MAGNETIC DOUBLE REFRACTION.[1]

By Arthur W. Ewell.

Dr. Quirino Majorana[2] has shown that certain specimens of dialyzed iron (a colloidal solution of peroxide of iron) become double refracting in a magnetic field, the optic axis having the direction of the magnetic lines of force.

It seemed to the author of interest to repeat Majorana's experiments with such specimens of dialyzed iron as could be obtained locally, to use an alternating magnetic field and to test other substances with a very sensitive apparatus for detecting double refraction, suggested by Lord Rayleigh.[2]

A magnet suitable for alternating currents was constructed by replacing the laminations of one of the shorter sides of the core of a five-kilowatt, core-type transformer, by laminations cut to give an air gap of 0.5 cm. between faces 1 cm. wide and 12.5 cm. long, outside of which the laminations were cut obliquely to concentrate the field. The core was wound with 86 turns of No. 2 cable which was calculated to give the maximum field with an alternating current of 60 amperes at 220 volts. The magnet was calibrated for direct currents by withdrawing from between the poles an exploring coil connected with a ballistic galvanometer with which it had been calibrated and for alternating currents, from the E.M.F., measured with a low reading a. c. voltmeter, induced in the same coil in the air gap.

[1] When this article was in type I became acquainted with the second paper by August Schmauss in No. 9 of this year's volume of Annalen der Physik, in which he describes the temperature reversal and more fully than I the behavior of glycerine and jelly solutions, and plausibly develops the theory that the phenomena are due to the solutions consisting of minute particles in suspension in a medium of different and differently varying permeability.

[2] Academia dei Lincei, Rendiconti; 1902, X., pp. 374, 463, 531, XI., pp. 90, 131. Phil. Mag., 1903, April, p. 486. C. R., 1902, pp. 159, 235.

Theoretical discussion by W. Voigt (who sought in vain for double refraction in heavy flint glass) in Ann. der Physik, 1902, VIII., p. 880.

Brief note by A. Schmauss in Ann. der Physik, 1903, III., p. 658.

[3] Phil. Mag., 1902, Dec., p. 678.

The liquid tested was contained in a trough with plate-glass ends which fitted into the horizontal air gap. The source of light was a three-glower 150 c. p. Nernst lamp, with the filaments vertical and the plane of the filaments oblique to give the equivalent of a very brilliant band of light of nearly the width of the air gap. Between the lamp and the magnet was a Nicol set at 45° to the magnetic field. On the other side of the magnet was a horizontal strained glass plate, in front of which was a Nicol, crossed with reference to the first, and finally a short-focus telescope. The strained glass plate was 0.28 cm. thick, 30 cm. long and 3.3 cm. broad. It rested edgewise on supports, near the middle, 3 cm. apart and the ends were pulled down by rubber bands towards the base on which these supports rested. The horizontal dark band, the neutral axis of the bent glass plate, was viewed through the telescope and its location fixed by two silk fibers attached to the glass strip parallel to the edges of the band. If any appreciable double refraction appeared in the air gap the dark band was displaced to a position where this double refraction was neutralized. The sensitiveness of the apparatus was determined from the observation that 100 g. pressure upon a piece of plate glass 2.5 cm. wide gave an appreciable upward movement of the band. According to Mascart,[1] for average crown glass, 10 kilos pressure per mm. width produces a difference of path of 0.5 λ. (This value was adopted by Lord Rayleigh and agrees well with the recent results of F. Pockels.[2]) I could, therefore, detect a difference of path of 0.0002 λ. The minimum difference which Dr. Majorana could detect was 0.004 λ. The greater sensitiveness of the optical apparatus much more than compensates for the weaker magnet, the maximum field which I could obtain being 7,000 units while Dr. Majorana's was 18,000. The length of his air gap was 7 cm. Crown glass, subjected to pressure behaves as a negative crystal. As the magnetic lines of force were horizontal an upward movement of the band indicated positive magnetic double refraction.

A large number of drug stores in Worcester, Boston, Lynn, Salem and other places in Massachusetts were visited or communi-

[1] Optique, t. II., p. 232.

[2] Ann. der Physik, 1902, VII., p. 745.

acted with in a search for very old specimens of dialyzed iron and a number of such specimens were obtained. Several specimens of fresh product and also of intermediate age were also secured. The older specimens gave enormous motion of the dark band, generally negative. Specimens fresh from the preparers gave positive double refraction of a few thousandths λ. Dialyzed iron carefully prepared according to the directions of Dr. Majorana showed no double refraction after ten days' dialysis. Majorana states that his own preparations were uncertain and never very active. Ferrous and ferric chloride gave slight positive double refraction.

The following substances in the densest solutions consistent with sufficient transparency, gave no double refraction : ferrous sulphate, ferric sulphate, iron alum, citrate of iron, tincture of dialyzed iron, eisen zücker, nickel chloride, nitrate and carbonate, colloidal nickel, cobalt sulphate, chloride and nitrate, manganous sulphate and chloride. Water and carbon bisulphide were also inactive.

For quantitative study of the dialyzed iron, the strained glass plate was replaced by a Babinet compensator. Unless otherwise stated the light from the Nernst lamp was filtered through several thicknesses of red glass, giving quite monochromatic light of measured wave-length 6,600 Ångström units. The movement of the wedge to introduce a difference of path of one wave-length of this red light was 15.2 cm.

The double refraction of a specimen of dialyzed iron was found quite definite for a given age, concentration, magnetic field and temperature as is illustrated by the following observations upon a dilution of what will be designated specimen F (over 8 years old), of concentration 1:40 (1 c.c. of dialyzed iron to 40 c.c. of water, density equal 1.0033). The figures for the movement of the band are the means of three independent (usually identical) readings and are all negative.

Amperes,	28	33	53	65	86
Movement of band,	1.2	3.2	5	6	7.5

Two days later, a different sample of the same solution.

Amperes,	36	60	80	23	50	91
Movement of band,	3	6.7	7.8	1.1	5.8	7.2

Freshly prepared dilution of same concentration.

Amperes,	38	61	16	49	70
Movement of band,	3	6.4	8.4	4.9	6.6

Another freshly prepared dilution upon the following day.

Amperes,	15	24	34	48	54	66	76
Movement of band,	.2	1	2.4	4.7	6	6.9	7.7

These results are plotted in Fig. 1, I., with the strength of field as abscissæ, determined from the current and calibration curve, and as ordinates, the difference in path, in terms of the wave-length of the red light, obtained by dividing the movement of the bands by 15.2.

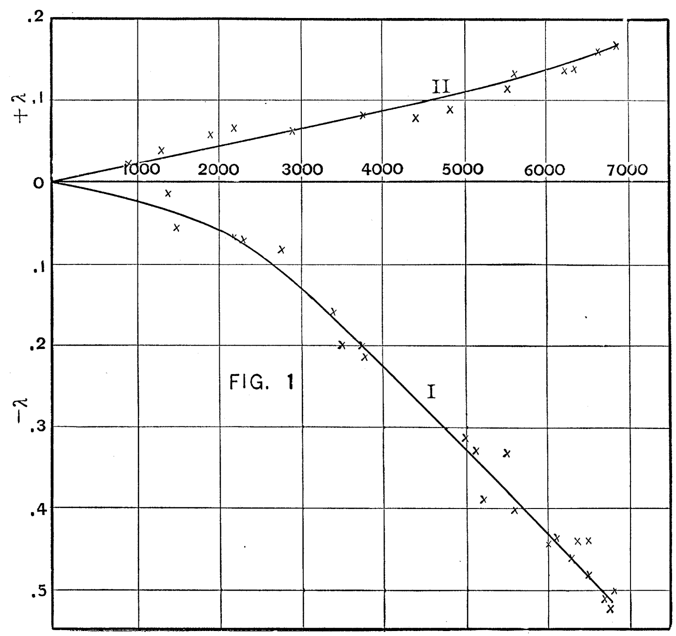
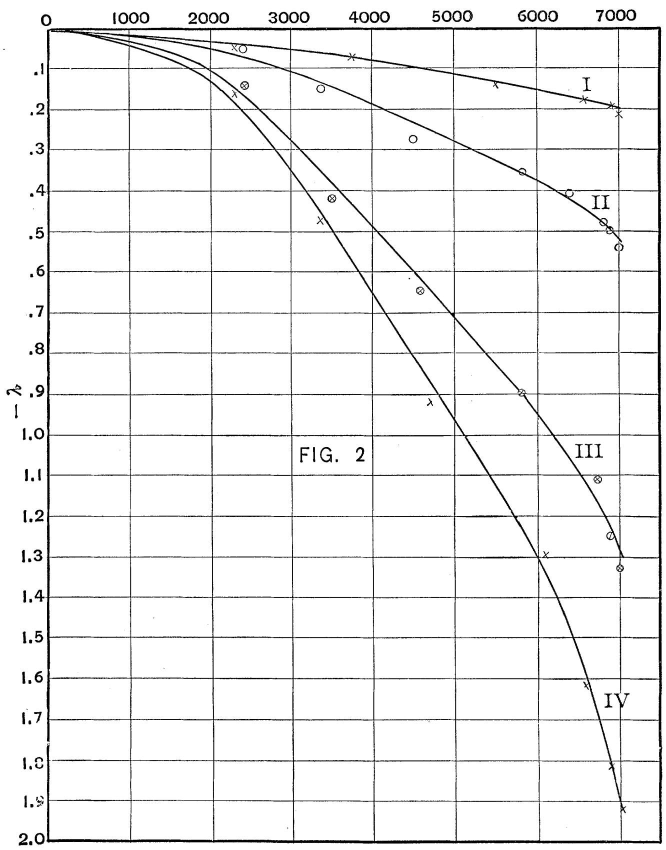


FIG. 1

In Fig. 1, II are plotted observations upon a 1 : 20 dilution of specimen B which was above five years old and which gave the greatest positive double refraction.

Figs. 2 and 3 illustrate the effect of varying the concentration. Fig. 2 represents observations upon specimen M which was at least seven years old and probably much older. The four concentrations were: I., 1 : 160; II., 1 : 80; III., 1 : 40; IV., 1 : 20. Fig. 3 gives similar observations upon specimen F of concentration: I., 1 : 80; II.

1 : 40 ; III., 1:20.[1] Three other specimens gave very similar results. On plotting the logarithms of these observations, curves are obtained which are very nearly straight lines inclined at an angle whose tangent is 2, indicating that *the double refraction is proportional to the square of the strength of field.* Figs. 2 and 3 show



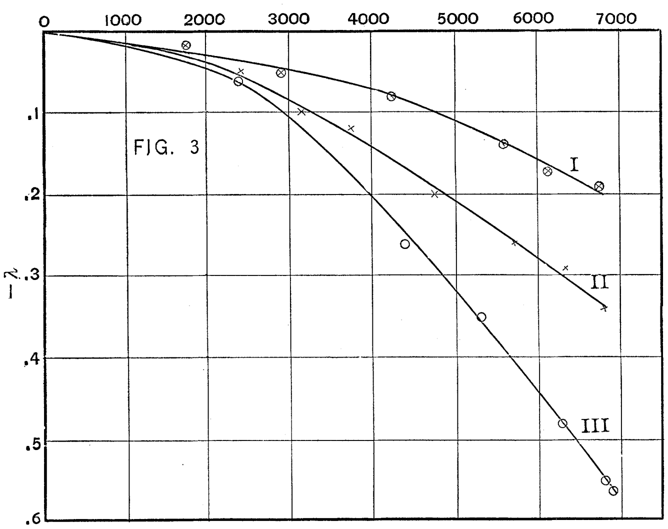
also that *the double refraction is proportional to the concentration for weak concentrations but for denser solutions does not increase in proportion to the concentration.*

Dr. Majorana concluded that the double refraction was proportional to the concentration but gives none of his observations. He also found the double refraction approximately proportional to the

[1] Fig. 3 represents observations at a higher temperature than Fig. 1.

square of the field, extending his observations to the limit of his more powerful magnet.

Dr. Majorana found but two unstable specimens which gave negative double refraction in weak fields. The most active specimens which he studied were positive in weak fields, reversed as the field



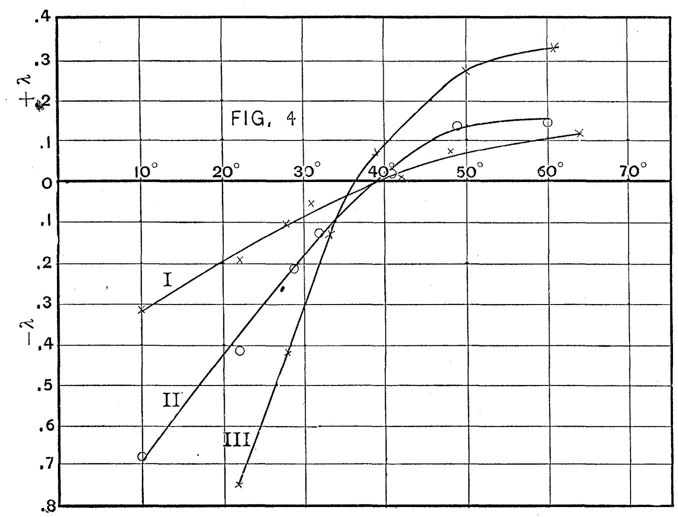
increased and for intense fields were strongly negative. I could detect no such reversal in weak fields. Even in fields so weak as to give a barely perceptible movement of the dark band in the Rayleigh apparatus the double refraction was still negative.

Specimen.	Field.	$(d.p.)_r$.	$(d.p.)_g$.	$\frac{(d.p.)_g}{(d.p.)_r}$
M 1 : 160	6,800	.27	.38	1.41
"	5,700	.20	.29	1.45
M 1 : 180	6,800	.48	.64	1.34
"	5,700	.37	.53	1.43
T 1 : 80	6,800	.31	.47	1.52
"	5,700	.24	.35	1.46
C 1 : 80	7,000	.13	.21	1.56

To determine the dispersion of the double refraction observations were made both with the red light and also with a green light of mean measured wave-length 5,300, obtained by filtering the light through a solution of potassium chromate and copper chloride. The iron solution absorbed all light beyond the green. The movement of the wedge corresponding to a difference of path of one wave-length was 12.9 mm. The final means of a number of observations upon the difference of path for the two wave-lengths are given below.

The quotient of the wave-lengths is 1.22 and the square of this quotient 1.48 which would roughly indicate that *the double refraction is inversely proportional to the square of the wave-length* which was Dr. Majorana's conclusion.

Upon applying alternating currents, for which the magnet was primarily constructed, it was observed that while the double refraction appeared at first, the position of the dark band was less definite



owing to its periodically varying position with the rising and falling field and that with the negatively active solutions, the activity decreased with prolonged application of the current and finally became zero. The cause of this second characteristic was soon found to be the heating of the solution owing to hysteresis in the iron of the magnet and thus being led to a study of the dependence upon temperature, the remarkable fact was discovered that *all these negatively active solutions gradually lose their negative activity as the temperature is raised until it becomes zero at about 40°, when, if* *the temperature is still further raised, they acquire positive activity. Upon cooling, negative activity returns of the same magnitude as before heating.*

Fig. 4 gives observations upon three concentrations of specimen *F* in a field of 6,800 units: I., 1 : 80; II., 1 : 40; III., 1 : 20. Fig. 5 represents observations upon a 1 : 80 dilution of specimen *T* which was at least five years old; I., red light, field = 5,700; II., red light, field = 6,800; III., green light, field = 6,800. Fig. 6, I., II. and III., are similar observations upon a 1 : 80 dilution of specimen *M*; I., red light, field = 5,700; II., red light, field = 6,800; III., green light, field = 6,800. Accurate readings could not be made at higher temperatures but qualitative observations indicated that near the boiling point the double refraction remained positive of

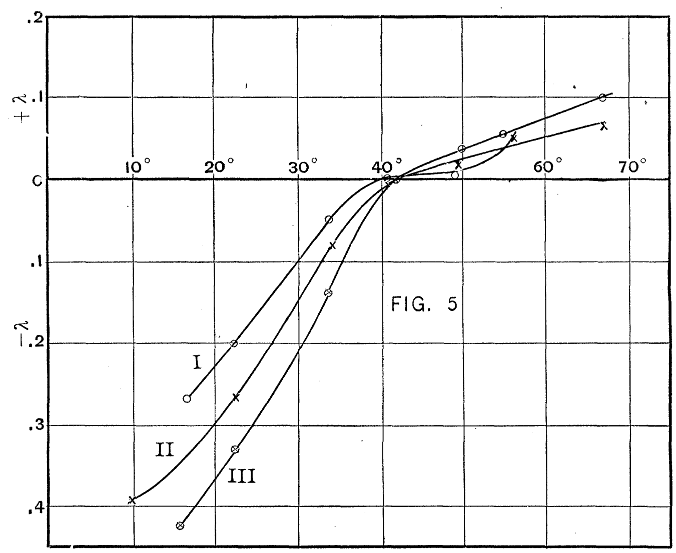


FIG. 5

about the same magnitude as at the highest temperatures represented in the figures. All the negative specimens, five in number, behaved similarly.

Positively active specimens showed simply a continuous decrease in activity with rise in temperature. Observations upon a 1 : 20 dilution of specimen B in a field of 6,800 units are given in Fig. 6, IV.

The Less Mechanical Freedom in a Solution the Less the Activity.

A 1 : 40 solution of F in glycerine was but slightly over half as active as a solution of similar concentration in water. 1 c.c. of F was dissolved in melted jelly composed of 2 grams of calves' foot gelatine to 10 c.c. of water to 10 c.c. of glycerine. As the jelly solidified the activity, measured at intervals in a direct field, decreased, becoming when the jelly was firm but 0.1 λ for a length of 2.9 cm.

A mixture of the positive B and strongly negative F might be either positive or negative according to the proportion. A mixture in the proportion of 10 : 1 was inactive.

Both positive and negative specimens were found paramagnetic by Quincke's manometric method.

Dr. Majorana also discovered magnetic dichroism, *i. e.*, an

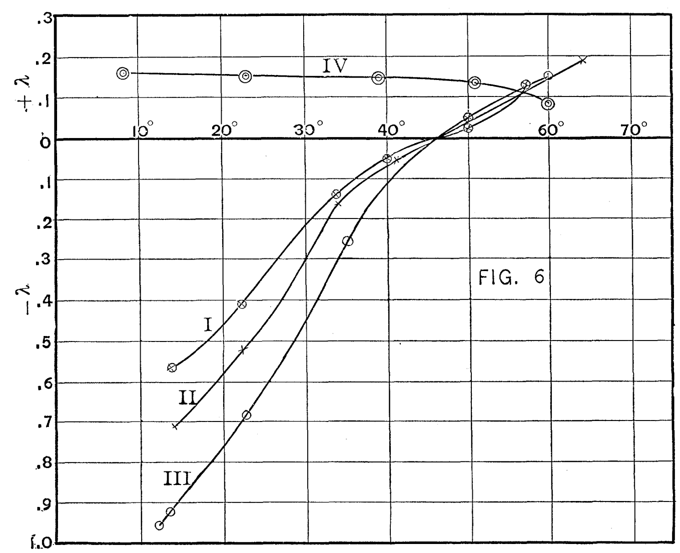


FIG. 6

unequal absorption of the light components parallel and perpendicular to the field, resulting in certain cases in a rotation of the plane of polarization. The author observed no such effect except in one specimen where there was a slight increased absorption for light polarized perpendicular to the field. Majorana found this dichroism conspicuous only in specimens which showed reversal in weak fields which was not characteristic of any of my specimens.

Dr. Majorana gives two methods for distinguishing active from inactive specimens: 1°, from the appearance in reflected light, the active having a turbid appearance. Some of my active specimens had this appearance and some did not and the same was true of inactive specimens. 2°, from the solubility of the precipitate upon adding nitric acid, the greater the insolubility the greater the activity. This rule applied better to my specimens, all those giving a readily soluble precipitate being little active, but when the precipitate was not readily soluble the insolubility was not uniformly proportional to the activity. This partial chemical difference suggested that the active solutions might be St. Gilles' modification of soluble iron oxide, but on preparing the latter it was found inactive.

In general the older a specimen, the greater the activity which was negative in the oldest specimens. Dr. Majorana considers that ferric chloride is eliminated by age. In confirmation, the author found that one drop of concentrated ferric chloride solution in 15 c.c. of F, 1 : 40, reduced the activity 30 per cent.

I wish to thank Prof. H. B. Smith for very kindly placing at my disposal the extensive facilities of the Electrical Engineering Department.

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