Short Note

In-beam study of $^{145}$Tb


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Abstract. The high-spin states of $^{145}$Tb have been studied in the $^{118}$Sn($^{32}$S, 1p4n) reaction at $^{32}$S energies from 161 to 175 MeV using techniques of in-beam $\gamma$-ray spectroscopy. Measurements of $\gamma$-ray excitation functions and $\gamma$-$\gamma$-t coincidences were performed with 12 BGO(AC)HPGe detectors. Based on the measured results of $\gamma$-$\gamma$ coincidences, $\gamma$-ray anisotropies and DCO ratios, a level scheme for $^{145}$Tb was established for the first time. The observed excited states show typical irregular pattern in a spherical nucleus, and the low-lying levels have been interpreted qualitatively with a particle-core coupling.

PACS. 23.20.Lv Gamma transitions and level energies – 27.60.+j 90 $\leq A \leq 149$

The $N = 80$ $^{145}$Tb nucleus has one proton particle and two neutron holes outside the doubly closed nucleus $^{140}$Gd, and its high-spin states should be formed by excitations of valence nucleons. The $N = 80$ isotones $^{141}$Pm and $^{143}$Eu show a particle-core coupling behavior along their yrast lines [1–3], suggesting that the low-lying states in $^{145}$Tb might be interpreted by coupling the h$_{11/2}$ valence proton to the excited states in the doubly even core $^{144}$Gd [4,5]. Before the present study, the information on the level structure in $^{145}$Tb was much limited to a few excited levels observed in $^{145}$Dy $\beta^+$/EC decay [6]. Many prompt $\gamma$-rays belonging to the $^{145}$Tb nucleus have been identified by the $\gamma$-neutron and $\gamma$-charged particle coincidence measurements [7], but they have not been placed in a level scheme. Additionally, a superdeformed band has been observed in $^{145}$Tb which was produced with the $^{112}$Sn($^{37}$Cl, 2p2n) and $^{118}$Sn($^{31}$P, 4n) reactions [8]. In the present paper, we report a level scheme for $^{145}$Tb up to an excitation energy of 5.3 MeV.

The excited states in $^{145}$Tb were populated via the $^{118}$Sn($^{32}$S, 1p4n)$^{145}$Tb reaction. The $^{32}$S beams were provided by the tandem accelerator at the Japan Atomic Energy Research Institute (JAERI). The target is an enriched $^{118}$Sn metallic foil of 1.8 mg/cm$^2$ thickness with a 5 mg/cm$^2$ Pb backing. In order to determine the optimum beam energy and to identify transitions in $^{145}$Tb, first, the excitation functions for producing $\gamma$-rays were measured at the beam energies of 161, 168 and 175 MeV. Then, the beam energy of 165 MeV, at which the yield of $^{145}$Tb was a maximum, was chosen to populate the high-spin states in $^{145}$Tb. $\gamma$-γ-t coincidence measurements were carried out at this optimum beam energy with 12 BGO(AC) HPGe detectors, having energy resolutions of 1.9–2.3 keV at 1.33 MeV. Here, $t$ refers to the relative time difference between any two coincident $\gamma$-rays detected within ±200 ns. These detectors were divided into 3 groups positioned at 32$^\circ$ ($\pm$148$^\circ$), 58$^\circ$ ($\pm$122$^\circ$), and 90$^\circ$ with respect to the beam direction so that the DCO ratios (Directional Correlations of $\gamma$-rays deexciting the Oriented states) could be deduced. All the detectors were calibrated using the standard $^{152}$Eu and $^{133}$Ba sources. A total of $300 \times 10^6$ coincidence events were accumulated. After accurate gain matching, these coincidence events were sorted into two asymmetric matrices whose $y$-axis was the $\gamma$-ray energy deposited in the detectors at any angles and $x$-axis was the $\gamma$-ray energy deposited in.

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the detectors at 32° and 90°, respectively. By gating on the y-axes with suitable γ-rays, two spectra measured at 32° and 90° angle positions were obtained. After correcting for the overall detection efficiency of the detectors at each of the two angles and normalizing the two spectra with respect to each other, γ-ray anisotropy was deduced from the intensity ratio in the two spectra. Typical γ-ray anisotropies observed for the known γ-rays in this experiment were 1.5 for stretched quadrupole transitions and 0.7 for stretched pure dipole transitions. Therefore, we assigned the stretched quadrupole transition and stretched dipole transition to the γ-rays of 145Tb with anisotropies around 1.5 and 0.7, respectively. The reliability of the γ-ray anisotropy analysis was checked using the known γ-rays produced in the 150Nd(13C, α3n)156Gd reaction [9].

Assignments of the observed γ-rays to 145Tb were based on the γ-ray excitation functions and on the observation of γ-X and γ-γ coincidences. These assignments are consistent with the results suggested by the γ-neutron and γ-charged particle coincidence measurements [7]. Gated spectrum was produced for each of the γ-rays assigned to 145Tb. Selected spectra are shown in fig. 1. Based on the analysis of the γ-γ coincidence relationships, a level scheme for 145Tb is proposed for the first time as shown in fig. 2. The orderings of the transitions in the level scheme are fixed either with the help of some cross-over transitions or from the consideration of intensity balance in the gated spectra. The spins for the levels have been proposed according to the analysis of DCO ratios and γ-ray anisotropies. So far, we do not know whether the πd3/2 or the πh11/2 is the 145Tb ground state [6]. In the decay study of 145Dy, the 640 keV transition populating the πh11/2 state in 145Tb was observed [10]. Thus, the present work suggests that the level scheme of 145Tb is built on the πh11/2 level. Figure 2 shows that the decay flux goes through the 640 and 906 keV transitions, the latter being