Determining the Verdet Coefficient of Olive Oil with Faraday Rotation

Matthew Dharmawan, Saahit Mogan, Orkideh Khoshsorour, Anisha Yeddanapudi, Tony Zhou   Mentor: Aarabhi Achanta

University of California, Berkeley   Undergraduate Lab at Berkeley, Physics & Astronomy Division

Abstract

Faraday rotation is a phenomenon in which the polarity of light changes as it travels through a medium with free electrons and a magnetic field. In this project, a laser diode emits light through olive oil under a magnetic field, ending its travel at a photodiode. Two permanent circular magnets with polarizer films attached to each magnet surround the cuvette containing the medium between them. The setup allows careful determination of the Verdet coefficient. The literature cites a Verdet coefficient of 192-198 deg T^{-1} m^{-1} [2]. By fitting the intensity of the transmitted laser light as a function of polarizer angle using Malus' Law and determining the Verdet coefficient from the fit, we yielded a value of 193 ± 405 deg T^{-1} m^{-1} with a laser of 650 nm.

Background Information

Faraday rotation is a phenomenon that results in the polarization of a wave, which is proportional to the projection of the magnetic field along the axis of wave propagation. The effect is commonly measured through the resulting angle of propagation [1].

Understanding the effects of Faraday rotation and the relation to plasma is useful in radio astronomy and the plasma emissions received from space [3][7]. The Faraday Effect is a common phenomenon that is observed within the measurement of radio waves. Additionally, different angles of polarizations can inform observers of the material that the waves have passed through, as shown by the formula for the Verdet coefficients (Eq. 1). Knowing the material that a radio wave travels through allows researchers to determine the possible celestial objects within its path allowing for further astronomical research [5]. The Faraday effect is also important for fiber-optic telecommunications systems, as the polarization of light as it moves through varying materials affects its functionality [7].

Theory

The strength of the Faraday rotation of a wave through a medium is characterized by a Verdet coefficient. Specifically, for a magnetic field that is parallel to the path of the wave, the Verdet coefficient can be described by [1][2]

$$\theta = VBL \qquad \text{(Eq. 1)}$$

where V is the Verdet coefficient, B is the strength of the magnetic flux density, L is the path length in the material, and θ is the angle of polarization.

The Verdet coefficient is largely dependent on the wavelength of the propagating wave, and a higher Verdet coefficient results in a larger angle of polarization. Additionally, different materials have different Verdet coefficients and for that reason it becomes critical to run experiments as a means to consistently determine the Verdet coefficients of a large variety of materials.

To measure the intensity of the transmitted light through two crossed linear polarizers we can use Malus's Law [2], which states

$$I(\theta) = I_0 \cos^2(\theta + \varphi) + c \qquad \text{(Eq. 2)}$$

where I is the transmitted intensity, I_0 is the maximum intensity of the light passing through, and θ is the angle between the two polarizers, as shown in Figure 1. For our purposes, we will also be using a phase shift in the argument of the cosine, described by φ, and a vertical shift, described by c, to account for any ambient noise or light [2][4].

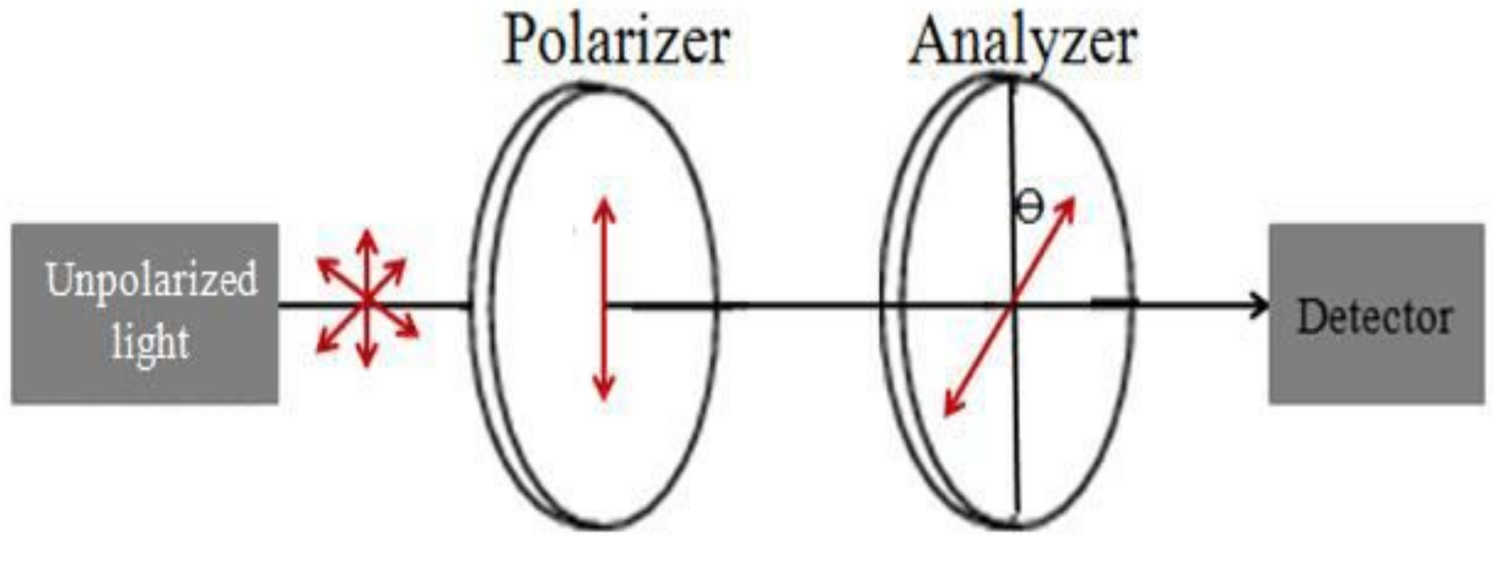

Figure 1: A visual depiction of Malus' Law [6].

Methods

Set up the laser and photodiode as described in Figure 2 in a dark room. Next, turn on the power supply for the photodiode and the laser, and adjust the intensity unit of measurement. Turn off the power supply of the laser then set up the proper arrangement as described in Figure 2 in a dark room to prevent noise on the photodiode measurements. Make sure that the cuvette is empty for an initial sampling as the control. Put the magnets into the magnet holders and turn on the power source for the laser.

Adjust the analyzer to achieve the highest extinction on the photodiode, then measure and record the angle and photodiode intensity as the analyzer is rotated a total of ~180°. Next, turn off the power source for the laser and remove the cuvette and fill it with olive oil. Repeat the process with olive oil within the cuvette and repeat for multiple trials.

For the magnetic field measurement, We measured the magnetic field along the beam path of the laser at 5 mm increments from one end of the cuvette to the other using a gaussmeter.

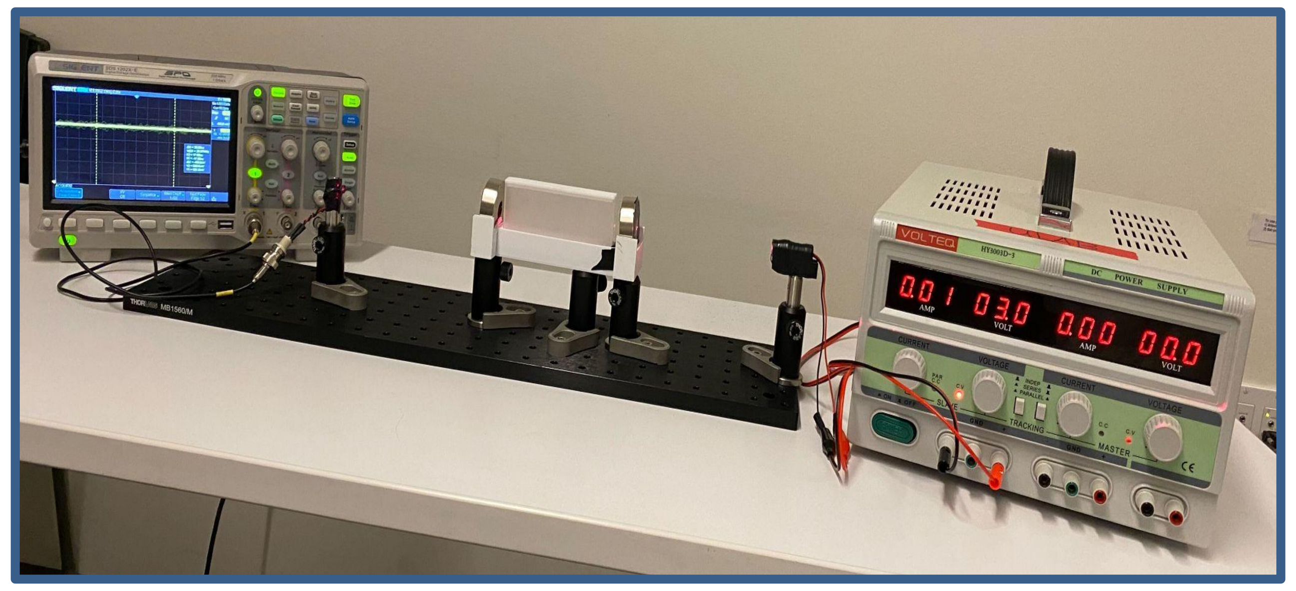

Figure 2: An image of the setup, with a laser, two polarizer films, two magnets, cuvette, oscilloscope, and power supply.

Data Reduction and Analysis

First, we measured the magnetic flux density using a gaussmeter and plotted the results in Figure 3. The measured angle and photodiode intensity for both the oil and air datasets are then plotted, and the best trials from each medium are selected. The criteria for this selection is that the plot resembled a cosine squared plot. A few of the initial datasets were discarded because the photodiode was being oversaturated and did not accurately measure the light hitting it. The voltage is then decreased accordingly. In total, one trial for air and three trials for oil are used for the fitting (Figure 4). The data points are then plotted to a cosine squared function with amplitude, phase shift, and vertical parameters. The curve fit provided us with the phase shift for air to be 86.384° ± 2.119° and the phase shift of oil to be 87.503° ± 1.007°. The difference in phase shift is then divided by the strength of the B field integrated along the path length of the beam which results in a Verdet coefficient for olive oil at 650 nm of 193 ± 405 deg T^{-1} m^{-1}. This agrees with previously measured values, which show that the coefficient lies between 192-198 deg T^{-1} m^{-1} [2]. However the error in our determined value is far too great to conclude much.

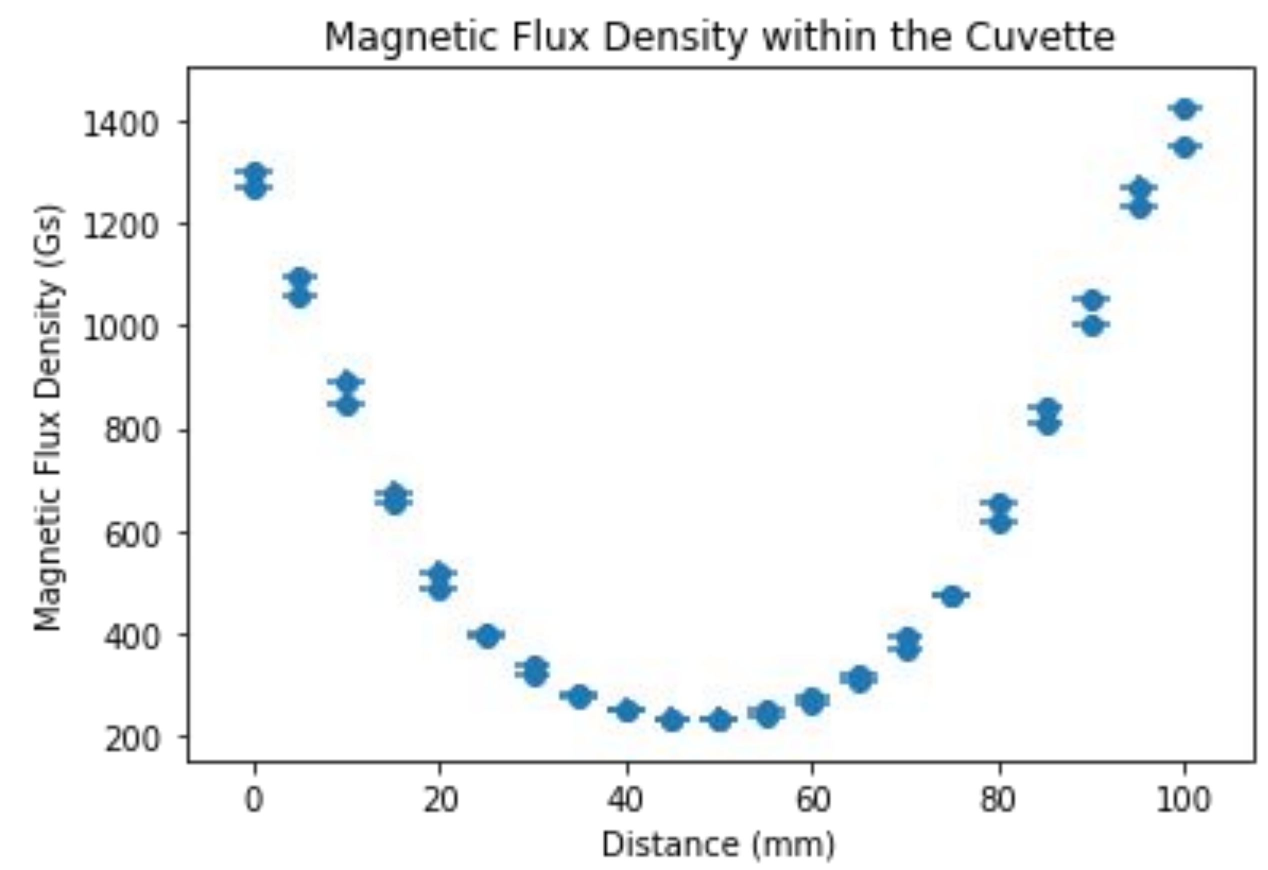

Figure 3: The magnetic flux density in the cuvette, as a function of distance with respect to one end of the cuvette.

Results

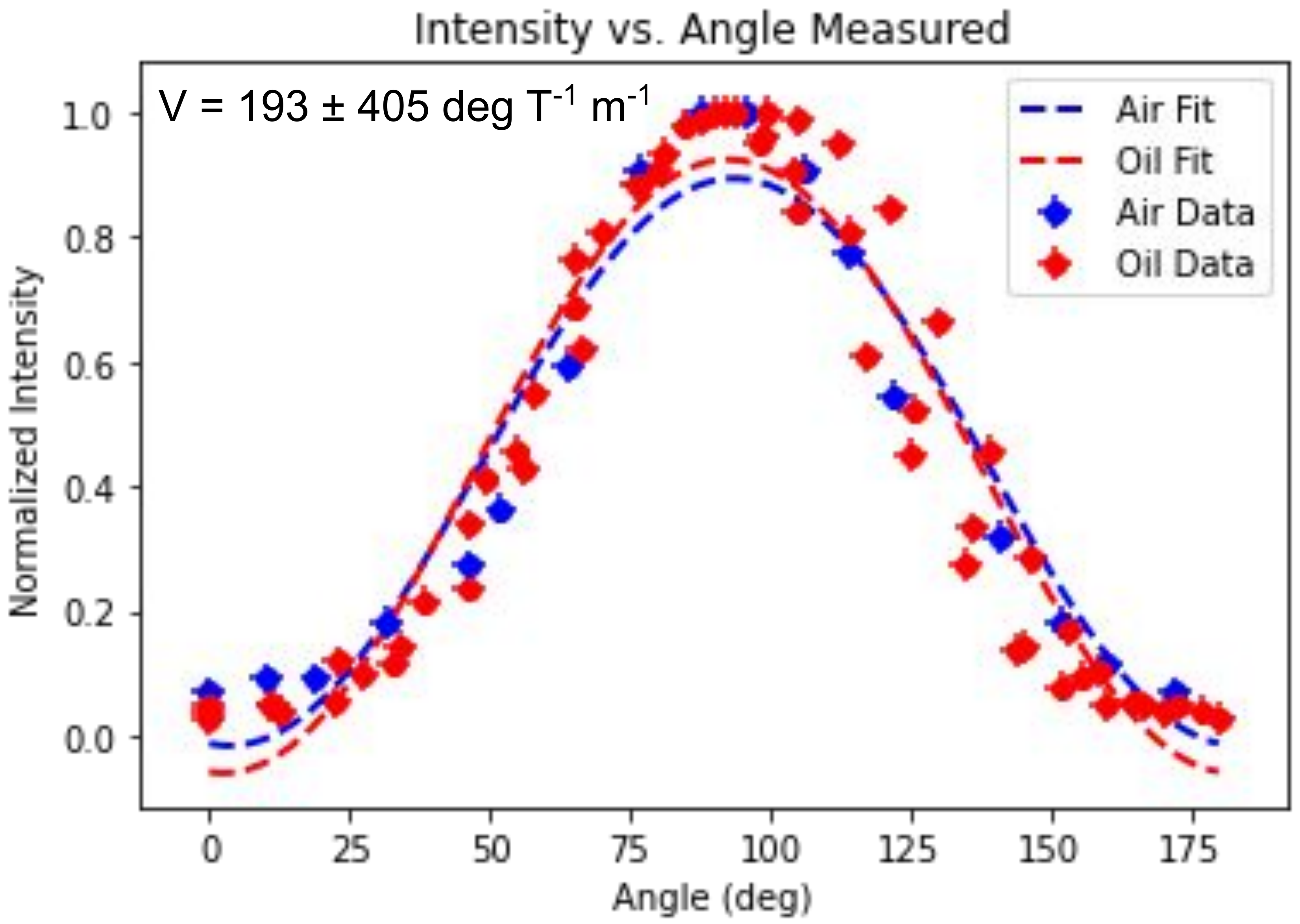

Figure 4: The plot of normalized intensity versus the angle. Note that the oil fit is shifted to the left, causing a different measured angle. That difference is the angle of polarization.

Sources of Error

Our value for the Verdet coefficient, while accurate, is very imprecise. This is due to many factors but is mainly due to the imprecision of the angle measurement technique. Our technique had multiple flaws that were due to the limitations of the equipment available to us. We were only able to change the angle of the in relatively large increments compared to the phase shift we expected to measure. This, combined with the fact that the angle measurements were done in multiple steps, may have also introduced error. We end up with an error of 405° T^{-1} m^{-1} which is larger than the measured Verdet coefficient itself. Therefore, we cannot conclude that we confirmed the Verdet coefficient found for olive oil in the literature [2].

Some other sources of error we encountered were accidentally oversaturating the photodiode which was corrected for by discarding that dataset, and the imprecision of the oscilloscope reading (precision of 4 mV), leading to more imprecise measurements for angles with high extinction which was corrected for by setting the 'Acquire' mode of the oscilloscope to 'Average' which helped but not by an appreciable amount. Another issue we encountered was that the linear polarizers were not ideal and their extinction/transmission ratio was subpar.

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