Spectroscopy of the lightest nuclei in the Lanthanide region

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INTRODUCTION

One of the most exciting subjects in contemporary nuclear physics is the study of nuclei at the limits of stability with respect to particle emission. Recently, there has been an intensive experimental activity in measuring the proton decay and a large variety of proton emitters were observed in the region of heavy nuclei with 50 < Z < 82. Very recently the proton radioactivity from ^{117}La [1], ^{121}Pr[2], ^{131}Eu and ^{141}Ho [3] has been identified. The proton decay rates deviates significantly from calculations assuming spherical configurations, thus indicating the onset of large deformations in the drip line nuclei below Z=69. However, a detailed study of the structure of these nuclei can only be performed by means of γ-ray spectroscopy using large detector arrays coupled with efficient light charged particles detectors, since the cross section for their population with the presently available stable beams are very low.

The lightest nuclei in the lanthanide region for which spectroscopic information has been published are ^{123}La [4], ^{124}Ce [5], ^{125}Pr [6] and ^{128}Nd [7]. These data indicate a strong quadrupole deformation β_2~0.35.

In order to establish the lowest single-particle excitations close to the point of the predicted [8] maximum deformation in this mass region (N,Z=64), we have studied the structure of the $^{122}La_{65}$, $^{123}Ce_{65}$ and $^{127}Nd_{67}$ nuclei with the GASP+ISIS+neutron ring setup.

We would like to stress that in our previous experiment for the study of nuclei in this mass region, we have used the GASP+ISIS+RMS setup and identified for the first time excited states in ^{126}Pr [9], as well as new bands in ^{122}Ba [10], ^{125,126}Ce [11] and ^{128}Nd [7].

EXPERIMENTAL DETAILS

We used the ^{40}Ca+^{92}Mo reaction, with a 200 MeV ^{40}Ca beam of 5 pnA intensity. The target was a stack of two self-supporting ^{92}Mo foils enriched to 97%, with a thickness of 0.5 mg/cm^2 each. The nuclei of interest $^{122}La_{65}$, $^{123}Ce_{65}$ and $^{127}Nd_{67}$ were populated via the 2αpn, 2αn, and αn channels, respectively, with cross-sections of around 8, 3 and 0.3 mb, respectively. The use of the neutron detectors recently installed in the GASP array was absolutely necessary for the selection of the lightest nuclei populated in the reaction.

The experimental setup was carefully prepared, to minimize the absorption of the low energy X-rays. The tuning of the signal processing electronics to optimize the detector response in the energy range below 50 keV led to an increased coincidence rate between the X and γ rays.

The assignment of the observed γ-ray cascades to a specific residual nucleus was done using the following selection method. The nuclides with different Z were distinguished by means of the coincidence X-rays as measured by the GASP detectors. The selection with respect to the number and type of evaporated charged particles were performed with the ISIS detector. The γ-lines belonging to the lightest nuclei were assigned based on the spectra in coincidence with the evaporated neutrons which hit the detectors mounted at forward angles in the GASP array.

PRELIMINARY RESULTS

The data of the present experiment were summed to the data of our previous experiment [9] performed at a beam energy of 190 MeV, getting therefore a total of 5.9x10^9 Compton-suppressed events. The events were sorted according to the number of charged particle and neutron detectors that fired in coincidence. For each charged particle and neutron combination Eγ-Eγ and Eγ-Eγ-Eγ matrices were produced off-line for further analysis.

We present here preliminary results on only one of the nuclei of interest populated in the reaction, ^{122}La. The level structure of ^{122}La was mainly deduced from the analysis of the 1α1p- and 2α1p-gated spectra, which presented a reasonable good statistics to enable the analysis of the triple coincidences and therefore to eliminate the strong contaminating γ-lines of ^{122}Ba populated via the 2α2p reaction channel. We have identified for the first time excited states in ^{122}La, which thus becomes the lightest Lanthanum isotope with known spectroscopic information. The observed rotational cascades were separated in three bands. Two of the observed bands are linked by several transitions, while the third one is floating.

The assignment of the observed bands to ^{122}La is based on the internal conversion X-rays seen in the spectra in coincidence with the γ-rays of the bands, and on the coincidence with the neutrons. As can be seen in fig. 1, where spectra in coincidence with one γ-ray assigned to the new bands in ^{122}La obtained from the 2α1p and 2α1p1n matrices are shown, even if the statistics of the 2α1p1n spectrum is low, the γ-rays present in the 2α1p spectrum are clearly seen.

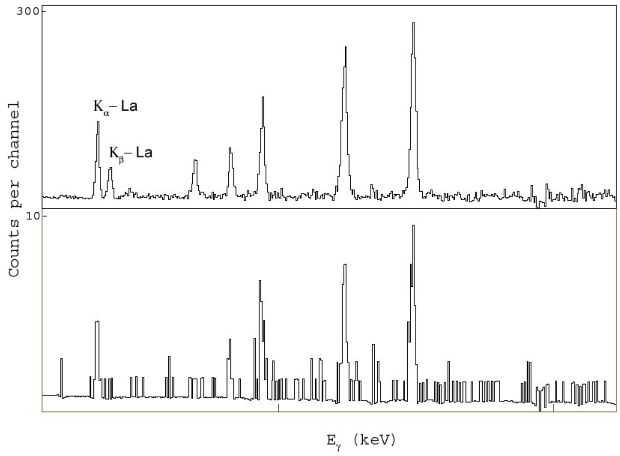

Fig. 1. Spectra in coincidence with one γ-ray assigned to ^{122}La, extracted from the 2α1p matrix (upper panel) and 2α1p1n matrix (lower panel).

One of the observed bands has properties (aligned single-particle angular momentum, signature staggering, etc.) similar to the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands observed in the neighboring odd-odd nuclei. In order to see how the level spacing in the two signature partners changes with decreasing neutron number, we plotted in fig. 2a and 2b the systematics of the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in the sequence of the odd-odd lanthanum nuclei. As we can see, there is significant decrease of the level spacing between ^{124}La and ^{122}La, nuclei with N=67 and N=65, respectively. This could be related to the closeness to N=66, the neutron number for which maximum deformation is expected in this region.

The data analysis is in progress, and we hope to identify new excited states also in the other nuclei at the limit of stability, ^{123}Ce and ^{127}Nd, that are also unknown from the spectroscopic point of view.

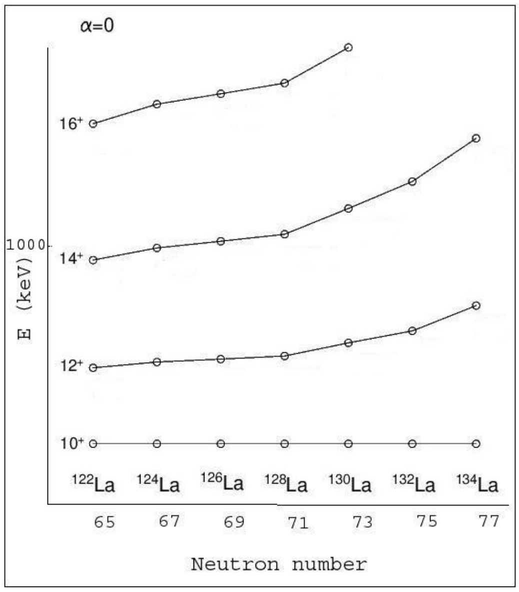

Fig. 2a. Systematics of the excitation energy for the α=0 signature of the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in the series of La nuclei.

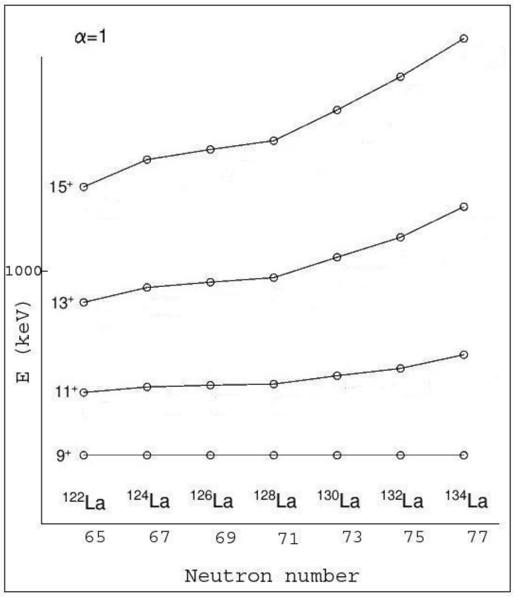

Fig. 2b. Systematics of the excitation energy for the α=1 signature of the $\pi h_{11/2}\otimes\nu h_{11/2}$ bands in the series of La nuclei.

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