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Short Note

In-beam study of ^{145}Tb

X.H. Zhou[1,a], Y. Zheng[1], Y.H. Zhang[1], Z. Liu[1], Q.Y. Pan[1], Z.G. Gan[1], T. Hayakawa[2], M. Oshima[2], T. Toh[2], T. Shizuma[2], J. Katakura[2], Y. Hatsukawa[2], M. Matsuda[2], H. Kusakari[3], M. Sugawara[4], K. Furuno[5], and T. Komatsubara[5]

[1] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, 730000, PRC
[2] Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan
[3] Chiba University, Inage-ku, Chiba 263-8512, Japan
[4] Chiba Institute of Technology, Narashino, Chiba 275-0023, Japan
[5] Institute of Physics and Tandem Accelerator Center, University of Tsukuba, Japan

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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 γ-ray spectroscopy. Measurements of γ-ray excitation functions and γ-γ-t coincidences were performed with 12 BGO(AC)HPGe detectors. Based on the measured results of γ-γ coincidences, γ-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 $90 \le A \le 149$

The $N = 80$ ^{145}Tb nucleus has one proton particle and two neutron holes outside the doubly closed nucleus ^{146}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 β^+/EC decay [6]. Many prompt γ-rays belonging to the ^{145}Tb nucleus have been identified by the γ-neutron and γ-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 γ-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. γ-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 γ-rays detected within ±200 ns. These detectors were divided into 3 groups positioned at 32° (±148°), 58° (±122°), and 90° with respect to the beam direction so that the DCO ratios (Directional Correlations of γ-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 300×10^6 coincidence events were accumulated. After accurate gain matching, these coincidence events were sorted into a symmetric matrix and an asymmetric DCO matrix for off-line analysis. In order to extract information concerning γ-ray anisotropies, the coincidence data were sorted into two asymmetric matrices whose y-axis was the γ-ray energy deposited in the detectors at any angles and x-axis was the γ-ray energy deposited in

[a] e-mail: ysg@ns.lzb.ac.cn

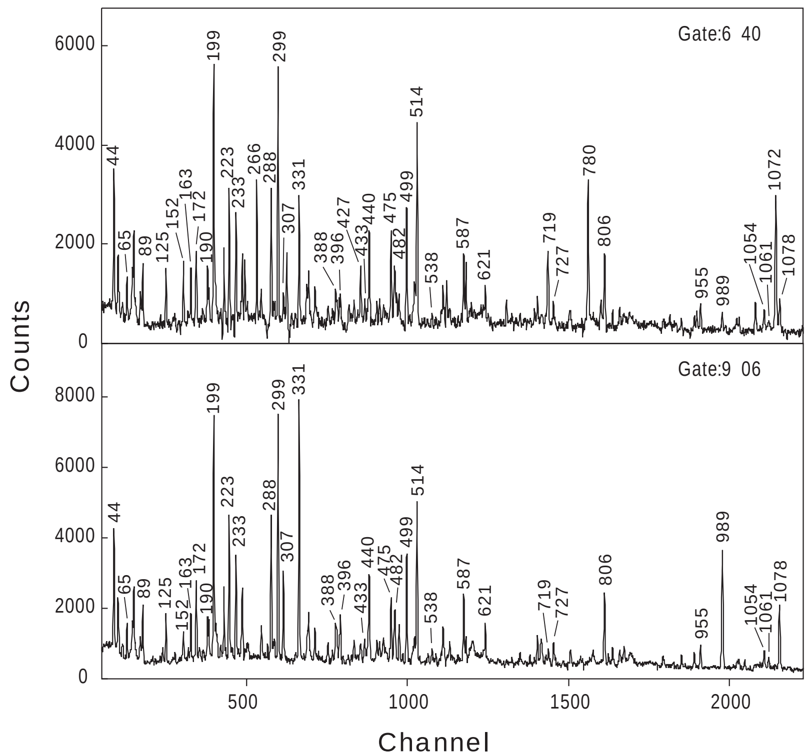

Fig. 1. Spectra of γ-rays gated on the 640 and 906 keV transitions, respectively.

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 ^{145}Tb 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 ^{150}Nd(^{13}C, α3n)^{156} Gd reaction [9].

Assignments of the observed γ-rays to ^{145}Tb 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 ^{145}Tb. Selected spectra are shown in fig. 1. Based on the analysis of the γ-γ coincidence relationships, a level scheme for ^{145}Tb 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 $\pi d_{3/2}$ or the $\pi h_{11/2}$ is the ^{145}Tb ground state [6]. In the de-

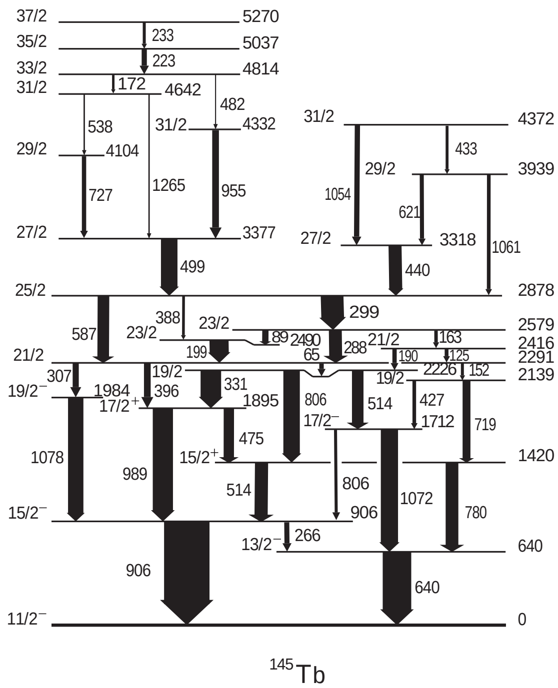

Fig. 2. Level scheme of ^{145}Tb proposed in the present work.

cay study of ^{145}Dy, the 640 keV transition populating the $\pi h_{11/2}$ state in ^{145}Tb was observed [10]. Thus, the present work suggests that the level scheme of ^{145}Tb is built on the $\pi h_{11/2}$ level. Figure 2 shows that the decay flux goes through the 640 and 906 keV transitions, the latter being the strongest γ-ray observed in ^{145}Tb. The low-lying levels have been established for example from the gated spectra shown in fig. 1, where it can be seen that the 266 keV transition is in coincidence with the 640 keV line but not with the 906 keV one. The 989, 514 (doublet) and 475 keV transitions are in coincidence with both of the 640 and 906 keV lines, while the 780 keV line is in coincidence only with the 640 keV one. This coincidence pattern, together with energy sum relationships of the involved transitions firmly established the low-lying states with spin values from 13/2 to 19/2. With similar considerations the other levels have been established.

As shown in fig. 2, the level scheme of ^{145}Tb displays irregular level spacings and many parallel decay branches in the yrast cascade, indicating that the excited states are formed primarily by the excitations of valence nucleons. Comparing the level structure in ^{145}Tb with those above the $\pi h_{11/2}$ level in the light odd-mass $N = 80$ isotones [1–3], it is naturally to interpret the 640 (13/2) and 906 keV (15/2) yrast levels by couplings the $h_{11/2}$ proton to the ^{144}Gd 2^+ core state at 743 keV. The 2^+ level in ^{144}Gd is predominantly formed by two neutron holes in the $s_{1/2}$ and $d_{3/2}$ orbitals [4, 11]. Similarly, the 1712 (17/2) and 1984 keV (19/2) yrast levels might have a nature of $\pi h_{11/2} \times 4^+$ (^{144}Gd). Thus, the first yrast levels in ^{145}Tb should have negative parities. In the ^{144}Gd core, the 3^- octupole state was observed at 1702 keV, and the octupole excitation was suggested to have the main $h_{11/2}d_{5/2}^{-1}$ proton particle-hole configuration with admixture from the neutron $f_{7/2}s_{1/2}^{-1}$ and $h_{9/2}d_{3/2}^{-1}$ contributions [4, 5]. Therefore, one would expect in ^{145}Tb a multiplet of positive-parity states of $\pi h_{11/2} \times 3^-$ character at excitation energies around 1.7 MeV. From the dipole characters of the 989 and 780 keV transitions, spin values of 15/2 and 17/2 are assigned to the states at 1420 and 1895 keV, respectively. These states likely correspond to the two highest-spin members of the $\pi h_{11/2} \times 3^-$ septuplet. As mentioned above, the main component of the ^{144}Gd octupole excitation is the $h_{11/2}d_{5/2}^{-1}$ proton particle-hole configuration, which can couple with the $h_{11/2}$ valence proton to give a maximum spin of 15/2 only. When the $h_{11/2}$ valence proton is coupled to the 3^- core state, the main $h_{11/2}d_{5/2}^{-1}$ component of the octupole state should be effectively blocked out by the Pauli principle in the 17/2 state, and its energy will consequently be pushed up. The analogous case was observed in ^{147}Tb [12–14]. The magic shell closure for the protons at $Z = 64$ is weaker than the one for the neutrons at $N = 82$, and the protons can be easily excited across the $Z = 64$ shell gap. The $\pi(h_{11/2}^2 d_{5/2}^{-1})$ and $\pi(h_{11/2}^2 g_{7/2}^{-1})$ states breaking the proton shell closure were observed in ^{147}Tb at excitation energies around 3 MeV [12–14]. Above the 19/2 level at 1984 keV, it might be expected that the states with excitation energies up to 3377 keV result from the $\pi(h_{11/2}^2 d_{5/2}^{-1})$ and $\pi(h_{11/2}^2 g_{7/2}^{-1})$ proton excitations or the coupling of the $h_{11/2}$ proton to the 5^- and 7^- yrast states in ^{144}Gd. The 5^- and 7^- yrast levels in the core ^{144}Gd were identified to be neutron-hole excitations of $h_{11/2}^{-1}s_{1/2}^{-1}$ and $h_{11/2}^{-1}d_{3/2}^{-1}$ [4, 11]. But obviously the present work does not distinguish between the proton- and neutron-hole excitations. It is interesting that the level scheme is divided into two separate parts above the 2878 keV level.

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