

# THE MEAN DEPTH AT WHICH ROENTGEN RAYS ORIGINATE WITHIN A SILVER TARGET.

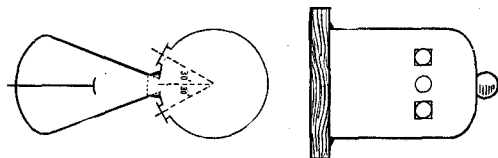
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THE modern theory of Roentgen rays states that these rays consist of waves in the ether caused by accelerations received by negatively charged corpuscles during the time in which the cathode rays penetrate the target (or anti-cathode) of the X-ray bulb.

In the *Physical Review*, vol. xxx No. 1, Jan., 1910, Dr. Wm. R. Ham has given a method by which he was able to determine for various potentials the mean depth beneath the surface of a lead target at which the rays originate. In the same

FIG. 1.

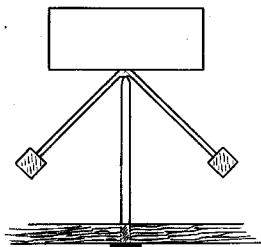


article he shows that the depth at which the rays originate depends on the depth "at which on the average, as many of the cathode particles which have entered the target are suffering accelerations in one direction as in any other." This depth is called the *depth of complete scattering*.

The present research was an effort to determine (a) the mean depth at which, for a given potential, Roentgen rays originate in a silver target, and (b) to determine the depth of complete scattering for silver at a given potential. Due to a break in the apparatus the completion of the second part of the experiment has been somewhat delayed. The apparatus used was practically the same as was

used by Dr. Ham (see Fig. 1). The X-ray bulb was in the form of a bell-jar of 7 cm. radius and of 16 cm. height. The flange was accurately ground to a plane surface and fitted to a thick plane glass plate. Three holes each 2 cm. in diameter were drilled into the side of the bell-jar at a height of 10 cm. above the flange in such a way that the angular distance along the cylindrical surface of the bell-jar from the centre of one hole to the centre of the next was 30 degrees. Into the central hole was cemented a funnel-shaped tube which held the cathode. The air-pump was attached to this tube. Into the two other holes were ground short glass cylinders. Each of these carried a small glass window. These two windows were cut from the same

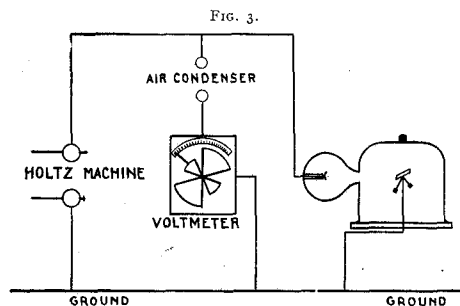
FIG. 2.



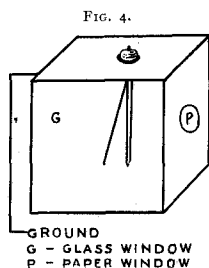
sheet of glass and were of the same thickness. The joints between the windows and their cylinders and between the cylinders and the bell-jar were made air-tight by means of Kotinsky cement. All other joints were made air-tight by means of mercury seals. These joints were so perfect as to hold a good vacuum for several months.

The target (see Fig. 2) was pivoted on an upright post at the centre of the bell-jar so that it could be placed at any desired angle to the cathode stream. Iron balancing weights made it possible to adjust the target magnetically from the outside of the tube. The positions chosen were such that the normal to the target passed through one or the other of the windows

mentioned above, *i.e.* the cathode stream made an angle of 30 degrees with the normal to the target. The tube was excited by means of a 12 plate Holtz machine electrically driven. Fig.



3 shows the scheme of electrical connections. A gold-leaf electroscope (Fig. 4) provided with a micrometer-microscope was placed opposite each window and the amounts of the discharges

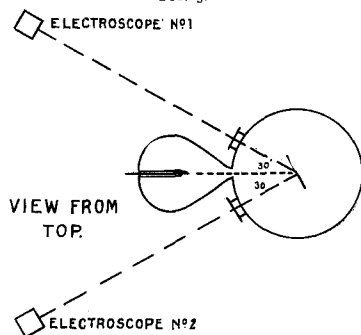


were taken as proportional to the intensities of the X-rays. Each electroscope was cubical in shape and was made of sheet brass. Two large glass windows and one small paper window were provided in each as shown in the figure. An 8 c. p. incandescent

bulb was placed near one of the windows to illuminate the gold leaf. The microscope was placed so as to point towards the opposite window and its scale was thus illuminated directly by the lamp above mentioned. The X-rays were admitted through the paper window. All rays except those from the uniform windows were screened off by means of thick lead sheets.

The electroscopes were charged to a P. D. of 340 volts by means of a battery of dry cells the positive end of which was grounded. The relative positions of cathode target and electroscopes are shown in Figs. 5 and 6. For convenience of reference

FIG. 5.



the parts are lettered as in the above-mentioned article by Dr. Ham.

Let  $o$  be the source of some ether pulse and let  $o$  be so situated as to be at the mean depth at which X-rays originate.

Let  $l_1 - l_2 = x$  = the excess of silver which the pulse has to traverse in passing to electroscop No. 1 over that which it traverses in passing to No. 2.

Let  $h$  be the perpendicular distance from  $o$  to the surface of the target.

Let  $d$  be the distance from  $o$  to the point at which the cathode ray enters the target.

Let  $\theta_0$  be the angle which the lines from the electroscopes to the target make with the cathode-ray stream.

Let  $\theta$  be the angle which the normal to the target makes with the cathode ray stream.

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

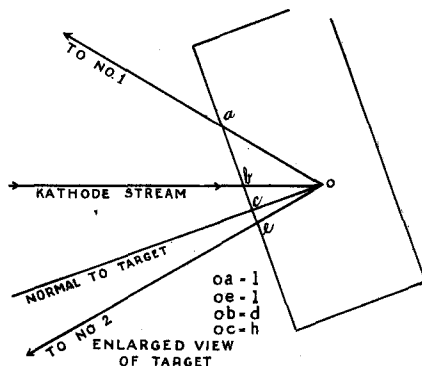
$$\text{But} \quad h = d \cos \theta.$$

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

$$\text{or} \quad x = dF(\theta, \theta_0).$$

It is evident from the figure that the rays going to electroscope No. 1 must travel a greater distance through the target

FIG. 6.



than must the rays going to electroscope No. 2. They will therefore suffer more absorption. If  $I_0$  represents the intensity of the ray going towards No. 2 at the moment of emergence from

the target, and if  $I$  represents the corresponding intensity of the ray going towards No. 1, then

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

where  $x$  is defined as above and  $\lambda$  is the coefficient of absorption.  $\lambda$  is found experimentally for each potential used.  $I$  and

TABLE I.

TO FIND THE COEFFICIENT OF ABSORPTION OF SILVER FOR X-RAYS GENERATED FROM A SILVER TARGET AT A POTENTIAL OF 17,000 VOLTS.

Time Min.	Discharge		Discharge cor. for natural leak		No. 1 cor. for calibration	Per cent. re- maining after absorption
	No. 1	No. 2	No. 1	No. 2		
21	26.7	89.8	25.8	88.8	86.7	32.1
24	27.9	90.2	26.8	89.0		
28	29.8	93.0	28.7	91.7		
			81.3	269.5		
24	26.9	90.6	25.8	89.4	85.3	31.6
24	29.0	94.6	27.9	93.4		
24	27.3	88.1	26.2	86.9		
			79.9	269.7		
22	29.1	92.0	28.1	90.9	88.0	32.7
22	26.9	88.0	25.9	86.0		
25	29.6	92.2	28.5	91.0		
			82.5	268.8		
21	26.4	90.0	25.3	89.0	85.3	32.1
22	28.5	88.8	27.5	87.7		
22	28.1	90.1	27.1	89.0		
			79.9	265.7		

Average per cent. remaining, 32.1.

Greatest deviation from average, 1.9 per cent.

Thickness of absorption sheet  $= x = 0.00263$  cm.

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

$$\lambda = 432.1$$

$I_0$  are directly proportional to the readings of the electroscopes. Therefore  $x$  is known. The value of  $d$  may then be calculated

from the equation  $x = d F(\theta_0, \theta)$ . For the actual angles used  $F(\theta_0, \theta) = 0.866$  so that

$$d = \frac{x}{0.866}.$$

The electroscope discharges were corrected for the natural rate of leak. By simultaneously determining the amounts of the discharges under exactly similar conditions the ratio between

TABLE II.

TO FIND THE COEFFICIENT OF ABSORPTION OF SILVER FOR X-RAYS GENERATED FROM A SILVER TARGET AT A POTENTIAL OF 10,000 VOLTS.

Time	Discharge		Discharge cor. for natural leak		No. 1 cor. for calibration	Per cent. remaining after absorption
	No. 1	No. 2	No. 1	No. 2		
71	21.0	87.8	17.9	84.4	59.1	23.3
72	22.0	87.8	18.8 +	84.3		
74	22.0	88.1	18.7 +	84.8		
			55.4 +	253.5		
83	20.6	84.4	16.9	81.4	53.9	22.3
80	20.3	85.1	16.8	81.3		
71	19.9	82.9	16.8	79.5		
			50.5	242.2		

Average per cent. remaining, 22.8.

Greatest deviation from average, 2.2 per cent.

Thickness of absorption sheet  $= x = 0.00263$  cm.

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

$$\lambda = 562.1$$

Summary of results on coefficient of absorption.

At 17,000 volts,  $\lambda = 432.1$  } for absorption of rays from a silver target by a  
At 10,000 volts,  $\lambda = 562.1$  } sheet of silver.

their readings was determined. Then by means of this ratio the corrected reading of No. 1 was expressed in terms of the reading that would have been shown by No. 2 under similar conditions.

## Average rate of natural leak of electroscopes:

Electroscope No. 1.....0.044 divisions per minute.

Electroscope No. 2.....0.048 divisions per minute.

## Calibration of electroscopes under similar conditions:

## Rays generated by lead target.

1.065 (X-rays generated at 17,000 volts)

1.065

1.068 (X-rays generated at 10,000 volts)

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1.066 mean.

## Rays generated by silver target.

1.073 (X-rays generated at 17,000 volts)

1.068

1.058 (X-rays generated at 10,000 volts)

1.065

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1.066 mean.

$$\text{Weighted mean} = \frac{\text{No. 2}}{\text{No. 1}} = 1.067.$$

## FINAL RESULTS.

At 17,000 volts,  $x=0.000080$  cm.At 17,000 volts,  $d=0.000092$  cm.At 10,000 volts,  $x=0.000047$  cm.At 10,000 volts,  $d=0.000054$  cm.

$$\frac{10,000}{17,000} = 0.59-. \quad (1)$$

$$\frac{0.000054}{0.000092} = 0.59-. \quad (2)$$

From (1) and (2) it is seen that the mean depth at which X-rays originate within a silver target is directly proportional to the potential employed in generating the rays.



In conclusion I desire to thank Dr. Wm. R. Ham for his continual assistance and his helpful suggestions during the course of the experiment. Thanks are also due to Mr. F. C. Miller for valuable aid rendered during the progress of the work.

TABLE III.

TO FIND THE MEAN DEPTH AT WHICH X-RAYS ORIGINATE IN A SILVER TARGET (a) WHEN THE RAYS ARE PRODUCED AT A POTENTIAL OF 17,000 VOLTS, (b) WHEN THE RAYS ARE PRODUCED AT A POTENTIAL OF 10,000 VOLTS.

P. D. = 17,000 VOLTS.

Time	L* R†	Discharge		Discharge cor. for natural leak		Calibration	Final No. 1	$\frac{I}{I_0} = e^{-\lambda x}$
Min.		No. 1	No. 2	No. 1	No. 2			
26	L	81.0	89.7	79.9	88.5	1.073	85.8	0.969
25	R	79.6	82.7	78.5	81.5		84.2	0.967
27	R	77.7	80.0	76.5	78.7	1.068	81.3	0.963
23	L	77.7	86.0	76.7	84.9		81.5	0.965
							Mean,	0.966

P. D. = 10,000 VOLTS.

61	L	82.8	91.0	80.1	88.1	1.065	85.3	0.968
67	R	84.9	88.4	82.0	85.2		87.3	0.976
72	R	84.1	87.1	80.9	83.6	1.058†	86.2	0.970
76	L	83.2	90.1	79.9	86.5		85.1	0.984
							Mean,	0.974

\* Readings marked L were taken with the normal to the target making an angle of 30 degrees to the left of the kathode stream.

† Readings marked R were taken with the normal to the target making an angle of 30 degrees to the right of the kathode stream.

‡ The value 1.066 was used in calculation as there was noticed to be some fluctuation in the voltage while the last reading was being taken.

The calibration  $\left( = \frac{\text{reading of No. 2}}{\text{reading of No. 1}} \right)$  was found for each pair of read-

ings as follows,  $\frac{1}{2} \left( \frac{\text{reading of No. 2 L}}{\text{reading of No. 1 L}} + \frac{\text{reading of No. 2 R}}{\text{reading of No. 1 R}} \right)$ .