A STUDY OF THE SHAPE OF THE AgL, MoK AND CuK LINES

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Abstract

The $L\alpha_1\alpha_2$ lines of silver at 4.15A were resolved by the double x-ray spectrometer, which was enclosed in hydrogen to reduce air absorption. The width of $L\alpha_1$ at half maximum was 4.5 X.U. The separation of $\alpha_2-\alpha_1$ agreed within experimental error with the value of 8.18 X.U. given in the tables. The MoK lines were studied at first, second and fourth orders. The widths of α_1 and α_2 were the same, 0.281 X.U. The Mo$K\beta_{12}$ separation was 0.567 X.U. No trace of fine structure was found. The CuK lines showed the following effects at both first and second orders. The Cu$K\beta_{12}$ doublet, width 0.97 X.U. showed three partially resolved components, assumed to be β_1, β_2 and β' in order of increasing wave-length. The last was about 3.5 percent of the total intensity and its distance from β_1 was 1.34 X.U. The $\beta_2-\beta_1$ separation was estimated at 0.38 X.U. There is an excess of energy on the short wave-length side of β_1 indicating possibly a fourth component. The width of Cu$K\alpha_1$ was 0.61 X.U. No change in width was found between 15 kv. and 40 kv. Both α_1 and α_2 were steeper on the short wave-length side. This agrees with the observations of Valasek and others. The height of α_1 was more than twice that of α_2, but α_1 was enough narrower so that the ratio of areas was about two. No indication of fine structure was found. All x-ray lines were studied by means of the universal type of two crystal spectrometer described in an accompanying paper. The MoK and CuK lines were checked on a spectrometer of the type used by Davis and Purks. The three sets of crystals used in the above investigation were examined in the parallel position. One set showed a doublet structure.

Introduction

THE original purpose of the following investigation was the study of the L lines of silver. The curves shown in Fig. 2 of Ag$L\alpha_1\alpha_2$ represent the first measurements of absolute intensity by other than the photographic method. Because the lines were so wide a study of the CuK and MoK lines was made with the spectrometer to ascertain whether some of this width was due to the apparatus. The MoK lines have been investigated by Ehrenberg and Mark,[1] Ehrenberg and Susich,[2] Davis and Purks,[3,4] Allison and Williams[5,6] and Mark and Susich[7] using the double x-ray spectrometer. The same method has been applied to the CuK lines by Ehrenberg and Susich and by Purks.[8] Valasek[9]

[1] Ehrenberg and Mark, Zeits. f. Physik **42,** 807 (1927).
[2] Ehrenberg and Susich, Zeits. f. Physik **42,** 823 (1927).
[3] Davis and Purks, Proc. Nat. Acad. Sci. **13,** 419 (1927).
[4] Davis and Purks, Proc. Nat. Acad. Sci. **14,** 172 (1928).
[5] Allison and Williams, Phys. Rev. **35,** 1476 (1930).
[6] Allison and Williams, Phys. Rev. **35,** 149 (1930).
[7] Mark and Susich, Zeits. f. Physik **65,** 253 (1930).
[8] Purks, Phys. Rev. **31,** 931 (1928).
[9] Valasek, Phys. Rev. **36,** 1523 (1930).

has investigated the K lines of Mo and Cu and other elements using the photographic method of Siegbahn.

Apparatus

The spectrometer used in the following study employed the universal type of crystal mounting described elsewhere by the author.[10] It consisted of an accurately divided circle 13.6 inches in diameter which could be turned through any angle by means of a micrometer tangent screw. See Fig. 1. The circle and tangent screw had formerly been part of a circular dividing engine.

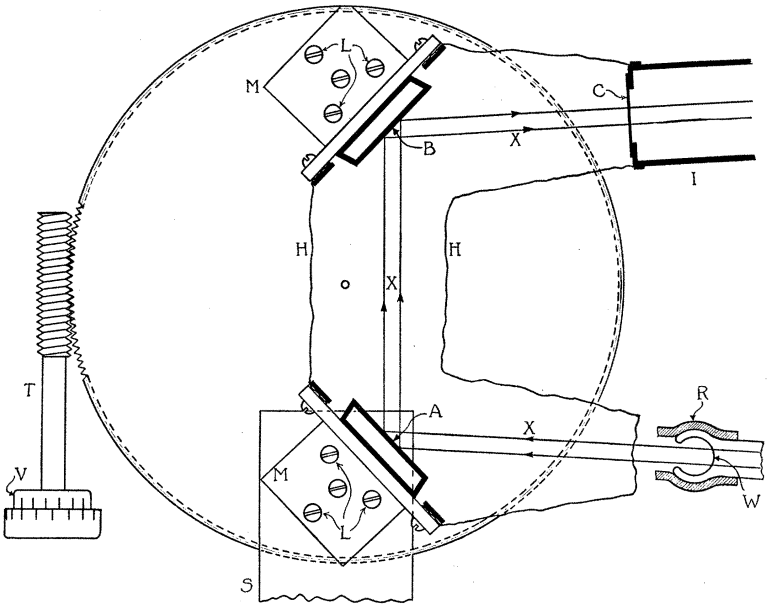

Fig. 1. Universal type of double x-ray spectrometer adapted for the study of the Ag$L\alpha_{12}$ lines. T-tangent screw fitted with vernier V. A, B-calcite crystals. M-crystal mountings fitted with levelling screws L. Crystal A is mounted on shelf S. Crystal B is mounted on the circle. W-thin glass window of x-ray tube 0.00011 cm thick. R-rubber tube. H-thin rubber sheeting filled with hydrogen to reduce air absorption. I-ionization chamber filled with air. C-cellophane window 0.001 in. thick. X-the portion of x-ray beam reflected from both crystals. This is as wide as the focal spot on the target.

Crystal A was fastened rigidly to a shelf which projected over the circle. Crystal B was fastened rigidly to the circle. Both were at the same level and placed symmetrically with respect to the axis of the circle. With this arrangement it was possible, by adjusting the position of the x-ray tube, to study x-ray lines incident on the crystals at any angle. The axis of the circle was adjusted vertically within 10 seconds of arc by means of levelling screws and a sensitive spirit level, which was placed on the circle and rotated. A spectrometer telescope fitted with a Gauss eye piece and carrying the above level was used to adjust each crystal in the vertical plane within one minute

[10] Spencer, Phys. Rev. **38**, 618 (1931).

of arc. Small plate levels of the type used on surveyor's transits were then adjusted on the crystal mountings so that any later deviation from level could be detected. The height of the ionization chamber window and target of the x-ray tube were adjusted level with the centers of the crystals by means of a Keuffel and Esser hand level.

The ionization chamber consisted of a small aluminum cylinder 4×9 cm long which was filled with methyl bromide. A Compton type electrometer with a capacity of 10 cm was used. The total capacity of the system including the electrometer was 22 cm with the needle of the electrometer grounded, but when the electrometer was used at a sensitivity of 12,000 mm per volt at one meter the capacity was 100 cm. This increase in effective capacity with sensitivity has been discussed by J. J. Thompson,[11] A. H. Compton and K. T. Compton[12] and others. The electrometer was later adjusted to 3,000 mm per volt using a different suspension. This was the most satisfactory sensitivity as the electrometer was more stable and yet had 60 percent of its former charge sensitivity. The electrometer scale was so curved that the deflection was proportional to the time. The ordinates in Figs. 2–6 are in cm per second at a distance of 3 meters.

The high voltage equipment was the same as used by Davis and Purks.

The results obtained for the Mo and CuK lines were checked on a second spectrometer of the same design as that used by Davis and Purks.[4,5] Crystal B could be rocked about both the horizontal and vertical axes. For this reason this spectrometer was also used to study the crystals in the parallel position.

The Double Crystal Spectrometer for Soft X-rays

The value of $2d$ for calcite is 6.06A so that wave-lengths up to nearly this value can be studied. However, for wave-lengths longer than 2A the absorption in the walls of the x-ray tube and even in air becomes very large.

The x-ray tube was provided with a thin glass window of the type described by Slack.[13] This window was 0.00011 cm thick and was estimated to transmit 75 percent of the Ag$L\alpha_1$ radiation, which has a wave-length of 4.15A. The thickness of the window was measured by application of an interference method described by Wood.[14] For this purpose a 50-watt tungsten lamp with clear glass bulb was used to illuminate the window. The images of the filament formed by the two surfaces of the thin window were then examined by a direct vision spectroscope. The glass window was also examined for uniformity. This was done by looking through it at a sodium light made by holding a piece of glass in a flame. Newton's rings were seen very faintly, but clearly enough to detect any asymmetry.

These windows are so delicate that a puff of air on the convex side will cause them to collapse, although they will stand a pressure of one atmosphere on the concave side. In order to withstand the pressure incident to the glass

[11] J. J. Thompson, Phil. Mag. **46,** 536 (1898).
[12] A. H. Compton and K. T. Compton, Phys. Rev. **14,** 85 (1919).
[13] Slack, J.O.S.A. and R.S.I. **18,** 123 (1929).
[14] Wood, Physical Optics, p. 157.

blowing when sealing the window on to the x-ray tube, a back pressure must be used. This was done by inflating a toy balloon and slipping it over the neck of the window.

The second problem connected with soft x-rays is their absorption in air. This problem was solved by surrounding the crystals and the entire path of the beam by thin rubber sheeting. See Fig. 1. This was kept filled with hydrogen thus eliminating most of the absorption along the path of the beam from the x-ray tube to the window of the ionization chamber. The ionization chamber contained dry air. The partition between the chamber and the hydrogen consisted of a sheet of cellophane 0.001 inches in thickness, which transmitted about 60 percent of the Ag$L\alpha_1$ radiation.

Crystal Curves in the Parallel Position

Three pairs of crystals were studied in the parallel position using Mo$K\alpha_1$ at first order. Pair No. 1 was used by Davis and Slack[15] in studying the refraction of x-rays. They obtained curves as narrow as 6 seconds at half maximum. The author found widths from 12 seconds upwards. At times a double peak appeared with a separation of 13.5 seconds and a total width about 33 seconds. The doublet appeared when the slits limiting the vertical angle were widened. These crystals were also used by Davis and Purks[4,F] in their study of the MoK radiation, but were not studied in the parallel position at that time. This greater width and double peak would indicate that these crystals have altered since the experiments of Davis and Slack.

Crystal pairs No. 2 and No. 3 were cut from the same block of calcite as the pair described by Davis and Purks[16] for which a width of 4.5 seconds was obtained. They were examined by a method described by Davis and Stempel.[17] The beam was limited horizontally by a 0.01 cm slit. Curves taken at various points along crystal pair No. 2 varied in width from 5.2 to 8.9 seconds. Near one end a progressive shift in the peak of 5.5 seconds was observed, indicating that at least one of the crystals was not plane. Crystal pair No. 3 was examined in a similar manner, the widths ranging from 5.2 to 8.2 seconds. No shift in the peak was found.

The Ag$L\alpha_1\alpha_2$ Lines

A curve of the Ag$L\alpha_{12}$ doublet (see Fig. 2) was taken with crystal pair No. 1 on the universal type of spectrometer illustrated in Fig. 1. The width at half maximum of $L\alpha_1$ at 25 kv was found to be 420 seconds or 4.5 X.U. The separation between α_1 and α_2 agrees within experimental error with the 765 seconds corresponding to 8.18 X.U. given in the tables.

At 5000 volts the Ag$L\alpha_{12}$ lines were too weak for precise measurements. However, no change in width at this voltage was found.

The International Critical Tables state that the relative intensity of $L\alpha_2$ to $L\alpha_1$ for tungsten is 11.5 percent. The tungsten $L\alpha_{12}$ doublet is more

[15] Davis and Slack, Phys. Rev. **27,** 18 (1926).
[16] Davis and Purks, Phys. Rev. **34,** 181 (1929).
[17] Davis and Stempel, Phys. Rev. **19,** 504 (1922).

easily resolved than the silver $L\alpha_{12}$ doublet. The same ratio of intensity was assumed to hold for the silver $L\alpha_{12}$ lines. Therefore, the shape of Ag$L\alpha_2$ is shown in Fig. 2 with the same width at half maximum as Ag$L\alpha_1$. Subtracting Ag$L\alpha_2$ from the experimental curve shows that Ag$L\alpha_1$ is asymmetrical having an excess of energy on the short wave-length side. This becomes quite

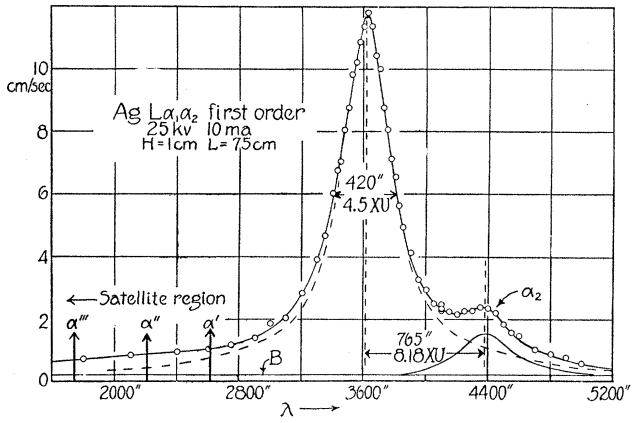

Fig. 2. Ag$L\alpha_1\alpha_2$ at 25 kv and 10 m.a. taken at first order on the double crystal spectrometer shown in Fig. 1. Angles are twice the value for a single crystal. B is the base line measured at 0 and 6200 seconds. The Ag$L\alpha_1\alpha_2$ separation calculated from the tables is 765 seconds, which is in agreement with the data. Arrows give the position of reported statellites.

large in the region of the satellites studied by Richtmyer.[18] Later the satellite region was studied in more detail. The x-ray tube was gassy and finally broke down completely before accurate measurements could be made.

Mo$K\alpha$ and β Lines

Curves of the Mo$K\alpha$ and β lines were taken on the universal spectrometer at fourth order with crystal pair No. 1 previously described. The widths of α_1 and α_2 at half maximum were 86 and 88 seconds. For Mo$K\alpha_1$ this would correspond to a width at first and second orders of 19.4 and 39.3 seconds. The same crystals gave widths at these orders of 32 and 42 seconds. These crystals as stated before gave very wide rocking curves at first order, in the parallel position.

The widths of Mo$K\alpha_1$ at first and second orders using crystal pair No. 2 were 18.3 and 39.5 seconds. The second order value of 39.5 seconds corresponding to 0.281 X.U. is considered the most reliable. This is the average of four curves. Fig. 3 shows a typical curve of Mo$K\alpha_1$ at second order. The dotted line represents a Gaussian type of curve which has the same height and same width at half maximum. It is seen that the x-ray line is sharper at the peak and flares out at the base more than the Gaussian curve. This is typical of all x-ray lines studied.

[18] Richtmyer, Phys. Rev. **36,** 1044 (1930).

The vertical slit used was one cm high at a distance of 75 cm from the target which was assumed to be a point source. The maximum deviation due to vertical divergence was 2.2 seconds as calculated from the formula

$$\delta_m = \psi^2 \tan\theta.$$

A graphical method of finding the effect of vertical divergence on the shape of the x-ray line is described in another paper.[1] When this is applied, the correction at any point is negligible, since it is less than the deviations in the

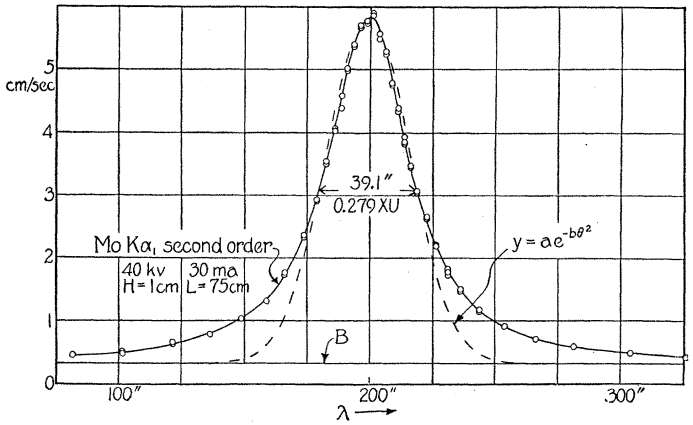

Fig. 3. Typical curve of Mo$K\alpha_1$ at 40 kv and second order. B is the base line measured at 0 and 500 seconds. The dotted line is that of a Gaussian curve with the same height and the same width at half maximum. The flaring out at the base is typical of x-ray lines. Angles are twice the value for a single crystal.

data. The effect of the crystals likewise should be negligible at second order. Davis and Purks[16] found that a pair of crystals cut from the same block of calcite gave in the parallel position a width at half maximum for Mo$K\alpha_1$ at second order of 1.25 seconds. It is assumed, therefore, that the curve of Mo$K\alpha_1$ in Fig. 3 is free from instrumental errors. The reason for the flaring out at the base is unknown. The same crystals i.e. pair No. 2, on another spectrometer at second order gave 39.5 seconds and at first order gave various widths from 37 down to 24 seconds, the width depending on the part of the crystals used. Tests made by rocking crystal B vertically showed that the large width was not due to faulty alignment. The large variation in widths at first order would indicate that these crystals were not perfect. However, the

TABLE I. *Mo$K\alpha_1$. Full width at half maximum uncorrected for crystal width or angle of vertical divergence.*

	Order	$\Delta\theta$	$\Delta\lambda$
Davis and Purks	2	25 sec.	0.18 X.U.
Allison and Williams	2	39.4	0.281
Mark and Susich	2	45.4	0.32
Mark and Susich (topaz)	2		0.288
Spencer	2	39.5	0.281

widths found in the parallel position should not have caused such large variations.

Allison and Williams report widths at half maximum of 22.4 and 39.4 seconds at first and second order. It has been pointed out in a previous paper[1] that the widths of the curves of Allison and Williams were not properly corrected for vertical divergence. Therefore, the uncorrected widths alone are compared. It is difficult to estimate from their curves the method by which the base line was determined. The author usually measured the base line at a point quite distant from the line.

Mark and Susich[8] obtain a width of 45.4 seconds corresponding to 0.32 X.U. at second order. They do not explain how the base line was estimated. They used both calcite and topaz, the latter giving a width of 0.288 X.U.

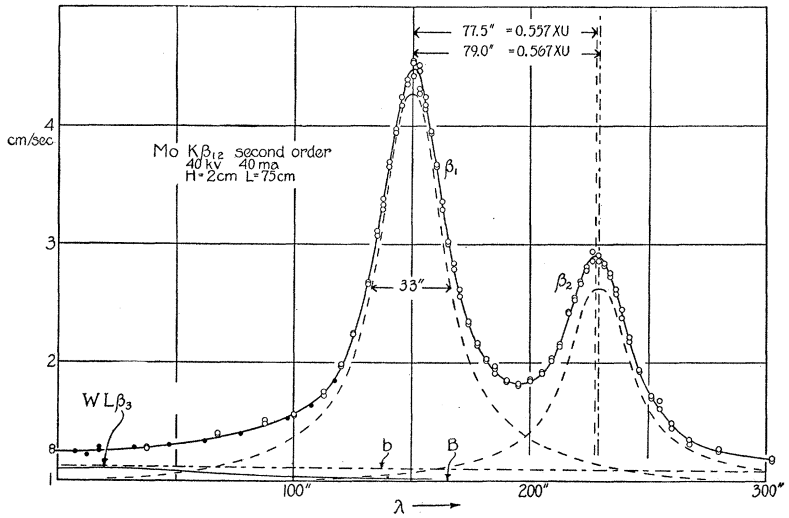

Fig. 4. Mo$K\beta_{12}$ at second order and 40 kv. The shape of W$L\beta_3$ was estimated from a study of W$L\beta_2$. *B* is the base line measured at 550 sec. *b* is the base line assumed in the neighborhood of the curve. The curve was analyzed into two components 79.0 seconds apart. Note that the experimental peaks are about 1.5 seconds closer together.

The Mo$K\beta_{12}$ doublet is shown in Fig. 4 at second order. The temperature was held constant within a range of 0.3°C. Further investigation in the region of the Mo$K\gamma$ line showed that the $L\beta_2$ line of tungsten was present, probably due to a thin layer of tungsten sputtered on the target from the filament. Knowing the relative intensity of W$L\beta_2$ and W$L\beta_3$ from the International Critical Tables, an estimate of the intensity of the latter was made. This is shown in Fig. 4 and explains the asymmetry of the base of the Mo$K\beta_{12}$ lines.

The Mo$K\beta_{12}$ separation at second order uncorrected for the effect of the components on each other was 77.5 seconds corresponding to 0.557 X.U. With the base line *B*, the height of the saddle between β_1 and β_2 was 24 percent of the height of β_1. The height of β_2 was 55 percent of the height of β_1. The Mo$K\beta_{12}$ doublet was also studied at first order. The uncorrected separation was 37.6 seconds corresponding to 0.548 X.U. The saddle was 39 percent

of the height of β_1 indicating poorer resolving power. An analysis of the effect of the crystal width on the shape of the curve at first order using the graphical method previously described, accounted for only part of the difference in resolving power. The vertical slit at second order was 2.0 cm high at a distance of 75 cm from the target. This should cause a depression at the peak of β_1 of less than the errors in the data. At first order the height of the vertical slit was only one cm. This would cause an even smaller depression at the peak.

Each component of the doublet is elevated upon the side of the other component. This effect tends to make the separation of the peaks of the actual curve less than the true separation. The curve was analyzed into two components using the method of DuMond and Kirkpatrick.[19] The separation and base line must first be assumed. If the resulting form of the components is not reasonable, then the assumed separation may be varied. A separation of 79 seconds corresponding to 0.567 X.U. was obtained. The $K\beta_1\beta_2$ doublet arises from the M_{22}, M_{21} levels which also give rise to the $L\beta_3\beta_4$ lines. The Mo$K\beta_{12}$ separation as calculated from the $L\beta_3\beta_4$ separation should be 0.563 X.U. corresponding to 78.4 seconds at second order.

The separation may also be estimated from the relativity correction formula of Sommerfeld.

$$\Delta\nu = \frac{R\alpha^2}{54}(Z - d)^4\left[1 + \frac{279\alpha^2}{432}(Z - d)^2 + \cdots\right]$$

$$\Delta\lambda = \lambda^2\Delta\nu.$$

Using for the screening constant d the usually accepted value of 8.4 ± 0.2 the Mo$K\beta_{12}$ separation was calculated to be 0.568 ± 0.014 X.U. corresponding to 79.1 ± 1.9 seconds at second order.

TABLE II. *Mo$K\beta_1\beta_2$ doublet separation.*

	Order	$\Delta\theta$	$\Delta\lambda$
Davis and Purks	1	40 sec.	0.585 X.U.
Davis and Purks	2	76	0.546
Allison and Williams	1	39.1	0.571
Allison and Williams	2	77.8	0.559
Mark and Susich (topaz)	2		0.59
Int. Crit. Tables	2	78.6	0.565
Spencer (uncorrected)	1	37.6	0.548
Spencer (uncorrected)	2	77.5	0.557
(corrected)	2	79.0	0.567
Calculated from $L\beta_3\beta_4$ separation	2	78.4	0.563
Fine structure formula	2	79.1	0.568 ± 0.014

The first measurements of the Mo$K\beta_{12}$ separation using the double x-ray spectrometer were made by Davis and Purks. They obtained 40 seconds at first order corresponding to 0.585 X.U., and at second order obtained 76 seconds corresponding to 0.546 X.U. Allison and Williams obtained a value of 77.8 seconds at second order corresponding to 0.559 X.U.

[19] DuMond and Kirkpatrick, Phys. Rev. **37**, 136 (1931).

Davis and Purks[5] report the existence of fine structure in their second order curves of the Mo$K\alpha$ and β lines. Other investigators including the author have failed to find any trace of this fine structure. As previously noted crystal pair No. 1 used by Davis and Purks at the present time gives rather wide rocking curves in the parallel position and at times shows a doublet structure with a separation of about 14 seconds.

The effect of such a doublet structure would be to spread an x-ray line out into two components, each as broad as the original line. The final curve would be broader than that obtained by a good pair of crystals. This is borne out by

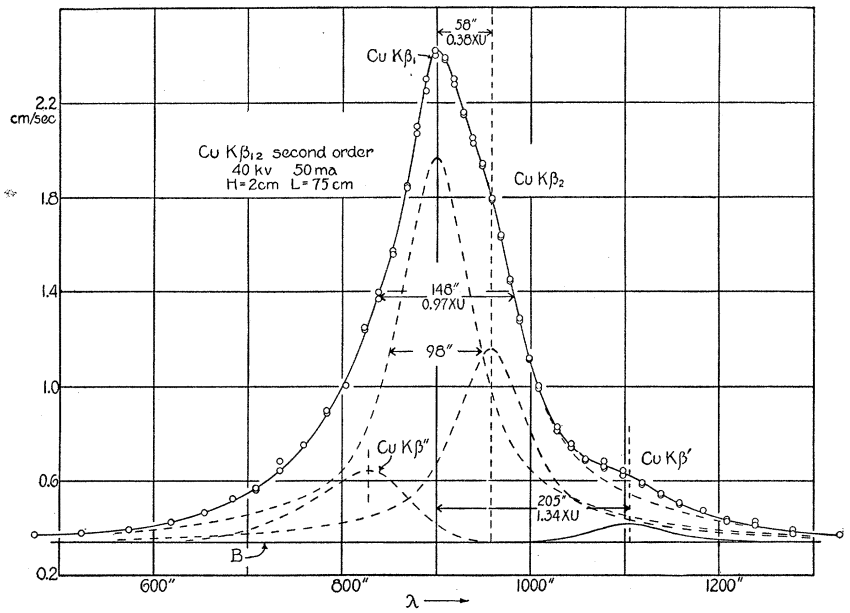

Fig. 5. Cu$K\beta_{12}$ at second order and 40 kv. B is the base line measured at 0 seconds. The β_{12} separation predicted by the Sommerfeld fine-structure formula is 0.381 X.U. corresponding to 58 seconds. This agrees with the break in the slope. A weak component β' is seen on the long wave-length side. Another component β'' was added on the short wave-length side in order to make the β_1, β_2 components symmetrical. This arrangement is arbitrary as the components themselves may be asymmetrical. The intensities in order of increasing wave-length are β'' 13 percent, β_1 56 percent, β_2 28 percent and β' 3.5 percent.

the relative widths of Mo$K\alpha_1$ taken on crystal pairs Nos. 1 and 2 by the author. These have already been discussed. The second order curves taken by Davis and Purks[5] on the other hand appear to be narrower than those taken by the author. See Table I.

Cu$K\alpha$ and β Lines

The Cu$K\beta_{12}$ doublet, or rather triplet, is shown in Fig. 5 taken with crystal pair No. 2 at second order. The width at half maximum is 148 seconds corresponding to 0.97 X.U. A break in the slope of the curve occurs at 0.38 X.U. on the long wavelength side of β_1. This is assumed to be β_2. A third component

is noted at 1.34 X.U. on the long wave-length side of β_1 with about 3.5 percent of the total energy. This is called β'.

The same crystals showed these details nearly as definitely at first order. Crystal pair No. 1 indicated these components at second order but gave a perfectly symmetrical curve at first order probably due to its poor resolving power.

The same fine-structure formula which was used above in the case of the Mo$K\beta_{12}$ doublet was here used to calculate the Cu$K\beta_{12}$ separation. This was calculated to be 0.381 ± 0.015 X.U. corresponding to 58.4 ± 2.3 seconds at second order. A vertical dotted line in Fig. 5 has been placed at this distance and coincides with the break in slope of the curve.

An attempt was made to analyze the curve corrected for β' into two components using the method of DuMond and Kirkpatrick.[19] The solution was very asymmetrical having an excess of energy on the short wave-length side.

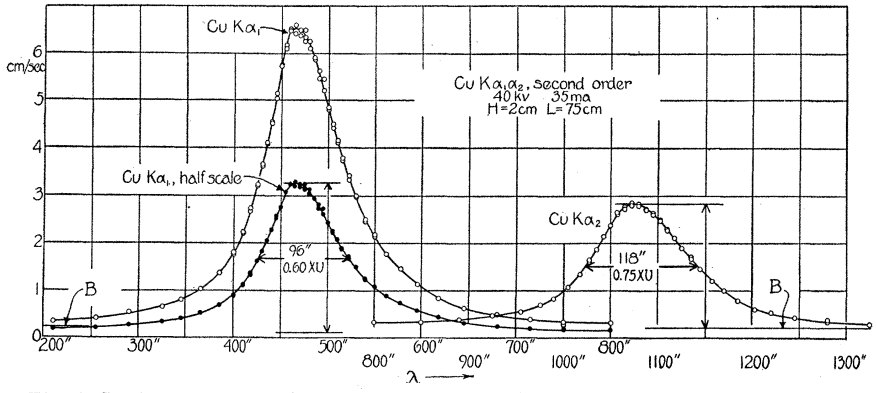

Fig. 6. Cu$K\alpha_1$ and α_2 at 40 kv. and second order. The two curves have been made to overlap in order to conserve space. Cu$K\alpha_1$ is also shown drawn to half scale. *B* is the base line measured at 0 and 1500 seconds. The following effects are noted. Cu$K\alpha_1$ is more than twice as high as Cu$K\alpha_2$ but is enough narrower so that the ratio of the areas is very nearly two. Both lines are steeper on the short wave-length side.

Two other possibilities were considered. First, all the excess energy may belong to β_1. Secondly, both components may be symmetrical, the excess energy indicating another component β''. The last solution was carried out. See Fig. 5. The separation of $\beta_1 - \beta''$ was 71 seconds corresponding to 0.46 X.U. The intensity of the various components in percentage of the total intensity is as follows, β_1 56 percent, β_2 28 percent, β' 3.5 percent, β'' 13 percent. The above solution is rather arbitrary and should be considered as a description of the data rather than as a correct analysis of the physical components.

The asymmetry due to β'' was also observed by Purks[9] who studied the Cu$K\beta_{12}$ doublet at second order with crystal pair No. 1. His value of the β_{12} separation was 0.32 X.U. The $\beta' - \beta_1$ separation was 0.8 X.U., the intensity of β' being greater than that given in Fig. 5.

The Cu$K\alpha_1\alpha_2$ lines were studied at 40 kv at first and second orders on the universal spectrometer. They represent the results of a fourteen hour con-

tinuous run in which the temperature was constant within a range of 0.3°C. The widths of α_1 and α_2 at second order are 96 and 118 seconds, corresponding to 0.60 and 0.75 X.U. See Fig. 6. The separation at first and second orders is 3.80 and 3.84 X.U. which is a little less than the 3.86 X.U. given by Siegbahn.[20] An average of first and second orders shows that both α_1 and α_2 are about 1.26 times steeper on the short wave-length side. The effect then, of poor resolution as in a single crystal spectrometer with wide slits, is to move the position of the peak toward the position of the center of gravity of the line. This would affect to some extent the determination of the wave-length of the peak but not the separation of $\alpha_1\alpha_2$. The ratio of the heights of α_1 to α_2 was 2.44, the ratio of the areas being 2.06. A curve of α_1 taken at 20 kv showed no change in width due to voltage.

The universal type of spectrometer made possible a measurement of the angle between first and second orders for Cu$K\alpha_1$. The angle corrected for refraction was found to be 24 seconds less than the 32° 35′ 25″ calculated from values given by Siegbahn.[20] A correction for the thermal expansion of calcite reduced this by 8 seconds. Another 8 seconds may be accounted for by measuring the midpoint at half maximum instead of the peak. A correction for vertical divergence would have increased the discrepancy by about 5 seconds. The remaining error of about 13 seconds is probably in the circle. No other test of the circle was made.

In order to check some of the above results Cu$K\alpha_1$ and α_2 were also studied on the second spectrometer at 40 kv using the same crystals at first order. The width of α_1 was 0.69 X.U. compared with 0.61 X.U. obtained from the previous first order curve. However, no change of width occurred at 15 kv. At 40 kv the height of α_1 was 2.25 times the height of α_2. A difference in the slopes of each line was also observed, though less marked than before.

An examination of former curves of the CuK and Ni$K\alpha_1$ and α_2 lines taken with crystal pair No. 1 at first, second and third orders shows similar effects.

Valasek[10] has observed the difference in slopes of the Cu$K\alpha$ lines with the photographic method. This has also been detected by Seljakow, Krasnikow and Stellezsky.[21]

A study of the spectrometer was made in order to find a possible explanation for the ratio of the heights of α_1 to α_2. For the later curves the x-ray tube was 75 cm from crystal A. Therefore, with the target fixed in position the change in angle between Cu$K\alpha_1$ and α_2 would cause the beam to move sidewise about 0.05 cm at crystal A. For the earlier curves the movement was only 0.025 cm. A curve was made of the distribution of energy across the beam coming from the focal spot. This was done by placing a narrow slit in the beam and moving the tube horizontally as was done by Richtmyer,[22] in the case of the single crystal spectrometer. The focal spot was 0.5 cm wide at half maximum. Slits at least one cm wide were used for the Cu curves so it is not probable that the ratio of heights for α_1 and α_2 was due to the beam

[20] Siegbahn, Spectroscopy of X-rays.

[21] Seljakow, Krasnikow and Stellezsky, Zeits. f. Physik **45**, 548 (1927).

[22] Richtmyer, Phys. Rev. **26**, 724 (1925).

impinging on the edge of the slit. Steps in the crystals should have little effect, since the sidewise movement was small compared with the total width of the beam.

Purks[9] has studied the $K\alpha_1$ and α_2 lines of Cu and Ni using crystal pair No. 1 and at second order resolves the lines into components. If the extra components which Purks finds on the long wave-length side of Cu$K\alpha_1$ and α_2 were smoothed over, they would account for the difference in slopes of the two sides found by the author. Poor resolving power would do this. However, crystal pair No. 1 used by Davis and Purks[5,6] and Purks[9] at the present time gives wider rocking curves than crystal pair No. 2 used to obtain the curves of the MoK and CuK lines shown in this paper. The author has reduced the effect of accidental variations in intensity by taking many of the points in duplicate and checking at various places along the curve at the end.

In conclusion, the author wishes to express his appreciation to Professor Bergen Davis for his interest in the work and for the use of the splendid high voltage equipment and facilities for pumping x-ray tubes, previously assembled by him and his colleagues.