The Zeeman Effect of the Hyperfine Structure of Optically Excited Mercury Resonance Radiation

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Magnetic fields from 0 to 2000 gauss are applied to the mercury resonance line λ2537A and the Zeeman patterns for the hyperfine structure determined. The results indicate close agreement with the explanation of Schuler and Keyston. The Paschen-Back effects for the hyperfine structure of the isotopes 199 and 201 are worked out and experimental evidence is offered in support of the hypothesis of Goudsmit and Bacher that the Zeeman effect for the hyperfine structure may be treated in the same manner as the Zeeman effect for the fine structure if the appropriate change in quantum numbers is made.

INTRODUCTION

IF THE explanation of the hyperfine structure of mercury resonance radiation, λ2537A, $1^1S_0-2^3P_1$, offered by Schuler and Keyston[1] is accepted, certain predictions can be made as to the expected polarization and also as to the behavior of the components in a magnetic field. Larrick and Heydenburg[2] have studied the polarization and have also restated the explanation of Schuler and Keyston. It is the purpose of this paper to report on an investigation of the effect of applying magnetic fields to optically excited mercury resonance radiation. From the viewpoint of hyperfine structure these fields would be considered strong inasmuch as complete overlapping of the components was obtained. However, from the standpoint of fine structure they are very weak fields. Optically excited radiation was chosen because of the necessity of using a source of light having the smallest possible breadth of spectral line.

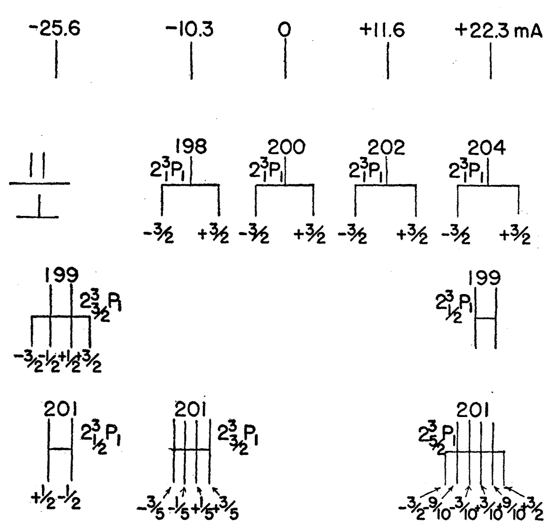

FIG. 1. Parallel and perpendicular splittings computed on the basis of Schuler and Keyston's assignment of quantum numbers and nuclear magnetic moments.

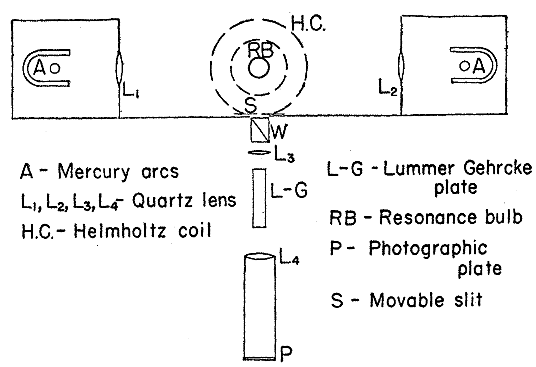

FIG. 2. Diagram of apparatus.

Figure 1[3] shows the parallel and perpendicular splittings computed on the basis of Schuler and Keyston's assignment of quantum numbers and nuclear magnetic moments. To calculate these splittings one computes the Landé hyperfine structure factor,[4] (g_f), for the upper 2^3P_1 level.

* The investigations were performed during summer appointments at The State University of Iowa, Iowa City, Iowa.
[1] H. Schuler and J. E. Keyston, Naturwiss. **31**, 676 (1931).
[2] L. Larrick and N. P. Heydenburg, Phys. Rev. **39**, 289 (1932).
[3] The notation used in all the figures and in the discussion is that used by H. E. White, *Introduction to Atomic Spectra* (McGraw-Hill, 1934), Chapter 18.
[4] Equation 18.52, page 374, H. E. White, *Introduction to Atomic Spectra*.

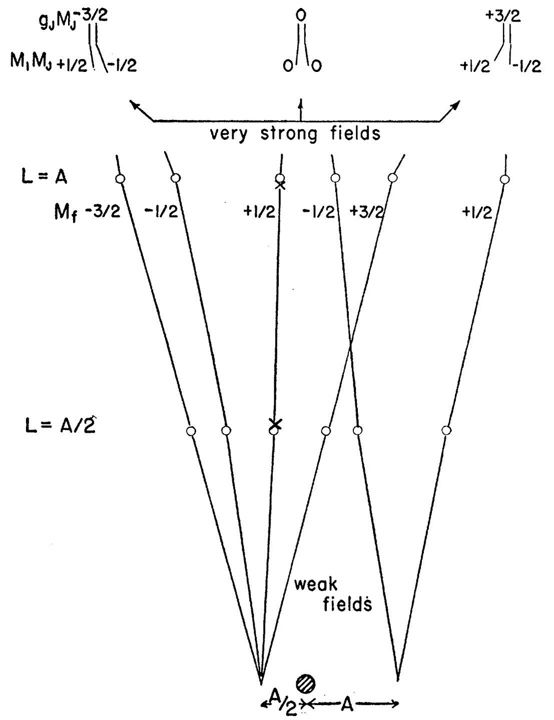

FIG. 3. Theoretical Zeeman splittings to be expected for the odd-numbered Hg isotope, 199.

Since the lower level, 1^1S_0, does not split the theoretical splitting of the lines themselves is that of the upper level.

APPARATUS

A diagram of the apparatus is shown in Fig. 2. The source of radiation for the optical train through the Lummer-Gehrecke interferometer to the photographic plate was within the resonance bulb. This resonance bulb had a tube extending downward about 25 cm containing a drop of mercury. The vapor pressure in the bulb was reduced by maintaining the tube at 0°C, during the time that pictures were being taken. The magnetic field was produced by a Helmholtz coil made of copper tubing carrying a stream of water to remove excess heat. The coil produced a magnetic field of 5.46 gauss per ampere and was capable of carrying a current of 600 amperes. The mercury arcs used to excite the radiation in the resonance bulb were water cooled to decrease the width of the spectral line and magnetically deflected to eliminate self reversal. The Lummer-Gehrecke plate was 4.92 mm thick so that the

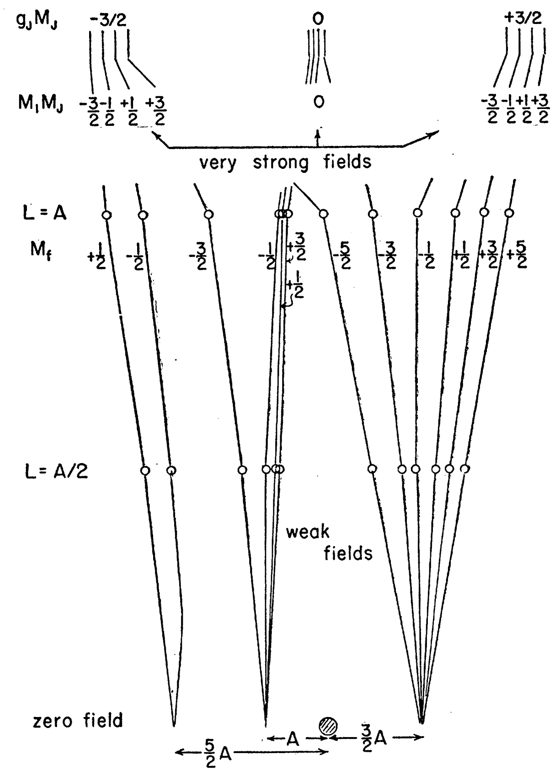

FIG. 4. Theoretical Zeeman splittings to be expected for the odd-numbered Hg isotope, 201.

order separation is 45.1mA and produced a pattern previously described by Ellett and MacNair.[5] Unfortunately this order separation is such that the +22.1 and the −25.6 milliangstrom components overlap making the magnetic analysis of these components difficult. The slit, Wollaston prism, and the quartz lens, L_3, produced two slightly diverging, approximately parallel beams of light, one polarized parallel to, the other perpendicular to the magnetic field. The camera lens focused the interferometer pattern of the Lummer-Gehrecke plate superimposed on the double image of the slit. A slight sidewise change in the position of the slit made it possible to secure on the same photographic plate patterns of two different fields. This proved to be very useful in establishing the identity of the various components as the field changed from one value to the next. The Lummer-Gehrecke plate and camera were care-

[5] A. Ellett and W. A. MacNair, Phys. Rev. **31**, 180 (1928).

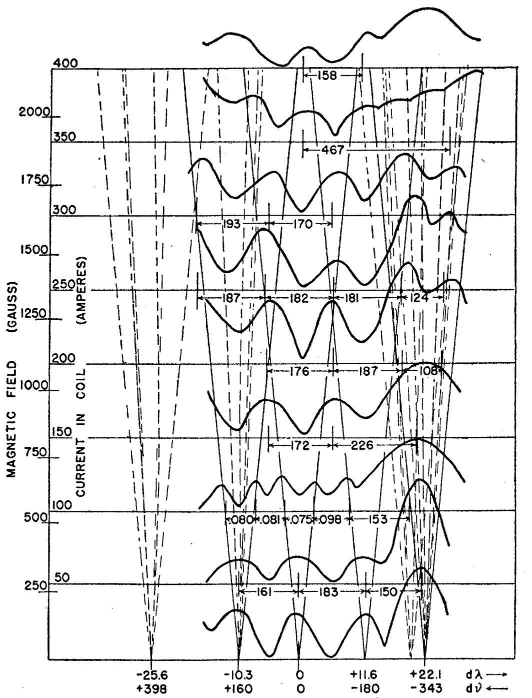

FIG. 5. Zeeman separations for the perpendicular components of Hg resonance radiation. Full lines for even-numbered isotopes. Dotted lines for odd-numbered.

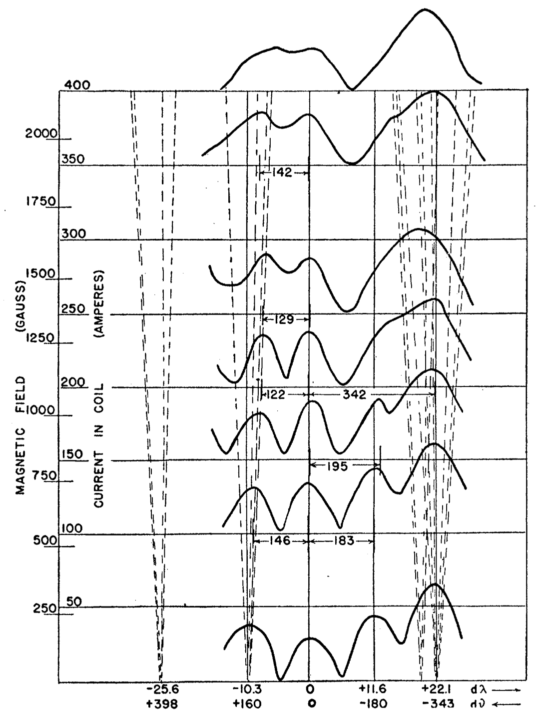

FIG. 6. Zeeman separations for the parallel components of Hg resonance radiation. Full lines for even-numbered isotopes. Dotted lines for odd-numbered.

fully shielded from scattered light and excess heat. The microphotometer traces of each of the plates used in each of the measurements were obtained with a high precision microphotometer.

The Paschen-Back Effect

Goudsmit and Bacher[6] have pointed out that the formulae developed by Darwin for the Zeeman effect as applied to fine structure will also apply to the hyperfine structure if the appropriate change in quantum numbers is made. On the basis of these ideas the theoretical splittings to be expected for the odd isotopes has been worked out and is shown graphically in Figs. 3 and 4. Attention is called to the fact that in Fig. 3 the component with the displacement $\frac{1}{2}A$ and $M_f=+\frac{1}{2}$ is evidently the component which MacNair has reported to be displaced from the zero component in accord with the equation $d\lambda=-25.6+0.089H^{\frac{1}{2}}$, Darwin's theory gives $E=-\frac{1}{4}A-\frac{3}{4}L+\frac{1}{4}(9A^2+6AL+9L^2)^{\frac{1}{2}}$ with the displacement measured from the center of gravity of the line. At $L=A$ and $L=\frac{1}{2}A$ the two equations, if the appropriate change in units is made, are in agreement to within 1 percent. In Fig. 3, two crosses indicate this agreement graphically. Because of the overlapping of the two components $+22.1$ and -25.6 milliangstrom units in the Lummer-Gehrecke patterns the author was unable to observe this shift experimentally. In Fig. 4, the zero field component with a displacement A to the left of center of gravity breaks into 4 Zeeman splittings, three of which shift toward the center of gravity. Experimentally it was observed (see Fig. 6) that for the parallel components there is very good agreement with this theoretical displacement.

Results

The microphotometer traces were measured to obtain the $d\lambda$ separation in milliangstrom units and the corresponding $d\nu$ in reciprocal centimeters. The height of the peaks above the general blackening of the photographic plate was taken as a rough measure of intensity of the

[6] S. Goudsmit and R. F. Bacher, Phys. Rev. **34**, 1499 (1929).

components. These measurements enable the sketching in of the microphotometer traces with intensity as ordinates and position of the components as abscissae. These traces are placed one above the other to show the progressive change in the pattern as magnetic fields of greater and greater strength were applied. The results for the perpendicular components are shown in Fig. 5 and the parallel components in Fig. 6. In both of these figures the vertical lines or the lines at a small angle from the vertical represent the theoretical splitting for the even-numbered isotopes as shown in Fig. 1 and for the odd-numbered isotopes as shown in Figs. 3 and 4. The splittings for the even-numbered and the odd-numbered isotopes are shown as full and dotted lines, respectively. The perpendicular components show $\frac{3}{2}$ splitting which is to be expected on the basis of Schuler and Keyston's explanation and which has previously been reported by MacNair.[5] The examination of the experimental results for the parallel components show that the -10.3 component shifts toward the zero component in agreement with the theoretical prediction of Darwin's theory but which for the range of fields used is not in agreement with the results of MacNair.

ACKNOWLEDGMENTS

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The Paschen-Back Effect

V. Theory of the Effect for Intermediate Coupling

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General spectroscopic theory has been applied to the Paschen-Back effect and simplified methods developed for determining the positions of the energy levels and intensities of lines for cases of intermediate coupling. They are expressed in terms of *LS*-coupling as the zero-order functions.

A COMPLETE theory of the Paschen-Back effect for intermediate coupling in two-electron spectra was first given by Houston[1] (in essence) for the case of one electron in an *s* state and was later completed and experimentally verified by Green and Loring[2] and by Jacquinot.[3] Houston's zero-order approximation, while satisfactory for the particular example studied, proves unwieldy, however, when applied to more complicated configurations. Since the publication of Houston's paper, a very considerable body of theoretical work has been carried out, and spectroscopic theory has been advanced to the point where the problem of the Paschen-Back effect can be stated in general terms for any kind of coupling. While it is useful to be able to state the general solution to any problem, it is the actual application of the problem to particular cases that is of prime interest to the experimental physicist; and it is the purpose of the present paper to express the solution in terms that are very easily interpreted in terms of a coupling system that is familiar to everybody; namely, *LS*-coupling.

[1] W. V. Houston, Phys. Rev. **33**, 297 (1929).
[2] J. B. Green and R. A. Loring, Phys. Rev. **46**, 888 (1934).
[3] P. Jacquinot, Thesis, (Paris, 1937).