THE EFFECT OF MAGNETIZATION ON THE OPACITY OF IRON TO RÖNTGEN RAYS.

BY A. H. FORMAN.

IN a previous paper[1] the results covering the investigation of the effect of magnetizing the iron in a plane perpendicular to the path of the Röntgen rays were published. The results were negative with a set up of apparatus sensitive enough to detect a change of one part in ten thousand under the most favorable conditions.

The work has been continued attempting to reach the same sensibility with the iron magnetized in a direction parallel to the path of the Röntgen rays. This proved rather difficult as it was necessary to magnetize a thin sheet of iron perpendicular to its plane and yet have a free path on both sides of the iron for the Röntgen rays. An electromagnet with hollow poles, as shown in Fig. 1, was designed and built. With this electromagnet it was possible to produce a field of 3,500 gauss perpendicular to the plane of the iron. However, the stray field from the electromagnet was quite strong in the vicinity of both the *X*-ray tube and the ionizing chambers. In the vicinity of the *X*-ray tube it caused trouble by deflecting the cathode stream. The stray field also acted on the secondary rays from the walls of the ionizing chamber first used and thus masked any effect there might be.

The deflection of the cathode stream was prevented by using neutralizing coils, as shown in Fig. 1. By their use the stray field was neutralized except for a small component of field parallel to the path of the cathode rays. The first ionizing chamber which was used is described in the previous paper. It was found that nearly all the ionization was produced by secondary rays from the inside walls of the chamber and this seemed to be the reason for the change in ionization due to the stray field. To prevent these secondary rays from reaching the walls, a conical chamber (Fig. 2) was built. Although the ionization seemed to be unaffected by the magnetic field, it was comparatively small, and so lowered the sensibility of the apparatus. With a view of overcoming the defects of these two ionizing chambers a third one, shown in Fig. 1. was built. It gave a large amount of ionization, and when placed quite

[1] PHYS. REV., April, 1914, pp. 306–313.

a distance from the electromagnet made possible a sensibility of the same magnitude as in the first work and it was not affected by the stray magnetic field.

Fig. 1 shows the final set up of the apparatus. The ionizing chambers consist of two lead cylinders which are grounded. Inside each are two brass posts which support sheets of aluminum leaf, alternating as shown. In one of the chambers one set of the aluminum leaves is charged to a

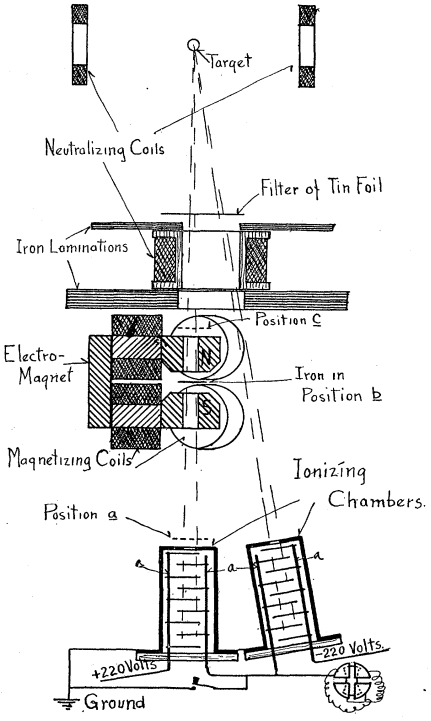

Fig. 1.

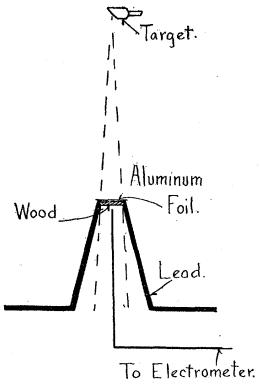

Fig. 2.

p.d. of + 220 volts, while in the other chamber the corresponding leaves are charged to a p.d. of − 220 volts. The remaining set of leaves in each chamber are connected together to a grounding switch and to one of the quadrants of a Dolezalek electrometer.

Perfect electrostatic screening of the system is effected by the use of a solid screening of tin-plate as in the earlier work.

The Röntgen rays pass through the top of the chambers and strike the aluminum, producing secondary rays which ionize the air between the leaves. The electric field due to a p.d. of + 220 volts causes a + charge to flow towards the electrometer from one chamber, while the p.d. of

— 220 volts causes a — charge to flow from the other chamber. When there is a perfect balance between the two chambers no charge accumulates and there is no deflection of the electrometer. A small change in the ionization of either chamber causes a charge to pile up and the electrometer deflection is proportional to the change in ionization and the time the grounding switch is open. The method of taking observations and calculating the sensibility are the same as explained in the first paper.

Observations made with this set up and using the same piece of iron that was used in the earlier work show an increase in the opacity of the iron when it is magnetized in a direction parallel to the Röntgen rays (perpendicular to the cathode stream of the *X*-ray tube). The effect seems to be about 5 parts in a thousand for a field of 3,500 gauss. Since soft iron is saturated at an induction of about 15,000, we have the iron molecules only slightly oriented in a field of 3,500 gauss, and so no doubt a greater effect would be found with a field of 15,000 or more gauss.

There was a feeling from past experience that the observed effect might be due to some secondary cause rather than the change in opacity of the iron. To check this the iron was put in position *a* (Fig. 1) or over the ionizing chamber where the field would be comparatively weak. In this position with the conditions the same as when the iron was in position *b* (Fig. 1) no effect was observed. Thinking that the effect when the iron was in position *b* might be due to the effect of the magnetic field on the secondary rays coming from the iron, the iron was placed in position *c*. Here it would be in a comparatively weak field, but the secondary rays from the iron would pass through the magnetic field of 3,500 gauss. With the iron placed in this position no effect was observed.

As a further check a filter of tinfoil was placed below the *X*-ray tube and above the iron. This filtered out the rays which were likely to produce secondary rays in the iron and gave more consistent readings by making the condition of balance between the two chambers more stable. Next the effect of stopping the secondary rays produced in the iron, before they reached the ionizing chambers, was tried by covering the top of each chamber with tinfoil. In all these cases the effect of magnetizing the iron was evident. Tables I., II., III. and IV. give the readings with the tinfoil filter. These data include only two voltages across the *X*-ray tube, viz., 21 and 81.5 K.V. Measurements were made without the tinfoil filter for voltages of 21, 27, 32.5, 45 and 51.8 K.V. and indicated an effect almost equal for all these voltages but slightly smaller in magnitude than with the tinfoil filter. The source of current was a high tension rectifying machine and the voltage was measured in terms of the effective voltage, so that the values above are less than the maximum or peak voltage across the *X*-ray tube.

TABLE I.

Filter of Tinfoil and Iron in Position b.

Mili-Amp.	K. V.	Electrometer Deflection. Mag. Current Off.	Mag. Current On.	Mili-Amp.	K. V.	Electrometer Deflection. Zero Setting of Lead Strip.	Setting Changed 2 Mm.
5	27	82					
5.1	26.4	55		5	27		121
5.05	26.7		70	5	27		124
4.9	27.3	73		5	27		124
4.95	27.2		71	5	27	94	
4.9	27.3		72	5	27	100	
4.95	27.2	59		5	27	94	
5	27	50		5	27		128
4.95	27.2		67				
4.8	27.6		79				
5	27	59					
5	27		67				
Mean deflection ...63 ± 3.3			71 ± 1.21	Mean deflection..96 ± 1.35			124.2 ± 0.97
Difference.....			8 ± 3.55	Difference.....			28.2 ± 1.66
Proportional change = 0.00388 ± 0.00163				Sensibility per scale division = 0.000485 ± 0.000028			

The experimental work indicates that the iron is less transparent to the more penetrating Röntgen rays when it is magnetized in a direction parallel to the path of the Röntgen rays.

Since the Röntgen ray is due to a disturbance created by an electron

TABLE II.

Filter of Tinfoil and Iron in Position b.

Mili-amp.	K. V.$_2$	Electrometer Deflection. Mag. Current Off.	Mag. Current On.	Mili-Amp.	K. V.	Electrometer Deflection. Zero Setting of Lead Strip.	Setting Changed 2 Mm.
5	81.5	−36		5	81.5	60	
5	81.5	−44		5	81.5	60	
5	81.5	−35		5	81.5		76
5.1	81.5		−26	5	81.5		69
4.9	81.5		−30	5	81.5		74
5.1	81.5		−31	5	81.5	55	
5	81.5	−37		4.9	81.5	60	
4.9	81.5		−32	5	81.5		76
5	81.5		−31				
Mean deflection. −38 ± 1.37			−30 ± 0.7	Mean deflection..58.7 ± 0.8			73.7 ± 1.11
Difference.....			8 ± 1.54	Difference.....			15 ± 1.37
Proportional change = 0.007 ± 0.00156				Sensibility per scale division = 0.0009 ± 0.0000835			

TABLE III.

Filter of Tinfoil with Iron in Position b and with Tinfoil Over Top of Each Ionizing Chamber.

Mili-amp.	K. V.	Electrometer Deflection. Mag. Current Off.	Mag. Current On.	Mili-amp.	K. V.	Electrometer Deflection. Zero Setting of Lead Strip.	Setting Changed 2 Mm.
5	81.5	−25		5.1	81.5	59	
4.9	81.5	−26		5	81.5	57	
5	81.5		−20	5	81.5	57	
5	81.5		−20	5.1	81.5		69
5	81.5	−25		5	81.5		74
5.1	81.5	−26		5	81.5		76
5.1	81.5		−19	5	81.5	59	
Mean deflection		−25.5 ± 0.19	−19.66 ± 0.27	Mean deflection		58 ± 0.354	73 ± 1.4
Difference			5.84 ± 0.33	Difference			15 ± 1.44
Proportional change = 0.005 ± 0.000595				Sensibility per scale division = 0.0009 ± 0.000088			

whose motion is in the direction of the cathode stream of the *X*-ray tube, we would expect the absorption of energy from the Röntgen rays to be by those parts of the molecule free to vibrate in the same plane. And unless the molecule is symmetrical about all its axes, there is a plane

TABLE IV.

Filter of Tinfoil with Iron in Position c.

Mili-amp.	K. V.	Electrometer Deflection. Mag. Current Off.	Mag. Current On.	Mili-amp.	K. V.	Electrometer Deflection. Mag. Current Off.	Mag. Current On.
5.1	26.5	62		4.9	81.5	42	
5	27	62		5	81.5	38	
5	27		61	5	81.5		42
5	27		62	5	81.5		40
5	27	57		5.1	81.5	37	
5.1	26.5	60		5.1	81.5		36
5	27		60				
Mean deflection		60.25 ± 0.79	61 ± 0.387	Mean deflection		39 ± 1.40	39.3 ± 1.18
Difference			0.75 ± 0.875	Difference			0.3 ± 1.6
Proportional change = 0.0003 ± 0.000425				Proportional change = 0.00027 ± 0.0013			

through it where the absorption is a maximum. Magnetizing the iron will tend to align the molecules so that they will have their planes of maximum absorption parallel to one another. If the planes of maximum absorption are parallel to the cathode stream of the *X*-ray tube, then the iron will seem more opaque. The results of this work indicate that the plane of maximum absorption of the iron molecule is parallel to that of the electronic orbits which make up the elementary magnet.

It seems to the author that the failure of the Röntgen ray to ionize all the molecules of a gas through which it passes may be explained as due to the molecule having only one plane in which it can absorb sufficient energy from the Röntgen ray for ionization. As soon as time will permit, the effect of a magnetic field will be tried on the opacity of oxygen in an attempt to see if this is true.

In conclusion the author wishes to express his indebtedness to Prof. Shearer for the use of his *X*-ray laboratory and the generous loan of a Coolidge *X*-ray tube, without which this last work would have been impossible. He wishes also to thank Prof. Merritt for the encouragement received during the slow progress of the work.

September 20, 1915.