Separation and Identification of Overlapping Hyperfine Structure Components: Application to Mercury Resonance Radiation*

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A new technique has been developed for the separation of overlapping lines in the hfs pattern of atomic energy levels. By a combination of magnetic scanning and double resonance it was possible to resolve the 2537 A line of mercury. By plotting the maxima of the microwave resonance *versus* scanning field, a separate curve was obtained for each F level of the odd isotopes. In the same way we obtained a curve showing the maxima of the resonance signals from all of the even isotopes. Information about the odd isotopes obtained from a 3000-Mc/sec "double-resonance" experiment is also reported. Only minor disagreements with existing data were observed.

INTRODUCTION

THE work reported here is part of an investigation of the hfs of atomic excited states. The techniques used are based mainly on "double resonance" and "magnetic scanning" principles, which seem more suitable than conventional atomic beam methods and, in addition, yield information about the isotope shift.

The present experiment was designed for the study by a magnetic scanning technique of the hfs of the $6\,^3P_1$ level of the mercury isotopes, which gives rise ($^3P_1-{}^1S_0$) to the 2537 A line; in this respect, it is a continuation of previous work.[1] However, the overlapping lines of the hfs can be completely separated without relying on pure isotopes by concurrently performing a "double resonance" experiment.[2]

Atomic vapors illuminated with light of the proper wavelength emit "resonance radiation." Maximum intensity is obtained when the wavelength of the illuminating radiation corresponds to the exact energy difference between the resonance level and the ground state. However, these levels are displaced for the various isotopes and if the nucleus possesses a magnetic or electric moment the levels are further split according to the state of total angular momentum (F number). Thus, if we illuminate the vapor with a monochromatic light of variable wavelength the resonance radiation will reveal the hfs pattern of the line. Such a light source was obtained by placing a pure Hg^{198} lamp in a variable magnetic field; this splits the 2537 A line into a triplet, since $I=0$ and the ground state is single. By taking light along the axis of the field, only the two σ components are present, one of them being eliminated by the use of a $\frac{1}{4}\lambda$ plate and a Glazebrook prism.

The "double resonance" experiment consists of producing a transition between the m sublevels of the excited state ($\Delta F=0, \pm 1$) by means of the magnetic field associated with radio-frequency or microwave radiation; a complete description is given in reference 2. If mercury vapor placed in a magnetic field is excited by polarized resonance radiation, the m sublevels of the excited state will be unequally populated, with the consequence that the re-emitted optical radiation will be partially polarized. If, further, the condition for rf resonance is established, the atoms in the vapor while in the excited state will undergo transitions between two sublevels, equalizing the populations; this will result in a change of the polarization of the re-emitted optical radiation which can be easily detected.

The isotopes found in natural mercury are the even ones, $Hg^{198,200,202,204}$ ($I=0$), and the two odd ones Hg^{199} ($I=\frac{1}{2}$) and Hg^{201} ($I=\frac{3}{2}$). For the even isotopes, excitation with π radiation along the direction of the magnetic field will lead only to the state $m=0$ (see Fig. 1), so that the re-emitted radiation, in the absence of depolarizing effects, will be pure π radiation. If resonance is established, the two states $\Delta m=\pm 1$ will be populated, and σ radiation will be observed. For the odd isotopes the situation is more complicated, since π excitation leads to states that emit both σ radiation and π radiation when returning to the ground state. However, transitions in the excited state will change the ratio of σ radiation to π radiation, and resonance

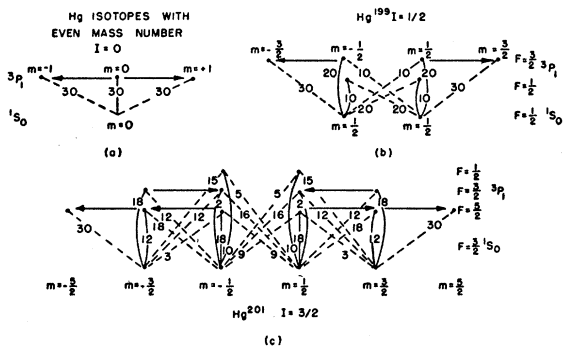

FIG. 1. Possible transitions from $^1S_0$ to $^3P_1$.

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[1] Bitter, Davis, Richter, and Young, Phys. Rev. **96**, 1531 (1954).

[2] J. Brossel and F. Bitter, Phys. Rev. **86**, 308 (1952).

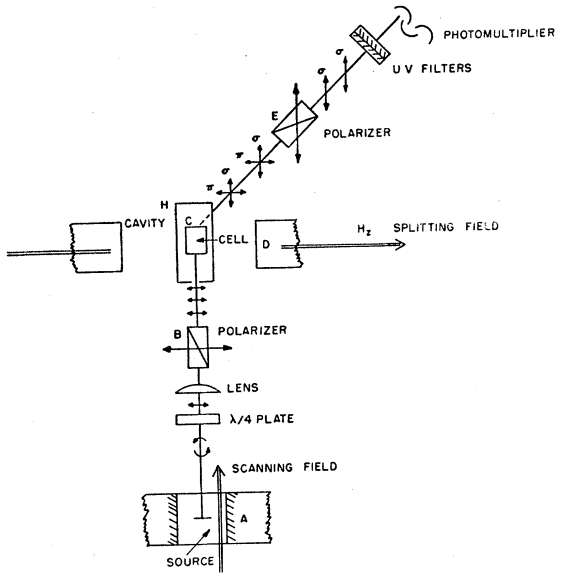

FIG. 2. Schematic diagram of the apparatus.

can be still detected by an increase of the re-emitted σ component.

In Fig. 1 (reproduced from reference 2) the relative transition probabilities are shown, and it is seen that if the exciting optical radiation is π, only, the following $\Delta F=0$, $\Delta m=\pm 1$ transitions can be observed:

1. Even isotopes
$$m=0\rightarrow\begin{cases}m=+1,\\ m=-1.\end{cases}$$
2. Hg^{199} in the $F=\frac{3}{2}$ level:
   (a) $m=-\frac{1}{2}\rightarrow m=-\frac{3}{2}$,
   (b) $m=\frac{1}{2}\rightarrow m=\frac{3}{2}$.
3. Hg^{201} in the $F=\frac{3}{2}$ level:
   (a) $m=\frac{3}{2}\rightarrow m=\frac{1}{2}$,
   (b) $m=-\frac{3}{2}\rightarrow m=-\frac{1}{2}$.

   Hg^{201} in the $F=\frac{5}{2}$ level:
   (c) $m=\frac{3}{2}\rightarrow m=\frac{5}{2}$,
   (d) $m=-\frac{3}{2}\rightarrow m=-\frac{5}{2}$,
   (e) $m=\frac{1}{2}\rightarrow m=\frac{3}{2}$,
   (f) $m=-\frac{1}{2}\rightarrow m=-\frac{3}{2}$.

Transitions cannot be observed in the $F=\frac{1}{2}$ levels because π excitation does not lead to unequal population of the excited state sublevels.

By choosing a sufficiently high radio-frequency, each of the transitions given above will occur for a different magnetic-field value; this is the result of the difference of the atomic g factors for each F level. It is also true within the same F level, provided we operate in the nonlinear region where F ceases to be a good quantum-number.

These two techniques were combined in the following way (see Fig. 2). The wavelength of the source was varied by the "scanning" magnetic field and used to excite the π component of the mercury atoms in the resonance cell; the "splitting" magnetic field on the absorption cell was then set for one of the above-mentioned transitions [1 through 3(f)]. No resonance signal was obtained unless the initial sublevel was populated, which in turn depended on the wavelength of the exciting optical radiation. Thus, by scanning through the whole hfs pattern and plotting the amplitude (maximum) of the microwave resonance as a function of the scanning field, we locate the position of a single Zeeman level relative to Hg^{198}. The width of the curve obtained from such a plot is of the order of magnitude of the Doppler width of the scanning line; however, since the curve is completely resolved, it is symmetric, thus allowing an extremely accurate determination of the center position. The energy difference between the actual location of the Zeeman level and the zero-field position of Hg^{198} is given in cm^{-1} by

$$\Delta E=g_J\mu_B B \text{ cm}^{-1},$$

where B is the "scanning" field in gauss, μ_B is the Bohr magneton, and g_J is the g factor for the $^3P_1$ level of Hg^{198}.

Thus, it is possible to observe the Zeeman levels of a hfs pattern one by one by adjusting the splitting field. Nevertheless, since all of the even isotopes have the same g factor it is not possible to look at each of them separately in the general case. Fortunately, in the 2537 A line of mercury the even isotopes are spaced at intervals of approximately 150×10^{-3} cm^{-1}, so that the scanning curve is partially resolved. The peaks have a symmetric shape yielding precise values for the locations of the Zeeman components. The obvious advantage of this method over conventional microwave or radio-frequency resonance techniques is that it gives the isotope shift.

Furthermore, the establishment of a resonance between the m sublevels of the excited state, which is a necessary step in the present experiment, in itself furnishes information about the atomic g factors and the interaction energy constants—and thus the nuclear moments—of the odd isotopes. The values obtained in this experiment from such observations depend on the magnetic field, and their accuracy is limited, especially if the transitions occur within the same F level. For such transitions, ($\Delta F=0$), reasonably accurate results can be obtained only after the nuclear and electronic angular momenta begin to decouple.

In thepre sent experiment the above resonances were successfully observed and were used for the determination of the zero field values of the hfs pattern. We operated at a microwave frequency of 3054 Mc/sec. The observed transitions 2(a) and 2(b) were used for the determination of the magnetic dipole interaction constant of Hg^{199}; the observed transitions 3(a) and 3(c) were used for the determination of the magnetic dipole and electric quadrupole interaction constants of Hg^{201}. These values complemented the zero field pattern of the hfs for which the $F=\frac{1}{2}$ levels of both Hg^{199} and Hg^{201} were missing. They also checked within the

experimental error with the $F=\frac{3}{2}$, $F=\frac{5}{2}$ interval of Hg^{201} obtained from the scanning data.

We were not able to observe the remaining transitions; 3(a), because it occurs for 3000 Mc/sec at 8 kilogauss; 3(c) and 3(f), because of reduced transition probabilities; and 3(b), because the frequency is too large. However, the radio-frequency for such a "scanning-double resonance" experiment must be chosen just above the value needed for resolving the double resonance of all Zeeman levels; for mercury this is about 250 Mc/sec. The use of 3000 Mc/sec in the present study was imposed mainly by the available equipment.

EXPERIMENTAL ARRANGEMENTS

The apparatus used is illustrated in Fig. 2. The scanning magnet (A) was an air-core solenoid with an inside diameter of 4 inches and capable of producing fields up to 50 kilogauss. The source was an electrodeless discharge consisting of a 5 mm Vycor tube containing argon at a pressure of a few millimeters and pure Hg^{198}. It was excited by 3000 Mc/sec microwaves and cooled by a dry nitrogen blast kept at 0°C. A current-stabilized power supply was used for the microwave generator (magnetron). Special care was taken in the design of the cooling features. It was thus possible to stabilize the light source within three parts in 1000 over periods of hours and to avoid all of the unpleasant effects that usually accompany electrodeless discharges.

The light source was focused by means of a quartz lens and then passed through a Glazebrook prism (B) cemented with glycerine, finally reaching the resonance cell (C) with its electric vector polarized parallel to the "splitting" magnetic field H_z. A $\frac{1}{4}\lambda$ plate could be inserted before the polarizer.

The resonance cells were made from fused, optically polished quartz in cubical form with 10-mm sides, one face being drawn out into a long tail. The vapor pressure was controlled by driving all of the mercury into the tail and keeping it at the desired temperature. Because of the dimensions of the cell, optimum signal was obtained at a temperature of 25°C; if the tail was kept at 0°C the signal diminished to one-third of its previous value.

The splitting magnet (D), an iron-core magnet with a 2-inch gap, was capable of producing up to 8 kilogauss; a pair of auxiliary high impedance coils was used to provide an automatic sweep of the fixed field up to 15 gauss on either side. A cylindrical microwave cavity containing the resonance cell was placed between the pole faces of the magnet. The cavity was tuned for its lowest TM mode at 3040 Mc/sec, and the microwave magnetic field was perpendicular to the constant field, H_z. Finally, the resonance radiation observed perpendicularly to the direction of the field passed through the analyzer (E), which admitted only the σ component, then through two Corning No. 9863 uv transmitting filters, and was detected by a 1P28 photomultiplier.

The microwave setup consisted of a current-stabilized power supply that fed a QK61 magnetron which was capable of delivering up to 50 watts through a $\frac{7}{8}$-inch coaxial waveguide. Relative power measurements were made with a TVN-3EV thermistor bridge, connected to the line by a directional coupler. The frequency was measured with an S-band echo box which had been calibrated against a harmonic of a crystal oscillator, the basic frequency being measured with a Hewlett-Packard counter. These measurements are considered reliable within 1/50 000.

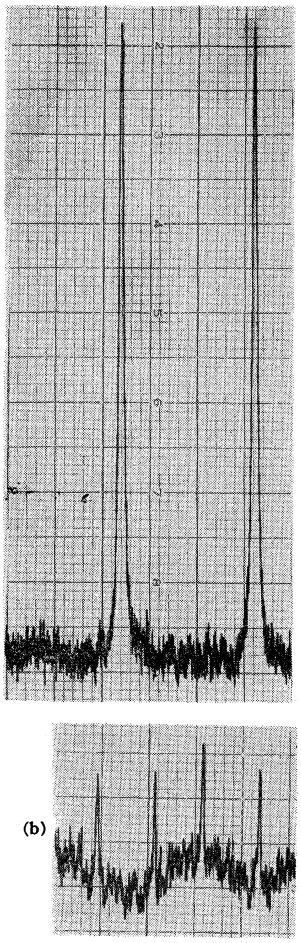

FIG. 3. (a) Resonance signal from an even isotope (Hg^{198}); (b) Resonance signal from Hg^{201} $F=\frac{3}{2}$, $m=\frac{3}{2}\rightarrow m=\frac{1}{2}$.

The signals obtained from the photomultiplier (of the order of 10^{-8} amp) were fed to the dc y amplifier of a 304 Du Mont oscilloscope. Its x axis was driven by the magnet sweep circuit, so that a display of the resonance curve was obtained. This picture was then fed to a Leeds and Northrup strip chart recorder from which the maximum value of the resonance curve was measured for each different value of the "scanning" field. The over-all response time of the detection system was governed by the recorder response, which was 1 sec for full-scale deflection. When data were taken the magnetic field was swept at the rate of 2 cycles per minute.

The "scanning" field had been calibrated by proton resonance before and after the final runs. The solenoid

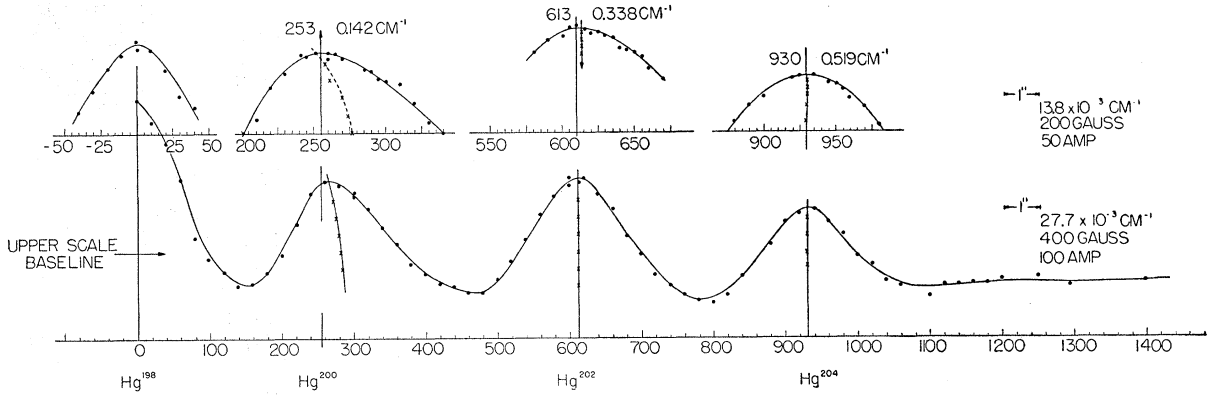

FIG. 4. Scanning curve for even isotopes.

current (of the order of 2400 amp for 10 kilogauss) was measured with a Leeds and Northrup potentiometer through an auxiliary shunt. The splitting field was continuously measured with a proton resonance magnetometer built into the apparatus. The magnetometer signal was fed to the z axis of the detection oscilloscope, thus providing an accurate visual means for setting the proton resonance on the mercury resonance while the field was continuously swept. The proton resonance frequency was then measured with a Signal Corps BC221 frequency meter.

OBSERVED RESULTS

A necessary condition for a successful scanning curve was the realization of good double-resonance signals. For the even isotopes we obtained a signal-to-noise ratio over 20; for the odd isotopes the signals were of inferior quality. The best signal and worst signal that were used are shown in Fig. 3. The observed resonances are given in Table I.

With the splitting field set for resonance in the even isotopes, a scanning curve was obtained (Fig. 4). Each point on this curve represents the maximum of the double-resonance signal at this value of the scanning field. While the actual data were being taken, we kept returning every half-hour to the zero-field value to check the correctness of our observations.

The curve of Fig. 4 was taken without a $\frac{1}{4}\lambda$ plate, since there are no even isotope lines at shorter wavelengths than Hg^{198}; but with a $\frac{1}{4}\lambda$ plate the asymmetry of the Hg^{200} peak was greatly reduced. The scanning curve is not completely resolved. We attribute this fact to the presence in the exciting radiation of the central (unshifted) Zeeman component, which is also responsible for the "background" signals appearing at the high values of the scanning field. In the upper part of the figure a "fine" scanning curve of the peaks is reproduced.

Since the sublevel which is originally populated is unshifted by the "splitting" field, the location of the peaks of the scanning curve corresponds to the location of the even isotope lines in the zero-field pattern of the hfs. These values, as obtained from four different scanning curves, are given in Table II; the tolerances give the standard deviation which was estimated from these four curves, the main contribution coming from the fluctuations of the scanning field.

For the odd isotopes, the scanning curve has only a

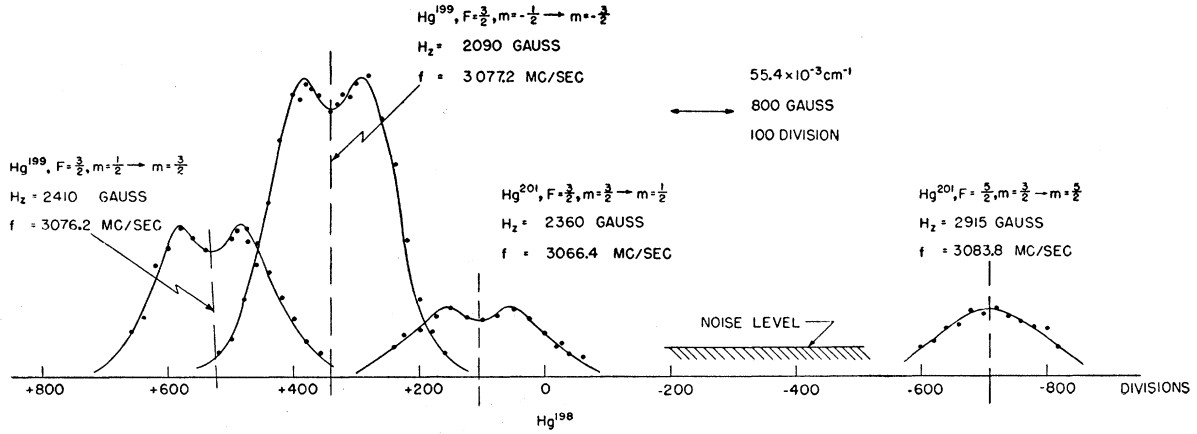

FIG. 5. Scanning curve for odd isotopes.

TABLE I. Observed microwave transitions between magnetic sublevels in the $^3P_1$ state of mercury.

Isotope	F level	Transition	Microwave frequency Mc/sec	Magnetic field (proton frequency) kc/sec
Even		$m=0\rightarrow\begin{cases}m=+1\\m=-1\end{cases}$	3054.0	6253.9±1
Hg^{199}	$\frac{3}{2}$	$m=-\frac{1}{2}\rightarrow m=-\frac{3}{2}$	3054.0	8844.2±1
	$\frac{3}{2}$	$m=\frac{1}{2}\rightarrow m=\frac{3}{2}$	3054.0	10 198.3±2
Hg^{201}	$\frac{3}{2}$	$m=\frac{3}{2}\rightarrow m=\frac{1}{2}$	3054.0	10 019.8±2
	$\frac{5}{2}$	$m=\frac{3}{2}\rightarrow m=\frac{5}{2}$	3054.1	12 316.4±2

single peak, from which we obtained the location of the initial Zeeman level, with respect to Hg^{198}, for this particular value of the "splitting" field. In Fig. 5, the four different scanning curves have been superimposed; each of them was obtained for the field value shown in Table III. To obtain the zero-field value of the F level to which the Zeeman level belongs we had to calculate the energy difference by using the known "splitting" field and the interaction constants. This was done fairly easily by solving the secular determinant for the intermediate region (according to Schmidt[3]). The results are summarized in Table III.

Finally, from the microwave resonance data of Table I we were able to obtain the following information:

(a) The atomic g factor of the level

$$g_J=g_{\text{proton}}\times(m/M)\times(f_{\text{Hg}}/f_{\text{proton}}).$$

By using the even-isotope data and $g_{\text{proton}}=5.58501$ and $M/m=1836.12$, we obtain $g_J=1.484\pm0.001$. The same value was observed—within the experimental error—for all even isotopes.

(b) The magnetic dipole interaction constant for Hg^{199}. By using the $m=-\frac{1}{2}\rightarrow m-\frac{3}{2}$ data, we obtain $a=(\Delta y^2-\Delta yH)/(H-\frac{3}{2}\Delta y)=(491.37\pm1)\times10^{-3}$ cm^{-1}. By using the $m=+\frac{1}{2}\rightarrow m+\frac{3}{2}$ data, we obtain $a=(H\Delta y-\Delta y^2)/(H-\frac{3}{2}\Delta y)=(491.45\pm0.5)\times10^{-3}$ cm^{-1}.

(c) The magnetic dipole and electric quadrupole interaction constants for Hg^{201}. By using the $F=\frac{5}{2}$,

TABLE II. Hyperfine structure of the $^3P_1$ state of mercury as obtained by the methods described in this paper, and by other methods. The line positions are given in units of 10^{-3} cm^{-1}.

Isotope	F level	Zero-field position from Hg^{198}	Zero-field position from Hg^{200}	Brix and Kopferman from Hg^{200}	Brix and Kopferman from Hg^{198}	Bitter *et al.*[1] from Hg^{198}
204		−519±3	−363±4	−354	−514	−500
201	$\frac{5}{2}$	−491±4	−335±5	−329	−489	−451
202		−339±3	−183±4	−179	−339	−328
200		−156±3	0	0	−160	−157
201	$\frac{3}{2}$	−22±3	134±4	136	−24	
198		0	156±3	168	−8	0
199	$\frac{3}{2}$	230±4	386±5	389	229	219

[3] Th. Schmidt, Z. Physik **111**, 332 (1938–39).

TABLE III. Summary of results on the hyperfine structure of the $^3P_1$ state of the odd isotopes as computed from observations on magnetically displaced levels.[a]

Isotope	F level	Zeeman level excited	Location with respect to Hg^{198} cm^{-1}	Splitting field (f_p) kc/sec	Energy difference in cm^{-1} from center of gravity	Shift of Zeeman level due to splitting field cm^{-1}	Zero-field location of F level cm^{-1}
Hg^{199}	$\frac{3}{2}$	$m=-\frac{1}{2}$	$+188.7\times10^{-3}$	8915.0	$\epsilon=-\frac{1}{4}a-\frac{1}{2}H+\frac{1}{2}[(\frac{1}{2}a+H)^2+2a^2]^{\frac{1}{2}}=0.2030$	$\Delta\epsilon=+42.5\times10^{-3}$	$(231.2\pm2)\times10^{-3}$
$a=0.491$ cm^{-1}	$\frac{3}{2}$	$m=\frac{1}{2}$	$+292\times10^{-3}$	10 283.5	$\epsilon=-\frac{1}{4}a+\frac{1}{2}H+\frac{1}{2}[(\frac{1}{2}a-H)^2+2a^2]^{\frac{1}{2}}=0.3103$	$\Delta\epsilon=-64.8\times10^{-3}$	$(227.2\pm4)\times10^{-3}$
Hg^{201}	$\frac{3}{2}$	$m=\frac{3}{2}$	$+58.1\times10^{-3}$	10 034	$\epsilon=\frac{1}{4}a-3b+\frac{1}{2}H+[25b^2+(25/16)a^2+\frac{1}{4}H^2+bH+\frac{1}{4}aH+(25/2)ab]^{\frac{1}{2}}=0.2695$	$\Delta\epsilon=-80.3\times10^{-3}$	$(-22.2\pm3)\times10^{-3}$
$a=-0.182$ cm^{-1} $b=-1.03\times10^{-3}$ cm^{-1}	$\frac{5}{2}$	$m=\frac{3}{2}$	-392.1×10^{-3}	12 412	$\epsilon=\frac{1}{4}a-3b+\frac{1}{2}H-[25b^2+(25/16)a^2+\frac{1}{4}H^2+bH+\frac{1}{4}aH+(25/2)ab]^{\frac{1}{2}}=0.1753$	$\Delta\epsilon=-99.3\times10^{-3}$	$(-491.4\pm4)\times10^{-3}$

[a] In the formulas of column 6, a is the magnetic dipole and b the electric quadrupole interaction constant. The values used for the computation are given in column 1 for each isotope. H is proportional to the magnetic field: $H=g_J\mu_B B$ in cm^{-1}, where g_J is the atomic g factor = 1.484, μ_B is the Bohr magneton, and B is the splitting field in gauss. The last column, which gives the final results, is also reproduced in Table II. The tolerances again indicate the standard deviation which arises in this case, mainly, from the uncertainty with which we were able to locate the center of the scanning curve.

TABLE IV. Magnetic dipole and electric quadrupole interaction constants (in units of 10^{-3} cm^{-1}) observed for the $^3P_1$ state of the odd isotopes of mercury.

Isotope	Type of interaction	Interaction constant	Brix and Kopferman	Present investigation Microwave data	Present investigation Scanning data	Other[a] microwave data
Hg^{199}	magnetic dipole	a	493	491.45±0.5	···	495±8
Hg^{201}	$F_{\frac{5}{2}}-F_{\frac{3}{2}}$	$\frac{5}{2}a+10b$	465	465.21±0.5	469±6	···
	magnetic dipole	a	−181.7	181.36±0.5	···	···
	electric quadrupole	b	−1.03	−1.18±0.08	···	···

[a] From Bogle, Dodd, and McLean, Proc. Phys. Soc. (London), **B70**, 796 (1957).

$m=+\frac{3}{2}\rightarrow m=+\frac{5}{2}$ data, we obtain

$$\tfrac{5}{2}a+10b=\frac{\Delta y^2-\Delta yH}{\frac{2}{5}H-\Delta y}=(-465.21\pm0.7)\times10^{-3}\text{ cm}^{-1},$$

which is the spacing between the $F=\frac{5}{2}$ and $F=\frac{3}{2}$ levels of Hg^{201} at zero field. To interpret the data of the $F=\frac{3}{2}$, $m=+\frac{3}{2}\rightarrow m=+\frac{1}{2}$ transition we had to use a computational method, since the solution of a third-order equation is involved. Using these data and the above-obtained value for $\frac{5}{2}a+10b$, we get

$$a=(-181.36\pm0.5)\times10^{-3}\text{ cm}^{-1},$$
$$b=(-1.18\pm0.08)\times10^{-3}\text{ cm}^{-1}.$$

These closed-form formulas are derived by subtracting the energy values of the two Zeeman components of the transition and solving for a and b.[4] As before, $H=g_J\mu_B B$ in cm^{-1} and $\Delta y=f_{\text{Hg}}/c$ is the energy difference in cm^{-1} corresponding to the transition. For comparing our results with previous investigations we have included in column 5 of Table II the data given by Brix and Kopferman in the 1951 edition of the Landolt-Börnstein Tables. They were obtained from a compilation of data from purely optical work and are based mainly on the work of Schüler and Keyston.[5]

As can be seen, our data are not in agreement with the values given by Brix and Kopferman. However, in column 6 of Table II, we repeat their data—after shifting the origin from Hg^{200} towards Hg^{198} by 160 $\times10^{-3}$ cm^{-1} so that they can be compared with our own data given in column 3. We then notice a very close agreement, within the experimental error, except for Hg^{198}, for which we are inclined to believe that our data are better, because they are free from any influence of the nearby Hg^{201} ($F=\frac{3}{2}$) line. In column 7 we give the data reported in reference 1 as measured from Hg^{198}.

As to the interaction constants of the odd isotopes, the results are summarized in Table IV, and again agreement exists within the experimental error.

No attempt was made to calculate the moments from the hfs data. However for the quadrupole moment of Hg^{201}, according to the calculation of Schüler and Schmidt,[6] we obtain from our data

$$Q^{(201)}=(0.58\pm0.18)\times10^{-24}\text{ cm}^2.$$

This can be compared with the result obtained from pure quadrupole resonance by Dehmelt *et al.*,[7] as interpreted by Pound and Wertheim,[8]

$$Q=(0.46_{-0.11}{}^{+0.28})\times10^{-24}\text{ cm}^2,$$

Also, recent optical measurements by Murakawa[9] on other lines of mercury lead to a value of $Q=(0.45\pm0.04)$ $\times10^{-24}$ cm^2.

The main objective of the present study was to demonstrate the possibility of separating overlapping lines of a hfs pattern, as was indicated by two of us (P. L. S. and F. B.). The technique and the apparatus described are now being used for the study of the 65-hour and 25-hour radioactive Hg^{197}. It is expected to lead to satisfactory results, since the unavoidable presence of the natural mercury lines should no longer hinder the observation of the Hg^{197} lines.

Furthermore, the "scanning" setup has the advantage of facilitating a double-resonance experiment by reducing the background, since only one, or very few, Zeeman levels are being populated.

ACKNOWLEDGMENT

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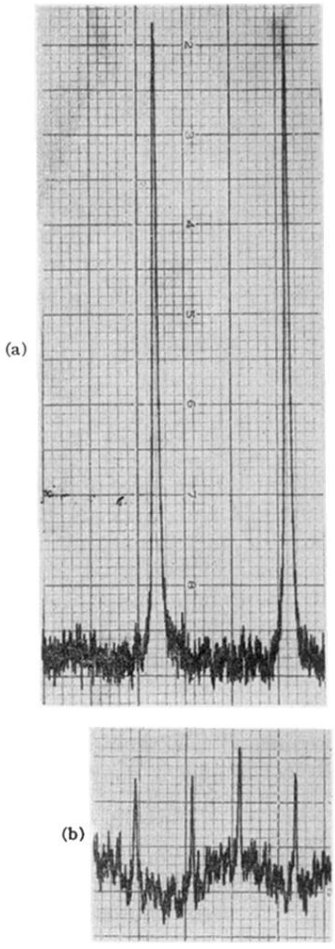
[4] A. Melissinos, Quarterly Progress Report, Research Laboratory of Electronics, Massachusetts Institute of Technology, January 15, 1956 (unpublished), p. 36.
[5] H. Schüler and J. E. Keyston, Z. Physik **72**, 423 (1931).
[6] H. Schüler and Th. Schmidt, Z. Physik **98**, 239 (1935).
[7] Dehmelt, Robinson, and Gordy, Phys. Rev. **93**, 480 (1954).
[8] R. V. Pound and G. K. Wertheim, Phys. Rev. **102**, 396 (1956).
[9] K. Murakawa, Phys. Rev. **98**, 1285 (1955).



(a)

(b)

FIG. 3. (a) Resonance signal from an even isotope (Hg^{198}); (b) Resonance signal from Hg^{201} $F=\frac{3}{2}$, $m=\frac{3}{2}$ $\rightarrow m=\frac{1}{2}$.