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Structure in ^{200}Tl and the odd-even staggering in $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ bands

A. J. Kreiner* and M. A. J. Mariscotti
Departamento de Física, Comisión Nacíonal de Energía Atómica, Buenos Aires 1429, Argentina

C. Baktash, E. der Mateosian, and P. Thieberger
Department of Physics, Brookhaven National Laboratory, Upton, New York 11973
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States of ^{200}Tl, populated through the ^{198}Pt(^{6}Li,4n) reaction at E = 30 to 40 MeV, were studied using in-beam γ-ray spectroscopy techniques. An almost completely new level scheme is presented comprising the $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ two-quasiparticle band which in this case is built on an $I^\pi = 7^-$ isomeric state ($T_{1/2} = 4.8 \pm 0.2$ ns) in contrast to $I^\pi = 8^-$ for all the lighter doubly odd Tl isotopes studied up to now. The systematic variation of the odd-even staggering present in these bands offers arguments to support the interpretation that this phenomenon is related to the signature dependence of the Coriolis interaction.

[NUCLEAR REACTIONS ^{198}Pt(^{6}Li,4n), E=30–40 MeV, measured E_γ, I_γ, $\sigma(E_{^6\text{Li}}, E_\gamma, \theta_\gamma)$ γ-γ coin. ^{200}Tl deduced levels, J, π, $T_{1/2}$. Ge(Li) detectors, enriched target.]

I. INTRODUCTION

Doubly odd Tl nuclei in the mass range A = 192–198 have been studied quite intensively during the last few years both from an experimental and a theoretical point of view.[1-8] The main result of these studies was the discovery of a negative parity two-quasiparticle (2qp) band structure successfully interpreted to be of $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ character. These bands start with a set of transitions whose energies are unusually small as compared to energies in related bands of neighboring odd nuclei[9-12] (i.e., $\tilde{\pi}h_{9/2}$ and $\tilde{\nu}i_{13/2}$ bands in odd Tl and Hg nuclei, respectively). Therefore it was not possible to determine the exact number of γ rays comprising these multiplets. As a consequence of this, the interpretation of the odd-even staggering in these bands remained uncertain.[2-5] Another feature noted[7,8] was the increase of the transition energies within the multiplet with increasing neutron number. Hence, the chance of observing all members was thought to be somewhat better in the nucleus ^{200}Tl and this gave the motivation for the present study.

II. EXPERIMENTAL PROCEDURES AND RESULTS

A. Singles measurements

The experimental results presented here were obtained at the Brookhaven National Laboratory Tandem facility. A 5 mg/cm^2 ^{198}Pt target (96% enrichment) was bombarded with a ^{6}Li beam in the 30–40 MeV energy range in order to study the excitation function of the ^{198}Pt(^{6}Li, 4n)^{200}Tl reaction which was found to have its maximum at 35 MeV. Figure 1 shows a γ-ray spectrum measured at 90° to the beam direction with a Ge (Li) counter. It is interesting to point out that apart from the xn reactions, which are normally the dominant ones in this region of the nuclidic chart, also ^{198}Au, and to a lesser extent ^{200}Hg, are strongly produced by the ^{6}Li projectile. Angular distributions of the radiation were measured in the 22°–115° range and the results from a conventional analysis in terms of $W(\theta) = A_0[1 + a_2P_2(\theta) + a_4P_4(\theta)]$ are given in Table I. Total transition intensities are given in those cases where information on multipolarity is available and ΔI has been determined on the basis of a $\chi^2(\delta)$ fit. In addition, activity spectra were accumulated off beam and followed over some period of time in order to gain additional information on which nuclear species were produced.

B. Coincidence measurements

A conventional fast-slow three parameter ($E_{\gamma_1} - E_{\gamma_2} - t_{\gamma_1\gamma_2}$) coincidence experiment was performed and raw data were stored event by event on magnetic tapes. Extensive scanning provided coincidence and time relations among the γ rays. The most important result of the present work is the establishment of a cascade of γ rays built on a nanosecond isomer (see next section) with a lifetime of 4.8 ± 0.2 ns. Figures 2 and 3 show spectra in coincidence with some of the intense members of the cascade (119.2, 217.2, and 229.8 keV) and with two of the transitions depopulating the isomeric band head state (490.4 and 357.9 keV), respectively. In addition, Fig. 3 (bottom) shows a summed coincidence spectrum in which some of the crossover transitions and also smaller

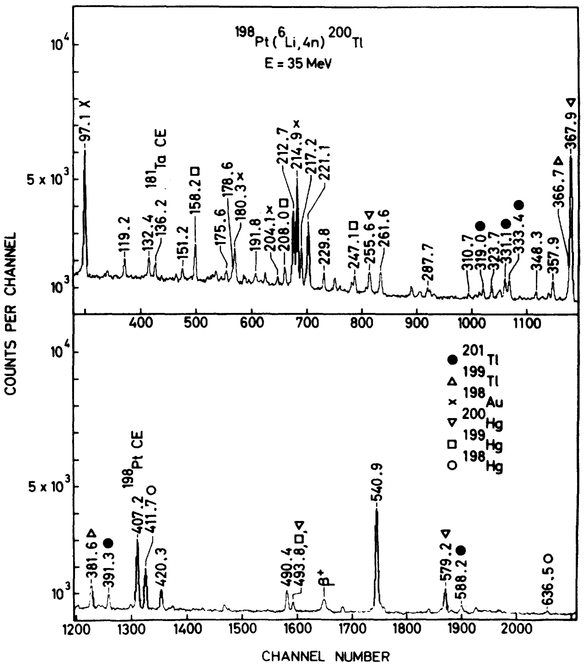

FIG. 1. γ-ray spectrum for the ^{198}Pt(^{6}Li, $4n$)^{200}Tl reaction at E (^{6}Li) = 35 MeV. Transitions in ^{200}Tl are labeled only by their respective energies.

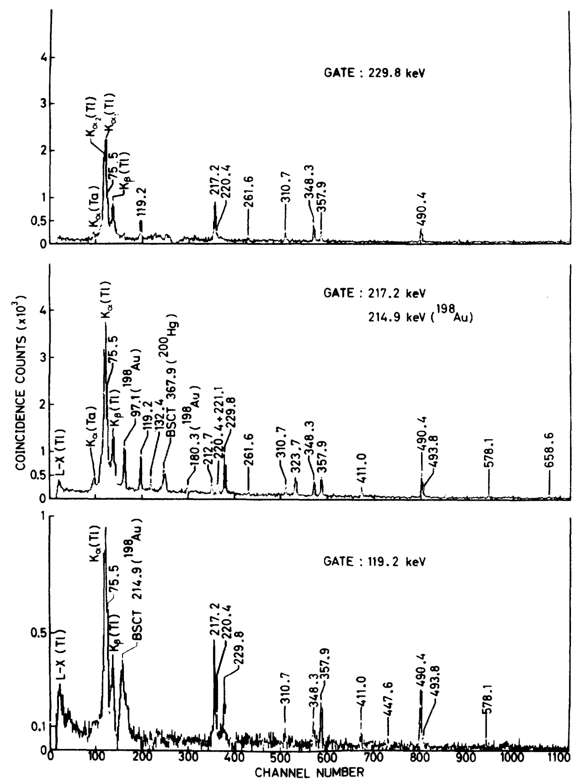

FIG. 2. Spectra in coincidence with three members of the main cascade. The 217.2 keV gate region is contaminated with a 214.9 keV γ ray belonging to ^{198}Au (Ref. 14). BSCT denotes the backscattering peak of the indicated γ ray.

lines are displayed more clearly. Backscattering peaks (BSCT) are seen in some of these spectra due to the face to face geometry of the two Ge (Li) counters. Constant fraction trigger levels were set as low as possible and γ-ray energies were observed down to around 10 keV (L x ray region). Table II shows the results of a quantitative evaluation of the coincidence spectra belonging to the principal cascade which was referred to above.

III. THE LEVEL SCHEME

The level scheme for ^{200}Tl proposed in this work is shown in Fig. 4. It is mainly constructed on the basis of the extensive coincidence data discussed in the preceding section. The only two previously known[13] states reached using the ^{201}Hg (p, $2n\gamma$) reaction and also populated with the present one are characterized by $I^{\pi} = 7^{+}$ (at 753.6 keV) and $I^{\pi} = 4^{-}$ (at 540.9 keV). Other low spin states are known from the ^{200}Pb ground state decay[14] but are not observed here. Owing to the presence of the intruding 4^{-} below the 7^{+} state, the latter is much more short-lived in ^{200}Tl than in the lighter doubly odd isotopes where it decays through electron capture into the corresponding Hg nucleus. In addition, an isomeric transition of 221 keV ($T_{1/2} = 0.33 \pm 0.05$ μs) was identified in ^{200}Tl in proton bombardments of Tl (Ref. 15) but was not placed in a level scheme. In our experiment, in the spectrum in prompt coincidence with the 540.9 keV line, the 212.7 and 221.1 keV γ rays clearly stand out along with a small fraction of the 261.6 keV γ ray which leaks through the isomeric 762.0 keV level. From the K x ray intensity present in this spectrum and the known $E3$ multipolarity[13] of the 212.7 keV γ ray it is possible to obtain the K-shell conversion coefficient α_K for the 221.1 keV transition yielding a value compatible only with $E1$ multipolarity ($\alpha_K = 0.06 \pm 0.02$). The spectra in coincidence with the 212.7 and 221.1 keV γ rays clearly show the weak 217.2 keV branch of the 4^{-} state decay to the 323.7 keV level. This intermediate level most likely has $I^{\pi} = (2^{-}, 3^{-})$ in analogy to the situation in ^{198}Tl (Ref. 1). The analogy with ^{198}Tl can be further exploited to get an indication of positive parity for the levels at 886.0, 1173.7, and 1349.3 keV. In fact, the energies and angular distributions of the γ rays within this cascade (132.4, 287.7, 420.3, and 175.6 keV) are very similar to those in ^{198}Tl. This conclusion is further corroborated by an intensity balance

TABLE I. ^{200}Tl γ-ray energies, angle integrated γ intensities, angular distribution coefficients, multipolarities, and total transition intensities in the ^{198}Pt(^{6}Li, 4n) reaction at E (^{6}Li) = 35 MeV.

E_γ [a] (keV)	I_γ [b]	a_2	a_4	Multipol.	I^{tot}
75.5[c]	26			$\Delta I=1;M1$	126
119.2	12	−0.16 ± 0.03	0.03 ± 0.05	$\Delta I=1;M1$	79
132.4	16	−0.05 ± 0.02	d	$\Delta I=1;M1$	83
151.2	12	0.16 ± 0.05	−0.06 ± 0.09		
175.6	15				
178.6	11				
191.8	14				
212.7	110	0.06 ± 0.04	0.01 ± 0.06	$E3$[e]	422
217.2	36 }	−0.23 ± 0.05	−0.12 ± 0.10[f]	$\Delta I=1;M1/E2$[g]	72
217.2[c]	8 }				
220.4[c]	5 }	0.01 ± 0.02	0.02 ± 0.03	$\Delta I=1;E1$	5
221.1	80 }			$\Delta I=1;E1$	85
229.8	20	−0.21 ± 0.04	0.08 ± 0.07	$\Delta I=1;M1/E2$	38
261.6[h]	40	−0.26 ± 0.03	−0.03 ± 0.06	$\Delta I=1;M1/E2$	64
287.7	20	0.37 ± 0.04	−0.14 ± 0.06	$\Delta I=0,2;M1$ or $E2$	
310.7	7	−0.23 ± 0.13	d	$\Delta I=1;M1/E2$	10
323.7	18				
348.3	13	−0.42 ± 0.05	d	$\Delta I=1;M1/E2$	17
357.9	43	−0.04 ± 0.04	d	$\Delta I=1;E1$	44
411.0[c]	9				
420.3	47	−0.62 ± 0.09	−0.13 ± 0.09	$\Delta I=1;M1/E2$	55
490.4	100	0.35 ± 0.01	−0.02 ± 0.02	$\Delta I=0;E1$	102
493.8[c]	9 ± 3[i]			$E1$	9 ± 3
540.9	476	0.08 ± 0.02	−0.01 ± 0.04	$\Delta I=2;E2$	488

[a] $0.1 \leq \Delta E_\gamma \leq 0.2$ keV.
[b] Errors range from 5 to 15% unless otherwise stated.
[c] Energies and intensities obtained from coincidence data. 75.5 keV γ ray unresolved in singles from x-ray background. 411.0 and 493.8 keV lines obscured in singles by ^{198}Hg and ^{199,200}Hg γ rays, respectively (see Ref. 14).
[d] Fitted with the constraint $a_4 = 0$.
[e] Taken from Ref. 13.
[f] Doublets unresolved in singles.
[g] $M1/E2$ denotes quadrupole admixture.
[h] Also coincident with Hg x-rays.
[i] Side feeding into the state depopulated by 493.8 keV has been neglected.

at the 886.0 keV state which implies $M1$ character for the 132.4 keV transition, and also $E1$ character for the 357.9 keV transition. The presence of this $\Delta I = 1$ "interband" transition is a new feature of the decay scheme as compared to ^{198}Tl and is accompanied by a positive anisotropy for the 490.4 keV γ ray which is of opposite sign to that of the transitions depopulating the bandhead of negative parity in all other Tl isotopes previously studied.[1,3,6,8] A $\chi^2(\delta)$ analysis of the angular distribution for the 490.4 keV γ ray yields the $\Delta I = 0$ possibility as the most likely one [$\chi_{9\to 7}{}^2 = 27$, $\chi_{8\to 7}{}^2 = 16$ ($\delta_{min}{}^2 = 0.19$), and $\chi_{7\to 7} = 6$ ($\delta_{min}{}^2 = 0.03$)]. In view of the importance of establishing the bandhead spin unambiguously an independent experiment was performed[16] to measure the conversion coefficient of this line. The pure $E1$ multipolarity obtained is only compatible with the mixing ratio for $\Delta I = 0$. All the available evidence points to $I^\pi = 7^-$ for the spin-parity indicating that the 7^- state has crossed below the 8^- state which is the bandhead in all lighter Tl isotopes. Another new feature is the appearance of the weak 493.8 keV out-of-band transition. This line is weakly but consistently seen to be in coincidence with the negative parity intraband transitions while it is not with the 490.4 and 357.9 keV γ rays. Conversely, in the spectrum in coincidence with the 493.8 keV line the cascade members 119.2, 217.2, and 229.8 (weak) keV are seen while the 490.4 and 357.9 keV γ rays are missing. It must be concluded that the 493.8 and 490.4 keV transitions

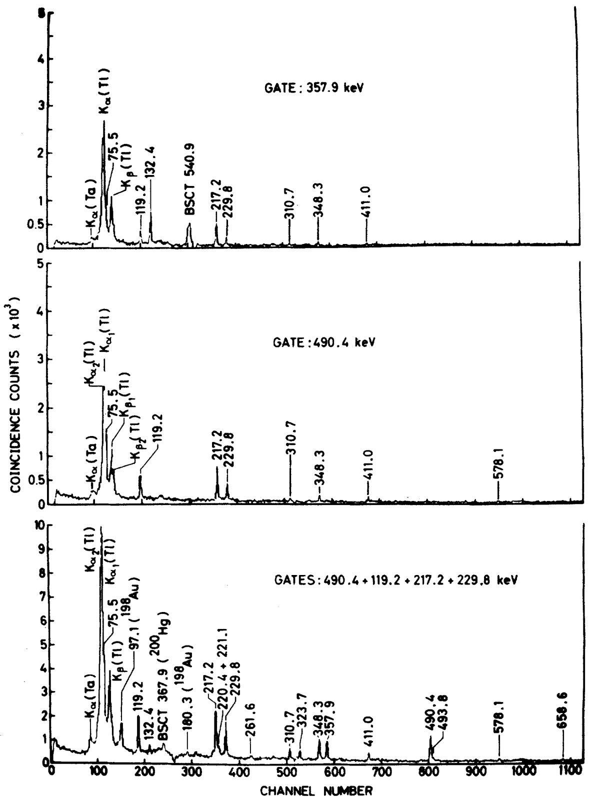

FIG. 3. Coincidence spectra gated with 357.9 and 490.4 keV transitions in ^{200}Tl (upper part). A summed spectrum is shown in the lower part.

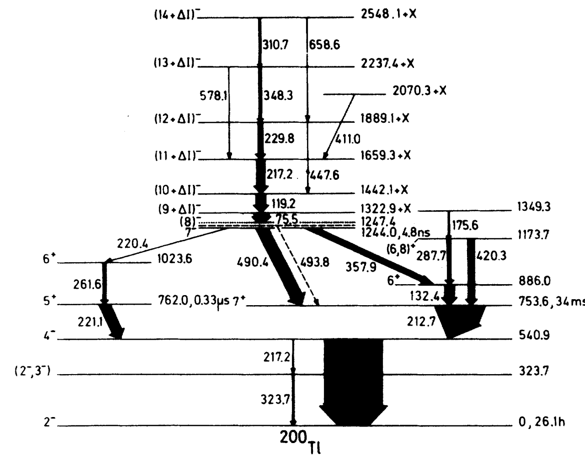

FIG. 4. Proposed level scheme for ^{200}Tl. The dotted line (1247.4 +X keV excitation energy) allows for an unobserved low energy transition. This possibility introduces an uncertainty X and ΔI in the level energies and spin values for the negative parity band (see text).

are parallel to each other. The most natural assumption seems to be that the 493.8 keV γ ray depopulates the 8^- state which now lies about 3 keV above the 7^- state. The branching ratio of intraband (3.4 keV, $M1$) to out-of-band (493.8 keV, $E1$) transitions is 13 ± 4 as obtained from coincidence spectra. This value is in good accord with the branching ratio obtained by assuming the partial half-life for the 493.8 keV line to be the same as for the corresponding $8^- \rightarrow 7^+$ transition in ^{198}Tl, and adopting a single-particle value for the intraband $M1$, 3.4 keV line. Other possible multipolarities for the 3.4 and 493.8 keV transitions are unlikely. However, due to the fact that the evidence for the placement of the weak 493.8 keV line relies on poor statistics, the level at 1247.4 keV has been drawn with a dashed line and its spin is in parentheses.

The band on top of the 7^- isomeric state has been constructed on the basis of a quantitative evaluation of the intensities in coincidence (see Table II), adopting $M1$ character for the $\Delta I = 1$ cascade transitions, and of the existence of crossover γ rays. In principle one could think of the existence of an additional $\Delta I = 1$ transition be-

TABLE II. Total coincidence transition intensities for the set of lines belonging to the main cascade in ^{200}Tl.[a]

Gate energy \ E_γ	75.5	119.2	217.2	229.8	310.7	348.3	357.9	410.8	490.4
119.2	43		33	15	3	7	10	5	24
217.2	114	93		52	11	22	25	14	46
229.8	68	48	67		12	26	12		26
310.7	23	18	15	13		14	1		5
348.3	30	26	30	28	12		4		12
357.9	59	34	34	17	4	3		5	
490.4	100	61	48	32	5	9		7	

[a] Errors range from 20% to around 30%. $M1$ character is adopted for the $\Delta I = 1$ intraband transitions (see Sec. III).

tween the 75.5 keV line and the 8^- state. Low energy $M1$ lines are very easy to miss because below a certain energy they are almost completely converted. In view of this, efforts were made to measure the γ-ray spectrum down to the lowest possible energy and it was possible to observe Tl L x rays ($\simeq 12$ keV) in coincidence. There is not enough intensity in the L x ray peak to account for an unobserved transition and we may at least set an upper limit of about 10 keV for its energy. Owing to this remaining uncertainty, especially considering that there might be states (7^- and 8^-) as near as 3 keV apart, and also theoretical considerations (see next section), provision was made for an unobserved transition. This has been indicated in Fig. 4 by a dotted line and the addition of a ΔI spin uncertainty. ΔI is most likely restricted to the values 0 or 1. Other features of the scheme such as the spin sequence of the 762.0 and 1023.6 keV levels at the left of Fig. 4 follow from a joint consideration of coincidence and angular distribution data.

IV. DISCUSSION AND CONCLUSIONS

Two alternative explanations have been proposed for the origin of the odd-even staggering in the $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ bands of doubly odd Tl isotopes. One of these uses a model which consists of two noninteracting quasiparticles coupled to a rotor and ascribes the staggering to the signature dependence of the Coriolis interaction.[1,3,4] It has the advantage of being able to describe on the same footing the very similar staggering phenomenon in doubly odd and related $\tilde{\pi}h_{9/2}$ bands in odd Tl isotopes but requires, in its present form, the assumption of an as yet unobserved low-energy transition in order to obtain agreement with the data. The other approach[2,5] [which is identical except for the inclusion of a proton-neutron ($p-n$) interaction between the valence particles] explains the staggering by means of a completely different mechanism, namely, a $(-1)^J$ dependence of the residual p-n force ($\vec{J}$ being the total intrinsic angular momentum $\vec{J} = \vec{j}_n + \vec{j}_p$), thus abandoning the very suggestive analogy between odd and doubly odd structures.

The implications of the new ^{200}Tl data for the above-mentioned controversy will be discussed in the following paragraphs. One of the motivations for undertaking the present study was the expectation that the splitting of the multiplet of states arising from the $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ system, for small values of the collective angular momentum,[4] would be somewhat larger in ^{200}Tl than that in the lighter Tl isotopes. The likelihood of observing the hitherto missing transition was, therefore, thought to be enhanced. When N increases, while the proton remains predominantly in the $\Omega = \frac{9}{2}$ state, the neutron Fermi level λ_n emerges from the $i_{13/2}$ subshell[7,8] and the large Ω_n Nilsson states go up in energy. This will increase the splitting of the $J > 8$ states in the multiplet if other parameters such as the core spectrum (see discussion below) remain constant. As the data show (see Table III), the expectation regarding the expansion of the multiplet is only partially fulfilled as only one of the transitions belonging to the multiplet in ^{200}Tl (75.5 keV) is slightly larger than the corresponding one in ^{198}Tl (71 keV). Thus, one is in a similar situation for ^{200}Tl as for ^{198}Tl as far as the detection of the missing transition is concerned. In the present experiment, however, the upper energy limit for this transition has been substantially lowered. Should no additional transi-

TABLE III. Transition energies in ground state bands of even-even Hg, $\tilde{\pi}h_{9/2}$ bands in odd Tl, and $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ bands in odd-odd Tl nuclei.

I^π_{e-e}	I^π_0	I^π_{0-0} ($\Delta I = 0$ or 1)	^{196}Hg ΔE_I[a]	^{197}Tl ΔE_I	^{196}Tl ΔE_I	^{198}Hg ΔE_I	^{199}Tl ΔE_I	^{198}Tl ΔE_I	^{200}Hg ΔE_I	^{201}Tl ΔE_I	^{200}Tl ΔE_I
0^+	$\frac{9}{2}^-$	8^-									
		$(9+\Delta I)^-$			61			71[b]			75
		$(10+\Delta I)^-$			109			122			119
2^+	$\frac{11}{2}^-$	$(11+\Delta I)^-$	426	388	271	412	369	259	368	319	217
	$\frac{13}{2}^-$	$(12+\Delta I)^-$		308	236		332	246		333	230
4^+	$\frac{15}{2}^-$	$(13+\Delta I)^-$	635	416	397	636	416	401	579	391	348
	$\frac{17}{2}^-$	$(14+\Delta I)^-$		299	267			297			311

[a] Transition energies are given in keV. $\Delta E_I = E_I - E_{I-2}$ for even-even and $\Delta E_I = E_I - E_{I-1}$ for odd and doubly odd nuclei.

[b] This transition was recently measured (Ref. 16).

tion be present, the simple two-noninteracting-quasiparticles plus rotor model would be insufficient to explain the phase of the staggering, and some ingredient would be lacking.

On the other hand, a systematic comparison of neighboring odd and doubly odd Tl isotopes, including ^{200}Tl, provides strong evidence supporting the interpretation that the signature dependence in the Coriolis interaction and not the residual p-n force is responsible for the staggering.

Table III gives the transition energies for the first members of the ground state bands in the even-even Hg cores, the $\bar{\pi}h_{9/2}$ bands in odd Tl, and the $\bar{\pi}h_{9/2}\otimes\bar{\nu}i_{13/2}$ bands in odd-odd Tl. In spite of the uncertainty about the existence of a missing transition, the apparent regularity of the transition energies of the upper members of the band allows a fairly straightforward identification of states from one isotope to the other. However, the spin values of the odd-odd nuclei, $I_{o\text{-}o}$, remain undetermined by one unit for $I_{o\text{-}o} > 8$, and this has been indicated in Table III with a spin uncertainty ΔI of one unit. In contrast to the remarkable constancy of the E_{2^+} energy in the Hg isotopes in the mass range $A = 192$–196 (423, 428, and 426 keV for ^{192,194,196}Hg, respectively, Ref. 14), which is reflected in the constancy of the $\bar{\pi}h_{9/2}$ and $\bar{\pi}h_{9/2}\otimes\bar{\nu}i_{13/2}$ bands, we note a monotonic decrease of this energy in going from $A = 196$ to $A = 200$ (see Table III). This is accompanied by a decrease in the $\Delta E_{11/2^-} \equiv E(\frac{11}{2}) - E(\frac{9}{2})$ transition energy and a decrease in the amount of staggering involving $\Delta E_{13/2^-}$ and $\Delta E_{11/2^-}$ for $A = 197$ to 201. In ^{201}Tl, $\Delta E_{13/2^-}$ is even slightly larger than $\Delta E_{11/2^-}$. The same phenomena occur in the doubly odd nuclei; the $\Delta E_{(11+\Delta I)^-}$ transition energies decrease and the staggering involving the corresponding $\Delta E_{(12+\Delta I)^-}$ and $\Delta E_{(11+\Delta I)^-}$ transitions follows almost the same pattern as for the odd Tl. To visualize these systematic staggering and energy trends in odd and doubly odd Tl isotopes and their relationships to the E_{2^+} Hg core energies, it is useful to define a new variable S which gives a quantitative representation of the amount of staggering. Only three transitions are known for several odd Tl isotopes. Therefore, we shall choose a definition based on the lowest three transition energies, e_1, e_2, and e_3 for the odd cases and the energies e_1, e_2, and e_3 of the transitions preceding the low energy multiplet in the odd-odd cases. Defining the staggering variable S as

$$S = \frac{e_1 + e_3 - 2e_2}{e_1 + e_3 + 2e_2},$$

we see that $1 > S > -1$ (for $\Delta I = 1$ bands) and obviously $S = 0$ for $e_1 = e_2 = e_3$. It is also easy to see that $S = 0$ for any three consecutive transitions in a

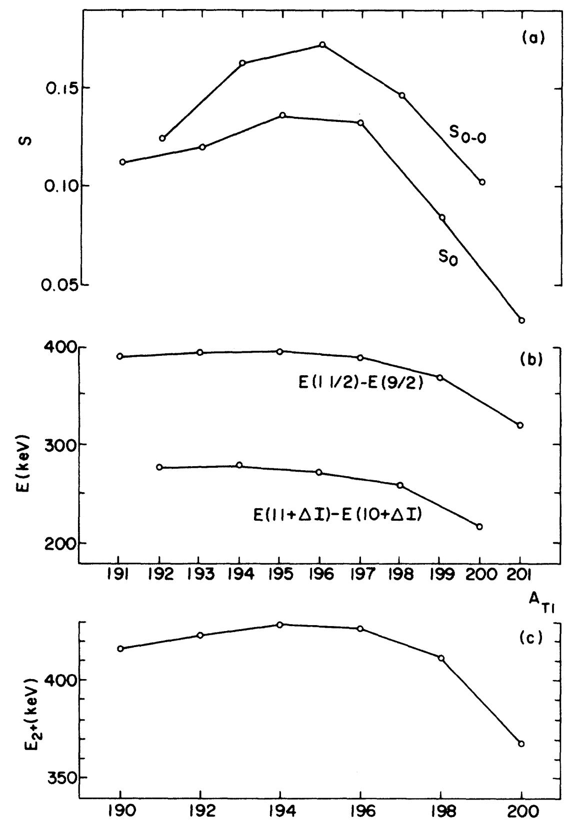

FIG. 5. (a) Plot of staggering parameters for doubly odd (S_{o-o}) and odd (S_o) Tl isotopes as a function of mass number. The staggering parameter is defined as $S = (e_1 + e_3 - 2e_2)/(e_1 + e_3 + 2e_2)$ where e_1, e_2, and e_3 are the lowest three transition energies of the relevant band for odd nuclei and for the odd-odd cases they represent the transitions preceding the low energy multiplet. (b) Plot of $e_1 = E(\frac{11}{2}) - E(\frac{9}{2})$ for odd and $e_1 = E(11 + \Delta I) - E(10 + \Delta I)$ for odd-odd Tl nuclei. (c) Variation of E_{2^+} in the associated even-even Hg core nuclei.

rigid rotor band.

The variations of S and e_1 with the atomic number A for both odd and doubly odd Tl isotopes are shown in Figs. 5(a) and 5(b), respectively. The corresponding E_{2^+} energies of the Hg cores are plotted on Fig. 5(c). In terms of the particle plus axially symmetric rotor description a smaller E_{2^+} core energy means a more adiabatic situation and hence a smaller Coriolis interaction implying in turn a diminished staggering. In addition, the decrease of $E_{2_1^+}$ at the neutron-rich side is accompanied by an increase of the energy of the second excited 2^+ state (2_2^+) (Ref. 14) which in the framework of a triaxial rotor picture indicates a shift of the average value of the asymmetry parameter γ toward 60° (Ref. 17). This will also tend to attenuate the staggering in the odd system.[18] Within the context of particle plus rotor models, the behavior observed in the doubly odd nuclei strongly suggests that the mechanism behind the staggering entails an interaction of the particles with the core rather than among the valence particles themselves.

It is interesting to note not only that certain transition energies in the ^{200}Tl band are smaller than those for ^{198}Tl but that this holds in general for most of the spectrum, reflecting the decrease in the core energies. As the states of the multiplet also contain a small amount of collective energy, the expansion tendency implied by a rising λ_n as discussed above could be partially compensated by a decrease in the core energy.

The fact that the 7^- state becomes the band head in ^{200}Tl, in contrast to all the other cases studied up to now, was not expected. However, the model calculations[1] predict the 7^- state to be very close to the 8^- state, and this result supports the general idea of a quasidegenerate multiplet.

In summary, the data presented in this paper establish a new case of a $\tilde{\pi}h_{9/2} \otimes \tilde{\nu}i_{13/2}$ structure, similar to those already found in several lighter Tl isotopes. Special points with respect to this structure which emerge from this investigation are (a) the appearance of the 7^- state as the band head instead of the 8^- as in the other cases; (b) the establishment of 10 keV as an upper energy limit for the transition energy of any unobserved member of the low-lying multiplet; and (c) the confirmation of the trend already suggested in ^{198}Tl concerning the decrease in the amount of level staggering.

The problem of the existence of a missing transition still remains unsolved, and its nonexistence would imply a deficiency of the two-noninteracting-quasiparticles plus rotor model in predicting the phase of the staggering. However, the observed neutron-number dependence of the level staggering is not expected if the origin of the phenomenon were to be a $(-1)^J$ oscillating component in the residual p-n force as in the alternative description.[2]

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*Present address: Department of Physics, Brookhaven National Laboratory, Upton, N. Y. 11973.

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