Eur. Phys. J. A **13**, 5–8 (2002)

THE EUROPEAN PHYSICAL JOURNAL A

Systematics of high-spin isomers in N = 83 isotones and a high-spin isomer beam

Y. Gono[1], A. Odahara[2], T. Fukuchi[1], E. Ideguchi[3], T. Kishida[4], T. Kubo[4], H. Watanabe[1], S. Motomura[1], K. Saito[1], O. Kashiyama[1], T. Morikawa[1], B. Cederwall[5], Y.H. Zhang[6], X.H. Zhou[6], M. Ishihara[4], and H. Sagawa[7]

[1] Department of Physics, Kyushu University, Fukuoka 812-8581, Japan
[2] Nishinippon Institute of Technology, Kanda, Fukuoka 800-03, Japan
[3] Department of Chemistry, Washington University, St. Louis 63130, USA
[4] RIKEN, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan
[5] Royal Institute of Technology, S-104 05 Stockholm, Sweden
[6] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China
[7] University of Aizu, Fukushima 965-8580, Japan

Received: 1 May 2001 / Revised version: 14 December 2001

Abstract. Isomers in $N = 83$ isotones of $Z = 60$–66, were studied systematically. Their spins and parities are $49/2^+$ and 27^+ for odd and odd-odd nuclei, respectively. Nearly constant excitation energies of these isomers indicated a decrease of a $Z = 64$ shell gap energy as Z decreases from 64 to 60 within the framework of a deformed independent-particle model (DIPM). Their configurations are $[\nu(f_{7/2}h_{9/2}i_{13/2}), \pi(h_{11/2})^2]_{49/2^+}$ and $[\nu(f_{7/2}h_{9/2}i_{13/2}), \pi(h_{11/2})^2(d_{5/2})^{-1}]_{27^+}$ for odd and odd-odd nuclei, respectively. The shape of the yrast states changes suddenly at spin 49/2(odd) and 27(odd-odd) from a near spherical to an oblate shape. Transitions from isomers are highly hindered because of the shape changes. They may be categorized to be shape isomers. The development of a secondary beam produced by using these high-spin isomers is also described.

PACS. 21.10.-k Properties of nuclei; nuclear energy levels – 27.60.+j $90 \le A \le 149$

1 Introduction

Nuclear isomerism stems from various origins, such as very low transition energies and/or high-multipolarities of transitions. Fission isomers have been well known to be caused by large shape differences of isomers from those of the states to which isomers can decay energetically and from the view point of transition multipolarities. Later a high-spin isomer was found in ^{147}Gd [1]. The shape of this isomer was found to be oblate by a measurement of a quadrupole moment [2]. A g-factor of the isomer was also experimentally determined [3]. Based on this g-factor, a configuration of $[\nu(f_{7/2}, h_{9/2}, i_{13/2}), \pi(h_{11/2})^2]_{49/2^+}$ was proposed for the isomer. These deformation and configuration were reproduced well by a deformed independent-particle model (DIPM) calculation [4]. This calculation also showed that yrast states in ^{147}Gd are all near spherical up to the isomer. So one sees that this isomer is caused by the sudden shape change like fission isomers.

Thereafter we found the same kind of isomers systematically in $N = 83$ isotones using many heavy-ion reactions. These are isomers with excitation energies and half-lives of 35 ns at 9.0 MeV, $> 2\,\mu$s at 8.6 MeV, 0.96 μs at 8.8 MeV, 10 ns at 8.6 MeV and 1.3 μs at 8.6 MeV in ^{143}Nd [5], ^{144}Pm [6], ^{145}Sm [7], ^{146}Eu [8] and ^{148}Tb [9], respectively.

Though the isomers in $N = 83$ isotones with $Z > 65$, namely ^{149}Dy [10], ^{150}Ho [11] and ^{151}Er [12], were reported, level schemes were not well established. Therefore, the excitation energies and spin parity assignments of these isomers remained of some uncertainty.

In ^{149}Dy, DIPM predicts an isomer with spin parity $49/2^+$ at about 8.5 MeV although a previous work [10] reported a high-spin isomer of spin parity $(45/2^+)$ at about 7.4 MeV. Considering the fact that DIPM reproduced so well the characteristics of the high-spin isomers in $N = 83$ isotones with $Z = 60$–65, it seemed to us that there might be some missing transitions under the isomer. The same kind of discrepancies exist in spin values and the excitation energies of isomers in ^{150}Ho and ^{151}Er. So further experiments on these isotones were started.

In this report, the development of a secondary beam from these isomers is also described.

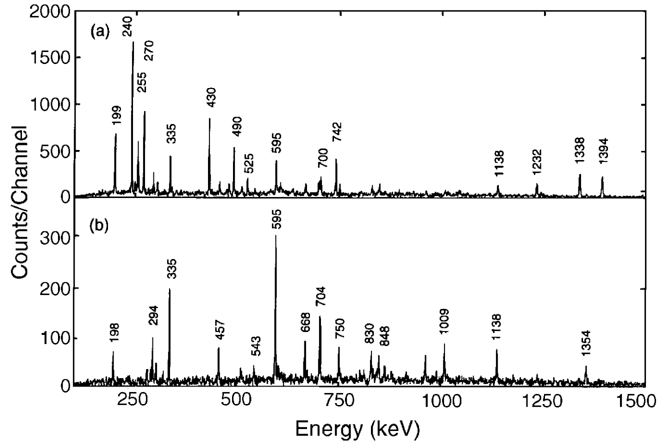

Fig. 1. Spectra obtained by gating on a 935 keV γ-ray in a prompt (a) and delayed (pre-prompt) (b) matrix.

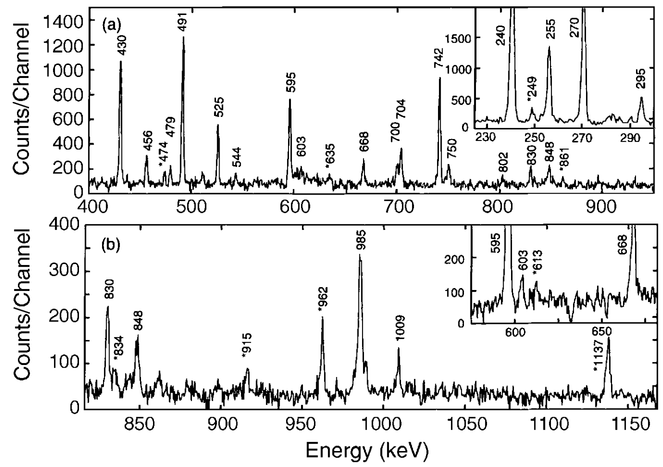

Fig. 2. Spectra obtained by setting gates on 430, 985, 1338 keV (a) and 595 keV (b) in prompt matrix.

2 Experiments and results

The experiment on ^{149}Dy was carried out using a reaction ^{141}Pr(^{16}O, p7n) ^{149}Dy [13]. A self-supported natural Pr of 9.4 mg/cm^2 was used. An ^{16}O beam of 165 MeV was provided by the cyclotron of the Center for Nuclear Study, University of Tokyo. Five sets of HPGe of 28% relative efficiency with BGO anti-Compton shields were used for $\gamma\gamma$-coincidence experiments. These detector sets were used also in the previous experiments on other $N = 83$ isotones. Coincident events of 1.7×10^8 were collected in 70 hour beam time.

Coincidence data were analyzed off line. E_γ-E_γ matrices were made by setting gates on prompt and delayed part of a $\gamma\gamma$ time spectrum. Examples of gated spectra are shown in fig. 1. Figures 1(a),(b) were obtained by gating on a 935 keV γ-ray in a prompt and delayed (pre-prompt) matrix. Three isomers were reported in ^{149}Dy [10] previously. Their excitation energies and half-lives are 1073 keV, 12.5 ns, 2660 keV, 510 ms and 7.4 MeV, 28 ns. In fig. 1(a), transitions between two isomers at 2.66 MeV and 7.4 MeV are seen. On the other hand, transitions above the 7.4 MeV isomer are clearly seen in fig. 1(b).

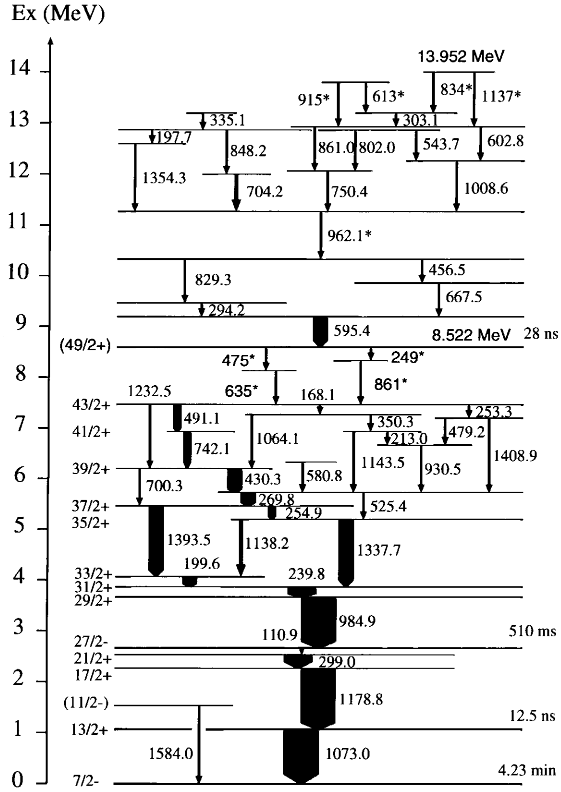

Fig. 3. A proposed level scheme of ^{149}Dy. Transitions with asterisks are newly added ones.

Figures 2(a) and (b) show spectra obtained by setting gates on 430+985+1338 keV γ-rays and 595 keV γ-ray in prompt matrix. Four and five transitions were newly found below and above the 7.4 MeV isomer. Sum energies of newly found transitions, in fig. 2(a), of 249, 861 keV and 635, 475 keV are the same. They are tentatively placed just below the 7.4 MeV isomer as parallel cascades as shown in a proposed level scheme of fig. 3.

3 Discussion

The resulting excitation energy of the isomer was used in a systematics of isomers in $N = 83$ isotones in fig. 4. The excitation energy of high-spin isomer in ^{149}Dy follows the constancy of them in lighter isotones. This is well reproduced by DIPM which predicted this isomer at 8.1 MeV with spin parity of $49/2^+$. The deformation parameters of yrast states in ^{149}Dy as well as in ^{147}Gd with experimental values of $13/2^+$, $27/2^-$ and $49/2^+$ isomers in ^{147}Gd are plotted in fig. 5. A sudden shape change was also seen in ^{149}Dy between spin 47/2 and 49/2 states. The calculated configuration of this isomer in ^{149}Dy is the same as those in lighter isotones, *i.e.* $[\nu(f_{7/2}h_{9/2}i_{13/2}), \pi(h_{11/2})^2]_{49/2^+}$. Two protons are filling already, in a ground state of ^{149}Dy, $h_{11/2}$ orbit which locates above the sub-shell closure of $Z = 64$. This constancy of the excitation energies in

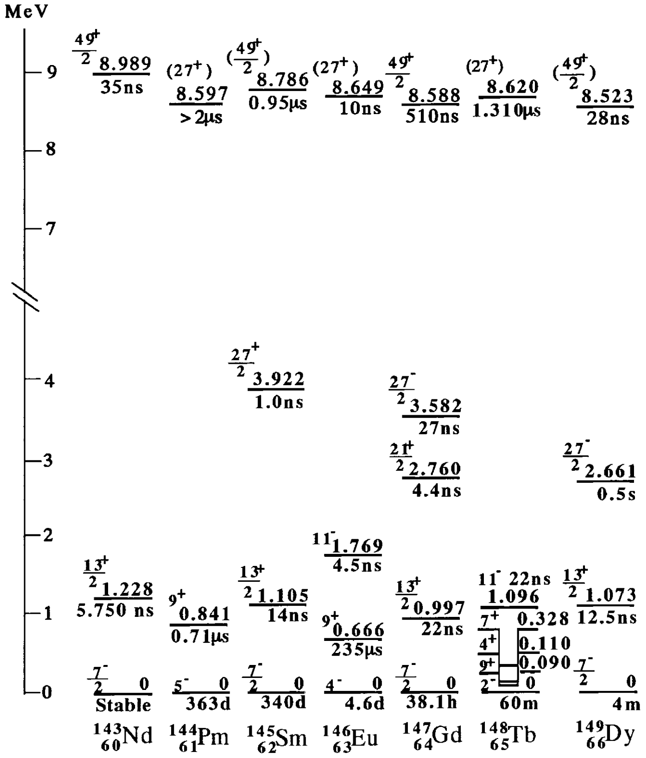

Fig. 4. Systematics of isomers in $N = 83$ isotones.

$N = 83$ isotones through $Z = 60$ to 66 support that these isomers are oblate-shape isomers since the shell gap of $Z = 64$ disappears around a deformation parameter $\beta = -0.2$. In the Nilsson diagram rather large shell gaps appear in a deformation $\beta = -0.2$ region at $Z = 66$ and 68. Therefore it may be worthwhile to extend this study to heavier $N = 83$ isotones, ^{150}Ho and ^{151}Er.

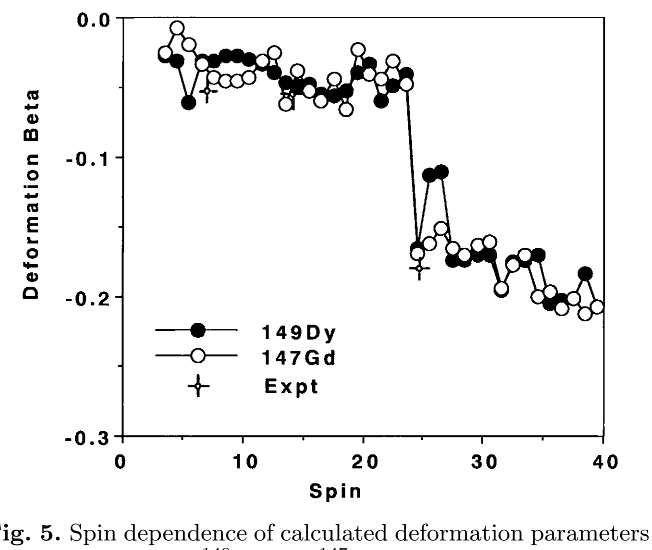

Fig. 5. Spin dependence of calculated deformation parameters β for yrast states of ^{149}Dy and ^{147}Gd. Calculations were made by using DIPM. Experimental points are taken from ref. [2].

4 Development of a high-spin isomer beam

The isomers in ^{144}Pm [6] and ^{145}Sm [7] were found by using reactions in inverse kinematics, *i.e.* ^{14}N (^{136}Xe, 6n) ^{144m}Pm and ^{16}O (^{136}Xe,7n) ^{145m}Sm, using a ^{136}Xe beam provided by the RIKEN Ring Cyclotron (RRC). They were found in a series of experiments searching for the isomers by using a gas-filled recoil separator system. Filling gases to equilibrate charge states worked as targets. Then isomers produced in these reactions and recoiling out of targets have enough energy to induce secondary reactions, *e.g.*, 7.2 MeV/u for ^{145m}Sm when one uses 8 MeV/u ^{136}Xe beam. They were separated from the primary beam to be developed as a secondary beam [14] using RIPS [15] at RIKEN. This isomer beam is expected to be very effective to produce cold compound nuclei with very high spins.

A new type of windowless gas target [16] was used to accept a 100 pnA primary beam of ^{136}Xe. A target thickness reached to 0.7 mg/cm^2. Then 10^5 pps isomers were brought to a secondary target. The secondary-beam intensity of 10^5 was obtained on a secondary target constantly. However a high purity of the secondary beam could not be kept for a few days which were necessary for secondary fusion reaction experiments. Main contaminants were scattered ^{136}Xe ions which were originated from the entrance and exit holes of the gas target. This was improved later by putting 100 μm Ta sheets with slightly smaller holes for all the holes through which a primary beam and a reaction product passed.

The primary beam was stopped by a ladder slit which is shown in fig. 6 placed at dispersive focal plane between two dipole magnets. This slit could be remotely controlled in positions and widths. This structure was necessary because ^{136}Xe with various charge states could be brought to different places in this focal plane.

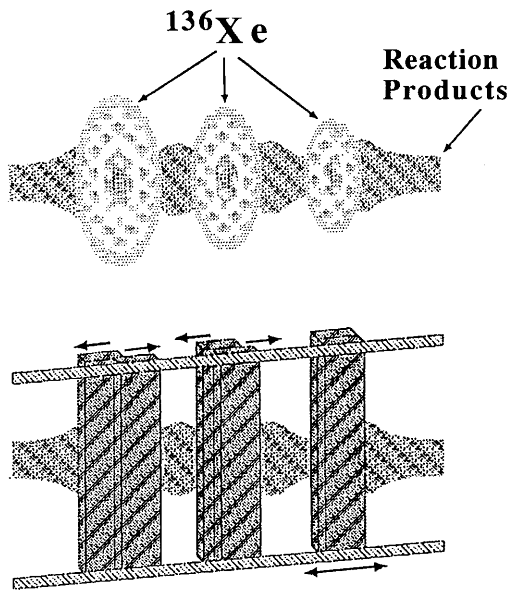

Fig. 6. A ladder slit used to separate reaction products from a primary beam. Both primary beam and reaction products are distributed to many charge states.

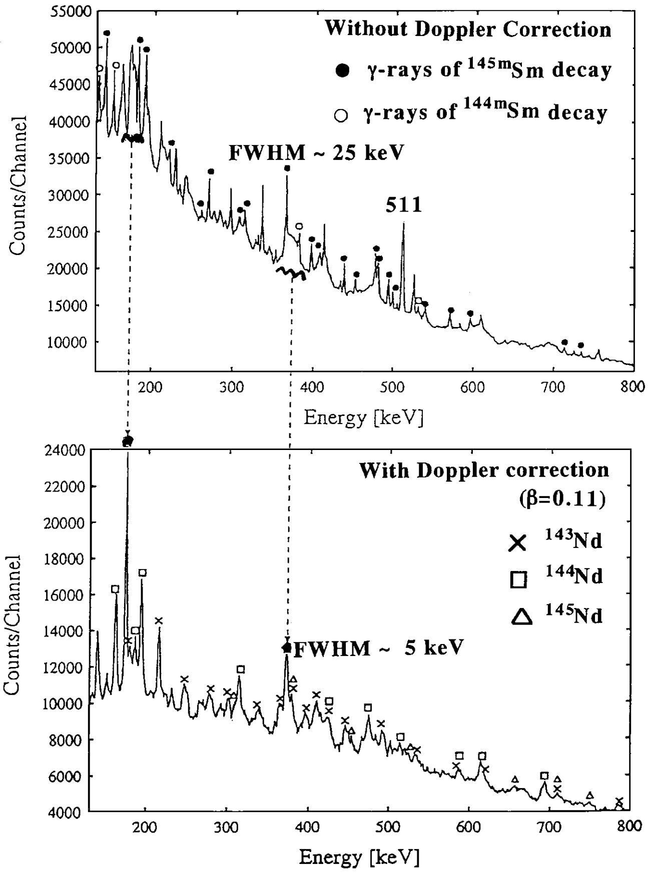

Fig. 7. Effectiveness of a germanium telescope system. A peak width could be reduced in FWHM from 25 keV for an uncorrected to 5 keV for a corrected spectrum at a recoil velocity of $\beta = 0.11$.

A germanium (Ge) telescope which consisted of a segmented and a clover Ge was developed. The segmented Ge was a planar detector of $50 \times 50 \times 20\,\text{mm}^3$ and segmented to 25 pixels of $10 \times 10 \times 20\,\text{mm}^3$. This system was necessary to correct Doppler broadening of the energy of a gamma-ray emitted from nucleus running with a velocity of 10% that of light. The correction worked properly as shown in fig. 7.

The development of the high-spin isomer beam has been nearly completed.

References

1. M.W. Drigert *et al.*, Nucl. Phys. A **515**, 466 (1990) and references therein.
2. O. Hausser *et al.*, Nucl. Phys. A **443**, 135 (1985).
3. O. Hausser *et al.*, Phys. Rev. Lett. **42**, 1451 (1979).
4. T. Dossing *et al.*, Phys. Scr. **24**, 258 (1981).
5. X.H. Zhou *et al.*, Phys. Rev. C **61**, 014303 (2000).
6. Y.H. Zhang *et al.*, High Energy Phys. Nucl. Phys. **20**, 385 (1996).
7. A. Odahara *et al.*, Nucl. Phys. A **620**, 363 (1997).
8. E. Ideguchi *et al.*, Eur. Phys. J. A **6**, 387 (1999).
9. E. Ideguchi *et al.*, Z. Phys. A **352**, 363 (1995).
10. M. Gupta *et al.*, Phys. Rev. C **54**, 1610 (1996).
11. J. McNeill *et al.*, Z. Phys. A **325**, 27 (1986).
12. S. Andre *et al.*, Z. Phys. A **337**, 349 (1990).
13. T. Fukuchi, Master thesis, Kyushu University (2000).
14. Y. Gono *et al.*, Nucl. Phys. A **588**, 241c (1995).
15. T. Kubo *et al.*, Nucl. Instrum. Methods B **70**, 309 (1992).
16. T. Kishida *et al.*, Nucl. Instrum. Methods A **438**, 70 (1999).