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Short note

Yrast bands in N = 91 isotones

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Abstract. The in-beam spectroscopy on $N = 91$ isotones has been carried out using the ^{12}C + ^{150}Nd reaction. The $\nu i_{13/2}$ and $\nu h_{11/2}$ bands of ^{153}Sm have been extended up to $33/2^+$ and $31/2^-$, respectively. Two new γ-rays have been located on the top of the unfavored band with $\nu i_{13/2}$ configuration in ^{157}Dy. Two identical relationships have been established in the low-spin region of the yrast $\nu i_{13/2}$ configuration between ^{153}Sm and ^{155}Gd, and between unfavored bands of ^{155}Gd and ^{157}Dy. Here all these nuclei have the same neutron number $N = 91$.

PACS. 23.20.Lv Gamma transition and level energy – 27.70.+q $150 \leq A \leq 189$

The identical bands have been discovered in superdeformed(SD) rotational bands around ^{152}Dy [1]. After this discovery, many identical bands have been observed in the SD bands. I. Ahmad *et al.* have pointed out several ground-state bands have been identical in nuclei in $A \sim 240$ region [2]: the transition energies of the ground bands in ^{240}Pu, ^{244}Cm, ^{246}Cm and ^{250}Cf are similar within 2 keV for the states lower than 8 $\hbar$, while in ^{236}U and ^{238}U the energies are the same within 1 keV for the states lower than 24 $\hbar$. These phenomena for both normal bands and SD bands have been discussed generally by C. Baktash *et al.* [3]. However, the mechanism of the identical bands in low-spin states has been an open problem.

Nuclei in the mass ~ 150 region have been understood by interplay of collective motions and single-particle excitations. Nuclear deformations have a gradual transition from spherical shape in closed shell to a prolate deformation in neutron rich region. The last neutron of odd-N nuclei can occupy the $h_{11/2}$ or $i_{13/2}$ orbital near the Fermi surface in the single-particle states. It was reported that transition energies of the favored band with the $3/2[651](i_{13/2})$ configuration are identical in the γ-ray energies region between 300 and 700 keV in ^{155}Gd and ^{157}Dy from the experiment using ^{9}Be + ^{150}Nd reaction [4]. It has also been known that the proton [411]3/2 band in ^{155}Tb and the neutron [505]11/2 band in ^{155}Gd are identical in the range of γ-ray energy between 300 and 500 keV; both nuclei have the same even-even ^{154}Gd core [3]. Further investigation on the rotational bands of odd-A nuclei in $A \sim 150$ region is desirable to clarify the situation in which the identical bands occur in this mass region. In our previous paper, the details of the in-beam γ-ray experiment of ^{155}Gd and its nuclear structure were discussed [5]. During the experiment for ^{155}Gd using the ^{12}C + ^{150}Nd reaction, the high spin-states of ^{157}Dy and ^{153}Sm have also been observed. In this paper we report the existence of identical bands in the $N = 91$ isotones of ^{153}Sm, ^{155}Gd and ^{157}Dy. The nucleus ^{153}Sm is located near the neutron rich region, so that there is no typical (HI, xn) reaction that can populate the high-spin states of ^{153}Sm using heavier ion than alpha particle. In previous research for ^{153}Sm, the high-spin states have been studied using ^{150}Nd(α,nγ) reaction [8,9], and two rotational bands have been known with $\nu i_{13/2}$ and $\nu h_{11/2}$ configurations up to $21/2^+$ and $19/2^-$ respectively.

The nucleus ^{153}Sm was produced with the reaction ^{150}Nd (^{12}C, 2α1n) ^{153}Sm using the 65 MeV ^{12}C beam from the tandem accelerator at Japan Atomic Energy Research Institute (JAERI). The target was a self-supporting ^{150}Nd metallic foil enriched to 96.1 % with a thickness of 2 mg/cm^2. Gamma-rays from excited states populated after the reaction were detected with an array [6] of 11 HPGe detectors with BGO Compton suppressors, in coincidence with the particles detected by the Si-ball [7] parti-

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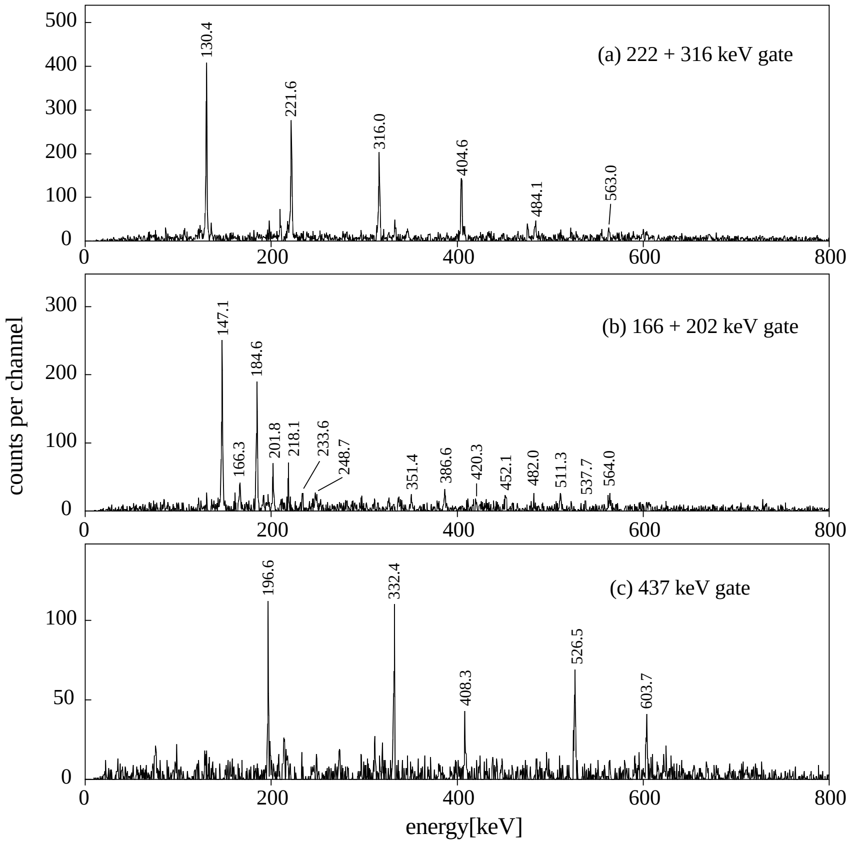

Fig. 1. (a) and (b) show gated spectra in ^{153}Sm and (c) shows $E2$ cascades in the unfavoured band of ^{157}Dy.

cle filter which was made up of 20 detector segments. The HPGe detectors were placed at the angles of 32°, 58°, 90°, 122° and 148° with respect to the beam direction. The energy resolutions of HPGe detectors were 2.0−2.3 keV at 1.3 MeV. The efficiencies of typical HPGe detectors were about 40 % relative to 3″ × 3″ NaI detector. Since the compound nucleus ^{162}Dy produced by ^{12}C+^{150}Nd fusion reaction is located in the neutron-rich region, dominant products in this reaction were the Dy isotopes through neutron evaporation channel. The Si-ball was used to identify the nuclei produced by α evaporation channel with a small cross-section. The experimental data were recorded on magnetic tapes event by event when two or more HPGe detectors and at least one segment of the Si-ball were fired. A smaller number of accidental events without the charged particle evaporation were also taken. The double or higher fold γ-γ coincidence events were sorted to E_γ-E_γ matrices which were tagged by the number of proton(s) and/or α particle(s) detected by the Si-ball. Approximately 2 × 10^7 γ-γ coincidence events were collected. The gated spectra were constructed from the 4096 × 4096 matrices. Relative intensities were derived from the gated spectra.

Figure 1 shows some gated spectra for ^{153}Sm and ^{157}Dy. The favored bands with $i_{13/2}$ configuration are observed in ^{153}Sm (fig. 1(a)) and fig. 1(b) shows typical $E2$ cascades and $M1$ interband transitions of the high-K $\nu h_{11/2}$ bands. The level scheme of ^{153}Sm was constructed from γ-γ coincidence relationships and intensity balances (fig. 2). Table 1 shows the γ-ray energies and relative intensities. The $\nu i_{13/2}$ and $\nu h_{11/2}$ bands were extended up to $33/2^+$ and $31/2^-$, respectively, in the present experiment. In the ^{157}Dy nucleus, two γ-rays are newly located on the top of the unfavored band with $i_{13/2}$ configuration (see fig. 1(c)).

In fig. 3, the yrast bands in ^{153}Sm, ^{155}Gd, and ^{157}Dy are compared with each other. It can be seen that the transition energies are similar within a few keV in these

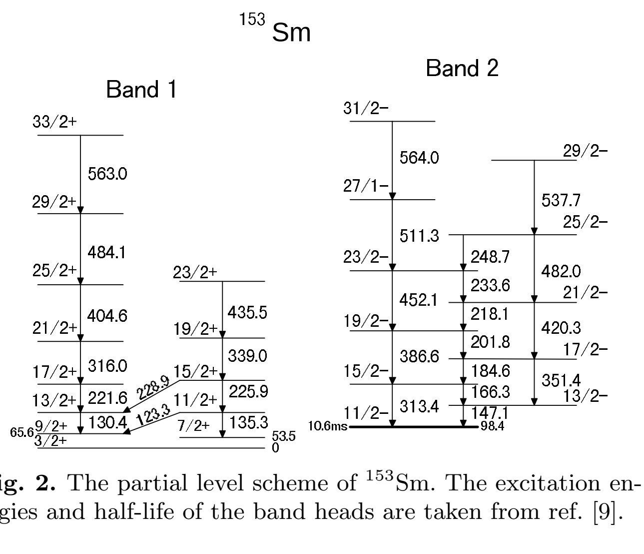

Fig. 2. The partial level scheme of ^{153}Sm. The excitation energies and half-life of the band heads are taken from ref. [9].

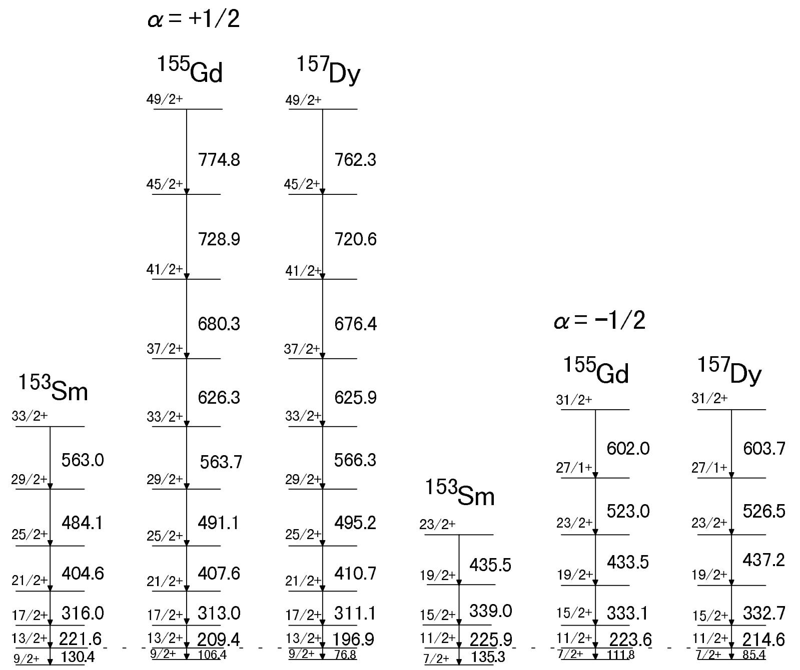

Fig. 3. Comparison of the yrast bands in ^{153}Sm, ^{155}Gd [5], and ^{157}Dy [4].

Table 1. Table 1 γ-ray energies, relative intensities of ^{153}Sm. The uncertainties of γ-ray energies vary from 0.2 keV to 0.8 keV.

E_γ	Intensity
123.3	433(68)
135.3	311(52)
130.4	690(130)
221.6	1000
228.9	164(21)
235.9	512(52)
316.0	542(32)
339.0	427(26)
404.6	300(21)
435.5	125(11)
484.1	247(19)
563.0	250(20)
147.1	420(67)
166.3	458(69)
313.4	118(14)
184.6	442(67)
351.4	207(16)
201.8	305(33)
386.6	197(15)
218.1	164(19)
420.3	162(14)
233.6	89(12)
452.1	123(11)
248.7	40(7)
482.0	105(11)
511.3	94(10)
537.7	59(8)
564.0	77(9)

$N = 91$ isotones. To make this clear, the differences, ΔE, of the corresponding γ-ray energies are shown in fig. 4, which are subtractions of γ-ray energies in the lighter nucleus from those in the heavier nucleus. The ΔE between ^{153}Sm and ^{155}Gd in fig. 4(a) shows the yrast bands are identical within ± 7 keV in these nuclei. In fig. 4(b), the

Table 2. The theoretical and experimental deformation parameter β_2, which are taken from ref. [11,10].

	^{150}Nd	^{152}Sm	^{154}Gd	^{156}Dy	^{158}Er
Theory		0.236	0.234	0.229	0.218
Experiment	0.282	0.252	0.256	0.243	0.214

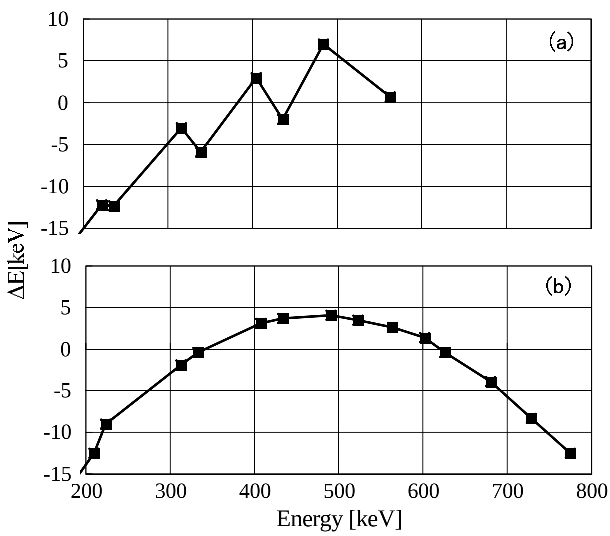

Fig. 4. The differences ΔE of the corresponding γ-ray energies in the neighboring $N = 91$ odd-A isotones. (a) E_γ(^{155}Gd)-E_γ(^{153}Sm) (b) E_γ(^{157}Dy)-E_γ(^{155}Gd).

yrast bands in ^{155}Gd and ^{157}Dy seem identical within ± 5 keV in the range of γ-ray energies from 300 to 700 keV. The tendencies lower than 600 keV are similar in both figures, but there is no data above 600 keV in fig. 4(a). In this figure, the ΔE has a splitting between different signatures, while in fig. 4(b) the ΔE shows no signature dependence.

In the case that odd-A nuclei have identical bands, it might be expected that the corresponding even-even cores have also identical bands. We found that the ^{152}Sm and ^{154}Gd, the even-even cores of the odd-A nuclei mentioned above, have an energy difference within 9 keV, which is larger than that of neighboring odd-A nuclei, and for the ^{154}Gd and ^{156}Dy the differences are even larger. For these even-even cores, we can get the information on the deformation parameter β_2 from both the theoretical study using the shell correction method with an average Wood-Saxon potential [10] and the experimental study using the measured $B(E2, 0^+ \to 2^+)$ values (table 2).
The nuclei of Sm, Gd and Dy among the $N = 90$ isotones have similar β_2 values, which might provide good grounds for the occurrence of the identical bands. However, these even-even cores show no identical bands. The polarizing effect of the $\nu i_{13/2}$ orbital might induce the manifestation of the identical bands in the $N = 91$ isotones.

Baktash *et al.* [3] discussed the identical bands with seniority $= 0$ and classified them into isotopes(N and $N{+}2$) and alpha-chain(N, Z and $N{+}2$, $Z{+}2$). The identical bands discussed in this paper belong to the isotones which is the third criterion.

In summary, the high-spin states of ^{153}Sm and ^{157}Dy were studied using the ^{12}C + ^{150}Nd reaction. The Sm nuclei were populated through two α evaporation channels with small cross-section. The high-spin states of ^{153}Sm were extended up to $33/2^+$ and $31/2^-$. Identical relationships were found between yrast rotational bands of ^{153}Sm and ^{155}Gd. The energy differences in the corresponding even-even cores are larger than those in these nuclei.

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