A Critical-Absorption Photometer for the Study of the Compton Effect.

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[PLATE 10.]

1. *Introduction.*

That a change of wave-length occurs in X-ray scattering was first indicated by absorption measurements with the ionisation chamber, which showed that the absorption coefficient of a light element like aluminium was slightly greater for the scattered than for the primary X-rays. Later* more conclusive and direct evidence was obtained when spectrometric analysis of the scattered X-rays was made first by the ionisation and afterwards by the photographic method. This analysis disclosed the existence of an unshifted as well as the shifted line, and showed also that the latter becomes relatively more prominent with diminishing wave-length and lower atomic number of the scattering element. After the main features of the Compton effect were established by means of spectrometric measurements, however, absorption measurements with the ionisation method have again been employed for a detailed study of the phenomenon, for such measurements are much quicker than the spectrum experiments, where the final energy available is much smaller on account of the double scattering involved.†

As mentioned above, the absorption measurements were based on the slight increase in the absorption coefficient of a light element when the wave-length changes from the unmodified to the modified value. The much larger and sudden diminution in absorption of X-rays when the frequency is altered from the short to the long wave-length side of the critical K-absorption limit of the element used as a filter, furnishes us with an easy and convenient method of exhibiting the wave-length change in X-ray scattering. In the present paper will be described a photographic wedge photometer based on this principle, which enables the characteristics of the Compton effect to be readily observed. It may be pointed out that the same idea could no doubt be utilised also in connection with the ionisation measurements of the Compton effect.

* A. H. Compton, 'Phys. Rev.,' vol. 22, p. 408 (1923). P. A. Ross, 'Proc. Nat. Acad. Sci.,' vol. 10, p. 304 (1924). H. M. Sharp, 'Phys. Rev.,' vol. 26, p. 691 (1925). Y. H. Woo, 'Phys. Rev.,' vol. 27, p. 119 (1926), etc.

† De Foe, 'Phys. Rev.,' vol. 27, p. 675 (1926).

2. *Principle and Description of the Photometer.*

The application of the idea of critical absorption demands a proper choice of the wave-length and the absorber. In other words, the wave-length λ of the radiation used should be so related to the critical K-absorption limit λ_κ of the absorber, that whereas λ is slightly smaller than λ_κ, the wave-length λ_ϕ of the modified ray given by the well-known Compton equation

$$\lambda_\phi - \lambda = 0\cdot0243\,(1 - \cos\phi) \qquad (1)$$

becomes greater than λ_κ when the angle of scattering is larger than some convenient angle ϕ_0. Confining ourselves to the characteristic K-radiation alone, a reference to the tables shows several substances for the target for which suitable absorbers are available. In Tables I and II is given a list of elements of moderate atomic numbers suitable for use as targets and absorbers, and the minimum angle of scattering ϕ_0 at which the combination becomes effective for exhibiting the Compton effect.

Table I.

At. No. of Target.	Target.	Ab-sorber.	ϕ_0	
			K_{α_2}	K_{α_1}
			°	°
21	Sc	Ca	115	125
22	Ti	Sc	37	49
31	Ga	Cu	121	132
32	Ge	Zn	134	148
33	As	Ga	62	72
34	Se	Ge	49	60
35	Br	As	22	40
38	Sr	Br	131	141
40	Zr	Rb	93	104
41	Nb	Sr	81	90

Table II.

At. No. of Target.	Target.	Ab-sorber.	ϕ_0	
			K_{α_2}	K_{α_1}
			°	°
42	Mo	Y	55	60
44	Ru	Nb	34	49
45	Rh	Mo	23	42
46	Pd	Mo	103	114
48	Cd	Ru	80	91
49	In	Rh	74	85
50	Sn	Pd	59	71
51	Sb	Pd	108	120
		Ag	57	69
52	Te	Ag	103	115
		Cd	49	62

In the present experiments the radiation from a tin target of a metal Shearer tube operated at about 60 K.V. was employed, and a palladium foil was used as filter. The wave-lengths of the characteristic radiations K_{α_1} and K_{α_2} for tin are $0\cdot490$ and $0\cdot494$ A.U. respectively, whereas the critical K-absorption limit of palladium is $0\cdot506$ A.U.

Equation (1) then gives $\phi_0 = 71°$ for the K_{α_1} line and $\phi_0 = 59°$ for the K_{α_2} line. Consequently, as ϕ is increased from a small to a large angle, the transparency of the palladium foil will undergo an enormous increase on passing these values of ϕ_0. To be more definite, the transparency of a foil 0·1 mm. thick will be increased nearly four hundred times in this process. Further, provided $\phi > \phi_0$, the transmitting power will be seen obviously to depend upon the relative proportions of the modified and the unmodified scattering in any given case, increasing with the former.

For the measurement of the intensity of the X-rays transmitted by the foil in any given case, a comparative method is adopted, the thickness of a light element like aluminium or iron, which is equivalent as regards absorption to the palladium being determined. To be able to do this from a single exposure, a wedge of such element (in the present case steel) with a suitable gradient of thickness is exposed side by side with the foil, the photographic plate being placed behind the combination and almost in contact with it. The resulting photograph will show two patches corresponding to the foil and the wedge respectively (see figs. 1 and 2, Plate 10), and the point of the wedge which possesses the same transmission as the foil can be determined by inspection, or more accurately with a microphotometer. Obviously the point of equality would shift towards the thinner end of the wedge as the modified radiation having wave-length $\lambda_\phi > \lambda_\kappa$ increases in proportion. It may be added that, for 0·1 mm. of palladium, the equivalent thickness of steel would be 0·6 and 0·08 mm. respectively when the whole of the scattering radiation lies on the short or the long wave-length side of the critical limit. The two dots in the figure correspond to two holes drilled in the steel wedge to serve as reference marks. Both the foil and the wedge were fixed in a metal plate with a suitable rectangular aperture, which was so designed as to serve as a plate-holder also. Arrangements were made to keep the photographic plate always in the same position with respect to the steel wedge. In order to protect the apparatus from stray radiation, the experimental beam was allowed to enter it only through a long lead tube.

3. *Experimental Results.*

Observations were made with three radiators, namely, carbon, aluminium and iron at various scattering angles. The results are set forth in Tables III and IV, where t in the last column represents the thickness of the steel wedge at the point of equal transmission. Figs. 1 and 2 (Plate 10) correspond to the scattering from carbon at 60° and 90° respectively. Figs. 3 to 8 are the reproductions of the microphotometer curves corresponding to the scattering from carbon at the various angles. In these curves the right-hand part corresponds to palladium, and the zero of the galvanometer falls outside the

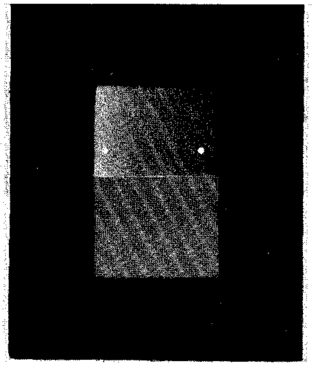

FIG. 1. $\phi = 60$

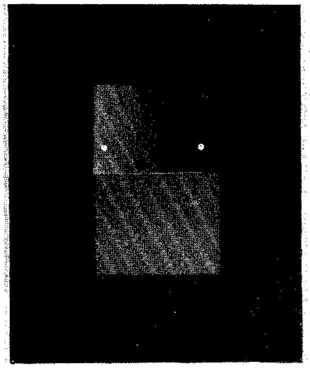

FIG. 2. $\phi = 90$

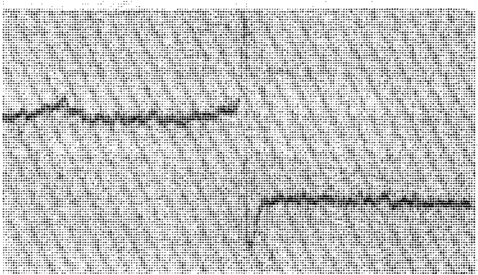

FIG. 3. $\phi = 45$

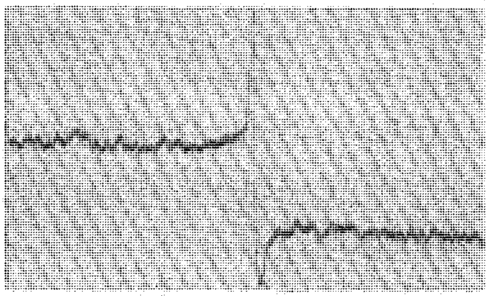

FIG. 4. $\phi = 60$

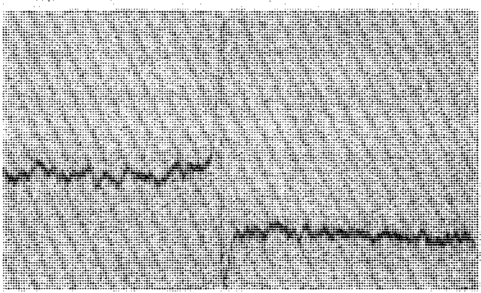

FIG. 5. $\phi = 75$

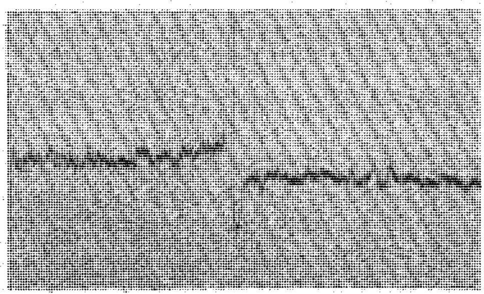

FIG. 6. $\phi = 90$

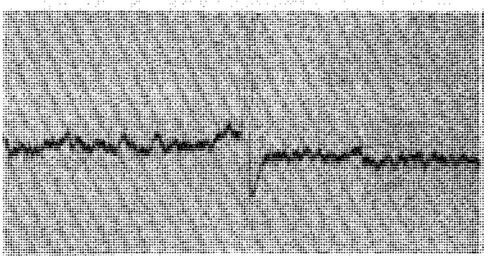

FIG. 7. $\phi = 105$

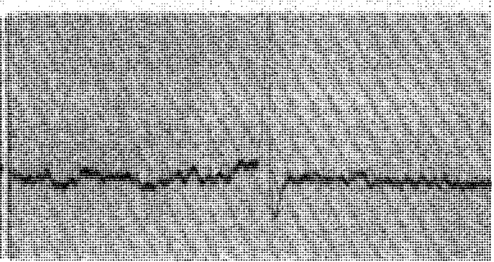

FIG. 8. $\phi = 120$

figures on the upper side. The microphotometer used was of the Moll type. For obtaining these intensity curves the negatives were run from top to bottom (figs. 1 and 2) across the same point of the wedge in each case.

Table III.

Radiator.	ϕ	t
	°	mm.
Carbon	45	0·32
,,	60	0·31
,,	75	0·27
,,	90	0·22
,,	105	0·22
,,	120	0·22

Table IV.

Radiator.	ϕ	t
	°	mm.
Aluminium	45	0·36
,,	60	0·36
,,	90	0·33
,,	120	0·33
Iron	60	0·35
,,	90	0·34
,,	120	0·34

In case of scattering from carbon a cylindrical rod of carbon about 2 cm. in diameter was irradiated so that the cross-section of the beam was a little greater than the diameter of the rod. To get the scattering from the more absorbing elements, namely, aluminium and iron, the primary beam was incident, nearly grazing the surface. The time of exposure for carbon was 10 minutes in each case, whereas exposures of 30 and 60 minutes were given in the case of aluminium and iron respectively. It may be remarked that the soft fluorescent radiation in the latter two cases would be cut off automatically to a large extent by the photometer itself.

From a survey of the observations given above the following characteristics of the Compton effect are brought out.

1. The change of wave-length of the modified line as a function of the scattering angle ϕ is given by equation (1). For, as calculated from that equation, the modified $K_{\alpha 2}$ and $K_{\alpha 1}$ remain on the short wave-length side of the critical absorption limit till angles of scattering 59° and 71° respectively are reached. Hence, the point of equality of transmission between the steel wedge and the palladium foil should remain practically fixed as the angle of scattering is increased till it reaches the value 59°. A considerable change at 71° is also to be expected. In agreement with these indications, the microphotometer records (figs. 3 to 6) show that there is practically no change till an angle 60° is reached, and that the most rapid change occurs between 60° and 90°.

2. The modified scattering is more prominent in the case of light radiators. Thus, while the change in the point of equality for carbon as we pass from

$\phi < \phi_0$ to $\phi > \phi_0$ is large enough to be clearly detected by the eye (compare figs. 1 and 2, Plate 10), the change is much less for aluminium and still less for iron.

3. The ratio of the modified to the unmodified radiation continues to increase with increased angle of scattering. This is clearly shown in the case of carbon by the sequence of the microphotometer records (figs. 5 to 8) for scattering angles 75°, 90°, 105° and 120°.

The reason why the arrangement does not show the expected sensitiveness is that there is a considerable amount of white radiation mixed with the characteristic in the case of heavy target like tin. In addition there is the K_β also to be considered. The sensitiveness will therefore obviously be increased if suitable filters are employed for cutting off the K_β and most of the white radiation on either side of the K_α lines. This will, however, mean an increased exposure. A still better method would be to employ the radiation from a comparatively light element, in which case the white radiation will be relatively much less prominent. Even as it is, the apparatus is capable of readily exhibiting the main features of the Compton effect in an unambiguous manner.

4. *Summary.*

The great difference in transmission through a filter on the two sides of the K-absorption edge forms the basis of a very simple and convenient method of studying the characteristics of the Compton effect. For this purpose the material of the target for the X-ray tube and the material of the filter placed in the path of the scattered X-rays are so chosen that the unmodified scattered ray lies on the short-wave side of the limit, while the modified ray scattered through a sufficiently large angle is on the long wave-length side of the limit. The increased transparency for the scattered radiation at such angles is readily shown by a photographic plate exposed to the scattered radiation behind the filter, a steel wedge placed side by side with the filter forming the standard of comparison. The point of equality of transmission between wedge and filter shifts further and further towards the thin edge of the wedge with increasing proportion of modified to unmodified scattering. The known features of the Compton effect are unambiguously indicated.