PROTON EXCITATIONS IN THE SD NUCLEI OF THE MASS 190 REGION*

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(Received December 18, 1995)

The study of ^{193}Tl, using EUROGAM phase 2 gamma array, revealed five superdeformed bands (SD) in this nucleus. The measured value of $gK = 1.4pm0.17$ for the two signature Yrast SD bands confirms the [642]5/2 intruder configuration for the odd proton. A saturation of the dynamic moment of inertia $\mathcal{I}^2$ is observed for these two bands. It can be understood in terms of an exhausted quasi-neutron alignment in the presence of substantially reduced quasi-proton alignment due to the Pauli blocking. From band interactions and $\mathcal{I}^2$ behaviours, intrinsic configurations involving the [411]1/2 and [651]1/2 proton orbitals, are assigned to the excited SD bands.

PACS numbers: 21.60. Cs, 21.10. Ky, 21.10. Re, 27.80. +w

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* Presented at the "High Angular Momentum Phenomena" Workshop in honour of Zdzisław Szymański, Piaski, Poland, August 23–26, 1995.

A striking difference between the SD nuclei of the mass-190 region and those in other mass regions is the behaviour of the dynamic moment of inertia $\mathcal{I}^2$. While the $\mathcal{I}^2$ patterns of the SD bands near $A \approx 130$ and $A \approx 150$ show pronounced differences (closely correlated to the high-N proton and neutron intruder orbital occupancy), the majority of the SD bands in the mass 190 region display the same large, smooth increase of $\mathcal{I}^2$ in the rotational frequency range $0.15 < \hbar\omega < 0.40$ MeV. This behaviour of $\mathcal{I}^2$ has been interpreted [1, 2] as resulting from the gradual alignment of quasiparticles occupying high-N intruder orbitals (originating from the $i_{13/2}$ proton and $j_{15/2}$ neutron orbitals) in the presence of pair correlations. In this picture, Pauli blocking of high-N intruder orbitals is expected to induce a flattening of the $\mathcal{I}^2$. Such effects are indeed observed in some odd-Hg [3, 4] and odd-Pb [5, 6] SD nuclei, where the blocking of the $N = 7$ quasineutron or $N = 6$ quasiproton alignment is thought to be responsible for the flattening of the $\mathcal{I}^2$. In some odd-odd Tl isotopes [7, 8], the blocking effect of both the $N = 7$ quasineutron and $N = 6$ quasiproton is also observed. A direct consequence of these interpretations would be that, after the quasiparticle alignments have taken place, the $\mathcal{I}^2$ will exhibit a saturation towards a rigid-body value. Indeed, a onset of saturation of the $\mathcal{I}^2$ has been observed in ^{192}Hg [9], and even more significantly a marked decrease of the $\mathcal{I}^2$ was seen in ^{194}Hg [10], for rotational frequencies $\hbar\omega > 0.4$ MeV. In the present work, from the study of their magnetic properties, the two yrast SD bands in ^{193}Tl [11] have been unambiguously assigned to the configuration where the single proton is occupying the $i_{13/2}$ intruder orbital. The two bands have been extended to higher rotational frequencies, and their moment of inertia has been found to exhibit a saturation for $\hbar\omega > 0.32$ MeV, reflecting the combined effects of the proton pairing blocking and the complete $j_{15/2}$ neutron alignment. In addition to the two known Yrast SD bands [11], three other excited SD bands have been discovered in the ^{193}Tl nucleus [12, 13] and assigned to particle and hole states involving the [411]1/2 and [651]1/2 proton orbitals.

The experiment was carried out at the newly operating Vivitron tandem accelerator at CRN Strasbourg. Excited states in ^{193}Tl were populated with the reaction ^{181}Ta (^{18}O, $6n$) ^{193}Tl at a beam energy of 110 MeV. The target consisted of a stack of two self-supporting ($\approx 500\mu\text{g/cm}^2$) ^{181}Ta foils. The γ-rays emitted in the reaction were detected with the EUROGAM2 detector array [14], consisting of 126 Compton-suppressed Ge detectors (24 quad-clover and 30 large volume Ge detectors). Approximately $0.8 * 10^9$ γ-ray coincidence events were recorded to tape for which at least 5 unsuppressed Ge detectors had fired. After unfolding, a total of $8 * 10^9$ quadruple suppressed γ^4 coincidences was obtained.

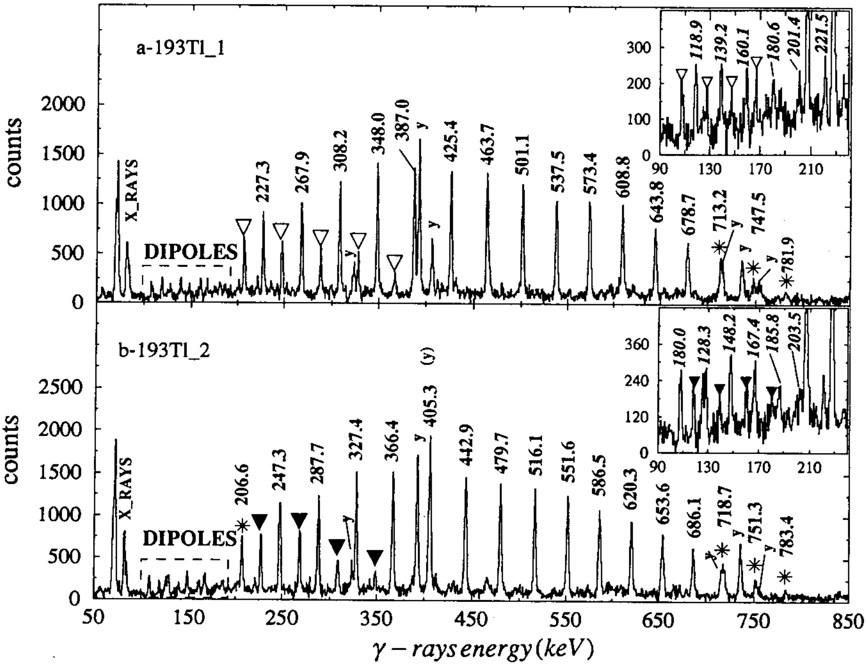

Fig. 1. Spectra of SD bands 1 and 2 in 193Tl. The spectra are from quadruple coincidences showing γ rays in coincidence with three γ-rays that are in the band of interest; a — band 1 (all indicated transitions are used as gates except the 227,782 and 817 keV); γ-transitions in band 2 in coincidence with band 1 are indicated by empty triangles. b — band 2 (all indicated transitions are used as gates except the 207, 247, 751, 783, 817 keV); γ-transitions in band 1 in coincidence with band 2 are indicated by full triangles. The dipole transitions linking the band 1 and band 2 are indicated in boxes. The γ-transitions connecting low-lying normal deformed states are labelled by "y". The newly observed transitions are indicated by stars for both bands. Typical transition energy uncertainties are 0.3 to 0.5 keV.

The triple-gated spectra of the two signature partner Yrast SD bands (band 1 and band 2) in ^{193}Tl, obtained in the present experiment, are displayed in Fig. 1. Band 1 was found to have an intensity of 90% relatively to band 2. All transitions reported earlier [11, 15] are clearly observed, together with known ^{193}Tl Yrast transitions associated with the decay out of the SD bands. The higher selectivity of the EUROGAM2 array enables us to extend the bands to higher and lower transition energies. In the spectrum of band 1 (Fig. 1a), γ-transitions of band 2 can clearly be seen, up to $\approx$ 400 keV. The corresponding cross-talk transitions are seen at energies ranging from 100 keV to 200 keV, as indicated in the Fig. 1a. In the spectrum of band 2 (Fig. 1b), the situation is reversed and transitions in band 1 are seen, as well as cross-talk transitions. Information on transition multipolarities has been obtained by measuring the ratio of the γ-ray intensities detected in the clover detectors, near 90°, to the intensities detected in the single detectors nearer 0° and 180° to the beam direction. This ratio indicates that the cross-talk transitions are of $\Delta L = 1$ type in contrast with the $\Delta L = 2$ inband transitions. The interband transitions together with the transitions in band 1 and band 2 can be organized in a unique way as

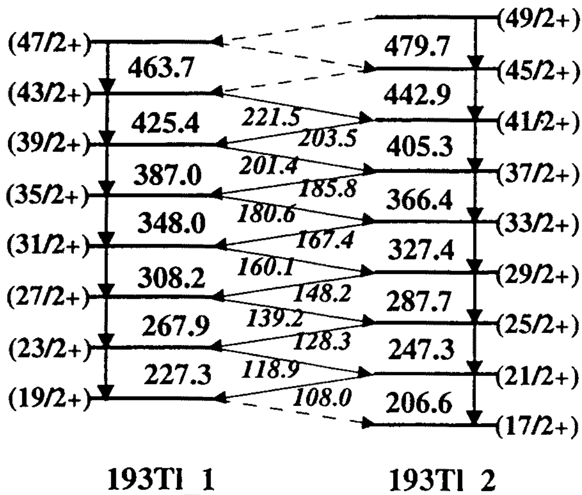

Fig. 2. Low energy part of the level scheme for the pair of signature partner bands in ^{193}Tl. The energies of the dipole transitions (shown in boxes in Fig. 1) are assigned within a 0.2 to 0.3 keV uncertainty.

shown in Fig. 2. Having in mind the fact that band 1 and band 2 are probably signature partners [11, 15], it is, therefore, suggested that in this case the two-way cross talk would most likely indicate the presence of M1 decays. This assumption is corroborated by the evaluation of the conversion coefficient values extracted from total intensity conservation. In order to extract the M1 strengths from the $I_\gamma(\mathrm{M1})/I_\gamma(\mathrm{E2})$ branching ratios, two different methods have been used [15, 16]. Values of $(g_K - g_R)K/Q_0$ have been extracted for several SD states in both signature partner bands. Taking the quadruple moment $Q_0 = 19 \pm 2$ eb, which is the average of the measured quadruple moments in the even-even neighboring ^{192}Hg [17] and ^{194}Pb [18] nuclei, and the g_R-factor equal to Z/A, the experimental value of g_K, obtained from both methods, is found to be equal to 1.46 ± 0.17. This value is close to the theoretical one, obtained by Semmes *et al.* [19], for the 81$^{\mathrm{th}}$ proton being on the $i_{13/2}$ $(\Omega = 5/2)$ intruder orbital, for the two signature partner SD bands in ^{193}Tl. It is worth pointing out that the renormalization factor for the magnetic moment due to the intrinsic spin $g_s^{\rm eff}/g_s^{\rm free}$ has been extracted from the measured value of g_K and was found to be equal to 0.7 ± 0.2.

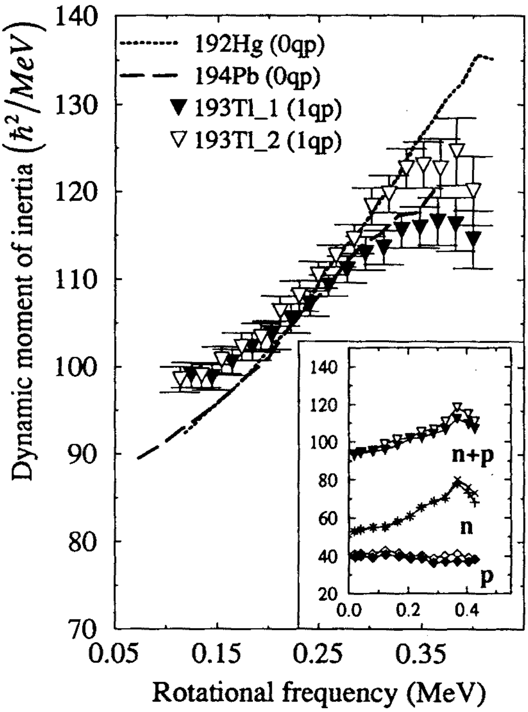

Fig. 3. Experimental dynamic moments of inertia as a function of $\hbar\omega$ for the SD bands: ^{193}Tl 1 (full triangle), ^{193}Tl 2 (empty triangle), ^{192}Hg (dotted line), ^{194}Pb (dashed line). The inset shows results from new theoretical calculations [20] for the Yrast SD configuration ($\pi i_{13/2}$) in ^{193}Tl. The three sets of curves in the inset represent the calculated total $\mathcal{I}^2$ values and their decomposition into neutron and proton contributions for both signature partners of the $[642]5/2^+$ orbital.

With the extension of the two SD bands towards higher energies, it is now possible to extend the dynamic moments of inertia $\mathcal{I}^2$ up to frequencies $\hbar\omega \approx 0.4$ MeV as is shown in Fig. 3. For both bands a change in slope of the $\mathcal{I}^2$ with $\hbar\omega$ is noticeable at low ($\hbar\omega \approx 0.15$ MeV) and high ($\hbar\omega \approx 0.32$ MeV) frequencies. Furthermore a smooth turnover of the $\mathcal{I}^2$'s can be seen around $\hbar\omega \approx 0.36$ MeV. The $\mathcal{I}^2$ moments of inertia of the vacuum SD bands in the neighboring even-even isotones ^{192}Hg [9] and ^{194}Pb [18] are displayed for comparison in the same figure 3. At low frequencies these zero-quasiparticle SD bands have a reduced $\mathcal{I}^2$ values compared with the one-quasiproton bands in ^{193}Tl. This is what one expects for odd nuclei: a substantial increase of the moment of inertia due to the well known blocking effect, that reduces superfluidity and hence increases $\mathcal{I}^2$. At intermediate rotational frequencies 0.2 MeV$< \hbar\omega <$ 0.3 MeV, all the SD bands shown in figure 3 exhibit roughly the same increase of $\mathcal{I}^2$. Generally, this increase is qualitatively understood in the 190 mass region in terms of gradual alignment of $\nu j_{15/2}$ and $\pi i_{13/2}$ in the presence of pairing correlations [1, 2]. Having in mind that the $i_{13/2}$ proton orbital is blocked for pairing correlations in the ^{193}Tl SD bands, the relatively small differences in the $\mathcal{I}^2$ between ^{192}Hg, ^{193}Tl and ^{194}Pb (see Fig. 3) can be taken as an evidence for a relatively small contribution of the $\pi i_{13/2}$ quasiparticle alignment to the increase of the dynamic moment of inertia. In other words, mainly the $\nu j_{15/2}$ quasiparticle are contributing to the rise of $\mathcal{I}^2$ at the intermediate rotational frequency range (0.2 MeV$< \hbar\omega <$ 0.3 MeV). This is confirmed by recent studies of the SD odd Pb isotopes, where the blocking of the $j_{15/2}$ neutron orbital was found to affect the flattening of the $\mathcal{I}^2$ moments of inertia [5, 6] more dramatically than in the SD odd Hg isotopes [3, 4]. Furthermore, the $\mathcal{I}^2$ of the vacuum SD band in ^{194}Pb exhibits the same slope at intermediate rotational frequencies as band 1 in ^{193}Tl. This suggests that pairing correlation for protons are weaker in Pb isotopes than in Hg isotopes. The saturation of the $\mathcal{I}^2$ at $\hbar\omega \approx 0.32$ MeV in ^{193}Tl SD bands indicates that the alignment of the $j_{15/2}$ neutron quasiparticle is exhausted. In the ^{192}Hg vacuum SD band the $i_{13/2}$ quasiproton alignment takes over and the $\mathcal{I}^2$ continues to increase until a beginning of saturation at $\hbar\omega \approx 0.4$ MeV. It is worth pointing out that recent theoretical calculations, where deformation and pairing effects are treated self-consistently by means of the cranked Strutinsky–Lipkin–Nogami approach and where a quadruple pairing interaction is included [20], reproduce very well the dynamic moment of inertia of the Yrast SD bands in ^{193}Tl (see the inset of Fig. 3).

Three new excited SD bands have been observed in ^{193}Tl. Their intensities were found to be 60%, 40% and 10%, respectively (intensities are given relatively to band 2). The assignment of these three SD bands to ^{193}Tl is based on the observation of γ-transitions between known normally deformed states of this nucleus in coincidence with the bands. The dynamic moments of inertia of the three SD bands are shown in Fig. 4. In this figure one can see that the dynamic moments of inertia of band 3 and band 4 exhibit a dramatic change at rotational frequency $\hbar\omega \approx 0.35$ MeV. This could be taken as an evidence of interaction between the two SD bands, which in turn is indicating that both bands are built on configurations with the same parity and signature. The quasiproton routhian diagram of the SD ^{193}Tl indicates that the [411]1/2 ($\alpha = -1/2$) and [651]1/2 ($\alpha = -1/2$) are the most plausible configurations for band 3 and band 4, respectively. Indeed,

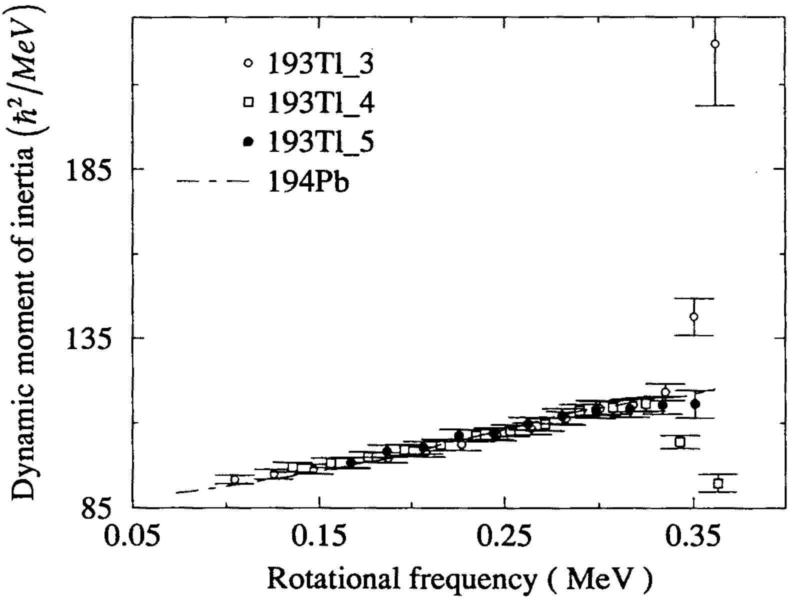

Fig. 4. Plot of the $\mathcal{I}^{2}$ moments of inertia as function of rotational frequency for bands 3, 4 and 5.

these two orbitals exhibit a crossing at $\hbar\omega \approx 0.4$ MeV and are the lowest quasi-particle configurations for proton excitations. The next lowest quasi-proton state is expected to be the positive signature partner of the [411]1/2. We tentatively assign band 5 to this configuration. The down-sloping $N = 7$ proton orbital ([770]1/2, $\alpha = -1/2$) is ruled out as a candidate for these excited SD bands because it is expected to produce a band with the fingerprint of crossing with one of the $N = 5$ orbitals lying beneath. In the other hand such SD band should exhibit a fairly different dynamic moment of inertia due to the occupancy of a high j and low Ω intruder orbital. The above proposed configuration assignment is also supported by the fact that band 3 and band 5 have very close transition energies (see Fig. 4), which is expected for two signature partner SD bands built on the [411]1/2 proton orbital with a decoupling parameter $a = -1$.

We are thankful to all those responsible from CRN Strasbourg for the operation of the Vivitron. We also would like to thank all those involved in the setting up and commissioning of EUROGAM2, especially D. Curien, G. Duchene and G. de France. The EUROGAM project is funded jointly by EPSRC (UK) and IN2P3 (France). One of us (ANW) acknowledges the receipt of an EPSRC postgraduate studentship.

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