BREADTH OF THE COMPTON MODIFIED LINE WITH THE DOUBLE CRYSTAL SPECTROMETER

By Archer Hoyt and Jesse DuMond
California Institute of Technology, Pasadena

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Abstract

Three experimenters using the double crystal spectrometer have recently reported very much narrower structure for the Compton modified line than the structure observed photographically by DuMond and Kirkpatrick with the multicrystal spectrograph whose resolution was entirely adequate to reveal such a narrow structure. We have repeated the experiment using a double crystal spectrometer similar to theirs. The results obtained are in satisfactory agreement with the previous observations of Compton line breadth by DuMond and Kirkpatrick with the multicrystal spectrograph and in disagreement with the experimenters who used double crystal spectrometers. The conclusions drawn are: (1) The Compton modified line due to Mo $K\alpha$ radiation scattered by graphite at angles of $165° \pm 10°$ and examined with the double crystal spectrometer has a breadth of from 21 to 22 XU at half-maximum height; (2) Under the above conditions there is no appreciable separation of the $K\alpha$ doublet in the shifted position; (3) No fine structure exists in the scattered spectrum of intensity greater than one-fifth the modified line intensity; (4) The ratio of modified to unmodified line intensity is estimated at (7.3:1); (5) There appears to be no essential difference between the results obtained with the single crystal, multicrystal and double crystal spectrometers in the study of this problem.

Purpose of Investigation

VERY early in the study of the Compton effect it was suspected that the modified line might be broader than either the primary line or the unmodified line. Ross[1] was apparently the first to attribute this breadth to the momenta of the scattering electrons. An experiment by Sharp[2] using a single crystal photographic spectrometer at large scattering angle established the fact that the modified line has greater breadth than the primary line or than the unmodified lines.

In the early experiments resolution and homogeneity of scattering angle were sacrificed more or less in order to obtain sufficient intensity for ionization spectrometers or to give photographic spectra in reasonable times. It was therefore difficult to arrive at more than qualitative conclusions as to the breadth and structure of the Compton line. One such qualitative test is to observe whether the $K\alpha$ doublet present in the primary radiation can or cannot be resolved in the modified radiation. In one of the early photographic spectra published by Ross the modified line did appear to be faintly resolved. The resolution of the spectrograph was however barely sufficient to separate the unmodified scattered doublet and the conclusion to be drawn from this

[1] Ross, Proc. Natl. Acad. 9, 246 (1923).
[2] Sharp, Phys. Rev. 26, 691 (1925).

photograph as to the breadth of the modified line remains consequently quite uncertain. Indeed the apparent resolution of the modified doublet might even be attributed to an accident of the photographic emulsion as Compton suggests in "X-Rays and Electrons," page 293.

More recently one of us in collaboration with H. A. Kirkpatrick has shown[3] by means of the multicrystal spectrograph that the breadth of the Compton modified line obeys, as a function of the scattering angle, the law to be expected on the hypothesis that the broadening is a Doppler effect of the moving electrons that scatter the radiation. This law is given roughly by the approximate equation for the breadth

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

Thus for small scattering angles and hard primary radiation the modified line should be narrower than for larger scattering angles and soft primary radiation. Less marked differences in the breadths of the modified lines for different scattering materials might also be expected. *In comparing experimental results on the breadth of the modified line it is therefore essential to be sure that the conditions of the experiment are essentially the same.*

In a previous article one of us[4] has shown that the breadth and structure of the modified line for scattering of Mo$K\alpha$ radiation at large angles by beryllium was consistent with the assumption of two electrons per atom of beryllium dissociated to form a free electron gas of the type postulated by Fermi and Sommerfeld. The observed shape of the modified line from beryllium could be quite consistently accounted for as a Doppler broadening caused by electrons having the statistical velocity distribution quantitatively predicted by Sommerfeld's theory. (The correctness of the assumption of two free electrons per atom in beryllium has recently received support in the study of BeK lines from the work of Martin Söderman.)[5] The modified Compton line from beryllium for Mo$K\alpha$ primary radiation scattered at large angles was observed to be about 22 XU broad at half-maximum, a value much too great to permit resolution of the α doublet which has a separation of only 4 XU.

Measurements of the breadth of the modified Mo$K\alpha$ line scattered at large angles by graphite made with the multicrystal spectrograph show also breadths of the same order of magnitude at half-maximum, again about 22 XU. The resolution was entirely adequate to separate the unmodified $K\alpha$ doublet and the inhomogeneity of scattering angle less than one degree. This breadth is in agreement with the electron velocities to be expected in graphite.

In view of the foregoing the authors of this paper were much astonished to read reports of three other investigators[6] each using a double crystal spectrometer who found much narrower Compton modified lines in quite violent

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

[4] J. W. DuMond, Phys. Rev. **33**, 643 (1929).

[5] Martin Söderman, Zeits. f. Physik **65B**, 656 (1930).

[6] Davis and Mitchell, Phys. Rev. **32**, 331 (1928); J. A. Bearden, Phys. Rev. **36**, 791 (1930); M. A. Gingrich, Phys. Rev. **36**, 1050 (1930).

disagreement with the above results. In one case the $K\alpha$ doublet of molybdenum scattered at large angles by graphite appeared as two extremely sharp peaksin the modified position almost completely resolved.

Some essential and hitherto unsuspected difference might exist between the methods of studying the Compton line with the double spectrometer and with the single spectrometer. The purpose of the present research was therefore to reveal any such effect as well as to check the work of the above mentioned investigators.

Method

Spectrometer. The double crystal calcite spectrometer with internal grid ion chamber and Hoffman type electrometer have been extensively described in another article[7] and need therefore no further space.

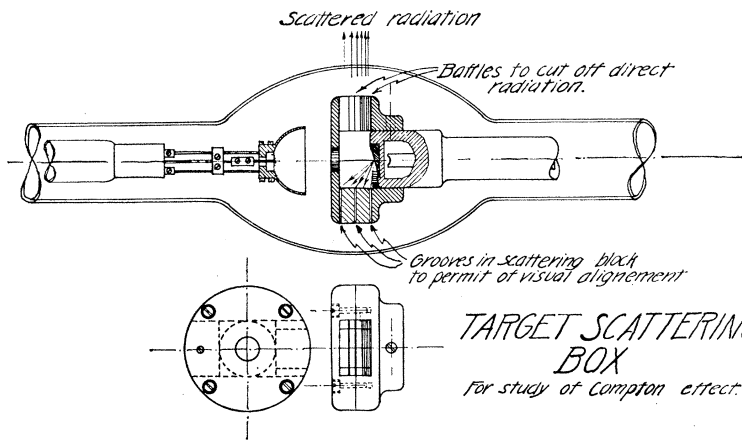

Fig. 1. Special x-ray tube for the study of x-rays scattered at large angles provided with scatterer in vacuum in close proximity to target.

Special x-ray tubes. Two types of tube were tried. These are shown in Figs. 1 and 2. The tube shown in Fig. 1 is provided with a cylindrical copper housing carried on the front end of the target. This housing contains on one side the scatterer and on the opposite side an opening filled with thin steel sheets whose planes are parallel to the face of the target.

These sheets are so spaced that the direct radiation from the focal spot cannot issue between them due to its obliquity. They however permit the scattered radiation from the scatterer to issue freely. The scatterer is traversed by three fine slits parallel to the face of the target, one at the center, one at the side nearest the target and one at the side nearest the cathode. The tube was aligned with the spectrometer by sighting at the crystals through these slits and between the steel sheets. Without this precaution the tube might have been so positioned that the parallel rays demanded by the bicrystalline reflection would be oblique to the steel sheets and considerable loss of scattered intensity would have resulted.

[7] DuMond and Hoyt, Phys. Rev. **36,** 1702 (1930).

The scatterer was wide enough so that the selective reflection could take place over nearly the entire area of the two calcite crystals.

Considerable difficulty was encountered from gas given off by the graphite scatterer during the operation of the tube. After a gas discharge occurred in the tube it became difficult to reproduce conditions of voltage, current and x-ray intensity accurately. A large number of observations must be made in order to distinguish between accidental fluctuations in the readings and real characteristics of the spectrum and the chance that a gas discharge might occur before a sufficient number of readings could be made was deplorably high. The best of a number of curves taken with this tube is shown in Fig. 3. In the others the accidental fluctuations were even more pronounced. That such fluctuations are accidental is evident from the fact that they are not in the least reproducible.

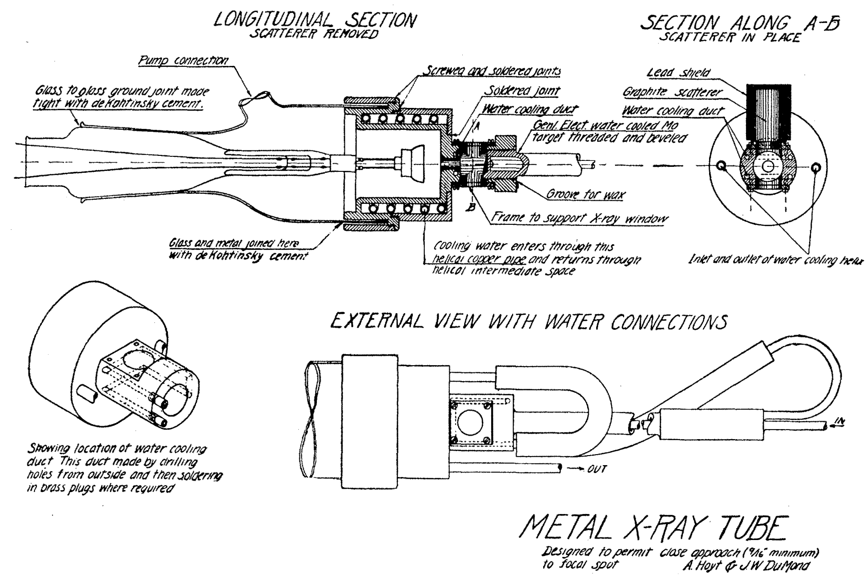

Fig. 2. Special metal x-ray tube for the study of x-rays scattered at large angles provided with windows in close proximity to target to permit placing the scatterer outside vacuum.

On account of these difficulties the tube illustrated in Fig. 2 was constructed to permit a close approach of the scatterer to the focal spot while having the scatterer outside the tube. The windows in this tube are $\frac{1}{2}$ inch inch away from the center of the target. At first mica windows were used on this tube but these were several times destroyed by puncture, probably by fast electrons rediffusing from the focal spot. A thin mirror surface of beryllium deposited on the mica window by evaporation and placed on the inward side to conduct away such fast electrons did not suffice to prevent puncture. Finally aluminum windows 0.003 in. thick were resorted to. The direct radiation has to pass once through the window nearest the scatterer and the scattered radiation passed through both windows. These three passages had the effect of reducing the intensity by about 30 percent.

The graphite scatterer is cylindrical in form, 25 mm in diameter and 48 mm in length. It is completely enclosed in a lead housing 3 mm thick fitting closely about it. The front end of the graphite cylinder is turned down to such a diameter (18 mm) as to fit in direct contact with the entire x-ray window. The effect of the graphite alone could be ascertained by taking control readings with the graphite block removed.

The face of the molybdenum target was bevelled at an angle of 13° with the axis of the tube to reduce the absorption of the characteristic radiation excited in the deeper parts of the target and also to prevent the direct radiation from falling on the spectrometer.

The glass parts of the tube were jointed to each other and to the metal parts with de Khotinsky cement. The target was screwed into place and made tight with the same cement as were also the windows. For this reason the rather elaborate system of water cooling ducts shown in the drawing was provided. It was found entirely adequate to maintain all the joints cold enough to operate very satisfactorily.

Vacuum was maintained in this tube by a two stage mercury diffusion pump hanging under the spectrometer table. This pump was supported from the same rotating false table top[7] to which the x-ray tube was attached so that the pump and x-ray tube moved together as the spectrum was explored, and no flexible vacuum joints were necessary. An internal liquid air trap in a right angle bend in the vacuum line between the pumps and the tube was used instead of the more common type so as to minimize the obstruction offered to the issuance of gas from the tube.

The two curves obtained with this tube are shown in Figs. 4 and 5. It should be noted that much less power was used in this work than was used by two of the above mentioned experimenters. The x-ray tube ran at about 60 K.V. c.p.d.c. and 10.6 and 14.6 ma. in the two cases.

Results

All three curves shown here exhibit deplorably large accidental fluctuations in the readings relative to the faint effects studied. For this reason as large a number of readings as possible were taken. *In every case we have indicated the actual value of every single reading taken by plotting it as one point. No readings taken have been omitted.* In work of this kind there is grave danger of arriving at wrong conclusions by unintentional biased weighting of the observations due to omissions. It was felt to be too misleading to publish only the averages of several readings as this gives no idea of the order of accuracy or reproducibility involved.

Taken alone we do not feel that the curve in Fig. 3 made with the scatterer in the vacuum has enough points to be conclusive.

The other two curves seem to us to definitely indicate a broad diffuse structure for the Compton modified line from Mo$K\alpha$ scattered at large angles by graphite in very satisfactory agreement with the curves obtained at large angles with the multicrystal spectrograph. The smooth curve which we have drawn is intended to guide the eye over the observed points on the steep sides of the intense unmodified lines. We hope the reader will pardon our continuation of these smooth curves through the modified region where they can only be taken as suggesting the general trend of the observations.

A few points were taken with the graphite scatterer removed, the tube running at the same voltage and current as before removal. The modified scattering disappears as would be expected but the unmodified lines are only partly diminished. The amount of this diminution indicated in Figs. 4 and 5 is to be taken as a measure of the unmodified scattering of the graphite. The line intensity remaining in the unmodified position after removal of the graphite is due principally to (1) unmodified scattering of primary radiation at small angles (where it is strong) at the window nearest the spectrometer and

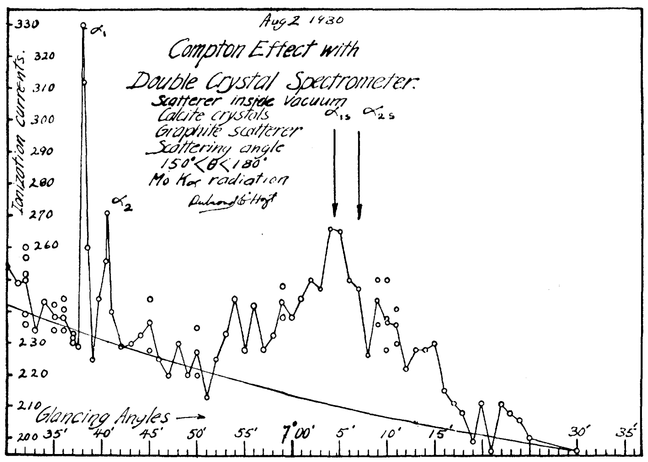

Fig. 3. Spectrum of x-radiation (Mo $K\alpha$) scattered at large angles by graphite with scatterer inside vacuum. The tube shown in Fig. 1 was used.

(2) fluorescence of the molybdenum films unavoidably deposited on both windows by vaporization from the target.

The unmodified lines have been plotted in Fig. 6 to a scale one fifth as high and five times as broad as in Fig. 4 to facilitate measuring their areas for the purpose of estimating the ratio of modified to unmodified intensity. The area thus obtained was multiplied by the ratio of the diminution in peak value of α_1 on removal of the graphite to the peak value with graphite in place in order to obtain the contribution of the graphite scattering alone. These curves in Fig. 6 give a clearer idea of the shape of the unmodified lines given by the double spectrometer here used and its resolving power. The vertical divergence or maximum obliquity of the rays with a plane normal to the dihedral angle formed by the two crystal faces did not exceed two degrees.

The maximum false broadening of the shifted radiation due to the inhomogeneity of scattering angle in these experiments is only 2 X.U.

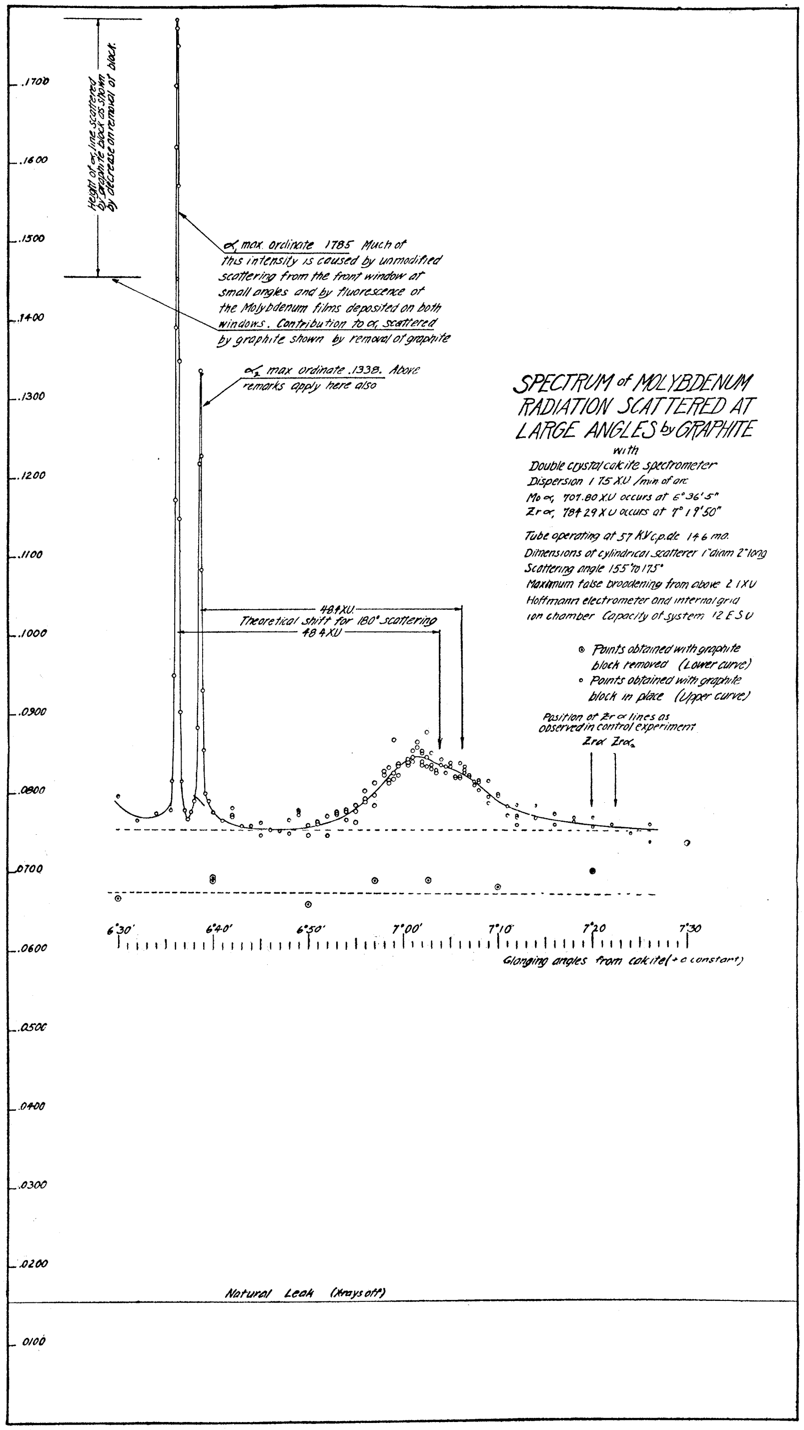

Fig. 4. Spectrum of x-radiation (Mo$K\alpha$) scattered at large angles by graphite with scatterer outside vacuum. The tube shown in Fig. 2 was used.

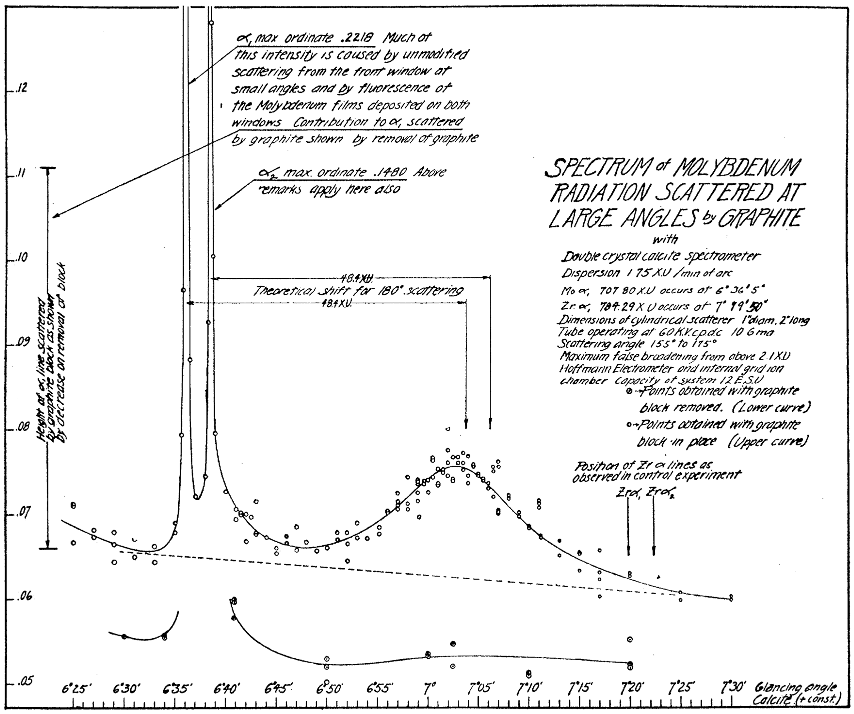

Fig. 5. Spectrum of x-radiation (Mo$K\alpha$) scattered at large angles by graphite with scatterer outside vacuum. The tube shown in Fig. 2 was used.

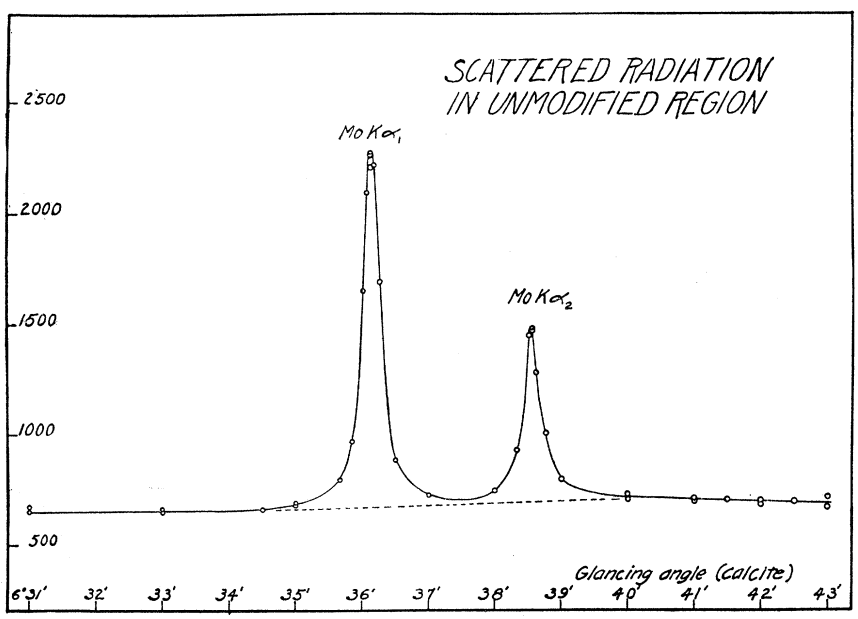

Fig. 6. Unmodified lines of Fig. 4 replotted to one-fifth the scale of ordinates and five times the scale of abscissae.

Conclusions

1. The Compton modified line due to Mo$K\alpha$ radiation scattered by graphite at angles of $165° \pm 10°$ and examined with the double crystal spectrometer has a breadth of from 21 to 22 XU at half-maximum height.

2. Under the above conditions there is no appreciable separation of the $K\alpha$ doublet in the shifted position.

3. No fine structure exists in the scattered spectrum of intensity greater than one fifth the modified line intensity.

4. The ratio of modified to unmodified intensity is estimated at 7.3:1.

5. There appears to be no essential difference between the results obtained with the single crystal, multicrystal and double crystal spectrometers in the study of this problem.

No explanation has been found for the discrepancy between the results of the three observers above referred to and the results here reported. Of the three the one who obtained the sharpest lines used far greater absolute x-ray intensities incident on his scatterer than were used in the present work. It seems quite out of the question however to suppose that his incident energy was sufficient so profoundly to modify the statistics of electron motion in the scatterer as to give a modified line so much sharper than those reported here.