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THE POSITION AND STRUCTURE OF THE MODIFIED LINE OF THE SPECTRUM OF SCATTERED X-RAYS

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Abstract

Measurements have been made by both photographic and single-crystal ionization methods of the shift in wave-length of scattered x-rays at angle of about 170°. The photographic method was that introduced by Sharp, but the $K\beta$ line of molybdenum was used. Two exposures of several hundred hours each were obtained. Analyses of the microphotographic records gave, from the shift of the center of gravity of the lines, $h/mc=0.02305$A, and from the shift of the peaks, $h/mc=0.2374$A. From the difference between different exposures, it is suspected that some hidden source of error is present, perhaps due to the effect of the $K\gamma$ line. Some 600 ionization curves give as an average $h/cm=0.0240\pm0.00024$A. These results, compared with those of other experimenters, fail to indicate any definite departure from the theoretical value of $h/mc=0.2422$A. This does not support the findings of Davis and Purks, who report a value of 0.022A. The form of the spectral lines observed seems inconsistent with a fine structure of the modified line such as reported by Davis and Purks. The modified line is however found to have a considerable natural breadth.

THE well-known expression given by A. H. Compton for the change of wave-length of x-rays scattered at any angle,

$$\delta\lambda = \frac{h}{mc}(1 - \cos\phi), \tag{1}$$

has been tested by many experimenters.[2] Though the results of most of these investigations have been in close agreement with the theoretical formula, recent studies by Davis and Purks and by Davis and Mitchell have appeared to show a wave-length change considerably smaller than the predicted value. It has therefore seemed worth while to try some new experiments of a precision type to measure the wave-length change. Both photographic and ionization methods were employed.

[1] A. H. Compton, Phys. Rev. **21**, 207 and 483 (1923).

[2] E.g. A. H. Compton, Phys. Rev. **22**, 409 (1923); P. A. Ross, Proc. Nat'l Acad. **10**, 304 (1924); H. M. Sharp, Phys. Rev. **26**, 691 (1925); Kallmann and Mark, Naturwissenschaften **14**, 3 (1925); Davis and Mitchell, Phys. Rev. **32**, 331 (1928); J. W. M. DuMond, Phys. Rev. **33**, 643 (1929); Davis and Purks, Phys. Rev. **34**, 1 (1929).

Photographic Method

The photographic method employed was in principle the same as that used by Sharp.[2] The apparatus consists of an x-ray tube with narrow glass walls and a thin glass window w (Fig. 1). The rays are scattered from a paraffin radiator R through an angle ϕ of almost 180°, and are reflected from a polished calcite crystal, through a 0.1 mm. slit S. The spectrum is recorded on a photographic plate P. This construction gives only small variations in the angle of scattering for rays coming from different parts of the scattering block.

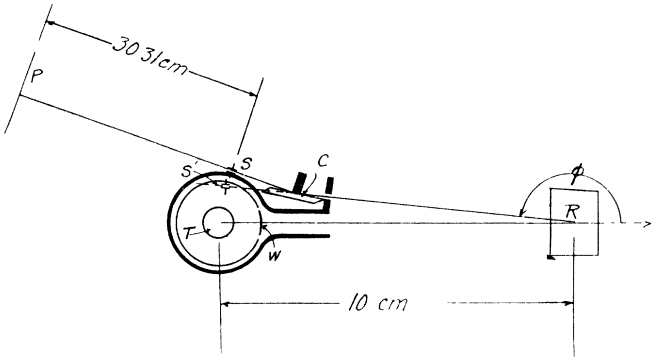


Fig. 1. Arrangement of apparatus.

In Sharp's experiments it was not possible to resolve the α doublet of the molybdenum rays which were used, and still retain sufficient intensity, and this incomplete resolution made necessary complicated corrections. In the present experiments, therefore, the measurements were made on the $K\beta$ line of molybdenum, which is a doublet so narrow that it may be treated as a single line.

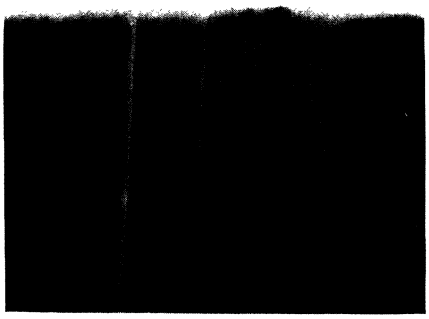


Fig. 2 Photograph of Mo K spectrum.

Two good exposures of several hundred hours were made, with the tube operating on a diffusion pump, at about 38 m.a. and 40 peak kv. To obtain standard reference lines, a molybdenum plate was placed in front of the paraffin radiator, and in some 50 hours a fluorescence spectrum of suitable

intensity was recorded without changing the position of the photographic film. Figure 2 shows one of the photographs thus obtained. The α_1, α_2, β and γ lines of the fluorescent spectrum are clearly visible, as well as the short wave-length continuous spectrum, the modified β line, and (faintly) the modified α line.

A microphotometric record of this film (the average of 11 curves on different parts of the spectral lines), taken with a Moll microphotometer, is shown in Fig. 3.

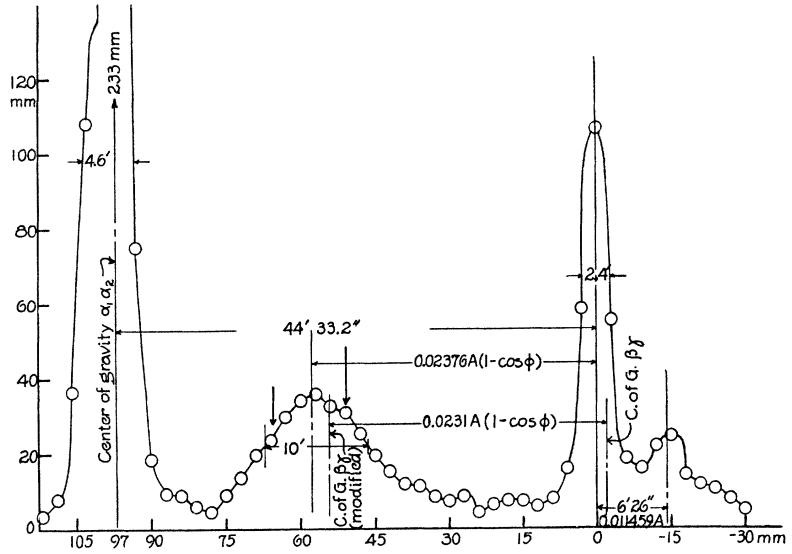


Fig. 3. Microphotometric analysis of Fig. 2. Mo K radiation; scatterers Mo plate and paraffin; $\phi = 169°$. Mean microphotometric curve.

Making use of Allison and Armstrong's values for the wave-lengths of the molybdenum K lines, the mean of several measurements on the *center of gravity* of the modified $\beta\gamma$ line (cf. Fig. 3) give,

$$\delta\lambda = \lambda_{\beta\gamma}\text{mod} - \lambda_{\beta\gamma} = 0.045686A.$$

The mean value of $1-\cos\phi$ was found to be 1.9816, whence by Eq. (1),

$$h/mc = 0.02305A.$$

A similar measurement on the *peaks* of the β line and the β modified line, after correcting for the effect of the unresolved γ modified line in the manner described by Sharp,[2] gives

$$h/mc = 0.02374A.$$

For each individual film the consistency of the measurements was such as to indicate an error of about 1 percent. The results of the two films differed however by about 2.5 percent. This discrepancy suggests that there may be a hidden source of error, perhaps in the effect of the γ line on the position

of the modified peak which, would vary with the conditions of exposure and development. The measurement on the center of gravity depends upon the selection of a base line, and is thus less reliable than the measurement of the peak. It is doubtful therefore whether the observed difference between these results and the value $h/m=0.02422$A, calculated[3] from the accepted values of the constants, is of real significance.

Ionization Method

The values of h/mc obtained from these photographs depart from the accepted value of this quantity in the same direction though not as far as do the values obtained by Davis and his collaborators using the double crystal spectrometer. It was thought worth while therefore to repeat the measurement by an ionization method which should be free from the errors suspected in the photographic work.

In this method two Pyrex x-ray tubes with molybdenum targets were placed side by side, and a Soller[4] slit was used to increase the intensity of the modified radiation to be measured. Because of the low intensities of scattered radiation, an accurate determination of the position of the modified β line could not be made. The α doublet was therefore used, assuming in all calculations that $I_{\alpha_1}=21_{\alpha_2}$, so that the common center of gravity would be 1/3 of their separation distance from α_1.

The experimental arrangement is shown in Fig. 4. To prevent melting

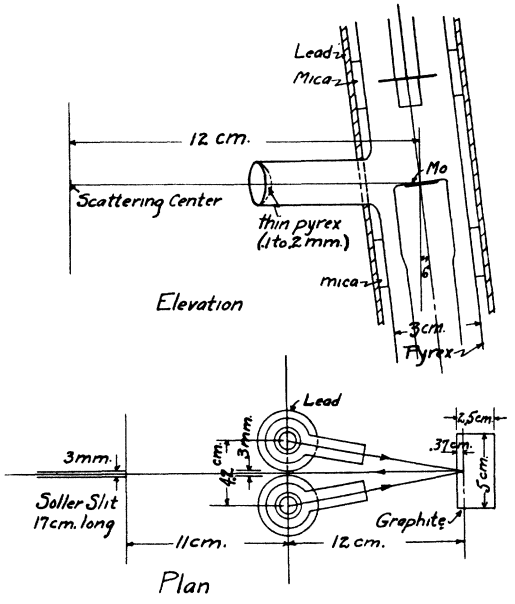


Fig. 4. Experimental arrangement for the ionization method.

[3] This is the average of the values 0.02417 and 0.02428 calculated by Birge (Rev. of Mod. Phys. 1, 64, 1929) from the spectroscopic and the deflection values of e/m respectively.

[4] W. Soller, Phys. Rev. **23**, 292 (1924).

of the waxed ground joint near the cathode of the x-ray tube, it was necessary to maintain a jet of compressed air on each tube. The tubes were operated continuously at 50 kv peak and about 30 m.a. each. The ionization chamber was sulphur insulated and filled with argon. A block of graphite was used as the scattering material. The angle measurements were made from a slow motion screw attached to a Bragg spectrometer. Calibration by a mirror, lamp and scale, showed the readings to be reliable to within 3 seconds over the range of angles used.

Some six hundred runs were made over both the modified and the unmodified lines, and the difference between the positions of their peaks noted. This gave

$$\delta\theta = 27' 11.6'',$$

whence, using $D_{\text{calcite}} = 3.029\text{A}$,

$$\delta\lambda = 0.04757A.$$

The mean scattering angle was 168° 39′, whence

$$(1 - \cos\phi) = 1.9804,$$

and by Eq. (1),

$$h/mc = 0.0240 \pm 0.00024A,$$

This result differs from the theoretical value of 0.02422A by less than the probable experimental error.

TABLE I. *Comparison of results.*

Author	Method	h/mc	Probable error per-cent	Deviation from theory percent
Theory	Accepted values of constants	0.02422	0.3	—
Kallmann and Mark	Mo K, photographic	0.0242	1.	0
Sharp	Mo K, photographic	0.02432	0.4	0.4
Davis and Purks	Mo K ionization double crystal	0.0221	—	−9.
Dumond[5]	Mo K Photographic	0.0234	—	−3.
Nutting[6]	Mo K, (Photographic (peak)	0.02374	1(?)	−2.
Nutting	Mo K ionization, single crystal	0.0240	1	−0.9
Gingrich[7]	Mo K ionization Double crystal	0.02424	0.2	0.1

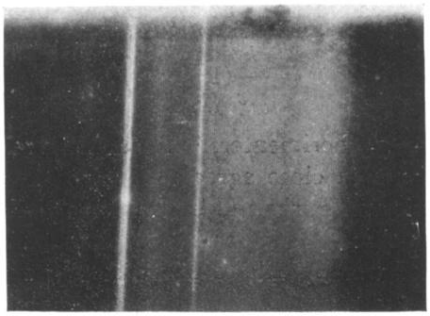
[5] This is the writer's estimate from the data published by DuMond.
[6] The measurement on the center of gravity is not included for reasons given above.
[7] N. S. Gingrich, *Phys. Rev.* **36**, 364 (1930).
This result was published after the work here described was completed.

It will be seen that most of the experiments lie somewhat below the value required by theory. However, the deviation is smallest for the experiments that seem to be most reliable, and it thus appears doubtful whether the difference is a real one At least it can be said that the large deviation of the measurement of Davis and Purks is not confirmed by the other measurements.

Structure of Lines

In the photographic method, there was a maximum spread of the modified line of 2.86 percent due to scattering angle variation. As is shown in Fig. 3, the modified line is not symmetrical, the long wave-length side being steeper. If we assume the same three principal components of the β modified line (neglecting γ of 1/7.7 the intensity) as those given by Davis and Purks[2] for the α_1 line, they would have produced a high peak at the position indicated in Figure 3 by the long arrow and a much weaker one further out (shorter arrow). There is a mere suggeston only of such components in the curve. There seems to be no way in which sharply defined components such as those reported by Davis and Purks could form a curve like the one found in these experiments.

An examination of Figure 2 shows that the resolving power of the spectrograph was sufficient to separate the lines of the α doublet of molybdenum, which are 0.0043A apart. The range of wave-lengths of the modified line due to the variation of 2.86 percent in $(1-\cos\phi)$ is 0.0007A, which is small in comparison with the apparent width of about 0.004A of the β line. This means that the variation in scattering angle results in no appreciable widening of the lines. The apparent broadening of the modified line as compared with the fluorescent lines must therefore mean a variation in wave-length of the rays scattered at a definite angle, in accord with the conclusion of previous observers.



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