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A DETERMINATION OF THE WAVE-LENGTH OF THE Kα LINE OF CARBON

By B. B. Weatherby

Abstract

A simplified type of vacuum spectrometer utilizing a plane glass grating with 250 lines per mm was used to measure the wave-length of the $K\alpha$ line of carbon. A water-cooled metal x-ray tube with tungsten cathode was connected directly with the spectrometer without the interposition of any absorbing screen in the x-ray beam. The measurements were made under varying conditions. The angle of incidence being varied from 20′ to 50′ and the distance from grating to plate from 50 cm to 80 cm. A weighted mean of all determinations gives the wave-length of the $K\alpha$ line of carbon as 45.4A.

Introduction

Within the last year the extension of the diffraction grating method to soft x-rays has led to the measurement of a number of soft x-ray wave-lengths. The region investigated lies in the gap previously existing between the soft x-rays and the extreme ultra-violet. The gap between 27A and 136A has been worked on by Hunt[1] and by Thibaud,[2] using the plane grating, and by Osgood[3] using a concave grating. Dauvillier[4] using a fatty acid crystal has also made some measurements in the same region. The theory of using a line grating at grazing incidence with the x-rays striking within the angle of total reflection was first given by A. H. Compton.[5]

Unfortunately the results obtained by the investigations above referred to are not concordant, a variation of from 0.2A to 2A occurring on some of the lines. The wave-length of the $K\alpha$ carbon line, for example, varies from 43.96A according to Osgood to 46.0A according to Hunt. Dauvillier obtained 45.5A while Thibaud gives 44.9A. Since, because either of grease vapors or residual gases, this line appears on nearly all plates irrespective of the material of the cathode or anti-cathode, it makes a very good line to be used for reference or standardization purposes. It therefore seemed advisable to determine with some care the wave-length of the $K\alpha$ carbon

[1] Hunt, Phys. Rev. **30**, 227 (1927).
[2] Thibaud, Phys. Zeits. **29**, 241 (1928).
[3] Osgood, Phys. Rev. **30**, 567 (1927).
[4] Dauvillier, Jour. d. Physique **8**, 1 (1927).
[5] A. H. Compton, Phil. Mag. **45**, 1121 (1923); Proc. Nat. Acad. Sci. **11**, 598 (1925).

line. This has been done with a new form of vacuum spectrometer as a preliminary to a more extended investigation and is reported in this paper.

Apparatus

The apparatus is shown in Fig. 1. A brass tube 120 cm long and 11 cm in diameter was threaded at both ends. A brass cap *C* was screwed on one end and then waxed, while to the other end was fastened an ordinary T-casting *A*. The whole was then silver-plated to help prevent the emission of occluded gases. Both cathode and anti-cathode were fastened to the center of brass disks which were sealed to the side arms of the T with wax. The anticathode of copper was internally water-cooled. The angle on the face was about 10°. The cathode was made of heavy copper tubing and had a current-carrying capacity of 25 amps. It was externally water-cooled. A shield *B* was affixed to the cathode in order to place the first slit in the optical shadow of the filament. A heavy tungsten filament using about 15 amps. was placed 1 cm from the anti-cathode. Oxide filaments were tried but were discarded because the coatings disintegrated too rapidly under the

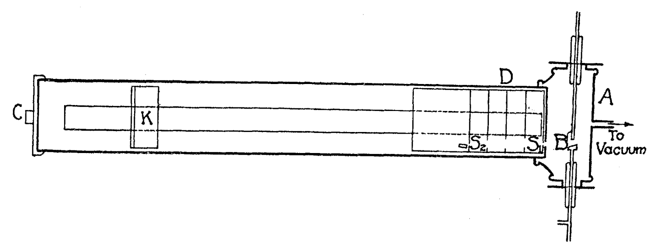

Fig. 1. Diagram of apparatus.

positive ion bombardment. The voltage for the x-ray tube was obtained from a 2000 volt d.c. generator. Transformers giving a R.M.S. voltage of 4400 were also used but did not give any better results than the generator and caused trouble by producing arcs in the tube.

The whole apparatus was evacuated by two stages of mercury diffusion pumps backed by a rotary oil pump. A vacuum of 0.0002 mm could be maintained during the operation of the x-ray tube.

An optical bench, one meter long, of heavy steel was made to carry the elements of the spectrometer. This was inserted at the *C* end of the apparatus. The front platform *D* carried the slit system and the grating. The distance apart of the slits was 18 cm. The slit width was adjustable being usually from 0.2 mm to 0.3 mm. The slit S_1 fitted snugly against a brass disk, with a rectangular opening in it, which closed the end of the spectrometer tube. There was a system of diaphragms between S_1 and S_2 to exclude visible light from the spectrometer.

The grating was mounted immediately behind the second slit. It could be adjusted and locked in any position. The grating was of glass and had 250 lines per mm. The constant was measured using the 5461A line of mercury. This determination was certainly more accurate than the rest of the experiment. The aperture of the grating was 5 mm and it was ruled up to each edge. Larger aperture gratings were tried but had a tendency to broaden the lines and to make the location of the effective center of the grating more difficult. The angle of incidence varied from 25′ to 50′. The plate holder K could be moved along the platform and clamped in any position. It consisted of a light-tight box with a hinged iron lid on the front. The lid could be raised or lowered by means of an electromagnet outside the tube, an arrangement permitting the tube to be cleaned without fogging the plate. Distances from grating to plate of from 50 to 80 cm were ordinarily used.

Several kinds of plates were tried. Oiling of the plates was found unnecessary. Eastman Kodak Co. No. 36, a fairly fast plate, was found to be most satisfactory. Contrast plates with contrast developer gave less fogging but also less line intensity.

Procedure

The ordinary formula $n\lambda = D(\sin i \pm \sin\theta)$ used for the plane grating may be modified to $n\lambda = D\alpha(\alpha + 2\theta)/2$ for tangent incidence. Since that portion of the direct beam passing by the grating and also the reflected beam are of considerable width care must be exercised in the method of measuring the plate. Suppose in Fig. 2 that AC represents the width of the direct beam

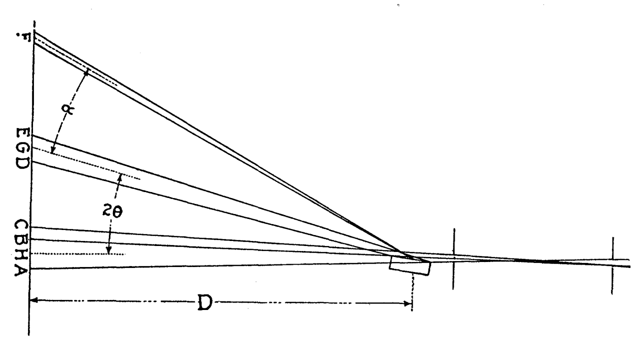

Fig. 2.

in the absence of the grating. On interposing the grating, part of this beam is cut off and only the part BC will remain. The portion cut off by the grating will be reflected to DE and diffracted to F. The maximum width of the diffracted line for plate distances D up to 60 cm was 0.03 cm. Measurements were made to the center of this line. For the large plate distances the width of BC and DE became as great as 0.09 cm. Since it was necessary to measure the distances on the plate between direct, reflected and diffracted beam to at least 0.01 cm in order to obtain the wave-length within 0.2A the need for care in choosing the proper place in the direct and reflected beam from which to measure is evident.

An inspection of Fig. 2 will show that the portion of the direct beam AB which is cut off by the grating face is reflected to DE. The widths AB and DE are consequently equal. Thus the angle 2θ can be found by measuring the distance BE with a comparator since the edges of both the direct and reflected beam are sharp and since the distance D is known. The width of the reflected beam was also measured with a comparator. Both above measurements could be repeated to 0.001 cm.

The distance D was measured from the center of grating to the plate. Since the grating had a 0.5 cm aperture the maximum error in the measurement of this distance for $D=50$ cm was 1/2 percent. Obviously this percentage was less for the greater distances. The percentage error in D was probably considerably less than this since an error of 1/2 percent assumes that the effective "center" of the grating was at either of the two edges.

The angle α was measured from the center of the reflected beam to the center of the diffracted. Whenever possible this was done with a comparator. Frequently, however, the diffracted lines were too weak to stand the magnification of the comparator. In these cases the plate was fastened to a glass scale etched to 0.1 mm and the image of the one superimposed on the other was thrown on a screen by a projection lantern. This made a convenient method for measuring the distance GF to within 0.01 cm. The error in the computation of each plate by the above method of measurement should not be in excess of 0.2A. The mean value of a group of plates under varying conditions should give a wave-length value even closer than this.

Results

While other lines (several of which have been measured) appear on many of the plates beside the $K\alpha$ carbon line, they are not reported on in this paper. The iron line appears frequently. This is no doubt due to the use

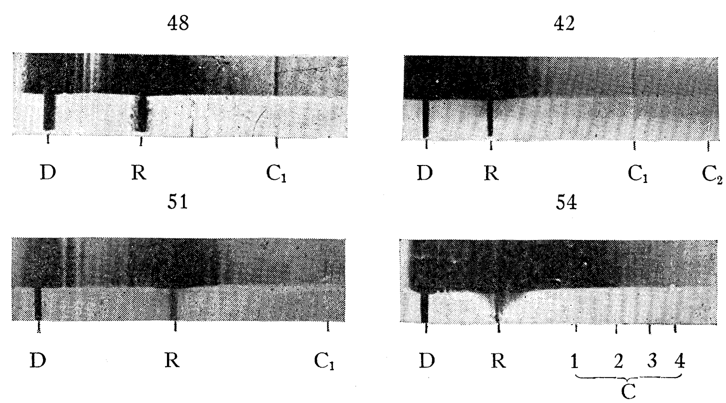

Fig. 3. Reproductions of spectra.

of steel screws for holding the hot filament in place. Although a copper anti-cathode was used, the copper lines do not appear on the plate. The copper wave-length is so short (13.3A) that it would fall in that portion of the plate fogged by visible light. Moreover, after a short time the anti-cathode was covered by a film of tungsten and other impurities. A covering of graphite was placed on the anti-cathode but did not increase materially the intensity of the carbon lines. In this work the carbon line always appeared if there was any other line present.

Exposures of as long as six hours were used for the large plate distances. With a plate distance of 30 cm from two to three hours sufficed. The usual plate current was about 40 milliamps. although this was run up to 90 milliamps. occasionally.

In Fig. 3 reproductions of plates No. 42, 48, 51, 54 are shown. The originals naturally show more detail than the reproductions. In the plates shown the lower half of the field was covered by carbon paper. There is a noticeable scattering and broadening of the x-ray beam on some of the plates due to this. However, on practically all the original negatives it was possible to locate the edges of the direct and reflected x-ray beams in the upper portion of the plate where the direct and reflected light appears. The lines on the plates taken with $D=80$ cm were too weak for reproduction but could be measured.

Table I gives the operating conditions for each of the plates. They were all taken with 2000 v. on the anti-cathode.

TABLE I. *Operating conditions for each plate*

Plate No.	D (cm)	θ^1	Exposure (hrs)	Plate Current (milliamps)	λ	Weight
42	50	33	3	45	45.2	3
43	50	33	3	35	45.3	1
44	81	30	5	40	45.4	2
45	81	32	6	55	45.5	1
46	50	33	3	40	45.4	2
47	50	27	3	40	45.4	2
48	50	45	4.5	45	45.5	2
50	60	51	5.5	25	45.4	3
51	60	51	6	50	45.3	3*
52	60	25	6	55	45.5	3
54	30	60	3	45**		

* Transformer at 4400 V.
** Plate distance too small to make accurate calculation.

A weighted mean of 11 observations give the value of the wave-length of the $K\alpha$ carbon line as 45.4A. The weights were assigned by giving those with the greater plate distances wider dispersion and finer lines a value of 3 and the others a value of 2 or 1 depending on how they met the above conditions.

In conclusion, the author wishes to express his thanks to Dr. C. B. Bazzoni under whose direction this work was undertaken and carried through and who has given several valuable suggestions.

RESEARCH SECTION RANDAL MORGAN LABORATORY OF PHYSICS,
UNIVERSITY OF PENNSYLVANIA,
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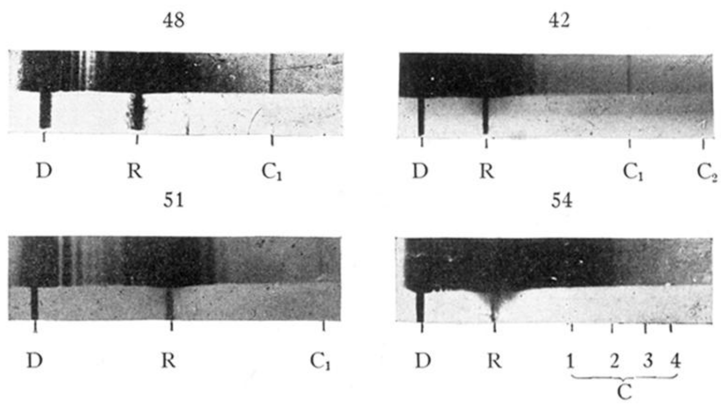

Fig. 3. Reproductions of spectra.