Structure change of ^{156}Yb at high-spin states*

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Abstract High-spin states of ^{156}Yb have been studied via the ^{144}Sm(^{16}O,4n)^{156}Yb fusion-evaporation reaction at beam energy 102 MeV. The positive-parity yrast band and negative-parity cascade have been extended up to higher-spin states, respectively. The characteristics of the negative-parity sequence above the 25^- state may related to the excitation from the nucleon in the $Z=64$, $N=82$ core. The E-GOS curve for the positive-parity yrast sequence in ^{156}Yb indicate that this nucleus may undergo an evolution from quasivibrational to quasirotational structure with increasing angular momentum. The Cranked Woods-Saxon-Strutinsky calculations by means of Total-Routhian-Surface (TRS) methods has been made to understand this structure change.

Key words high-spin states, ^{156}Yb, structure change, alignment, fusion-evaporation

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1 Introduction

The light rare-earth nuclei around A=150 mass region, which locate above the double-closed shells N=82 and Z=64, have attracted a lot of experimental and theoretical studies. These experimental studies led to the identification of many interesting phenomena. At the same time, theoretical studies of the nuclear structure properties over a wide range of isospin, not only for the ground states[1—3] but also for the low and high-spin states[4—6], have been made to try to understand systematically the microscopic origin of these rich phenomena. Here, we report a study of high-spin states in ^{156}Yb, which are populated by the ^{144}Sm(^{16}O,4n)^{156}Yb fusion-evaporation reaction.

2 Experiment

The present experiment was performed at the HI-13 tandem facility of the China Institute of Atomic Energy (CIAE). The ^{144}Sm(^{16}O,4n)^{156}Yb reaction was used to populate the high-spin states in ^{156}Yb at beam energy 102 MeV. The target was ^{144}Sm with a thickness of 1.2 mg/cm^2. The deexcitation γ rays were detected by an γ detector array which consists of 12 high-purity germanium (HPGe) detectors

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with BGO anti-Compton suppressors and 2 planar high-purity germanium (HPGe) detectors. A total of 2.2×10^8 coincident events were collected, from which a symmetric γ-γ matrix was built. In order to obtain the DCO intensity ratios, the detectors around 90° with respect to the beam direction were sorted against the detectors around 40° to produce a two dimensional angular correlation matrix.

3 Results and discussion

The spectroscopy of ^{156}Yb has been previously studied via ^{144}Sm(^{16}O,4n)^{156}Yb reaction by the Lister et al.[7]. The partial level scheme of ^{156}Yb, deduced from the present work is shown in Fig. 1. It was constructed from γ-γ coincidence relationships, intensity balances and DCO analyses. In the earlier study[7], the yrast even-spin positive-parity cascade in ^{156}Yb was established up to spin 10^+ at 2956 keV and one γ-ray transition of 614.5 keV was tentatively assigned to the positive-parity sequence due to its too weak intensity. All these transitions were also observed by the present work and four new coincident γ-ray transitions of 520.3, 641.9, 731.9 and 733.3 keV were observed in the γ-ray spectra. The DCO ratio analyses suggest that γ-ray transitions of 520.3, 641.9 and 731.9 keV have quadrupole transition characters.

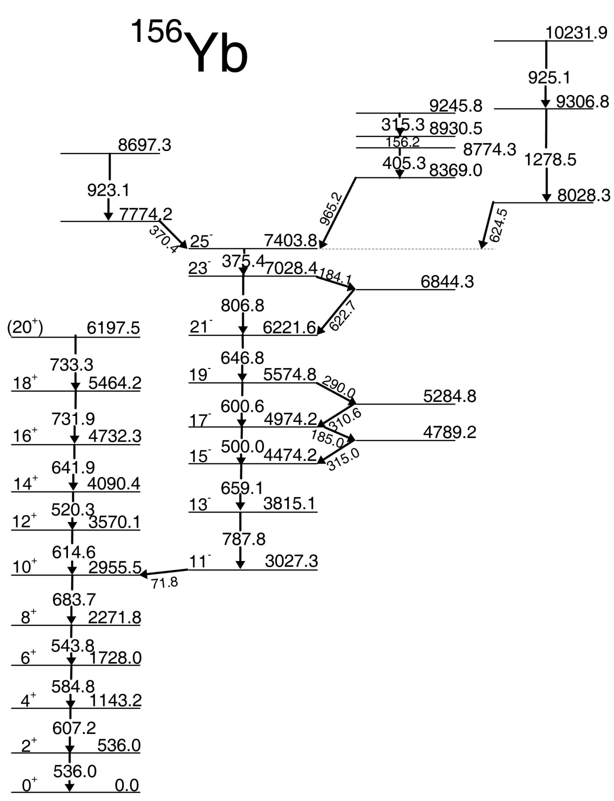

Fig. 1. Partial level scheme of ^{156}Yb. Energies are in keV.

A $J=11^-$ isomer has been observed in the N=86 isotones and the main configuration of its wave function was suggested to be the two neutron quasiparticle excitation $\nu(i_{13/2},h_{9/2})$. Built on the $J=11^-$ isomer in ^{156}Yb, an odd-spin negative-parity cascade up to spins 25^- at 7405 keV was found in Ref. [7]. In Ref. [7], four coincident γ-ray transitions were observed above the 25^- state. In the current study as shown in Fig. 1, above the 25^- state, the negative-parity sequence becomes irregular and fragments into several parallel branches. Since the angular momentum of these states above the 25^- state in ^{156}Yb is close to the maximum angular momentum possible from alignment of the valence particles outside the Z=64, N=82 core, these parallel cascades above the 25^- state in ^{156}Yb may involve the excitation from nucleon in the Z=64, N=82 core.

In contrast to the well defined rotational yrast bands observed in the neighboring even-A ^{158,160,162,164}Yb, the collective mode of motion in ^{156}Yb may have characteristic that ranges between quasivibration and quasirotation. This evolution from quasivibrational to quasirotational structure as a function of spin is manifest in the Fig. 2, where the E-GOS (E-Gamma Over Spin) curve is plotted. For a vibrator, the value of this ratio gradually diminishes to zero as the spin increases, while for an axially symmetric rotor it approaches a constant. As shown in Fig. 2, the E-GOS value of ^{156}Yb evolves from an approximate hyperbolic locus expected for quasivibrational structure to a constant, which is very close to the E-GOS value of good rotor ^{164}Yb. Our TRS calculations, which is shown in Fig. 3 indicate that the soft quadrupole deformation (β_2=0.139) at ground state in ^{156}Yb will be stabilized with the alignment of a high-j intruder $h_{11/2}$ proton pair. This may account for the evolution from vibrational to rotational structure in ^{156}Yb.

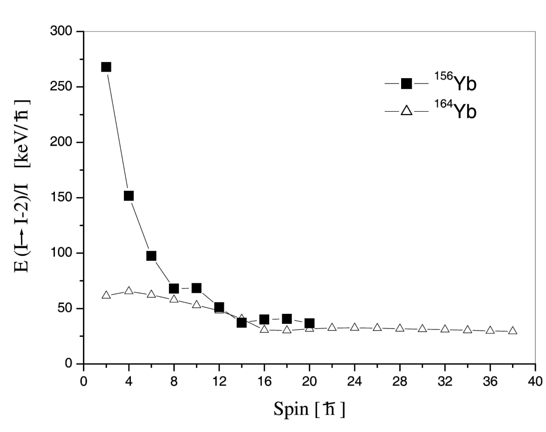

Fig. 2. E-GOS curves for the ^{156}Yb and ^{164}Yb.

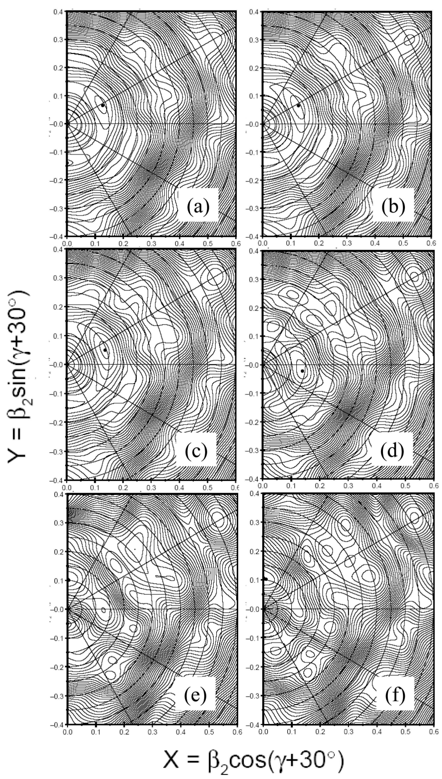

Fig. 3. TRS calculations for the yrast sequence in ^{156}Yb. The energy contours are at 200 keV intervals. The deformation parameters for the individual minima are (a) $\hbar\omega$ = 0.05 MeV, β_2 = 0.139, γ = −0.0°, and β_4 = 0.028; (b) $\hbar\omega$ = 0.15 MeV, β_2 = 0.142, γ = −2.9°, and β_4 = 0.030; (c) $\hbar\omega$ = 0.25 MeV, β_2 = 0.145, γ = −9.8°, and β_4 = 0.033; (d) $\hbar\omega$ = 0.35 MeV, β_2 = 0.141, γ = −39.0°, and β_4 = 0.029; (e) $\hbar\omega$ = 0.45 MeV, β_2 = 0.104, γ = 60.0°, and β_4 = 0.013; (f) $\hbar\omega$ = 0.55 MeV, β_2 = 0.106, γ = 60.0°, and β_4 = 0.013.

The excitation energy of the experimental positive parity states in ^{156}Yb minus a rigid rotor reference term is plotted in Fig. 4. The increase of energy as a function of spin has been observed, which also shows the evolution of rotation collectivity at high spin states. As shown in Fig. 3, at higher rotational frequencies above the alignment frequencies of the $h_{11/2}$ proton pair in ^{156}Yb, our TRS results predict a shape change with sizable alignments occurring: from prolate (γ=0°), via triaxial, to oblate (γ=60°). This shape change was also predicted by the theoretical calculations within the cranking approximation using the generalized Strutinsky methods[6] and has been observed in some experimental studies. For example, the spectroscopy studies of ^{160}Yb by Byrski et al. indicated that the nuclear shape will arrive γ=60° around spin 36$^+$ and band termination occurs.

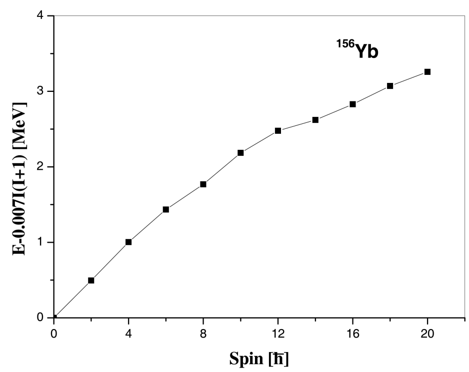

Fig. 4. Excitation energies of the yrast states as a function of spin for ^{156}Yb. A rigid rotor reference has been subtracted.

4 Summary

High-spin states in ^{156}Yb have been populated in the ^{144}Sm(^{16}O,4n)^{156}Yb fusion-evaporation reaction at beam energy 102 MeV. Based on the γ-γ coincidence relationships, intensity balances and DCO analyses, the level scheme of ^{156}Yb has been constructed. Several parallel cascades above the 25$^-$ state in ^{156}Yb were found in the present work. This pattern may involve the excitation from nucleon in the Z=64, N=82 core. The characteristic of E-GOS curve for the positive-parity yrast sequences in ^{156}Yb suggest that this nucleus may undergo an evolution from quasivibrational to quasirotational structure with increasing angular momentum. Our TRS calculations indicate that the alignment of a high-j intruder $h_{11/2}$ proton pair may be the origin of this structure evolution. At higher rotational frequencies for the ^{156}Yb, our TRS results predict a shape change with sizable alignments occurring: from prolate, via triaxial, to oblate.

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