A NEW DESIGN OF PRECISION X-RAY SPECTROMETER.

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Synopsis.

Principle of the Spectrometer.—The spectrometer is especially designed to make use of the "*Method of Displacement,*" already published, for the determination of X-ray wave-lengths. This method is briefly described.

Description of the Spectrometer.—A detailed description of the spectrometer with a plan and side elevation are given.

Adjustments.—The processes involved in the adjustment of the spectrometer for precision measurements on X-ray wave-lengths are explained in detail.

Verification of the Fundamental Assumption on which the "Method of Displacement" is Based.—The method requires that a portion of the length of a beam of X-rays, after reflection, shall be of constant width. The possibility of this has been previously demonstrated on theoretical grounds. An exploration of the reflected beam for the α_1 line of the K series of silver has been made and the results are found to agree with theory.

Principle.

A METHOD has been devised for measuring wave-lengths in the X-ray region of the spectrum, by Professor H. S. Uhler,[1] which promises to eliminate many of the errors involved in earlier methods. The method requires the use of two slits of equal width between the source of rays and the crystal and a means of displacing the photographic plate in a straight line parallel to the line of collimation of the spectrometer, the plate undergoing no rotation during the displacement. The glancing angle of reflection at the crystal is then determined solely by the distance apart of the spectral lines, taken on both sides of the direct image of the slits in the two positions of the plate, and the distance through which the plate has been displaced. These distances can both be measured on the same comparator, thus making the determination of glancing angles depend solely on two linear measurements in the same units.

This method of displacement for determining glancing angles was given a preliminary trial by Uhler and myself[2] in our work on the K series of gallium. The spectrometer we then used had not been constructed originally for this method, but the results obtained with the remodelled apparatus encouraged us to believe that with a properly designed instrument the method would be capable of great precision.

[1] Uhler, Phys. Rev., N.S., Vol. XI., No. 1, p. 1, 1918.

[2] Uhler and Cooksey, Phys. Rev., N.S., Vol. X., No. 6, p. 645, 1917.

Description.

The spectrometer is shown in plan and elevation in Figs. 1 and 2. The main part of the spectrometer consists of a heavy cast iron base A, in the form of a rectangle, about 78 cm. long by 29 cm. wide. At the center of one end of this base is a vertical bracket carrying a vertical slit, S_1, with adjustable gold jaws 2.4 mm. thick. The base A is provided on one side with a V rail and on the other with a plane surface running parallel to the long axis of the rectangle. Another rectangular base, L, having a foot with a V groove at each end of one side, and a foot with a plane bottom at the middle of the other side, can slide on the rails of base A toward or away from S_1. A Société Genevoise circular dividing engine, without its knife carriage, is bolted on the upper surface of L in such a manner that the axis of rotation of the revolving table is parallel to the long axis of S_1. The normal from the center of S_1 to the axis of rotation forms the collimating line of the spectrometer. A second slit, S_2, similar to S_1, is fastened to the base of the dividing engine

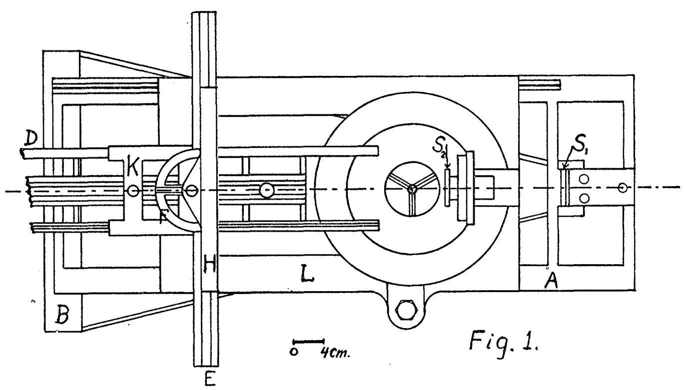

Fig. 1.

between its axis of rotation and S_1, and at the same height as S_1. S_2 is normally at a distance of 4.5 cm. from the axis of rotation, but this distance can be altered by a few centimeters. S_2 is provided with a slow motion adjustment by which it can be moved horizontally at right angles to the line of collimation. Another adjustment permits its rotation about this line or a parallel line as axis.

The face-plate of the dividing engine has fastened at its center a brass plate with three V grooves 120° apart, radiating from the axis of rotation. Two stands, not shown in the figures, are provided with three legs each to fit into these grooves. One of these stands has fastened to it the crystal holder. This holder has two horizontal linear adjustments, one parallel to, and the other at right angles to, the crystal face. A third adjustment permits the crystal to be rotated about a horizontal axis parallel to its face. The other stand supports a slit, S_3, used only in adjusting the spectrometer. This slit is of fixed width of about 0.02 mm., and the jaws of the slit, when in place, do not come above the collimating line. Thus this slit does not limit those rays coming through S_1 and S_2 which are directed above the collimating line when they reach the third slit. S_3 is provided with adjustments by which the center of the upper end of the opening between the jaws can be made to remain accurately in the axis of rotation while the divided circle is turned through 360°. This adjustment was made under a high-power microscope, provided with cross hairs, and the fact that it is possible to so adjust the slit that no motion of the point referred to can be detected when the divided circle is rotated shows that the axle and bearings of the dividing engine are very true.

On the dividing engine base, diametrically opposite S_2 is mounted a pair of rails, D, about 42 cm. long and 10 cm. between centers. The casting carrying these rails is pivoted on the engine base so that the rails can be made parallel to the line of collimation. One of these rails is

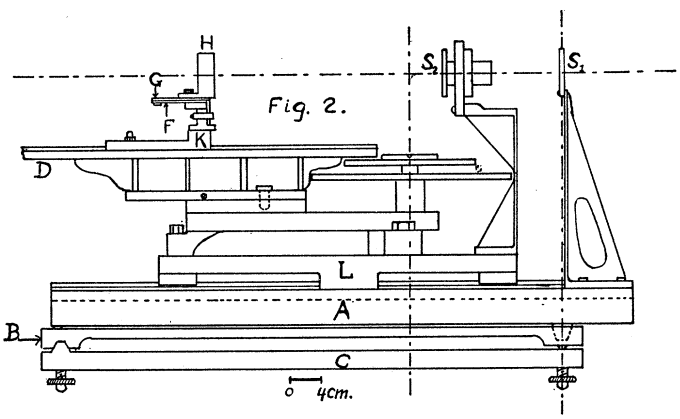

Fig. 2.

V-shaped in section, and the other square, with its upper surface plane. They were very carefully machined and ground smooth.

A carriage, K, fits on these rails and is furnished with a clamping screw to lock it tight to them at any point of their length. The extreme distance of this carriage from the axis of rotation of the spectrometer can be limited by an adjustable stop clamped to one of the rails, or by a rod of known length placed between the stop and the end of the carriage. It is this feature which permits the use of the "Method of Displacement" already referred to. The end of the carriage nearer S_2 has fastened to it a horizontal aluminium rail, *E*, 42 cm. long, with its long axis at right angles to the direction of motion of the carriage. The transverse section of this rail is an inverted T. A horizontal brass semicircle, *F*, with a flange projecting vertically downward can be clamped on the T rail at any point. A flat brass plate, *G*, rests on top of the semicircle and is pivoted at its center. It can be rotated on the semicircle and clamped at any desired angle, *F* and *G* together forming a sort of protractor.

The plateholder, *H*, is a cast aluminium rectangular box, with plane surfaces inside, against which the plate can be pressed flat by means of strong springs on a wooden cover at the back. To allow for variations in the thickness of plates, the cover is lined with thick felt on the inside. A rectangular opening about 24 cm. long by 1.5 cm. high is cut in the front of the box and covered with black paper. The paper can easily be removed to permit a view through the plateholder or the measurement of the distance from the plate to the axis of rotation. The plateholder accommodates plates 25.4 cm. by 3 cm., the latter figure being determined by the dimensions of the device for holding the plates on the comparator used for measuring them. The central portion of the bottom of the casting extends behind the plane of the back of the rectangle in the form of a tongue, the bottom of which was machined flat. This tongue is provided with two dowel pins and a screw by which the plateholder can be screwed tight to the azimuth plate, *G*.

ADJUSTMENTS.

The object of this method of mounting the plateholder is to be able to photograph several spectral lines at a long distance from the direct beam without having to use excessively long plates and to be able to adjust the plane of the plate so that it may be either at right angles to the collimating line, or to the beam reflected from the crystal. A very convenient use of the aluminium T rail is in taking what I call "Range Plates." In using two very narrow slits it is necessary to know very closely what setting of the crystal gives the best reflection for a particular wave-length. To ascertain this a series of exposures of equal length are taken on the same plate, the plateholder being displaced a small distance along the T rail between each exposure, and the crystal setting altered a small amount. A comparison of these exposures shows, not only the best setting of the crystal, but, if enough are taken, the effective range of reflection of the crystal for the particular width of slits chosen.

The object of mounting the plateholder, crystal, and S_2 on a separate base from that on which S_1 is mounted is to be able to conveniently vary the distance between S_1 and the axis of rotation of the spectrometer, which at the same time would, of course, vary the distance between S_1 and S_2. The distance of S_1 from the axis can be varied from about 11 cm. to about 35 cm.

The base A of the spectrometer is pivoted on a triangular cast iron base, B, in such a manner that A can be given a small rotation about the long axis of S_1 as axis. The base B rests, in turn, on a similar base, C, provided with ways on which B can slide a short distance at right angles to the collimating line. The base C is supported on leveling screws. Finally the table of the spectrometer can be rotated back and forth through a small angle by means of a spring motor connected to the tangent screw of the dividing engine through a connecting rod and crank.

The object of this rather elaborate mounting is to facilitate the lining up of the spectrometer with the focal spot on the anti-cathode of the X-ray tube. In working with soft X-rays it is necessary to have a window in the tube which will not absorb too much of the energy. Thin aluminium is very good for this purpose, but, when very thin, the window must be quite small, thus giving an emergent pencil of rays of small angular width. Experience has taught me that it is quite difficult, without special means, to make the collimating axis of the spectrometer coincide with the axis of this pencil. This adjustment is simple with the mounting described above. The instrument is first brought roughly into line with the aid of a fluorescent screen. A plate is then placed immediately behind S_1 and two exposures taken on it; a long exposure with the slit narrow and a short one with the slit wide open or removed entirely. This gives the projected images of the slit and the aluminium window superposed on each other. The center of the image of the window is then marked with a fine scratch, and the plate replaced in the position in which it was when the exposures were taken. By focusing the cross hairs of a microscope on the center of the image of the window, and moving the spectrometer across base C till the image of the slit comes under the cross hairs, S_1 is brought into the axis of the pencil of X-rays. In order to bring the collimating line of the spectrometer in coincidence with the axis of the pencil, S_3 is placed in position on the spectrometer table, and a plate placed immediately behind it. An exposure is then taken with S_1 narrow, and, if the lineup is badly out, another with S_1 wide open, and a screen placed directly above S_3. This gives two images, one above the other; the center of the upper one gives the position of the axis of the pencil, while the center of the lower one gives the position of the axis of rotation of the spectrometer with respect to the former. The plate is replaced on the spectrometer, and a microscope focused on the center of the upper image. The spectrometer is then rotated on base B, about S_1 as an axis, till the image of S_3 comes under the cross hairs. The axis of the pencil of rays coming through the window on the tube will then pass through S_1 and the axis of rotation of the spectrometer. This being done, a similar method of superposed exposures will show the position of S_2 with respect to the collimating line, and any error can be corrected by means of the transverse adjustment referred to above. By means of a pair of parallels temporarily supported on the divided circle and extending between S_1 and S_2, the plateholder can be placed first in front of one slit, and then in front of the other without any rotation about the normal to the plate. Images of both slits can be taken close together on the same plate and any lack of parallelism between the slits corrected by means of the rotational adjustment on S_2 referred to above.

The rails D are made parallel to the collimating line by making S_1 and S_2 very narrow, and taking one exposure on the upper half of the plate when it is directly over the bearing on which the rails are pivoted, and a second on the lower half of the plate when it is at the extreme end of the rails. The rails can then be rotated so that their extreme end moves through the distance between these images. The straightness of the rails was tested by covering the plate with a screen having a narrow horizontal slit, and taking exposures with S_1 and S_2 narrow and the plate at different positions on the rails, the horizontal slit being moved vertically by its own width between each exposure. At the time of writing, the rails have been found to be very true, though there seems to be a very slight transverse shift of the plate when moved between certain positions. This may be due to dirt, but if it persists in future tests it can easily be measured and allowed for in determining wave-lengths by the "Method of Displacement."

The azimuth angle between the normal to the plane of the plate and the collimating line is completely determined by the difference in distance between the same spectral line photographed on each side of the central beam in two different positions of the plate on the rails D, and the distance between these positions. This angle can be made zero by rotating the plate G on the circle F or can be applied as a correction in the calculation of wave-lengths.

If the plane of the crystal is not exactly parallel to the axis of rotation of the spectrometer, the lines taken on either side of the central beam will be inclined to each other by four times the angle between the plane of the crystal and the axis. If two plates are taken at the same distance from the axis of rotation, each with the same line on both sides of the central beam, and are then placed with their gelatin sides together, and the top of one at the bottom of the other, in such a manner that the corresponding lines on one side of the center are superposed, then the corresponding lines on the other side will be inclined to each other by eight times the angle of tilt of the crystal. This makes a very delicate method of detecting any error in the adjustment of the crystal face.

Verification of the Theory.

It has been shown theoretically by Uhler[1] that a certain portion of a beam of monochromatic X-rays passing through two slits of equal width and reflected from a crystal is of a rectangular cross-section in a plane normal to the mutually parallel long axes of the slits, the length of the rectangular portion being equal to the distance between the slits, and the width being equal to the width of the slits. I have explored this rectangular portion of the beam in the case of the α_1 line of the K series of silver. The distances from the axis of rotation to S_1 and S_2 were 20 cm. and 4.5 cm. respectively, thus making the rectangular portion of the reflected beam 15.5 cm. long. Exposures were taken on the same plate at both ends of the rectangle and at points one quarter, one half, and three quarters of its length. This was done with both slits about 0.02 mm. wide and again with them 0.1 mm. wide. During the exposures the crystal was rotated back and forth through an angle of $3'$ about the position which gave the best reflection.

The results of these photographs are in good agreement with Uhler's deduction that the portion of the reflected beam between the foci of the slits is rectangular in cross-section and of the same width as the slits. The exposures with the wider slits were purposely made short that they might bring out any lack of uniformity in the distribution of energy across the width of the beam at the different parts of its length. The results showed that the energy was fairly uniformly distributed and that, if the lines were thoroughly exposed, there should be no danger of an asymmetric blackening with respect to their axes.

Though this spectrometer has not yet been used for the direct determination of wave-lengths, every indication points to its giving a high degree of precision in such work. It should be pointed out here that there is nothing about the construction of the instrument to prevent its being used in the ordinary way for determining glancing angles by measuring the distance of the plate from the axis of rotation. Indeed, a determination of the glancing angle by both methods might give a measure of the depth of the mean reflecting plane of the crystal.

[1] *Loc. cit.*

In conclusion I wish to express my thanks to Professor Uhler for his many helpful suggestions and advice in connection with the design and adjusting of this instrument and especially for the plateholder and its adjustable mounting which were designed by him.

SLOANE PHYSICAL LABORATORY,
YALE UNIVERSITY,
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