Isotope Shifts of Neutron-Deficient Mercury Isotopes*

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Measurements on the isotope shift and optical hyperfine structure have been extended to the neutron-deficient mercury isotopes 193, 193^m, and 192. The shifts are -275 ± 15, -251 ± 8, and -284 ± 5 mK, respectively, referred to the isotope 196 as 0. An explanation of these shifts is given in terms of nuclear deformations. The spins of 193 and 193^m are $\frac{3}{2}$ and 13/2, as given earlier in preliminary reports. The quadrupole moment of 193 is calculated to be -2.0 ± 1.0 b.

I. INTRODUCTION

IN the past few years experimental techniques have advanced to the point that artificially produced isotopes can be studied by the techniques of optical spectroscopy. This allows the study of long chains of neutron-deficient isotopes. This paper continues our study of the optical spectrum of neutron-deficient isotopes of mercury.[1-3]

In this paper, results for the isotope shifts of Hg^{193}(4h), Hg^{193m}(11h), and Hg^{192}(4.8h) are reported, as well as hyperfine splittings determined from the spectroscopic data. In addition, the isotope shifts of Hg^{195}(9.5h) and Hg^{195m}(40h) have been remeasured in an effort to remove small but significant disagreements with others.[4]

The transitions observed were $(6s6p)^3P_1-(6s)^2\,{}^1S_0$ at 2537 Å, $(6s7s)^3S_1-(6s6p)^3P_0$ at 4047 Å, and $(6s7s)^3S_1-(6s6p)^3P_1$ at 4358 Å. The transition at 2537 Å yields a value for the relative isotope shift in the $^1S_0$ level, due to the extra $6s$ electron, as well as A and B splitting factors for the $^3P_1$ hyperfine intervals. The 4047-Å transition has no quadrupole interaction and so determines the nuclear spin directly by use of the interval rule. Finally, 4358 Å checks the hyperfine splitting in both the $^3P_1$ and $^3S_1$ level, since it connects them.

The experimental techniques used were the usual ones of optical spectroscopy, with a Fabry-Perot interferometer serving as the high-resolution element in most cases.[2] Isotopes were produced at the Berkeley 88-in. cyclotron and then loaded into electrodeless discharge lamps for analysis.

II. EXPERIMENTAL

Ideally, in the production of a mercury isotope for spectroscopic analysis, one would like to produce just the isotope under investigation, in order to avoid confusion in the resulting spectrum due to overlapping of spectral lines. One can approach these ideal conditions by a proper choice of reaction, a sharp energy selection of the cyclotron beam, and a proper treatment of the target to prevent the presence of any natural mercury.

In the course of this experiment, we have used the following reactions:

$$Pt^{194}(\alpha,3n)Hg^{195m},\quad Pt^{194}(\alpha,5n)Hg^{193m},$$
$$Au^{197}(\alpha,6n)Tl^{195}(\rightarrow\beta^+)Hg^{195},$$
$$Au^{197}(\alpha,8n)Tl^{193}(\rightarrow\beta^+)Hg^{193},$$
$$Au^{197}(\alpha,9n)Tl^{192}(\rightarrow\beta^+)Hg^{192}.$$

The platinum targets were necessary to produce the metastable species of the isotopes. The high energies of bombardment used in these reactions (50–70 MeV) very much favor the production of the high-angular-momentum $I=\frac{13}{2}$ metastable state over that of the ground state. Since these states have relatively long lifetimes compared to the time of construction of a light source, one can obtain interferograms with a rather large ratio of metastable to ground-state atoms. This is especially true of Hg^{193m}, where only 16% of the metastable species decays to populate the ground state. A disadvantage of this reaction is the fact that Pt^{194} is available only in 65% enriched isotopic abundance, and the other target isotopes (Pt^{195},Pt^{196}) produce unwanted mercury isotopes. Fortunately, the spectrum lines from these isotopes do not substantially overlap those from the isotopes under consideration.

A convenient process to produce the nuclear ground states of the mercury isotopes is via the decay of radioactive thallium. This process has the major advantage that in the decay process it is not energetically possible to populate the isomeric level. One also has more time to construct the light source (the added decay time of the thallium) and the light sources are easier to make because the different target material is easier to handle. There is some population of the isomeric state via (α,pxn) reactions, especially at high energies (>100 MeV) but the cross sections are rather small. The only real drawback of this method is the affinity of gold for mercury, so that extreme care must be taken in processing the target.[3]

Targets were used in the forms of thin foils (2–5 mils). These gave a reasonable energy discrimination, peaking the desired reaction and also making substantial quantities of the next higher even isotope. The even isotopes

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† Present address: Physics Department, University of Rangoon, Rangoon, Burma.
[1] A. C. Melissinos and S. P. Davis, Phys. Rev. **115**, 130 (1959).
[2] H. Kleiman and S. P. Davis, J. Opt. Soc. Am. **53**, 822 (1963).
[3] H. Kleiman, S. P. Davis, and T. Aung, Phys. Letters **13**, 212 (1964).
[4] W. J. Tomlinson, III, and H. H. Stroke, Nucl. Phys. **60**, 614 (1964).

served as internal standards relative to which hfs and isotope shift measurements were made. Energies between 50 and 125 MeV were used to peak the reactions $(\alpha,5n)$ through $(\alpha,9n)$. Integrated beam currents ranged from 15 to 30 μA h.

The construction of the light source was similar to that for the higher neutron number isotopes.[2] The target foil was sealed inside an electrodeless discharge lamp, and then the target matrix was heated either by an oxygen torch or by an induction heater, until the radioactive isotopes were distilled from the matrix. It was found that the presence of the matrix (Au or Pt) in the finished lamp had no inhibitory effect on the production of the spectrum of the radioisotope.

Spectrograms were recorded photographically, using as the instrument of high resolution either a Fabry-Perot interferometer crossed with a plane-grating monochromator, or the monochromator itself. In most cases, a filter of variable band pass[5] was used to restrict the spectral range examined. The dispersion of the plane grating was large enough so that one had no difficulty due to the overlapping of interferometer orders.

Plates were measured on a semi-automatic comparator, and the interferograms reduced on an IBM 7094, using a least-squares procedure.

III. RESULTS

The hyperfine structure of the odd isotopes will first be presented, since it is the total splitting and the positions of the individual components that determine the splitting factors and the center of gravity of a pattern, and hence the isotope shift. The derived A and B factors are given in Table I, and are compared with previous measurements where available.

The derived structure of the 2537-Å line is shown in Fig. 1. It is a composite of many grating spectrograms and interferograms. We have taken particular care in placing the components of 195^m, since doubt has been thrown on our previous results.[6] The position of the c component was determined from all our measurements, including those previously reported. The a and b components (shown dotted in the figure) were placed using the position of the c component and the precise A and B values of Smith.[7] We find no significant changes from our earlier results. Several cyclotron runs at a particular energy (to peak the production of a given isotope) were performed for each of the isotopes studied. In the case of 193, it was found necessary to perform runs at several energies, with each run selected so as to allow the measurement of one of the 193 components. At high energies the (α,pxn) reaction produced enough 193^m so that the 193C component was perturbed by the $193^m c$ component (see Fig. 1). However, so little 196 was produced that the 193A component could be measured. At lower energies the reverse was true and the 193C component could be measured.

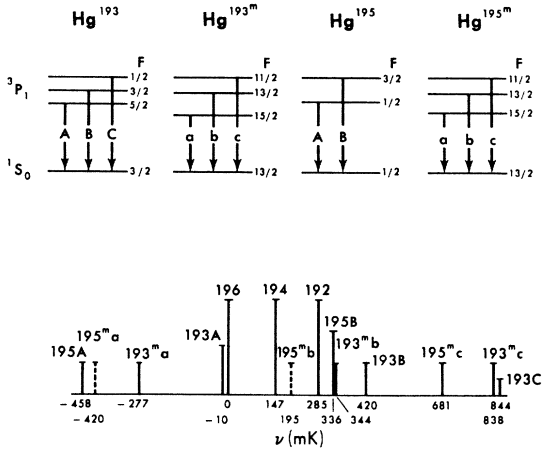

FIG. 1. Structure of 2537 Å for Hg^{192}-Hg^{196}.

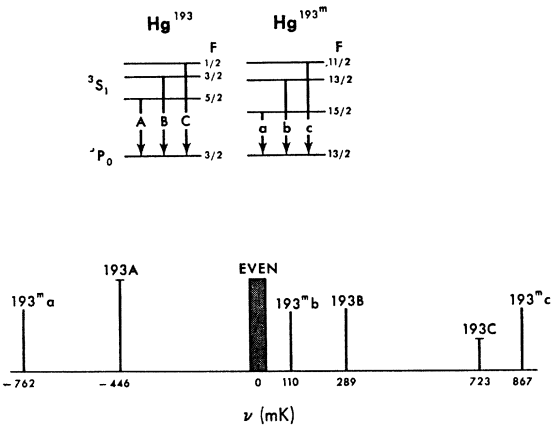

FIG. 2. Structure of 4047 Å for Hg^{193}, Hg^{193m}.

The hyperfine-structure measurements of the 4047-Å line yielded the nuclear spins of the 193 and 193^m isotopes, as given in preliminary reports.[3,8] Through the use of the interval rule, we obtained nuclear spins of $I(193^m)=(12.95\pm0.5)/2$ and $I(193)=(2.86\pm0.18)/2$, or $\frac{13}{2}$ and $\frac{3}{2}$, respectively. The isotope shifts of the even isotopes were too small to be resolved. The centers of gravity of the odd isotopes lie on top of the even ones to within ±8 mK. The structure of this line is shown in Fig. 2.

Only the hfs of the 193^m isotope could be studied in the 4358-Å line, but the measurements provided a check on the accuracy of the hfs determinations of the other two lines through comparison of the splittings in the $^3S_1$ and $^3P_1$ states. The comparison is shown in Table II, and the structure of the line in Fig. 3. The d component was blended with the even isotopes.

[5] J. Reader, L. C. Marquet, and S. P. Davis, Appl. Opt. 2, 963 (1963).

[6] W. J. Tomlinson, III, and H. H. Stroke, J. Opt. Soc. Am. 53, 828 (1963).

[7] W. W. Smith, Phys. Rev. 137, A330 (1965).

[8] S. P. Davis, H. Kleiman, and T. Aung, J. Opt. Soc. Am. 53, 506 (1963).

TABLE I. Splitting factors in mK for Hg^{193}, Hg^{193m}, and Hg^{195}.

	This work	Tomlinson and Stroke[a]	Smith[b]	Redi and Stroke[c]
Hg^{195} $A(^3P_1)$	529 ± 4	528.3±6.6	527.115±0.007	···
Hg^{193m} $A(^3P_1)$	−79.9± 0.5	−79.9±0.4	−79.989±0.003	···
$B(^3P_1)$	−25 ± 6	−25 ±6	−24.16 ±3.0	···
$A(^3S_1)$	−116.2± 0.7	−116.6±0.7	···	···
Hg^{193} $A(^3P_1)$[d]	−200 ±10	···	···	−204.4±0.5
$B(^3P_1)$[e]	40 ±20	···	···	···
$A(^3S_1)$	−292 ±10	···	···	···

[a] Reference 4.
[b] Reference 7.
[c] O. Redi and H. H. Stroke, Bull. Am. Phys. Soc. 10, 456 (1965).
[d] Vaule calculated using $A(^3S_1)$ of Hg^{198} and $A(^3P_1)/A(^3S_1)$ of Hg^{201}.
[e] Value calculated using Stroke's and Redi's value of $A(^3S_1)$.

The isotope shifts for 192–195 are shown in Table III, and compared with those obtained by Tomlinson and Stroke.[4] For the isotopes 194 and 195, the agreement is good. For 193, Tomlinson and Stroke give a tentative value based on an assumed spin value $\frac{1}{2}$ instead of the correct[3] one of $\frac{3}{2}$. Hence their value for the isotope shift is wrong. The large uncertainty in their value for 192 reflects a blending with the strong component $193^m b$.

The major discrepancy between our work and that of Tomlinson and Stroke is in the placing of the components of 195^m and 193^m relative to the even isotopes. In a previous work[2] we had measured the position of Hg^{195m} relative to Hg^{196}. In that work we used the hfs as obtained from the 4358- and 4047-Å lines to place the components of $Hg^{195m}a$ and $Hg^{195m}b$ relative to the $Hg^{195m}c$ component, which was directly measured relative to Hg^{196} in the 2537-Å line. The value we obtained for the 196–195^m isotope shift was 92.6±5 mK (1 mk = 0.001 cm^{-1}). Objections were raised at that time[6] that our hfs intervals might be perturbed by the presence of Hg^{197m} in our light sources, which would overlap the 195^m spectrum in the 4047–4048-Å lines, producing shifts of the centers of gravity of these components. It might be pointed out that if one uses the very precise A and B values of Smith,[7] and our placing of the $195^m c$ component, which is unperturbed by any other line, one finds an isotope shift of 86±5 mK relative to Hg^{196}.

However, as a further check on the placing of $Hg^{195m}c$ relative to the even isotopes, an interferometric measurement was made of the $195^m c$-$193^m c$ splitting as

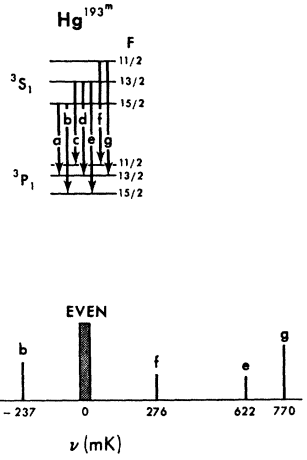

FIG. 3. Structure of 4358 Å for Hg^{193m}.

156±5 mK. This agrees with the values obtained by Walter and Stroke[8a] using magnetic scanning. Since $193^m c$ had been directly measured relative to Hg^{194} (see discussion below), and the Hg^{194}-Hg^{196} splitting was known, we were again able to calculate the Hg^{196}-Hg^{195m} isotope shift as 94±8 mK. Thus the internal consistency of our work gives us confidence in its correctness.

For 193^m, Tables I and III again show that there is good internal consistency and agreement. The shift was

TABLE II. Hyperfine intervals of Hg^{193m}.

	Line (Å)	Splitting (mK)
$^3P_1(11/2-15/2)$	2537	1115±7
	4358	1115±5
$^3P_1(11/2-13/2)$	2537	513±5
	4358	494±5
$^3S_1(11/2-15/2)$	4047	1629±6
	4358	1627±6
$^3S_1(11/2-13/2)$	4047	757±5
	4358	757±5

TABLE III. Isotope shifts (in mK) of Hg^{192}-Hg^{195}, relative to Hg^{198} as 0.

Isotope	This work	Kleiman and Davis[a]	Tomlinson and Stroke[b]
195	−211±5	−214±5	−214± 8
195^m	−237±5	−230±5	−220± 5
194	···	−280±7	−284± 7
193	−412±5	···	−302±20[c] / −350±26[c]
193^m	−388±8	···	−368± 6
192	−421±5	···	−441±20

[a] Reference 2.
[b] Reference 4.
[c] These values were tentative ones, based on an assumed spin of $\frac{1}{2}$.

[8a] W. T. Walter and H. H. Stroke, Massachusetts Institute of Technology Quarterly Progress Report No. 71, 1964 (unpublished), p. 35.

TABLE IV. Isotope shifts, staggering parameters, spins, and moments of mercury isotopes.

Isotope	Shift (mK)	γ	I	μ (nm)	Q[a] (barns)
[b]204	647.77± 0.43				
[c]203	531.0 ±25	0.67±0.29	5/2	0.839	0.45
[b]202	473.96± 0.15				
[b]201	350.80± 0.19	0.60±0.00	3/2	−0.551344	0.50
[b]200	297.29± 0.15				
[b]199	158.73± 0.21	0.27±0.00	1/2	0.497865	
[b]198	137.00± 0.00				
[d]197	46 ± 4	0.67±0.11	1/2	0.519014	
[d]197^m	62 ± 4	0.90±0.12	13/2	−1.0216	1.62
[b]196	0 ± 4				
[e,f]195	−74.0 ± 5	0.96±0.26	1/2	0.532892	
[e,f]195^m	−96 ± 5	0.65±0.26	13/2	−1.03907	1.41
[e]194	−143 ± 7				
[f]193	−275 ±15	0.12±0.24	3/2	−0.607 ±0.02	−2.0 ±1.0
[f]193^m	−251 ± 8	0.47±0.42	13/2	−1.0529	1.37
[f]192	−284 ± 5				

[a] Q values were obtained from Q^{201} and the ratio B/B^{201}; the B values were taken from either published level-crossing experiments or from our own data.
[b] F. Bitter, Appl. Opt. 1, 1 (1962).
[c] O. Redi and H. H. Stroke, Phys. Letters 8, 257 (1964).
[d] A. C. Melissinos and S. P. Davis, Phys. Rev. 115, 130 (1959).
[e] H. Kleiman and S. P. Davis, J. Opt. Soc. Am. 53, 822 (1963).
[f] Present work.

determined just as for 195^m using Smith's A and B values, since the 193$^m b$ component was blended with 192 and 195B. The placing of components relative to 194 was made on the basis of 3 interferograms taken with a 7-mm interferometer spacer. The estimated resolving power was greater than 10^6. The maximum deviation in these measurements was less than ±5 mK. Hence the center of gravity of the isotope was determined to less than ±5 mK, relative to 194 by two independent components on three different interferograms.

In this case, both the Hg^{193m}a and Hg^{193m}c components were free from overlapping, but Hg^{194} was overlapped by the Hg^{195m}b component which is situated 48 mK away. Photometric studies of the interferograms involved show that the ratio of Hg^{194}:Hg^{195m}c is greater than 10:1, leading to a maximum shift of 4.5 mK. This is too small to explain the discrepancies observed. Hence we conclude that there is a small but real discrepancy between our placing of the Hg^{195m} and Hg^{193m} components relative to the even isotopes, and the values measured by Tomlinson and Stroke.

In Table IV are listed the isotope shifts, spins, magnetic moments, quadrupole moments, and staggering parameters

$$\gamma=[(\text{I.S.})_A-(\text{I.S.})_{A-1}]/[(\text{I.S.})_{A+1}-(\text{I.S.})_{A-1}]$$

for all the isotopes between 204 and 192.

IV. DISCUSSION

The theory of the isotope shift was first attacked theoretically by Rosenthal and Breit[9], who used perturbation theory to derive an expression for the relative isotope shift. For the special case of the interaction of an s electron with a uniformly distributed sphere of charge, one obtains

$$\delta(\Delta T)_{\text{vol}}=\frac{12\pi R a_{\text{H}}^3}{hcZ}\frac{(1+\rho)\psi^2(0)}{(2\rho+1)(2\rho+3)\Gamma^2(2\rho+1)}\times y_0^{2\rho}\frac{\Delta y_0}{y_0}\quad(\text{cm}^{-1}),\quad(1)$$

where R is the Rydberg constant, a_{H} the radius at the first Bohr orbit for hydrogen, Z the nuclear charge, $\psi^2(0)$ the square of the nonrelativistic wave function at the center of the nucleus, $\rho^2=1-Z^2\alpha^2$, α the fine structure constant, $y_0=2Zr_0/a_{\text{H}}$ where r_0 is the nuclear radius, and $\Delta y_0/y_0$ is the fractional change in y_0 between two isotopes.

An improved theory by Bodmer,[10] which takes into account the distortion of the electron wave functions by the nuclear charge distribution, gives for the uniform sphere of charge

$$\delta(\Delta T)_{\text{vol}}=\frac{\alpha e^2}{2}\frac{a_{\text{H}}^2}{Z}\left(\frac{3-2\rho}{3+2\rho}\right)\left(\frac{2Z}{a_{\text{H}}}\right)^{2\rho}\times\frac{R^{2\rho}}{\Gamma^2(2\rho)}\frac{\delta R}{R}\psi^2(0)\quad(\text{cm}^{-1}).\quad(2)$$

In the case of mercury, using $R=1.2\times10^{-13}A^{1/3}$ cm, this becomes

$$\delta(\Delta T)_{\text{vol}}=0.91\times10^{-24}(\delta R/R)\psi^2(0)\quad(\text{cm}^{-1}).$$

For the 2537-Å transition, then,

$$\delta(\Delta T)_{\text{vol}}=0.91\times10^{-24}(\delta R/R)[\psi_{6s}{}^2(0)-\psi_{6p}{}^2(0)].\quad(3)$$

To evaluate this shift we make use of the value $\psi_{6s}{}^2(0)$

[9] J. E. Rosenthal and G. Breit, Phys. Rev. 41, 459 (1932).

[10] A. R. Bodmer, Proc. Phys. Soc. (London) A66, 1041 (1953).

of Hg II, calculated by Hartree and Hartree[11] as 7×10^{25} cm^{-3}. To apply this calculation to the Hg I atom, we must take account of the proper screening factors due to the extra 6s electron. These are given[12,13] for $\psi_{6s}^2(0)$ as 1.6 and $\psi_{6p}^2(0)$ as 1.05. Finally,

$$\delta(\Delta T)_{\text{vol}}=0.058 \text{ cm}^{-1}/\text{nucleon}.$$

We have used

$$\delta R/R=\delta M/3M=1/600.$$

This calculation has ignored all specific nuclear structure effects, even such gross effects as nuclear deformations, nuclear polarization, and the compressibility of nuclear matter. It is in relatively good agreement with the mean experimental isotope shift of 0.079 cm^{-1}/nucleon, considering the uncertainty in estimating the screening factors for the atomic wave functions.

Of greater interest is a study of the change of the isotope shift between pairs of isotopes. Here the energy shift due to an increase in mean nuclear charge radius can be expected to remain constant, and all the variation may be attributed to a change in the nuclear deformation. If one considers the equilibrium shape of the nucleus to be an ellipsoid of revolution, then the rotation of this ellipsoid leads to a time-averaged charge distribution which is trapezoidal. Calculations for this type of charge distribution have been performed by Meligy[14] and Bodmer.[15]

An alternative description of deformation effects, useful for nuclei close to magic numbers, is in terms of large contributions due to quadrupole vibrations. In the odd mercury isotopes a further complication will arise because of the coupling of the extra odd neutron to the deformed core giving rise to nuclear polarizations (or in single-particle language, configuration interaction) which will in turn give further contributions to the mean nuclear deformation.

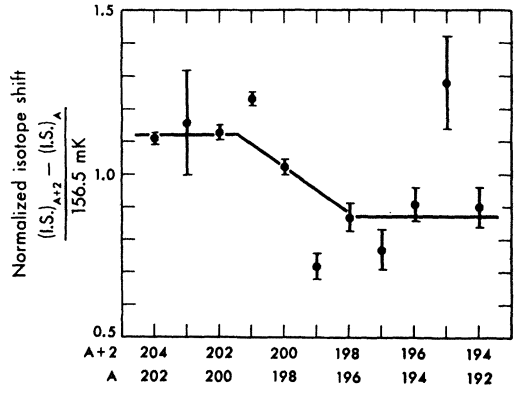

FIG. 4. Plot of normalized isotope shift versus atomic number. The isotope shifts have all been normalized to an isomeric isotopic shift of 156.5 mK. This removes all effects of atomic wave functions.

In view of the complexity of the situation near the magic numbers, it is fortunate that there exist several experimental parameters enabling one to extract information concerning the change in nuclear deformations. First, the deformation isotope shift measures the change in the mean-square deformation parameter $\langle\beta^2\rangle$ between two isotopes.[16]

$$\delta\Delta T_{\text{def}}=\tfrac{3}{10}(2\rho+3)A\,(\Delta\langle\beta^2\rangle/N)\delta(\Delta T)_{\text{vol}}. \quad (4)$$

In particular, for those cases where the entire shift is due to a change in mean deformations (i.e., isomeric shifts) one may set[16]

$$\frac{\delta R}{R}=\frac{2\rho+3}{8\pi}\Delta\langle\beta^2\rangle.$$

Here $\Delta\langle\beta^2\rangle$ represents the change in deformation between an isomeric state and the nuclear ground state. We might point out that in the case of the mercury isotopes under consideration, we have measures of not only the isotope shift and the isomeric shift, but the isotopic isomeric shift (I.I.S.), that is, the isotope shift between the $I=\frac{13}{2}$ isomeric states of Hg^{197}, Hg^{195}, and Hg^{193}. These relatively high-lying excited states will not exhibit strong surface vibrations and the major contribution to the deformation is expected to be a static deformation. Evidence from the quadrupole moments of these three species seems to indicate that the deformation parameter remains relatively constant and so the I.I.S. is due predominantly to a simple volume increase. If so, the isotopic isomeric shift measures δT_{vol}, the isomeric shift measures $\delta\Delta T_{\text{def}}$, and the isotopic shift measures $(\delta\Delta T_{\text{def}}+\delta\Delta T_{\text{vol}})$.

In plotting the information from the isotope shifts it was decided to use the value $\delta(\Delta T_{\text{vol}(A+2)-A})=156.5$ mK, as obtained from the I.I.S. since the quadrupole moments of the $I=\frac{13}{2}$ state indicate that the change in deformation energy in this state is small. If we then normalize to this constant volume effect, the isotope shift between pairs of isotopes, we obtain a normalized deformation shift. This normalized shift as a function of neutron number is plotted for the odd-even and even-even pairs in Fig. 4.

The two main features of Fig. 4 are the decrease in magnitude at $A=199$, as A decreases, and the anomalously large value at $A=195$. A curve qualitatively similar to this one has been observed by Kuhn and coworkers[17] in the region about the magic number $A=50$. A qualitative description for our results may be the

[11] D. R. Hartree and W. Hartree, Proc. Roy. Soc. (London) **A149**, 210 (1934).
[12] H. Kopfermann, *Nuclear Moments* (Academic Press Inc., New York, 1958), p. 173.
[13] J. Blaise, Ann. Phys. (Paris) **3**, 1019 (1958).
[14] A. S. Meligy, Nucl. Phys. **14**, 248 (1959/60).
[15] A. R. Bodmer, Nucl. Phys. **21**, 347 (1960).
[16] L. Wilets, *Handbuch der Physik* edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. 38, Part 1.
[17] H. G. Kuhn and S. A. Ramsden, Proc. Roy. Soc. (London) **A237**, 485 (1956).

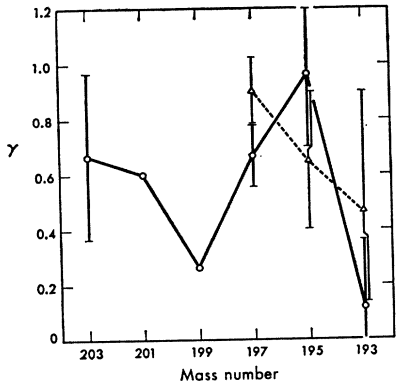

FIG. 5. Plot of staggering parameters γ versus mass number

$$\gamma_A=\frac{(\text{I.S.})_A-(\text{I.S.})_{A-1}}{\frac{1}{2}[(\text{I.S.})_{A+1}-(\text{I.S.})_{A-1}]}.$$

following. In the region above $A=199$ one has vibrational nuclei and as A decreases the data seem to indicate that the magnitude of the surface vibrations (hence the mean deformation) also decreases. In the transition from $A=200$ to $A=198$ static deformations become prominent. In going from 200 to 198 the mean value of $\Delta\langle\beta^2\rangle\approx 0$. Then a regular increase in deformation starts in the even-even nuclei as one gets further away from the closed shell at neutron number 126.

For the odd-even nuclei, at $A=195$ we have a change in the sign of the quadrupole moment and so a change in the deformation from a prolate to oblate deformation. Ford[18] has pointed out that although the quadrupole moments are small in this region the intrinsic deformations are large. Hence, if the deformation of Hg^{195} is larger than that of either Hg^{193} or Hg^{197}, we would find the large deformation contribution to the isotope shift observed. This also explains the alternation in sign of the isomeric shift. In both Hg^{193} and Hg^{197} the deformation of the ground state is smaller than that of the $I=\frac{13}{2}$ isomeric state leading to positive isomeric shifts. The Hg^{195} deformation, however, is larger than that of the isomers, and the isomeric shift has a negative sign.

In Fig. 5 a plot is made of the staggering parameter γ, for all the odd isotopes as well as for the $I=\frac{13}{2}$ isomeric states of Hg^{197}, Hg^{195}, and Hg^{193}. Tomlinson and Stroke[4] have suggested, on the basis of their data, an explanation for odd-even staggering in mercury isotopes. Essentially they attribute staggering to the higher efficiency of $i_{13/2}$ neutrons in deforming the nuclear core, as compared the lower angular momentum $p_{1/2}$ or $p_{3/2}$ neutrons of the ground state. Thus, in considering the sequence Hg^A, $Hg^{(A+1)m}$, $Hg^{(A+2)}$, one considers a sequence of $i_{13/2}$ neutrons being added, each of which makes equal contributions to the deformation shift. One predicts then no staggering for the mercury isomers. On the other hand, if one is looking at the ground-state isotope, where a $p_{1/2}$ or $p_{3/2}$ neutron has been added, not as much deformation results, and some staggering is predicted. If this assumption were correct, it would lead to a staggering parameter of 1 for the isomeric nuclei. Our data do not tend to support any such argument, since we see no regularities in the values of the staggering parameter. More likely, the amount of staggering shown by a particular odd nucleus depends sensitively on the admixture of nuclear states and the coupling scheme, making a separate detailed calculation necessary for each case.

ACKNOWLEDGMENT

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[18] K. W. Ford, Phys. Rev. **90**, 29 (1953).

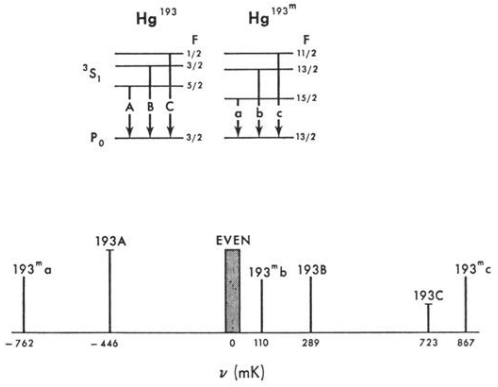

FIG. 2. Structure of 4047 Å for Hg^{193}, Hg^{193m}.

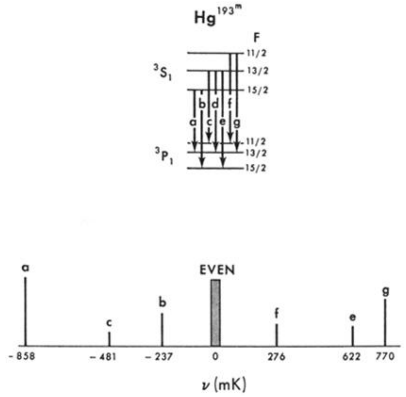

FIG. 3. Structure of 4358 Å for Hg^{193m}.