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High spin band structure in ^{139}Nd*

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Abstract High-spin states in ^{139}Nd nucleus have been reinvestigated with the reaction ^{128}Te (^{16}O, 5n) at a beam energy of 90 MeV. The level scheme has been expanded with spin up to 47/2 $\hbar$. At the low spin states, the yrast collective structure built on the $\nu h^{-1}_{11/2}$ multiplet shows a transitional shape with $\gamma \approx 32^\circ$ according to calculations of the triaxial rotor-plus-particle model. Three collective oblate bands with $\gamma \sim -60^\circ$ at the high spin states were identified for the first time. A band crossing is observed around $\hbar\omega \sim$0.4 MeV in one oblate band based on the 25/2$^-$ level.

Key words high-spin states, γ-γ coincidence, band crossing, oblate band

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1 Introduction

The odd-A ^{139}Nd nucleus with Z=60 and N=79 lies in the transitional region with the neutron number approaching the closed shell at N=82. In this region, their level structures exhibit complex characteristics as existence of competition between the collective motion and the single-particle motion. At high spin states, as the proton Fermi surface lies near the bottom of the $\pi h_{11/2}$ subshell and the neutron Fermi surface lies near the top of the $\nu h_{11/2}$ subshell, the rotational alignment of a pair of protons from the lower $h_{11/2}$ midshell drives the nucleus to a near-prolate ($\gamma \sim 0^\circ$) shape while the rotational alignment of a pair of $h_{11/2}$ neutrons from the upper midshell drives the nucleus to an oblate shape ($\gamma \sim -60^\circ$)[1] in the Lund convention[2]. Thus, the different excitations of quasiparticles may drive a nucleus to form different shapes and sometimes shape coexistence may be observed in a nucleus[3]. In previous publications, the high spin levels of many nuclei in this region, such as in ^{137}La[4], ^{137}Ce[5], ^{138}Pr[6], ^{137}Nd[7] and ^{140}Nd[8], have been extensively researched. In the previous works on ^{139}Nd, some lower spin levels by using the (^{16}O, 5n)[9] and (α, xn)[10, 11] reactions were reported. At very high spin states the triaxial superdeformed bands were observed through the (^{48}Ca, 4n) reaction [12]. In this article, we report on experimental research on high-spin states and collective-band structures in ^{139}Nd in more detail. When this work was in progress, Kumar et al. [13] published some high-spin states in ^{139}Nd. Comparing with the results obtained in Ref. [13], we updated the high-spin scheme of ^{139}Nd. Some new levels and transitions have been identified, a collective band structure reported in Ref. [13] is rearranged, and so that the three new oblate bands have been newly observed.

2 Experiment and results

High spin states in ^{139}Nd were populated via the ^{128}Te(^{16}O, 5n) fusion evaporation reaction at a beam energy of 90 MeV. An isotopically enriched ^{128}Te target of thickness 2.7 mg/cm^2 evaporated on a natural

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aurum backing of 22 mg/cm^2 was bombarded by a beam of ^{16}O ions accelerated by the HI-13 accelerator at the China Institute of Atomic Energy (CIAE). An array of fourteen Compton-suppressed Ge detectors was employed to measure the in-beam γ-rays. The resolutions of the Ge detectors are between 1.8 and 2.2 keV at 1.333 MeV γ-ray energy. A γ-γ coincidence matrix was built, from which the γ-γ coincidence dada analysis was carried out. After subtracting background, about 5.8×10^7 efficient coincidence events were collected. The γ-ray energies and efficiencies were calibrated with ^{152}Eu source. To determine the multipolarity of γ-ray transitions, five detectors near 90° with respect to the beam axis were sorted against the other nine detectors at 30°(three), 55°(one), 125°(one) and 150°(four) to produce a two dimensional angular correlation matrix from which it was possible to extract the average directional correlation of oriented state (DCO) intensity ratios. The γ-γ coincidence data were analyzed with the Radware software package[14]. The level scheme of ^{139}Nd deduced from the present study is shown in Fig. 1. It was constructed from the γ-γ coincidence, the relative transition intensities, and DCO ratio analysis. The transition intensities are represented by the width of arrows. Collective bands and cascades newly observed are labeled on the top of the scheme.

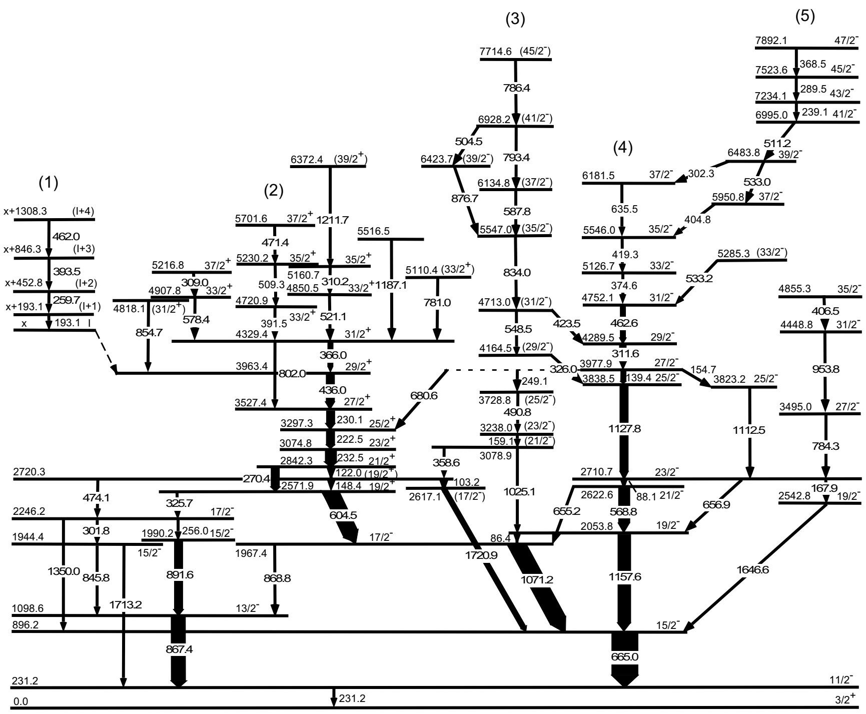

Fig. 1. Level scheme of ^{139}Nd.

3 Discussion

Shape transition is a very interesting phenomenon in A=135 transitional region. The prolate-oblate shape transition at the low spin states was reported in neighboring Ba[15], Ce[5, 16] and Nd[9] isotopes between N=77 and N=79. That is, in a isotopic chain the nucleus has a prolate shape with $\gamma < 30°$ at $N \leqslant 77$ and it has an oblate shape with $\gamma \geqslant 30°$ at $N \geqslant 79$. It has indicated that the sequence of the $13/2^-$ and $15/2^-$ levels of the $\nu h^{-1}_{11/2}$ multiplet is a signature of a prolate or an oblate shape. When the $15/2^-$ state lies up on the $13/2^-$ state, the nucleus has a prolate shape, whereas when the level inversion of the $13/2^-$ state and $15/2^-$ state occurs, the nucleus has an oblate shape. In order to further understand the structural characteristics at the low spin states in ^{139}Nd, we have performed calculations using the triaxial rotor-plus-particle model with a variable moment of inertia (VMI)[17—19]. In the calculations, the adjustable parameters are ε_2, γ and Coriolis attenuation factor χ. By varying the ε_2, γ and χ values, and by carefully comparing the calculated levels with the corresponding experimental ones, we determined these values used in the calculations as follows: $\varepsilon_2 = 0.11$, $\varepsilon_4 = 0.04$, $\gamma = 31.6°$ and $\chi = 0.76$. Other parameters were taken as standard. The results of our calculations and a comparison with experimental data are shown in Fig. 2. Generally, the agreement between the theoretical and experimental results is good. In the calculations, the levels are very sensitive to the parameters γ and χ, but not to ε_2 and ε_4. When we fixed other parameters, and changed the γ value from 0° to 45°, the levels varied with the γ value, as shown in Fig. 3. It indicates that the level inversion of $13/2^-$ state and $15/2^-$ state occurs around $\gamma = 31.6°$. The best agreement between calculational and experimental energy levels happens at $\gamma = 31.6°$. The prolate-oblate shape transition at the low spin states in the Nd isotopes indeed occurs between N=77 and N=79.

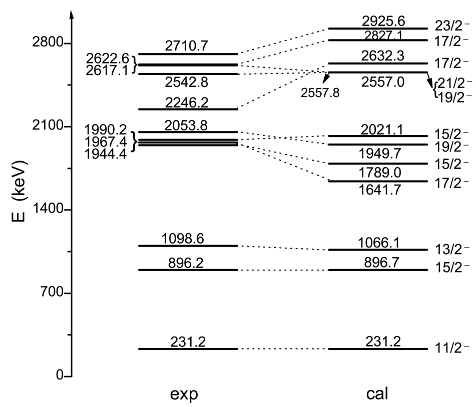

Fig. 2. Calculated levels of some members of the $\nu h^{-1}_{11/2}$ and comparison to the experiment for the ^{139}Nd.

The most interesting finding of the present study is the collective bands (1), (4) and (5). These three bands show similar features to the other known oblate bands in the $A\sim130$ region: (a) much stronger $\Delta I = 1$ transitions relative to the $\Delta I = 2$ transitions inside the band, (b) no signature splitting occurring, and (c) different moments of inertia ($J^{(1)}$) from those of prolate bands. Plots of the moments of inertia ($J^{(1)}$) of the collective bands (1), (2) and (3) in ^{139}Nd along with the oblate bands in ^{137}Ce[5], ^{138}Ce[20], ^{135}La[21], and ^{136}La[22] against the rotational frequency $\hbar\omega$ are shown in Fig. 4. One can see that the $J^{(1)}$ of the bands (1), (4) and (5) in ^{139}Nd show similar behavior to the oblate bands in the neighboring nuclei. Examining the band (4), we can see a backbending (band crossing) of band (4) occurs around at $\hbar\omega\sim$0.4 MeV. This band crossing may be caused by the alignment of a pair of protons, as the first alignment of a pair of neutron has happened to drive the nucleus to form the oblate shape at this band head level. The reason for this band crossing still needs to be confirmed by further works.

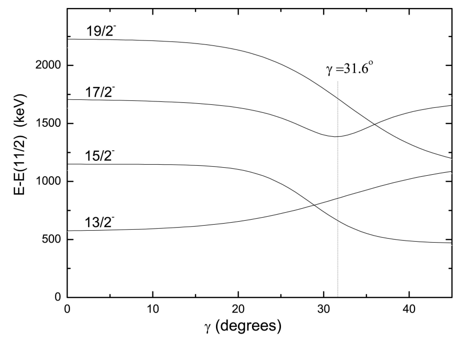

Fig. 3. The calculated some levels with γ value in ^{139}Nd. The vertical line indicates the experiment data. The energies of $11/2^-$ levels are taken as zero.

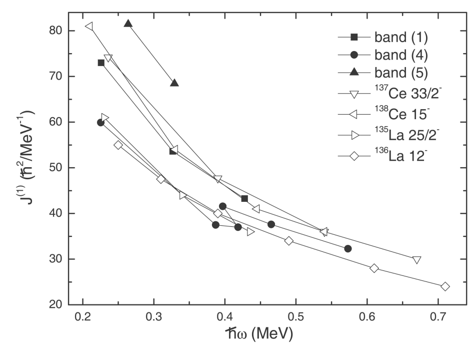

Fig. 4. Comparison of the moments of inertia ($J^{(1)}$) of bands (1), (4) and (5) in ^{139}Nd with the oblate bands in ^{137}Ce, ^{138}Ce, ^{135}La, ^{136}La and the prolate bands in ^{135}Ce.

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