X-RAY SPECTRA FROM A RULED REFLECTION GRATING

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We have recently obtained spectra of ordinary X-rays by reflection at very small glancing angles from a grating ruled on speculum metal. Typical spectra thus obtained are shown in the accompanying figures. From some of these spectra it is possible to measure X-ray wave-lengths with considerable precision.

In order to reflect any considerable X-ray energy from a speculum surface it is necessary to work at small glancing angles, within the critical angle for total reflection. (See A. H. Compton, *Phil. Mag.*, **45,** 1121 (1923).) Within this critical angle, which in our experiments, using wave-lengths less than 1.6 angstroms, was less than 25 minutes of arc, the diffraction grating may be used in the same manner as in optical work. The wave-length is given by the usual formula,

$$n\lambda = D\ (\sin\phi + \sin i)$$

where i is the angle of incidence and ϕ is the angle of diffraction for the nth order. For small glancing angles this may be more conveniently written as

$$n\lambda = D\ \{\cos\theta - \cos(\theta + \alpha)\}\ldots\ldots\ldots\ldots\ldots(1)$$

in which θ is the glancing angle and α is the angle between the zero order and the nth order. For the small angles employed this may be written to a very close approximation as

$$\lambda = \frac{D}{n}\left(\alpha\theta + \frac{1}{2}\alpha^2\right)\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In order that several orders of the spectrum should appear inside the critical angle, we had a grating ruled with a comparatively large grating space, $D = 2.000 \times 10^{-3}$ cm. Special pains were taken to obtain a well polished surface, and the ruling was rather light, so as to obtain good reflection from the space between the lines. The reflected beam thus obtained was just as sharply defined as the direct beam.

In our first trials the X-rays direct from the target of a water-cooled Coolidge tube were collimated by fine slits 0.1 mm. broad and about 30 cm. apart. There was some difficulty at first in determining the zero position of the grating but this was solved in the following manner. The primary X-ray beam was first allowed to fall directly upon the film. Then after a brief exposure the speculum grating was brought into the path of the beam by means of a slow motion screw and a longer exposure sufficed to record the reflected image of the zero order, together with the associated first and higher orders. We were able, from the lines thus obtained on the film, to measure both θ and α. Photographs of this type are shown in figure 2 for a copper tube and in figure 3 for a molybdenum tube.

We were not able, with the grating used, to separate sharply the different X-ray spectrum lines. Therefore in order to get a precise measurement of one particular line we reflected the $K\alpha_1$ line of molybdenum from a calcite crystal and studied this beam with the ruled grating. The experimental arrangement is shown diagrammatically in figure 1. Typical diffraction patterns are shown in figures 4 and 5 for two different angles of incidence

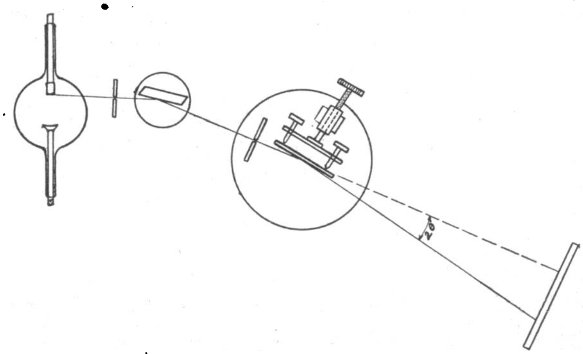

FIGURE 1

of the X-rays on the grating. It was found that the intensity of the spectrum obtained increased with the glancing angle, θ. Thus in figure 4, where $\theta = 0.00095$ radians, only the first order spectrum appears; whereas in figure 5, where $\theta = 0.00308$, there appear the first inside order and three outside orders. The exposure was in each case about 9 hours.

By solving equation 2 for α it will be seen that the inside order cannot appear unless θ is greater than a certain limiting angle. For precise wave-length measurements, however, it is important to have both inside and outside orders because an accurate setting is impossible on the broad zero order line. The image due to the direct beam can of course be made of any desired intensity by controlling the length of its exposure. If β_{-1} is the angle from the image of the direct beam to the first inside order, and β_{+1} that to the first outside order, the glancing angle θ is given by

$$\theta = \frac{\beta_{-1}^2 + \beta_{+1}^2}{2(\beta_{-1} + \beta_{+1})}. \qquad (3)$$

Using this value of θ, the wave-length can be calculated from equation 2. Following are some examples of measurements and calculations. From the film shown in figure 5 we measured $\beta_{-1} = 0.004815$, $\beta_{+1} = 0.00725$.

Thus from equation 3, $\theta = 0.003140$, and $\alpha_{-1} = -0.001462$ and $\alpha_{+1} = 0.000972$. Substituting these values in equation 2, we get $\lambda = 0.704$A.

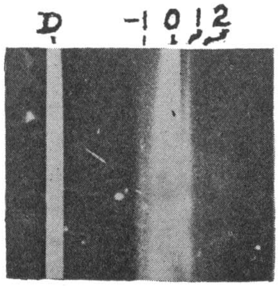

Fig. 3.

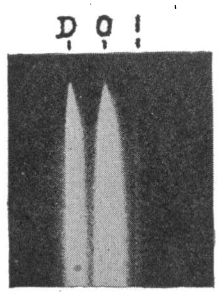

Fig. 4.

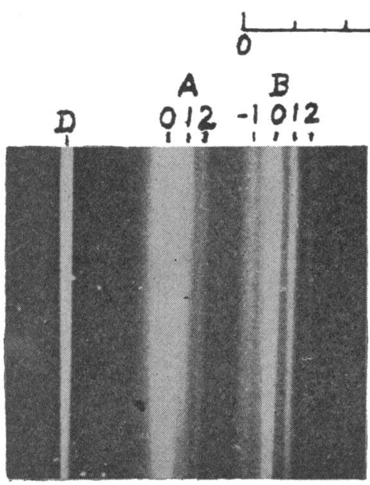

Fig. 2.

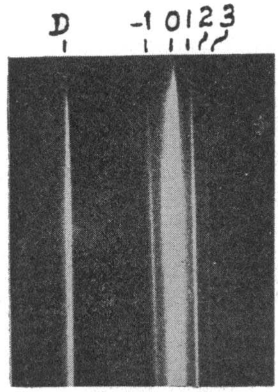

Fig. 5.

Figure 2. Spectrum of X-rays from copper target, excited at 20 kv. D = image of direct beam; for group A, glancing angle $\theta = 9'$, for B $\theta = 20'$. Numbers -1, 0, 1, 2 indicate the order of the spectrum. The absence of order -1 in group A is predicted by equation 2.

Figure 3. Spectrum of X-rays from molybdenum target, excited at about 35 kv.

Figures 4 and 5. Spectra obtained using the $K\alpha_1$ line of molybdenum.

The weighted mean value of our measurements on five films showing from 1 to 4 orders of the spectrum of the molybdenum $K\alpha_1$ line is

$$\lambda = 0.707 \pm 0.003\text{A}.$$

From crystal measurements this wave-length is determined as

$$\lambda = 0.7078 \pm 0.0002\text{A}.$$

The agreement is well within the probable error of our experiments. Our measurements of the spectra, obtained using a copper target, give in a similar manner wave-lengths intermediate between the α and β lines of copper, i.e., about 1.4 to 1.5A.

We see no reason why measurements of the present type may not be made fully as precise as the absolute measurements by reflection from a crystal, in which the probable error is due chiefly to the uncertainty of the crystalline grating space.

AN ATTEMPT TO TEST THE QUANTUM THEORY OF X-RAY SCATTERING

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According to the quantum theory of X-ray scattering worked out by A. H. Compton[1] and Debye[2] the following equation relates the angle ϕ at which a quantum is scattered and the angle θ at which the scattering electron recoils:

$$\tan \theta = -\frac{1}{1+\alpha} \cot \phi/_2. \qquad (1)$$

Here $\alpha = h\nu/mc^2$ and θ and ϕ are measured in the counter-clockwise direction. An attempt to test this equation has been made, using Geiger point-discharge counters to detect the recoil electrons and scattered quanta. Simultaneous registration of a recoil electron and a scattered X-ray quantum, at angles predicted by the above equation, would be evidence in favor of the radiation quantum theory of scattering.

The counters were mounted on arms pivoted at the center of a chamber which could be exhausted. Angles were measured by means of a divided circle mounted in the bottom of the chamber. A system of lead slits was provided both inside and outside the chamber to confine the X-rays to a narrow beam. The X-rays were supplied by a Coolidge tube rated at 200 K. V., and observations were made at 140 and 200 K. V.

Two types of observation were made, the first using a solid scattering target and the second using a gaseous target. In the first case, the counter apertures were covered with thin mica windows and the air exhausted from