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Shape Co-existence in ^{157}Yb *

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Abstract The excited states of ^{157}Yb have been studied in the ^{144}Sm(^{16}O,3n) reaction at ^{16}O energy of 90MeV using techniques of in-beam γ-ray spectroscopy. The level scheme for ^{157}Yb was established based on the measured results of γ-γ coincidences, γ-ray anisotropies and DCO ratios. The level scheme is dominated by two parallel de-exciting sequences with different characteristics, which correspond to collective rotation and single particle excitations, respectively. This shape co-existence, as well as the structural evolution of the yrast $\nu i_{13/2}$ band with increasing angular momentum, have been discussed briefly.

Key words γ-ray spectroscopy, level scheme, shape co-existence

In the rare earth region, the $N = 87$ nuclei are located in the transitional region. For the nuclei with $N < 87$, the excited states appear to consist mainly of proton and neutron quasiparticles coupled to large angular momenta[1-3], while the nuclei with $N > 87$ display a collective rotational decay pattern at low and moderately high spins which seems to terminate while the nucleus develops an oblate shape at higher spins[3-6]. Thus, the rare earth nuclei with 87 neutrons should manifest the pronounced transitional behavior in this region, and both rotational and single-particle degrees of freedom can coexist and generate angular momentum in the same nucleus[7-9]. Moreover, the theoretical calculations indicate that the nuclei with $N = 87$ should experience a special shape transition along the yrast line from prolate through triaxial to oblate, the so called band termination[8,9]. In such a case a nucleus undergoes a gradually loss of collectivity while the nuclear shape acquires an axial symmetry with respect to the direction of spin duo to the alignment of high-j quasiparticles. Therefore, the nuclei with $N = 87$ should provide a best environment to study the shape coexistence and shape transition effects through the interplay of individual and collective degree of freedom. Before the present study, the $13/2^+$ isomer with a quite pure $\nu i_{13/2}$ configuration and several low-lying levels were reported for ^{157}Yb[10-12], but a high spin level scheme has not been published formally.

The excited states in ^{157}Yb were populated via the ^{144}Sm(^{16}O,3n)^{157}Yb reaction. The ^{16}O beam was provided by the tandem accelerator at the China Institute of Atomic Energy (CIAE). The target is an isotopically enriched ^{144}Sm metallic foil of 1.3mg/cm^2 thickness with a 7mg/cm^2 Pb backing. This combination of projectile and target was used previously, and the beam energy of 88MeV was determined to be suitable for populating the high spin states in ^{157}Yb[12]. In the present work,

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γ-γ-t coincidence measurements were carried out at beam energy of 90MeV with 11 BGO(AC) HpGe detectors, having energy resolutions of 1.9—2.3keV at 1.33MeV. Here, t refers to the relative time difference between any two coincident γ rays detected within ± 100ns. These detectors were divided into 3 groups positioned at 35°(± 145°), 55°(± 125°), and 90° with respect to the beam direction so that the γ-ray anisotropies and DCO ratios (Directional Correlations of γ rays de-exciting the Oriented states) could be deduced. All the detectors were calibrated using the standard ^{152}Eu and ^{133}Ba sources. A total of 130×10^6 coincidence events were accumulated. After accurate gain matching, these coincidence events were sorted into a symmetric matrix and an asymmetric DCO matrix for off-line analysis.

Assignments of the observed γ rays to ^{157}Yb were based on the coincidences with the known γ-rays[11,12]. Gated spectrum was produced for each of the γ rays assigned to ^{157}Yb. Selected spectra are shown in Fig. 1. Based on the analysis of the γ-γ coincidence relationships, a level scheme for ^{157}Yb is proposed as shown in Fig. 2. The orderings of the transitions in the level scheme are fixed either with the help of some cross-over transitions or from the consideration of intensity balance in the gated spectra. The spins for the levels have been proposed according to the analysis of DCO ratios and γ-ray anisotropies. The weak cascade of 206 and 324keV transitions is in coincidence with all strong lines, excepting the 494keV one. Although the 206 and 324keV transitions have too weak intensities to determine their transition orders, with the addition of these two transitions in the level scheme the energy of all other levels is established firmly. Particularly, the excitation energy of the $13/2^+$ isomer is fixed at 530keV. In the previous work[12], the $13/2^+$ isomer was reported for ^{157}Yb, but its excitation energy remains unknown. The low-lying level structure of ^{157}Yb follows the systematics of the lighter $N = 87$ isotone very well[7—9]. In all of these isotones the $13/2^+$ isomers were observed, and these isomers are depopulated by a low energy transition to a $11/2^-$ state decaying to the $\nu f_{7/2}$ ground state.

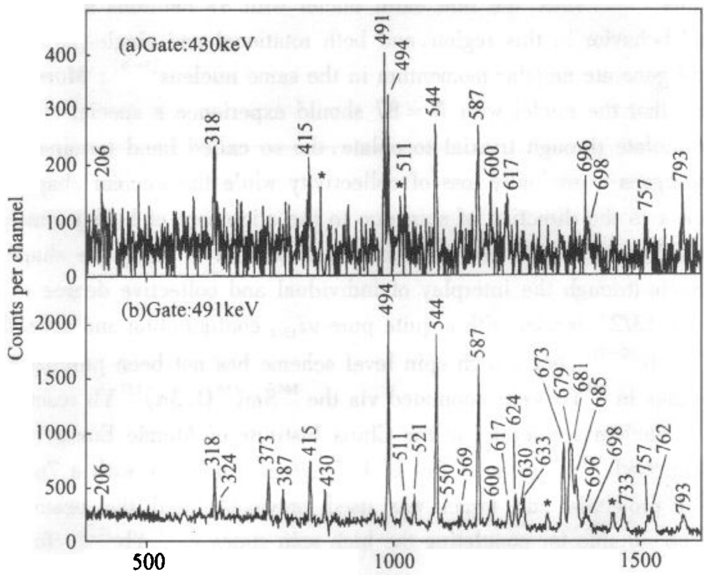

Fig. 1. Spectra of γ rays gated on the 430 and 491keV transitions, respectively.
The * symbols indicate contaminations.

Above the 13/2$^+$ isomer, the level scheme of ^{157}Yb is dominated by two characteristic sequences of transitions. One of them shows a regular rotation-like cascade of E2 transitions starting from the 13/2$^+$ isomer, and then its structure changes into a vibration-like excitation mode with five successive transitions with almost constant energies. Based on the systematics of the level structure in the N = 87 isotones[7—9], this sequence of transitions should be the $\nu i_{13/2}$ band, and it terminates at state with spin value of 45/2. The other one consists of irregular E2 transitions upto the 4706 keV level. These two sequences are interconnected by five transitions. The irregular sequence is very similar to that in the neighboring isotone of ^{155}Er[9], which has most likely the slightly oblate configuration of $\nu[f^3_{7/2} h_{9/2} i_{13/2}]$ suggested by the tilted Fermi surface calculation. The low-lying part of the $\nu i_{13/2}$ band exhibits collectivity in smoothly increasing transition energies. With increasing excitation energies the collective and single particle modes of generating angular momentum compete as demonstrated by the two parallel de-exciting sequences with different characteristics. The $\nu i_{13/2}$ band loses its collectivity as manifested by the appearance of equidistant spaced levels. In the region around excitation energy of 5MeV, the level scheme shows several competing de-excitation pathways consisting of cascade of dipole and quadrupole transitions with irregular energies. These observations indicate that the low-spin collective character of ^{157}Yb gives a way to single particle configurations at higher spins. This structural phenomena is similar to those in the lighter N = 87 isotones[7—9], in which the collective $\nu i_{13/2}$ bands terminate at $I^{\pi} \approx 41/2^+$ at the oblate shape configuration and particle-hole excitations dominate the higher-lying level structure. The shape evolution of the $\nu i_{13/2}$ bands in the N = 87 isotones has been interpreted quite well by the total energy surface calculation[8]. For these isotones, the Fermi level is positioned near the bottom of the $i_{13/2}$ shell. Therefore, the $i_{13/2}$ quasiparticles exert a strong polarizing force that drives continuously the nucleus toward increasing positive triaxial-γ deformation while increasing angular momentum, and finally reaches a $\gamma = 60°$ noncollective oblate shape, thus resulting in band termination[8]. It should be pointed out that the structural evolution of the $\nu i_{13/2}$ band in ^{157}Yb follows generally the systematic of the lighter isotones, but the detailed structure of these $\nu i_{13/2}$ bands is different. The $\nu i_{13/2}$ bands in ^{153}Dy and ^{155}Er display collective rotational behavior upto the terminating states, while the high-lying part of the $\nu i_{13/2}$ band in ^{157}Yb shows a vibration-like structure pattern.

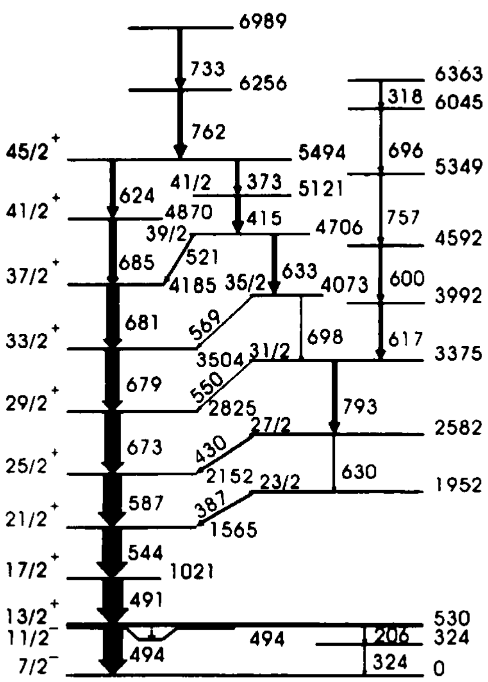

Fig.2. Level scheme of ^{157}Yb proposed in the present work.

In summary, the low-lying level scheme of ^{157}Yb show a coexistence of slightly oblate and weak prolate deformations. With increasing angular momentum, the $\nu i_{13/2}$ band in ^{157}Yb loses gradually its collectivity with its structure evolving into a vibration-like pattern, and finally this band gives a way to single particle excitations. The present work shows the N = 87 nucleus ^{157} Yb to be transitional in two respects. Not only it connects the isotopes ($N < 87$) that have spherical or oblate shapes to those($N > 87$) with pronounced prolate shapes, it also exhibit features of both groups.

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^{157}Yb的形状共存研究*

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摘要 利用在束γ谱学方法,通过反应^{144}Sm(^{16}O,3n)^{157}Yb研究了^{157}Yb的激发态能级结构.实验中使用的^{16}O束流能量为90MeV.基于实验得到的γ-γ符合关系、γ射线的各向异性度和DCO系数,建议了^{157}Yb的高自旋能级纲图.^{157}Yb的能级纲图主要由两串跃迁性质明显不同的级联能级组成,它们分别对应于$\nu i_{13/2}$转动带和单粒子激发态.着重讨论了^{157}Yb的形状共存和$\nu i_{13/2}$转动带随角动量的结构演化.

关键词 在束γ谱学 ^{157}Yb的能级纲图 形状共存

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