THE MAGNETIZATION OF IRON, NICKEL, AND COBALT BY ROTATION AND THE NATURE OF THE MAGNETIC MOLECULE

By S. J. Barnett

DEPARTMENT OF PHYSICS, OHIO STATE UNIVERSITY

Communicated by R. A. Millikan, January 15, 1917

In December, 1914, I described to the American Physical Society an extended series of experiments made in that year on the magnetization of large steel rods by mere rotation.[1]

Before these experiments were made only one method of magnetizing a body was known, viz., placing it in a magnetic field. These experiments not only revealed another and entirely new method, but they also confirmed completely the fundamental assumptions on which the results had been predicted: They proved, in a direct and conclusive way, on the basis of classical dynamics alone, without dependence upon the theory of radiation, (1) that Ampèreian currents, or molecular currents of electricity in orbital revolution, exist in iron; (2) that all or most of the electricity in orbital revolution is negative; and (3) that it has mass or inertia, so that each orbit behaves like a minute gyrostat and tends to set itself with the direction of revolution coincident with the direction of rotation of the body. It is in this way that magnetization of the body results. Furthermore, if we admit the classical theory of radiation, these experiments, together with the existence of residual or permanent magnetization, prove (4) that the arrangement of the electricity in the Ampèreian orbits is Saturnian rather than planetary.

If it is assumed that only one kind of electricity is in orbital revolution, and if the mass of a particle is denoted by m and its charge by e, theory shows that the rotation of a body with angular velocity n revolutions per second is equivalent to putting it in a magnetic field of intensity H, such that

$$H/n = 4\pi m/e. \tag{1}$$

If we assume that electrons alone are in orbital revolution, the value of the second member of this equation is -7.1×10^{-7} e. m. u. according to well known experiments on electrons in slow motion, and H/n should be equal to this quantity and identical for all substances. If positive electricity also participates, the magnitude of H/n should be smaller. The value of H/n in my 1914 experiments was -3.6×10^{-7} e.m.u.

A little later, in February and April, 1915, Einstein and de Haas[2] described to the German Physical Society successful experiments on the effect converse to mine, viz., rotation by magnetization, which had been predicted and looked for by O. W. Richardson in 1907; and de Haas[3] has recently continued this work in a somewhat different manner. Both investigations are indirect but excellent confirmations of my own earlier work. This work has also been confirmed by further experiments of my own of somewhat increased precision described before the American Physical Society in April, 1915.[1]

In the last year, with financial aid received from the University through the interest of the dean of the graduate school, Prof. W. McPherson, and with the help of Mrs. Barnett, I have extended the investigation to other specimens of iron and to cobalt and nickel. In all the earlier work the method of electromagnetic induction was used; this later work has been done by an entirely different method, viz., that of the magnetometer.

The magnetometer was an astatic instrument, and each rod under experiment, or rotor, about 30.5 cm. in length and from 2.3 cm. to 3.2 cm. in diameter, was mounted with its axis horizontal and normal to the magnetic meridian in the equatorial position of Gauss, which offered important advantages for this work. Calibrations were made by means of solenoids wound permanently on the rotors, and subsidiary solenoids wound on wooden cores.

To avoid magnetic and mechanical disturbances as much as possible, nearly all of the observations were made after one o'clock at night. This precaution, together with the use of true, carefully adjusted, and frequently oiled bearings, heavy mountings of bronze and concrete, and a special method of driving, eliminated mechanical disturbances very largely.

Disturbances due to variations of the earth's intensity were greatly reduced by mounting a compensating rod of the same substance and nearly the same size as the rotor in approximately the same position with respect to the upper magnetometer magnet as that occupied by the rotor with respect to the lower magnet.

Possible errors due to eddy currents in the rotor and to minute shifts of the rotor's axis in altitude or azimuth were avoided by compensating accurately the earth's intensity in the region occupied by the rotor by means of a very large coil traversed by a steady electric current. Much greater variations of the compensating current on both sides of the correct value than the maximum allowed in the rotation experiments produced no appreciable effect on the results obtained with some of the rotors and not more than small effects with the others. The magnetometer magnets, control magnet, compensating rod, and a small electric coil in series with the large coil and mounted near the upper magnetometer magnet to make the sensibility approximately independent of the compensating current, produced in the region occupied by the rotor intensities so small that their effect was negligible.

Rotation observations were made at equal intervals in sets of four as follows: The rotor was first driven (by means of an alternating current motor) at given speed in one direction and the magnetometer scale read; then the motor was reversed and the scale again read; then the readings were repeated in inverse order, all for the same speed. The double deflection obtained by subtracting the mean of the second and third readings from the mean of the first and fourth was the quantity sought. This process eliminated the difficulties due to the presence of residual magnetization of the rotor, the error due to magnetometer drift, and other possible errors. Error due to torsion of the rotor was found to be negligible by reversing some of the rotors in their bearings.

With nickel and cobalt observations were made at three speeds, and H/n was found to be independent of the speed within the limits of the experimental error, as had been found in the earlier experiments with iron.

Since mechanical disturbances were almost wholly absent and the magnetic disturbances became relatively less important with increased speed, the observations at the highest of the three speeds were more precise than the others. Table 1 contains the approximate results of the observations on four rods at the highest speeds. A few observations, consistent with the others, on a fifth rod, of soft iron, in poor condition are not included in the table.

TABLE 1.

ROTOR	MEAN SPEED	NO. OF SETS	$10^7 \times \frac{H}{n}$	AVERAGE DEPARTURE FROM MEAN
Steel (larger)	47 r. p. s.	21	5.2 e. m. u.	1.2
Steel (smaller)	44	21	5.2	0.5
Cobalt	45	79	6.1	0.8
Nickel	45	37	6.1	0.9

The mean value of H/n is in all cases less in magnitude than the standard value of $4\pi m/e = -7.1 \times 10^{-7}$ e.m.u. for electrons in slow motion, as was the case in the earlier experiments; but the experimental errors, on account of the great difficulties involved, are such that importance cannot in my opinion be attached to the discrepancy. The investigation must rather be taken as confirming equation (1) and the assumption that only electrons are in orbital revolution in all the substances investigated.

A more extended account of the investigation will be published in the near future.

[1] Barnett, S. J., *Physic. Rev., Ithaca, N. Y.*, (Ser. 2), 6, 1915, (239–270).
[2] Einstein, A., and de Haas, W. J., *Berlin, Verh. D. Physik. Ges.*, 17, 1915, (152–170, 203, 420).
[3] de Haas, W. J., *Amsterdam, Proc. Sci. K. Akad. Wet.*, 18, 1916, (1281–1299); *Sci. Abs., London*, A., 17, 1916, (351).

THE INTENSITIES OF X-RAYS OF THE L SERIES

By David L. Webster and Harry Clark

JEFFERSON PHYSICAL LABORATORY, HARVARD UNIVERSITY

Communicated by E. H. Hall, January 17, 1917

The purpose of this paper is to report briefly some preliminary results of a study of the intensities of X-rays belonging to the L series of platinum considered as functions of the potential producing them and in their relations to each other and to the general radiation.

Review of Previous Work.—Many of the phenomena observed here can be predicted, though with no certainty, by analogy with corresponding phenomena of the K series. The similarity of the two series appears in Moseley's laws[1] of frequency as a function of atomic number, and especially in the fact that each series is produced as fluorescence by a substance absorbing rays of a higher frequency. It has been found by one of us[2] that the K series rays, of rhodium at least, appear only at a potential high enough to produce general radiation of a frequency as great as that of the shortest line of the series. This may be called the critical potential. Since this result is obviously connected with the law that absorbed rays will produce the K fluorescence only if their frequency is above that of this line, it is reasonable to expect a similar law for the L series.

It must be remembered, however, that the L series is more complex than the K, both in the number of lines and in their gradual shifting relative to each other from element to element, shown in Moseley's graphs[1] of square root of frequency against atomic number of the emitting element. Moreover Kossel[3] has found reason to believe that platinum and gold each show two discontinuities of absorptive power as a function of frequency near the L series, one in the middle of the series and the other near the high frequency end. An explanation of this appears in a most exhaustive study of the positions of the L series lines of the heavy elements by Siegbahn and Friman[4] who have plotted $\sqrt{\nu}$ against N for twelve lines. Four of these graphs are linear and nearly parallel, while the eight others are not linear but are nearly