

# Faraday Effect Rotation for Water and Flint Glass

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This experiment is designed to measure the Verdet constant  $V$  through Faraday effect rotation of a polarized laser beam as it passes through different mediums, Flint Glass and water, parallel to the magnetic field  $B$ . As the  $B$  varies, the plane of polarization rotates and the transmitted beam intensity is observed. The angle through which it rotates is proportional to  $B$  and the proportionality constant is the Verdet constant times the optical path length. These are used to determine the Verdet constant for each medium and compared with standard known values. The value found through the experimental calculations are  $1.79 \times 10^{-5} \frac{\text{rad}}{\text{G cm}}$  for Flint glass and  $1.30 \times 10^{-5} \frac{\text{rad}}{\text{G cm}}$  for water where as the standard values are  $1.77 \times 10^{-5} \text{ rad/Gcm}$  for flint glass and  $3.80 \times 10^{-6} \text{ rad/Gcm}$  for water.

## INTRODUCTION

The phenomenon of the Faraday effect was first observed by Michael Faraday in 1845<sup>1</sup>. He discovered the concrete evidence for the relationship between the major branches of optics, magnetism and atomic physics. He found out that when a block of glass is subjected to a strong magnetic field, it becomes optically active. The effect occurs when the rotation of a linearly polarized wave passes through a thickness of a transparent medium<sup>2</sup>. The beam should be plane polarized, that is, it can pass through an analyzer without attenuation only when its axis is parallel to that of the analyzer. The propagation of the beam of light has to be parallel to the direction of the magnet field in order to observe the rotation in its plane of polarization. If the field is perpendicular to the beam, then there is no rotation. There should be a medium present where the beam and the magnetic fields will interact<sup>2</sup>. When non-magnetic materials like copper, lead, tin and silver are placed between the magnet, they cause no effect to polarized waves<sup>3</sup>.

A plane-polarized wave can be decomposed into two circularly polarized waves, one is Right Circularly and other Left Circularly Polarized. Their propagation is independent of each other<sup>4</sup>. Since their indices are different, their velocities are also different resulting in rotation. If the wave is reflected back and forth in the medium, rotation will exhibit a progressive increase<sup>5</sup>. Faraday had also suggested that the magnetic effect from an electric current in a solenoid can be used to replace permanent

magnets. The rotation in the plane of polarization is caused by circular birefringence and their relationship with the magnetic field in terms of Zeeman Effect. The rotation is given by the following expression<sup>1,6,7</sup>:

$$\theta = VBl \quad (1)$$

where  $\theta$  is the angle of rotation,  $B$  is the strength of the magnetic field in Gauss,  $l$  is the width of the medium in cm and  $V$  is Verdet constant. The expression for Verdet constant can be employed by a two step derivation. First step involves the discovery of Larmor frequency<sup>6</sup>. Second step is to use Larmor frequency in circular birefringence to find the Verdet Constant<sup>5</sup>. The final expression<sup>6</sup> for the Verdet constant is  $V = 1.0083 \frac{dn}{d}$ .

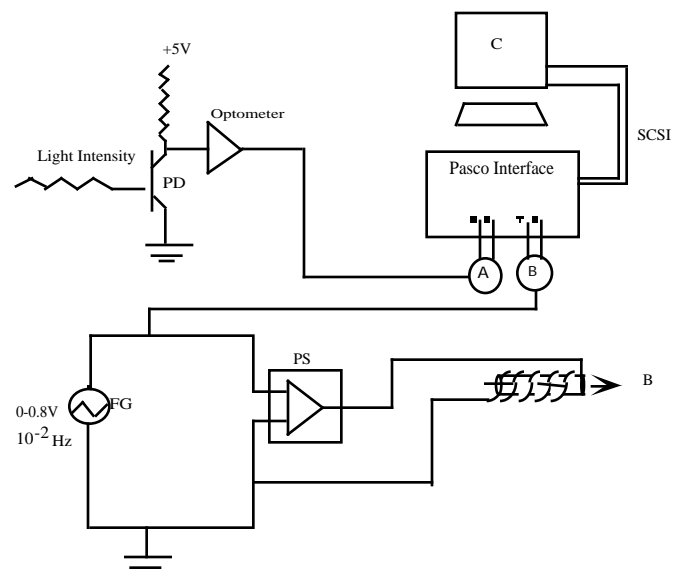


Figure 1:

This figure shows the schematic setup for the experiment. Abbreviations PS: Kepco Power Supply, PD: PhotoDiode, FG: Tektronix Function Generator. The magnetic field B is parallel to the direction of light. Voltage from the optometer and function generator goes to the Pasco interface which transmits those to C, Macintosh Quadra 700 computer

## EXPERIMENT

The magnetic field direction is parallel to the laser beam's propagation. The schematics are shown in Figure 1. Using a Gaussmeter, the variation of magnetic field is checked in the gap from left pole to right pole of the electromagnet. Various values for magnetic field at different currents from Kepco power supply are recorded. From these values of magnetic field's strength between the gap, average and minimum values,  $B_{av}$  and  $B_{min}$  are calculated. Their ratio,  $B_{min}/B_{av}$ , has one value  $0.93 \pm 0.06$ . At this point, a Tektronix TM503 FG Function Generator is introduced which is adjusted to give a saw-tooth output of 0-0.8 V with a frequency of  $10^{-2}$  Hz. This voltage determines the magnet's power supply current in the range 0-8A.

The He-Ne laser is aligned so that its beam goes through the hole in electromagnets. An Oriel Polarizer is placed in the path of the He-Ne polarized laser beam before it enters the hole in the electromagnet and an Oriel analyzer is placed where it emerges from the hole after passing through the material in the gap. The Analyzer is adjusted to allow minimum intensity of plane-polarized wave, that is detected by photodiode detector connected to a United Technology 350 Optometer. The data outputs from the Optometer and Tektronix Function Generator are connected to Pasco Scientific Signal Interface II CI-6560. The connections are made using long cables to reduce noise in the readings. This interface will submit both input data to Macintosh Quadra 700, which is equipped with Pasco Science Workshop 2.1.1. Now, a thick Flint Glass of length  $4.0 \pm 0.2$  cm is placed in the gap. On the computer, data of PhotoVoltage in mV (from optometer) and Current in A (from Function Generator) is displayed, tabulated and plotted for this run. The sampling rate for this experiment is set at 0.2 Hz. The smoothing function is introduced to smooth over every 20 readings for both data sets.

Similarly, a distilled water sample in a glass cuvette is placed in the gap and data is recorded.

## ANALYSIS AND INTERPRETATION

From the equation (1), the Faraday rotation angle is proportional to B, the magnetic field strength. Since  $I = I_0 \cos^2$ , where  $I_0$  is the maximum intensity passing through the Analyzer in the absence of a magnetic field<sup>4</sup>,

$$= \cos^{-1} \sqrt{\frac{I}{I_0}} \text{ where } I_0 \text{ is } 45.8 \pm 0.1 \text{ mV for Flint}$$

Glass and  $61.7 \pm 0.2$  mV for water. The expression for B, magnetic field for the thick glass is obtained by dividing  $B_{min}$  by  $0.93 \pm 0.06$  which gives  $B_{av}$ . The graph of  $B_{av}$  against  $\theta$  for glass is plotted and a linear curve is fitted (Figure 2).

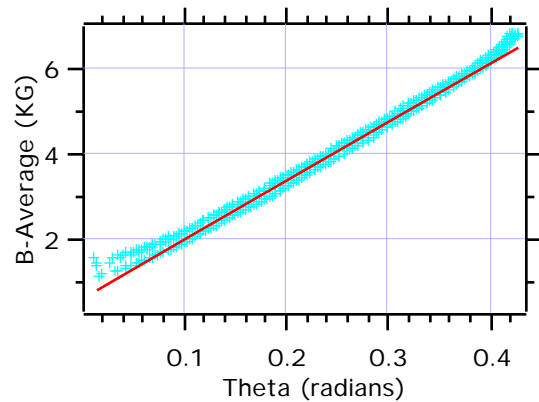


Figure 2: Flint glass. The curve fit gives the slope of  $13.93 \pm 0.08$  KG/radians. The equation is of the linear form  $a+bx$  where  $a$  is 0.08 and  $b$  is slope.

For the water sample, the field value is  $B_{min}$  because the sample has only length of  $1.0 \pm 0.1$  cm. A similar graph of  $B_{min}$  against  $\theta$  for the water sample is plotted as shown in Figure 3:

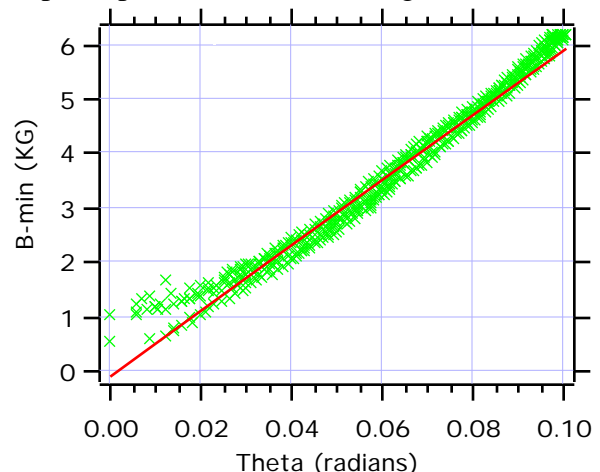


Figure 3: Water. The fit gives the slope of  $59.67 \pm 0.53$ .

From the values of slopes for Glass and water,  $13.93 \pm 0.08$  and  $59.67 \pm 0.53$  respectively, the values of Verdet constants for both can be obtained.

The Verdet constant for glass is  $1.79 \times 10^{-5}$  rad/Gcm. and for water is

$1.30 \times 10^{-5}$  rad/Gcm. The standard values for these are  $1.77 \times 10^{-5}$  rad/Gcm and  $3.80 \times 10^{-6}$  rad/Gcm. The value of the Verdet constant of water accounts for the effect of glass in the bottle walls (assume it is Flint Glass).

## CONCLUSION

This experiment has shown excellent results for Verdet constant in case of Flint glass but the result of water are not that reliable. The reason is that the path length for water was 4 times smaller than that of the glass. In this experiment, it is assumed that bottle's material is heavy flint glass. In order to improve the results of the Verdet constant for water, an empty bottle should be placed in the gap and the Faraday rotation measured.

One can also use the value of  $V$  where wavelength is 632.8 nm and find the rate of change of refractive index with

change of refractive index with wavelength can also be measured by passing laser light of different wavelengths through a prism of Flint Glass and compare to the value from the Verdet constant.

## ACKNOWLEDGMENTS

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- <sup>4</sup> Besancon, Robert M., Encyclopedia of Physics, (Van Nostrand, New York, 1958), p. 418.
- <sup>5</sup> Parker, Sybil P., McGraw-Hill encyclopedia of Physics , (McGraw-Hill, New York, 1991), p. 403-4.
- <sup>6</sup> Frank L. Pedrotti and Peter Bandettini, "Faraday Rotation in the Undergraduate Advanced Laboratory," *American Journal of Physics*, **58**, 542-545 (1989).
- <sup>7</sup> Frank J. Loeffler, "A Faraday Rotation Experiment for Undergraduate Physics Laboratory," *American Journal of Physics*, **51**, 661-663 (1983).