

as the maximum, the note for  $L_B$  0.023 will have to be  $d'''$  as in figure 1; such a note is out of immediate correspondence with figure 5; but otherwise not unexpected in its relation to  $g'$  and since the pipe is just 3 times as long as the short pipe. The distribution of notes in figure 1,  $L_B$ , may, therefore, again be taken here.

Adding  $L_1$  to  $L_B$  as heretofore, the graph  $L_1 + L_B$  of figure 3 is obtained, of which the notes for  $C = 0.1, 0.2$ , etc., microfarad must be the same as in the corresponding earlier curve of figure 1. This curve has actually captured two crests. If the lower one is taken at  $C = 0.5$  and  $g'$  ( $\omega^2 = 10^6 \times 5.91$ ),  $L_1 + L_B = 0.34$  which is satisfactory. The upper crest is hard to identify relative to figure 5. As an  $e''$  it is too low and as a  $g''$  too high; but the latter is more probable. If the crest is put at  $C = 0.14$  microfarad and the frequency  $g''$ ,  $L_1 + L_B = 0.30$  henry is the nearest approach. The crest found may be a superposition of the  $e''$  and  $g''$ , recalling the vagaries of figure 5. The crests of the latter displayed on figure 3 indicate that  $g'$  and its harmonics dominate the curve  $L_1 + L_B$  and that  $c'$ ,  $e'$ ,  $a'$ ,  $e''$  are without relevance. The purpose of using the electric oscillations to interpret the astonishing presence of very low notes associated with very short thin pipes has, therefore, in a measure, succeeded.

\* Advance note from a Report to the Carnegie Institute of Washington, D. C.

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## ON THE REFLECTION BY A CRYSTAL OF ITS OWN CHARACTERISTIC RADIATION

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In a separate note<sup>1</sup> Dr. S. K. Allison has published his present opinion of the trustworthiness of certain data obtained in experiments on the X-radiation from a molybdenum target reflected by a crystal of KBr. I am very glad that Dr. Allison has published this note, for it helps to clear up certain questions relating to the reflection of X-radiation by such crystals as KBr, KI, etc.

The curve to which Dr. Allison refers represents very well the main features of the molybdenum spectrum reflected by KBr and observed by its ionizing effect in a chamber containing methyl iodide. On the curve can be seen: (a) the short wave-length limit of the continuous spectrum, (b) the abrupt decrease in the ionization current at the critical ionization wave-length of the iodine in the chamber, (c) the K-series lines of molybdenum, reflected in four orders (and even the  $\gamma$ -line in the fifth) and, (d)

the sharp rise at the critical absorption wave-length of the bromine in the crystal. Owing to the very great absorption of the KBr for X-rays of wave-lengths as long as those employed in these experiments, the curve drops off rapidly on the long wave-length side of the last-mentioned sharp rise (*d*), giving the appearance of a peak. This rapid decline in the intensity of the continuous spectrum with increasing wave-length is shown at several places on the curve in different orders of reflection, and is an important point in connection with the discussion that follows.

In addition to the features (*a*), (*b*), (*c*) and (*d*), mentioned above, the curve shows certain irregularities at points corresponding to the wave-lengths of the bromine K-series lines. These were interpreted as indicating the reflection by the crystal of its own characteristic spectrum. Unfortunately many of these lie so close to the strong molybdenum lines that it is impossible to draw conclusions from them. The spectrum at the  $\text{Br}\gamma$  and  $\text{Br}\beta$  lines in the third order may have been incorrectly observed or recorded, as Dr. Allison suggests. In general, the  $\gamma$  and  $\beta$  lines lie so close to the critical absorption that it is not possible to distinguish between a line and a pure absorption peak, produced as described above. The  $\alpha$ -doublet, however, is far enough away not to be interfered with by the absorption. Bearing these points in mind the writer himself examined the spectrum at the  $\text{Br}\alpha$  line reflected in the second order, taking the readings of the electrometer many times. In every case the ionization current was larger at the  $\text{Br}\alpha$  peak than on either side of it. At that time, three observers, one in addition to Dr. Allison and the writer, agreed that this was so. It may be that the particular curve to which Dr. Allison refers somewhat exaggerates the effect. The writer believes, however, that at least a few per cent more radiation was reflected at the bromine  $\text{K}\alpha$  line than in its immediate neighborhood. He has seen so often a similar excess of radiation reflected in the first, second and third orders at the  $\text{K}\alpha$  line of one of the chemical elements in the reflecting crystal that he is convinced that a crystal does sometimes reflect an appreciable amount of its own characteristic radiation. The crystal does not, however, reflect a perceptible quantity of its own characteristic radiation in experiments of the kind under discussion, if it has been carefully selected from the point of view of perfection by observing the accuracy with which an impression produced by reflected rays on a photographic plate corresponds with the size and shape of the spectrometer's slit system. This question has been discussed in a previous Note in these PROCEEDINGS.<sup>2</sup>

The best explanation of this excess radiation reflected by an imperfect crystal at an angle corresponding to a  $\text{K}\alpha$  doublet may be that suggested in the March (1925) number of these PROCEEDINGS of the National Academy on page 178. In applying the idea there expressed to the present case we must remember that, owing to the great absorption of the continuous

spectrum by the crystal, a very large part of the ionization current at a point in the neighborhood of the  $\text{BrK}\alpha$  line reflected in the second order must be due to the fluorescent  $\text{BrK}\alpha$  radiation emitted by the crystal more or less uniformly in all directions. The excess exactly at the line itself simply means that there is an increase in this fluorescent radiation emitted in that particular direction. In one of the first Notes published from our laboratory on this subject it was pointed out that a crystal must reflect that part of its own fluorescent radiation which, travelling in the proper directions, strikes reflecting planes at the reflecting angles as given by the Bragg law. At that time it was not thought this reflection could account for the observed phenomena. The solid angle,  $\delta$ , within which the directions of monochromatic X-rays must lie in order that they be reflected from a given set of planes is extremely small and, therefore, the fraction of the total fluorescent radiation thus reflected by the planes of a perfect crystal must be small also. If, however, the crystal is not perfect, if, in particular, it has the kind of imperfections described in one of the last mentioned Notes in which the planes are displaced, but so as to remain approximately parallel to one of the crystal axes, then a much larger amount of the fluorescent radiation will be reflected. To fix our ideas suppose the spectrometer to be set for the reflection of X-rays having the wave-length of the  $\text{K}\alpha$  line, and consider the fluorescent radiation coming from a point,  $A$ , in the crystal. The ionization current due to the fluorescent radiation travelling straight from  $A$  to the ionization chamber depends upon the solid angle,  $S$ , subtended at  $A$  by the slit in front of the ionization chamber. The part of the fluorescent radiation from  $A$  which travels straight ahead in the direction of the primary beam will strike the reflecting planes at the proper angle for reflection and will be reflected into the ionization chamber. In the case of a perfect crystal, however, this reflected beam would produce a very small effect, for the solid angle,  $\delta$ , within which the rays must lie in order to be reflected is much smaller than  $S$ . If, however, many of the planes in the crystal are displaced as above described, X-rays travelling in the general direction of the original beam and contained in a solid angle much greater than  $\delta$  will find planes in the crystal at proper angles for reflection and will be thrown into the ionization chamber. If it happens that this solid angle is about equal to  $S$  a perceptible increase in the ionization current due to the reflected fluorescent radiation might occur. The relative magnitude of the effect would depend on the reflecting power of the crystal planes and upon differences in absorption due to differences in the paths traversed by the reflected rays and those travelling straight from  $A$  to the ionization chamber.

The breadth of a fluorescent line produced as described above depends upon the amount by which the reflecting planes departed from parallelism. In the case of a random distribution of planes such as in a finely divided

powder, one would not expect to observe a line, for the fluorescent radiation would be reflected more or less uniformly in all directions.

<sup>1</sup> Following paper in this issue, p. 143.

<sup>2</sup> Armstrong, Duane and Havighurst, *Proc. Nat. Acad. Sci.*, **11**, 218 (1925).

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NOTE ON THE "SELECTIVE REFLECTION" OF X-RAYS BY  
CRYSTALS OF POTASSIUM BROMIDE

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Walter<sup>1</sup> has studied the reflection of X-rays by crystals of KBr by photographic methods, in an attempt to detect selective reflection of radiation having the wave-lengths of the K series of bromine. No such effect could be detected by a study of the photographs which he obtained. Later, in a paper by Allison and Duane,<sup>2</sup> a curve showing the results of an investigation by the ionization chamber method of the reflection of X-rays by KBr was published. This curve showed a very slight effect at the position of BrK $\alpha$  in the first order, and more positive indications of a selective reflection in higher order where the total intensity was quite low.

Armstrong, Duane and Havighurst,<sup>3</sup> continuing the investigation of the reflection of X-rays by alkali halide crystals, found that if the crystals were carefully selected for perfection, by observing the sharpness of the photographic registration of a reflected X-ray beam, no effects were obtained which could be ascribed to "selective reflection." Allison<sup>4</sup> had also found that no such effect existed in the reflection of X-rays by barite.

Recently Weber<sup>5</sup> and Kulenkampff<sup>6</sup> have carefully investigated the reflection of X-rays by KBr, using photographic methods. The spectra of Weber were obtained by the wedge-crystal method, while Kulenkampff tried both this method and the method of the rotating crystal in his attempt to detect the selective reflection. Both investigators conclude that no such effect can be detected in the spectra obtained from well-formed crystals, as was found by Armstrong, Duane and Havighurst.

Both Weber and Kulenkampff remark that it is difficult to understand how the Br lines in the higher order spectrum published by Allison and Duane can be explained as due to crystal imperfections. They are quite correct in this criticism. It is the purpose of this note to make plain that certain portions of the curve referred to<sup>2</sup> are now regarded by the writer as unreliable. In particular, no confidence can be placed in the portion