# ALIGNED $\nu i_{13/2}$ BANDS COUPLED TO DIFFERENT SHAPES IN $^{186}$Hg ☆

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The structure of $^{186}$Hg has been studied through the $^{156}$Gd($^{34}$S, 4n) reaction. Three bands with even spin and parity are observed; two of them are established up to high spin and are found to cross with little interaction at $I = 16^+$. Cranked shell model calculations suggest that these two bands can be associated with a decoupled $\nu i_{13/2}$ pair based on a prolate and on an oblate or triaxial shape, respectively.

It is known that rotation-alignment of a high-$j$ quasiparticle provides a driving force towards oblate shapes ($\gamma = +60°$) at the beginning of a shell and towards prolate shapes ($\gamma = -120°$) at the top of the shell. Recent calculations [1] indicate the interesting new result that this driving force tends to smoothly change $\gamma$ from $+60°$ to $-120°$ as the shell is filled. The light Hg isotopes are well suited for a study of shape transitions induced by rotation-aligned $\nu i_{13/2}$ quasiparticles since the Fermi level lies in the middle of the shell. Furthermore, they are also known to be soft, as exhibited by the crossing of two bands in $^{184,186,188}$Hg, one built on a near-spherical and one on a deformed shape [2–4]. Potential energy surface calculations [5] explain the observed coexistence in a quantitative way. Two minima in the deformation energy are found corresponding to a small oblate ($\epsilon_2 = -0.12$) and, at a slightly higher excitation energy, to a sizable prolate deformation ($\epsilon_2 = +0.22$). This is the result of a delicate balance between the $Z = 80$ proton system, which prefers slight oblate deformations (as in the heavier Hg isotopes) and the $N = 104$–$108$ neutron system, which favors strong prolate deformations (as in the well-deformed rare earth nuclei).

In the present work the structure of $^{186}$Hg was investigated at high spin. Two bands with even spin and parity were established up to $I^\pi \sim 22^+$. Both bands display irregularities in the energy spacing and furthermore are found to cross with little observable interaction. The results are interpreted in the framework of the Cranked Shell Model (CSM) [6]. They strongly suggest the coexistence of well-developed rotational bands based on *both* prolate *and* oblate or triaxial shapes.

In the experiment a 1.0 mg/cm$^2$ $^{156}$Gd target backed with 50 mg/cm$^2$ lead was bombarded

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with $^{34}S$ ions from the Argonne superconducting linac. Coincidences ($\gamma$–$\gamma$), angular distributions and excitation functions were measured. It was inferred from the total $\gamma$ energy and the $\gamma$-multiplicity information obtained from a large NaI(Tl) sum-spectrometer that fission is a strongly competing channel in the present target–projectile combination.

The resulting level scheme is shown in fig. 1 where transitions are placed within three bands. From the coincidence data, it was possible to

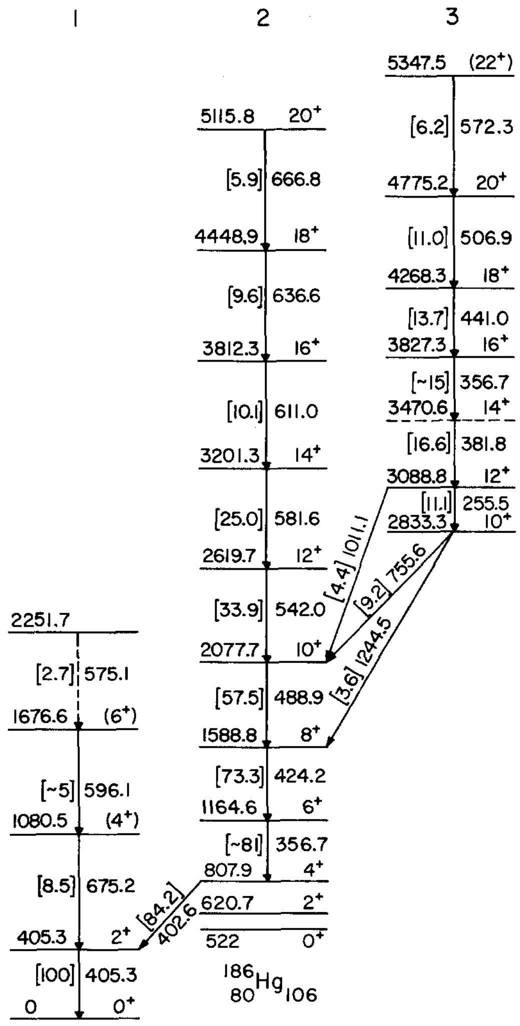


Fig. 1. The level scheme of $^{186}Hg$ as deduced from this work. Relative transition intensities normalized to 100 for the $2 \rightarrow 0$ transition are given in brackets.

add a 2252 keV state to the previously established [7] oblate band (band 1) built on the $2^+ \rightarrow 0^+$ transition. However, its population is weak and no useful angular distribution information could be obtained. The deformed band (band 2) previously established up to $14^+$ [2] is now extended up to $20^+$. Three new transitions have been placed on top of the 3201 keV $14^+$ state on the basis of coincidence relationships, singles and coincidence intensities. Spin and parity assignments are supported by the stretched E2 character of the angular distributions.

Seven states connected by stretched E2 transitions have been grouped into a third band. The deexcitation of this new band proceeds through transitions feeding the $8^+$ and $10^+$ levels of the deformed band discussed above. The $10^+$ spin assignment to the 2833.3 keV level was based on: (i) the angular distribution measurement for the 755.6 keV transition ($A_2/A_0 = 0.33 \pm 0.20$, $A_4/A_0 = -0.11 \pm 0.21$), (ii) the presence of the 1011.1 keV line in the coincidence spectra which shows an anisotropy ($A_2/A_0 = 0.34 \pm 0.29$) compatible with an E2-character, and (iii) the existence in the coincidence data of a 1244.5 keV transition of undetermined anisotropy. A difficulty in the analysis of this band arises from the fact that the 356.7 keV line, assigned here as $16^+$–$14^+$, is not resolved from the $6^+$–$4^+$ yrast transition. Thus, the relative ordering of the 356.7 and 381.8 keV transitions is uncertain. The angular distribution of the 357 keV doublet is similar to that of all other E2 transitions, indicating E2 character for both components. Information on the decay of a 80 $\mu$s isomer and an extended account of the present results will be published elsewhere [8].

The behavior of the various bands is shown in fig. 2 in plots of the angular momentum $I_x$ and the routhian $E'$ against the rotational frequency $\omega$. Band 2 experiences a gentle upbending at $\hbar\omega = 0.30$ MeV, whereas band 3 shows a strong backbending occurring at $\hbar\omega = 0.18$ MeV. Crossings between band 3 and bands 1 and 2 occur at $\hbar\omega = 0.24$ MeV and $\hbar\omega = 0.28$ MeV, respectively.

Calculations were performed in the frame-

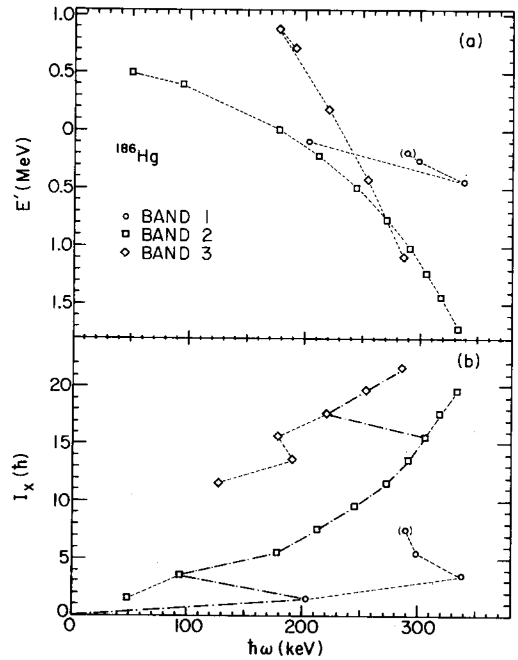


Fig. 2. (a) Experimental routhian $E'$ and (b) angular momentum $I_x$ as a function of $\hbar\omega$ for $^{186}$Hg; $\omega(I) = \frac{1}{2}[E(I+1) - E(I-1)]$, $I_x = I + 1/2$, and $E' = \frac{1}{2}[E(I+1) + E(I-1)] - \omega(I)I_x$. The dashed–dotted line drawn in (b) links the yrast levels.

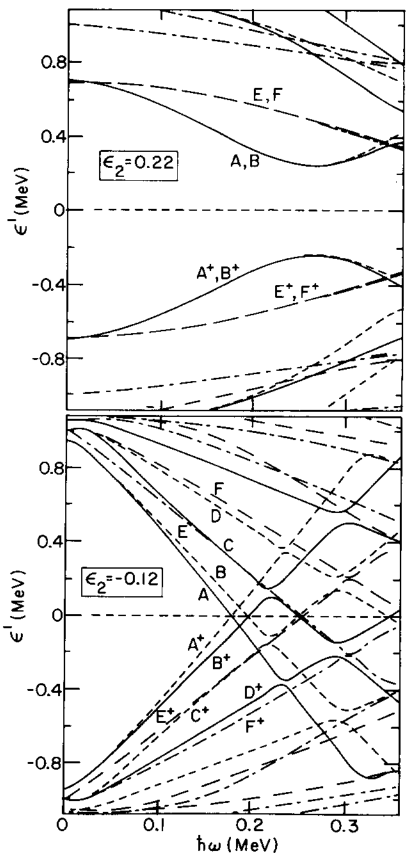


Fig. 3. Quasineutron routhians for $^{186}$Hg. The CSM calculations are presented here for prolate (upper part) and oblate deformation (lower part) with the respective parameters ($\epsilon_2 = 0.22$, $\epsilon_4 = 0$, $\Delta = 0.934$ MeV) and ($\epsilon_2 = -0.12$, $\epsilon_4 = 0$, $\Delta = 0.646$ MeV). The curves labeled A, B, C and D represent the $i_{13/2}$ states, those labeled E and F are $N = 5$ levels. The solid lines correspond to $\alpha\pi = (+1/2, +)$; dotted lines $(-1/2, +)$; dashed lines $(+1/2, -)$ and dashed–dotted lines $(-1/2, -)$.

work of the CSM formalism [6], which has been very successful in describing complex band structures in deformed nuclei and in some transitional nuclei. In fig. 3 quasineutron routhians for $^{186}$Hg as a function of $\hbar\omega$ are presented here for the prolate and oblate deformations of ref. [5], which agree nicely with those deduced from the measured lifetimes [4] of the $6_1^+$ and $2_1^+$ levels.

For the two deformations, crossings with proton orbitals were found to occur for frequencies higher than those considered in figs. 2 and 3. This property is based on CSM calculations and on comparisons with available information on the behavior of $i_{13/2}$, $h_{9/2}$ and $h_{11/2}$ orbitals in the neighbouring odd-proton Au isotopes [8].

In the case of a prolate deformation, a first crossing of the deformed "ground band" with the $i_{13/2}$ rotation-aligned neutron band is expected to occur around $\hbar\omega \simeq 0.25$ MeV with a strength $V \simeq 0.5$ MeV (upper part of fig. 3). This sizable interaction should smooth out the band-crossing, i.e. a gradual gain in alignment ($\simeq 2.8\hbar$) should be observed in the experimental spectrum rather than a backbending. This is in qualitative agreement with the behavior observed in band 2. If the low spin members ($2 \leqslant I \leqslant 10$) of this band are chosen as the reference configuration [6], a smooth alignment gain occurs around $\hbar\omega \gtrsim 0.3$ MeV (fig. 2b). This experimental frequency is slightly higher than the one calculated, which is not peculiar to $^{186}$Hg. A similar effect has been reported for several well-deformed nuclei in the rare-earth region in cases where $i_{13/2}$ aligned neutron bands are involved and has been attributed to the reduced value used for the pairing gap (see e.g. ref. [6]). The observed gentle upbending suggests that the interaction is indeed strong and the experimental alignment gain is modest ($\sim 3.7\hbar$) though slightly larger than the one calculated.

Band 3 becomes yrast for states with spin $I \geqslant 18$. The data show strong evidence for a structure very different from band 2. In the $I_x$ versus $\omega$ plot of fig. 2b, band 3 does not exhibit any of the gradual upbending observed in band 2. This suggests that band 3 must also be constructed from $i_{13/2}$ quasineutrons since the presence of at least one such particle will block the decoupling of the $i_{13/2}$ quasineutron pair responsible for the upbend in band 2. The positive parity of band 3 clearly indicates the presence of a pair of decoupled $i_{13/2}$ neutrons. Furthermore, the extremely small interaction between band 2 and 3 (<5 keV) is an additional hint for the different intrinsic structure.

A possible explanation is that band 3 contains an aligned $\nu i_{13/2}$-pair coupled to a core which has a shape different from the prolate ($\gamma = 0$) one of band 2. An oblate shape ($\gamma = -60°$) is suggested by data on heavier $^{188-198}$Hg isotopes [9, 10], where $\nu i_{13/2}$ rotation-aligned bands built on weakly deformed oblate cores have been observed. In these other cases, experimental band-crossing frequencies and gains in alignment were reproduced satisfactorily in the framework of the CSM.

A CSM calculation (bottom of fig. 3) with an oblate shape ($|\epsilon| = 0.12$, $\gamma = -60°$) predicts a first crossing of the aligned band with the oblate ground band at $\hbar\omega = 0.18$ MeV and the gain in alignment of $12\hbar$, consistent with experiment. As shown in fig. 2a, bands 1 and 3 cross at $\hbar\omega \simeq 0.24$ MeV. The CSM frequency underestimates the experimental value in a way similar to what is found for the upbending in band 2 and reflects a systematic trend mentioned above. The gain in alignment is somewhat difficult to deduce from the measurement in view of the limited information about the behavior of the oblate ground band. With the first two states of band 1 taken as reference, an alignment of $\simeq 11\hbar$ is deduced from fig. 2b for states below the irregularity in band 3. On the other hand, for higher frequencies ($\hbar\omega >$ 0.2 MeV) the steeper slope of band 3 indicates a moment of inertia, $\mathcal{J}^{(2)} = dI_x/d\omega$, larger than that of the reference configuration. Consequently, the alignment gain in this region as computed from the difference in $I_x$ between the two trajectories in fig. 2b should only be regarded as an upper-limit ($\sim 15\hbar$) and the CSM value of $12\hbar$ is compatible with the data. The irregularity associated with band 3 at $\hbar\omega =$ 0.19 MeV is not well understood, but may be related to the interaction between levels A and C at $\hbar\omega \sim 0.1$ MeV (fig. 3).

The large difference between the values of $\mathcal{J}^{(2)}$ for band 3 ($\mathcal{J}^{(2)} = 59\ \mathrm{MeV}^{-1}\hbar^2$) and for band 1 ($\mathcal{J}^{(2)} = 16\ \mathrm{MeV}^{-1}\hbar^2$) is not observed in the heavier Hg isotopes, where these values tend to be equal for the oblate rotation aligned and the ground band. This may indicate that the shape associated with band 3 is triaxial rather than oblate. Indeed, it is expected [1] that with decreasing neutron number the deformation parameter $\gamma$ for the $\nu i_{13/2}$-aligned band changes from $\gamma = -60°$ towards $\gamma = -30°$, consistent with the observation of coexisting oblate and prolate deformations in the lighter Hg isotopes.

In summary, the present investigation suggests that the yrast structure in $^{186}$Hg changes from an oblate to a prolate shape for $I \geqslant 4$ and then to oblate or triaxial shape for $I \geqslant 18$. The first shape transition has previously been understood in terms of the larger moment of inertia associated with the prolate deformation [3,5]. The emergence of the oblate or triaxial structure for the highest spins is due to the shape driving force acting on a soft core which is provided by rotation-alignment of a high-$j$ particle in the case where the Fermi surface is close to the middle of the shell. This is in line with the expectation outlined above and is supported by CSM calculations. Further measurements in neighbouring odd-$A$ Hg nuclei will be necessary to test these suggestions. Oblate and prolate shapes are believed to coexist in $^{187}$Hg and $^{185}$Hg [11] and the behavior of rotational bands developing on $\nu i_{13/2}$ one quasiparticle states in both minima should be particularly illuminating.

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