Gamma ray spectroscopy of ^{197}Tl using α beam

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Introduction

The nuclei near A ~ 190 in the Pb region are known for rich variety of structural phenomena and very interesting shape properties. The ground state of the odd-A Tl nuclei are $1/2^+$ corresponding to the occupation of the unpaired proton in the $3s_{1/2}$ orbital below the Z = 82 spherical shell closure. The low-lying excited levels in the odd-A Tl nuclei have been interpreted as due to the $\pi d_{3/2}$ and $\pi d_{5/2}$ orbitals. However, band structures built on the $J^\pi = 9/2^-$ state, in the odd-A Tl nuclei, have been interpreted as the rotational bands based on the proton $9/2^-$[505] Nilsson state [1, 2]. This state, originated from the $\pi h_{9/2}$ orbital above the Z = 82 spherical shell closure, is accessible by the odd-proton in Tl nuclei for oblate deformation. The properties of this intruder orbital (e.g deformation driving effect, the aligned angular momentum, particle alignment frequency etc.) could be obtained by studying this band up to high spins. On the other hand, the proton $13/2^+$[606] Nilsson state, originated from the $i_{13/2}$ orbit, may also be "low" lying for the oblate deformation. For the Tl nuclei in mass number close to 200, the neutron numbers favor the oblate deformation as they occupy the upper part of the $i_{13/2}$ orbital. Therefore, the intruder levels can be investigated from the excited states in the heavy mass Tl nuclei in mass region A ~ 190. Moreover, excited states in these nuclei will also feature the multi-quasiparticle states, originated from the odd-proton and the aligned neutron pairs. Many of these states may not be yrast in nature and hence, should be studied by light ion induced reactions.

Bands based on intruder $9/2^-$[505] and $13/2^+$[606] Nilsson states have been found in the neutron deficient (N < 114) odd mass Tl isotopes [2, 3]. In the present work, we have studied the excited states in ^{197}Tl by α-induced reaction, in order to investigate the yrast and near yrast states in this nucleus. The gamma ray spectroscopy of ^{197}Tl was studied by R. M. Lieder et al. [4] way back in 1978 using two Ge(Li) detectors. The spin-parities of the excited states were assigned, in the above work, from the angular distribution of the gamma rays. However, in such measurements, the parity of the states, which is important in order to identify the configuration of the states, remained tentative without polarization measurements.

Experimental Details

Excited states in ^{197}Tl were populated by the fusion-evaporation reaction ^{197}Au(^{4}He, 4n)^{197}Tl at 48 MeV of beam energy from the K = 130 Cyclotron at VECC, Kolkata. The target used was a self supporting 5 mg/cm^2 gold foil. The experimental set up consisted of a single crystal HPGe, one clover HPGe and one LEPS (HPGe) detector placed, respectively, at 30°, 90° and 135° angles with respect to the beam direction and in a median plane configuration. A 50 element multiplicity filter, consisted of two arrays of 25 BaF_2 crystals each, was also used. The energy and timing from each HPGe detector and an RF-γ TAC were recorded in list mode with a γ-γ trigger. The level scheme was constructed from the analysis of γ-γ matrix. Coincidence time window of ±50 ns was selected from the prompt peak of RF-γ TAC to construct the matrix. The γ–γ matrix contained about 4.3×10^7 coincidence events. The J^π assignment of the states has been done from the multipolarity (λ) and the type (E/M) of the emitted γ-rays deduced from the DCO and the polarization (PDCO) analysis.

Results and Discussion

Two band-like structures built on $9/2^-$ (B1) and $15/2^+$ (B2) states, originated respectively, from the intruder $\pi h_{9/2}$ and the 3qp configuration, were known in ^{197}Tl [4]. In the present work, all the gamma rays in these two bands were observed. Moreover, a $13/2^+$ state corresponding to the $\pi 13/2^+[606]$ Nilsson orbital have been assigned for the first time in ^{197}Tl. The 557.6-keV gamma ray from the 1553 keV state, which feeds the known $11/2^-$ state in ^{197}Tl, has been found to be of E1 type from the polarization (see Fig. 1) and the DCO ratio measurements. Therefore, the 1553-keV state has been proposed to be $13/2^+$ state with the above configuration. The excitation energy of this state follows the systematic of the Tl isotopes as shown in Fig. 2, where the variations of the excitation energies of the $13/2^+$ states in the odd-A Tl and Bi isotopes are plotted with neutron number.

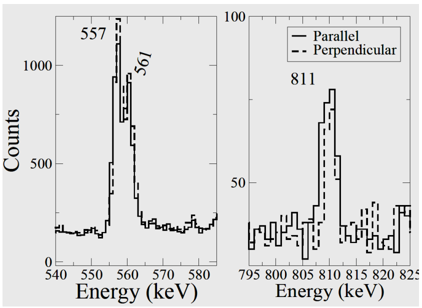

Fig. 1 The perpendicular (dashed) and the parallel (solid) components of three γ-rays in ^{197}Tl obtained from the PDCO analysis in the present work. The correction factor due to the asymmetry of the setup was $a = 0.99(1)$.

Similarly, the E1 character for the 561- and M1 + E2 character for 811-keV γ rays, deduced in the present work, indicate that the J^π of the 2114-keV state is $15/2^-$ as opposed to $15/2^+$ assigned previously [4]. The band B2 of Ref. [4] has, therefore, been proposed to be based on this $15/2^-$ band head with $\pi i_{13/2} \otimes \nu i_{13/2} p_{3/2}$ configuration. The aligned angular momentum (i_x) have been shown in Fig. 3, as a function of rotational frequency ħω, for the two bands in ^{197}Tl. The difference in the initial values of i_x confirms the 1qp and 3qp nature of these two bands. In both the bands, the band crossings are clearly observed at a similar frequency of ħω ~ 0.3 MeV.

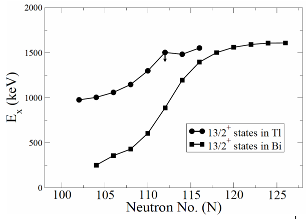

Fig. 2 Excitation energy (E_x) of $13/2^+$ state in Tl and Bi isotopes as a function of neutron number.

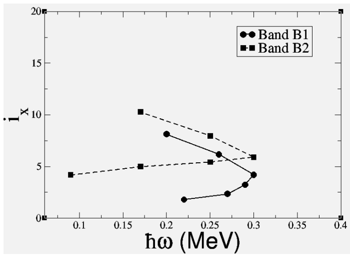

Fig. 3 Alignment (i_x) vs. rotational frequency (ħω) for the bands B1 and B2 in ^{197}Tl.

The total routhian surface (TRS) calculations have been performed for the various 1qp and 3qp configurations of ^{197}Tl to understand the shape driving effects of the corresponding orbitals and the band crossing phenomena. The details of the experiment, analysis and theoretical calculations will be discussed in the symposium.

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