RESOLUTION OF THE LINE $L\beta_2$ INTO ITS DIAGRAM COMPONENTS AND THE RELATIVE WIDTHS OF SOME X-RAY SPECTRUM LINES

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Abstract

According to the energy-level diagram applicable to atoms which have lost one electron from an inner level the line $L\beta_2$ should be double, since it consists of electron transitions from the levels $N_{IV}N_V \rightarrow L_{III}$. The weaker component is designated as $L\beta_{15}$ following Crofutt. The present paper describes the results of an investigation of the line in 77 Ir, 81 Tl, and 92 U, using the double spectrometer. In 77 Ir the line $L\beta_2$ has such a great intrinsic width that β_{15} could not be separated from it although the dispersion and resolving power of the instrument were ample. In Tl 81 a better but not complete resolution was obtained. In 92 U a practically complete separation was found. The average of the wave-length separations observed in two experiments on uranium is 1.86 X.U. Using the combination principle and Lindberg's M-series measurements the separation should be 1.94 X.U. The Burger-Dorgelo rules predict a relative intensity of 9:1 and this was found to represent the facts within the rather large experimental error. Experiments are reported on the intrinsic widths of certain lines in the L-series of thallium and lead, taken at 34 kilovolts. The data reveal the following facts (1) Although the wave-length breadth ($\Delta\lambda$) of $L\alpha_1$ is greater than any of the other lines measured except $L\beta_4$, the energy breadth (ΔV) is less than that of the other lines. (2) $\Delta\lambda$ for $L\beta_4$ is 2–3 times as great as that of any other line measured. These results are compared with certain remarks by Coster on the width of x-ray spectrum lines.

THIS paper concerns investigations in the L-series carried out with the double x-ray spectrometer as previously used by Ehrenberg and Mark,[1] Ehrenberg and von Susich,[2] and Bergen Davis[3] and his associates. A description of the double spectrometer used in this work will appear soon in another journal.[4] The x-ray tube was of the usual water cooled type described in previous papers by the author.[5] All the investigations reported were carried out at 34 kilovolts and 8 milliamperes. It is well known that one of the advantages of the double spectrometer is the possibility of using wide slits. This meant the use of a wide window on the x-ray tube to pass the rather soft rays under consideration. Mica windows proved unsatisfactory due to electrostatic puncturing, so an aluminum foil window 0.0035 cm thick was used. The original intention in undertaking the work reported here was

[1] Ehrenberg and Mark, Zeits. f. Physik **42**, 807 (1927).

[2] Ehrenberg and v. Susich, Zeits. f. Physik **42**, 823 (1927).

[3] Bergen Davis and Harris Purks, Proc. Nat. Acad. Sci. USA **13**, 419 (1927) and succeeding papers.

[4] J. W. Williams and S. K. Allison, J.O.S.A. and R.S.I. in print.

[5] S. K. Allison, Phys. Rev. **30**, 245 (1927).

to supplement some relative intensity measurements made by the author with a single spectrometer in thallium, lead, and bismuth where the lines $L\beta_1$ and $L\beta_2$ were not resolved. Although complete resolution of these lines was obtained in thallium it became apparent that there are complicating factors which make it essential that great care be used in making intensity measurements with the double spectrometer and that several subsidiary researches would have to be carried out before the meaning of the measurements would become clear. Accordingly the original project was temporarily abandoned and other somewhat less exacting investigations carried out.

The intensity-wave-length curves for Tl $L\beta_2$ showed unmistakable evidence of a weak component on the long wave-length side. This is due to the double character of this line, representing the transitions $N_{IV}N_V \rightarrow L_{III}$. The transition $N_V L_{III}$ is the main line $L\beta_2$, $N_{IV}L_{III}$ the weaker component of

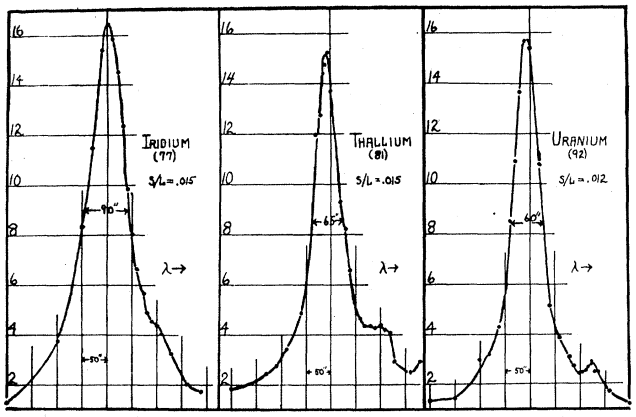

Fig. 1. The $L\beta_2$ and its weaker component in iridium, thallium, and uranium. Ordinates are proportional to electrometer deflections in millimeters per second.

longer wave-length. The situation is exactly analogous to that of $L\alpha_1\alpha_2$ and the extension of the sum rules of Burger and Dorgelo to x-ray spectra by Sommerfeld[6] and Coster and Goudsmit[7] predict the intensity ratio 9:1 in both cases. Fig. 1 shows the $L\beta_2$ line as it appeared in these experiments in iridium, thallium, and uranium. These curves were taken with both crystals at first order so the dispersion is twice that of a single crystal spectrometer at first order. In an analysis of the double spectrometer Schwarzschild[8] has shown that the condition that the width of the lines observed should not be due to geometrical factors in the instrument is

$$s/L << \{(\text{angular width measured})/\tfrac{1}{2}(\tan\theta_1 \pm \tan\theta_2)\}^{1/2}$$

providing the faces of both crystals are vertical. s is the effective height of the slits, L the distance between the stops controlling the vertical height

[6] A. Sommerfeld, Ann. d. Physik **76,** 284 (1925).
[7] Coster and Goudsmit, Naturwissenschaften **1,** 11 (1925).
[8] Schwarzschild, Phys. Rev. **32,** 162 (1928).

and θ_1 and θ_2 the glancing angles on crystals A and B respectively. The + sign is to be taken in the anti-parallel position, and the − sign in the parallel position. In the experiments on $L\beta_2$ s/L was 0.015 for iridium and thallium, and 0.012 for uranium. The factor on the right hand side of Schwarzschild's criterion was 0.048 for Ir, 0.044 for Tl, and 0.048 for U. An appreciable fraction of the width observed may therefore be due to geometric causes. Nevertheless it is clear that the wave-length width of Ir $L\beta_2$ is considerably greater than Tl $L\beta_2$ or U $L\beta_2$.

It has been previously claimed by Crofutt[9] that the components of $L\beta_2$ in tungsten had been resolved using a single spectrometer with a rock-salt crystal. The failure of the double spectrometer with calcite crystals to resolve these lines in iridium indicates that the separation observed by Crofutt was spurious. Crofutt denotes the weaker component by β_{15} and that symbol will be used in this discussion. As is seen in Fig. 1 the separation in uranium is almost complete. Results of the measurements on thallium and uranium are shown in Table I.

TABLE I. *Separation and relative intensity of L* β_2, β_{15}.

	$\Delta\theta$	$\Delta\lambda$	$\Delta\lambda$ (calc)	Intensity ratio
Thallium	110 sec.	1.60 XU.	1.74 XU.	9:1
Uranium	123	1.80		13:1
Uranium	132	1.93		10:1
Uranium ave.	128	1.86	1.94 Av	11:1

The values of $\Delta\lambda$(calc.) were obtained by the combination principle from the data of Lindberg[10] on the M-series wave-lengths since the same frequency difference should exist between the lines $M_{\text{III}}N_{\text{IV}}$ and M_{III} N_{V}. The relative intensities are the maximum ordinates of the curves representing the two components, with base lines computed on the same assumptions as used by Allison and Armstrong[11] in their work on the separation and relative intensities of the components of Mo$K\beta_1$. The assumption is made that $L\beta_2$ and $L\beta_{15}$ have the same width which means that the intensity estimates are rather crude. These two lines are part of the compound doublet $\gamma_1\beta_2\beta_{15}$, analogous to $\beta_1\alpha_1\alpha_2$ and the present measurements, together with previous work shows that these two compound doublets obey the Burger-Dorgelo rules as extended to x-ray spectra.

Figure 2 shows curves obtained for the widths of certain lines in the L-series of lead and thallium. These were obtained at 34 kilovolts and 8 milliamperes. For all these experiments the ratio s/L was 0.012. The results on these wave-length breadths are not considered final, in the sense that all contribution to the breadths in Fig. 2 are due to the intrinsic widths of the lines themselves compounded with the width of reflection of a single wave-

[9] Crofutt, Phys. Rev. **24,** 9 (1924).
[10] Lindberg, Zeits. f. Physik **50,** 82 (1928).
[11] Allison and Armstrong, Phys. Rev. **26,** 701 (1925).

length from a highly perfect calcite crystal. The width of the rocking curves at the parallel position as shown in Fig. 2 was 24 seconds at half maximum. All widths of curves given in this paper refer to the total width at half maximum. The widths referred to in the papers of Ehrenberg and Mark, and Ehrenberg and v. Susich are the half-breadths at half maximum. The width

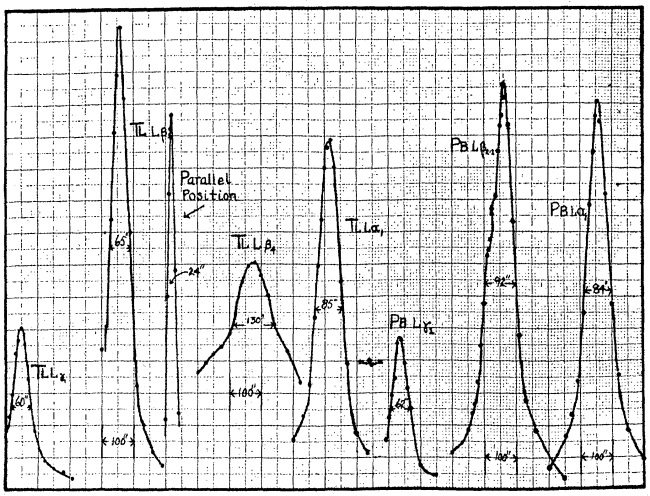

Fig. 2. Curves showing relative widths of certain x-ray lines. Ordinates are proportional to rates of deflection of the electrometer.

of 24 seconds was taken at a glancing angle of 9°19′. This indicates that the crystals used were not as perfect as have been obtained by other investigators. Work is now going on in an attempt to make the results more precise and trustworthy. Due to the relation

$$H_\lambda = (H_2^2 + H_1^2)^{1/2}$$

where $H\lambda$ is the intrinsic width at half maximum, H_2 and H_1 are the observed widths in the anti-parallel and parallel positions respectively; for the large H_2's measured here the H_1 of 24 seconds introduced no large correction. It was assumed that H_1 is constant throughout the wave-length region measured.

TABLE II.

Line	H_2	$(H_2^2-H_1^2)^{1/2}$	$\Delta\lambda$	ΔV
Tl $L\alpha_1$	84.5 sec.	80.8	1.16 XU.	9.8 volts
Tl $L\beta_4$	130	128	1.86	21.3
Tl $L\beta_1$	65	60.4	0.87	10.4
Tl $L\gamma_1$	60	55.0	0.80	13.2
Pb $L\alpha_1$	84	80.6	1.16	10.4
Pb $L\gamma_1$	62.5	57.6	0.84	14.8

The column headed $\Delta\lambda$ was calculated from the preceding column by the formula

$$\Delta\lambda = \tfrac{1}{2}\lambda \cot\theta\Delta\theta.$$

Two important facts appear in Table II are (1) Although the wave-length breadth of $L\alpha_1$ is greater than $L\beta_1$ or $L\gamma_1$, the voltage breadth is less, (2) The line $L\beta_4$, the only line measured involving the level L_1, is very much broader than these other lines, both in wave-length and voltage.

Figure 2 also shows an attempt to separate the lines $L\beta_1$ and $L\beta_2$ of lead. The lines are not separated but it is clear that $L\beta_2$ is on the short wave-length side of $L\beta_1$.

The results on the widths of the lines may be compared with some comments of Coster[12] on the width of x-ray lines. Coster states that in general the widths of lines involving transitions between so-called "elliptic orbits" on the classical quantum theory is greater than those involving circular orbits. This is not entirely confirmed here inasmuch as it applies to $L\alpha_1$, for in these experiments this line had a greater wave-length breadth than any other line measured involving the L_{II} L_{III} orbits. It must be noted, however, that the voltage or energy width of the $L\alpha_1$ line is less than that for any of the others measured which agrees with the ideas underlying Coster's remarks. Probably the two chief causes of the widths observed here are (1) "spark" lines on the short wave-length side of the diagram lines, and (2) deviation of the energy levels from true doublet levels due to Hund coupling with incompleted outer shells in the atom. The great width of $L\beta_4$ involving the orbits L_IM_{II} is perhaps the best illustration of the effect of "elliptic" orbits. It is interesting to note that this class of lines constitutes the exceptions to the Burger-Dorgelo rules.

[12] Coster, Zeits. f. Physik **45**, 797 (1927).