NOTE ON THE EXPERIMENTAL DETERMINATION OF THE
RELATIVE INTENSITIES OF SOME OF THE MOLYBDENUM
AND COPPER K SERIES LINES AND THE TUNGSTEN
L SERIES LINES

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The first precision measurements of the relative intensities of X-ray lines were those of Duane and Stenström on the K series of tungsten and Duane and Patterson on the L series of tungsten and the K series of molybdenum. The relative intensities of the K series lines of rhodium are given in curves shown still earlier by Duane and Hu in their study of absorption and emission frequencies.

Further interest in the experimental determination of the relative intensities of X-ray lines has been stimulated by the recent extension to X-ray spectra of the rules which Burger and Dorgelo have given for relative intensities in the optical region.

We have recently redetermined the relative intensities of the strong L series lines of tungsten and the K series lines of molybdenum, and have also studied some of the copper K series lines and the weaker lines in the tungsten L spectrum. Our investigations were made by means of the ionization method used by Duane and his collaborators. Our apparatus, however, had several improvements over that with which their work was performed. The crystal table could be turned with precision through a few seconds of arc, and its position read on the Génévoise scale with which the spectrometer was provided. The employment of tubes with water-cooled targets permitted the use of much more power than that used in the previous experiments. The source of power was a new high-capacity storage battery capable of furnishing 50,000 volts and allowing operation of the tube at high power for much longer intervals than before.

For the experiments on the molybdenum spectrum we used tubes with water-cooled molybdenum targets. For the study of the tungsten and copper spectra we had a tube with a water-cooled anode which consisted of a tungsten button embedded in copper. The copper K lines were emitted strongly from the copper part of the target. The radiation used in the spectrometer emerged from the tube through a very thin mica window on the end of a long arm.

Except in the investigation of the molybdenum Kα doublet, the reflected beam of X-rays entered the ionization chamber through a very thin mica window, as in the experiments of Duane and Patterson on the tungsten L series lines. The ionization chamber was filled with methyl iodide vapor.
The K Series Lines.—The ratio 2:1 predicted by the extension of the rules of Burger and Dorgelo for the components of the Kα doublet has been verified for a wide range of elements by the researches of Duane and Stenström, Duane and Patterson, and Siegbahn and Záček. We have not made a careful study of these lines. An interesting interpretation of the relative intensities in the Kα doublet has been given by Stoner, who has recently proposed a new scheme of electron distribution among atomic levels. He considers that the observed ratio 2:1 may be explained on the assumption that there are twice as many electrons in the L22 orbit as in the L41 orbit.

In our recent separation of the Mo Kβ doublet in the 4th and 5th orders we found the relative intensity $β_1: β_2$ to be 2:1, in agreement with the predictions of Sommerfeld and Coster and Goudsmit. According to Stoner’s scheme the observed ratio could be used as an indication that there are twice as many electrons in the M22 orbit as in the M41 orbit, provided the electrons in the intervening L orbits be assumed to have little disturbing influence on the transitions from the M group to the K group.

We have not been able to test the theoretical predictions for the Kγ doublet, as the two components have not yet been separated.

We have made several measurements of the relative intensity of Mo Kβ to Kγ in the first order, and have found for the average value 7.7:1. Duane and Patterson gave 6.3 for the first order and 5.46 for the second order. They obtained these ratios by assuming the intensity of each peak to be proportional to the height of the peak above the base-line. This method is sufficient for a first approximation; but, since both the β and γ lines are doublets of unequal wave-length separation, a better method is probably to take the area under each peak as proportional to the intensity. This we have done, and we have also applied corrections, in the case of the γ line, for the critical absorption due to the target. In these determinations the variation of the voltage and the tube current through a fairly wide range appeared to have no effect upon the relative intensities.

The average of our two determinations of the relative intensity of Cu Kβ to Kγ gives the ratio 100:2.4, or 42:1. Since, however, the γ line is very weak, and the critical absorption lies near it, estimates of its intensity are not very reliable.

Duane and Stenström found the relative intensity of β to γ in the K series spectrum of tungsten to be 35:15, or 2.3:1. The intensity of Kβ relative to Kγ for rhodium, obtained from the curves shown by Duane and Hu, lies between those for tungsten and molybdenum.

These values for the ratio Kβ: Kγ illustrate the decrease in intensity of γ with decreasing atomic number. No quantitative theory has yet been proposed to account for the relative intensities of such lines.

The intensity of Kβ relative to Kα has been measured for several ele-
ments by Unnewehr and by Siegbahn and Záček. On account of the large correction for absorption by the targets of our X-ray tubes, we have been unable to obtain satisfactory values for this ratio, although Unnewehr has applied to his measurements a correction for this absorption effect.

We have also investigated the copper spectrum in the region of the non-diagram lines $K\alpha_3$, $K\alpha_4$, reported by Dolejsek and Dolejsek and Siegbahn, and interpreted as spark lines by Wentzel. Although the Cu $K\alpha_1$ and $K\alpha_3$ lines were very strong, there was no satisfactory evidence of the $K\alpha_4$, $\alpha_4$ lines at 30,700 volts. The intensity of this doublet relative to $K\alpha_1$ must be less than 1:100.

The $L$ Series Lines of Tungsten.—We have made three determinations of the relative intensity of $L\alpha_2$ to $L\alpha_3$ and find for the average the value 10.0:1, the same as that obtained by Duane and Patterson. The ratio predicted from the extension of the rules of Burger and Dorgelo is 9:1. Sommerfeld has pointed out that according to Stoner's scheme the ratio would be 6:4, and has remarked that the simple interpretation of relative intensities in terms of the relative numbers of electrons in the orbits is evidently inadequate in the case of compound doublets such as $L\alpha_1$, $\alpha_3$, $\beta_1$.

In addition to the strong lines of the $\beta$ group, $\beta_1$, $\beta_2$, $\beta_8$, $\beta_4$, we have measured also the lines $\beta_6$, $\beta_7$, $\beta_9$, $\beta_{10}$. We have not found evidence of the line $\beta_9$ and the lines $\beta_{15}$ and $\beta_{16}$ of Crofutt, although our failure to do so is doubtless due to the fact that our slits were not sufficiently narrow. An attempt is now being made to separate $\beta_5$ and $\beta_{10}$ in the third order.

Duane and Patterson found $\beta_1$, $\beta_8$, $\beta_9$, $\beta_4$ proportional to the numbers 100, 55, 16, 9. The average of our series of measurements of the $\beta$ group gives the relative intensities of the lines $\beta_1$, $\beta_8$, $\beta_9$, $\beta_4$, $\beta_6$, $\beta_7$, $\beta_9$, $\beta_{10}$ proportional to 100, 49.3, 15.0, 7.7, 0.47, 2.0, 0.4, 0.68, 0.60. Since $\beta_8$ and $\beta_{10}$ are on the short wave-length side of the absorption $L\alpha_2$, which appeared as the critical absorption of the target, the values given for their intensities relative to the other $\beta$ lines can be considered only as minimum values. These two lines appeared to be of about equal intensity. The $L\alpha_2$ absorption also complicated the choice of a proper base-line for $\beta_5$. The line $\beta_6$ appeared as a shelf on the long wave-length side of $\beta_1$. The values of the relative intensities of these weak lines among themselves are thus not very reliable; but they serve, at least, to give an idea of the magnitude of the lines relative to the stronger ones.

According to our measurements the lines $\beta_3$, $\beta_4$ have a relative intensity which is close to the ratio 2:1 predicted by Sommerfeld and Coster and Goudsmit. Stoner has remarked that the ratio of $\beta_3$ to $\beta_4$ obtained by Duane and Patterson suggests the ratio 2:1 for the relative numbers of electrons in the $M_{22}$ and $M_{31}$ orbits.

We have also measured the relative intensities of the lines $\gamma_1$, $\gamma_2$, $\gamma_3$, $\gamma_4$, $\gamma_5$, $\gamma_6$. In some instances we obtained evidence of $\gamma_8$, but were not
always able to measure its intensity, as the height of the peak above the
general radiation varied. The estimation of the intensity of \( \gamma_8 \) was complicate
by the \( L_4 \) absorption, which lies close to the line.

The results of our determinations give the intensities of the lines \( \gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, \gamma_6, \gamma_8 \) proportional to the numbers 100, 14.0, 22.3, 7.0, 3.0, 2.3, 1 (?). Duane and Patterson found the first four of these lines pro-
portional to 100, 14, 18, 6. If their curves are corrected for incomplete resolution by a method described elsewhere\(^\text{14}\) by us, a value of the ratio \( \gamma_8:\gamma_1 \) is obtained which is nearer our value of 1.59:1. In this case, then,
there is an apparent exception to the extension of the rules of Burger and
Dorgelo and to Stoner’s scheme, according to both of which the ratio should be 2:1. Since the lines are close together, corrections for absorption by
materials in the path of the beam are negligible. On the basis of the
measurements of Duane and Patterson, Stoner has suggested that the failure of the simple ratio to hold in this case, in which the transitions are
from the \( N \) to the \( L \) groups, may be due to disturbing factors introduced
by the intervening electrons of the \( M \) group.

The measurements of relative intensities such as \( \alpha_1:\beta_1 \) and \( \beta_2:\gamma_1 \), for
which the ratio predicted by the extension of the rules of Burger and
Dorgelo is 9:5, is of great interest. In our researches such determinations
were complicated by the absorption in the target; consequently our results
are not of great value in testing theoretical predictions. We found \( \alpha_1 \) to
be slightly less intense than \( \beta_1 \), and \( \beta_2 \) to be less than twice as intense as
\( \gamma_1 \). The correction for absorption, however, could not bring both ratios
to the value of 9:5, for it would change both in the same direction.

More detailed accounts of these investigations will appear soon.

We wish to acknowledge our indebtedness to Professor William Duane,
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\(^1\) National Research Fellow.
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\(^14\) Physic. Rev. (in print).