ON THE PRINCIPLE OF COMBINATION AND STOKES' LAW IN THE X-RAY SERIES.

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Synopsis.

New X-Ray Line γ_6 for Elements Tantalum to Uranium.—The two emission lines γ_2 and γ_3 are found to be in reality three lines. The new line γ_6 has *wave-lengths* of 1110, 1072, 842, 630 and 593 $\times$ 10^{-11} cm. for Ta, W, Tl, Th and U respectively. In the cases of Ir, Pt and Au it is too near γ_2 and in the cases of Pb and Bi too near γ_3 to be separated.

New Absorption Lines of the M-series.—Ma_1, Ma_2 and Ma_3 have been measured for *bismuth*, and Ma_4 and Ma_5 for *thorium and uranium*, the *wave-lengths* being, respectively, 4762, 4569, 3894, 2571, 2388, 2385 and 2228 $\times$ 10^{-11} cm.

Identification of the Line for Tantalum and Tungsten.—For all the elements Os to U, the difference in wave-lengths of $\beta_2 - \beta_5$ is equal to about 29 $\times$ 10^{-11} cm. If this difference is the same for Ta and W also, the β_5 lines for these elements must be the lines 1220.8 and 1250.6, respectively, instead of those ordinarily assumed.

Measurement of La, and La_2 for Tungsten by a different method gave the same wave-lengths as those found by Duane and Patterson.

Relationships between Emission and Absorption X-Ray Spectra.—(1) *Stokes's law* seemed not to hold in the case of W. It was thought the apparent discrepancies might be due to an error in the measurement of La_1 and La_2, but these measurements were found correct; however, the discrepancies disappear if we identify β_5 with 1220.8 instead of 1212.5 and if we associate γ_2 and γ_3 with La_3 and the new line γ_6 with La_2. (2) *Relations between frequencies.* The frequencies of seven of the L-series lines are each approximately equal to the difference between the frequency of an La-line and that of an Ma-line.

In a previous note I called attention to the fact that Stokes' law holds for the L-series of the elements Pt $-$ U. For W however the limiting wave-lengths La_1 and La_2 seemed to be much larger than the wave-lengths β_5 and γ_2 respectively; and I suggested a possible source of error in the method by which Duane and Patterson determined the absorption-wave-lengths of tungsten. On account of the great theoretical importance of this matter I have repeated the measurements, but with essentially the same result as these authors. To avoid every kind of complication I proceeded in the following manner. Use was made of a water-cooled bulb with aluminium-cathode, constructed by Prof. Siegbahn and described by A. Hadding.[1] This bulb has the great advantage

[1] Zeitschrift für Physik, *3*, 369, 1920.

that the slit of the spectrograph can be placed very near to the anticathode. It was driven with a current up to 15 mA and a tension of about 40 kV. First the absorption spectrum was taken with an iron anticathode and the absorbing substance placed between the bulb and the slit. Part of the slit was covered with a thick lead screen, so that only the upper part of the plate was exposed. In order to eliminate effects due to inhomogeneities of the absorbing screen, this was turned round during the exposure. Then the iron anticathode was replaced by a tungsten one, the absorbing substance was removed and by a suitable adjustment of the lead screen an emission-spectrum could be obtained on the lower part of the same plate. The plates demonstrated quite obviously that the absorption wave-lengths are considerably larger than the wave-lengths thus far denoted by β_5 and γ_2. For purposes of control the $L\alpha_2$ and the $L\gamma$-lines of gold and lead were taken in the same way; but, as might be expected, no such a difference was found here.

Now we may escape from the theoretical difficulty lying in an exceptional condition of the tungsten-spectrum by assuming, as already has been done by Hoyt[1] and by Dauvillier,[2] that the β_5-line of this element has not as yet been identified accurately. As may be seen from Table I.

Table I.[3]

	U.	Th.	Bi.	Pb.	Tl.	Au.	Pt.	Ir.	Os.	W.	Ta.
$\beta_2 - \beta_5$ ..	28.58	28.49	30.63	30.48	29.56	29.55	29.40	29.87	28.38	29.41	30.32

the wave-length difference $\beta_2 - \beta_5$ is nearly constant from U down to Os. If now we take for β_5 of W the line 1212.8 and for Ta the line 1250.6 then for these elements the difference $\beta_2 - \beta_5$ likewise remains nearly the same.

As regards the line γ_2, the situation is more complicated than could be anticipated formerly. Recently I have taken new photographs of the emission-lines of the elements Ta – U with the same metal bulb.[4] I find, that instead of the lines thus far denoted by γ_2 and γ_3, we must assume three lines.[5] One of these, which we may call γ_6, lies at a constant wave-length-distance from γ_1. The frequency-difference $\gamma_{\gamma 6} - \gamma_{\beta 5}$ is

[1] Proc. Nat. Ac. Sc. Washington, Nov., 1920.

[2] Comptes Rendus, 11 April, 1921.

[3] The wave-lengths are given in cm. $\times 10^{-11}$.

[4] See Zeitschrift für Physik, *6*, 158, 1921.

[5] An analogous hypothesis was pronounced some time ago in a letter from Mr. Wentzel to the author.

the same as the difference $\gamma_{\beta 1} - \gamma_{\alpha 2}$. For the elements Ta and W, γ_6 is of very small intensity relatively to the other γ-lines; but, in the neighborhood of Pt there is a sudden rise in its intensity. A similar change has been observed for β_5. Moreover, there are two lines γ_2 and γ_3, which lie at about the same wave-length-distance from one another and which both have about the same intensity. Only for the elements Ta, W, Tl and U was γ_6 separated from the lines γ_2 and γ_3, but where complete separation did not occur, a corresponding broadening and darkening of γ_2 or of γ_3 could usually be observed.

TABLE II.

	γ_1	γ_6	γ_2	γ_3	$\gamma_1 - \gamma_6$	$\gamma_2 - \gamma_3$
U...........	612.83	592.6	604.4	597.0	20.23	7.4
Th..........	651.03	630.1			20.93	
Bi..........	810.65	787.4	792.9	787.4	23.25	5.5
Pb..........	837.08	813.70	818.2	813.70	23.38	4.5
Tl...........	865.29	841.7	844.7	837.9	23.59	6.8
Au..........	924.37	901.25	901.25	859.68	23.12	5.57
Pt..........	955.45	931.7	931.7	925.6	23.75	6.1
Ir...........	988.41	963.6	963.6	956.6	24.8	7.0
W...........	1,095.53	1,072.0	1,065.84	1,059.65	23.53	6.19
Ta..........	1,134.71	1,110.0	1,102.0	1,096.2	24.71	5.8

In Table II. the wave-lengths of the lines γ_1, γ_6, γ_2 and γ_3 and the wave-length-differences $\gamma_1 - \gamma_6$ and $\gamma_2 - \gamma_3$ are given in cm. 10^{-11}. It seems to be most probable that only γ_6 is connected with the La_2-discontinuity, whereas γ_2 and γ_3 both belong to La_3.

Thus far only three absorption-discontinuities Ma_1, Ma_2 and Ma_3 in the M-series of U and Th were known, these corresponding to the measurements of Stenström. I have succeeded in measuring two other discontinuities Ma_4 and Ma_5 of shorter wave-length of U and Th and Ma_1, Ma_2 and Ma_3 of Bi, with the following provisional results:

TABLE III.

	Ma_1	Ma	Ma_3	Ma_4	Ma_5
U..............	3,491	3,326	2,873	2,385	2,228
Th.............	3,721	3,552	3,058	2,571	2,388
Bi..............	4,762	4,569	3,894		

The values for Ma_1, Ma_2 and Ma_3 of U and Th were taken from Stenström's dissertation. As is seen from Table IV. the frequencies of the lines l, η, α_1, α_2, β_1, β_3 and β_4 are each equal to the difference of an L-absorption-frequency and a M-absorption-frequency.

TABLE IV.[1]

	l	$L\alpha_1-M\alpha_5$	η	$L\alpha_2-M\alpha_5$	α_1	$L\alpha_1-M\alpha_1$	α_2	$L\alpha_1-M\alpha_2$
U.......	855.84	855.1	1,134.95	1,131.8	1,003.23	1,002.17	990.37	989.21
Th......	819.19	818.8			955.78	954.80	944.08	943.15
Bi.......					789.54	797.43	790.20	789.35

	β_1	$L\alpha_2-M\alpha_2$	β_3	$L\alpha_3-M\alpha_3$	β_4	$L\alpha_3-M\alpha_4$
U............	1,269.08	1,265.87	1,286.29	1,285.78	1,222.53	1,220.86
Th...........	1,194.94	1,193.15	1,211.67	1,209.77	1,155.00	1,151.86
Bi............	959.93	958.16	973.85	975.86		

Apart from the accidental errors there seems to be a systematic deviation between the line-frequency and the difference of the absorption-frequencies, so that we may conclude that there must be a small systematical error either in my measurements of the lines or in the work of Duane and Patterson. If this is the case, it is most probable that the same error should be found in the measurements of all the elements. We should therefore be inclined to conclude that for the elements Pt, Au, Tl, Pb and Bi, and perhaps for W also, the absorption-wave-lengths are a little shorter than the corresponding wave-lengths β_5 and γ_6 and that the difference should correspond to a difference of about 5–10 volts.

A superficial examination of my plates does not give the impression that the absorption-wave-lengths are shorter than the corresponding emission-wave-lengths. But the selective absorption commences with a faint white line, which may be tentatively considered as an image of the slit just as the black emission-lines are. This shows that the electron "prefers" the absorption of a very definite wave-length, which is at the same time the smallest frequency it is able to absorb. To estimate this frequency we are to measure the middle of the white absorption-line relatively to the middle of the black emission-lines. I hope to have later the opportunity to study this problem with the required accuracy with the photometer-method.

It gives me great pleasure to express my thanks to Professor Siegbahn, who put the apparatus of his laboratory at my disposal and advanced the work by his great interest.

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[1] The frequencies have been calculated in multiples of the Rydberg constant (limiting frequency of the Lyman series of hydrogen).