Faraday Rotation: Quantifying the Intensity of Magnetism and the Polarization of Light

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ABSTRACT

The Primary objective of this experiment is to determine the Verdet constant of an unknown material by measuring the intensity of the Faraday Effect. The Faraday Effect is essentially the conceptual predecessor to Faraday Rotation. Faraday Rotation relies upon on measuring the angle of polarization of light by varying the intensity of the magnetic field of a solenoid; the unknown material is situated inside of the solenoid, where the cross sectional area of the rod is perturbed by the coherent diode laser source. By using Faraday Rotation, students will be able to quantify the relationship between the intensity of a magnetic field created by a solenoid and the augmented plane of polarizations of light passing through said solenoid. This is in essence the Verdet constant, which by definition is the intensity of the Faraday Effect for a material. This experiment consists of three major portions I) Malus' Law II) F.R. due to DC & III) F.R. due to AC, outlined in experimetal set up and procedure.The final calculated value for Verdet constant of the given unknown material is inaccurate based on a few factors. However, the errors causing the miscalculation and misreadings were later identified.

Faraday Rotation Experiment

1 Introduction

Faraday Rotation demonstrates the relationship between the magnitude magnetic field and the planar polarization of light. This effect is widely known in the Astronomical world and utilized to determine the magnetic fields of different objects in space. Michael Faraday discovered this effect, in 1845, that when light is passed through transparent dielectrics, the polarization of light can be rotated with a magnetic field induced parallel to the path of the light. The angle of rotation can be calculated by the given equation:

$$\theta = \gamma \cdot l \cdot B \tag{1}$$

where γ is Verdet constant, l is the length of the solenoid, and B is the magnetic field of the solenoid. Notice that the value of Verdet constant depends on the identity of dielectric material. In addition, the magnetic field of solenoid can be determined through its linear relationship with the current passing through the solenoid I by using the following equation:

$$B = (11mT/A) \cdot I$$

In this lab, Faraday Effect is demonstrated with magnetic fields that are generated by DC and AC currents passing through a solenoid and the objective is to obtain a Verdet constant equal to the constant of previously measured experiments. Furthermore, Malus's Law is utilized to verify the experiment set up, help to calibrate the system and determine the angle of rotation for the polarization for later calculations.

2 Experimental Setup

Generally for this lab setup, a red laser diode (approximately $\frac{650nm}{3mW}$) is utilized as the coherent light source. The laser must intersect the middle of the cross sectional area of the rod inside the solenoid; therefore, stricking the photo detector at the other end of the set up. The laser's light transverses right to left as pictured in $Fig.1$ Please note that the choice of the polarizer is arbitrary however $\underline{ONE}$ polarizer must remain in stasis, while the other will be used as the angle adjustment. At the opposite end, a polarizer with Vernier Scale as well as a photodetector are situated as stated above, so that the light can go through the polarizer then effectively strike the photodetector in a consistent manner. A multimeter and an oscilloscope are also used to measure the voltage output of the light source. Make sure that the polarizer in closest to the laser is set to 90 $^\circ$. If this polarizer is moved, it could effect the alignment of the laser during the procedure and create a false measurement. Our group chose to move the Vernier

Polarizer as outlined by the laboratory quick start guide. Thus when ”rotate polarizer” is mentioned, it prefers to the one with Vernier Scale.

1_Full_Set_Up.jpg

8_FLUKE_Mult_IMG_5442.jpg

Multimeter.JPG

2_Crown_Lockin_Amp.jpg

Figure 1. General Setup

2.1 Malus’s Law

To begin, set the 3 position switch in the off position and rotate the solenoid out of the path of the light source. Next, connect the BNC labled ”PHOTODIODE” with T fitting to the orange ExTech multimeter. Set the ExTech multimeter to measure VDC (dashed and solid line). Apply the power to the apparatus, and set the polarizer to 0°, the polarizer must begin at zero degrees.. Adjust the laser so that the maximum voltage can be measured by the red multimeter. Laser position is adjusted so that the multimeter reads the highest output voltage and may be recorded, record this measurement. Then, rotate the polarizer until the meter shows roughly 80% - 90% of the initial voltage. Record the angle as well as the voltage output (1). Next, rotate the polarizer in the opposite direction until the same voltage is measured. Record both values as the last step (2). To determine the angle of maximum intensity, take the average of measurement (1) and (2). Record the angle and the output voltage. Set the polarizer to the angle from the previous step, then add 5 ° (please refer to $Fig.2$. Write down polarizing angle and the corresponding voltage. Repeat this step with 5 ° increments until the total angle reach 120 ° or more (the greater the amount of data points the better the plot you will produce).This works as the two degree values will be different with respect to the origin so the average is taken to establish the location of the maximum. Here, students may exploit the FWHM (Full width Half Maximum).

2.2 Faraday Rotation Due to a DC Field

The setup of this experiment is similar to Malus’s Law’s. No need to make major adjustment. However, one more additional multimeter, DC power supply, and a glass rod (acting as a dielectric material) are needed. DO NOT forget to insert the dielectric rod of unknown material inside of the solenoid, or you might yourself measuring the Verdet constant of air which is zero. Before proceeding, set the ”Fluke 75” multimeter to measure AC current (wave symbol). Set the polarizer to the determined maximum angle from the experiment above. Then, rotate the polarizer to add 45 ° to the previous angle. Add the glass rod inside of the solenoid and rotate it into the path of the light source. Record the angle and voltage as this output is the initial intensity for later calculations. Next, turn on the power supply and set the 3 position switch to DC setting. Adjust the voltage of the DC power supply so that the ”Fluke 75” multimeter measures 1A. Record the measured data. Change the voltage and record the current (in the range of 1A to 3A) as well as adjusted voltage. Perform the previous step at least 5 times for accurate measurement.

2.3 Faraday Rotation Due to a AC Field with Lock-in Amp

In this experiment, instead of using DC current to generate a magnetic filed, this experiment uses AC current from the Lock-in Amp. To start this experiment, connect the BNC connector with T fitting. Next, set the oscilloscope to AC coupling and connect the current transformer to the oscilloscope input 1. Switch the 3 position switch to AC. Then, connect the Output of the Lock in Amp to the right red multimeter and set to measure VDC.

For the Lock-in Amp, make sure the sensitivity is set to 10 mV, and ”Flat” is selected for filters mode. The arrow keys can be use to adjust the sensitivity if needed as well as the ”MODE” button for filters. Next, set ”Tuning” of the Lock-in Amp to ”SET OSC LEVL.” After that, use the arrow keys below the display screen to adjust the parameter of the input voltage such that the "Fluck 75" reads 1A. To synce the phase different between the input signal and the internal reference, press the red auto button, and then press the auto phase button. Similarly to the experiment above, adjust the polaraizer back to the determined maximum angle from the experiment above. Then, rotate the polarizer to add 45°to the previous angle. Record the output voltage from the red multimeter. Repeat the measurement for multiple currents by adjusting the parameter of the Lock-in Amp.

$$I = I_0 \cdot cos^2(\theta)$$

Malus_Law.JPG

Figure 2. Malus's Law: Intensity vs. Angle

2.4 Faraday Rotation Due to a DC Field and a AC Field with Lock-in Amp

During the procedure, the current measurement is done by the "Fluke 75" multimeter instead of the oscilloscope because of convenience. The Verdet constant of a glass rod is determined through the relationship between the light intensity and the DC current, shown in Figure 3. Figure 4 also displays the same relationship but for AC current. By finding the same max voltage of 74mV after turning on the solenoid with either AC or DC. The angle of the polarizer with respect to its origin is compared and a difference of about 2.85°is obtained. Comparing the result from the DC field (Figure 3) to AC field (Figure 4), both show that the collected data are inaccurate. DC field gives 0.0023 rad/(Tm) as the value of the constant, AC field yeilds a value of 0.0116 rad/(Tm). In order to improve the measurement, the best choice is ensuring that the laser is working at max intensity and that the alignments are more precise. Additionally, the light source was able to move Furthermore, reduce the light pollution from other source can improve the accuracy of the multimeter.

$$\theta = \Delta I/(2 \cdot I_0)$$
$$B = (11mT/A) \cdot I$$

Intensities_Current.JPG

Figure 3. Intensity vs. DC Current

Systematic Errors

Different factors of error are identified, such as .

Standard Error of Measure

References

"Faraday Effect." Wikipedia, Wikimedia Foundation, 7 Nov. 2018.

AC_Intensity_Current.JPG

Figure 4. Intensity vs. AC Current