The L Absorption Discontinuities of Bismuth

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The problem of obtaining a thin enough absorber was solved by using the bismuth in solution. Bismuth nitrate dissolved in dilute nitric acid was held in one cell, while in another like cell was put only the dilute acid. The difference in the absorption of these two cells was then due entirely to the bismuth atoms, since the absorption of the $(NO_3)_3 \cdot 5H_2O$ group added with each Bi atom almost exactly balanced that of the water and acid displaced. The cells had been balanced by trial and error, until their absorption was the same, both when they were filled with water and when they were empty. The solution was analyzed to find the amount of bismuth, and the thickness of the cell was measured with a microscope, so that μ/ρ could be found. This was measured at twenty wave-lengths between 0.56 and 1.54A. By plotting these values, the equations of the four branches of the curve were obtained.

$$(\mu/\rho)(L_{\mathrm{I}}) = 2.438\lambda^{2.5}; \quad (\mu/\rho)(L_{\mathrm{II}}) = 2.548\lambda^{4}; \quad (\mu/\rho)(L_{\mathrm{III}}) = 2.51\lambda^{3}; \quad (\mu/\rho)(M) = 1.860\lambda^{2.715}.$$

The magnitudes of the discontinuities, r, where r(I,II) is the ratio of μ/ρ on the short wave-length side of L_{I} to that on the long wave-length side, are r(I,II) 1.161; r(II,III) 1.572; r(III,M) 2.393) r(I,M) 4.37.

APPARATUS

FOR these measurements an ordinary glass x-ray tube and a single crystal spectrometer were used. The wave-lengths that were studied were in all cases characteristic lines of the elements, and therefore the tube was constructed so that targets could easily be changed. The intensities of the beam were measured with an ionization chamber and a Compton electrometer. The slits were fixed at 0.2 mm width and were soldered to the ends of a tube 30 cm long so that after cellophane had been waxed over the ends the space between them could be evacuated and thus cut down the absorption of the beam.

Because the absorber was in solution, two cells of a certain thickness had to be built to hold it. To do this two plates of steel about 4 cm square were each ground to a thickness of 2.82 mm and a hole was cut in each that was about 1.5 cm square. Then sheets of mica were clamped to the front and back of each and holes were drilled so that the solution could be introduced into the enclosed space from the top. In order that there would be the same thickness of mica, in the windows of each cell, a piece of mica one inch by two inches was split to the desired thickness and then cut into two one-inch squares. One piece was then put on one cell and the other on the other cell. This process was then repeated for the remaining window of each cell. The cells were made water tight and the metal was protected from being attacked by the acid, by a thick layer of stopcock grease. The supports for these cells were placed between the second slit and the crystal, and in them were two pins that fitted in two reamed holes in the cells so that they were always replaced in exactly the same position.

METHOD

Following the method of Stephenson,[1] the absorber was held in solution. For success with this method there must be a large difference in the absorption of the dissolved substance and of the solvent. The reason for the two cells was that the intensity through the Bi solution could quickly be compared to the intensity coming through the acid alone. Therefore one cell was filled with $Bi(NO_3)_3 \cdot 5H_2O$ in a dilute nitric acid solution, and the other was filled with the same strength of acid solution. The reading through the former was the I, through the latter the I_0. Since the cells were quite easily removed, they were changed at the end of every reading which made the variations due to slight changes in the power output of the tube, average out very quickly.

Three methods were used to determine the thickness of the cell that contained the bismuth. In the first place it was built to be 2.82 mm thick. Secondly it was obtained by measuring the cell's absorption when filled with water and by using the known value for the absorption coefficient of

[1] R. J. Stephenson, Phys. Rev. **43**, 527 (1933).

water. This gave a value of 2.77 mm. The most accurate value, however, and the one on which the values of μ/ρ are based, were obtained with a very sharply focussed microscope that would measure vertical distances. It was focussed first on one sheet of mica in the cell and then on the other, this gave an average thickness of 2.78 mm. A solution of seventy-five grams of bismuth nitrate, containing an unknown amount of water of crystallization, in 500 cc of dilute nitric acid was made up and was analyzed through the courtesy of the chemistry department. It was found in this way that the solution contained 0.06238 gram of the element bismuth per cubic centimeter. For actual use this was diluted a certain amount at each wave-length so that the bismuth would absorb approximately half of the power going through the solution. Then the value of the mass absorption coefficient could be calculated from the equation $\mu/\rho=(1/\rho x)\log \times(I_0/I)$, where x is the average thickness of the cell and ρ is the number of grams of bismuth per cc.

One of the possible sources of error in this system was that the cells might not be of the same thickness. Before any readings were taken, therefore, they were checked and adjusted until the x-ray absorption of water in each of them was the same. There remained, however, the chance that they might change with time, so at the time of each set of readings at every wave-length they were rechecked with water in both cells, and the correction, if any, was applied to the readings taken at the time. These were found to be less than one percent at all but the very longest wave-lengths.

A second correcting factor considered was the absorption of the other atoms in the bismuth nitrate molecule, and the decreased absorbing power of the bismuth solution compared to the acid alone, due to the displacement of some of the water and some of the acid molecules by the bismuth molecules. These effects were calculated to be about one percent of the total absorption, but were in opposite directions, so that the net result was that the true absorption of the bismuth atoms was less than a quarter of one percent greater than that measured by this method. This was considered as below the accuracy of measurement, and therefore negligible.

Results

The average values of μ/ρ obtained are given in Table I. In Table II values of μ/ρ for bismuth as calculated with Jönsson's formula, and other values interpolated from Allen's data on lead, are compared with those obtained in this experiment.

In Fig. 1, log μ/ρ is plotted against log λ. The points enclosed in the brackets were not considered when plotting the curve, for they seemed to be unreliable. These points were taken at the Au $L\gamma_1$ line, which fell just 3 X.U. from the L_{III} limit. The trouble seemed to be that since the angular width of the slits was 10^{-4} radian, the wave-length range reflected from one position of the crystal was 6.2 X.U., and consequently some of the base line radiation was of high enough frequency to fall on the other side of the limit. This was particularly bad at this wave-length because the line was only about one-third the intensity of the background radiation, so that variations in it were very disturbing.

However, two other peculiar points were found that are not shown on this diagram. From the third order of the crystal the wave-length range reflected was 2 X.U., and consequently the Zr $K\alpha_1$ and $K\alpha_2$ lines could be resolved since they were 7 X.U. apart. It happened that the L_{II} limit fell between these two lines, and so the attempt was made to measure μ/ρ first on one side of the limit and then on the other, so as to get the magnitude of the discontinuity almost

TABLE I. *Average values of* μ/ρ.

μ/ρ	63.9	117.8	128.6	135.5	121.9	132.7	135.9	89.14	104.9	119.1
λ	0.558	0.708	0.745	0.753	0.764	0.781	0.784	0.792	0.838	0.873
μ/ρ	145.7	47.73	59.53	79.26	100.0	124.2	150.1	177.5	225.1	
λ	0.921	0.925	0.954	1.013	1.118	1.205	1.274	1.389	1.537	

TABLE II. *Comparison of values of μ/ρ.*

Source/λ	0.558	0.755	1.118	1.537
Jönsson	75	170	108	236
Allen	75	170	108	238
Author	64	136.5	100	225.1

Jönsson, Diss. Uppsala (1928).
S. J. M. Allen, Unpublished data prepared for Smithsonian Tables.

independently of the slopes of the curves on each side. The values obtained did not give a very good value of the size of the jump, and both points were much too low compared to the results in the first order of the crystal that are shown on the graph. Here again the trouble probably arose from the fact that some of the background radiation included with the line lay on one side of the limit and some lay on the other, so that it could not be corrected for.

Except for these two, all of the points obtained fitted reasonably well the four straight lines drawn in Fig. 1. Since all of these are straight lines they can be described by the equation

$$\mu/\rho = C\lambda^n,$$

where C and n vary from branch to branch of the curve. This gives

$$(\mu/\rho)L_{\mathrm{I}} = 2.438\lambda^{2.5}, \quad (\mu/\rho)L_{\mathrm{II}} = 2.548\lambda^{4},$$

$$(\mu/\rho)L_{\mathrm{III}} = 2.251\lambda^{3}, \quad (\mu/\rho)M = 1.860\lambda^{2.715},$$

as the equations of the four branches.

Since the absorption due to scattering is negligibly small at such long wave-lengths and in an absorber of such high atomic number as was used in this experiment, the discontinuity of the fluorescence coefficient can be taken as the ratio of μ/ρ on the short wave-length side of the limit to μ/ρ on the long side, which we shall call r. The log r for each jump is just the length of each discontinuity in Fig. 1, which gives

$$\log r(\mathrm{I,II}) = 0.065; \quad \log r(\mathrm{II,III}) = 0.1965;$$

$$\log r(\mathrm{III},M) = 0.379;$$

$$\log r(\mathrm{I},M) = \log r(\mathrm{I,II}) + \log r(\mathrm{II,III}) + \log r(\mathrm{III},M) = 0.6405;$$

$$\log r(\mathrm{II},M) = \log r(\mathrm{II,III}) + \log r(\mathrm{III},M) = 0.5755.$$

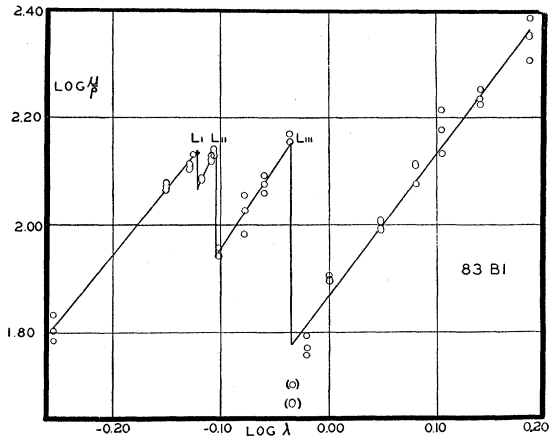

FIG. 1. Plot of log (μ/ρ) as a function of log λ.

In Table III are given the values of r obtained, together with those of several other observers on some of the neighboring elements. The ratio $E(L_{\mathrm{I}})/E(M_{\mathrm{I}})$ gives a value for the total jump $r(I,M)$ of 4.15 as compared with 4.37 obtained in this experiment.

TABLE III. *Values of the ratio r between the value of μ/ρ on the short wave-length side of the limit to that on the long wave-length side.*

Element	r(I,II)	r(II,III)	r(III,M)	r(I,M)	r(II,M)	Author
78 Pt	1.247	1.371	2.477	4.23	3.41	Backhurst
	1.13	1.58	2.68	4.79	4.23	Wolf
79 Au	1.2	1.4	2.5	4.2	3.5	Dauvillier
	1.26	1.36	2.52	4.25	3.37	Backhurst
	1.16	1.36	2.47	3.78	3.28	Küstner
	1.10	1.62	2.70	4.81	4.36	Wolf
	1.164	1.393	2.480	4.02	3.46	Uber and Patten
80 Hg	1.18	1.39	2.45	4.02	3.40	Uber
81 Tl	1.15	1.33	2.36	3.64	3.15	Küstner
82 Pb	1.12	1.40	2.38	3.70	3.21	Küstner
83 Bi	1.161	1.572	2.393	4.37	3.76	The author

Dauvillier, Comptes Rendus **178**, 719 (1924).
Backhurst, Phil. Mag. **7**, 353 (1929).
Küstner, Phys. Zeits. **33**, 46 (1932).
Uber and Patten, Phys. Rev. **42**, 229 (1932).
Uber, Phys. Rev. **38**, 217 (1931).
Wolf, Ann. d. Physik (5) **16**, 973 (1933).

The relative amount of absorbing done by the three L levels at any wave-length can be found from Fig. 1 by projecting the other three branches of the curve on to that wave-length. This will divide the vertical line into three parts. The ratios of the anti-logarithms of these three parts is equal to the relative absorption of the three

levels. This ratio was found to be 19 : 40.2 : 43.1 at the L_I limit. This does not agree with the value 19 : 32 : 49 given by Patten[2] for the five elements Au(79) to Bi(83), and neither does it compare well with the ratio interpreted from Wolf's curve for gold; 19 : 70 : 72.

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[2] C. G. Patten, Phys. Rev. **45**, 131 (1934).

The Nuclear Spin of Deuterium

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By the methods of photographic photometry, the alternating intensities in emission of the $\Delta v=0$ sequence of the Fulcher bands of deuterium have been investigated in order to determine the nuclear spin. The alternation of intensities was determined for the P, Q and R branches of each of the 5 bands studied. The average value of g_s/g_a obtained from 4 plates is 1.97 ± 0.03. This value agrees best with the theoretical ratio of 2 and a consequent nuclear spin of 1. Since the even rotational levels are more intense than the odd levels, the nucleus obeys Bose-Einstein statistics.

THE nuclear spin of rare isotopes such as H^2, N^{15}, O^{17}, O^{18} is of the utmost importance in any theory of the nucleus but because of the low abundance of such nuclear species, it will probably be rather difficult to obtain this information. This is not true, however, for deuterium since it is possible to separate it almost completely from the more abundant protium. Measurements of the alternation of intensities in the molecular spectrum of deuterium seemed to offer the simplest approach to the problem of the determination of its nuclear spin. We[1] have therefore made such measurements on the P, Q and R branches of 5 bands in the $\Delta v=0$ sequence of the Fulcher bands of deuterium as analyzed by Dieke and Blue.[2]

The nuclear spin of protium is well established as $\frac{1}{2}$. Relative intensity measurements have been made on the protium molecular spectrum by Kapuscinski and Eymers[3] and on the acetylene spectrum by Childs and Mecke.[4] Specific heat measurements at low temperature also give the nuclear spin.[5]

These methods are all applicable to deuterium and in addition we may mention the magnetic deflection method of Breit and Rabi[6] and the study of scattering as proposed by Sexl.[7] Hyperfine structure cannot be used.

Since it is known[8] that the lines in the molecular spectrum of deuterium alternate in intensity, it follows at once that the spin cannot be zero. By analogy with N^{14}, deuterium would probably have a spin of 1, and if its nucleus consists of one proton and one neutron[9] this would be consistent with a spin of $\frac{1}{2}$ for each. This result is also indicated by the conservation of spin momentum in nuclear disintegrations involving deutons[10] and by a study of the ortho-para deuterium conversion.[11] From the latter experiment, it is also concluded that the deuton obeys Bose-Einstein statistics.

[1] Murphy and Johnston, Phys. Rev. **45**, 550 (1934).
[2] Dieke and Blue, Nature **133**, 611 (1934).
[3] Kapuscinski and Eymers, Proc. Roy. Soc. **A122**, 58 (1929).
[4] Childs and Mecke, Zeits. f. Physik **64**, 162 (1930).
[5] Dennison, Proc. Roy. Soc. **A115**, 483 (1927).
[6] Breit and Rabi, Phys. Rev. **38**, 2082 (1931).
[7] Sexl, Naturwiss. **22**, 205 (1934).
[8] Lewis and Ashley, Phys. Rev. **43**, 837 (1933).
[9] Heisenberg, Zeits. f. Physik **77**, 1 (1932).
[10] Raether, Naturwiss. **22**, 151 (1934).
[11] Farkas, Farkas and Harteck, Proc. Roy. Soc. **A144**, 481 (1934).