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Identification of intruder $\pi i_{13/2}$ state in ^{197}Tl

H. Pai[1,a], G. Mukherjee[1,b], S. Bhattacharya[1], C. Bhattacharya[1], S. Bhattacharyya[1], T. Bhattacharjee[1], S. Chanda[2], S. Rajbanshi[3], A. Goswami[3], M.R. Gohil[1], S. Kundu[1], T.K. Ghosh[1], K. Banerjee[1], T.K. Rana[1], R. Pandey[1], G.K. Prajapati[1], S. R. Banerjee[1], S. Mukhopadhyay[1], D. Pandit[1], S. Pal[1], J. K. Meena[1], P. Mukhopadhyay[1], and A. Choudhury[1]

[1] *Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, INDIA*
[2] *Physics Department, Fakir Chand College, Diamond Harbour, West Bengal, INDIA*
[3] *Saha Institute of Nuclear Physics, Kolkata 700064, INDIA*

Abstract. The high-spin states in ^{197}Tl were studied by populating them using the ^{197}Au(α, 4n)^{197}Tl reaction at 48 MeV of beam energy. $\gamma-\gamma$ coincidence data were taken using a combination of clover, LEPS (low energy photon spectrometer) and single crystal HPGe detectors. The polarization and DCO measurements were performed for definite spin and parity assignment of the excited states. The $\pi i_{13/2}$ intruder state has been identified for the first time in this nucleus. The total Routhian surface calculations have been performed to study the shape and deformation of ^{197}Tl for different configurations.

1 Introduction

The $\pi h_{9/2}$ and $\pi i_{13/2}$ orbitals which lie above the $Z = 82$ shell closure are considered as the "intruder" orbitals for Tl ($Z = 81$) nuclei as they intrude near the Fermi levels of Tl for oblate and prolate deformations. Therefore, it is interesting to study the effect of these orbitals in breaking the spherical symmetry in odd mass Tl nuclei by inducing non-spherical shapes in them. Moreover, the $\pi i_{13/2}$ level lies above the $Z = 92$ spherical sub-shell closure and hence, the "intruder" $\pi i_{13/2}$ level in the lighter Tl nuclei provides a play ground to study the properties of the levels for the heavy nuclei above $Z = 92$ which are otherwise difficult to study. Rotational bands based on the intruder $\pi h_{9/2}$ and $\pi i_{13/2}$ levels with oblate and prolate deformations have been reported in the odd-A $^{189-193}$Tl [1] nuclei. For the heavier ^{195,197}Tl isotopes, however, although the $\pi h_{9/2}$ bands are observed, no excited state corresponding to the intruder $\pi i_{13/2}$ orbital has been identified, so far [2]. In the present work, the γ-ray spectroscopy of ^{197}Tl has been studied in order to investigate the proton intruder states and the multi-quasiparticle states in this nucleus. The excited states in ^{197}Tl were earlier studied in 1978 using two Ge(Li) detectors [2].

2 Experimental setup, Results and Discussion

The excited states of ^{197}Tl were populated by fusion evaporation reaction ^{197}Au(^{4}He, 4n)^{197}Tl using 48-MeV α beam from the K-130 cyclotron at Variable Energy Cyclotron Centre, Kolkata. A 5 mg/cm^2

[a] e-mail: hari.vecc@gmail.com,hpai@ikp.tu-darmstadt.de
[b] e-mail: gopal@vecc.gov.in

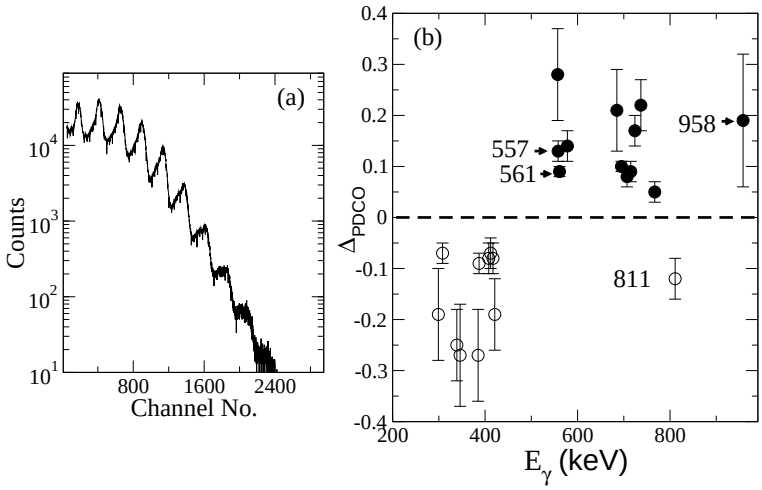

Figure 1. (a)Multiplicity spectrum from the present work and (b) Preliminary values of the polarization asymmetry (Δ_{PDCO}) for different γ transitions. The solid and open circles correspond to electric and magnetic type of transitions, respectively.

self supporting ^{197}Au target was used. A single-crystal large HPGe detector (80% relative efficiency), a clover HPGe detector and a LEPS detector were used in this experiment which were placed in a median plane at 30°, 90° and 135° angles, respectively, with respect to the beam direction and at a distance of 12 cm from the target. A 50-element (25 each on the top and on the bottom) BaF_2 multiplicity array [4] was also used to get the event multiplicity. A multiplicity spectrum of different folds obtained in the present work is shown in figure 1(a). It can be seen that significant counts are recorded even for higher folds events with maximum multiplicity of $M_{max} \sim 10$ has been observed. 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 (between single-crystal HPGe and clover HPGe detectors) with a time window of ±50 ns, chosen from the prompt peak of RF-γ TAC. A total of $\sim 4.3 \times 10^7$ coincidence events were accumulated and analyzed using the Radware package [5].

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 [6] and the gated polarization asymmetry (Δ_{PDCO}) [7] analysis. Preliminary results of the Δ_{PDCO} gated by the single-crystal HPGe detector are presented in figure 1(b). Single gated γ-ray spectra from the γ-γ matrix are shown in figure 2. All γ transitions known from the previous work [2] have been confirmed in this work. An improved level scheme of ^{197}Tl is shown in figure 3. The DCO ratio measurements indicate that the 557.5 keV transition is a dipole. The detailed analysis of the polarization measurements and their comparison with the calculated values are in progress but the the preliminary results of the Δ_{PDCO} measurements indicate that the 557- and 561-keV γs from 1553- and 2114-keV states, respectively, are of E1 type. Hence, the spin and parity of the 1553- and 2114-keV states are deduced as $13/2^+$ and $15/2^-$, respectively, contrary to the earlier assignments. A mixed dipole (M1+E2) character obtained for the 811-keV γ from the 2114-keV state to the 1303-keV state supports the new J^π assignments. With these new assignments, the band B2 becomes a negative parity band which was earlier assigned as a positive parity one. Moreover, the J^π of the 1953- and 1867-keV states have also been modified from the

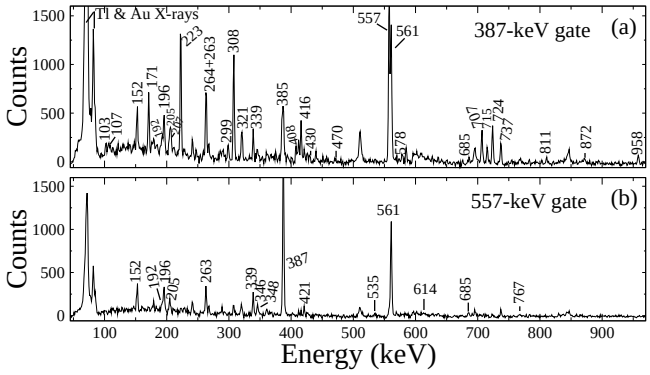

Figure 2. Coincidence spectra gated by (a) 387-keV and (b) 557-keV γ transitions in ^{197}Tl.

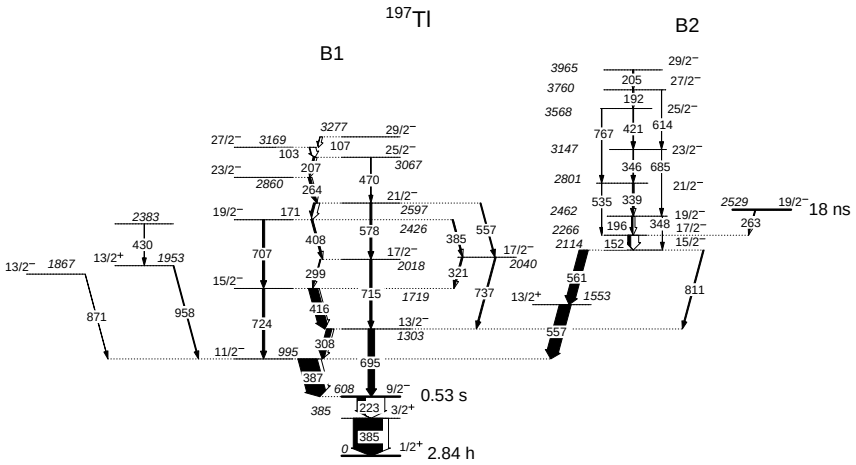

Figure 3. Level scheme of ^{197}Tl proposed in this work.

previous assignments [3] based on the preliminary assignment of multipolarity and transition type for the 958- and 871-keV γ rays.

Out of the two $13/2^+$ states at 1553 keV and 1953 keV, observed in our work, the former one has been proposed to be the candidate for the intruder $\pi i_{13/2}$ configuration due to its strong decay to the $11/2^-$ state of the $\pi h_{9/2}$ band similar to those observed for the lighter isotopes [1, 8]. No band structure has been observed based on this state.

A new configuration of $\pi i_{13/2} \otimes \nu i_{13/2} \nu j$ ($j = p_{3/2}, f_{5/2}$) has been proposed assuming negative parity for the band B2. It may be noted that the band B2 is very similar to the three quasi-particle band in ^{195}Tl [2] but with opposite parity.

Total Routhian surface (TRS) calculations have been performed to study the deformation for the $\pi h_{9/2}$ (band B1) and the $\pi i_{13/2}$ configuration in ^{197}Tl using the Hartee-Fock-Bogoliubov code of Nazarewicz *et al.* [9]. The detail procedure has been outlined in Ref. [10]. A deformed Woods-Saxon potential and pairing interaction was used with the Strutinsky shell corrections method. These calculations suggest $\beta_2 \sim 0.08$ and $\gamma \sim -50^o$ for ^{197}Tl in $\pi i_{13/2}$ configuration while $\beta_2 \sim 0.15$ and

$\gamma \sim -58^o$ in $\pi h_{9/2}$ configuration, i.e near oblate shape for both the configurations. The calculated deformations, however, indicate that though a well developed band structure is expected for the well deformed $\pi h_{9/2}$ configuration but for the $\pi i_{13/2}$ configuration a rotational band may not be realized for its near spherical shape. This is in conformity with the experimental observations.

3 Summary

The high spin states in odd-A ^{197}Tl have been studied by γ ray spectroscopy. The DCO ratio and the polarization asymmetry ratio measurements were performed for the precise determination of spins and parities of the levels. Based on the preliminary results, the hitherto unknown proton $i_{13/2}$ intruder state has been identified in the present work, for the first time in Tl isotopes heavier than ^{193}Tl and a negative parity for the band B2 has been assigned. Oblate deformation for the $\pi h_{9/2}$ configuration and a near spherical shape for the $\pi i_{13/2}$ configuration in ^{197}Tl were obtained from the TRS calculations, in agreement with the experimental observations.

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References

[1] W. Reviol et al., Phys. Scr. **T 56**, 167 (1995); W. Reviol et al., Nucl. Phys. **A 548**, 331 (1992).
[2] R. M. Lieder et al., Nucl. Phys. **A 299**, 255 (1978).
[3] D. Venos et al., Nucl. Phys. **A 280**, 125 (1977).
[4] Deepak Pandit et al., Nucl. Ins. Meth. **A 624**, 148 (2010).
[5] D. C. Radford, Nucl. Ins. Meth. **A 361**, 297 (1995).
[6] A. Krämer-Flecken, et al., Nucl. Ins. Meth. **A 275**, 333 (1989).
[7] K. Starosta et al., Nucl. Ins. Meth. **A 423**, 16 (1999); G. Duchene et al Nucl. Inst. Meth. **A 432** (1999) 90; H. Pai et al., Phys. Rev. **C 85** 064313 (2012).
[8] P.M. Raddon, et al., Phys. Rev. **C 70** 064308 (2004); G.J. Lane, et al., Nucl. Phys. **A 586** 316 (1995).
[9] W. Nazarewicz et al., Nucl. Phys. **A 512**, 61 (1990); ibid **A 435**, 397 (1985).
[10] G. Mukherjee et al., Nucl. Phys. **A 829**, 137 (2009); H. Pai et al., Phys. Rev. **C 85** 064317 (2012).