# The Tungsten X-Ray Spectrum with a Mica Spectrometer

By

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The X-ray spectrum belonging to the L-series of tungsten has been throughly investigated by Dershem,[1] Overn[2] and Siegbahn[3] in recent years. The results obtained by these authors on the prominent lines are in fair agreement with each other. But in regard to some of the faint lines there remain some ambiguities as to their wave lengths and even to their existence.

The arrangement employed in the present experiment is essentially the same as that used in the former experiment[4] carried out by one of the writers. The X-rays from the tungsten anticathode of a Coolidge tube is analysed by a bent mica spectrometer which is represented diagramatically in Fig. 1. Here B is a lead box, S the slit the width of which is 0.15 mm., C is a wooden cylinder of radius 36.10 mm. and on its surface a sheet of mica of a thickness of 0.06 mm. is just fastened. Consequently the value of 36.16 mm. is taken as the radius of ths cylindrical mica. The perpendicular distance SA from the slit S to the film side of the photographic plate P is represented by a, the perpendicular distance from the center of the cylindrical mica to

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1 Dershem, Phys. R., **11**, 471, (1918).

2 Overn, Phys. R., **14**, 137, (1919).

3 Siegbahn, Phil. Mag., **38**, 639, (1919).

4 Yoshida, Mem. Coll. Sci., Kyoto, **4**, 343, (1921).

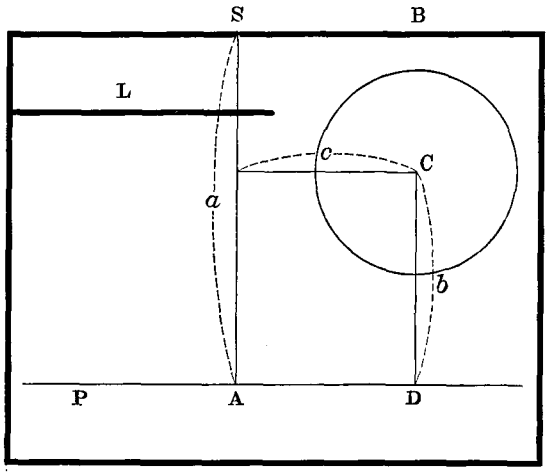


Fig. 1.

the film side of the photographic plate and that to the line SA are represented by b and c respectively. The values of a, b and c are not the same throughout the experiment and their numerical values corresponding to the three photographic plates measured in the present experiment are given in Table I.

TABLE I.

| | a in mm. | b in mm. | c in mm. |
|---|---|---|---|
| Plate No. 3 ... | 235.8 | 137.9 | 57.1 |
| Plate No. 4 ... | 196.8 | 97.2 | 57.1 |
| Plate No. 5 ... | 157.4 | 60.1 | 56.6 |

The photographic plates No. 3 and No. 5 are reproduced in the annexed figure. In the case of the plate No. 3, the distance b was very large, and consequently the greatest dispersion was attained in this case. On the contrary, in the case of the plate No. 5, the photographic plate was brought nearest to the cylindrical mica ; and the spectral lines of longer wave lengths were obtained in this case by sacrifice in the dispersion. Here it is to be noted that many faint lines which were visible on the original plate are absent in the reproduction.

The time of exposure was from 30 to 50 hours, using the current of the order of from 4 to 7 milliamperes and the potential differences

of the order of several ten kilovolts. All of the prominent lines of the L-series of tungsten were visible in all the orders up to the fifth or more. Moreover many weak lines showed themselves in the photographs. The wave lengths of these weak lines which were in the region of shorter wave lengths than the fifth order spectrum of the L-series were determined by interpolation from the wave lengths of the lines $\alpha_2$ $\alpha_1$ $\beta_4$ $\beta_1$ $\beta_3$ $\beta_2$ $\gamma_1$ of the L-series given by Siegbahn.[1] The grating constant of the mica now used was calculated from the wave lengths of the prominent lines of the L-series of tungsten, the values of a, b, c and the radius of the cylindrical mica mentioned before. The value of this grating constant thus calculated came out to be 9,858 Å.U. The wave lengths of the many weak lines which were in the region of longer wave lengths than the fifth order spectrum of the L-series were calculated from the values of this grating constant, a, b, c and the radius of the cylindrical mica mentioned before.

Most of the weak lines in the region of the shorter wave lengths than the fifth order spectrum of the L-series appeared both in the third and the fifth order, and some in the fourth as shown in Table II. The wave lengths of these lines determined from the photographs No. 3, No. 4 and No. 5, and also their average values are given in

TABLE II.

Wave lengths in Å.U.

| lines | Plate No. 3 | | | | Plate No. 4 | | | Plate No. 5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | third order | fourth order | fifth order | means | third order | fifth order | means | third order | fourth order | fifth order | means |
| $\eta$ | — | 1.414 | — | 1.414 | — | — | — | — | 1.414 | 1.415 | $1.414^{5}$ |
| | 1.287 | 1.288 | $1.287^{4}$ | $1.287^{5}$ | 1.289 | $1.287^{8}$ | $1.288^{4}$ | 1.287 | 1.288 | 1.286 | $1.287^{0}$ |
| | $1.236^{5}$ | — | $1.237^{3}$ | $1.236^{9}$ | 1.234 | 1.236 | $1.235^{0}$ | — | — | $1.235^{4}$ | $1.235^{4}$ |
| | 1.221 | — | $1.221^{4}$ | $1.221^{4}$ | — | 1.222 | 1.222 | — | — | $1.220^{6}$ | $1.220^{6}$ |
| | 1.211 | — | 1.212 | $1.211^{5}$ | 1.210 | 1.211 | $1.210^{5}$ | — | — | $1.212^{8}$ | $1.212^{8}$ |
| $\beta_5$ | 1.202 | — | 1.200 | $1.201^{0}$ | 1.202 | 1.201 | $1.201^{5}$ | — | — | $1.200^{6}$ | $1.206^{6}$ |
| | 1.130 | — | 1.129 | $1.129^{5}$ | 1.128 | — | 1.128 | — | — | — | — |
| | 1.070 | — | $1.071^{4}$ | $1.070^{7}$ | 1.072 | 1.071 | $1.071^{5}$ | — | — | — | — |
| $\gamma_2$ | 1.065 | 1.064 | $1.065^{4}$ | $1.064^{8}$ | 1.065 | 1.064 | $1.064^{5}$ | 1.065 | — | — | 1.065 |
| $\gamma_3$ | 1.059 | $1.058^{5}$ | 1.059 | $1.058^{8}$ | 1.058 | 1.060 | $1.059^{0}$ | $1.057^{7}$ | — | — | $1.057^{7}$ |
| $\gamma_4$ | 1.025 | — | $1.025^{4}$ | $1.025^{2}$ | 1.025 | — | 1.025 | 1.025 | — | — | 1.025 |

[1] Siegbahn, loc. cit.

TABLE III.

Wave lengths in Å.U.

| lines | Siegbahn | Dershem | Overn | Plate No. 3 | Plate No. 4 | Plate No. 5 | mean value |
|---|---|---|---|---|---|---|---|
| $l$ | 1.67505 | — | — | — | — | — | — |
| $\alpha_2$ | 1.48452 | $1.482^{8}$ | $1.483^{9}$ | | | | |
| $\alpha_1$ | 1.47348 | $1.472^{2}$ | $1.473^{1}$ | | | | |
| $\eta$ | 1.4177 | $1.416^{3}$ | — | 1.414 | — | $1.414^{5}$ | $1.414^{3}$ |
| $\beta_4$ | 1.29874 | $1.297^{7}$ | $1.298^{4}$ | | | | |
| | 1.2871 | $1.286^{8}$ | $1.287^{2}$ | $1.287^{5}$ | $1.288^{4}$ | $1.287^{0}$ | $1.287^{6}$ |
| $\beta_1$ | 1.27917 | $1.278^{4}$ | $1.279^{3}$ | | | | |
| $\beta_3$ | 1.26000 | $1.258^{6}$ | $1.259^{8}$ | | | | |
| $\beta_2$ | 1.24191 | $1.241^{6}$ | $1.243^{4}$ | | | | |
| | 1.2395 | — | $1.235^{5}$ | $1.236^{9}$ | 1.235 | $1.235^{4}$ | $1.235^{8}$ |
| | 1.2205 | $1.220^{2}$ | $1.221^{2}$ | $1.221^{2}$ | 1.222 | $1.220^{6}$ | $1.221^{3}$ |
| | 1.2118 | — | $1.213^{2}$ | $1.211^{5}$ | $1.210^{5}$ | $1.212^{8}$ | $1.211^{6}$ |
| | — | $1.209^{8}$ | $1.209^{7}$ | — | — | — | — |
| $\beta_5$ | 1.2031 | — | $1.202^{1}$ | 1.201 | $1.201^{5}$ | $1.200^{6}$ | $1.201^{0}$ |
| | — | $1.177^{3}$ | — | — | — | — | — |
| | 1.1284 | $1.129^{2}$ | $1.130^{2}$ | $1.129^{5}$ | 1.128 | — | $1.128^{8}$ |
| $\gamma_1$ | 1.09553 | $1.095^{3}$ | $1.096^{7}$ | | | | |
| | — | — | $1.079^{4}$ | — | — | — | — |
| | — | $1.070^{5}$ | $1.072^{4}$ | $1.070^{7}$ | $1.071^{5}$ | — | $1.071^{1}$ |
| $\gamma_2$ | 1.06584 | $1.064^{8}$ | $1.065^{9}$ | $1.064^{8}$ | $1.064^{5}$ | 1.065 | $1.064^{8}$ |
| $\gamma_3$ | 1.05965 | $1.058^{7}$ | $1.059^{6}$ | $1.058^{8}$ | 1.059 | $1.057^{7}$ | $1.058^{5}$ |
| | — | $1.042^{7}$ | $1.044^{6}$ | — | — | — | — |
| $\gamma_4$ | 1.02647 | $1.025^{3}$ | $1.026^{1}$ | $1.025^{2}$ | 1.025 | 1.025 | $1.025^{1}$ |
| | — | — | $.792^{8}$ | — | — | — | — |
| | — | — | $.710^{8}$ | — | — | — | — |
| | — | $.706^{8}$ | $.706^{5}$ | — | — | — | — |
| | — | — | $.629^{1}$ | — | — | — | — |

Table II and Table III. The wave lengths of the spectrum lines belonging to the L-series obtained by Siegbahn, Dershem and Overn are, for the sake of reference, also given in Table III. The wave lengths of most of the lines, excepting a few, were in fair agreement with those given by the other authors. For the line $\eta$ the wave length obtained in the present experiment came out somewhat smaller than those given by Siegbahn and Dershem. For the line 1.2395 Å.U. of Siegbahn the writers' value is smaller by 0.0037 Å.U., the value being $1.235^{8}$ Å.U., which is in fair agreement with that given by Overn. The line $1.071^{1}$ Å.U. observed in the present experiment seems to be the same as that obtained by Dershem and Overn at $1.070^{5}$ Å.U.

and 1.072[4] Å.U. respectively. As this line under consideration appeared both in the third and the fifth order spectrum of the plates No. 3 and No. 4, there seems to be no doubt as for its real existence. Lastly it must be noted that the values of the wave lengths of the prominent lines of the L-series were omitted in the Table II and III, for the Siegbahn's values for the wave lengths of these lines were relied on in determining the wave lengths of the other weak lines given in these tables.

It was already stated that many weak and diffuse lines made their appearance in the region of longer wave lengths than the fifth order spectrum of the L-series as is seen in the plate No. 5. The wave lengths of these lines were calculated, for the present, by considering that they were due to the so-called reflection from the cleavage surface of the cylindrical mica. Here it must be remarked that, as these lines were very diffuse, their wave lengths thus determined would not be accurate. Many of these lines were seen in the positions of the prominent lines of the L-series in the higher orders than the fifth as shown in Table IV. The wave lengths calculated are in accordance with those given by Siegbahn and others within the limit of experimental errors. From such consideration, it may be concluded that with a mica X-ray spectrometer the X-ray spectrum of the L-series of tungsten are obtainable up to the seventh and even up to the tenth order.

TABLE IV.

Wave lengths in Å.U.

| 6th order | 7th order | 8th order | 9th order | 10th order | Wave lengths given by Siegbahn | lines |
|---|---|---|---|---|---|---|
| 1.098 | 1.099 | 1.098 | 1.105(?) | 1.095 | 1.09553 | $\gamma_1$ |
| 1.244 | 1.245 | 1.244 | — | — | 1.24191 | $\beta_2$ |
| — | 1.262 | — | — | — | 1.26000 | $\beta_3$ |
| 1.283 | 1.282 | — | — | — | 1.27917 | $\beta_1$ |
| 1.299 | 1.291 | — | — | — | 1.29874 | $\beta_4$ |
| 1.479 | 1.486 | — | — | — | 1.48452 | $\alpha_1$ |

TABLE V.

Wave lengths in Å.U.

| | | |
|---|---|---|
| 7.90 | 9.28 | 10.25 |
| 8.06 | 9.42 | 10.62 |
| 8.16 | 9 59 | 10.77 |
| 8.59 | 10.04 | |

Besides the lines above stated, eleven lines of unknown origin were also detected in the photographs. Their wave lengths calculated in an ordinary way were tabulated in Table V. Of course it might be possible that these obscure lines were due to the reflections from the cylindrical mica in some unknown manner; and the values of the wave lengths given in Table V must be regarded as a mere indication of their positions on the photographic plate in reference to the other determinate lines of known origin.

In conclusion the writers wish to express their hearty thanks to Prof. Mizuno for the interest he has taken in the research.

Plate No. 3

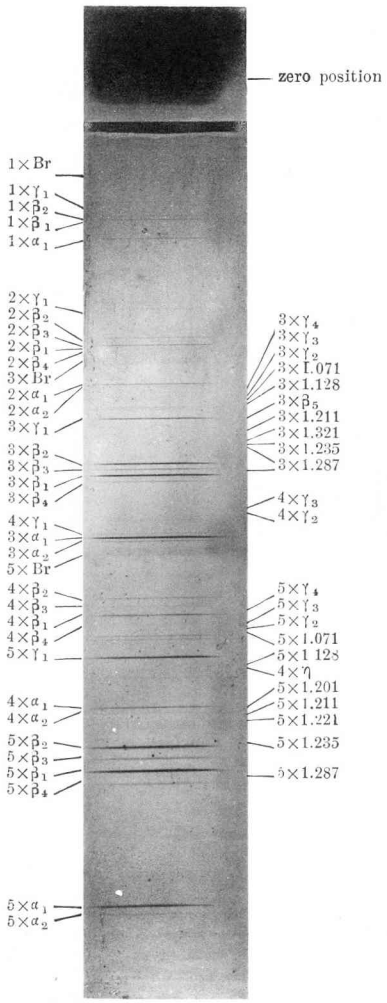


Plate No. 5