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Authors
Proetel, D.
Diamond, R.M.
Stephens, F.S.

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NUCLEAR DEFORMATIONS IN ^{186}Hg FROM LIFETIME MEASUREMENTS*

D. Proetel, R. M. Diamond, and F. S. Stephens

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

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Using the recoil-distance Doppler-shift method, we have measured the half-lives of the 2^+, 4^+, 6^+ and 8^+ states in ^{186}Hg following the reaction ^{170}Yb(^{20}Ne,4n)^{186}Hg. We find a strong enhancement of the $6^+ \rightarrow 4^+$ transition probability, $B(E2,\ 6^+ \rightarrow 4^+) = 1.9 \pm 0.8\ e^2b^2$, over the $2^+ \rightarrow 0^+$ value, $B(E2,\ 2^+ \rightarrow 0^+) = 0.28 \pm 0.05\ e^2b^2$. These results indicate that ^{186}Hg makes an angular-momentum-induced transition from nearly spherical to strongly deformed shapes.

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The mercury nuclei, with 80 protons, lie within the transitional region between the well deformed rare-earth nuclei and the spherical lead nuclei. Since they are so close to the magic proton number Z = 82, it would be interesting to know whether they show rotational behavior around N = 104 (as do the Pt isotopes with Z = 78) or whether they remain vibrational like the heavier Hg isotopes. Three recent experiments bear on this question. The first consisted of the discovery [1] of a large and sudden increase of the ground-state mean square radii in ^{183}Hg and ^{185}Hg relative to ^{187}Hg. This measurement was interpreted as the onset of stable quadrupole deformation

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in ^{185}Hg, and values of $|\beta(^{185}Hg)| = 0.23$ and $|\beta(^{183}Hg)| = 0.25$ were reported [1]. In the second experiment [2], the α decay of ^{188}Pb into ^{184}Hg has been studied, but no 2^+ state below 300 keV has been found, leaving doubts about a large deformation in ^{184}Hg. Very recently [3], we reported on the results of a study of gamma-ray spectroscopy following (HI,xn) reactions leading to ^{186}Hg. From the spectrum of the yrast states of this nucleus, we proposed that both spherical and deformed shapes occur. The energy of the 2^+ state at 405.3 keV is very similar to the energies of the 2^+ states in the heavier, almost spherical or vibrational Hg nuclei, while above the 4^+ state we observed a rotation-like band very similar to the one of ^{184}Pt. This nucleus, with a 2^+ state at 162.1 keV, can probably be considered as a rotational nucleus. Also, there exist a number of potential-energy-surface calculations [4-8] for the mercury isotopes which predict a transition around N = 104 from small oblate to rather large prolate deformation, as the neutron number decreases.

In order to confirm such a shape transition, we measured the lifetimes of the 2^+, 4^+, 6^+ and 8^+ states in ^{186}Hg; from the reduced E2 transition probabilities so obtained, values for the deformation can be extracted. The Doppler-shift recoil-distance method was used to measure these lifetimes. A stretched, self-supporting ^{170}Yb foil, 0.8 mg/cm^2 thick, was bombarded with a ^{20}Ne beam of 108 MeV from the 88" Cyclotron at the Lawrence Berkeley Laboratory. The recoiling ^{186}Hg nuclei were stopped in a Bi stopper and the target-stopper distance was determined with a micrometer screw. Gamma-ray spectra at various target stopper distances are shown in Fig. 1. From the energy difference between the shifted and stopped position of the various transitions in ^{186}Hg we deduced, after correction for the solid angle of the Ge(Li) detector, a recoil velocity of v/c = 1.00%. This recoil velocity was enough to separate the stopped peak from the Doppler-shifted peak for the $6^+ \rightarrow 4^+$, $8^+ \rightarrow 6^+$ and $10^+ \rightarrow 8^+$ transitions but led to a rather complex structure for the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ doublet. The relative intensity of these two transitions was taken to be 100 and 95, respectively, according to data from a Pb-backed target. The intensity of the shifted $2^+ \rightarrow 0^+$ peak was obtained by fitting it to the line shape of the shifted $6^+ \rightarrow 4^+$ transition (from the run at d = 2.1 mm) which lies close in energy. For the $4^+ \rightarrow 2^+$ transition the stopped peak was fitted to the corresponding peak in the Pb-backed run. From these three pieces of information the ratios of the stopped intensity over the total intensity were determined for the two transitions. The shifted and stopped peaks of the $6^+ \rightarrow 4^+$, $8^+ \rightarrow 6^+$ and $10^+ \rightarrow 8^+$ transitions have been fitted with the shifted peaks of the run at d = 2.1 mm and with the stopped peaks of the run with the Pb-backed target. With this procedure, we avoided possible errors due to long-lived isomeric population of these states or to stopping of recoiling nuclei in the target. The zero point was determined by moving the plunger towards the target until a good electrical contact between target and stopper was made.

Figure 2 shows, on a semi-logarithmic plot, the ratios of the stopped intensity over the total intensity for the decay of all the states from 2^+ to 10^+. It is apparent from these decay curves, especially for the short-lived 8^+ and 10^+ states, that we are dealing with two components; the longer one has a half-life of approximately 37 psec and corresponds to about 30% of the intensity.

To extract the lifetimes of the 2^+, 4^+, 6^+ and 8^+ states, we assumed that these states are fed to the same extent by the 37 psec state(s). These contributions are shown as dashed lines for the 2^+ and 6^+ decay curves and were subtracted from the data prior to further analysis. The corrected decay curves were then fitted simultaneously as the decay of a three-step cascade. The computer program, which fitted the slopes of the decay curves as well as their displacements, also allowed for feeding of the whole cascade through three arbitrary states which simulated all the preceeding short-lived transitions. This fitting procedure was applied to the $10^+ \rightarrow 8^+ \rightarrow 6^+ \rightarrow 4^+$, $8^+ \rightarrow 6^+ \rightarrow 4^+ \rightarrow 2^+$, and $6^+ \rightarrow 4^+ \rightarrow 2^+ \rightarrow 0^+$ sets of data. In the fitting routine, the zero point was a free parameter and the value obtained was 10 μm - 20 μm further out than the measured one. This can be explained by a small misalignment of target and plunger and/or irregularities in the target.

The results of our measurement are summarized in Table 1, which shows the transitions, their energies, and half-lives. The errors in the half-lives of the 2^+ and 4^+ states are mainly due to the evaluation of the stopped and shifted intensities in the $2^+ \rightarrow 0^+$ and $4^+ \rightarrow 2^+$ doublet, whereas the error in the $6^+ \rightarrow 4^+$ transition probability comes largely from uncertainties in the amount and lifetime of the dealyed feeding. These uncertainties do not cause such a large error since they do not affect the displacements of the decay curves very much. (The fit for the uncorrected data yields $t_{1/2}$ = 16, 11, and 7 psec for the 2^+, 4^+ and 6^+ states, respectively.) For the half-life of the 8^+ state, only an approximate value has been given since the subtraction of the tail leaves only three significant data points. Although the energy of the $6^+ \rightarrow 4^+$ transition is only 356.7 keV compared to 405.3 keV for the $2^+ \rightarrow 0^+$ transition, a dramatic enhancement is apparent for the decay rate of the 6^+ state ($t_{1/2}$ = 5 psec) compared to that for the 2^+ state ($t_{1/2}$ = 18 psec). The lower decay energy disfavors the lifetime of the 6^+ state by a factor of ≈ 2; so the B(E2, $6^+ \rightarrow 4^+$) is approximately seven times larger than the B(E2, $2^+ \rightarrow 0^+$) and reaches a value close to those found in rotational nuclei. The last column in Table 1 lists the values for the deformations $|\beta|$ calculated on the basis of the rotor model [9]. We get $|\beta| = 0.13 \pm 0.01$ for the 2^+ state and $|\beta| = 0.27 \pm 0.05$ for the 6^+ state; thus ^{186}Hg increases its deformation by a factor of two between these states.

These results show that ^{186}Hg is weakly deformed in its first excited state, but changes to a strongly deformed shape by the 6^+ state. This process could have several causes. The simplest one would be centrifugal stretching. This could occur if the potential energy as a function of deformation has a minimum at small deformation and a shoulder or second minimum at larger deformation and somewhat higher energy. The lower yrast states are then confined in the first well at small deformation. But the centrifugal potential, proportional to $\frac{\hbar^2}{2\mathfrak{J}} I(I+1)$, has to be added to the ground-state ($I = 0$) potential, and this eventually produces a lower relative energy in the second well for higher spin values.

Preliminary data on the energies of the yrast states in the neighboring nuclei, ^{188}Hg and ^{184}Hg, show a similar discontinuity. This occurs in ^{188}Hg at higher spin values, and in ^{184}Hg at lower ones. Also, a similar enhancement of the transition probabilities between the rotational states above the discontinuity over the $2^+ \rightarrow 0^+$ decay rate has been found recently in ^{184}Hg [10]. Thus, all these mercury isotopes show both spherical and deformed shapes in their yrast band. The various potential-energy-surface calculations [4-8] are also in good agreement with such an angular-momentum-induced shape transition.

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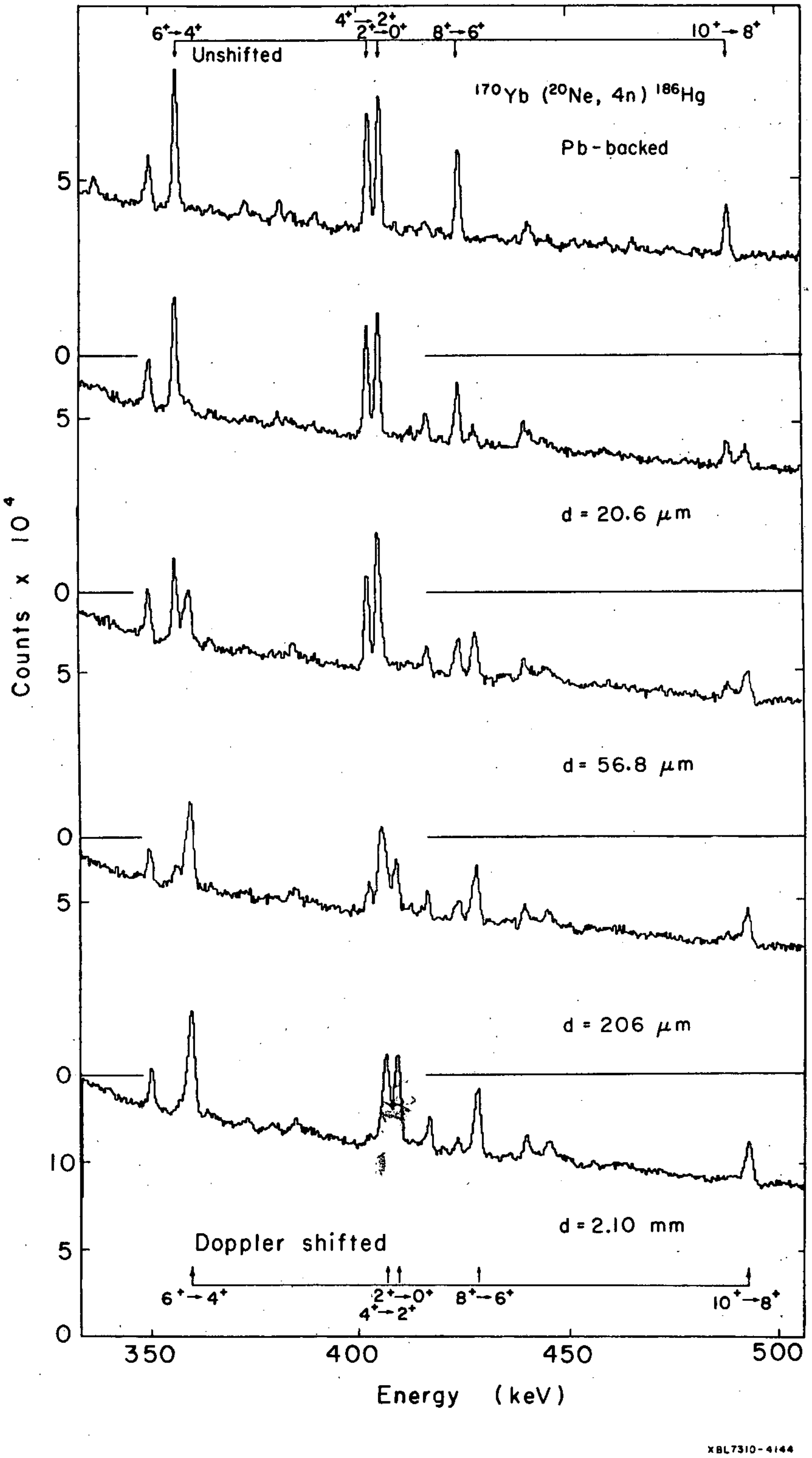
Table 1. Half-lives and Deformations of States in ^{186}Hg.

Transition	Energy keV	$t_{1/2}$ psec	B(E2) e^2b^2	Deformation β
$2^+ \rightarrow 0^+$	405.3	18 ± 3	0.28 ± 0.05	0.13 ± 0.01
$4^+ \rightarrow 2^+$	402.6	9 ± 3	0.6 ± 0.2	0.16 ± 0.03
$6^+ \rightarrow 4^+$	356.7	5 ± 2	1.9 ± 0.8	0.27 ± 0.05
$8^+ \rightarrow 6^+$	424.2	≈ 3	≈ 1.4	≈ 0.22

Figure Captions

Fig. 1. Partial γ-ray spectra from ^{170}Yb(^{20}Ne,4n)^{186}Hg at 108 MeV incident energy for various target-stopper distances.

Fig. 2. Recoil-distance decay curves for the 2^+, 4^+, 6^+, 8^+, and 10^+ states in ^{186}Hg, as obtained in the reaction ^{170}Yb(^{20}Ne,4n). The solid lines are the computer fits to the corrected data points (for details see text) with the long-lived tails, shown as dashed lines, added back in.



6⁺→4⁺
Unshifted
4⁺→2⁺
2⁺→0⁺
8⁺→6⁺
10⁺→8⁺
$^{170}Yb(^{20}Ne, 4n)^{186}Hg$
Pb-backed
d = 20.6 μm
d = 56.8 μm
d = 206 μm
d = 2.10 mm
Doppler shifted
Counts x 10⁴
Energy (keV)
350
400
450
500
XBL7310-4144

Fig. 1

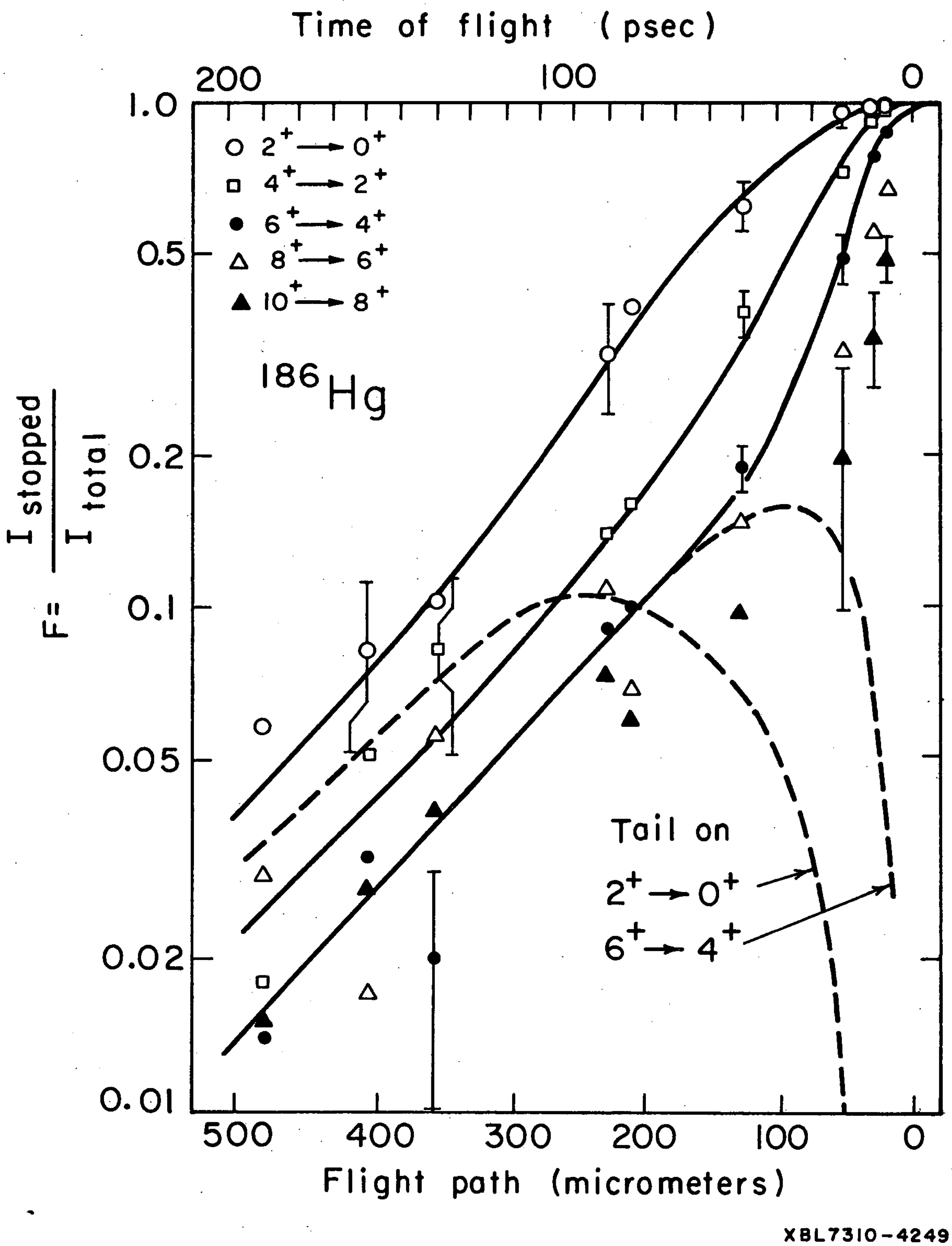

Time of flight (psec)
200
100
0
1.0
0.5
0.2
0.1
0.05
0.02
0.01
2+ → 0+
4+ → 2+
6+ → 4+
8+ → 6+
10+ → 8+
186Hg
F= I stopped / I total
Tail on
2+ → 0+
6+ → 4+
500
400
300
200
100
0
Flight path (micrometers)
XBL7310-4249

Fig. 2

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LAWRENCE BERKELEY LABORATORY
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BERKELEY, CALIFORNIA 94720