THE L-SERIES IN THE TUNGSTEN X-RAY SPECTRUM.

By Oswald B. Overn.

Synopsis.

Tungsten X-ray Spectrum, L-series; Wave-lengths.—Dershem's results were verified, for the most part within 1/10 per cent., except in the case of 1.777×10^{-8} cm. which was found to have a wave-length of 1.202×10^{-8} cm. Six new lines were discovered, four of which may belong to tungsten: 1.236, 1.213, 1.079 and 0.793×10^{-8} cm. This last line appeared light in contrast to the dark bromine absorption band in which it was located; an explanation of this fact is suggested. Dershem's method was used with a very thin crystal and with very long exposures of the Coolidge tube. Four photographs are reproduced.

Tungsten X-ray Spectrum, L-series; Two Groups of Lines Suggested.—Sixteen lines fall into two groups, each line of one having a wave-length 1.151 times that of of the corresponding line of the other.

Molybdenum X-ray Spectrum, K Series.—Three faint lines were measured which may belong to this series, wave-length 0.711, 0.706 and 0.629×10^{-8} cm.

Bromine X-ray Absorption Band.—Evidence of discontinuity found.

Silver X-ray Absorption Band.—Evidence of discontinuity found.

Thickness of a Soluble Crystal.—Determined by a simple method.

In a recent paper[1] Dershem has given the results of photographs of the tungsten X-ray spectrum obtained by the use of a thin crystal of rock salt wherein he finds this spectrum to contain nineteen wave-lengths in the L-series which he claims to have measured to an accuracy of one tenth per cent. The large number of lines discovered for the first time by Dershem made it seem of importance to verify his work. With this in mind, the present experiments were undertaken with the additional object of finding more lines if possible.[2]

The apparatus was the same as that employed by Dershem. The distance of the plate from the axis of the crystal was kept in the neighborhood of 30 cm. Although slits of various widths were used, the best results were obtained with a slit of the same width as that used by Dershem, namely, .032 cm. Except for a few changes in minor details, the method of measuring the plates was also the same as that used by Dershem. Seed's X-ray plates were used.

The departures from Dershem's method were as follows:

1. The length of exposure was made from two to six times as great

[1] Physical Review, N.S., Vol. XI., June, 1918, p. 461.

[2] For accurate measurements of the L series of tungsten by various investigators the reader is referred to citations in Dershem's article, *loc. cit.*

as the longest exposure used by Dershem. The actual length of exposure ranged from 10 hours to 31 hours per degree of rotation of the crystal, the power input being kept the same as in Dershem's work.

2. The thickness of the paper envelope enclosing the plate was reduced to half.

3. A thinner crystal was used, the crystal used for most of the work having an average thickness of .0077 cm. This was measured as follows:

The thickness of the crystal and glass to which it was fastened with wax was measured with a micrometer caliper. The crystal was then dissolved in cold water and the thickness of the glass and sealing wax again measured. The difference was considered the thickness of the crystal.

No difficulty such as that described by Dershem due to the cracking of crystals when ground down to small thicknesses was experienced. Indeed one crystal was ground down to a thickness of less than .003 cm. and was used successfully in making a photograph of the spectrum. This photograph is shown in Fig. 4. The fogging of the plate seems to be materially diminished by the use of a very thin crystal.

Experimental Results.

The wave-lengths corresponding to the lines found on the various plates are given in Table I. Most of the plates were exposed over a limited portion of the spectrum and hence all the lines are not found on any one plate.

Where two plates are listed together they have been exposed on opposite sides of the apparatus and averaged. This, however, does not mean that every line appeared on both plates. The number of plates on which each line was observed is therefore placed in parentheses immediately at the left of each wave-length. The final averages are not weighted but each value is counted once for each plate on which that line appeared from which that value was calculated. Each plate, in turn, represents from five to ten separate observations.

Average values of wave-lengths greater than 1.0×10^{-8} cm. have an estimated accuracy of one tenth per cent. Others are estimated to be accurate within two tenths per cent. Dershem's values are placed in the last column for comparison.

These results not only verify Dershem's work but also show the existence of six more lines not observed by Dershem. If we add to this list the L-series line found by Siegbahn[1] which has a wave-length of about 1.66×10^{-8} cm., the total number of lines exclusive of the K-lines

[1] Deutsch. Phys. Gesell., Verh. 18, 5, pp. 150–153, 1916.

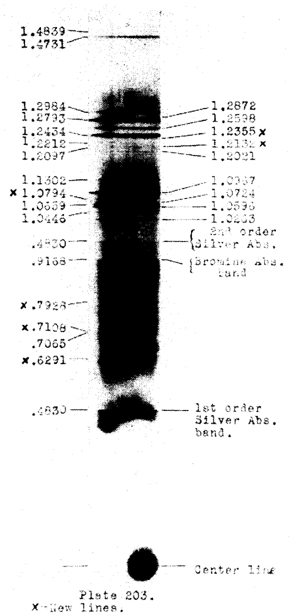

FIG. 1.

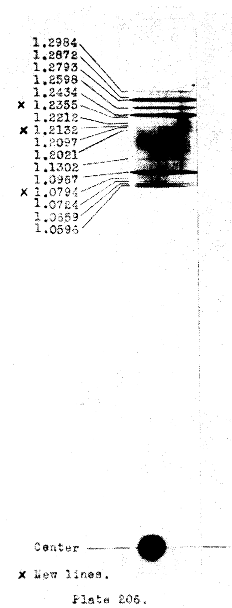

FIG. 2.

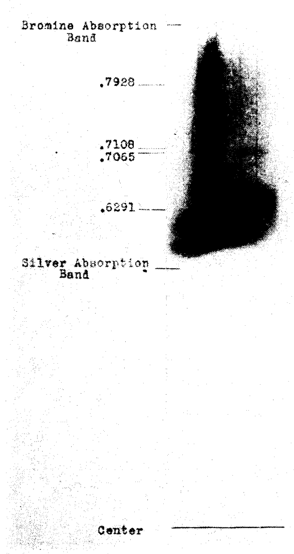

FIG. 3.

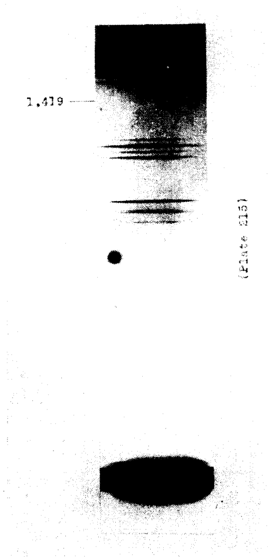

FIG. 4.

OSWALD B. OVERN.

is found to be 25. Whether or not these are all due to tungsten is however open to dispute as will be shown below.

Table I.

Wave-lengths in 10^{-8} *cms. Grating constant for rock salt* = 2.814×10^{-8} *cm.*

Plates 202, 203.	Plates 205, 206.	Plates 210, 213.	Plate 214.	Plate 216.	Average.	Dershem's Values.
(1) 1.484^0				1.483^8	1.483^9	1.482^8
(2) 1.473^1			1.473^5	1.472^6	1.473^1	1.472^2
(1) 1.299^2	(2) 1.298^5			1.296^5	1.298^4	1.297^7
(1) 1.287^6	(2) 1.287^0			1.287^1	1.287^2	1.286^8
(2) 1.279^4	(2) 1.280^8		1.278^3	1.277^0	1.279^3	1.278^4
(2) 1.260^3	(2) 1.260^6		1.259^0		1.259^8	1.258^6
(2) 1.242^5	(2) 1.245^4		1.241^2		1.243^4	1.241^6
(1) 1.235^3	(2) 1.234^8			1.238^0	1.235^5	
(1) 1.221^4	(2) 1.221^6			1.220^3	1.221^2	1.220^2
(1) 1.213^3	(2) 1.213^6			1.212^5	1.213^2	
(1) 1.209^7	(2) 1.210^3			1.208^4	1.209^7	1.209^8
(1) 1.202^0	(2) 1.202^4			1.201^8	1.202^1	1.177^3
(1) 1.130^1	(2) 1.130^4			1.129^9	1.130^2	1.129^2
(2) 1.096^6	(2) 1.097^8		1.094^9	1.096^2	1.096^7	1.095^3
(1) 1.079^2	(2) 1.079^5				1.079^4	
(1) 1.071^9	(2) 1.072^6				1.072^4	1.070^5
(2) 1.065^7	(2) 1.066^8		1.064^6	1.066^0	1.065^9	1.064^8
(2) 1.059^7	(2) 1.060^4		1.058^0	1.059^5	1.059^6	1.058^7
(1) 1.043^0	(1) 1.046^3				1.044^6	1.042^7
(2) 1.025^9	(2) 1.027^0		Plate 211	1.025^7	1.026^3	1.025^3
		(2) $.792^8$			$.792^8$	
(1) $.711^4$		(2) $.709^9$	$.709^9$	$.712^9$	$.710^8$	
(2) $.707^4$		(2) $.705^6$	$.705^5$	$.707^7$	$.706^5$	$.706^8$
		(2) $.629^1$			$.629^1$	
Br. (2) $.916^8$		(2) $.915^7$		$.919^2$	$.916^8$	$.915^9$
Ag. (3) $.483^4$		(1) $.481^9$		$.484^4$	$.483^0$	$.483^3$

The positions of all these lines in the spectrum are shown in Figs. 1, 2, and 3.

It will be noticed that the agreement between the present results and those of Dershem is within one tenth per cent. save in the cases of the wave-lengths, 1.243^4, 1.096^7, 1.202^1, 1.072^4 and 1.044^6. In the case of the first two, this difference can be explained by the fact that these lines, being very intense, are overexposed on my plates with a consequent widening of the image. Since the long wave-length edge of the line is measured, over-exposure will make the results a trifle too large. The discrepancy cannot be explained in this way for the other lines since they did not appear to be overexposed. The line 1.202^1 is listed by Dershem as 1.177^3. Since Dershem's value was found from observations on only one plate and mine from observations on four plates which agree well together (see Table I.) it is probable that Dershem's value for this wave-length is in error far beyond his limit of experimental error.

The wave-length 1.416^3 listed by Dershem has not been included in Table I. because it is the writer's opinion that this is the second order of the wave-length $.706^5$ found on most of the plates. This second order line has appeared on only one of these plates (see Fig. 4) sufficiently strong to admit of measurement. This plate was exposed in a small apparatus and the measurement is not considered as accurate as the others. The value found is 1.419. If this is a second order line its true wave-length is .709 which does not compare so badly with the wave-length $.706^5$. The line $.706^5$ forms quite a close doublet with the line $.710^8$ and it would therefore be reasonable to expect both lines to appear in the second order if one does. However, the intensity of the line $.710^8$ is so small in comparison to that of the line $.706^5$ that it is very difficult to bring it out even in the first order and hence it could not be expected to appear in the second order. A reference to Fig. 4 will show that the observed line is very faint.

The line of wave-length $.792^8$ appears light on the plates in contrast to the others which appear dark (see Fig. 3). There may be two explanations for this:

1. It may be the edge of an absorption band due to some substance through which the rays pass before reaching the plate. The rays pass through glass, air and paper. The edge of the absorption band would be at the short wave-length end of the spectrum of some element contained in these substances but the K-series wave-lengths of these substances are far too large for this region. The "J radiations" for carbon, oxygen and aluminium, evidence for which has been found by Barkla and White,[1] are far too short for this region. Therefore this assumption is not very probable.

2. It may be the convergence wave-length of the L-series or some other series in the tungsten spectrum. The end of a series would appear as a dark band with a lighter region at the short wave-length end. This sudden change from dark to light is probably what has been observed here. As seen from the photographs, this line is in the region of the bromine absorption band and the general blackening of the plate makes it hard to observe.

The line of wave-length 1.2132 makes a close doublet with the line 1.209^7 already found by Dershem (see Figs. 1 and 2). The close proximity of these two lines which are clearly resolved shows that the resolving power of the apparatus with the crystal used was at least 336 for that wave-length.

[1] Phil. Mag., 34, p. 270, Oct., 1917.

An examination of the bromine and silver absorption bands reveals several sudden but faint changes in the intensity of the blackening of the plate. This may indicate that this region is rich in spectrum lines. An attempt has been made to measure the wave-lengths of some of these but the work has not progressed far enough to make the results of any value.

Of the lines which stand out prominently in this region, the wave-lengths $.710^8$ and $.706^5$ are within two per cent. of the wave-lengths of the K-series alpha lines of molybdenum found by other observers.[1] The wave-length $.629^1$ is within two per cent. of the value given by Blake and Duane[2] for the edge of the absorption band of molybdenum and hence may correspond to the K-series beta line of molybdenum. It is therefore probable that these three faint lines are the K-series lines of molybdenum produced by the molybdenum used in the construction of the Coolidge tube.

Two Groups in L-series.

A scrutiny of the wave-lengths thus far discovered revealed the fact that they may be divided into two groups which are exactly similar. Since the α line of Moseley is the principal line of one group and the β line holds the same relative position in the other group, they have been called the "α group" and "β group" respectively. Their arrangement is shown in Table II.

Table II.

α Group.		β Group.	
λ.	λ/λ_α.	λ.	λ/λ_β.
1.4839	.993	1.2872	.994
1.4731 = λ_α	1.000	1.2793 = λ_β	1.000
1.2984	1.134	1.1302	1.132
1.2598	1.169	1.0967	1.167
1.2434	1.185	1.0794[3]	1.185
1.2355[3]	1.192	1.0724	1.193
		1.0659	1.200
1.2212	1.206	1.0596	1.207
1.2132[3]	1.214		
1.2097	1.217		
1.2021	1.225	1.0446	1.225
		1.0263	1.246

[1] Kaye, "X-Rays," second edition, Longmans, p. 226.
Also Malmer, Phil. Mag., 28, 1914, p. 787.

[2] Physical Review, X., Dec., 1917, p. 700.

[3] Lines found for the first time in this work.

Table II. is unique and gives evidence to show that there are at least two distinct series of lines in the L-series. The similarity of the two groups is shown by the second and fourth columns. There are two lines missing from each group to make it correspond to the other group which gives a possible suggestion as to where to look for new lines.

Any line in the β group may be found from the corresponding line of the α group by dividing its wave-length by 1.151.

A further discussion of these line groups will be left for a later paper.

In conclusion the writer wishes to thank the Staff of the Physics Department of the State University of Iowa for the encouragement and inspiration received from them and especially Professor G. W. Stewart who suggested the problem. He is also indebted to Dr. Elmer Dershem for his initiation into the technique of the experimental work.

Physical Laboratory,
The State University of Iowa,
July, 1918.

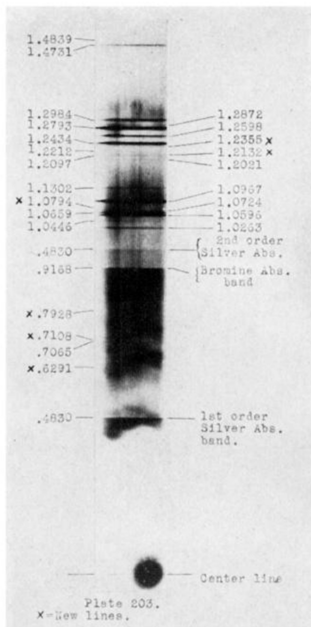
1.4839
1.4731
1.2984
1.2793
1.2434
1.2212
1.2097
1.1302
× 1.0794
1.0659
1.0446
.4830
.9158
×.7928
×.7108
.7065
×.6291
.4830
1.2872
1.2598
1.2355 ×
1.2132 ×
1.2021
1.0967
1.0724
1.0596
1.0263
2nd order Silver Abs.
Bromine Abs. band
1st order Silver Abs. band.
Center line
Plate 203.
×=New lines.

FIG. 1.

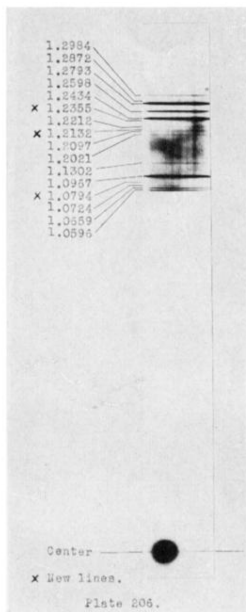
1.2984
1.2872
1.2793
1.2598
1.2434
× 1.2355
1.2212
× 1.2132
1.2097
1.2021
1.1302
1.0957
× 1.0794
1.0724
1.0659
1.0596
Center
× New lines.
Plate 206.

FIG. 2.

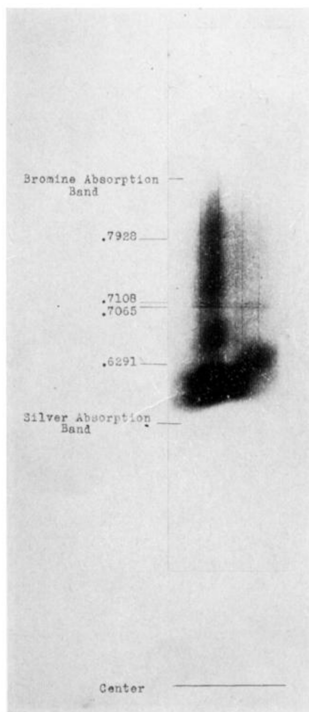
Bromine Absorption Band
.7928
.7108
.7065
.6291
Silver Absorption Band
Center

FIG. 3.

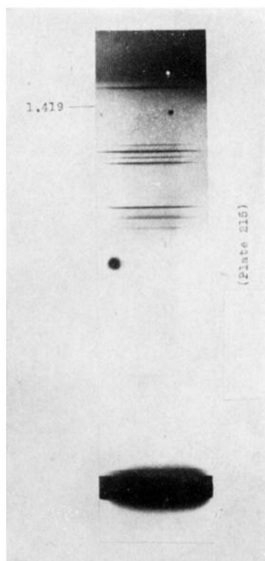

FIG. 4.