Coexistence of different band structures in odd-odd ^{194}Tl

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Introduction

The thallium nuclei (Z = 81) are situated in a transition region between the deformed prolate rare earth nuclei and the spherical lead nuclei at Z = 82. Thallium nuclei are spherical in their ground state; it has just one single hole in the $3s_{1/2}$ orbital in a lead core. However, strongly coupled rotational bands based on the “intruder” $9/2^-[505]$ Nilsson state originating from the $h_{9/2}$ proton orbital with oblate deformation have been identified in odd-A Tl isotopes [1-4]. On the other hand, decoupled $i_{13/2}$ neutron bands have been found in odd-A Hg isotopes in A = 190 mass region [5,6]. Therefore, in the odd-odd Tl isotopes, collective rotational bands based on $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration are expected in this region. Indication of such bands has been reported in a few doubly-odd Tl isotopes in this mass region [7-13]. But in most cases, there are ambiguities on level energies, spins and parities. Moreover, both the odd proton and the odd neutron in an even-A Tl nucleus occupy high-j orbitals. So, different kinds of collective and single particle excitations, including magnetic rotation and chiral doublet bands are expected. Recently chiral doublet bands have been observed for the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration in ^{198}Tl [13]. Therefore, detailed experimental and theoretical studies are needed to understand the structure of the bands based on the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration in odd-odd Tl nuclei.

In this work, we have studied the detailed spectroscopy of ^{194}Tl with an aim, in particular, to study different band structures in this odd-odd nucleus. In an earlier work, the gamma ray spectroscopy of ^{194}Tl was done by Kreiner et al. using two Ge(Li) detectors [9], but the information was limited to a few energy levels up to ~ 2 MeV with uncertain spin-parity and level energy assignments.

Experimental Details

The excited states in ^{194}Tl were populated via the fusion-evaporation reactions ^{185,187}Re(^{13}C,xn) at 75 MeV using ^{13}C beam from the 14-UD BARC-TIFR Pelletron at Mumbai, India. Gamma rays were detected using INGA with 15 Clover detectors. The target was a thick (18.5 mg/cm^2) natural rhenium. The clover detectors were arranged in six angles with two clovers each at ±40° and ±65° while four clovers were at 90° and three were at -23° angles. A digital data acquisition system having digitization rate of 100 MHz was used for the first time with INGA, to record the trigger less, time stamped data. The data were filtered with the condition that at least two clover detectors are fired in coincidence. The coincidence time window was selected as 1.5 µs. The level scheme was constructed from the analysis of γ–γ matrix and γ–γ–γ cubes. The γ–γ matrix contained about 2.4×10^9 coincidence events. Coincidence time window of ±400 ns was selected to construct the matrix and the cube. The J^π of the states were assigned from the multipolarity and the type (E/M) of the emitted gamma rays, deduced from the DCO and polarization (IPDCO) analysis.

Results and Discussion

An improved level scheme of ^{194}Tl established from the present work is shown in Fig. 1 which is extended up to 4.1 MeV of excitation energy. A total of 19 new gamma rays have been found and placed in the level scheme. Apart from the yrast band B1, which is extended beyond the band crossing region, we have identified two new bands B2 and B3 based on 16^- and 18^- states respectively. In band B1, we have identified a 137-keV E2 transition between 10^- and 8^- state, from single and double gated spectra. As a result, definite excitation energies (with respect to the 7^+ isomeric state) above 8^- has been established. The 741.9-, 458.6-, 289.4-keV γ rays, reported in ref. [9], were not observed in our data. Instead, the 468-, 292-, 478-, and 249-keV M1+E2 along with the cross-over E2 transitions were observed above the 1640-keV state.

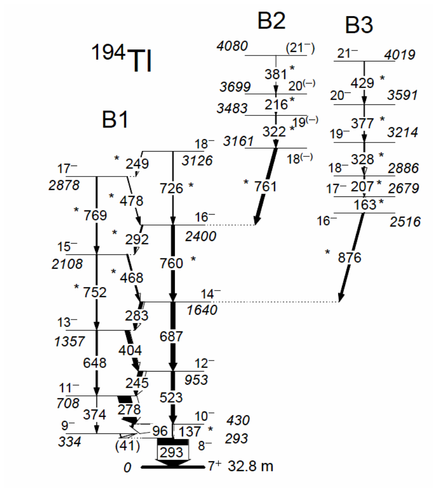

Fig. 1 The Level scheme of ^{194}Tl obtained in the present work (* indicates the new γ-rays).

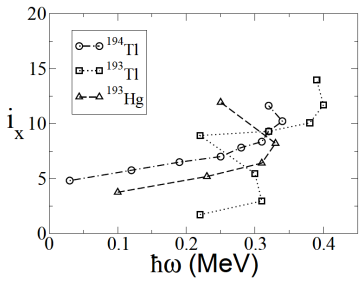

Fig. 2 i_x (alignments) vs. $\hbar\omega$ (rotational frequency) plot for the band B1 in ^{194}Tl, $\pi h_{9/2}$ band in ^{193}Tl and $\nu i_{13/2}$ band in ^{193}Hg.

The alignment (i_x) plot for the band B1 is shown in Fig. 2 as a function of rotational frequency $\hbar\omega$. An initial value of $i_x \sim 5\hbar$ in ^{194}Tl can be understood from the values of $i_x \sim 1.7\hbar$ for the $\pi h_{9/2}$ band in ^{193}Tl and $i_x \sim 3.7\hbar$ for the $\nu i_{13/2}$ band in ^{193}Hg (also shown in Fig.2). This strongly supports the $\pi h_{9/2} \otimes \nu i_{13/2}$ configuration assigned for the band B1. The band crossing occurs in this band at $\hbar\omega_c \sim 0.34$ MeV (see Fig.2). The second neutron pair alignment takes place at about the same frequency in odd-A ^{193}Tl. Therefore, the band crossing in ^{194}Tl is suggested to be due to the alignments of $i_{13/2}$ neutrons. The crossing frequency in ^{194}Tl agrees well with that in ^{192}Tl ($\hbar\omega_c \sim 0.32$ MeV), and ^{196}Tl ($\hbar\omega_c \sim 0.31$ MeV). A configuration of $\pi(h^2_{9/2}s^{-1}_{1/2}) \otimes \nu(i^{-2}_{13/2}p_{3/2})$ has been proposed for the band B3 by comparing its excitation energy, spin and alignment values with the systematic. The DCO and the IPDCO values indicate that the γ-rays in this band are predominantly M1 type. No cross-over E2 transition has been observed in this band. This band seems to follow the same general features of MR bands and hence, the states seem to have generated by shears mechanism. A semiclassical formalism [14], used to describe this band, gives an effective particle-hole interaction of V_2 = 1661 keV. This compares well with the value of V_2 per particle-hole pair obtained for the Pb nuclei in this region.

An oblate shape ($\beta_2 \sim 0.15$ & $\gamma \sim -57°$) for the band B1 and a near spherical shape ($\beta_2 \sim 0.06$) for B3 are obtained from the TRS Calculations [15]. These are consistent with the experimental results. The band crossing in B1 has also been described by these calculations. The details of the experiment, analysis and theoretical calculations will be discussed.

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