# IV. NUCLEAR MAGNETIC RESONANCE AND HYPERFINE STRUCTURE

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## A. HYPERFINE STRUCTURE OF THE $^3P_1$ STATE OF MERCURY BY DOUBLE-RESONANCE METHODS

### 1. In a Magnetic Field

The work on the $^3P_1$ state of mercury has been completed. Detailed results are given in an S. M. thesis submitted to the Department of Physics, M.I.T., by A. C. Melissinos. The object of this study was the investigation of the hyperfine structure of the 2537 A line of natural mercury by a magnetic scanning technique.

The whole hyperfine pattern was scanned by a variable energy monochromatic line, obtained from an $Hg^{198}$ electrodeless discharge tube placed in a variable magnetic field. The separation of the overlapping hyperfine structure lines was obtained by producing a microwave resonance between the m-sublevels of the different isotopes.

Resonances were observed in the even isotopes, and their positions were located with respect to $Hg^{198}$ to within $\pm 3 \times 10^{-3}cm^{-1}$. Resonances were also observed in the $Hg^{199}$, $F = 3/2$ level, and $Hg^{201}$, $F = 5/2$ and $F = 3/2$ levels; their zero-field values are given within $\pm 4 \times 10^{-3}cm^{-1}$. The nature of the experiment does not permit the observation of resonances in the $F = 1/2$ levels of both $Hg^{201}$ and $Hg^{199}$.

The performance of the double resonance, per se, provided the following additional information.

a. Even isotopes: verification of the g-factor in intermediate fields, which was consistent with the existent data.

b. $Hg^{199}$: a value of the magnetic dipole hyperfine interaction from two different resonances within $\pm 2 \times 10^{-3}cm^{-1}$.

c. $Hg^{201}$: a value of the magnetic dipole and electric quadripole hyperfine interaction within $\pm 2 \times 10^{-3}cm^{-1}$.

Lifetime measurements indicated narrower lines at higher vapor pressures, but it was not possible to obtain positive evidence of such an effect.

We plan to improve the equipment in order to increase considerably the accuracy of the microwave resonance, measurements, and then to extend the present method to radioactive $Hg^{197}$.

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## B. REDUCTION OF DRIFT IN DOUBLE-RESONANCE EXPERIMENTS

In the past, double-resonance experiments were plagued by four kinds of drift: (a) lamp-intensity drift; (b) photomultiplier cathode-sensitivity and amplification drift;

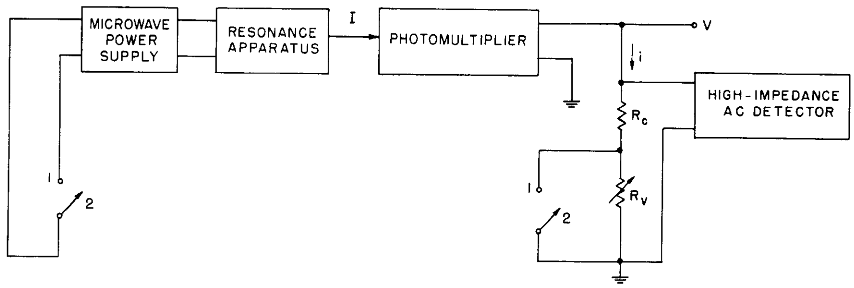


Fig. IV-1. Diagram of the system.

(c) photomultiplier dark-current drift; (d) gas-density drift in the resonance cell induced by change in temperature. Fluctuations that obscure or distort the desired microwave induced resonance are produced at the photomultiplier output by these variations.

Some of the previously used methods of eliminating these difficulties are: (a) stabilization of the light source by control of the power supply and cooling; (b) temperature control of the resonance cell; (c) monitoring of the lamp intensity by a second photomultiplier.

The elimination of drift is, in any case, limited by the natural photomultiplier noise level (1), whose signal-to-noise ratio is $\left(i_p/2e\Delta f\right)^{1/2}$, where $i_p$ is the cathode photocurrent, e is the electronic charge, and $\Delta f$ is the bandwidth of the detector. This expression is, of course, equal to $(\epsilon n/2\Delta f)^{1/2}$, where n is the number of photons per unit time arriving at the photocathode, and $\epsilon$ is the efficiency of the photocathode.

A suggested drift-reducing measurement method is shown in Fig. IV-1. The two switches are ganged, are operated at some fixed frequency, and are closed for approximately half of the cycle. The drift during the short time of the switching cycle can be neglected. $R_v$ is adjusted so that V is essentially constant during one cycle. Let $i_1$, $i_2$ be the photomultiplier output currents with switches closed and open, respectively; and let $I_1$, $I_2$ be the resonance output light intensities with switches closed and open, respectively. Then we have

$$i_2 (R_c + R_v) = i_1 R_c$$

$$\frac{i_1 - i_2}{i_2} = \frac{R_v}{R_c}$$

If dark current is neglected for the moment, the above result does not depend either on photomultiplier sensitivity or light intensity, since the two are, in any event, directly proportional (1).

More explicitly, let $i_b$ be the background photocurrent at the anode (dark current plus current from unshielded room light); and let K be the proportionality constant that relates changes in light intensity to changes in photomultiplier output current. Then we have

$$i = i_b + KI$$

$$\frac{R_v}{R_c} = \frac{i_1 - i_2}{i_2} = \frac{K(I_1 - I_2)}{i_b + KI_2}$$

$$\frac{R_v}{R_c}\left(1 + \frac{i_b}{KI_2}\right) = \frac{I_1 - I_2}{I_1}$$

$$\frac{R_v}{R_c}\left(1 + \frac{i_b}{i_2 - i_b}\right) = \frac{I_1 - I_2}{I_1}$$

Of course, if $i_b$ is very small compared with $i_2$, then

$$\frac{I_1 - I_2}{I_2} = \frac{R_v}{R_c}$$

Consider the relative error, E, which is introduced by fluctuations $\Delta i_b$ and $\Delta i_2$ in $i_b$ and $i_2$. If we assume that $i_b << i_2$, then

$$E = \Delta \log\left(1 + \frac{i_b}{i_2 - i_b}\right)$$

$$E \doteq \frac{i_2 \Delta i_b - i_b \Delta i_2}{i_2^2}$$

If $\Delta i_2$ is of the order of $\Delta i_b$, then $E \doteq \Delta i_b/i_2$.

If $R_v$ is properly balanced, the voltage at V will be dc plus drift. If $R_v$ is not properly balanced, the voltage at V will be ac plus drift, plus a drift-modulated square-wave voltage at the switching frequency. Hence, it is convenient to place at V a narrow-band, high-impedence, voltage-indicating device, peaked at the switching frequency – as, for example, a narrow-band amplifier followed by an oscilloscope.

A usable switching frequency can be chosen through an experimental noise spectrum of the output of the photomultiplier when the light source is viewed directly. Any frequency so chosen that the experimental noise level does not exceed the natural noise level is suitable.

Any time difference in the two switching circuits should produce a rectangular wave, even at perfect balance. The first harmonic of this wave, which can be easily computed from the waveform, may, depending on its magnitude, obscure the exact balance point.

A switching method that can provide a high degree of simultaneity for both circuits is the following. Near resonance, when an appreciable voltage appears across $R_v$, a mechanical switch is placed across $R_v$. Off resonance, when no appreciable voltage appears across $R_v$, the switch is placed, instead, across a resistor that is in series with a second resistor and a voltage supply. In either case, the square-wave voltage appearing across the switch is amplified, limited, and used to shut the microwaves off and on electronically. A mechanical switch that should provide excellent characteristics is the mercury relay (Western Electric types 275B, 276B, and D-168479, for example).

The measurement technique described in this report should eliminate the first two drift difficulties. The third is not eliminated but can be estimated. The fourth will be eliminated only if the resonance-cell gas density is so low that the resonance shape is not disturbed by small changes in gas density, and if nearly all of the radiation reaching the photomultiplier is resonance radiation.

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References

1. R. W. Engstrom, J. Opt. Soc. Am., 37, 420-431 (June 1947).

## C. LIFETIME OF $5^3P_1$ LEVEL OF CADMIUM

A tentative value of 1.1 μsec for the lifetime of the $5^3P_1$ level in cadmium was obtained by the double-resonance technique. This is about half the value obtained previously by a variety of techniques. The two most recent values are 2.1 μsec and 2.05 ± .05 μsec. The first was obtained by measuring the absorption of a continuous spectrum by cadmium vapor (1); the second, by measuring the decay in intensity of resonance radiation from a low-pressure vapor sample after the source of illumination was suddenly turned off (2). The reason for the discrepancy is not apparent. Since it has been found that the lifetime, as measured by the double-resonance method, depends on the vapor pressure in a complicated way, it will be necessary to repeat the experiment for several different pressures.

A new method for obtaining the resonance curves was developed. Instead of putting the output of the detecting photomultiplier tube directly into a galvanometer, which gives fluctuating readings because of changes in lamp intensity, vapor pressure, and phototube sensitivity, a null method is employed. The radiofrequency transmitter is turned on and off at 30 cps. The current from the phototube, thereby modulated at 30 cps, is fed through two variable resistors in series. One of these resistors is shorted out simultaneously with the turning on of the transmitter, and unshorted with the turning off of the transmitter. This is accomplished by means of a pair of motor-driven switches run by a synchronous motor. The voltage developed across the two resistors is fed into a narrow-band amplifier whose output appears on the face of an oscilloscope. The resistor that is shorted and unshorted is adjusted until a null trace is obtained. Very smooth curves were obtained by this method, which is adaptable to every sort of double-resonance experiment.

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References

1. R. B. King and D. C. Stockbarger, Astrophys. J. 91, 488 (1940).
2. C. G. Matland, (abstract) Phys. Rev. 91, 436 (1953).