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X-RAYS OF LONG WAVE-LENGTH FROM A RULED GRATING*

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Abstract

By the use of a grating ruled on glass (200 lines per millimeter) at grazing incidence (20′ to 40′) in vacuum, the following lines have been obtained: $M\alpha$ of platinum (6A); $K\alpha$ of aluminum (8.3A); $L\alpha$ of copper (13.3A); $L\alpha$ of iron (17.7A); $L\alpha$ of chromium (21.5A); $K\alpha$ of carbon (45.8A). A water-cooled metal x-ray tube with hot lime-coated platinum cathode was used. This was connected directly to the spectrometer with no absorbing film between the anticathode and the photographic plate. Wave-lengths were determined with reference to $L\alpha$ of copper and also directly by calculation from the constants of the spectrometer.

Introduction

It has been shown[1] recently that x-ray spectra can be obtained from a grating ruled on speculum metal if the radiation strike the grating sufficiently near grazing incidence to be within the angle of total reflection.[2] In the experiments referred to the K characteristic radiation of molybdenum and copper were used. It was found necessary first to eliminate the general radiation by reflecting the x-rays from a calcite crystal before they fell on the grating. Further experiments,[3] in which a grating ruled on glass was used, have given some of the strong lines of the K spectrum of copper and iron, thus extending the range investigated directly by this method to approximately 2 Angstrom units. For longer wave-lengths the radiation becomes so absorbable that the experiments have to be carried out in vacuum. The present investigation was undertaken to extend the measurements by this method to longer wave-lengths by the use of a vacuum spectrometer.

Method

The principle involved in the method is illustrated by Fig. 1. If x-rays, which have passed through slits S_1S_2, fall on the surface of the grating G at an angle of incidence θ which is within the angle of total reflection for the

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[1] A. H. Compton: Proc. Nat. Acad. Sci. **11**, p. 598 (1925).

[2] A. H. Compton: Phil. Mag. **45**, p. 1121 (1923).

[3] J. Thibaud: Revue d'optique theorique et instrumentale, **5**, p. 97 (1926).

radiation under consideration, the totally reflected x-rays will strike the plate P at R and the radiation diffracted by the grating at a point S. D is a portion of the direct beam which is used as a reference line. If λ is the wave-length of the incident radiation, α the angle between the regularly

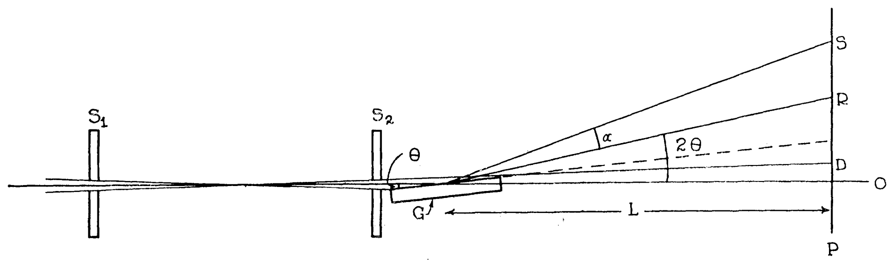

Fig. 1.

reflected and diffracted beams, d the distance apart of the lines of the grating, and n the order of the spectrum, it can be shown that

$$n\lambda = \tfrac{1}{2}d(\alpha^2 + 2\alpha\theta) \qquad (1)$$

The location of the center O of the direct image and the effective center of the grating presents some difficulty in this method since most of the direct beam is cut off by the grating. These can be found either by making a preliminary exposure before the grating is in place or by determining the relative separation of the same two lines on plates exposed at different known distances from the grating and then projecting back to the point of convergence at the grating, thereby determining the effective distance L from the grating to the plate.

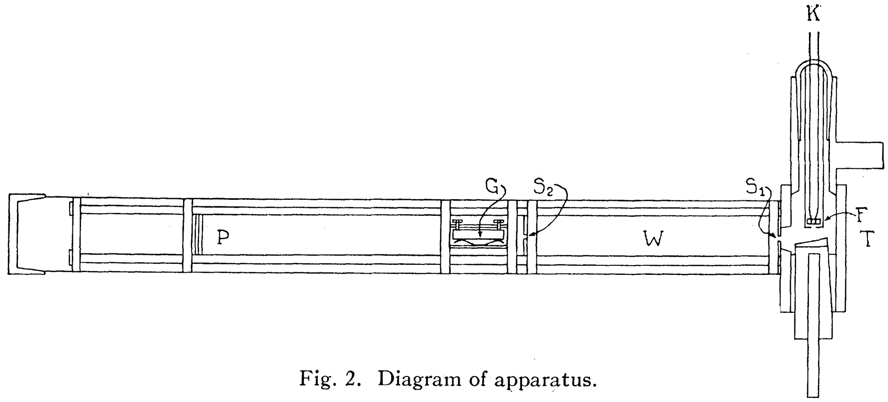

Fig. 2. Diagram of apparatus.

Apparatus

The apparatus is shown in Fig. 2. It consisted of a metal x-ray tube T with water-cooled anticathode A, and water-cooled jacket, attached directly, with no separating film or diaphragm between, to the large brass tube W which contained the spectrometer proper. The cathode K was made of Pyrex glass with tungsten leads and an oxide coated platinum ring-shaped filament F which was heated by current from a storage battery with rheostat in circuit to control the current through the tube. Both the cathode and the anticathode were removable to make possible replacement of the filament and changing of the anticathode material. The spectrometer proper consisted of two adjustable steel slits S_1S_2, a plane grating[4] G ruled on glass (200 lines per mm, aperture 8000 lines), which was held by springs against adjustment screws to control the angle of incidence, and a photographic plate P mounted in a metal cassette. These essential parts were all mounted on a rigid metal frame which could be slid in and out of the brass tube, thus permitting adjustment of the slits and grating and the distance apart of the different members before placing the whole unit in the brass tube. Taper joints sealed with pizein wax were used throughout. The entire apparatus was pumped to an x-ray vacuum by the use of a two-stage mercury condensation pump in series with a rotary oil pump. The cassette was provided with a hinged cover, controlled from behind, which was opened after the frame holding the spectrometer parts had been inserted in the brass tube, and closed again after exposure to the x-rays, so that the cassette could be removed to develop the plate.

The slits S_1S_2 were approximately 0.5 mm wide and 20 cm apart. The grating was placed immediately beyond the second slit and adjusted so that a part of the direct beam passed by the farther edge of the grating and fell on the plate to serve as a line of reference in computing the wave-lengths. The graduations extended to within 5 mm of the end of the grating. The angles of incidence of the grating were $20'$ and $40'$, respectively, in the two series of measurements reported. The photographic plate was located at distances of from 10 to 30 cm from the grating. Contrast plates, developed in contrast developer, were used. These were found to give more satisfactory results than fast plates because the latter showed so much surface fogging, due to scattered x-rays, that the spectral lines were obscured. Ten kilovolts were applied to the tube. This is much in excess of the theoretical minimum required to excite the lines under investigation, but a large increase in intensity was thereby gained which offset the disadvantage of additional fogging, due to scattered radiation of shorter wave-lengths emitted at the higher voltage. It may also be noted that this latter radiation is largely eliminated by increasing the angle of incidence beyond the angle of total reflection for the radiation of shorter wave-lengths than that under investigation. The times of exposure were from twenty minutes to one hour, with a tube current of ten milli-amperes. The use of a hot, lime-coated platinum cathode insured an adequate supply of electrons at a sufficiently low temperature to prevent the presence of much ordinary light, and thus permitted the elimination of all films and screens between the anticathode and the photographic plate. This allowed the full intensity of radiation to

[4] The grating was ruled by Dr. W. Souder at the Bureau of Standards.

reach the plate and eliminated the possibility of selective absorption. Hot tungsten cathodes were tried and found to cause excessive fogging.

Results

The results are shown in Fig. 3. The effect of covering part of the plate with thin black paper is shown for the copper spectrum in the first series and for all the spectra in the second series. Only the central image *D* and total reflection line *R* due to the more penetrating part of the general radiation passed through. The spectrum lines were entirely cut off. Since the graduations extended 4 cm lengthwise of the grating and reflection took place from the entire area, the spectral lines are rather broad. This, together with the fact that the dispersion was not great, did not permit resolution of the weaker lines. The wave-lengths given in the accompanying table are, therefore, assigned to the intense $K\alpha$ lines. The chromium line was too faint for

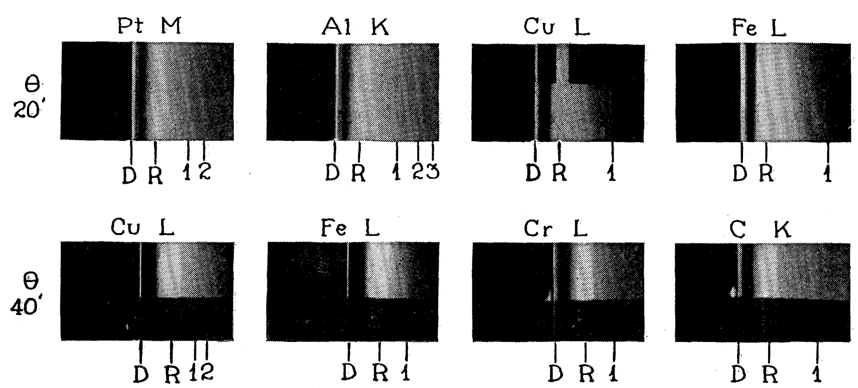

Fig. 3. X-ray spectra from a ruled grating. *D* is the direct beam, *R* the line of total reflection, 1, 2, 3 the order of the spectra.

accurate measurement. The apparatus in these preliminary experiments was arranged primarily to secure the greatest possible intensity, since the lines were all rather weak, and was not well suited to precise quantitative measurements. This was due to the width of the slits, the nearness of the plate to the grating, and the aperture of the grating which not only caused the broadening of the lines above referred to but introduced an uncertainty as to the location of the effective center of the grating. To identify the lines the wave-lengths given in Table I have been calculated by assuming the value for the wave-length of copper $L\alpha$ radiation obtained by crystal measurements; that is, 13.3A and computing from this value the corrected distance to the reference point on the plate for all the other wave-lengths. In the first series the first order $L\alpha$ line was chosen because the second order was faint, and in the second series the second order $L\alpha$. The values agree in most cases within 0.1A with those found by reflection from crystals, given in the last column.

A direct calculation of the wave-lengths was also made. For this the effective center of the grating was first determined by measuring the relative separation of the first and second order Al $K\alpha$ lines when the plate was located at 10, 20 and 30 cm from the grating for the first series; and also from the distance of the first order C $K\alpha$ lines from the central reference line when the plate was at 10 and 15 cm from the grating in the second series; and then projecting back to the points of convergence on the grating. The angle of incidence on the grating was determined accurately by measurement with telescope and scale. From these data the position of the center, O, (Fig. 1), can be found and the angle of diffraction α computed. The wave-lengths can then be computed by substituting the values thus obtained in Eq. (1). The results are shown in Table II. This method of computing the center of the system is not very precise but had to be resorted to in these initial experiments since it was not convenient to locate the center by making a preliminary exposure of the photographic plate before the grating was in place.

TABLE I

Wave-lengths of various x-ray lines as computed from grating measurements using Cu Lα as a standard.

Element	Line	Wave-length from grating $\theta=20'$ $n=1$	$20'$ 2	$20'$ 3	$40'$ 1	$40'$ 2	Wave-length from crystals
Pt	$M\alpha$	6.0A	6.0A	5.9*A			6.0A
Al	$K\alpha$	8.4	8.4	8.3*			8.3
Cu	$L\alpha$	(13.3)†	13.5		13.1A	(13.3)A†	13.3
Fe	$L\alpha$	17.8			17.8		17.7
C	$K\alpha$				46.0		45.5

* Faint.
† Used as reference line in computing wave-lengths.

TABLE II

Direct calculation of x-ray wave-lengths from grating constants.

Element	Line	Wave-lengths (Angstroms)
Pt	$M\alpha$	6.1
Al	$K\alpha$	8.5
Cu	$L\alpha$	13.6
Fe	$L\alpha$	18.0
C	$K\alpha$	45.8

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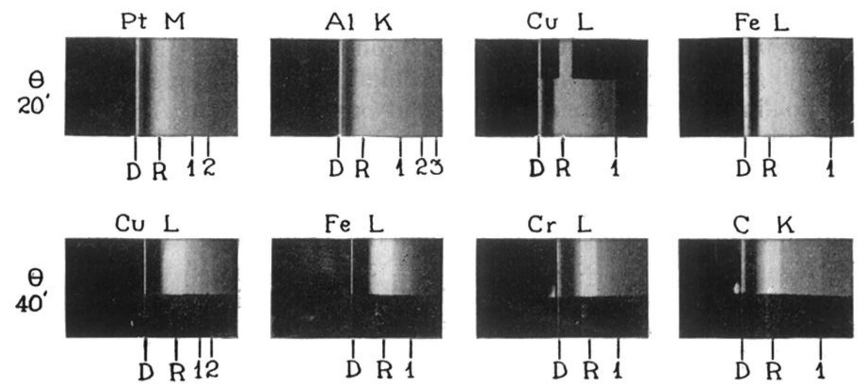

Fig. 3. X-ray spectra from a ruled grating. *D* is the direct beam, *R* the line of total reflection, 1, 2, 3 the order of the spectra.