THE MEAN DEPTH OF FORMATION OF X-RAYS IN A PLATINUM TARGET.

By Laura G. Davey.

W. R. HAM has shown[1] that X-rays are formed on an average, not on the surface of a target, but some little distance inside, this distance being called "the mean depth of formation" of X-rays. He was the first to measure this distance for any kind of target, using for his measurements a lead target.

The theory was as follows: If the normal to the target is not midway between the electroscopes (Fig. 1) the rays from a given point in the target have to pass through a greater thickness of the target in going to one electroscope than to the other. Let O (Fig. 1) be the source of an ether-pulse so situated as to be at the mean depth at which the X-rays originate. Let $l_1 - l_2 = x =$ the excess of target the pulse has to traverse in going to R over that which it traverses in going to L; $d =$ the distance from O to the point at which the cathode ray particle enters the target; $h =$ the perpendicular distance from O to the surface of the target; $\theta =$ the angle which the normal to the target makes with the cathode stream; $\theta_0 =$ the angle which the lines from the electroscopes to the target make with the cathode stream. Then

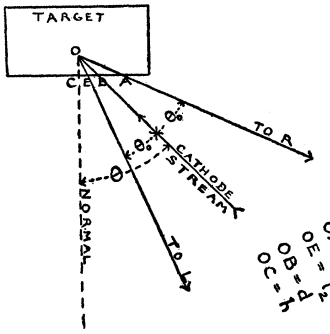

Fig. 1.

$$x = h\left\{\frac{1}{\cos(\theta + \theta_0)} - \frac{1}{\cos(\theta - \theta_0)}\right\}.$$

But

$$h = d\cos\theta.$$

Therefore

$$x = d\cos\theta\left\{\frac{1}{\cos(\theta + \theta_0)} - \frac{1}{\cos(\theta - \theta_0)}\right\}$$

or

$$x = d \cdot F(\theta, \theta_0).$$

---

[1] W. R. Ham, Phys. Rev., XXX., 1, Jan., 1910.

Let I_L = intensity of X-rays directed towards L,
I_R = intensity of X-rays directed towards R.
Then

$$I_R = I_L \epsilon^{-\lambda x}$$

where x is defined as above and λ is the coefficient of absorption found experimentally for the voltage used.

Ham has found that d for lead is 4.2×10^{-5} cm. at 14,000 volts and 6.4×10^{-5} cm. at 21,300 volts, thus proving that the mean depth of formation of X-rays is directly proportional to the potential difference across the tube. Ham's work was done with a specially constructed tube made from a bell-jar with windows of a uniform thickness inserted at the proper angles. The target was pivoted and was moved magnetically from the outside. The tube was attached to a Holtz pump during the entire time of taking readings so that there was always mercury vapor present. The means of excitation was a Holtz machine.

About a year later with the same apparatus W. P. Davey[1] measured the mean depth of formation in a silver target and found it to be 5.4×10^{-5} cm. at 10,000 volts and 9.2×10^{-5} cm. at 17,000 volts, thus confirming the fact that the mean depth of formation of X-rays is directly proportional to the potential difference across the tube.

It seemed that it would prove interesting to repeat the experiment with a standard platinum-target tube excited by a commercial "interrupterless" (transformer) machine. The thickness of the glass of various X-ray tubes was investigated and as long as the measurements were made on an arc whose plane was perpendicular to the axis of the tube the variations in thickness were negligible. This was to have been expected from the mechanics of glass blowing.

An attempt was first made to use ionizing chambers connected to a quadrant electrometer, thus using a null method much like the one of Ham, Lassalle and Smith[2] but this proved unsuccessful because of the disturbances due to the powerful variable static field of the transformer circuit. An arrangement was then set up as follows:

T (Fig. 2) is a platinum-target tube mounted so that it can be rotated through 180° about the axis *OO*. The target is set at an angle of 45° to the cathode stream.

SS and *KK* are thick lead screens.

CC are lead curtains over the apertures in *KK* which can be lowered to cut off direct radiation or raised to allow radiation to pass through.

BB are lead boxes serving to cut off secondary rays from the electro-

---

[1] W. P. Davey, Journal of the Franklin Inst., March, 1911.

[2] Ham, Lassalle and Smith, Jour. Franklin Inst., July, 1911.

scopes *L* and *R*, and (being permanently grounded) also acting as static shields.

L and *R* are set at an angle of 20° to the cathode stream. The amount of discharge of the electroscope is read by the microscopes *MM*.

The target was first turned so as to have its plane vertical and facing towards the electroscope *L*. Then the tube was brought into a definite condition (6° Benoist[1]) such that the electrostatic voltmeter *V* registered 43,000 volts. The electroscopes were charged to 200 volts. Then the tube was run approximately four seconds with the holes in *KK* closed by the curtains *CC*, thus giving the amount of discharge caused by spontaneous ionization and secondary radiation. Then the curtains were raised and the amount of discharge due to spontaneous ionization, secondary radiation, and primary radiation was observed. From these two readings the amount of primary radiation was computed. Then the tube was rotated 180° and readings were again taken both with curtains down and up. Lastly a piece of platinum .00269 cm. thick was inserted in the path of the rays going toward *R* and the above observations were repeated.

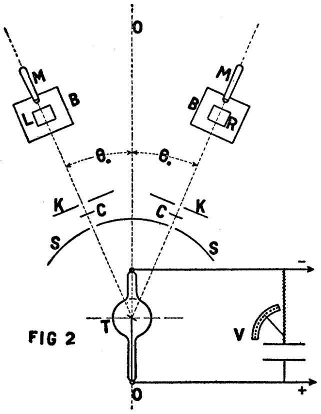

Fig. 2.

TABLE I.

TO FIND λ AT 6° B.

	R	*L*	*R* Corrected for Natural Leak and Secondary Radiation.	*L* Corrected for Natural Leak and Secondary Radiation.
Without Pt....	4.40	16.9	3.89	14.9
With Pt......	1.51	16.0	1.00	14.0

In order to avoid inaccuracy due to inequalities in times of exposure the following method of treating the data was used. Without any platinum,

$$Lm = R,$$

where *m* is the factor of proportionality. From the above data,

$$m = \frac{389}{1490}.$$

---

[1] The penetrating ability of an X-ray beam is expressed in the Benoist scale in terms of the thickness in millimeters of Al which offers the same opacity to the rays as is offered by a sheet of Ag .11 mm. thick.

Therefore during the time the run was made with the platinum, R would have deflected

$$14m = \frac{339 \times 14}{1490} = 3.65$$

if there had been no platinum. But the platinum reduced the reading to 1.00.

Now if

$$I_0 = \text{intensity of X-rays without Pt.} = 3.65,$$

and if

$$I = \text{intensity of X-rays with Pt.} = 1.00,$$

and if

$$x = \text{thickness of the Pt.} = .00269 \text{ cm.},$$

then

$$I = I_0 \epsilon^{-x\lambda}$$

becomes

$$1.00 = 3.65 \epsilon^{-.00269\lambda}$$

at 6° Benoist, and

$$\lambda = 481.$$

TO FIND THE MEAN DEPTH OF FORMATION OF X-RAYS INSIDE THE PLATINUM TARGET.

R was calibrated in terms of L as follows: If R and L were exposed to exactly the same radiation then the deflection of R might be expressed in terms of the deflection of L thus:

$$Rk = L.$$

Let R_1 = the reading of R when the target faces R,
L_1 = the corresponding reading of L,
R_2 = the reading of R when the target faces L,
L_2 = the corresponding reading of L.

Then,

$$\frac{R_1 k}{L_1} = \frac{L_2}{R_2 k},$$

from which

$$k = \sqrt{\frac{L_1 L_2}{R_1 R_2}}.$$

TABLE II.

	R	L	R Corrected for Natural Leak and Secondary Radiation.	L Corrected for Natural Leak and Secondary Radiation.
Target facing L...	4.05	20.1	$3.79 = R_2$	$17.7 = L_2$
Target facing R...	4.40	16.9	$3.89 = R_1$	$14.9 = L_1$

Whence

$$k = 4.23.$$

Therefore,

$$kR_1 = 4.23 \times 3.89 = 16.45$$

and

$$kR_2 = 4.23 \times 3.79 = 16.03.$$

We may therefore write,

Table III.

	I_L	$I_R = kR_2$	$I_R = kR_1$
When target faces L......	17.7	16.03	
When target faces R......	14.9		16.45

Now when the target faces L,

$$I_R = I_L \epsilon^{-\lambda x}$$

and when the target faces R,

$$I_L = I_R \epsilon^{-\lambda x}.$$

Hence,

$$\epsilon^{\lambda x} = \frac{17.7}{16.03} = \frac{16.45}{14.9} = 1.10$$

and

$$x = .00020- \text{ cm.},$$

$$d = \frac{x}{.891} = .00022 \text{ cm. at } 6° \text{ Benoist.}$$

Since it has been shown[1] that the depth of formation of X-rays in a target is directly proportional to the P.D. across the tube, and since this is directly proportional to the "hardness" of the tube in ° Benoist between the limits of 3° B. and 8° B., it follows that the depth of formation of X-rays in a platinum target in a tube of hardness $H°$ B. is

$$\frac{H}{6} \times .00022 \text{ cm.} = .00004\, H \text{ cm. nearly.}$$

I wish to express my appreciation to Prof. E. L. Nichols and to Prof. J. S. Shearer for their many kindnesses throughout the course of the work and to my husband for aid in taking data.

Department of Physics,
Cornell University.

---

[1] W. R. Ham, loc. cit.; W. P. Davey, loc. cit.