

# Lawrence Berkeley National Laboratory

## Recent Work

### **Title**

EVIDENCE FOR STRONGLY DEFORMED SHAPES IN 186Hg

### **Permalink**

<https://escholarship.org/uc/item/62c674qs>

### **Authors**

Leigh, J.R.

Maier, K.H.

Stephens, F.S.

### **Publication Date**

1973-06-01

EVIDENCE FOR STRONGLY DEFORMED  
SHAPES IN  $^{186}\text{Hg}$

RECEIVED  
LAWRENCE  
RADIATION LABORATORY

JUN 28 1973

D. Proetel, R. M. Diamond, P. Kienle, J. R. Leigh,  
K. H. Maier, and F. S. Stephens

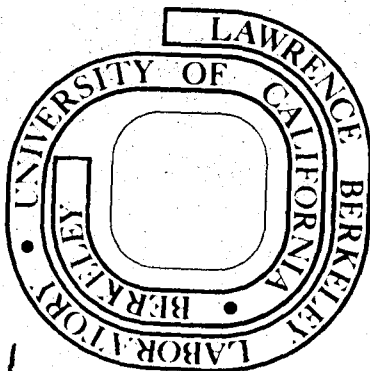
LIBRARY AND  
DOCUMENTS SECTION

June 1973

Prepared for the U. S. Atomic Energy Commission  
under Contract W-7405-ENG-48

TWO-WEEK LOAN COPY

This is a Library Circulating Copy  
which may be borrowed for two weeks.  
For a personal retention copy, call  
Tech. Info. Division, Ext. 5545



34C

## **DISCLAIMER**

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

EVIDENCE FOR STRONGLY DEFORMED SHAPES IN  $^{186}\text{Hg}^*$

D. Proetel<sup>†</sup>, R. M. Diamond, P. Kienle<sup>††</sup>, J. R. Leigh<sup>†††</sup>,  
K. H. Maier<sup>‡</sup>, and F. S. Stephens

Lawrence Berkeley Laboratory  
University of California  
Berkeley, California 94720

June 1973

Abstract:

By means of gamma-ray spectroscopy following (HI,xn) reactions a scheme for the yrast states in  $^{186}\text{Hg}$  up to the  $14^+$  state has been established. From the spectrum we conclude that  $^{186}\text{Hg}$  makes a rather sudden angular-momentum-induced change in deformation from small values at low spins to rather large values at higher spins. This is in qualitative agreement with several potential energy surface calculations and leads to an interpretation of previously measured large isotopic shifts in rms radii from  $^{187}\text{Hg}$  to  $^{183,185}\text{Hg}$  as a sudden onset of stable quadrupole deformation.

Recently in an optical pumping experiment a strong deviation of the isotopic shift (IS) of the 2537 Å spectral line for the nuclei  $^{185}\text{Hg}$  and  $^{183}\text{Hg}$  from the smoothly varying isotopic shifts in the heavier Hg nuclei with  $A = 187$  to 204 has been reported.<sup>1</sup> The IS is related to the change in nuclear charge radius  $\delta \langle r^2 \rangle$  and for the nuclei  $^{183,185}\text{Hg}$  a charge volume has been determined

which is as big as that of  $^{196}\text{Hg}$ . The IS can also be written in terms of a change of the deformation squared,  $\delta \langle \beta^2 \rangle$ , and values of  $\delta \langle \beta^2 \rangle = 0.061$  and  $0.051$  have been reported for the nuclei  $^{183}\text{Hg}$  and  $^{185}\text{Hg}$ , respectively.

This discovery has raised the question as to whether these anomalous IS's are due to a sudden onset of static quadrupole deformation in the light Hg nuclei which, with  $Z = 80$ , are almost proton magic. Earlier measurements<sup>2</sup> of the  $\alpha$ -decay of  $^{188}\text{Pb}$  into  $^{184}\text{Hg}$  did not show any rotational fine structure and in case this  $\alpha$ -decay is not strongly hindered a lower limit of 300 keV for  $E_{2+}$  in  $^{184}\text{Hg}$  has been set. If so the conclusion has been drawn that  $^{184}\text{Hg}$  can hardly be a rotational nucleus with a deformation of  $\beta = 0.25 - 0.30$ , a value suggested by the IS measurements on the odd-mass nuclei. Therefore, with reference to theoretical calculations<sup>3,4</sup> the existence of "bubble" nuclei with low density in the center has been considered as a possible explanation for the anomalous IS measurements.<sup>2</sup>

In the present letter we report on some results of in-beam and off-beam  $\gamma$ -ray spectroscopy on  $^{186}\text{Hg}$  following  $(\text{HI}, \text{xn})$  reactions performed at the HILAC in Berkeley. Figure 1 shows part of the  $\gamma$ -spectrum obtained from bombarding a lead-backed  $^{162}\text{Dy}$  target of  $1 \text{ mg/cm}^2$  thickness with  $^{28}\text{Si}$  at 135 MeV incident energy. In-beam and off-beam excitation function measurements as well as cross bombardments with  $^{40}\text{Ar}$  on  $^{150}\text{Sm}$  and  $^{20}\text{Ne}$  on  $^{170}\text{Yb}$  show that the lines marked as transitions in  $^{186}\text{Hg}$  are associated with the mass chain  $A = 186$ . Particle- $\gamma$  coincidence experiments verified that they do not originate from the evaporation of charged particles, so we conclude that they really are transitions in  $^{186}\text{Hg}$ . Gamma-gamma coincidence measurements show that they all are in cascade with each other, and their angular distributions, measured at  $90^\circ$ ,  $45^\circ$ , and  $0^\circ$ ,

indicate that they have stretched E2 multipolarity. Table I lists the  $A_2$  terms of their angular distributions (neglecting  $A_4$  terms). The crucial point is the ordering of the levels. This has been determined by measuring the relative intensities of these de-excitation  $\gamma$ -rays in three different modes: from in-beam spectra ( $^{162}\text{Dy} + ^{28}\text{Si}$  at 135 MeV), from the decay of a  $100 \pm 10$   $\mu\text{sec}$  isomeric state in  $^{186}\text{Hg}$ , and from  $\beta$  decay of  $^{186}\text{Tl}$  (which was produced in the reaction  $^{159}\text{Tb} + ^{32}\text{S}$  at 164.5 MeV, 178 MeV, and 191 MeV). The results are listed in Table I as columns a), b), and c), respectively. They leave little doubt about our assignment of the level ordering for the states in  $^{186}\text{Hg}$ . (It should be noted here, that the nature of the isomeric state in  $^{186}\text{Hg}$  and its mode of decay are not clear at this time).

The pattern of these states in  $^{186}\text{Hg}$  is very peculiar. The 405.3 keV energy of the  $2^+$  state is reduced by only a few keV from the  $2^+$  energies of the heavier even-even Hg nuclei which scatter around  $420 \pm 10$  keV in the Hg isotopes with  $188 \leq A \leq 198$ . But whereas the  $4^+ \rightarrow 2^+$  and  $6^+ \rightarrow 4^+$  transition energies increase significantly and about equally in the heavier Hg isotopes, one observes a drop to 402.6 keV and 356.7 keV, respectively, in the case of  $^{186}\text{Hg}$ . For comparison Table I shows the energies of the corresponding transitions in  $^{190}\text{Hg}$  which might be considered as representative for the heavier Hg isotopes. Above the  $4^+$  level the transitions connecting the states with higher angular momentum in  $^{186}\text{Hg}$  then increase monotonically in energy (in fact, linearly in a plot of  $2\mathcal{E}/\hbar^2$  versus  $\hbar^2\omega^2$ ). This suggests that in the ground state and the first excited  $2^+$  state,  $^{186}\text{Hg}$  is not much different from the heavier Hg isotopes with a deformation of  $|\beta| \approx 0.1$ . At higher angular momenta it then makes a rather sudden change toward larger deformation which

it keeps approximately constant up to the  $14^+$  state. This assumption gets support from the similarity of the  $6^+ \rightarrow 4^+$ ,  $8^+ \rightarrow 6^+$ , and  $10^+ \rightarrow 8^+$  transition energies in  $^{186}\text{Hg}$  with those of the isotone  $^{184}\text{Pt}$  (see Table I), which is a reasonably good rotational nucleus. An estimate of the magnitude of the deformation based on the energy of the  $6^+ \rightarrow 4^+$  transition in  $^{186}\text{Hg}$  yields  $|\beta| \approx 0.25$ .

This behavior of the yrast states in  $^{186}\text{Hg}$  can be understood in terms of a potential energy as a function of deformation which has a minimum near  $|\beta| \approx 0$  and a second minimum (or shoulder) at a larger deformation and higher energy. The energy of the lowest  $2^+ \rightarrow 0^+$  transition (in the first well) would then be relatively high. At larger spins the centrifugal energy term, proportional to  $\frac{\hbar^2}{2\mathcal{J}} I(I+1)$ , will concentrate the wave function at larger deformation, so that there will be a rapid change to transition energies characteristic of the more deformed well. The fact that we do not see a transition from the  $4^+$  state to a second  $2^+$  state suggests that there is no deep second minimum at  $|\beta| \lesssim 0.3$ . This interpretation is very consistent with recent potential energy surface calculations for even-even Hg isotopes.<sup>5-7</sup> The ground-state potential energy surfaces show a minimum at small oblate deformation and a widening at larger prolate deformation for the heavy Hg isotopes. This widening develops into a shallow second minimum which is dropping with decreasing mass number and it becomes the absolute minimum at  $A = 182$ . In  $^{186}\text{Hg}$  the oblate minimum is only 0.5 MeV lower than the prolate one, which could explain the experimentally observed energy spacings. Negative deformation for the ground states of these light Hg isotopes is not unreasonable because oblate deformation has been measured in nearby Pt- isotopes<sup>8</sup> and oblate deformation for the heavy Hg isotopes is implied by the observation<sup>9</sup> of decoupled bands in  $^{195,197,199}\text{Hg}$ . The

potential calculations describe the nuclei only in their ground states and do not include zero point vibrational energies, but their qualitative agreement with the experimental spectrum of  $^{186}\text{Hg}$  makes it desirable to undertake an investigation of the dynamics in order to make a more quantitative comparison.

In a conclusion, we believe that evidence has been found for a large angular-momentum-induced change in the deformation of the  $^{186}\text{Hg}$  yrast states. To our knowledge, such large changes have not been observed previously. Such a picture can provide a basis for understanding the large rms radii observed by Otten et al. for  $^{183}\text{Hg}$  and  $^{185}\text{Hg}$ . A spin of  $1/2$  has been determined for these nuclei<sup>1</sup> and it seems likely that the  $1/2$  [521] Nilsson orbit, which decreases appreciably in energy as  $\beta$  increases, becomes the ground state in these nuclei. The gain in energy of this orbit with increasing deformation (specialization energy) is no doubt partly responsible for the sudden onset of ground state deformation at just this point in the odd-A Hg nuclei.



References

\* Work performed under the auspices of the U. S. Atomic Energy Commission, and partially supported by the West German BMBW and the Kultusministerium of Bavaria.

† On leave from Sektion Physik der Universität München, 8046 Garching, W. Germany.

†† On leave from Physik Department der Technischen Universität München, 8046 Garching, W. Germany.

††† Present address: Nuclear Physics Division, Australian National University, Canberra, Australia.

‡ Permanent address: Hahn-Meitner-Institut, Berlin, W. Germany.

1. J. Bonn, G. Huber, H.-J. Kluge, L. Kugler and E. W. Otten, Phys. Letters 38B, 308 (1972).
2. P. Hornshøj, P. G. Hansen, B. Jonson, A. Lindahl and O. B. Nielsen, Phys. Letters 43B, 377 (1973).
3. C. Y. Wong, Phys. Letters 41B, 451 (1972).
4. K. T. R. Davies, C. Y. Wong, and S. J. Krieger, Phys. Letters 41B, 455 (1972).
5. Chin Fu Tsang and Sven Gösta Nilsson, Nucl. Phys. A140, 275 (1970).
6. A. Faessler, U. Götz, B. Slavov, and T. Ledergerber, Phys. Letters 39B, 579 (1972).
7. U. Götz, H. C. Pauli, K. Alder, and K. Junker, Nucl. Phys. A192, 1 (1972).
8. J. E. Glenn, R. J. Pryor, and J. X. Saladin, Phys. Rev. 188, 1905 (1969).
9. D. Proetel, D. Benson, M. R. Maier, R. M. Diamond, and F. S. Stephens, to be published.

Table I. Properties of Transitions in  $^{186}\text{Hg}$ .

Transition	Energy	$A_2$	Relative Intensities			$\frac{\hbar^2}{2J}$	Energies in	
			a)	b)	c)		$^{184}\text{Pt}$	$^{190}\text{Hg}$
$2^+ \rightarrow 0^+$	405.3	0.17	100	100	100	67.5	162.1	416.4
$4^+ \rightarrow 2^+$	402.6	0.18	84	79	50	28.8	272.7	625.1
$6^+ \rightarrow 4^+$	356.7	0.22	76	48	30	16.2	362.5	730.2
$8^+ \rightarrow 6^+$	424.2	0.23	63	21	20	14.1	431.6	
$10^+ \rightarrow 8^+$	488.9	0.26	41			12.9	475.8	
$12^+ \rightarrow 10^+$	542.0	0.17	27			11.8		
$14^+ \rightarrow 12^+$	581.6	0.38	16			10.8		

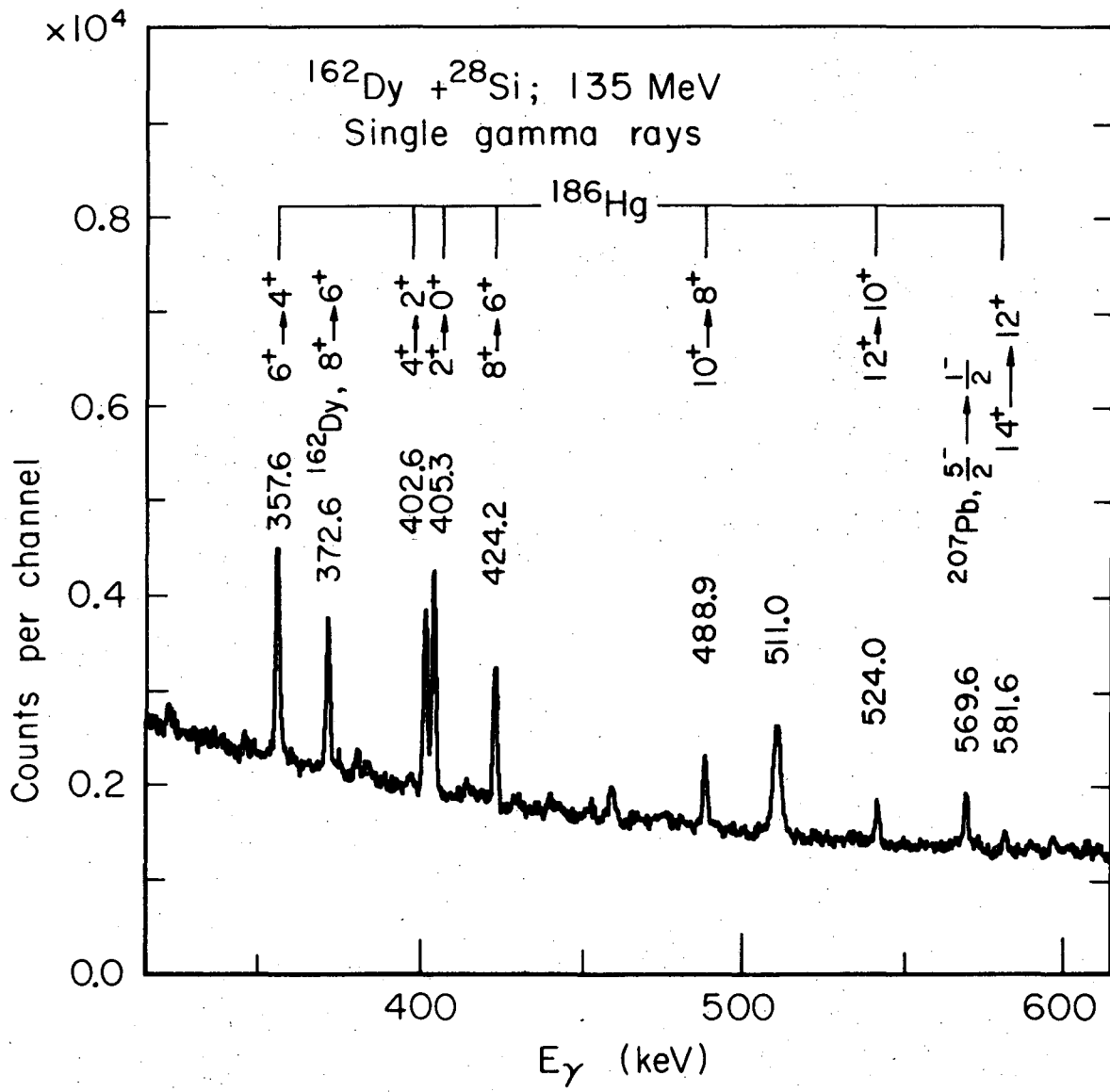
a) In beam ( $^{162}\text{Dy} + ^{22}\text{Si}$ , 135 MeV).

b) Decay of an isomeric state with  $t_{1/2} = 100 \pm 10$   $\mu\text{sec}$ .

c)  $\beta$ -decay of  $^{186}\text{Tl}$ .

Figure Captions

Fig. 1. Part of the  $\gamma$ -spectrum obtained by bombarding a  $1 \text{ mg/cm}^2$  thick lead backed target of  $^{162}\text{Dy}$  with  $^{28}\text{Si}$  ions of 135 MeV. The arguments which led to the assignments of the lines are given in the text.



XBL 736 - 3222

Fig. 1

LEGAL NOTICE

*This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.*

TECHNICAL INFORMATION DIVISION  
LAWRENCE BERKELEY LABORATORY  
UNIVERSITY OF CALIFORNIA  
BERKELEY, CALIFORNIA 94720