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

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IN a general way it would seem natural to expect that a change in the molecular arrangement of iron by magnetization, which produces the phenomenon of magneto-striction, should to some extent also affect the opacity of the iron to Röntgen rays. The investigations along this line have all given negative results. Experiments[1] in which the polarized secondary rays were used instead of the ordinary Röntgen rays have been tried with negative results.

In the winter of 1909, the author found indications of a positive character using a rough photographic method. The photographs indicated a slight increase in the opacity when the iron was magnetized in a direction parallel to the axis of the X-ray tube and perpendicular to the Röntgen rays. Because of their magnitude and the possibility that they were due to secondary causes, these results were not conclusive. It was therefore decided to see if they could be duplicated with an apparatus utilizing the ionizing power of the Röntgen rays. A method was devised which was much more sensitive than any used before and capable of detecting a change in the opacity of one part in ten thousand under the most favorable conditions.

Tests using this method, in which the iron was magnetized in a plane perpendicular to the Röntgen rays, with its direction of magnetization parallel to the axis of the X-ray tube, and also with its direction of magnetization perpendicular to this axis, gave negative results. The following is a description of the apparatus and the method of making the tests.

The apparatus finally adopted is shown in Fig. 1. The ionizing chambers consist of upright lead pipes (*CC*) soldered to a horizontal sheet of lead (*MM*). In the axis of each pipe is an insulated bare wire. The two wires are also connected to a grounding switch as shown. The ionizing chambers are both insulated and one maintained at a potential of + 220 volts and the other at a potential of − 220 volts. Two screens, one of lead and the other of a mixture of white-lead and putty, were used to stop rays other than those passing through the iron and entering the

[1] J. C. Chapman, Phil. Mag., Vol. 25, p. 792.

ionizing chambers. There is a possibility that very hard rays might even pass through these screens into the space below the charged plates and there ionize the air. This would cause a leakage to the wires and thus mask the effect of the charge which leaks to them in the ionizing chambers. To prevent this a grounded guard plate (*G*) was put below the lead sheets (*MM*). The potential of the wires is very small so that the leakage from the wires to the guard plate is quite small and negligible, while the ionization which results under the charged plates is taken care of by leakage to the grounded guard plate. If the Röntgen rays do get below the lead plates (*MM*) their effect is therefore inappreciable.

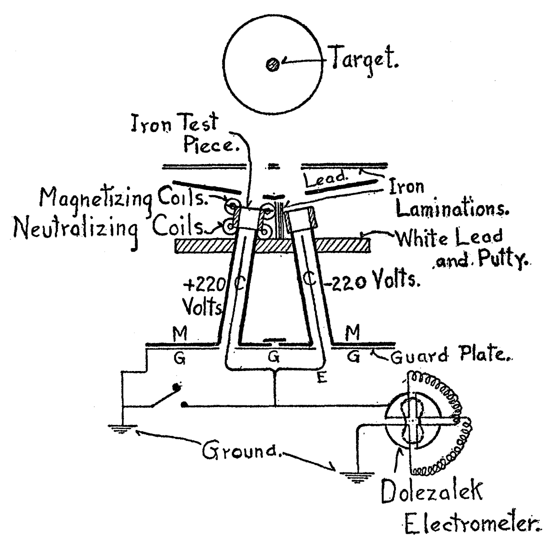

Fig. 1.

The piece of iron to be magnetized is fastened to the yoke of an electromagnet so that it completes the magnetic circuit as shown in Fig. 2. In the course of the experimental work, it was found that the stray field from the magnetizing coils disturbed the balance between the two chambers by deflecting the cathode ray in the X-ray tube. To prevent this two similar coils were placed under the magnetizing coils and connected in series with them so that they set up an opposing flux. This neutralized the effect of the stray field in the vicinity of the cathode ray. A screen of two sheets of iron was placed between the coils and the X-ray tube as an additional precaution. The magnetic effect was screened from the other piece of iron by iron laminations placed between the two pieces as shown in Fig. 1.

Perfect electrostatic screening of the electrometer system was obtained by use of a solid screening of tin-plate, except where the light was reflected from the electrometer mirror. This opening was screened by using a glass cell filled with a solution of NH_4Cl and grounded. The balance between the two ionizing chambers was made by sliding a narrow wedge of lead foil in and out across the top of one of the chambers, using a micrometer screw to adjust the position of the wedge. The electrometer which was used gave a deflection of 84 cm. at a distance of 1 meter, with its needle charged to 62 volts, and a difference in potential of 1 volt across the quadrants.

With the two chambers charged oppositely as indicated, ionization in each tends to neutralize the charge that leaks to the wire from the other, and when there is a perfect balance no charge accumulates on the wire. A very slight change in ionization of either chamber causes a piling up of a charge on the wire, and the deflection of the electrometer is proportional to the change in ionization and the time that the grounding switch is open.

The sensibility of this system is so great that difficulty was experienced at first in getting a balance between the chambers because of disturbances due to a change in the hardness of the X-ray tube. A very slight change in the potential difference across the X-ray tube would destroy the balance. It was therefore necessary to connect a high tension electrostatic voltmeter across the X-ray tube, and take observations for definite potential differences. In taking the readings the following method was used. With the grounding switch closed, a current was sent through the X-ray tube and as soon as this tube had reached the desired condition, the grounding switch was opened. After the switch had been open for five seconds the current through the X-ray tube was stopped and the electrometer deflection observed. The deflection thus obtained is proportional to the charge which accumulates in five seconds, due to the difference in ionization in the chambers.

The effect of the magnetization of the iron on the change of the balance was tried with rays of three degrees of penetrability. Measured by the equivalent spark between sharp points, the potential difference across the X-ray tube was respectively 4.2, 7 and 10.5 cm. The iron used was 0.08 mm. thick and had the following chemical analysis: 0.093 per cent. silicon, 0.06 per cent. sulphur, 0.008 per cent. phosphorus, 0.24 per cent. manganese, 0.1 per cent. carbon and 99.47 per cent iron.

It was magnetized to saturation by sending a large current through the magnetizing coils and it was demagnetized by sending 60-cycle alternating current through the coils and reducing the current by steps to zero.

Tests were made in which the iron was turned with its direction of magnetization parallel to the axis of the X-ray tube, and also with its direction of magnetization perpendicular to this axis. Since the tube varied in hardness even during an observation, it was necessary to take a number of readings with the iron first magnetized and then demagnetized. To guard against any shift due to secondary causes, observations were made in pairs, first with the iron demagnetized and then with the iron magnetized.

The sensibility of the apparatus was tested by finding the smallest change in the area of the iron, penetrated by the rays entering the chamber, which produced a change of balance appreciably greater than any effect noticed in the magnetization tests. The area of the iron penetrated by the rays entering the ionizing chamber was slightly less than the area of the ionizing chamber opening, since the iron was a little distance above the chamber (see Fig. 2). The diameter of the effective area was found experimentally by sliding a lead strip (edge on) across the top of the iron and parallel to a diameter of the opening of the chamber, and finding the first point where a change of balance was produced. It was then moved across the entire opening and another point found where a change of balance was produced. The distance between these points is the diameter of the circle penetrated by the rays entering the ionizing chamber. To get the smallest change in area which could be detected, the lead strip which extended about one fourth of the diameter inside the circle, was moved through the smallest distance that would appreciably disturb the balance. This distance multiplied by the thickness of the lead strip gives the increment in area. The total area is found by subtracting the area covered by the lead strip from the area of the effective circle, and the sensibility is expressed as the ratio of the change in area to the total area. In one of the tests the values were as follows: Diameter of effective circle 19 mm. Thickness of strip 0.86 mm. Area covered by the strip 3.44 sq. mm. Distance strip was moved to change balance 0.05 mm. Hence the sensibility was 0.043 divided by 280, or 0.00015.

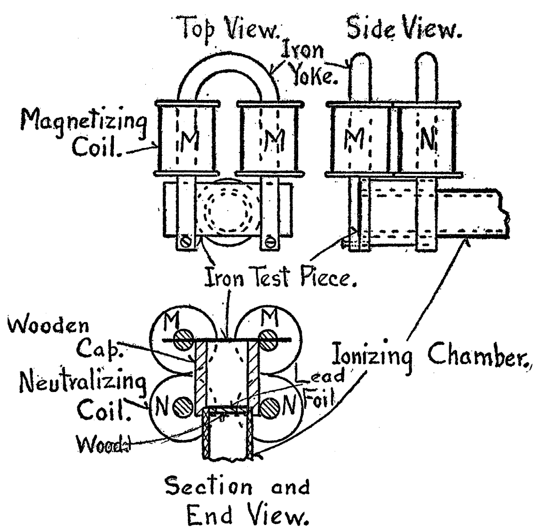

Fig. 2.

The sensibility depends upon the total number of rays passing through the iron into the ionizing chamber, and this depends on the degree of penetrability of the rays and the current passing through the X-ray tube. The sensibility was therefore determined for each degree of penetra-

TABLE I.

Magnetic Field Perpendicular to Axis of X-ray Tube.				Magnetic Field Parallel to Axis of X-ray Tube.				Sensibility Test. Proportional Change of Area=0.0015.			
X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflection.	
Miliamps.	Equivalent Spark-gap.	Iron Demagnetized.	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Iron Demagnetized.	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Zero Setting of Lead Strip.	Setting Changed 0.5 mm.
5	4.2 cm.	57		5	4.2 cm.	64.5		5	4.21 cm.	64	
5	4.2	71.5		5	4.2	61.5		5	4.21	64	
5	4.2		49.5	5	4.21		64.5	5	4.2	69.5	
5	4.23		48	5	4.2	63		5	4.22	58.5	
5	4.23	57.5		5	4.21	66		5	4.23		43
5	4.2	51.5		5	4.22		62	5	4.23		42.5
5	4.25		39.5	5	4.23		70	5	4.23	52.5	
5	4.24		50	5	4.23	66		5	4.25	52.5	
5	4.2	25						5	4.25		32
5	4.25	40						5	4.26		21
5	4.25		46					5	4.28	27.5	
5	4.25		41.5					5	4.25	28.5	
5	4.25	35.5						5	4.26	24.5	
5	4.25	24						5	4.27		−5
								5	4.26		−7.5
Mean deflection Difference = 0.45		45.25	45.7	Mean deflection Difference = 1.3		64.2	65.5	Mean deflection Difference = 27.9		48.9	21

TABLE II.

Magnetic Field Perpendicular to Axis of X-ray Tube.				Magnetic Field Parallel to Axis of X-ray Tube.				Sensibility Test. Proportional Change of Area=0.00015.			
X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflect.	
Miliamps.	Equivalent Spark-gap.	Iron Demagnetized.	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Iron Demagnetized	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Zero Setting of Lead Strip.	Setting Changed 0.05 mm.
3	7.3 cm.	55.5		4	6.95 cm.	37.5		4.7	7 cm.	−55	
3.2	7.1	−65		4	6.8	−21.5			7.07	−66	
3.2	7.1		−180	4	6.9		19.5	5	7	−68	
3.15	7.2		−180	4	6.95		180	5	7		170
3.3	7.35	89		4	6.95	105		5	7.03		140
3.5	7.1	46		4.2	6.75	−12		4.5	6.85		90
3.6	7.2		−54	4.2	6.75		−31	4.8	6.95	−180	
3.7	7.25		−42	4.1	6.8		−14.5				
4	7.1	−91.5		4	6.8	56.5					
4	7.1		35.5	4.1	6.75	21					
3.9	7.1		40	4.15	6.75		21				
3.9	7.1	−180		4.15	6.75		−31				
3.6	7.1		−33.5								
3.5	7.1		−110								
3.5	7.1	−180									
3.7	7.1	−108									
Mean deflection. Difference = 11.		−54.5	−65.5	Mean deflection. Difference = 8.1		32.1	24	Mean deflection. Difference = 225.		−92	133

TABLE III.

Magnetic Field Perpendicular to Axis of X-ray Tube.				Magnetic Field Parallel to Axis of X-ray Tube.				Sensibility Test. Proportional Change of Area=0.00018.			
X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflect.		X-ray Tube.		Electrometer Deflect.	
Miliamps.	Equivalent Spark-gap.	Iron Demagnetized.	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Iron Demagnetized.	Iron Magnetized.	Miliamps.	Equivalent Spark-gap.	Zero Setting of Lead Strip.	Setting Changed 0.06 mm.
1.5	10.55 cm.	59		1.9	10.5 cm.	23		—	9.65 cm.	77	
1.6	10.5	35		1.9	10.6	88.5		—	9.55	80	
1.55	10.53	26		1.95	10.6	84.5		1.5	9.45	2.1	
1.85	10.53		20	1.8	10.6	100		1.5	9.45		−23
1.85	10.53		22	1.8	10.6	180		1.4	9.55		19
1.85	10.53		65	—	10.55		17	1.5	9.45		−27
1.8	10.5	−2		1.9	10.6		170	1.5	9.35		23
1.8	10.42	−2.5		2	10.6		18	1.2	9.35		−180
1.7	10.5	27.5		1.9	10.45	−180		1.4	9.4		−175
1.7	10.53	37		1.95	10.6	89.5					
1.7	10.53		31	1.9	10.55		75				
1.5	10.53		42.5	1.95	10.5		30				
1.6	10.53	38.5		1.95	10.45	−170					
1.5	10.53	54.5		1.8	10.55	33					
1.5	10.62		77.5	1.8	10.6		87				
1.65	10.55		24	1.85	10.6		64				
1.8	10.5		33	1.8	10.55	26					
1.55	10.53	52		1.8	10.55	18					
1.5	10.5	50		1.85	10.5		−31.5				
1.5	10.53		63	1.9	10.45		−180				
1.5	10.53		53	1.85	10.5	−47					
1.5	10.53	57									
Mean deflection. Difference = 1.1		38.3	37.2	Mean deflection. Difference = 8.6		20.4	31	Mean deflection. Difference = 120.1		59.6	−60.5

bility. For the softer rays the sensibility was 0.0015, for the medium rays it was 0.00015 and for the hardest rays it was 0.00018. The reason that the sensibility for the run with the hard rays was less than that of the medium rays is that the X-ray tube used for the hard rays was smaller and a smaller current was sent through it.

The preceding tables give the results of the tests.

In some of the tests the values differ considerably. This is because of the high sensibility of the apparatus and the fact that the condition of the X-ray tube varied. It will be noticed that in the magnetization tests the mean values agree closely, thus showing that as a whole there is no change in the balance. In the sensibility tests the change in ionization is evident from the mean values of the deflections and their differences. We therefore conclude that there is no effect due to the magnetization of the iron, with the magnetization in a plane perpendicular to the Röntgen rays and either parallel or perpendicular to the axis of the X-ray tube, unless it is less than the effect produced by shifting the lead strip. In the case of the soft rays it must be less than 0.0015, medium rays less than 0.00015, and hard rays less than 0.00018. In the earlier tests an effect was observed when the magnetizing current was on, but this was found to be due to the deflection of the cathode ray of the X-ray tube, which is probably the cause of the positive results obtained at first photographically. Investigations have been started using a field of 3,500 gauss parallel to the Röntgen rays and perpendicular to the plane of the iron.

As is evident, the method which has been used in this work has the great advantage that even though the ionization in each chamber is quite large, the electrometer measures only the small difference in the ionization. And since this method gave such a high degree of sensibility, it seems to the author that it would be quite useful in other fields of investigation where the changes sought for are likely to be quite small.

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