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High Spin Level Structure in ^{153}Dy and Shape Changes in Neutron-Deficient Dy Nuclei

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High spin state in ^{153}Dy is studied up to 81/2 h through the in-beam γ-ray spectroscopy technique. The reaction of ^{122}Sn (^{36}S, 5n) is used at a beam energy of 165 MeV. Above the I = 47/2 h isomeric state, complex single-particle structure is dominant along the yrast line and in its close vicinity. Nuclear shape changes of neutron deficient Dy isotopes with neutron number N and spin I are discussed.

1. INTRODUCTION

The high spin state of nuclei at A = 150 region has received great attention during the past decade, especially after the discovery of the superdeformed bands in ^{152,151}Dy [1,2]. Many experiments have been performed to study the discrete γ-ray spectroscopy for both the superdeformed and the normally deformed structures.

Rapid structural and shape changes in neutron deficient Dy isotopes have been found with the variations of neutron number N and spin I. When $N \leq 86$, these nuclei have near spherical shape in

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their ground state and become oblate at higher angular momentum. Those nuclei with $N \geq 90$ maintain their prolate deformation from the ground state even in very high spins [3]. The transitional nuclei ^{153,154}Dy (N = 87, 88) which lie between the two groups are slightly prolate-shaped in their ground state, and become oblate at higher spins, which implies a change from collective to aligned particle structure. Very high spin state with novel features in ^{154}Dy was found in a recent study [4]. Some research on ^{153}Dy [5-7] revealed the level structure at low and medium high spins. An I = $47/2^{(-)}$ isomeric state was also identified. However, only a few transitions have been found above this isomer.

It is obviously important to understand the behavior of ^{153}Dy nucleus at high spin in order to make a systematic comparison for the nuclei in this mass region. Therefore, we made a further experimental study by using the in-beam γ-ray spectroscopy technique.

2. EXPERIMENT AND DATA ANALYSIS

The high spin state of ^{153}Dy was populated via the reaction ^{122}Sn(^{36}S, 5n) with a 165 MeV beam from ATLAS (Argonne Tandem Linac Accelerator System). The data were first used for high spin state study of ^{154}Dy [4], where most of the relevant experimental details can be found. The target thickness was 1 mg/cm^2. The decay γ-rays were detected with eight Compton-suppressed Ge spectrometers, of which three were positioned at 34.5°, two at 90° and three at 145.5° with respect to the beam direction. Fourteen BGO hexagons were used as multiplicity filter.

Most of the data were analyzed at Tsinghua University. Fig. 1 shows a spectrum of γ-ray in coincidence with 214 keV transition depopulating the $47/2^{(-)}$ isomeric state. Based on the coincident relationship and the γ-ray intensity, a new level scheme, shown in Fig. 2, was established with a spin of up to about 81/2 $\hbar$. All the γ-rays reported by Jansen *et al.* [6] were observed. In addition, more than 50 new lines were identified, most of which were located above spin $47/2^{(-)}$. The γ-ray spectra are very complex due to the existence of many γ-rays from competing reaction channels ($^{151,152,154-156}$Dy) and to the fact that some γ-rays of ^{153}Dy have very similar energy levels and thus overlap one another. It was a crucial step to resolve these γ-rays, such as the fourfold 636 keV, the threefold 609 keV and the twofold 533, 958 keV etc. They were placed in the level scheme after a careful examination of the coincidence relationships and the intensity obtained from different gate spectra. The excellent energy resolution of the spectrometers was certainly very helpful. The spin assignments were based on the directional correlation ratios (DCO) [8], in which the ratios of coincidence intensity between 90° and 34.5° (also 145.5°) detectors were measured, and thus ΔI of the γ-ray transition was deduced. It should be noted that while the DCO measurement is very helpful in finding the multi-polarities of γ-rays, it does not reveal the electric or magnetic nature of γ-rays. In addition, the parity of $47/2^{(-)}$ level, which served as the basis of our parity assignments, was only assigned tentatively from a previous experiment [7]. Therefore, the parties of all the levels above the 47/2 isomer were assigned only tentatively. They remain to be verified by further experiments. A parity change was assumed above the $49/2^{(-)}$ (6549 keV) level. The stretched dipole transitions 281.3 keV (depopulating the 53/2 level) and 169.3 keV (depopulating the 51/2 level) were both quite strong, but no cross-over E2 transition was found from 53/2 to 49/2. Therefore, the parities of the levels between 51/2 and 81/2 in the decay sequence on the right-hand side were assumed to be positive.

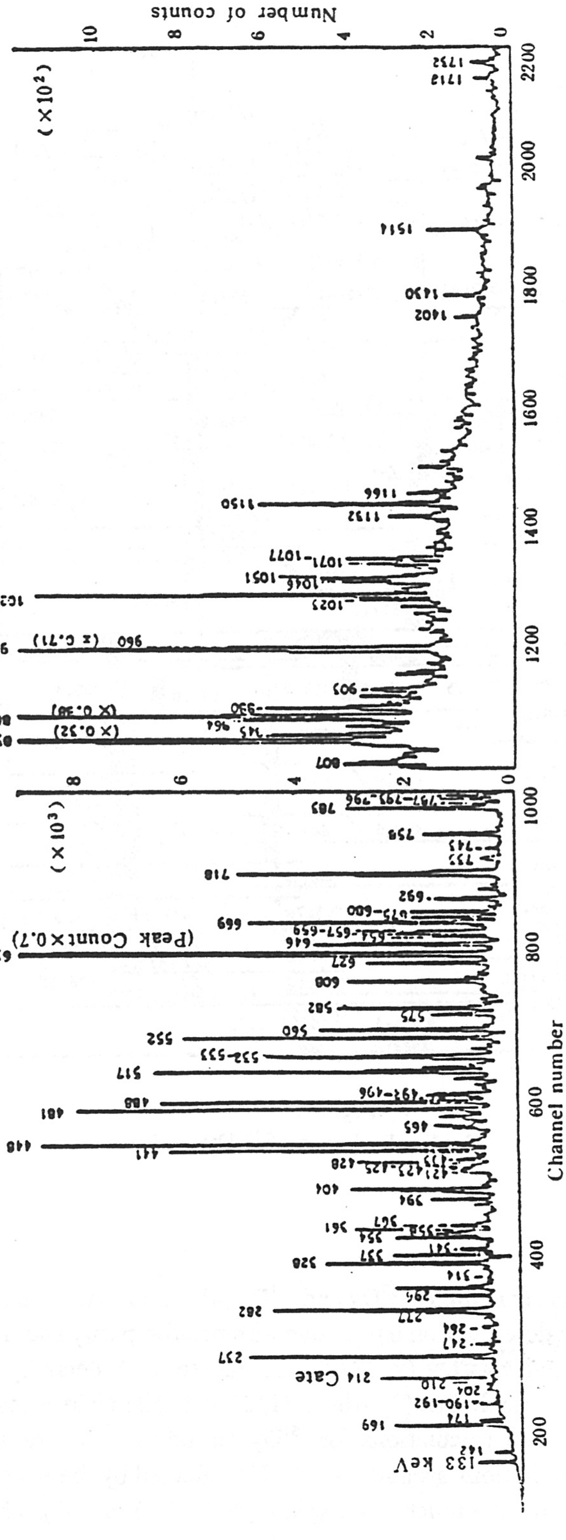

Fig. 1
The 214 keV gate spectrum. Identified ^{153}Dy transitions are marked by their energy levels.

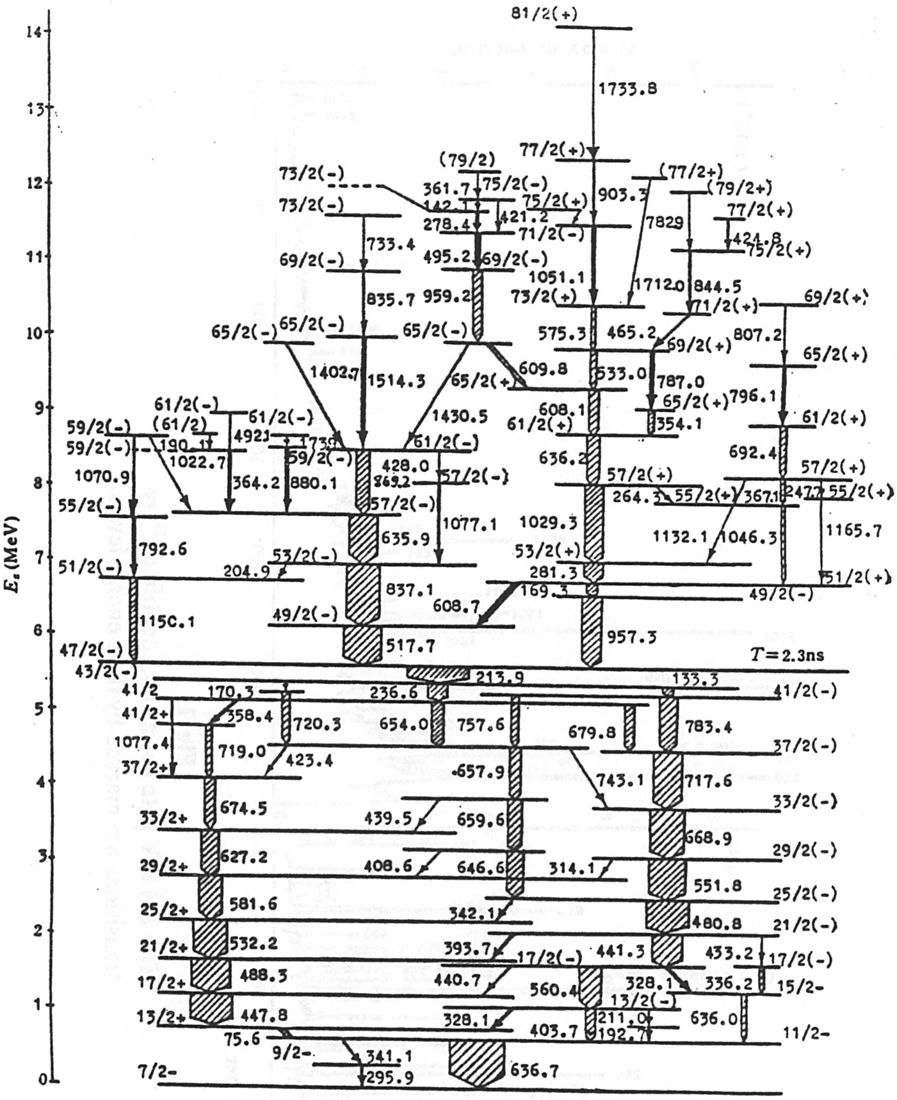

Fig. 2
The level scheme of ^{153}Dy.

3. DISCUSSION

By comparing the level structure of ^{153}Dy and ^{154}Dy [4], similarity can be found at lower spins. Both of them have two main de-excitation bands, one with positive parity and the other with negative one. The positive parity band in ^{153}Dy (νi 13/2) exhibits strong collectivity. The plot of angular momentum Ix versus $\hbar\omega$ is a straight line [7]. Above $41/2^+$, the collectivity is lost, just like the S-band in ^{154}Dy. The band termination calculations for ^{154}Dy reproduced the transition from collective rotation to single-particle excitations around $I = 36^+$ [9] reflected by the irregular energy spacings. This band termination appears at a much lower spin ($I > 41/2\,\hbar$) in ^{153}Dy. This trend also exists in

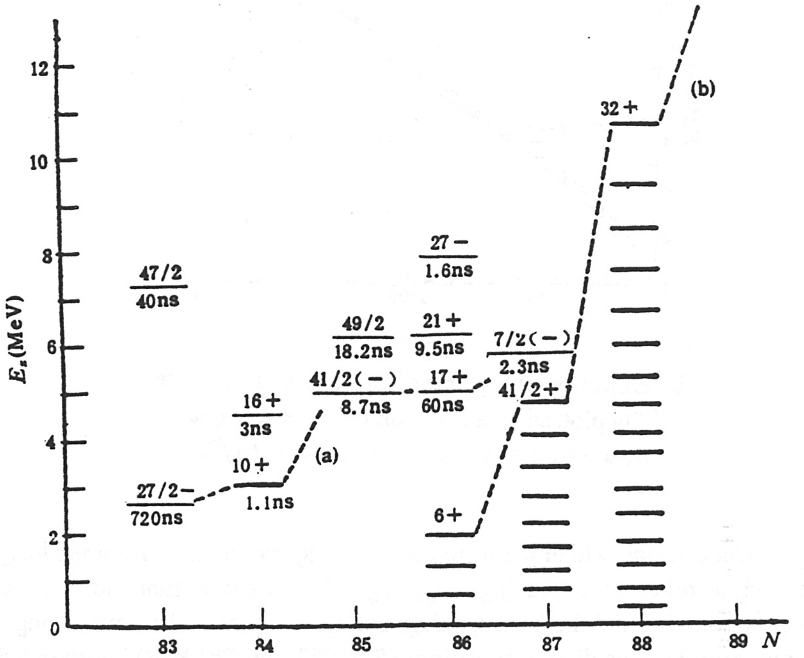

Fig. 3
The isomers (a) and the band terminating energy (b) of Dy nuclei versus neutron number [7,11,12].

the negative parity band. Around an excitation energy of 5 MeV, there are several competing de-excitation pathways consisting of dipole and quadrupole transitions, which shows the competition between the collective and the single-particle type of motions. This could also be attributed to a triaxial deformation. Up 40 47/2, and isomeric state ($T_{1/2}$ = 2.3 ns) indicated the dominance of single-particle motion.

Fig. 3(b) shows a systematic comparison of the terminating energy and spins of the collective bands in Dy isotopes [7,11,12]. For $N \leq 85$, no collective band was found. For N = 86 (^{152}Dy), collective band populated weakly. With N increasing, the band terminating energy increases, indicating stronger collectivity. The collectivity was established completely for $N \geq 89$.

The existence of the isomers in light mass Dy isotopes is a conspicuous feature. More than a decade ago, Bohr and Mottelson [10] proposed that the manifestation of special structure effects in nuclei with high spins could be the occurrence of yrast traps, i.e., the existence of yrast isomers which marks the alignment of individual nucleons and the formation of oblate shape [1]. The isomers of Dy nuclei are shown in Fig. 3(a). The excitation energy of the lowest isomer in each Dy isotope grows along with the increase of the number of neutrons when $N \leq 87$. At least two isomers were observed for $N \leq 86$ nuclei and only one for N = 87. It has not been observed when $N \geq 88$. This clearly demonstrates a trend from single-particle to stronger collective motion, and shows the transition from oblate shape to prolate. There have been some theoretical calculations for these isomers [11] and the results are generally in agreement with experimental measurement. The isomer in ^{153}Dy was

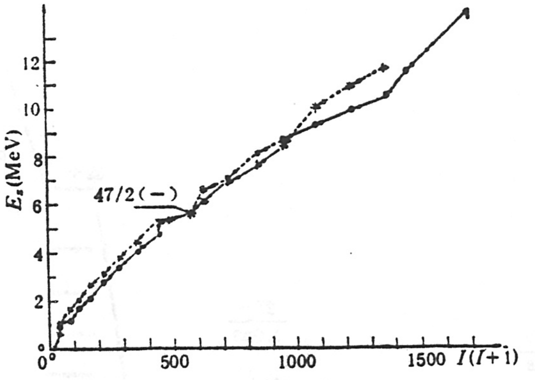

Fig. 4
The excitation energy Ex of two main cascades in ^{153}Dy plotted as a function of $I(I + 1)$. The yrast and noyrast lines cross at $I = 61/2$.

not included in the calculations, which seems to have a configuration of two aligned $h_{11/2}$ protons and three neutrons lying at different orbits ($f_{7/2}$, $h_{9/2}$, $i_{13/2}$). Fig. 2 shows that the level scheme above $47/2^{(-)}$ is extremely complex and the level spacings are quite irregular. But two strong cascades can be seen. There are several strong dipole transitions (518, 957, 169, 281 keV) between 5.5 and 7 MeV. Above these transitions, the decay cascade on the left-hand side (possibly with negative parity) consists of a series of quadrupole transitions, and the decay cascade on the right-hand side (possibly with positive parity) includes quadrupole transitions and two dipole transitions with high transitional energy (1051, 903 keV). There are several other weaker decay sequences and many side-feeding transitions. All these pathways finally feed into the $47/2^{(-)}$ isomer, which then de-excites through the 214 keV transition. Not so many high spin levels near the yrast lines have been observed in $^{148\text{-}152}$Dy isotopes [12]. Further theoretical studies are needed to understand the nature of each individual level. Moderately collective state was observed at very high spins in ^{154}Dy [4] above the region where the single-particle motion is dominant. This phenomenon has not been observed in ^{153}Dy.

Fig. 4 shows much of the excitation energy as a function of $I(I + 1)$. Only two main de-excitation sequences are included. At low spins, the yrast line follows the even parity band. Above the isomer ($I = 47/2^{(-)}$), it follows the possibly odd parity cascade at the beginning. Then this cascade and the possibly even parity cascade cross each other at 61/2, above which the yrast line follows the possibly even parity levels. A similar situation was observed in other Dy isotopes (for example, ^{148,151}Dy). This indicates the intersection of the decay pathways of different single-particle structures.

4. SUMMARY

In neutron deficient Dy isotopes, more collective character or less single-particle character was observed with the neutron number N increasing, and vice versa with the spin I increasing. This is an indication of nuclear shape change. ^{153}Dy and ^{154}Dy are transitional nuclei. This experiment established the energy levels of ^{153}Dy nucleus at very high spin through the discrete γ-ray spectroscopy study.

This new level scheme revealed the strong single-particle character of ^{153}Dy above the isomer (I = 47/2). It also exhibited how ^{153}Dy nucleus changes from collective to the single-particle configurations as the angular momentum increases, i.e., from prolate, via triaxial, to oblate shape while maintaining its very complex single-particle character at very high spin state. It is important to understand this transitional behavior in order to determine the phase change of nuclear shape with the change in the number of neutrons and angular momentum in the A = 150 region [13]. It also provides experimental information for further theoretical study.

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