COMPARATIVE STUDIES OF MAGNETIC PHENOMENA. III.

Magnetic Induction in a Group of Oblate Spheroids of Soft Iron.[1]

By S. R. Williams.

In the relation[2] between the Joule magnetostrictive effect and the magnetic induction in the same specimen of steel, I have pointed out that the maximum elongation of the steel rod in the Joule effect and the knee of the induction curve occur at the same magnetic field strengths. If the change in length of the steel rod is due to the orientation of elongated elementary magnets[3] then the orientation of these same elements, possessing the property of permeability, will produce in their turning changes in the magnetic induction. That is saying that the variation of B with H in the ordinary magnetization curve is not alone due to the intrinsic value of the permeability of the elementary magnets but is influenced by the orientation of those same elementary magnets. It is a well-known fact that an elongated piece of iron will turn so that its greatest length is parallel to the field imposed upon it. The converse of this must hold that if an elongated piece of iron is turned in the magnetic field, the magnetic flux will be changed in the piece of iron because a piece of ferro-magnetic substance sets itself in a magnetic field so that the magnetic resistance is a minimum.[4]

The occurrence of the maximum elongation and the knee of the induction curve at the same field strength emphasizes the point of view that there is some factor in the specimen of iron being investigated which simultaneously changes the length of the specimen and also varies the induction. This factor, I believe, is the elementary magnet. In this series of comparative studies on magnetic phenomena I have been trying to find some point of view that will unify our present knowledge of magetic phenomena and so far have found the idea of an elementary magnet, described in a previous paper, as being exceedingly helpful. No stress is laid on the theory only in so far as it leads to new facts.[5]

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[1] Read by title at the Cambridge Meeting of the Amer. Phys. Soc., Apr., 1912.

[2] Phys. Rev., p. 258, Vol. 34, Apr., 1912.

[3] Phys. Rev., p. 40, Vol. 34, Jan., 1912.

[4] Starke, Experimentelle Elektricitatslehre, p. 75, 1904.

[5] Rücker, Pres. Address, B. A., Glascow, 1909. See Mellor, Higher Mathematics for Students of Chemistry and Physics, p. 365.

To give added support to the suggestions offered above, the magnetic induction in a group of oblate spheroids of soft Swedish iron was studied to see if their orientation produced an effect on the magnetic flux. Oblate spheroids were chosen as the form for the "elongated particles" because this was the shape ascribed to the nucleus of the model of the elementary magnet.

It is evident that if a definite number of these oblate spheroids were laid with the minor axes on the same straight line and touching each other that their total length would be less than though the same number were laid with major axes on a similar line. A change in length of such a group, due to their orientation, is obvious. The magnetic induction, however, may be considered at greater length and this paper has for its object the study of the magnetic induction in a group of twenty-seven oblate spheroids of soft Swedish iron, arranged in the form of a cube with nine spheroids on a side. The minor axes measured one centimeter and the major one and one half centimeters.

Miss Laura Anderegg, a graduate student in the department, carried out the measurements in the following way:

MISS ANDEREGG'S EXPERIMENTS.

The spheroids were laid up in the form of a cube as shown in Fig. 1 and paraffine poured in around them. This kept the spheroids in a definite position while testing the magnetic induction. This cube of spheroids was placed inside of a small secondary coil whose dimensions were, length 10.7 cm., cross-section 6.5 cm. square and the number of turns, 170. This coil was connected in series with a ballistic galvanometer and with its core of spheroids placed at the center of the large solenoid described in a former paper.[1] The induction was studied by the ordinary ballistic method employed in testing specimens of iron, steel, etc. As only relative values were wanted the deflections of the ballistic galvanometer were used to represent the total flux through the secondary.

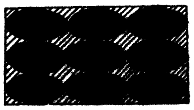

Fig. 1.

In Fig. 2 is shown the relative values for the magnetic flux, (1) when the spheroids were removed from the secondary, (2) when the spheroids were in the secondary and the equatorial planes *normal* to the imposed magnetic field and (3) when the spheroids were in the secondary but the equatorial planes *parallel* to the field. In both curves 2 and 3 there was the same amount of ferromagnetic substance present but the orientation of the elementary units with respect to the field produced a comparatively

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[1] PHYS. REV., p. 41, Vol. 34, Jan., 1912.

large change in the magnetic flux; when the major axes were *parallel* to the magnetic field the flux was greater than when the major axes were *normal*. For curves 2 and 3, Fig. 2, the spheroids were laid so that they touched each other in two directions at right angles, as shown in Fig. 1. This made the length of the group shorter in one direction than in the other. When this shorter length was parallel to the imposed magnetic field there was less magnetic flux through the group than when the greater length was parallel. To make the outside dimensions of the group the same in all directions, the three layers shown in Fig. 1 were separated by strips of wood, as shown in Fig. 3. This was again tested when the equatorial planes were normal and when parallel to the field and the results are shown in curves 4 and 3 respectively. Curve 3 shows that the induction, parallel to the major axes, was the same as before the separation occurred, while 4 shows that a separation of the spheroids has decreased the magnetic flux in the direction in which the separation took place. This is an important result.

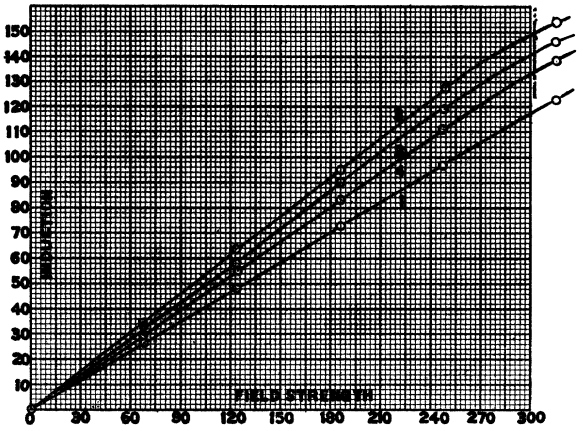

Fig. 2.

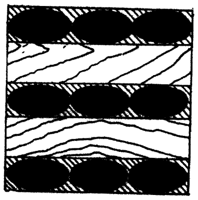

Fig. 3.

The spheroids were next set up so that their equatorial planes would make angles other than 0° and 90° with the imposed field. They were tested for 30°, 45° and 60° and the values fell between those of curves 2 and 3. The results seem to show that if one start with equatorial planes parallel to the imposed field that the magnetic flux decreases with the decrease of the diameter of the spheroids parallel to the field. The results of the experiments show that the magnetic flux in a group of spheroids may be influenced in two distinct ways: (1) by the orientation of the spheroids and (2) by their separation. The flux is greater the more nearly the greatest length is parallel to the field and is decreased by increasing the distance between the surfaces of the spheroids.

Discussion of Results.

These results obtained by Miss Anderegg throw light on several magnetic phenomena with which we are familiar.

1. *Magnetization Curves.*[1]—In the magnetization curves of soft annealed iron and glass-hardened steel there is a very marked difference in the change of B with H in the two specimens. The knee of the curve occurs at smaller field strengths for soft iron than it does for the hardened steel. Hardened steel makes the best permanent magnets. This would indicate that the elementary magnets are not as free to turn in the hardened steel as in the soft iron. Consequently it will take a greater field strength to orient the elementary magnets a given amount in hardened steel than it does in soft iron. If a part of the increase of B therefore is due to the orientation of the elementary magnets, it must follow that the knee of the induction curve will not occur at as low field strengths for hardened steel as for soft iron, because it will take a larger magnetic field to bring the elementary magnets, which are producing the changes in length, so that their greatest length is parallel to the imposed field and it is at this point that the knee of the induction curve occurs. Previous work has shown that the maximum elongation of hardened steel in the Joule effect occurs at higher values of field strengths than it does in soft iron. If now the change in length may be ascribed to the orientation of the elementary magnets it would seem that we had here a most remarkable relation of phenomena.

2. *Application to the Villari*[2] *Reversal Effect.*—As is well known, certain steels when stretched in a weak magnetic field increase their magnetization but if stretched in a strong field lose in magnetization. In a weak magnetic field it is assumed that the elementary magnets are turned more or less in all directions with a tendency for those producing changes in length to turn with equatorial planes parallel to the field imposed upon them. This is shown in the change in length phenomenon. If a pull be applied to a steel rod in a weak field it helps to set the elementary magnets more nearly parallel to the field and so the magnetization is increased. On the other hand if a strong field is applied, *all* of the elementary magnets are turned with the equatorial planes normal to the field. Let a pull be applied to the rod in this last state when the magnetic

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[1] Hadley, Mag. and Elec. for Students, p. 390.

[2] Villari, Pogg. Ann., 1868.

field has sufficient power to hold the elementary magnets fixed and the only thing that can occur is a separation of the elements. These experiments show that separating the spheroids decreases the magnetization. This is what occurs when a steel rod is stretched in a strong magnetic field.

3. *Application to Maurain's*[1] *Experiments.*—Maurain has pointed out that iron electrolytically deposited in a magnetic field shows anisotropic properties, *i. e.*, the elementary magnets seem to have been deposited with a definite orientation and therefore the intensity of magnetization has different values in different directions for the same field strength. Gans[2] has recently thrown doubt on the anisotropic property of iron but as Vallauri[3] has pointed out, Gans worked with too great a field strength (1,250 gauss). At such field strengths the elementary magnets are all turned in a definite direction and no matter in what direction such a field is applied to a specimen of iron it will force all of the elementary magnets with equatorial planes normal to the field. The group of spheroids used in these experiments is a model of the electrolytically deposited iron which shows different intensities of magnetization in different directions and the æolotropic property[4] of iron is a phenomenon which we should expect to find at proper field strengths.

In crystalline media such as pyrrhotine[5] we have a very pronounced case of a definite orientation of the elements in which we have different magnetic properties in different directions. It is only a step farther to assume that in the case of crystals showing rotation of the plane of polarization we have another manifestation of this same definite orientation of the elementary particles. This is being investigated in a series of crystals here in our laboratory.

SUMMARY.

1. The results of this investigation show that the orientation of the ellipsoidal elements does affect the magnetic flux. This furnishes a possible explanation as to why the maximum elongation and the knee of the induction curve come at about the same field strength.

2. The behavior of the ellipsoidal elements shows that not only orientation but also the distance between the bounding surfaces of the ellipsoids affect the magnetic properties.

3. This study also points out a possible explanation of the æolotropic properties of iron electrolytically deposited and why in other specimens

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[1] Maurain, Phys. Zeitschr., 13, p. 314, 1912. Beetz, Pogg. Annal., CXL., p. 107, 1860.

[2] Gans, Phys. Zeitschr., 12, p. 911, 1911.

[3] Vallauri, Phys. Zeitschr., 13, p. 314, 1912.

[4] Klemencic, Phil. Mag., p. 424, Vol. 38, 1894.

[5] Weiss, Jour. de Phys., IV., pp. 469, 829.

of iron there appears to be no æolotropic properties at high field strengths.

4. I have attempted to show that because we have mechanical effects due to magnetization, such as we find in the magnetostrictive effects we must have some hypothesis of magnetization which will account for such phenomena. The ellipsoidal form of the elements, it seems to me, furnishes this part, as the elements are oriented under the influences of the forces operative upon them and produce changes in dimensions.

PHYSICAL LABORATORY,
OBERLIN COLLEGE, OBERLIN, OHIO.
March, 1912.

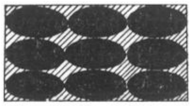

Fig. 1.

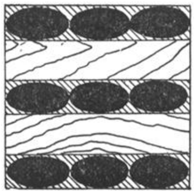

Fig. 3.