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Experimental Observation of High-spin states in ^{146}Sm Nucleus

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High-spin states of ^{146}Sm have been experimentally studied by using a ^{13}C (95 MeV) beam bombarding a natural thick Ba target; 17 new γ-rays and 11 new levels were found and assigned to the level scheme of ^{146}Sm which was extended up to 10.3 MeV excitation energy. Level structure still shows the characteristics of particle configurations. No long-lived high-spin isomer was found up to such high-excitation regions.

Key words: γ-rays, new energy levels, high-spin states.

1. INTRODUCTION

In the $A = 150$ rare-earth region, it is normally considered that the nuclei with neutron number $N > 88$ have the deformed shape and show the characteristics of the rotational band structure, while

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at the neutron deficient side with $N < 88$, the nuclei undergo the shape transition from the well-deformed shape to the spherical one with the decrease of the neutron number. Therefore, the level structure of high-spin states for the nuclei in this transition region contains the fruitful structure information. The ^{146}Gd (with $N = 82$ and proton number $Z = 64$) is a typical spherical nucleus and has characters [1] similar to those of the doubly closed nucleus ^{208}Pb. The structure properties of a nucleus would be greatly changed if several nucleons are added to or subtracted from ^{146}Gd. At high-spin states, these properties depend strongly on the specific quasiparticle configurations. Different models have been proposed trying to explain theoretically the nuclear structure characteristics. Although it is possible to explain some particular structure properties at high-spin states, the extension of these models to a larger nuclear region becomes unsuccessful, especially at higher spins and higher excitation energies where the higher level density and the configuration mixings make it difficult for the theoretical and experimental studies.

For the stable Sm isotopes, the high-spin states for ^{144}Sm ($N = 82$) show the typical features of spherical nucleus, while for ^{154}Sm ($N = 92$) it presents the band structure appearing in the well-deformed nuclei. For the nuclei between ^{144}Sm and ^{152}Sm, the high-spin level structure contains the shape transition information from spherical to deformed nuclei. With respect to the doubly closed ^{146}Gd, ^{146}Sm can be regarded as the coupling of two proton holes and two valence neutrons with ^{146}Gd core, the information of effective interaction among the quasiparticles can be obtained through the study of high-spin states in ^{146}Sm. In addition, at higher spin regions the energy levels are formed by the angular momentum alignment of several individual quasiparticles according to the prediction of Bohr and Mottelson [2], thus the nuclei are oblate. The level spacings of these high-spin states are irregular; as a consequence, the long-lived high-spin isomers (or yrast traps) may occur along the yrast line. Pederson *et al.* have found that there exists a "high-spin isomer island" in the $64 < Z < 71$, $83 < N < 88$ region [3]. It is directed by this conclusion that the investigation of high-spin isomers has been limited in this nuclear region for a long time. Recently, a systematic study has demonstrated that the high-spin isomers also exist in ^{144}Pm [4], ^{145}Sm [5], and ^{146}Eu [6] which are below the doubly closed ^{146}Gd nucleus. These results indicate that the high-spin isomer may exist in a larger nuclear region than conventionally considered. The study of high-spin states in ^{146}Sm may provide information about the existence or nonexistence of such isomers with the similar quasiparticle configuration as in ^{145}Sm since ^{146}Sm has one more neutron than ^{145}Sm. Furthermore, the level structure at higher excitation energies can also provide spectroscopic data for theoretical investigations.

2. EXPERIMENTAL METHOD

The experiment has been performed in the Tanden Accelerator Laboratory of the Japan Atomic Energy Research Institute (JAERI). The natural thick Ba target (72% abundance of ^{138}Ba) was bombarded by the 95 MeV ^{13}C beam, the high-spin states in ^{146}Sm were populated by using ^{138}Ba (^{13}C,5n) ^{146}Sm reaction. The standard in-beam γ-ray spectroscopic techniques were used including 5 BGO(AC)HPGe detectors for the measurement of single and coincident spectra. The coincidence events were recorded on the magnetic tapes in $\gamma_1 - \gamma_2 - t_{\gamma_1, \gamma_2}$ mode where $t_{\gamma_1} t_{\gamma_2}$ represents the time interval of the two detected γ rays. The detectors were calibrated by the standard ^{152}Eu source and also by the known in-beam γ-rays from ^{146}Sm; the typical energy and time resolutions were about 2.0-2.3 keV at FWHM for the 1.33 MeV γ-ray and 10 ns, respectively.

Since the level structure for ^{146}Sm is dominated by the quasiparticle configurations, the higher spin states are thus expected to be quickly populated by fusion evaporation reaction after emitting several statistic γ-rays. Therefore the discrete γ-rays at higher excitation energy and higher spin region can still be identified at both the single and coincident measurements using the normal detection system.

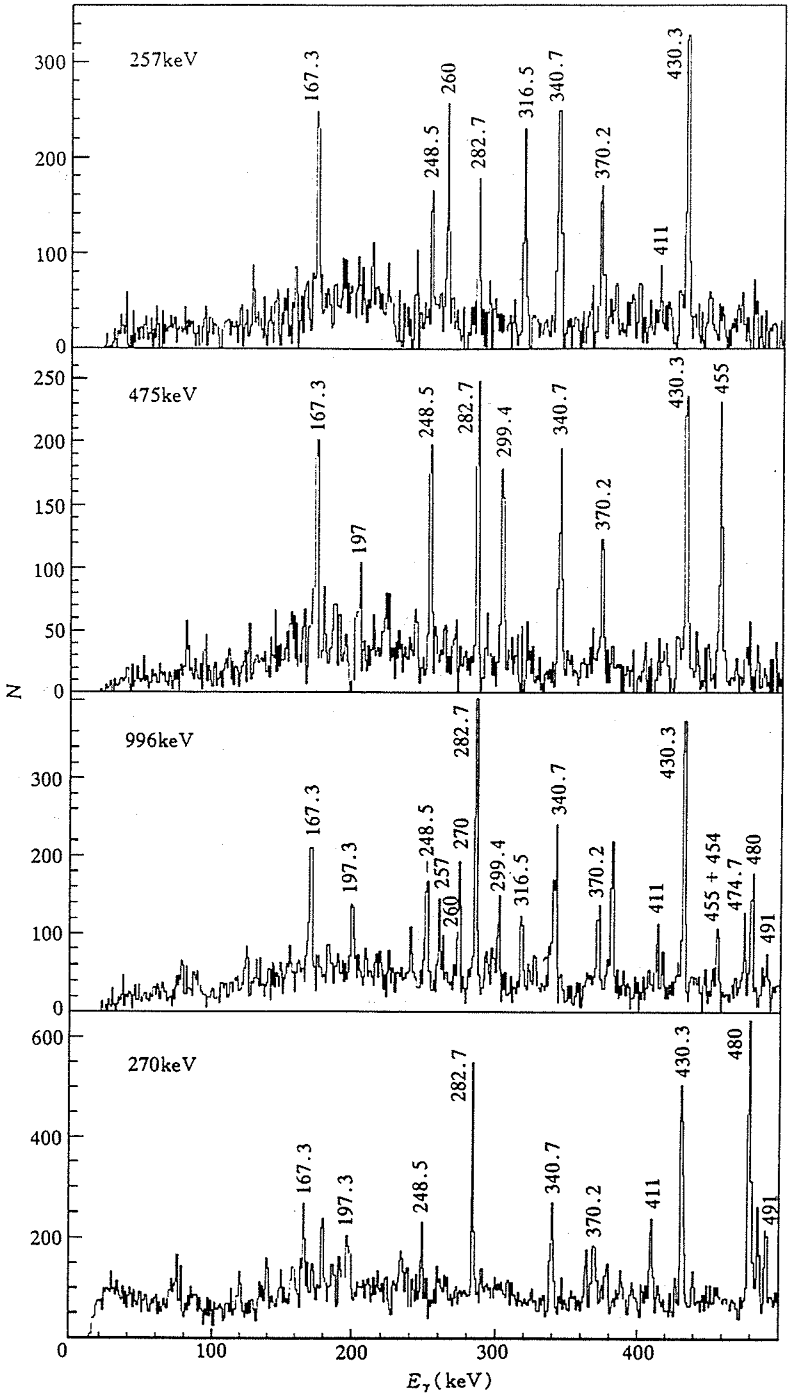

Fig. 1
Prompt coincidence spectra gated by several new γ-rays in ^{146}Sm.

In order to search for the high-spin isomers, the time window in γ-γ coincidence measurement is set to be 1 μs; thus, in the off-line data analysis, the prompt and delayed γ-γ matrix can be constructed by setting different time conditions. The detailed analyses for the prompt and delayed coincidence spectra of some known γ-rays and for the relative γ-ray intensities can provide the evidence for the existence of high-spin isomers. In the present experiment with 95 MeV ^{13}C beam, the production yields of the fusion-evaporation residues ^{145}Sm and ^{146}Sm are comparable. The analysis to ^{145}Sm shows that most of the γ-rays originated from the deexcitation of the high-spin isomer [5] with $J^\pi = 49/2^+$ and $T_{1/2} = 0.96$ μs at $E_x = 8.8$ MeV. The same analysis method is also applied to ^{146}Sm, no evidence has been found that there is a long-lived high-spin isomer in ^{146}Sm up to about 10 MeV excitation energy.

However, the detailed analysis to the experimental data shows that at least 16 new γ-rays can been attributed to the deexcitation of the high-spin states in ^{146}Sm. Figure 1 represents the coincidence spectra gated by 257, 270, 475, 996 keV lines where 430 keV line corresponds to the $6^+ \rightarrow 4^+$ transition in ^{146}Sm (though only the lower energy parts are given here).

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Through the careful analysis for the prompt γ-γ coincidence relations and for the relative γ-ray intensities, the level scheme up to $E_x = 10.26$ MeV has been constructed as shown in Fig. 2 in which the level structure below $E_x = 6.2$ MeV is consistent with the result of Refs. [7,8] except for 5 new γ-transitions identified by the present work. The γ-ray energies and the corresponding initial and final excitation energy are, respectively, 454 keV (5206 keV $\rightarrow$ 4753 keV), 656 keV (5874 keV $\rightarrow$ 5218 keV), 755 keV (5972 keV $\rightarrow$ 5218 keV), 614 keV (6131 keV $\rightarrow$ 5518 keV), and 257 keV (6131 keV $\rightarrow$ 5874 keV). The level scheme above 6.2 MeV is constructed by the present work including 12 new γ-rays and 11 new energy levels. With the bound of $E_x = 6177$ keV, the level scheme is separated into two parallel parts. It is clearly seen that the γ-transition energies up to 10 MeV excitation are still irregular; this indicates the characteristics of the single particle configuration. There are no extra γ-rays in the delayed coincidence spectra gated by any γ-transitions shown in the level scheme; for cascade transitions, no considerable variation of γ-ray intensity caused by the existence of a long-lived isomer has been found in the prompt coincidence spectra. These two facts also demonstrate that there is no long-lived high-spin isomer in ^{146}Sm up to 10 MeV excitation. This conclusion is in agreement with the systematics of neighboring $N = 84$ isotones.

Prior to this work, King *et al.* [7] and Kownacki *et al.* [8] have studied the high-spin states in ^{146}Sm and pointed out that the levels below $E_x = 4.1$ MeV are predominantly constructed by 4-quasiparticle configurations and by the coupling of two valence neutrons with the phonon states of the core. For the level in 4.1 MeV $< E_x <$ 6.1 MeV, no theoretical explanations have been reported. As the spin-parity determination for the new levels has not been made in this work, it is thus difficult to discuss their structure properties. However, through a systematic comparison, the possible configurations of $E_x = 10259$ keV and $E_x = 9843$ keV levels can be qualitatively discussed.

For the $N = 83$ isotones ^{147}Gd and ^{145}Sm, the fully aligned state with $\pi(h_{11/2})^2 \otimes \nu(f_{7/2}\, h_{9/2}\, i_{13/2})$ configuration form a long-lived high-spin isomer, i.e., for ^{147}Gd [9,10] an isomer with $E_x = 8.59$ MeV, $J^\pi = 49/2^+$, $T_{1/2} = 0.56$ μs; for ^{145}Sm [5] an isomer with $E_x = 8.786$ MeV, $J^\pi = 49/2^+$, $T_{1/2} = 0.96$ μs. The formation of such a high-spin isomer is due to the neutron excitation across $N = 82$ major shell and the occupation of the high-j Nilsson orbitals ($f_{7/2}$, $h_{9/2}$, and $i_{13/2}$). Correspondingly, the fully aligned high-spin levels in ^{148}Gd and ^{146}Sm with $\pi(h_{11/2})^2 \otimes \nu[(f_{7/2})^2\, h_{9/2}\, i_{13/2}]$ configuration are also expected to be isomeric. In fact, 27^- level at $E_x = 10318$ keV in ^{148}Gd is assigned to be with such a configuration [10] but not isomeric; this is interpreted as the 27^- and 25^- states being two multiplets of same quasiparticle configuration [11]. As for ^{146}Sm, it is considered that the levels at $E_x = 10259$ keV and $E_x = 9843$ keV may be also the two multiplets of the $\pi(h_{11/2})^2 \otimes \nu[(f_{7/2})^2\, h_{9/2}\, i_{13/2}]$ configuration as in the case of ^{148}Gd, so the J^π values can be proposed to be 27^- and 25^-. The level

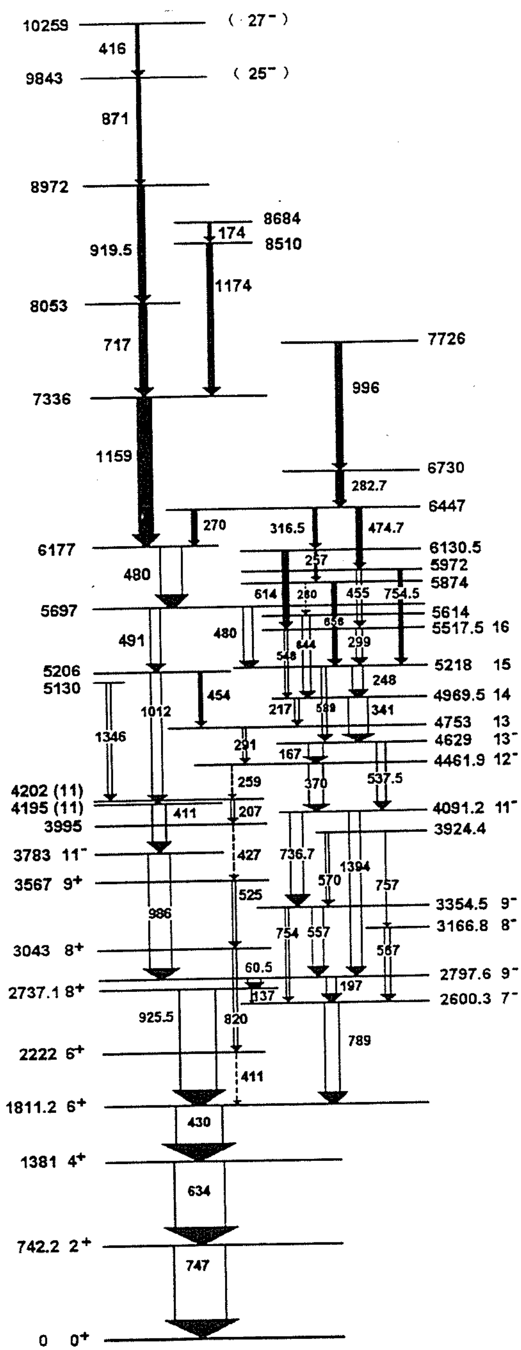

Fig. 2

Level scheme of ^{146}Sm proposed by present work.

Energies are in keV, the dashed lines represent that the γ-ray relative intensity cannot be obtained, the bold lines are the new transitions observed by present work, and the width of the lines indicates the γ-rays' relative intensity.

spacings (8448 keV for ^{146}Sm and 8510 keV for ^{148}Gd) between the fully aligned state (27^- level) and the $(\nu f_{7/2}^2)6^+$ state are very close to the excitation energies of corresponding high-spin isomers in ^{145}Sm and ^{147}Gd, respectively; furthermore, the $27^- \rightarrow 25^-$ γ transition energy (416 keV) is comparable with the value of $6^+ \rightarrow 4^+$ (430 keV) transition. Therefore, as far as the $27^- \rightarrow 25^-$ γ transition is concerned, only the change of wave functions of two-quasiparticle multiplet has been involved, i.e., $(\nu f_{7/2}^2)6^+ \rightarrow (\nu f_{7/2}^2)4^+$. This $(\nu f_{7/2}^2)6^+ \rightarrow (\nu f_{7/2}^2)4^+$ transition is very fast and leads to the 27^- states both in ^{146}Sm and in ^{148}Gd to not be isomeric. It is worthwhile to note that the above discussions are qualitative and need to be confirmed experimentally measuring the transition probability.

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