AN INVESTIGATION OF THE MAGNETO-OPTIC ROTATION OF POLARIZED LIGHT IN SELECTED SUBSTANCES

by

OTTO MARTIN MILLER

B. S., University of Nebraska, 1926

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1932

TABLE OF CONTENTS

PURPOSE

The purpose of this experiment was to build a piece of apparatus with which the effect of a magnetic field on the rotation of the plane of a beam of polarized light could be quantitatively studied. With this apparatus Verdet's constant for carbon disulfide and water solutions of glucose and fructose was found.

INTRODUCTION

In 1845 Michael Faraday discovered that the plane of polarization of a beam of polarized light was rotated when it passed through certain transparent substances in a magnetic field.

M. Verdet, a French scientist, further investigated this phenomenon, and in 1852 showed that the amount of magnetic rotation was dependent upon the nature of the medium, the intensity of the magnetic field, and the distance through which the light traversed the medium in the field. He formulated the law which bears his name, which states that the rotation between two points is directly proportional to the difference in magnetic potential between these points.

The constant of proportionality is known as Verdet's constant, and is expressed by the formula

$$\omega = \frac{\theta}{(V_a - V_b)}$$

where ω is Verdet's constant, θ is the total angle through which the plane is rotated while passing from A to B, and the expression $(V_a - V_b)$ is the difference in magnetic potential between the points A and B.

For a number of years after Verdet's work was published several scientists studied this so called "Faraday effect" and determined Verdet's constant for various substances. Notable among these scientists were Gordon, Rayleigh, Becquerel, Perkins, Quincke, Kundt, and Röntgen. In 1895, Rodger and Watson of the Royal College of Science in London designed a piece of apparatus especially for the purpose, and made some very careful determinations. It was after the pattern of their apparatus that the coil used in the present experiment was fashioned.

Since their time, it seems that not much work has been done along this line except in very specialized fields, such as studying the dispersion of polarized light by magnetic rotation, determining Verdet's constant for liquid oxygen, sodium vapor, and the like.

APPARATUS CONSTRUCTED FOR THIS EXPERIMENT

There are two methods of submitting transparent substances to the influence of a magnetic field. One of these

is the place the body in the interior of a helix. The other is to place the body between the pole pieces of an electromagnet.

The first method has the disadvantages of requiring more material and being more subject to the changes in temperature of the coil. Also, only clear transparent materials can be examined, since the light must traverse it through a greater distance.

The second method, however, is ill suited for absolute determinations on account of the extreme difficulty of measuring the value of the field produced. It cannot be calculated from the current flowing through the electromagnet as it can in a helix.

For this reason a helix was used.

The Helix

The reel upon which the wire was wound consisted of a brass tube 8.3 cm. in diameter, by 82 cm. long and two circular brass flanges 15 cm. in radius, set 46.5 cm. from one another, leaving the inner brass tube to protrude about 17.5 cm. at each end. A layer of empire cloth was shellaced to the inside surface of these flanges. Hard maple discs about 2.8 cm. thick, and of the same radius as the brass flanges, had been slipped over the long brass tube between the flanges, and were now forced tightly against the flanges.

These maple discs were mainly to furnish mechanical strength.

Two layers of empire cloth were wrapped on the brass core between the maple discs before the winding began.

An auxiliary coil, consisting of two layers of No. 22 D.C.C. magnet wire, was first wound on the core. There were 368 turns on the first layer, and 364 turns on the second. Two thicknesses of empire cloth were wrapped outside of this. The function of this auxiliary coil will be explained later.

The wire used for the main helix was No. 16 D.C.C. annunciator wire. It was first wound on two large wooden reels. A large amount of time was spent in improving faulty places in the insulation and in carefully filing down and soldering the ends of the various pieces together, wrapping the insulation around the joint so as to make as little irregularity in the size of the wire as possible.

Two wires were wound simultaneously, and were thus in contact for their entire length. By this means the insulation between adjacent turns could be tested at any time. In the process of winding, it was tested every other layer. As each layer was finished, the relative position of the two wires was reversed by giving them a half turn.

As each layer was wound, the number of turns of wire was carefully counted. As a means of checking this, and so that a permanent record could be kept, a piece of paper

was laid over each layer, and a pencil mark made on the paper parallel to the axis of the coil.

The circumference of each layer was carefully measured in at least three places, and the average taken. From this average the radius was determined.

As the winding of each layer was completed it was covered with one thickness of empire cloth to provide better insulation.

The radius of the brass flanges and wooden discs was about four centimeters greater than the radius of the outside layer of wire. A copper jacket was soldered on these flanges for most of the way around, and the space between the jacket and the coil filled with melted paraffine. This paraffine was kept above its melting point for about forty hours, enabling it to thoroughly seep in among the wires of the coil. This not only improved the insulation, but, in the case of minor short circuits due to self induction or other causes, the wax will melt and automatically heal the break. In addition to this, some of the heat produced in the coil will be taken up by the melting of the paraffine.

The entire coil rests on two hard maple supports, each fitted with leveling screws.

Table 1 gives the dimensions of the main coil.

Table 1. Dimensions of Main Helix

Number of layer	Average outside circumference (mm.)	Radius of layer (mm.)	Number single turns in layer
1	296.7	46.2	176
2	312.0	48.7	176
3	328.5	51.3	178
4	342.8	53.6	175
5	356.3	55.7	180
6	374.3	58.6	176
7	390.3	61.1	178
8	404.4	63.4	176
9	420.0	65.9	177
10	436.9	68.5	174
11	452.2	71.0	176
12	468.7	73.6	179
13	484.2	76.1	182
14	499.3	78.5	182
15	515.3	81.0	182
16	528.0	83.0	178
17	544.5	85.7	176
18	562.8	88.6	176
19	575.7	90.6	180
20	592.7	93.3	178
21	607.3	95.7	182
22	622.2	98.0	178
23	637.5	100.5	178
24	655.5	103.3	176
25	670.2	105.7	177
26	686.1	108.2	187

Total number of layers	26
Total number single turns	4627
Length of helix	41 cm.
Total amount of wire used	31 kg.

The Tube

The material to be examined is placed in a brass tube having an inside diameter of about 3.2 cm. and an approxi-

mate length of eighty-two centimeters. Its axis coincides with the axis of the helix. Brass caps were machined to fit the ends.

Small brass tubes for filling and emptying were fitted in each end, as were tubes half-way up in which calibrated thermometers were sealed. A hole about 1.5 cm. in diameter was cut out of the exact centers of the end caps, and sealed over with microscope cover glasses.

This entire inner tube was enclosed in the brass tube of the same length and of about 8.3 cm. in diameter, upon which the helix was wrapped. The spaces between the ends of the two tubes were covered with circular brass plates. Small brass tubes were fitted into holes near the ends of the larger tube, and thus water was circulated through it while readings were being taken. In this way the temperature of the material under examination was kept more nearly constant.

The Polarizer

An ordinary Nicol prism, set in beeswax and placed in the axis of a brass tube the same diameter as the one used to hold the material being examined, was used as a polarizer. It was mounted on V's on an upright attached to a base fitted with leveling screws.

The Analyzer

At the other end of the coil was a second Nicol prism used as an analyzer. The brass pipe in which this prism was mounted was machined down so as to just fit in a slightly larger brass tube, thus enabling the analyzing prism to be rotated.

Attached at right angles to the movable brass tube containing the analyzer was a large circle of quarter-inch triple ply oak veneer, reenforced by a heavy circular brass plate. A paper circle, fourteen inches in diameter, and graduated to fourths of a degree was glued to this slightly larger wooden circle.

At the bottom of the stand supporting the analyzer was a stationary pointer and a magnifying glass fitted with a hair line. By means of these, the number of degrees through which the circle had been rotated could be determined.

A telescope was fitted in the end of the brass tube containing the analyzing prism. The bases supporting the analyzer and the telescope were fitted with leveling screws.

The Electrical Connections

Double pole, double throw switches were used for reversing the currents in both the auxiliary and the main coils. In the case of the main coil, the switch was so ar-

ranged that a high, non-inductive resistance was automatically thrown in just before the circuit was broken. This helped to protect the insulation of the coil from damage due to the self-induced current.

The Source of Monochromatic Light

A glass tube about 2.5 cm. in diameter and 15 cm. long was fitted with a plug of glass wool, and a mixture of fine sand and pulverized sodium chloride was poured on this to a depth of about five centimeters. The sand helped to keep the salt from becoming caked. Stoppers containing smaller glass tubes were fitted in the end of this, and the gas passed through the pulverized salt before it entered the Fisher burner. An intense yellow flame resulted.

As a means of further assuring that the light would be monochromatic, it was made to pass through a column of potassium dichromate solution about five centimeters long, before entering the polarizing prism.

METHOD OF OBTAINING DATA

First, the sodium flame, polarizer, helix and analyzer were carefully lined up. The axes of the last three should coincide.

The current in the main coil was turned on, the analyzer set at the point where the beam was most completely ex-

tinguished, and the reading taken.

Each observation consisted of at least three such readings with the current flowing in one direction, then three with the current reversed, and two similar sets of three or more after the analyzing prism had been rotated through about 180°. The temperature at each end of the tube and the voltage across the coil, were taken at the beginning, the middle, and the end of each series of readings, and the average taken.

The auxiliary coil was used to aid in determining more accurately the darkest point. When the point was reached as nearly as possible by ordinary observation, a current was sent through the auxiliary coil, first in one direction, then in the other, slightly rocking the plane of polarization back and forth. If the analyzer was properly set, the slight illumination which occurred when the auxiliary current was applied was the same when the latter was reversed.

SOURCES OF POSSIBLE ERROR AND MEANS OF CORRECTION

One possible source of error is by using the wrong number of turns in the computations, either because of a mistake in counting, or on account of a short circuit. There is little chance for this error, however, because of the way the turns were counted and checked, and the fact that two wires were wound simultaneously. Testing the re-

sistance between the two circuits would reveal any shorts between adjacent turns, and testing the resistance of the two wires separately would reveal any between two layers of the same wire. The added resistance offered by the paraffine and the empire cloth would make any such shorts very improbable.

Another possible error is in the calculating of the coil constant because of irregularities in the winding, such as when the wire mounts from one layer to the next. Rodger and Watson found by experiment that when the liquid projected more than 20 cm. beyond the coil, there was no measurable error due to this cause.

An error in measuring the length of the tube, or in finding its position relative to the coil, is possible. However, a difference of one millimeter in the length of the tube makes a change of about one part in five thousand in the magnetic potential, an error so slight that it may be neglected.

The amount of rotation varies with the direction in which the light passes through the field. When the direction of the light is inclined to the lines of force at an angle of one degree, the error is in the order of one part in five thousand, which is negligible.

If the light used is not monochromatic, an error in reading may be made because of dispersion. With the source

of light used in this experiment, and the color filter, there was no observable dispersion, except for large rotations. Using a small current and thus keeping the angle of rotation small, therefore kept the dispersion negligible.

In the case of the sugar solutions, however, there was some dispersion to begin with, on account of the rotation caused by the sugar itself. More dilute solutions made the rotation, and therefore the dispersion, less.

Another possible source of error is in the inclination of the axis of rotation of the analyzing Nicol to the direction of the incident light. According to experiments by McConnel, an inclination of two degrees will cause an error of less than one minute in a double rotation of sixty degrees. In this experiment, practically all the double rotations were less than thirty degrees. Also, the Nicol was read in two positions, about 180° apart.

If an error was made in measuring the current, the magnetic potential difference would be calculated incorrectly. In this experiment, the ammeter used was first calibrated with a standard instrument in the electrical engineering department, and a correction curve drawn. The readings were carefully taken at least three times in each set, and the average used.

The determination of the temperature of the liquid is still another source of error. The two thermometers used

were first carefully calibrated. They were read three times each in each set of readings, and the average taken. Considerable time was allowed to elapse after the substance was put in the tube, and the current and water turned on, so that the temperature could reach equilibrium.

Impurities in the substances used, or dissolved out from the sides and ends of the tube, might change the amount the light was rotated. For this experiment the purest substances obtainable were used. The carbon disulfide was Baker's Analyzed, C.P. Mallinckrodt Glucose and Schering Levulose were used. The levulose was slightly yellowed due to age. The tube was carefully cleaned before each filling, and filled with the material to be tested. This was left for several hours, so that any soluble material in the tube itself would be dissolved. This was then drained off, and fresh material put in for the observations.

The cover glasses at the ends of the tube, and the Nicol prisms were in the magnetic field, and would tend to rotate the light themselves, thus causing an error. Readings were taken with the tube empty, and the current first off and then at its maximum value. No rotation could be observed.

Magnetic substances in the vicinity would distort the magnetic field and tend to change the magnetic potential between the ends. To prevent this error, no iron or other

magnetic substance was used in the construction of the apparatus. The experiment was performed as far from water and gas pipes as possible.

Still another possible source of error would be that caused by convection currents in the material being examined. The density of the liquid at the top of the tube would be less than at the bottom, and density affects the amount of rotation. However, since the temperature was nearly constant when the readings were being taken, the convection currents would be very slight. Also, if the analyzing Nicol were slightly off center, taking readings at about 180° apart would help correct any error due to convection currents.

Light reflected back through the tube by the end glass, and then back again and through the analyzer, would be rotated three times as much as that which had passed through the tube only once. This would make it more difficult to pick out the darkest point.

In double rotations of less than about 20° this effect was not noticeable. Therefore, the currents used were small, so that the rotation would be less.

In addition to this, the end glasses could be set at a slight angle to the incident light, but still parallel to one another. This would do away with this source of error entirely.

The smallest divisions on the rotating circle attached to the analyzing prism were fourths of a degree. Estimates were made to the twentieths of a degree. No doubt, some errors were made in these estimates. Taking the average of a large number of readings, as was done, would reduce the amount of this error.

A vernier reading to minutes could be quite easily made if necessary. However, considering the fact that the dark space was usually more than a degree wide, it would hardly have been worth while with the analyzer used.

Probably the largest source of error in the present experiment was the difficulty in picking out the exact darkest point where the analyzing Nicol crossed the beam of polarized light.

The auxiliary coil and reversing switch aided greatly in this in the case of the carbon disulfide. In the case of the sugar solutions, however, it was impossible to rock the plane of polarization sufficiently with the current which could be sent through the auxiliary coil.

A brighter source of light caused the dark region to be narrower, and hence the setting could be made more accurately.

In the case of the sugar, a dozen or more trials were usually made on each reading, coming in from both sides. Taking the average of these also cut down this error.

Possibly the use of a photoelectric cell could make more accurate readings possible.

For very accurate readings, a more refined type of analyzer should be used.

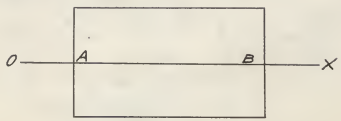
METHODS OF CALCULATING RESULTS

For a coil of infinite length, the magnetomotive force between the ends is equal to $\frac{4\pi NI}{10}$, where N is the total number of turns in the solenoid, and I is the current in amperes.

For more accurate work, corrections for the finite dimensions of the coil must be made. The following formula is the one ordinarily used for making this correction.

$$\text{m.m.f.} = \frac{2\pi nI}{10\ AB}\left[\sqrt{R^2+\overline{AX}^2}-\sqrt{R^2+\overline{BX}^2}-\sqrt{R^2+\overline{OA}^2}+\sqrt{R^2+\overline{OB}^2}\right]$$

In this equation, m.m.f. is the difference in magnetic potential between the points O and X, n is the number of turns on the layer under consideration, R is the radius of this layer, I is the current in amperes, and O, A, B, and X, are positions on the axis of the solenoid as shown in the following diagram.



The values obtained for the different layers are added together to find the total magnetic potential difference.

For the coil under consideration, the difference in magnetic potential between the ends of the tube was found to be 2844.29 times the current in amperes if the double turns were used in parallel, or twice that value if connected in series.

The most generally accepted equation for correcting for temperature when finding Verdet's constant for carbon disulfide was worked out experimentally by Bichot. It is as follows:

$$\omega_t = \omega_o (1 - .00104t - .000014t^2)$$

As far as is known, no means has yet been worked out for correcting for temperature for glucose and fructose solutions.

RESULTS OBTAINED

The results obtained in this experiment are shown in the following tables.

Table 2. Carbon Disulfide

I (amps)	2θ (degrees)	(V_a-V_b) (gilberts)	t (Cent.)	ω_t (minutes)	ω_o (minutes)
1.05	4.045	5973.019	20.5	.04063	.04177
1.55	6.162	8817.314	22.2	.04193	.04323
2.08	8.275	11832.267	21.0	.04196	.04317
2.53	10.454	14392.133	22.9	.04358	.04498
3.04	12.319	17293.314	21.7	.04274	.04402
3.54	14.646	20137.609	21.7	.04364	.04494
4.04	16.902	22981.904	22.0	.04413	.04547
4.52	18.461	25712.427	22.6	.04308	.04444
5.02	20.130	28556.722	21.6	.04229	.04356
5.52	23.512	31401.017	18.9	.04493	.04607
6.02	24.490	34245.312	18.8	.04291	.04400
7.50	30.420	42664.425	26.3	.04278	.04442
				Average--	.04417

Values for ω_o for carbon disulfide found by other experimenters are as follows:

Rayleigh	.04347
Becquerel	.04341
Quincke	.04564
Koepsel	.04332
Rodger and Watson	.04347

Table 3. Glucose Solution, Fifty Grams per Liter

	2θ (degrees)	t (Cent.)	ω_t (minutes)
	5.21	20.2	.01360
	5.11	20.3	.01334
	5.34	20.5	.01394
	6.17	21.0	.01610
	6.17	21.0	.01610
	5.44	21.0	.01420
	5.18	21.0	.01352
Average ----------	5.52	20.7	.01440

Table 4. Glucose Solution, Twenty-five Grams per Liter

	2θ (degrees)	t (Cent.)	ω_t (minutes)
	4.72	22.5	.01231
	4.79	22.5	.01251
	4.83	19.1	.01262
	4.86	19.2	.01269
	4.90	19.2	.01279
	4.77	20.0	.01247
	4.64	20.1	.01210
	4.69	20.1	.01224
	4.70	21.6	.01227
	4.71	21.7	.01230
	4.79	21.8	.01251
Average ---------	4.76	20.7	.01244

Table 5. Fructose Solution, Twenty-five Grams per Liter

	2θ (degrees)	t (Cent.)	ω_t (minutes)
	4.42	20.1	.01154
	5.17	20.4	.01350
	4.48	20.7	.01170
	4.51	23.1	.01177
	4.27	25.1	.01115
	4.16	20.6	.01086
	4.29	20.8	.01120
Average ---------	4.47	21.5	.01167

In all the sugar solutions, the current used was 4.04 amperes, with a consequent magnetic potential difference of 22981.904 gilberts. This current was large enough to produce an appreciable rotation, and at the same time not so

large as to melt much of the paraffine within a reasonable time. An average of about two hundred forty readings were taken on each of the three sugar solutions.

Glucose and fructose both have the property of multi-rotation. In the case of glucose, the specific rotation changes from +105° to +52.5° in a few hours time, while fructose changes from -104° to -92.3°.

The results given in the preceding tables were obtained from readings taken after the solutions had reached equilibrium. It was difficult to take accurate readings before, especially in the case of the glucose, owing to the large number that had to be taken to get a fair average, and the fact that the specific rotation was changing so rapidly.

As far as is known by the writer, no one has yet worked out a temperature correction for glucose and fructose solutions.

THEORETICAL DISCUSSION

Consider a uniform circular vibration expressed by the equations

$$x_1 = a \cos \omega t$$

$$y_1 = a \sin \omega t$$

If the sign of ω is changed, the equations for the circular vibration rotating in the opposite direction are obtained.

$$x_2 = a \cos \omega t$$

$$y_2 = -a \sin \omega t$$

Adding the x components, and also the y components of these two sets of equations, the resultant vibration is found to be expressed by the equations

$$x = 2a \cos \omega t$$

$$y = 0$$

It can be seen from this that two opposite circular vibrations combine into a simple rectilinear vibration, or conversely, a rectilinear vibration can be resolved into two opposite circular vibrations.

Hence, a beam of plane polarized light can be considered to be the resultant of two circularly polarized beams rotating in opposite directions.

In order to account for the rotation of a plane of polarized light by a magnetic field, one of the circular components would have to have an index of refraction in the material in the field different from that of the other. Brace has successfully separated these two circular beams, thus proving that this is true. Mills actually measured the velocities of the two beams in the magnetic field. It was found that the circularly polarized beam which rotated in the same direction as the conventional current producing the field, had the greater velocity.

Suppose that, in passing through the tube, the left

handed rotatory component is retarded in phase by an amount δ. Then, the equations of the transmitted vibrations could be expressed in the form

$x_1 = a \cos \omega t, \quad y_1 = a \sin \omega t$ (right handed);

$x_2 = -a \cos (\omega t + \delta), \; y_2 = a \sin (\omega t + \delta)$ (left handed).

Combining these two components, we have

$$x_1 + x_2 = x = a \cos \omega t - a \cos (\omega t + \delta) = 2a \sin \tfrac{1}{2}\delta \sin (\omega t + \tfrac{1}{2}\delta)$$

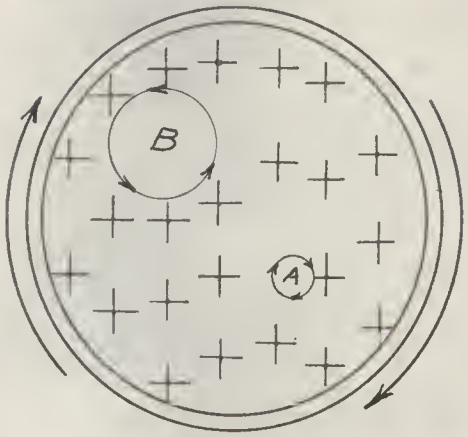
$$y_1 + y_2 = y = a \sin \omega t + a \sin (\omega t + \delta) = 2a \cos \tfrac{1}{2}\delta \sin (\omega t + \tfrac{1}{2}\delta)$$

These are first degree equations, and therefore represent straight lines. Combining them, a straight line vibration is produced, which makes an angle with the line of original vibration whose tangent is $\frac{x}{y} = \tan \frac{1}{2}\delta$.

Therefore, the plane of vibration of the polarized light is rotated through an angle equal to half the angle which the one rotatory component is behind the other, and in the direction of the rotation of the more rapid component.

The next thing to be considered is the explanation of why one of these circularly polarized beams should rotate faster than the other while passing through a material substance in a magnetic field.

The diagram below represents the cross-section of the core of a helix. The conventional current is flowing through the coil in a clockwise direction, and consequently the direction of the magnetic field in the core is perpendicularly into the paper.



According to the most generally accepted theory, an atom of any element consists of a positively charged nucleus around which one or more electrons are revolving. Those revolving electrons, in the atoms of the substance in the core of the helix, which are moving in a clockwise direction, (such as atom A) would have a greater centripetal force imposed upon them by the action of the magnetic field. Consequently their radii would be decreased. Since the amount of kinetic energy remains constant, their angular velocity would increase.

In a similar manner, the electrons revolving in a counter clockwise direction (such as atom B) would have the radii of their paths increased with a consequent decrease

in angular velocity.

Since all moving electrons carry a magnetic and also an electric field with them, the net effect of the above is that, in any small area of the cross section, the field is rotating clockwise. Its angular velocity is numerically equal to the difference between the two opposing angular velocities of the revolving electrons, irrespective of sign.

Assuming light to be an electromagnetic disturbance, a circularly polarized beam rotating in a clockwise direction, would have added to its angular velocity the velocity of the rotating field, when passing through the core of the helix. Similarly, the angular velocity of the component rotating in the opposite direction would be decreased by a like amount.

It was shown earlier in this discussion that the resultant plane polarized beam would be rotated in the same direction as the more rapidly rotating circular component. According to the theory just explained, this would be in the direction the conventional current was flowing through the helix. Experiment proves this to be the case.

A little reflection will show that, if the electrons were vibrating instead of moving in circular or elliptical paths, the result would be the same.

CONCLUSIONS

Since the value of Verdet's constant obtained in this experiment for carbon disulfide checks quite closely with the generally accepted value, the calculations on the coil constant are probably very nearly correct.

It was observed that the more concentrated solution of glucose had a greater value for Verdet's constant. However, the degree of rotation was not proportional to the concentration of solute present, nor was it to the density. Evidently a more complicated relationship exists.

According to this experiment, the more dilute solution of glucose had a slightly greater rotatory ability than the fructose solution of the same concentration. However, unlike their ordinary molecular rotation, they both rotate it in the same direction, namely, the direction of the conventional current in the coil.

SUGGESTIONS FOR FURTHER WORK

A large number of unsolved problems have suggested themselves during the working out of this experiment, especially in connection with the sugars.

For example, glucose, fructose, and many other organic compounds exhibit the property of multirotation. Their normal ability to rotate polarized light gradually decreases

until a constant value is reached several hours after the solution is made up. Does their ability to rotate light in a magnetic field also change? If so, is it in the same proportion as the change in molecular rotation?

What is the relationship between Verdet's constant and the concentration or density of the solutions used? If the concentrations of a glucose and of a fructose solution are the same, does the ratio of their magnetic constants remain the same, no matter what that concentration may be? If not, how does it change?

What is the equation for correcting for temperature for sugar solutions? Is it the same for all concentrations?

Glucose normally rotates light to the right. Fructose rotates it to the left. When they are mixed, the rotatory effect on the light is the difference between the two effects, taking into consideration the relative amounts of each present. A combination can be found where their effects will just neutralize each other, and the plane will not be rotated.

What effects would mixtures of different concentrations of these two sugars have on the magnetic rotation? Would they subtract their individual effects, or add them, or would there be a more complex relationship? Would there be a certain combination that would have no optical effect?

What effect does the solvent have on the magnetic

rotation? If alcohol, for example, were used instead of water as a solvent for these sugars, how would Verdet's constant be affected? Would the difference be the same as the difference between the constants for pure water and pure alcohol?

These are some of the interesting problems still to be solved. However, lack of time makes any further experimentation along this line impossible at this time.

ACKNOWLEDGMENTS

The writer is very much indebted to his major instructor, Professor E. R. Lyon for his sincere interest, timely suggestions, and valuable help during the time this problem was being worked out.

He is also grateful to Professors J. O. Hamilton, E. V. Floyd, and L. E. Hudiburg for their assistance and many helpful suggestions.

REFERENCES

Agerer, F.
1905. Magnetic Rotation in Salt Solutions. Sci. Abs. 8 (2107): 661.

Barker, Geo. F.
1892. Physics. Henry Holt & Co., New York. 902 pp.

Becquerel, H.
1898. The Faraday and Zeeman Effects. Sci. Abs. 1 (115): 679-689.

Borel, A.
1899. Magnetic Polarisation of Quartz. Sci. Abs. 2 (1142): 508.

Faraday, M.
1855. Experimental Researches in Electricity, Volume III. Bernard Quaritch, London. 588 pp.

Gordon
1877. Verdet's Constant in Absolute Units. Phil. Trans. 167 (Part I): 1-34.

Holmes, Marshall
1923. A New Phenomenon. Phil. Mag. 46 (Sixth Series): 335-336.

Larmor, J.
1900. Magneto Optic Rotation. Sci. Abs. 3 (821): 306-307.

Perkins, W. H.
1884. On the Magneto Rotary Polarisation of Compounds in Relation to their Chemical Constitution. Jour. Chem. Soc. 45: 421-580.

1902. The Magnetic Rotation of some Polyhydric Alcohols, Hexoses, and Saccharabioses. Jour. Chem. Soc. 81: 177-191.

1906. An Improved Apparatus for Measuring Rotations and Obtaining a Sodium Light. Jour. Chem. Soc. 89 (Part I): 608-618.

Preston, Thomas
1912. Theory of Light. Macmillan and Co., Ltd., London. 618 pp.

Rayleigh, Lord
1885. On the Constant of Magnetic Rotation of Light in Carbon Disulfide. Phil. Trans. 176 (Part II): 343-366.

1884. Preliminary Note on the Constant of Electromagnetic Rotation of Light in Carbon Disulfide. Proc. Roy. Soc. 37: 146-148.

Rodger and Watson
1895. On the Magnetic Rotation of the Plane of Polarization of Light in Liquids. Phil. Trans. 186 (Part II): 621-655.

Verdet, M.
1855. On the Optical Properties Developed in Transparent Bodies by the Action of Magnetism. Phil. Mag. 9 (Fourth Series): 481-509.

1856. Note on the Optical Properties of Transparent Bodies Submitted to the Action of Magnetism. Phil. Mag. 12 (Fourth Series): 483-485.

Wood, R. W.
1912. Physical Optics. The Macmillan Company, New York. 705 pp.

Plate I

Plate I is a photograph of the apparatus constructed for this experiment.

Plate I