in a wide angular coverage between 21° and 62°. The forward CD detector is made by two layers of 140 μm and 1500 μm, respectively, and it is used as a ΔE–E telescope to detect and identify charge particles.

3. Discussion

In the experiment, α or t transfer reactions were selected by detecting the complementary charged particle, t or α, in coincidence with the γ cascade. This gives a precise trigger on the final channel. Due to the high excitation energy, above the neutron threshold, γ emission is preceded by 2- or 3-neutron evaporation. Figure 1 shows the ΔE–E spectrum measured by the Si detectors. The most intense channels are the elastic scattering of ^{7}Li and protons (the latter were target contaminants), and the inelastic scattering of ^{7}Li and ^{19}F that cannot be identified since they were stopped in the ΔE detector. The channels of interest in this experiment correspond to the detection of α and t (t and α transfer respectively), whose events lie in the spectrum together with ^{7}Li elastic break-up. Thanks to the coincident detection of characteristic γ-rays, transfer events could be identified providing an estimate for the elastic break-up events of about 20% of the total α and t detected.

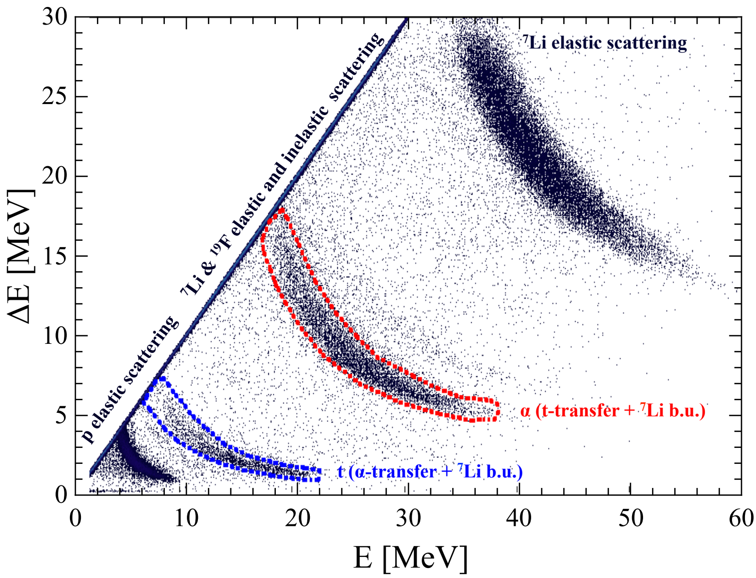

Fig. 1. E–ΔE spectrum measured by the Si telescopes of the T-REX setup. The regions delineated by dark grey/red and grey/blue dotted lines are associated to α and t particles, respectively. Elastic scattering of ^{7}Li and protons (contaminants on the LiF target) is also identified clearly, while diagonal events are associated to inelastic scattering of ^{7}Li and ^{19}F particles (fully stopped into the ΔE detector).

Figure 2 shows γ-rays measured in coincidence with α and t after 2- or 3-neutron evaporation. The spectra are Doppler corrected on an event-by-event basis. For this purpose, only the position of MINIBALL crystals has been used since the very inverse kinematics ensures that reaction products are limited in a small forward cone and travel downstream along the beam direction. Thus, to a first approximation, no recoil detection was needed for Doppler correction. Since reactions took place both on ^{98}Rb and ^{98}Sr (the two components of the beam), γ-rays in the two cases have been identified. While in the Rb case both 2- and 3-neutron evaporation chan-

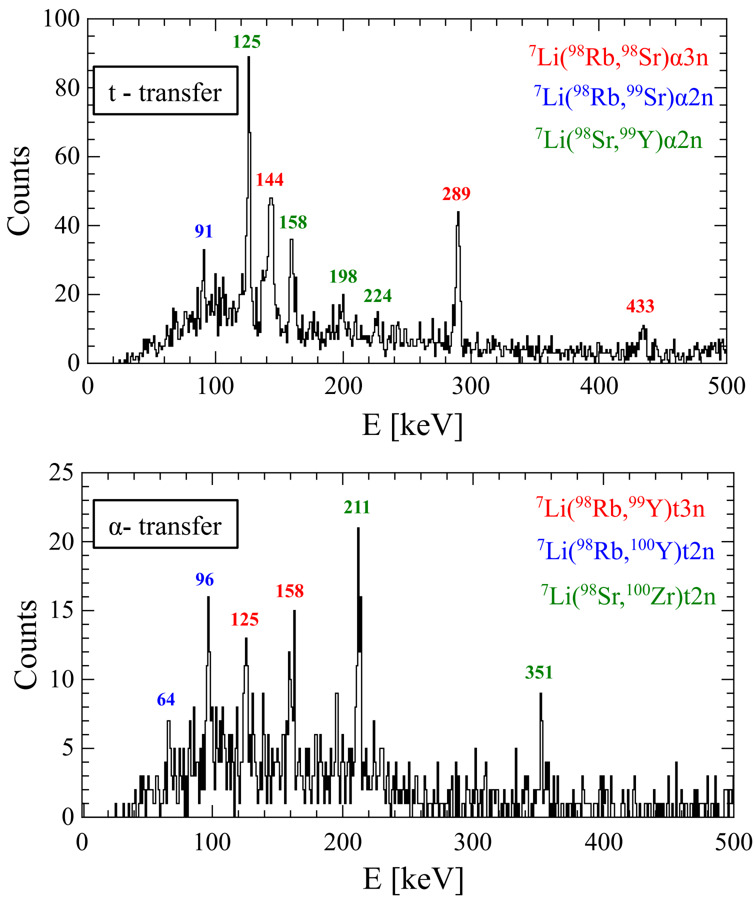

Fig. 2. γ-rays detected in coincidence with α (top panel) and t (bottom panel) corresponding to t and α transfer, respectively. In both spectra, transitions in Sr, Y and Zr isotopes can be identified and associated to different final channels, as explained in the text.

nels have been observed, in the Sr case only the $2n$-channel can be seen. By t-transfer on ^{98}Rb, $^{99-98}$Sr have been populated, while on ^{98}Sr the final channel is ^{99}Y. In the α-transfer channel, $^{99-100}$Y can be associated to reaction on ^{98}Rb, while on ^{98}Sr only ^{100}Zr can be observed. The difference in neutron evaporation can be associated to different neutron binding energy in the reaction products. The corresponding level schemes show that, in the t-transfer channel, states with spin up to $6\hbar$ have been populated, while in the α-transfer a maximum of $4\hbar$ has been seen. Despite the high excitation energy reached after the transfer (≈ 20 MeV in t-transfer and ≈ 15 MeV in α-transfer), only low-lying γ transitions belonging to the ground state bands have been measured after neutron evaporation. We speculate that the limited spin and excitation energy distribution here observed is probably related to the poor statistics collected in this first test experiment.

4. Conclusion

In this work, for the first time, the potential of cluster-transfer reactions in combination with radioactive beams as probes of nuclear structure properties has been studied. A test experiment has been performed at REX-ISOLDE using a ^{98}Rb/^{98}Sr beam on a ^{7}Li target. On the one hand, the analysis shows that particle-γ measurements make it possible to achieve a very clean identification of final reaction products. On the other hand, it has been seen that a large variety of nuclei has been populated with spin up to $6\hbar$, confirming the power of such a technique for nuclear structure studies. In the future, the same approach can be used to study even more exotic nuclei with a new generation of radioactive ion beams.

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