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FINE STRUCTURE OF THE SCATTERED RADIATION FROM GRAPHITE

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Abstract

This analysis of the "undisplaced" scattered radiation was made with double x-ray spectrometer previously described. (Davis and Purks, Proc. Nat. Acad. Vol. 13, No. 6, June 1927, Vol. 14, No. 2, Feb. 1928.) A special double target (Mo) x-ray tube was used with a block of graphite between the targets as the scattering element. The crystals were placed for reflection at first order. Four lines were observed: (a) an undisplaced line at position of Mo $K\alpha_1$; (b) a line displaced 80″ (0.0012A) from $K\alpha_1$ position; (c) a line displaced 140″ (0.002A) from $K\alpha_1$; (d) a line displaced 780″ (0.0113A) from $K\alpha_1$. These are all on the long wave-length side of Mo $K\alpha_1$. The undisplaced line (a) is scattered from whole atom. The line displaced (0.0113A) closely agrees with $h\nu' = h\nu - Ve$, where Ve is the energy level (287 volts) of the carbon atom. The line (b) is displaced (0.0012A). This is equivalent to 29 volts which does not agree with the L_{III} level of carbon (11.2 volts). The line (c) is displaced (0.002A). This is equivalent to 50 volts, and does not agree with the L_{I} level of carbon which is 34 volts. In the case of these two lines the relation $h\nu' = h\nu - Ve$ does not hold. A search was made for scattered radiation on the short wave-length side of the Mo $K\alpha_1$ position, corresponding to the relation $h\nu' = h\nu + Ve$. No positive results were obtained.

The recent improvement in the resolving power of the ionization x-ray spectrometer suggests its application to the further study of various x-ray phenomena. So far it has been applied to the investigation of fine structure in the K series of molybdenum,[1] copper and nickel,[2] and to the problem of the natural breadth of spectral lines.[1] In addition, some observations have been made on the effect of chemical combination on the structure of the K absorption limit (See article by Davis and Purks in this issue.)

The double x-ray spectrometer has the advantage that its resolving power is independent of the width of the slits. This fact permits sufficient energy to make it possible to observe effects that would be beyond the power of the single crystal instrument with the narrow slits that are necessary for high resolution.

[1] Davis and Purks, Proc. Nat. Acad. **13**, 419 (June, 1927) and **14**, 172 (Feb., 1928).

[2] Purks, Phys. Rev. **31**, 931 (June, 1928).

The spectrometer measurements of the "undisplaced" scattered radiation by Compton[3] and the photographs of this same radiation by Ross[4] show a broadening of the spectral line. The experiments here reported show that this broadening is due to fine structure and a small displacement.

Two separate experiments were made on the "undisplaced" scattered radiation from graphite: (1) with double target x-ray tube with the scattering element between the targets; (2) with two narrow cylindrical tubes placed side by side with the scattering element between them. The double target tube, the slits and the crystals are shown schematically in Fig. 1. The two targets are of molybdenum placed close together. The electron sources are two standard Coolidge cathodes. The scattering element C is a small prism of graphite about one centimeter broad at the base. The distance from the focal spots on the targets to the graphite is about 1.5 cm. The slits are 5 mm wide and 2 cm high. The crystals are of split calcite (Iceland spar) and are set for first order reflection.

The angular displacements ($2d\theta_1$) are the displacements of the analyzing crystal B from the undisplaced Mo $K\alpha_1$ position.

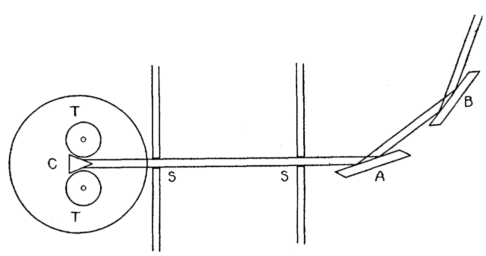

Fig. 1. Diagram of apparatus. T, T, targets of double x-ray tube; C, graphite scattering element; S, S, slits (5 mm wide); A collimating crystal; B, analyzing crystal.

The x-ray tube was carefully exhausted. The graphite element C was completely out-gassed by electron bombardment. The tube operated very steadily with 35 milliamperes on each target and a P.D. of 40000 volts. The total input was 2800 watts. The intensity of the scattered radiation made it possible to measure the fine structure with fair accuracy. Such an intense source is necessary. The undisplaced scattered radiation as ordinarily observed is here divided into four parts. In addition each of these parts is further reduced by two reflections.

In the case of experiment No. 2, the arrangement was similar to that shown in Fig. 1, except that instead of one double x-ray tube, two independent tubes were used. These tubes were each 4 cm in diameter. They were mounted side by side in a vertical position with a wedge of graphite between them.

The distance from the focal spots on the targets to the graphite was about 2.5 cm. The energy input was about the same as in the case of the double

[3] A. H. Compton, Phys. Rev. **22**, 409 (Nov., 1923).

[4] P. A. Ross, Proc. Nat. Acad. **10**, 304 (1924).

target tube. The results obtained in the two experiments are in agreement. The accuracy obtained is probably of the order of $2d\theta_1 = \pm 10''$ arc. This is equivalent to ± 0.15 X-Units.

The experimental curves obtained by experiment No. 1 (double tube) are shown in Fig. 2. Those obtained by experiment No. 2 are similar in character and position.

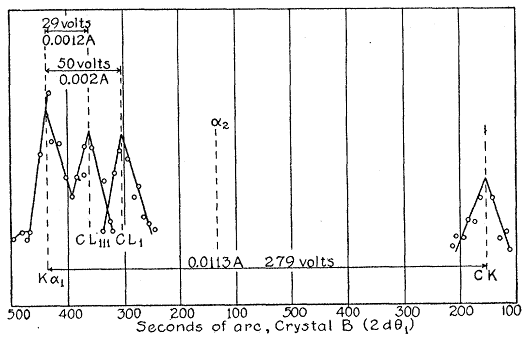

Fig. 2. Analysis of the "undisplaced" scattered radiation from carbon.

The so-called undisplaced scattered radiation from graphite is really composed of four frequencies. A line at position of Mo $K\alpha_1$, one displaced ($2d\theta_1 = 80''$), one displaced ($2d\theta_1 = 140''$) and still another displaced ($2d\theta_1 = 780''$), all on the long wave-length side of the Mo $K\alpha_1$ position. The results are given in Table I.

TABLE I. *Results of the two experiments.*

Observed	$2d\theta_1$	$d\lambda$	Volts	Carbon, energy, levels, volts.
		Experiment No. 1		
$K\alpha_1$	0	0	0	—
C L_{111}	80″	.0012	29	11.2
C L_1	140	.002	50	34
C. K.	780	.0113	279	287
		Experiment No. 2		
$K\alpha_1$	0	0	0	—
C L_{111}	90″	.0013	34	11.2
C L_1	158	.0023	57	34.
C K	780	.0113	279	287

The displaced lines are designated by C L_{111}, C L_1, and C K. They are ascribed to the two electrons in each of the L levels and the K level of the carbon atom.

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Since the wave-length at first order is expressed by $\lambda = 2d \sin\theta$, the corresponding $d\lambda$ is given by $d\lambda = d \cos\theta(2d\theta_1)$, where $(2d\theta_1)$ is the angular displacement of crystal B from the original Mo $K\alpha_1$ position.

The energy relations of a quantum $h\nu$ scattered from an atom have been given by Compton as[5]:

$$h\nu - h\nu' = Ve + mc^2[(1-\beta^2)^{-1/2} - 1] + Mv^2/2. \qquad (1)$$

The first term on the right represents the energy level of an electron. The second term is the kinetic energy of an electron after ejection. The last term which represents the kinetic energy of the atom imparted by the quantum is very small and may be neglected.

The second term on the right gives the normal Compton scattering from a free electron. The undisplaced $K\alpha_1$ line observed in these experiments arises from scattering from the whole atom. In this case all three terms on the right are practically zero.

The C K line corresponds to an energy loss of 279 volts. This is in good agreement with K energy level of carbon. The values of the K levels of carbon as given by the Report on Critical Potentials (Bulletin of the National Research Council, No. 48, 1924) range from 280 volts to 290 volts. A more recent determination by Dauvillier[6] gives 287 volts. The experimental value of 279 volts indicates that all the terms on the right of Eq. (1) are zero except the first. That is, $h\nu' = h\nu - Ve$. The quantum loses energy of lifting through the K level but does not give the electrons any energy or momentum.

The displacements of the two L_{11} and L_1 lines do not agree with the two L energy levels of carbon as determined from the carbon atom in the gaseous state. The relation $h\nu' = h\nu - Ve$ does not hold for these lines. Two views are suggested to account for the greater displacement. The L energy levels of crystal carbon may be much greater in the crystal form than in the gas form. This, however, is not probable as an energy change from 11 to 29 volts and from 34 to 50 volts would give a very large heat of formation of graphite, much larger than is actually observed. The other view is that the quantum lifts the L electrons to the limit of the atom and gives them energy and momentum. A difficulty, however, arises from the fact that the C L lines are just as narrow as the C K line or the α_1 line (see Fig. 2). If these electrons are given much energy and momentum after ejection the lines should be diffuse just as the Compton effect lines are diffuse. We have observed the Compton effect with the double x-ray spectrometer and the angular spread is very great. This is to be expected from the angle law $(1-\cos\theta)$. The x-rays falling on the scattering element (Fig. 1) are quite divergent. If the L electrons are given a kinetic energy after removal a broadening due to the angular divergence should be observed as in the Compton effect. The magnitude would be less. The narrowness of the C L lines indicate that the effect of divergence $(1-\cos\theta)$ is very small.

A search was made for scattered line radiation on the short wave-length side of the Mo $K\alpha_1$ position. Such scattered radiation might occur. If the atom were in an excited state, that is, if an L electron for example were at

[5] A. H. Compton, Phys. Rev. **24**, 168 (1924).

[6] Dauvillier, Jour de Phys. et La Radium, [VI], 7 No. 12 (Dec., 1926).

a higher level or at the limit, and were acted on by a quantum $h\nu$ at the moment of return, the energies might add. The emitted energy would be $h\nu' = h\nu + Ve$. No positive results were obtained, but we hope to return to the question again with a more intense source of energy.

The investigation of the scattered radiation will be continued by one of us (D. P. M.). It is proposed to ascertain if the displacement depends at all on the angle. Also, other scattering elements will be used such as beryllium and aluminium to determine the dependence of this effect on the values of the energy levels. It is possible also that the energy levels in the (CH) compounds, such as paraffin may differ from those of carbon in graphite.

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