Search for chirality in ^{193}Tl

J Ndayishimye[1,2], E A Lawrie[1], J L Easton[1,3], R A Bark[1], S B Bvumbi[1,6], T S Dinoko[1,3], P M Jones[1], A Kamblawe[1,2], E Khaleel[1,2], N Y Kheswa[1], J J Lawrie[1], S N T Majola[1,5], P L Masiteng[1,3,6], D Negi[1], J N Orce[3], P Papka[2,1], A A Pasternak[4], J F Sharpey-Schafer[3], O Shirinda[1], M A Stankiewicz[1,5], M Wiedeking[1], S M Wyngaardt[2]

[1] iThemba LABS, National Research Foundation, P.O. Box 722, 7129 Somerset West, South Africa

[2] University of Stellenbosch, P.O. Box 1529, Stellenbosch 7599, South Africa

[3] University of the Western Cape, Private Bag X17, 7535 Bellville, South Africa

[4] Cyclotron Laboratory, A.F. Ioffe Physical Technical Institute 194021, St. Petersburg, Russia

[5] University of Cape Town, Private Bag, 7701, Rondebosch, South Africa

[6] University of Johannesburg, P.O. Box 524, 2006 Auckland Park, South Africa

Abstract. A search for chiral bands in ^{193}Tl is under way using the ^{160}Gd(^{37}Cl,4n) reaction. Analysis of the level scheme and the spin and parity assignments is in progress. The previous level scheme of ^{193}T is modified and extended. Most importantly three rotational bands, that could be involved in a possible chiral structure are identified.

1. Introduction

Chirality refers to an object that is not identical to its mirror image. In this case the original and its image have different handedness, like our two hands. In the nuclear domain, chiral symmetry is defined in the angular momentum space. It was introduced by S. Frauendorf and J. Meng [1]. A nuclear chiral system can be built in a triaxially deformed nucleus if its total angular momentum has large projections along all three nuclear axes. For instance in an odd-odd nucleus the total angular momentum might be a sum of three nearly orthogonal angular momenta, those of the odd proton, the odd neutron, and the collective rotation of the core. These nearly-perpendicular angular momenta can then be oriented in a left-handed or a right-handed system ensuring that the nucleus exhibits chiral symmetry. The rotational angular momentum of triaxial nuclear core favours alignment along the intermediate nuclear axis. To form a chiral system the odd proton and the odd neutron should have a particle and a hole nature respectively, which ensures that their angular momenta favour alignments along the short and long nuclear axes respectively. In the laboratory reference frame, a chiral structure is exhibited by the observation of a doublet $\Delta I=1$ bands with the same parity and levels with similar excitation energy for the same spins [1, 2].

So far, candidate chiral doublet bands have been proposed in a number of odd-odd and odd-A nuclei [3]. Some of them were discovered in experiments done at iThemba LABS (A~80, A~100, A~130 and A~190) and (A~80). Moreover a new region of possible chiral symmetry in the heavier Tl isotopes was suggested at iThemba LABS. A candidate chiral pair was suggested in ^{198}Tl [4, 5] and perhaps the best chiral symmetry to date was found in ^{194}Tl [6]. Thus ^{193}Tl as a neighbour of ^{194}Tl is likely to be a very good chiral candidate.

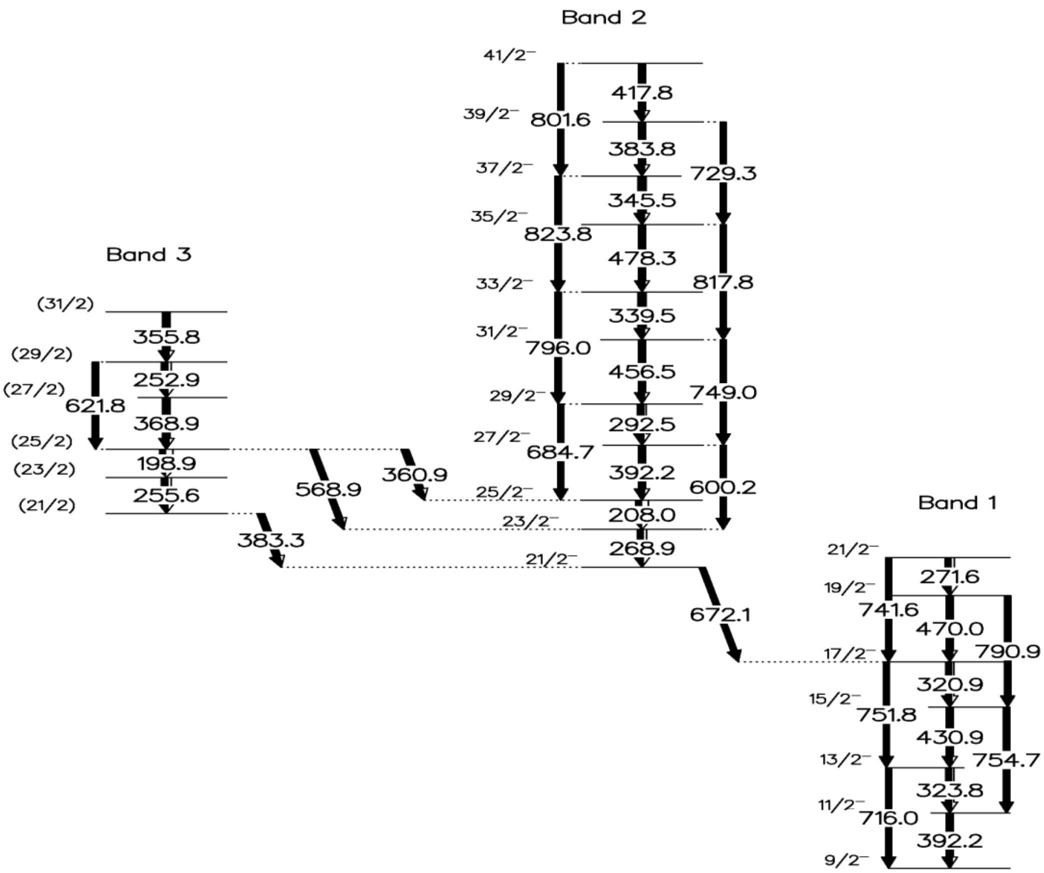

Figure 1: Partial revel scheme of ^{193}Tl [taken from 7].

Previous investigations in ^{193}Tl found a negative parity band (Band 2 in Figure 1) which is built on a $\pi h_{9/2} \times \nu i_{13/2}^2$ configuration [7]. The proton lies at the bottom of the $h_{9/2}$ shell and thus have predominantly a particle nature, while the neutrons occupy orbitals near the top of the $i_{13/2}^2$ shell and thus have predominantly hole nature. Therefore this configuration is suitable for a chiral symmetry system. Furthermore a weak band (Band 3 in Figure 1) with uncertain spin and parity assignments was also observed [7]. This weak band could be a chiral partner to Band 2. The question whether this band has the same parity as Band 2, and thus can be its chiral partner remained unsolved. We performed an experiment to extend the level scheme of ^{193}Tl and to determine the spin and parity of this weaker band. In addition measurements of the lifetimes of the levels of ^{193}Tl using the DSAM technique are planned.

2. Experimental methods and data analysis

Gamma spectroscopy studies of ^{193}Tl were performed using the ^{160}Gd(^{37}Cl,4n) reaction at 167 MeV, with a thin target of ~1.5mg/cm^2 and the 9 clovers of the AFRODITE array placed at 90^0 and 135^0 with respect to the beam direction. Two weekends of beam time were awarded for this thin target experiment. The trigger condition required at least two clovers firing in coincidence. The data were gainmatched and sorted into matrices which were used for construction of the ^{193}Tl level scheme based on coincidence relationships.

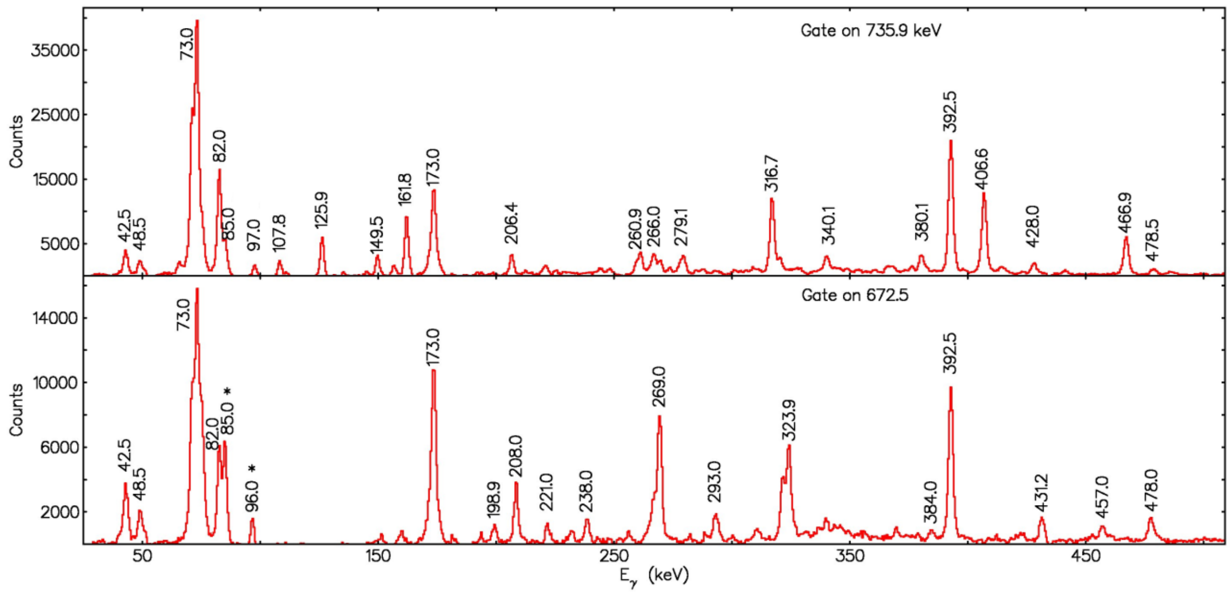

Figure 2: Two gated spectra showing the transitions in ^{193}Tl. The gamma rays that belong to Band 4 are observed in the spectrum gated on the 735.9 keV transition, while the spectrum gated on the 672.5 keV transition shows the gamma rays in Bands 2, 3 and 5. Star signs show the two low energy transitions (85.0 keV and 96.0 keV) which are placed at the band crossing region between Band 1 and Band 2.

3. Results and discussion

The experiment was optimized for lifetime measurements by choosing a reaction producing the ^{193}Tl nuclei at high recoil velocity. However, this reaction has a relatively low cross-section of about 30 mb. The data obtained in the thin target experiment was not sufficient to determine the spin and parity assignments of Band 3.

Nevertheless several modifications and extension of the previously proposed level scheme [7] were made. For instance two low energy transitions were added at the band crossing region between Band 1 and Band 2, thus changing the spin of the yrast chiral candidate band (Band 2) by 2ħ. The low energy 85.0 keV γ–ray which overlaps with the X-rays, can be clearly identified in the spectrum gated on the 672.5 keV transition, where a clear enhancement of the X-ray peak at 85.0 keV is observed in comparison with this peak in the spectrum gated in the 735.9 keV transition (see Figure 2). The gated spectra also show a new 96 keV transition in coincidence with the 672.5 keV transition. There is a 97 keV transition previously placed in coincidence with the 735.9 keV transition. We confirm this coincidence relationship, see Figure 2, but modify the placement of the 97 keV transition, because it is also in coincidence with both 406.6 keV and 466.9 keV transitions, in contrast to its previous placement in anti-coincidence with the 406.6 transition.

Many other modifications and some extension of the previous level scheme were performed in this work. Most importantly the placement of one band, now called Band 5 (see Figure 3) was revised. This band was previously placed above the 735.9 keV transition, but we found that it feeds the levels above the 672.5 gamma ray. This band is of particular interest, because it could play an important role in the chirality scenario. Concerning Band 3, none of the previously proposed linking transitions could be identified. The total level scheme of ^{193}Tl constructed so far is shown in Figure 3.

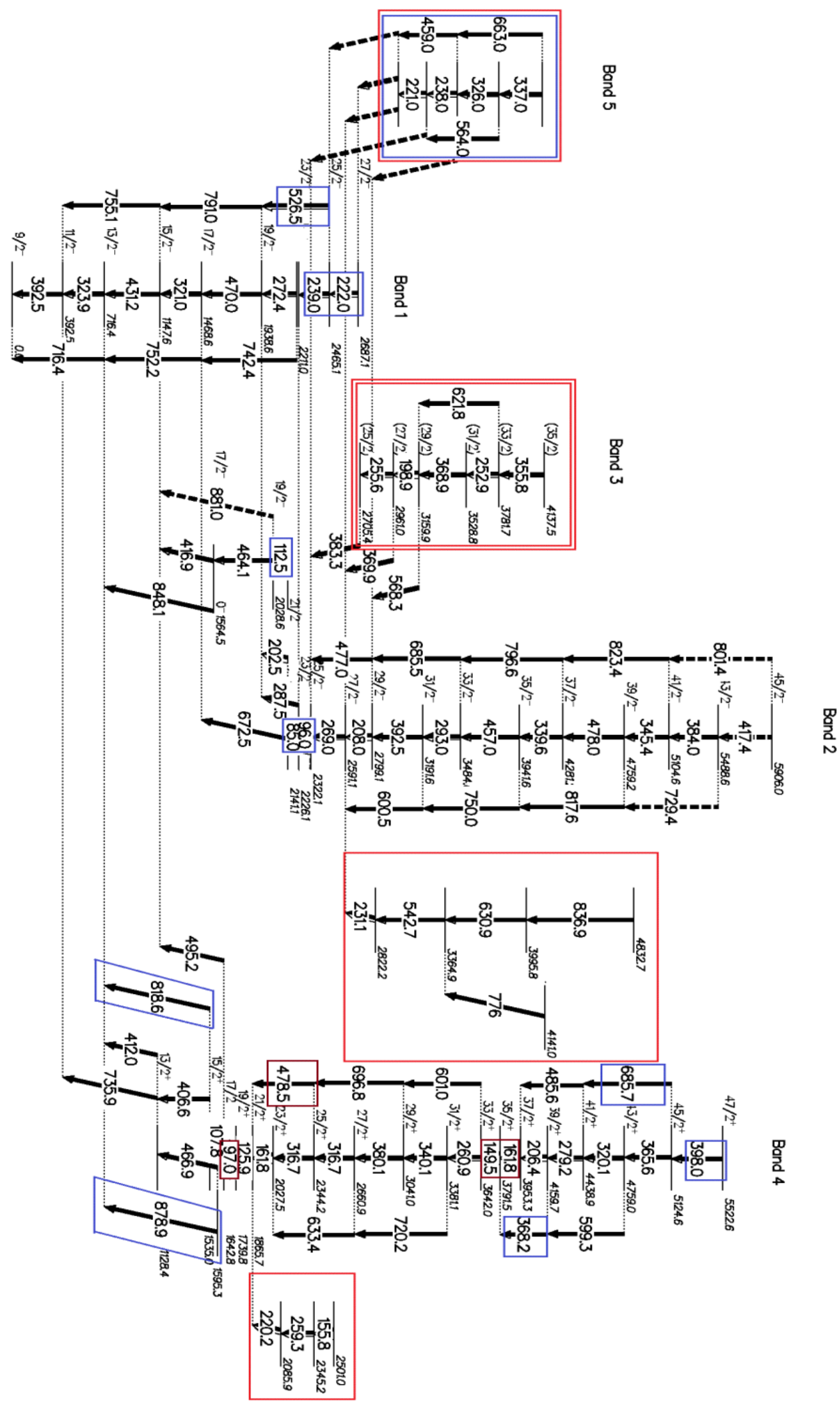

Figure 3: The level scheme of ^{193}Tl as constructed in this work. New transitions are shown in blues rectangles. Maroon rectangles show the transitions with revised placement. The two structures inside red rectangles are still under investigation. Bands 3 and 5, bounded by double rectangles are possibly part of a chiral structure, together with the previously observed Band 2. Band 5 is not yet linked.

Although some important modifications and an extension of the level scheme were performed, the data did not allow us to solve the question about the presence of chiral structure in this nucleus. More experimental data is needed. A proposal to use a new reaction with much larger cross section for the production of ^{193}Tl was submitted and approved. We anticipate that a new much larger data set will be collected soon.

References

[1] S. Frauendorf and J. Meng, Nucl. Phys. A617, (1997) 131
[2] S. Frauendorf, Reviews of Mod. Phys. 73 (2001) 463
[3] T. Koike et al., Nucl. Phys. A. 834 (2010) 36C)
[4] E.A. Lawrie et al., Phys. Rev. C 78, 021305(R) (2008)
[5] E.A. Lawrie et al., Eur. Phys. J. A 45, (2010) 39
[6] P.L Masiteng et al., Phys. Lett. B719 (2013) 83-88
[7] W. Reviol et al., Nucl. Phys. A548 (1992) 331