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The Hyperfine Structure of the Mercury Triplet $6^3P_{012}-7^3S_1$ in Optical Excitation

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The relative intensities of the hyperfine structure components of λ5461, λ4358 and λ4047 in optically excited mercury vapor were computed by using the energy level scheme and intensity distribution calculated by Schüler and Keyston, with the assumption of complete absorption of λ2537 and slight absorption of λ4358. Since the excitation is in two steps, the ratio of the intensities of the components due to the less abundant isotopes to those due to the more abundant is much less than in the normal low pressure arc, in which the excitation of each isotope is proportional to its concentration These calculations were checked experimentally. Mercury vapor in a quartz resonance cell was excited optically by a low pressure mercury glow discharge in a helical quartz tube. This source was found to have the energy distribution predicted by Schüler and Keyston indicating small reversal. The hyperfine structure was photographed with a Lummer plate and the intensities determined from microphotometer records. The intensities from the optically excited vapor were found to agree within experimental error with the computed values.

VARIOUS experimenters[1] have observed that the lines of the sharp series triplet $6^3P_{012}-7^3S_1$ of mercury showed marked differences in the relative intensities of their hyperfine structure under different conditions of excitation. These differences were due in the most part to self-absorption in the radiating sources. E. Hobart Collins[2] investigated with a Lummer plate the relative intensities of the hyperfine structure when the triplet was excited optically[3] at low pressures by absorption of λ4358 following the absorption of λ2537. The mercury vapor in a quartz resonance tube was excited by light from water-cooled, magnetically deflected quartz mercury arcs. Conspicuous differences were observed between the radiation excited by electron impact and that excited optically. λ5461, which in the unreversed arc has 12 components, showed only one in the optical excitation. In λ4358 and λ4047 some but not all the components which appear in the arc were found in the optically excited radiation. Since the intensities were estimated by assuming that the blackening of the photographic plate was proportional to the intensity and no calibration marks or intensity standards were used, the results were only qualitative. In each case the central component was relatively much stronger than the other components. Later Mrozowski[4] found only the central component present in the optically excited radiation. Still more recently Pool and Simmons[5] in similar experiments found the relative intensity of the central component much enhanced in the optical excitation, although the other components were observed.

Very careful measurements of the wavelengths of these lines have been made by Nagaoka[6] and others.[7] Several attempts to explain the structure[8] were made but none were very satisfactory until Schüler and Keyston[9] in 1931 developed a system of energy levels for these hyperfine structures based upon the assignment of the components to the various isotopes of mercury. It was assumed that the even isotopes (196, 198, 200 and 204) had a nuclear moment $I=0$ and that the odd isotopes (199 and 201) had nuclear moments of $I=1/2$ and $I=3/2$, respectively. These assumptions, together with the sum rule of Burger and Dorgelo[10] and the data determined by Aston on the abundance of the various

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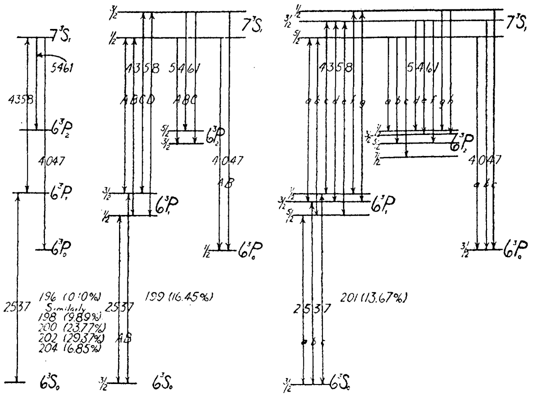

Fig. 1.

isotopes, enabled them to calculate the relative intensities of the hyperfine structure components of each of the lines as excited by electron impact, i.e., in an arc or glow discharge free from the effects of self-reversal. Observations made on a specially designed water-cooled mercury arc checked these observations quite satisfactorily. Fig. 1 shows the energy level system devised by Schüler and Keyston for λ2537 and the three lines of the triplet $6^3P_{012}-7^3S_1$. Since the hyperfine energy levels of all the even isotopes are single, the system of levels shown at the left represents any one of the even isotopes. Throughout this paper, the components arising from the even isotopes will be denoted by X, the isotope to which the particular component belongs being denoted by the subscript. The components arising from the isotope 199, as shown in the system of energy levels in the center of the diagram, will be denoted by upper case letters and those from isotope 201, shown on the right, by lower case letters. The figures in the parentheses beside the number designating the isotope give the abundance of the isotope as determined by Aston.

In the research described in this paper the intensity distribution of the hyperfine structure components of the lines of this triplet was measured under carefully controlled conditions of optical excitation and the results compared with those computed from the Schüler and Keyston scheme. The intensity distribution was also examined in an "unreversed arc" and found to agree with that predicted by Schüler and Keyston. By an unreversed arc is meant an arc or glow discharge in which the intensity distribution produced by electron impact is not appreciably altered by self-absorption.

In calculating the relative intensity distribution to be expected from optical excitation, we have, in general, to consider the absorption process as though we had seven distinct substances having different concentrations. For any substance the total excitation by electron impact depends upon its concentration and upon the excitation probability. Since the latter is the same for each isotope, we find for this type of excitation, under conditions for which there is no self-absorption, that the total radiation from each isotope is proportional to its relative abundance, N. With optical excitation, on the other hand, since this results in the case of the triplet under consideration from two-step absorption, the problem is quite different. In at least one of the steps the absorption is small so that it depends in amount upon the number of absorbing atoms n, the intensity of the impressed radiation I and the atomic absorption coefficient B, being approximately equal to nIB.

Now n for a resonance line, such as λ2537, depends directly upon the abundance of the isotope and I depends upon the same, if an unreversed arc is the exciting source. In the case of the even isotopes, which have only a single component in each line, for very weak absorption the relative absorption for λ2537 by any two of these would be in the ratio of the squares of their abundances. If now these isotopes absorb λ4358 from the same source and this absorption is also weak, since n is now proportional to N^2 we would have the relative number of atoms optically excited to the 7^3S_1 level in these two even isotopes proportional to N^3. If, however, the first step in the excitation, i.e., the absorption of λ2537 is very large, the relative amount of excitation of these isotopes would be proportional to the relative values of I from the two isotopes, so that the relative values of the final excitation to the 7^3S_1 level and the subsequent emission of the triplet would be proportional to N^2, as in the case of a single step. This illustration assumes that the absorption lines of the isotopes in question do not overlap, that is, one isotope can not absorb the radiation of the other.

TABLE I. *Absorption of* λ2537.

ISOTOPE 1	N 2	COMPONENT 3	I 4	UPPER LEVEL 5
201	13.67	a	6.84	5/2
		b	4.56	3/2
		c	2.28	1/2
199	16.45	A	5.48	1/2
		B	10.96	3/2
196	.10	X_{196}	.10	1
198	9.89	X_{198}	9.89	1
200	23.77	X_{200}	23.77	1
202	29.27	X_{202}	29.27	1
204	6.85	X_{204}	6.85	1

TABLE II. *Absorption of* λ4358.

COMPONENT 1	LOWER LEVEL (f_1) 2	I 3	$\frac{I}{N}$ 4	$\frac{A}{A_e}$ 5	$k'B$ 6	n IN LOWER LEVEL 7	I ABSORBED 8	UPPER LEVEL (f_2) 9	ι IN UPPER LEVEL 10
a	3/2	2.05	.15	.30	.45	4.56	4.21	5/2	27.14
b	5/2	4.79	.35	.70	.70	6.84	22.93	5/2	
c	1/2	1.90	.14	.42	.83	2.28	3.61	3/2	8.19
d	3/2	.61	.04	.13	.13	4.56	.37	3/2	
e	5/2	2.05	.15	.45	.30	6.84	4.21	3/2	
f	1/2	.38	.03	.17	.17	2.28	.14	1/2	3.78
g	3/2	1.90	.14	.84	.42	4.56	3.64	1/2	
A	3/2	1.83	.11	.33	.17	10.96	3.35	1/2	16.73
B	1/2	3.66	.22	.67	.67	5.48	13.38	1/2	
C	3/2	9.15	.56	.84	.84	10.96	83.70	3/2	87.04
D	1/2	1.83	.11	.17	.33	5.48	3.34	3/2	
X_{196}	1	.10	1	1	1	.10	.01	1	.01
X_{198}	1	9.89	1	1	1	9.89	97.81	1	97.81
X_{200}	1	23.77	1	1	1	23.77	565.01	1	565.01
X_{202}	1	29.27	1	1	1	29.27	856.73	1	856.73
X_{204}	1	6.85	1	1	1	6.85	46.92	1	46.92

In the case of two odd isotopes the calculation is, however, more complex since each of these lines is made up of several components. The calculations for one of these isotopes, 199, will be considered in detail below. Those for the other are omitted for lack of space.

In making the following calculations it is assumed that all the components of λ2537 are completely absorbed, an assumption which corresponds well with the experimental conditions of these tests. The radiation from the exciting source used is further taken as unreversed, that is, as having the energy distribution given by Schüler and Keyston. The details of the computation are shown in Table I for the absorption of λ2537. Column 1 shows the various isotopes of mercury and column 2 the abundance of each isotope as given by Aston: column 3 lists the components of λ2537, column 4 the intensity of each component according to Schüler and Keyston and column 5 the quantum number f of the upper hyperfine energy levels of each component. Since λ2537 is taken as completely absorbed the concentration n of atoms excited by absorption to the 6^3P_1 state in all the isotopes will have the same relative values as the corresponding emission lines in the source, that is $n=kN$, where k is a constant of proportionality. Table II shows the details of the computation for the subsequent absorption of λ4358. It is assumed that the components of λ4358 are only slightly absorbed, the absorption and therefore the contribution of each component to the number of excited atoms in the upper level being given by BIn. Column 1 shows the components of λ4358, column 2 the hyperfine quantum numbers f_1 for the lower levels, column 9 gives the corresponding values f_2 for the upper levels, column 3 the intensities of the lines according to Schüler and Keyston and column 4 I/N. In column 5 are the values of the Einstein atomic emission coefficients, A divided by a constant A_e, the value of the coefficient for the components from the even isotopes. These values of A were obtained from the relationship $A=(I/\Sigma I)A_e$, where the summation is over all the components originating at the upper level in question. In column 6 are the atomic absorption coefficients B, multiplied by a convenient constant k' obtained by the relationship $B=\text{const.}\ (p_2/p_1)A$, where $p_2=2f_2+1$ and $p_1=2f_1+1$. Column 7 gives the relative concentrations n of electrons in the lower level for each component of λ4358, resulting from the absorption of λ2537. For example, the absorption of component C of λ4358 in isotope 199 is $nIB=0.84\times 9.15\times 10.96$, since it arises from the 3/2 hyperfine level of the 6^3P_1 state. Again, the absorption of component D of λ4358 is given by $0.33\times 1.83\times 5.48$ since it arises from the 1/2 level of the 6^3P_1 state. These products are recorded in column 8. Both of these absorption processes result in excited atoms in the 3/2 level of the 7^3S_1 state so that the sum, 87.04, of the quantities absorbed gives a measure of the optical excitation of this level. Similarly, absorption of A and B results in the excitation of the 1/2 level of the 7^3S_1 state of isotope 199, the calculated value of which is 16.73. (See column 10.)

The optical excitation of the 5/2, 3/2 and 1/2 levels of the 7^3S_1 state of isotope 201 was computed in a similar manner, the process being more complex since for this isotope there are three hyperfine lower levels (6^3P_1) and three hyperfine upper levels (7^3S_1) for λ4358. The calculations for the even isotopes follow the same scheme except that all the levels are single and, therefore, each level is filled by absorption of only one component. The excitation of each upper level (column 9) for all the isotopes is given in column 10.

From the computed concentrations of atoms excited to the various levels of the 7^3S_1 state of the various isotopes and the previously calculated values of the emission coefficients (A), the relative intensities of the hyperfine structure components for the optical excitation of each of the lines of the triplet are found. These calculated values, expressed as percentages of the total radiation from all the isotopes for each line of the triplet, are given in Table III column 7 for λ5461, in Table IV column 7 for λ4358, and in Table V column 7 for λ4047.

The above calculations were made on the assumption that each component was absorbed separately, i.e., that the wavelengths of no two components were so close that there was appreciable overlapping of their line structure and a consequent mutual absorption. Since, however, there are extremely small differences between the recorded wavelengths of several components, the effect of this overlapping was considered. An outstanding example of such groups of components is a, A and X_{204} in λ2537; in λ4358 all the components emitted by the even isotopes form such a group. The above calculations were repeated assuming that such components overlapped completely, that is, that the wavelengths were exactly the same. The results gave the same general type of distribution of the intensities but did not agree as well with the experimental results as the simpler calculation, indicating that the effect of mutual absorption due to overlapping was small.

Calculations were also made neglecting overlapping and assuming that there was small absorption of λ2537 followed by a small absorption of λ4358. As pointed out above, the absorption of λ2537 would then be similar to that of λ4358 and there would be a still greater difference between the intensities of the components from the more abundant and less abundant isotopes. The results given by these calculations

TABLE III. *Hyperfine structure of λ5461.*

				Unreversed Arc		*Optical Excitation*	
Isotope 1	Upper level 2	Component 3	$d\nu$ (cm^{-1}) 4	Calc. 5	Expt. 6	Calc. 7	Expt. 8
201	5/2	*a*	−0.728	0.14	*	0.03	*
		b	−.431	1.23	1.3	.29	0.32
		c	0	5.44	5.4†	1.27	1.27†
	3/2	*d*	−.247	.23	.23‡	.024	.026‡
		e	0	1.46	1.5†	.16	.16†
		f	+.232	2.87	3.1	.30	.37
	1/2	*g*	+.158	1.14	1.2	.11	.12
		h	+.342	1.14	1.2	.11	.11
199	1/2	*A*	−.278	5.50	5.4‡	.98	1.04‡
	3/2	*B*	0	9.88	9.9†	4.60	4.60†
		C	+.790	1.10	1.1	.51	.51
196 198 200 202 204		*Central* (*X*'s)	0	69.88	69.75†	91.62	91.64†

* Component *a* was not observed because of its low intensity and unfavorable overlapping of orders.

† A procedure similar to that described in the previous note was followed for components *B*, *c*, *e* and the *X*'s, which are completely merged.

‡ *A* and *d* are not well resolved and *d* is very small. They were treated as one in measurement and in the table given the relative proportions determined by the calculated values.

TABLE IV. *Hyperfine structure of λ4358.*

				Unreversed Arc		*Optical Excitation*	
Isotope 1	Upper level 2	Component 3	$d\nu$ (cm^{-1}) 4	Calc. 5	Expt. 6	Calc. 7	Expt. 8
201	5/2	*a*	−0.555	2.05	2.4	0.48	0.47
		b	−.099	4.79	4.9	1.10	1.04
	3/2	*c*	−.164	1.90	2.0	.20	.25
		d	+.106	.61	.62*	.064	.064*
		e	+.556	2.05	2.0	.22	.25
	1/2	*f*	+.245	.32	.32	.037	.036
		g	+.505	1.90	2.0	.18	.25
199	1/2	*A*	−.960	1.83	1.8†	.32	.32†
		B	−.240	3.66	4.0	.65	.53
	3/2	*C*	+.106	9.15	9.3*	4.25	3.91*
		D	+.836	1.83	1.8†	.85	.85†
196 198 200 202 204		*Central* (*X*'s)	0	69.88	68.9†	91.62	92.04†

* *C* and *d* are not well resolved. A procedure similar to that described in the previous note was followed in obtaining their separate values.

† *A* and *D* were merged with the central components of adjacent orders and, therefore, could not be isolated. *A* and *D* together with the central components constitute 93.18 percent of all the components and in the table this total is divided among them according to the ratios determined by the theoretical values.

TABLE V. *Hyperfine structure of λ4047.*

				Unreversed Arc		*Optical Excitation*	
Isotope 1	Upper level 2	Component 3	$d\nu$ (cm^{-1}) 4	Calc. 5	Expt. 6	Calc. 7	Expt. 8
201	5/2	*a*	−0.394	6.84	6.3	1.59	1.69
	3/2	*b*	+.270	4.56	4.2	.48	.54
	1/2	*c*	+.668	2.28	2.1	.22	.27
199	1/2	*A*	−.743	5.48	5.0	.98	1.10
	3/2	*B*	+.330	10.96	10.0	5.11	5.18
196 198 200 202 204		*Central* (*X*'s)	0	69.88	72.6	91.62	91.22

are very far from agreement with the experimental results and are interesting only because they justify the previously assumed conditions of absorption.

EXPERIMENTAL

The resonance cell used was a straight quartz tube terminating in a curved horn. The straight portion was 20 cm long and 2.5 cm in diameter, the end toward the spectrograph being closed by a clear, polished, plane quartz window. The cell was connected to a mercury diffusion pump operating continuously during exposures. A small quantity of mercury was always present in the connecting tube which was kept at approximately 25°C giving a vapor pressure in the cell of 0.00184 mm of mercury. The exciting source was a quartz glow tube about 12 mm in diameter and 50 cm long. The electrodes of this tube were large hollow cylinders of aluminum. It was operated with a current of 100 milliamperes from a 3000 volt transformer. At this current the tube did not become very hot even after prolonged running; consequently the vapor pressure in the glow tube was low and the emitted line λ2537 was narrow and easily absorbed. This type of glow tube emits relatively little of the other lines, as for example λ4358. To increase the efficiency it was made in the form of a spiral of four turns, covering about 5.5 cm of the middle of the straight part of the resonance cell which was placed inside it with a clearance of 2 mm. To increase the amount of light available for excitation a thin cylindrical reflector was wrapped around the quartz spiral. Since ozone absorbs λ2537, strongly decreasing optical excitation, nitrogen was circulated continuously in the space between the resonance cell and the spiral during exposures. The results of observations on this tube given in columns 5 of Tables III, IV and V, showed that the hyperfine structure of the lines of the triplet emitted from this tube had very nearly the relative intensity distribution predicted by Schüler and Keyston for the intensities of lines excited by electron impact, justifying this assumption made in the above calculations.

Since the amount of λ4358 furnished by the glow tube was comparatively small, when measuring the hyperfine structure of λ5461 the radiation from the glow tube was supplemented by that from a pair of U-shaped, 5-ampere glass arcs which were placed around the quartz spiral after removing the reflector. To keep the arcs cool and prevent self-absorption, these arcs were made with large mercury pool electrodes and cooled by a draft of air from an electric fan. Measurements showed that these glass arcs provided less than half the λ4358 available for optical excitation. The energy distribution in the glass arcs varied slightly from the Schüler and Keyston distribution, so that some slight divergences from the calculated values of the relative intensities in the optical excitation of λ5461 may be attributed to this fact. To avoid complications these arcs were not used when measuring the optical excitation of λ4358 and λ4047.

The measurement of the hyperfine structure of the lines was made by means of a glass Lummer plate 4.64 mm thick and 12.0 cm long mounted between the collimating lens and the prism of a glass spectrograph. In order to avoid blurring the pattern the temperature of the Lummer plate and spectrograph was kept constant to better than 0.01°C during the exposures by lagging the spectrograph with layers of felt and by enclosing the entire spectrograph except for the slit in an asbestos walled enclosure in which the temperature was controlled thermostatically to 0.01°C. During the summer cold water from a tank kept at a constant temperature by an electric refrigerator was pumped through the coils inside the enclosure. During cooler weather the temperature of the room was thermostatically controlled at a temperature somewhat lower than that of the enclosure. In order to prevent vibration, all fan and pump motors connected with the temperature control system were run as slowly as possible and the supports for the moving apparatus, the spectrograph and the table upon which it rested were insulated with sponge rubber.

The lengths of exposure were from 5 minutes, when studying the structure from the glow tube, to 55 hours when studying the optical excitation. Eastman type G IV plates were used for λ5461 and Eastman 33 plates for λ4358 and λ4047. A fine grain developer was employed. Calibration marks were put on each photographic plate by exposing it for a time equal to that used for the Lummer plate pattern in a second spectrograph on the slit of which was focused the image of a calibrated platinum step wedge. The wedge was illuminated with light from a glass mercury arc, the intensity of this source being varied as necessary by placing colored celluloid filters before the arc. The density measurements were made from records taken by a Moll microphotometer. By means of the records and the calibration data, intensity-wavelength curves of the hyperfine structure patterns were constructed.

In each order on each plate used for calculation the shape of a typical component was determined from that of a strong well-resolved component. When it was possible, this component was selected from the exposure under consideration. If the exposure under examination was too weak or too strong to enable the shape of some well-resolved component to be determined accurately, a second exposure of suitable density was made on the same plate with the same exposure time to provide a suitable shape curve. Since the position of each component was accurately known, it was possible to build up a synthetic intensity distribution curve, adjusting the magnitudes of the curves for each separate component until the best fit with the experimental intensity curve was obtained. The area under each component curve, measured with a planimeter, was taken as proportional to the intensity of that component.

An estimate of the precision of such determinations was made by altering the intensity curve for any one component by a specific amount and readjusting the other components to obtain the best fit for the experimental curve. The estimated precision of the determination is of the order of 10 percent for strong moderately well-resolved components and 20 percent for weaker less well-resolved components. Since an exposure which gave the weak components a density suitable for measurement produced overexposure of the strong ones, it was found best to determine the relative intensities of the very strong and very weak ones by first determining their intensities relative to that of a component of intermediate intensity by using several exposures. For example, component A in λ5461 had a convenient intermediate intensity and was used as a reference component for that line. In the measurements of λ5461 the comparison of strong and weak components was expedited by use of a silvered filter of known transmission. A thin layer of silver was chemically deposited on a cover glass, one-half of which was then wiped clear leaving a sharp edge. This filter was placed against the slit face with the edge of the silvering in the center of the slit and parallel to its edges. In this manner two Lummer plate spectra of different densities and the same exposure time were taken together. Knowing the relative amounts of light transmitted by the clear and by the silvered glass, comparisons could be made between the weak components in the dense spectrum and the strong components in the less dense spectrum, with the same calibration marks.

In these measurements there was no appreciable error due to the scattered light. To decrease the amount of light reflected from the sides of the absorption cell, the entire cell was blackened except for the space covered by the exciting quartz spiral and a small portion of the window at the end where the light passed out to the spectrograph, the slit of which was about 5 cm from the window. To test for scattered light, a soft glass tube which eliminated the optical excitation by cutting out λ2537, was slipped between the resonance cell and the exciting quartz spiral. When this tube was in position, exposures made with the glow tube running showed no detectable blackening of the photographic plate for exposure times equal to those used for photographing the optical excitation.

RESULTS

The results of the calculations and the corresponding measurements are summarized in Tables III, IV and V for the lines λ5461, λ4358 and λ4047. In each of these tables, in column 3 are listed the components due to the isotopes listed in column 1. Column 2 gives the f number of the corresponding hyperfine 7^3S_1 level, the upper level of the transitions involved; column 4, the wave number separation of each component from the main component; column 5, the calculated distribution of intensity among the components for an unreversed arc according to the

Schüler and Keyston scheme; and column 6, the corresponding experimentally determined values from the quartz glow tube used in these experiments. Column 7 gives the calculated values for the optical excitation under the conditions assumed above and column 8 the values experimentally determined. It should be noted that for each line the intensities are expressed as percentages of the total radiation of this line including all the components.

A comparison of columns 5 and 6 shows that the energy distribution in the exciting source is sufficiently close to that given by Schüler and Keyston to justify the use of their intensity distribution in the computation of the intensities in the optical excitation. All the values check within 10 percent except for component *a* in λ4358 which is 2.05 as given by Schüler and Keyston and 2.4 as measured here.

That the optical excitation observed agrees well with that calculated is seen from a comparison of columns 7 and 8. The differences except in the case of *f* in λ5461; *c*, *e*, *g* and *B* in λ4358; and *b* and *c* in λ4047 are within 10 percent. In λ4358 these components are so situated in the pattern and of such a size as to make their measurement somewhat less precise than the measurement of the other components. As for the components *b* and *c* of λ4047, it may be noted that the measured values of the components due to isotope 201 are a little high in all three lines. These components, however, are the weakest and are less easily measured, partly due to the difficulty of estimating the continuous background in the Lummer plate spectrum.

The results for λ5461 should be somewhat more reliable than those for either λ4358 or λ4047. A larger number of measurements on more exposures were made for this line than for the other two and therefore a somewhat greater precision was obtained. The measurement of λ4358 was also complicated by the overlapping of orders and the fact that many of the components of this line are of approximately the same intensity and unfavorably grouped in the structure.

It should be noted that the components of the even isotopes of λ5461 are combined in the actual measurement with component *B* from isotope 199 and components *c* and *e* from 201, as these are practically identical in wavelength and, therefore, not separable. The values listed in the table were obtained from the total measured intensity of the central component which was divided in the proportions given by the calculations.

The experimental results verify the interesting conclusion derived from the calculations that the central component is remarkably enhanced as compared with the other components, due to the fact that the sum of the concentrations of the even isotopes which account for the major part of the central component is so much larger than the concentration of the odd isotopes which account for the other components; this increase is from approximately 70 percent of the total radiation in the case of the unreversed arc to approximately 91.5 percent in the case of optical excitation. For short exposures only the central component appears in the optical excitation which probably accounts for the failure of Mrozowski and other earlier experimenters to observe the weaker lines. The intensities found by Collins for those of the weaker lines which he observed are not checked in this work. The enhancement of the central component in the optical excitation was observed by Pool and Simmons who found in λ4047 the ratios of the intensities of components *A*, *a* and $B+b$ to that of the central component in the optical excitation when divided by the corresponding ratios for the arc to be 2.9, 2.8 and 2.9, respectively; for the same components, this research gives 5.7, 4.6 and 3.1, respectively. These differences might arise from slight differences in the intensities in the exciting light.

The close agreement between the calculated and the measured values of the intensities of the components of these lines in the optical excitation and a comparison of these with measurements on the radiation from the unreversed arc gives an independent check on the correctness of the Schüler and Keyston scheme. Since the relative decrease in the intensities in the former type of spectra with respect to the latter depends both upon the isotope concentration and upon the multiplicities of the levels in each isotope, a comparison of the two types of spectra is in most cases sufficient to determine definitely which components belong to each of the isotopes and to which hyperfine structure level each should be attributed.