Experiment: Faraday Effect — light interacting with magnetism

Goals

- ◇ Observe the nature of polarization of light.
- ◇ Evaluate the effect of current on the polarization of light as per the Faraday effect.
- ◇ Develop the ability to work with a signal processing unit and oscilloscope.

Personal Protective Equipment & Safety

In addition to the standard safety rules for Second-year Physics Lab Courses, this lab involves electronic equipment with cable connections that you will manipulate throughout the experiment, a small glass sample, and a low-power (Class 3R, 3 mW) laser. The Physics Undergraduate Labs (UGL) will supply personal protective equipment upon request. The following safety rules will be in effect for this lab:

- ◇ No food or drink will be allowed in the labs.
- ◇ Wear long pants, a dress, or the equivalent.
- ◇ Wear close-toed shoes.
- ◇ If you would like safety goggles, request them from your TA or bring your own. We recommend you consider using safety goggles when handling the glass rod.
- ◇ If you would like Nitrile gloves, request them from your TA. We recommend you consider using Nitrile gloves when handling the glass rod.
- ◇ Always turn power supplies off before setting up new electronic circuits.
- ◇ Unintentional or accidental exposure to direct or reflected beam from the laser has a low risk; the eye's natural reflex to blink should prevent damage. Avoid intentional exposure to direct or reflected beam.

Required, Suggested, & Optional Equipment for Students

- ◇ Lab Book #1 (A01-B) or #2 (A01-A & A03)
- ◇ Pens (Required)
- ◇ Ruler (Suggested)
- ◇ Nitrile Gloves (Suggested); Either UGL-Supplied or Student-Owned
- ◇ Safety Goggles (Suggested); Either UGL-Supplied or Student-Owned
- ◇ Lab Coat (Optional); Either UGL-Supplied or Student-Owned
- ◇ USB key (Optional)
- ◇ Laptop (Optional)

1. Background

The Faraday Effect in Context

> *Impelled by a belief in the unity of the forces in nature, Michael Faraday sought, and in 1845 provided, the first phenomenological evidence for the connection between light and magnetism when he discovered the effect that still bears his name. He found that plane-polarized light, propagating through matter parallel to a static magnetic field, underwent a systematic rotation of its plane of polarization.*[1]

Although carefully studied from the time it was discovered, the ability to rotate the polarization of light with nothing but a magnet (the Faraday effect, also known as Faraday Rotation) was not theoretically understood until the development of quantum mechanics. This understanding now allows physicists to consider the detailed interactions of individual electrons with both the light and magnetic field as a whole. This experiment, while humble in its impact to physics, has allowed for the exploration of long-held theories in greater depth.

Although the interaction between magnetic fields and light often yields a small effect, the Faraday effect is utilized frequently in several important applications. Astronomers use Faraday rotation to probe the magnetic fields and contents of the material between stars (the interstellar medium). The rotation of polarized lasers can be used as a detection mechanism for fluctuating magnetic waves. In modern fibre optic telecommunications networks this rotation forms the base for canonical optical isolators[2], a category of devices that prevents feedback from the transmission of light. These are just a few of the examples of how the Faraday effect continues to be key to the development of modern technologies.

The Faraday effect also provides an opportunity to explore digital signal measurement, an important technique necessary to modern physics. For instance, in this lab, a photodiode will be used to convert the intensity of a laser into a recordable voltage.

Theory

DC Faraday Rotation

This experiment utilizes a linear polarizer, which transmits light with a single plane of polarization. For linearly-polarized light incident on a linear polarizer, the transmitted intensity, I, is given by Malus' Law:

$$I = I_0 \cos^2(\theta - \theta_0), \tag{1}$$

where I_0 is the maximum transmitted intensity and $\theta - \theta_0$ is the angle between the transmission axis of the polarizer and the plane of polarization of the light. In other words, the plane of polarization of the incident light is at θ_0 and θ denotes the orientation of the polarizer.

In this experiment, a photodetector measures the light intensity and produces a voltage, V, proportional to the intensity, yielding:

$$V = V_0 \cos^2(\theta - \theta_0), \tag{2}$$

where V is the detector output voltage and V_0 is the voltage corresponding to the maximum transmitted intensity. Maximum transmitted intensity occurs when $\theta = \theta_0$ or $\theta = \theta_0 + \pi$.

In order to measure the Faraday effect, light from the linearly-polarized source is allowed to pass through a transparent rod of material placed in a solenoid, before reaching the polarizer. The Faraday effect causes a change in the plane of polarization of the light as it traverses the rod. This change is linear with distance, such that the plane of polarization of the light emerging from the rod becomes $\theta + \Delta\theta$ with

$$\Delta\theta = C_v B L, \tag{3}$$

where B is the strength of the magnetic field inside the solenoid, L is the length of the rod, $\Delta\theta$ is the change in rotation of the beam from its original polarization in radians, and C_v — the Verdet constant — is a parameter specific to the material that describes the strength of its Faraday response. For example, when the Faraday effect causes a $\Delta\theta = 5°$ rotation in the plane of the polarization of the light, the polarizer would have to be physically rotated through 5°, relative to the $B = 0$ setting, to yield the same detector voltage that had been recorded at $B = 0$.

The solenoid used for this experiment has well-known dimensions, allowing us to simplify the equation for the magnetic field along the central axis to:

$$B = kI, \tag{4}$$

where k is a calibration constant of the solenoid and I is the current supplied to the solenoid.

AC Faraday Rotation

In the AC measurement part of this experiment, the DC current in the solenoid is replaced by a sinusoidal AC current, I_{AC}, which in turn generates a sinusoidal AC magnetic field, B_{AC}, and Faraday rotation, $\Delta\theta_{AC}$. Equations (3) and (4) still hold true. In this experiment, the magnitude of the AC Faraday effect will remain small, allowing us to base our discussion on the assumption that $\Delta\theta_{AC} << 1$ rad. Then (for small $\Delta\theta_{AC}$), the AC Faraday rotation gives rise to an AC photodetector output voltage according to

$$\Delta V_{AC} = \Delta\theta_{AC}\frac{dV}{d\theta} \tag{5}$$

where $dV/d\theta$ is the derivative of V as defined in equation (2), using the values you will record with the glass rod inserted and no current supplied to the solenoid. It is calculated at the polarizer position, θ, (and has a maximum value of V_0 per radian when θ is 45 degrees from θ_0). The derivation of this equation down to variables that are given or measured in this lab is shown in Appendix A.

Methods

Apparatus

To analyze the Faraday effect you have been provided with a TeachSpin FR1-A, a photodetector apparatus that can be used to measure the intensity of light. The FR1-A consists of four basic components: a laser light source, a solenoid, a polaroid filter and a photodetector. In recent years we have replaced the FR1-A polaroid filter with a Thor-Labs 1/2" Linear Polarizer with N-BK7 Protective Window B Coating (LPNIRE050-B) mounted in Thor-Labs rotation mount (RSP05). In addition, a TeachSpin Signal Processor will be used to better resolve the signal, while a Tektronix TDS2022C oscilloscope will be used to display the resulting signal for analysis. A detailed description of each component is provided below, owing to the special considerations each requires.

Light Source

A red laser is used as the light source, producing a nominal wavelength of approximately 650 nm with a power output of about 3 mW (making this a Class 3R laser). The laser output is linearly polarized. The laser is powered by plugging the banana plugs from the laser into the corresponding coloured connections on the power adapter. This may already be done for you. **Do not plug the laser into the BK Precision power supply!**

The laser beam must be adjusted such that it traverses the central axis of the solenoid. The four nylon thumb screws on the laser mount will allow you to adjust the beam while sighting it on a white index card at various points between the light source and the photodetector. The beam must be centred both at the entrance and exit of the solenoid such that it falls directly on the photodiode of the detector. If your beam does not have a circular shape exiting the light source, you can minimize the chance of accidental internal reflection by ensuring that the shape of the laser beam is the same entering and exiting the solenoid. Do not over-tighten the screws; if necessary, coarse adjustments can be made by loosening the laser mounting post using the nut on the bottom of the stand. Though it is worth checking the alignment of the beam after each trial, the laser must be realigned after a dielectric sample is placed within the solenoid.

***Note:** The laser is extremely sensitive to its power source. Reversing the power supply voltage will likely destroy the laser. It is also important to protect both leads from electrostatic shock. Keep the connectors shorted to each other until they are connected to their power supply.

Solenoid

The solenoid has the following physical specifications:

- ◇ Length: 150 mm Wire
- ◇ Size: #18 gauge double insulated DC
- ◇ Turns/layer: 140 (total number labelled on each solenoid)
- ◇ Resistance: 2.6 Ω
- ◇ Number of Layers: 10
- ◇ Calibration Constant k: 11.1 mT/A

As previously mentioned, the magnetic field of a solenoid varies inside its length, with the field along the central axis being approximately uniform. Variation of this field may be significant for certain samples, particularly those that extend outside the coils.

The maximum safe continuous current that the solenoid can handle is 3.6 A; the provided BK Precision power supply can deliver currents between 0 to about 3.6 A. **The current cannot be set above 3.2 A for more than 10 minutes straight.** The supply has controls for both voltage and current, supplying a current consistent with the smaller of those two settings.

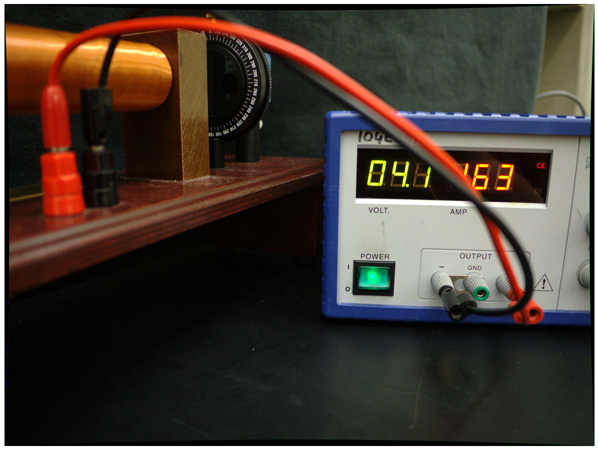

Figure 1: Implementation of the DC power supply. Note the C.C. symbol on the upper-right of the display indicates constant current mode.

While using constant current mode (C.C. will appear on the display) the voltage may need to be adjusted to maintain a constant current if the coil's resistance increases slightly from heating. Though the power supply can supply currents of up to 3.6 A, this level of current can quickly cause the unit to overheat. Take care to avoid overheating when using currents near the power supply's maximum.

Polarizer

Before the photodetector is a thin, linearly polarized polaroid film (a linear polarizer) in a calibrated mount. The film can be rotated to change the intensity of the beam incident on the photodetector; the circumference of the mount is ruled in 2° increments for this purpose. Magnifying glasses are provided to better read the angle of the polarizer.

Photodetector

The detector is a silicon photodiode connected in series to one of three resistors: 10 kΩ; 3 kΩ; or 1 kΩ. The photodiode is a current source, producing a linear voltage as long as the voltage measured is less than about 300 mV. If this voltage is exceeded, the photodiode may no longer provide a linear voltage response and may even become saturated, resulting in a sublinear output.

Given the limitation on the photodetector's voltage the load resistor may need to be switched, typically between the 3 kΩ and 1 kΩ settings. Given that the laser diode light source has a high intensity it can produce a large voltage in the photodetector – use the lower values of load resistors for the trials using higher intensities. The 10 kΩ setting should be used for observations of the DC Faraday effect, Method 1 (p. 8).

Magneto-optical specimen

A glass rod will be used as the magneto-optically active specimen. The rod is short enough so that, when centred in the solenoid, the nonconformity of the magnetic field along the length of the sample is negligible. At the same time, the rod must be long enough for a measurable polarization rotation to develop along its length. The specifications of the glass rod are:

- ◇ Diameter: 5 mm
- ◇ Length: 10 cm
- ◇ Material: Schott SF-57
- ◇ Verdet Constant: 21.0 $\pm$ 0.5 rad/T·m (calculated for 650 nm based on SPIE Digital Library, "Verdet constant and its dispersion in optical glasses", 1991)

To place the glass rod in the solenoid, remove the photodetector by loosening the post-holder screw, and the polarizer from its mount by loosening the screw at the top. Be sure not to put the face of the polarizer on the table. Place the rod on its soft foam rings inside the solenoid, using a long cotton swab to push the rod further inside. The glass rods are extremely fragile so they must not make contact with the sides of the solenoid; additional care must be taken to avoid touching the highly-polished ends of the glass to prevent obfuscation of the beam. (To later remove the glass rod from the solenoid, the polarizer must be detached again from its mount using the screw at the top, and the photodetector also removed from the stand; the cotton swab than can push the rod toward the polarizer end of the solenoid, where it can again be gently grabbed and taken to the glass rod storage case.)

Other equipment available

- ◇ Audio Amplifier
- ◇ Signal Processor/Lock-In Amplifier Unit
- ◇ Digital Oscilloscope
- ◇ Handheld Multimeter
- ◇ 3 x BNC Cables
- ◇ Plastic Container with 8 short BNC cables, 3 connectors, cue card, and magnifying glass
- ◇ Isopropyl Alcohol (for cleaning the ends of the glass rod)

Procedure

There will be three sets of procedures that you need to follow: setting the polarizer rotation; measuring the DC Verdet constant of the glass rod; and measuring the AC Faraday effect using the glass rod. **You will need to set the polarizer rotation at the beginning of each day in the lab.** Before each procedure, and whenever you reintroduce the glass rod into the solenoid, you should check the alignment of the laser beam (as described earlier in this manual).

Polarizer Rotation

1. Connect the photodetector directly to the oscilloscope. Ensure that the signal input channel is DC coupled and that the reading multiplier is $1\times$ (the default setting for some of the scopes is $10\times$, to compensate for probes that we do not use). **For these steps, be sure to set the oscilloscope input to DC coupling.** Throughout this lab, we will be using the cursor interface of the oscilloscope to measure the output voltage of the photodetector. In the DC portion, we will also use the cursors to measure the uncertainty of the signal. Turn on cursors by pressing the “Cursors” button on your oscilloscope to open the relevant menu and use the buttons on the right of the screen to navigate the menu. Be sure that “Amplitude” is chosen for the type of cursor and that the source for the cursor is set to the channel that you connected the photodetector to. This will cause two cursors to appear on screen.

   The cursors’ position on screen is adjusted by selecting the desired cursor using the buttons to the right of the screen, then adjusting the multipurpose knob at the top right of the screen. To measure the voltage in the following two steps, you should zoom in on the signal and then manually place either one of the cursors in the middle of the (fuzzy and thick) signal. Your voltage value will be listed below the cursor that you used in the menu on the right of your screen. To determine the uncertainty of your measurement, place one of the cursors at the “top” and the other at the “bottom” of the fuzzy DC trace. You can then read off the ΔV value given in the menu and divide it by two — this is your uncertainty. This is a “Limit uncertainty,” which is a very conservative way of estimating uncertainty. You will use a better method in the AC portions of the lab, but this technique works for your DC measurements.

2. With no sample inside the solenoid, measure the intensity (voltage) of the light transmitted through the polarizer as a function of the relative angle between them, using the position of maximum intensity as a reference. During these steps, make sure that the voltage of the photodiode does not exceed about 300 mV. You may need to reduce the resistance of the photodiode to do this.

   For setting the polarizer rotation, it is important to take several measurements of the voltage and angles near the maximum intensity and minimum intensities to verify that you have identified the maximum intensity. The minimum intensity will occur $\pm$90°from the maximum intensity.

   The first time you set the polarizer rotation of the empty solenoid, you must also take data to confirm Malus’s Law, you should aim to take ~ 20 data points stretching over a little before the a minimum intensity to the maximum intensity and then to a little after a minimum intensity (i.e., a little over 180°). We suggest taking ~ 3 points clustered near each minimum / maximum intensity and the remaining points spread across the full range of polarizer rotation you sample.

3. Next, insert the glass rod until it is approximately centred in the solenoid, where the magnetic field will be fairly uniform. Again make several measurements of the voltage and angles near the maximum and minimum intensities reported by the photodetector. The instructions for inserting the glass rod are described in detail in the Apparatus section.

DC Verdet Constant

Utilize the following two methods to determine the Verdet constant of the glass sample.

For both methods, you will have to answer the following questions as you complete both procedures and recording the answers in your lab book:

- ◇ **What happens when the direction of the current is reversed?**
- ◇ **Does the solenoid have an appreciable effect on the photodetector itself?**

DC Verdet Constant Method 1 — Maximizing Extinction

1. Set the polarizer at 90° with respect to the maximum intensity. This minimizes the intensity (maximizes the extinction) of the light reaching the detector. You can see this by sighting the beam on the white index card before the photodetector. Once the intensity is near the minimum, set the load resistor switch on the photodetector box to 10K. The 10 kΩ setting will give you ten times better resolution of the signal around the intensity minimum, compared to the 1 kΩ setting (there is no risk of saturating the photodetector near the minimum).
2. Connect the BK Precision unit to the solenoid and select a starting current.
3. Measure the change in the angle of rotation of the polarizer necessary to return to minimum intensity (maximum extinction) when the solenoid's magnetic field is turned on.
4. Find the rotation angle for a variety of currents, recording the angle and current in your logbook. As the change in rotation angle is small for the allowed currents, you should go up to the maximum allowed current to make measurements as well — just make sure to be aware of how long you keep a high current running through the solenoid. **Remember, the current cannot be set above 3.2 A for more than 10 minutes straight.**

DC Verdet Constant Method 2 — Returning to Fixed Intensity Value

1. Switch the load resistor on the photodetector back to 1 kΩ ("1K" setting), and set the polarizer at 45° with respect to the maximum intensity.
2. Repeat the procedure described in Method 1 (Steps 2–4). However, in Step 3, instead of adjusting the signal back to minimum intensity (maximum extinction), the polarizer must be adjusted such that the detector output returns to the value found before the magnetic field was turned on.

Intermission: measurement technique and uncertainty

So far in this lab, we have been estimating uncertainty in a quick and dirty fashion using limit uncertainty. This might strike you as rather unsatisfying, because it really does seem that we as physicists should be able to do better than just taking the limits of that fuzzy line. This notion is absolutely correct, but doing better takes a little bit more work. In this section, we are going to apply some of the statistical methods touched upon in class to really stress their ability to improve the certainty of your measurements.

In the upcoming AC section, when you are asked to "measure the voltage," use the cursors as above to produce the desired reading, **but instead of taking a single reading, repeat this measurement process 16–25 times**. Under the assumption that your measurements will be normally distributed around the "true" value (which in this case, they should), you will be able to use this host of measurements to produce a standard deviation of the mean, and this number is your uncertainty. We know this is a bit annoying, but when you compare the uncertainties produced by this technique to those in the DC section, you will see that it is night and day. These statistical methods are so good, in fact, that if you are extremely careful, you will be able to beat the "digitization uncertainty" (the smallest increment that the cursors can move) of the oscilloscope itself.

In order to measure the voltage, you will again be using the cursors. However, this time your signal will be a sine wave. To get a measurement of the voltage, set one cursor to the middle of the peak of the sine wave and the other cursor to the trough of the sine wave. The ΔV listed in the menu will be your voltage. This is a peak-to-peak voltage. However, the lab's digital multimeters, when set to AC, report RMS (root mean square) values for sinusoidal signals and Equation 5 requires the values be RMS. So the voltage measurements recorded in the AC portion of the lab need to be converted to RMS voltage. If the AC waveform is a sine wave, the RMS value, V_{RMS}, the peak value, V_p, and the peak-to-peak value, V_{p-p}, are related by:

$$V_p = \sqrt{2}V_{RMS} \text{ and } V_{p-p} = 2V_p. \tag{6}$$

Methods — continued

Procedures — continued

AC Faraday Effect

With a sinusoidal current passing through the solenoid, the Faraday effect will give rise to a small AC variation in the plane of polarization of the light transmitted from the glass rod, which will be manifested as an AC variation in the voltage transmitted by the polarizer, at the same frequency as the current. This AC amplitude will also change with the orientation of the polarizer. You can detect this by looking at the signal on the oscilloscope. The signal produced should be a sine wave when the polarizer is 45° to the maximum incidence of the beam found during the DC measurement. When the current amplitude in the solenoid is $\sim 200\,\mathrm{mA}$ RMS, the signal can be detected, but it is faint and noisy. Much higher sensitivity can be obtained with the aid of the TeachSpin Signal Processor, allowing for better and easier measurement of the Faraday rotation in the glass rod. During the following steps, you will observe how some of the components of the Signal Processor improve your ability to measure the signal.

1. A sine wave for AC magnetic field generation is obtained from the reference oscillator output of the TeachSpin Signal Processor unit (shown in Figure 2 below). However, this oscillator cannot supply much current on its own, so the oscillator output must be routed through a TeachSpin Audio Amplifier (use the AC input), which then drives the solenoid. For the Reference Oscillator, set the frequency range to 300 Hz – 1 kHz and start with an amplitude of around 1. Start with the attenuator setting of the Audio Amplifier at "1", which corresponds to maximum gain. In order to know the AC being fed to the solenoid, a battery-powered multimeter must be inserted in series between the Audio Amplifier and the solenoid (in most multimeters, AC is measured when the knob is turned to $\tilde{A}$). **Be sure to set the multimeter to the 300 mA AC setting when you take measurements or you will blow the fuse in the multimeter!** If you do not know how to wire this in series, ask a TA or professor to show you. Once this is set up, you can fiddle with the amplification and attenuation until the multimeter is reading about 200 mA alternating current.

   When AC current is supplied to the solenoid, you can observe the AC signal coming from the photodetector. **Be sure to set the oscilloscope input to AC coupling instead of DC, this will remove the DC level and display only the AC component**. The total light intensity is now the sum of a flat level (large for most settings of the polarizer) plus a small AC ripple (visible as a sine wave when the polarizer is 45° from maximum). If the AC signal is shaky, moving too rapidly across the screen or still appears as a straight line, there are several settings you can adjust — and you may need to adjust all four. (1) The Volts per division will likely need to be zoomed in to see the sine wave; (2) the seconds per division may need to be increased or decreased; (3) and the trigger settings may need to be set. To set the trigger, hit the "Trigger" menu button and then turn the dial until the arrow on the right side of the screen is below the peak of the sine wave. (4) Finally, you may need to adjust the fine frequency on the Reference Oscillator. By rotating the dial slowly, you can find a setting to produce an almost standing wave.

2. Check that your polarizer is still set 45° to the maximum incidence of the beam found during the DC measurement. Measure the voltage of the beam at this angle and take a few measurements of the current running through the solenoid during your 25 voltage measurements.

3. The Preamplifier and Filter modules of the Signal Processor can be used to improve the detection of a small AC Faraday signal. The Preamplifier (also known as a Preamp) makes the signal easier to detect by increasing the amplitude of the signal relative to the minimum voltage resolutions of the meter and the scope. In addition to the signal of interest, however, there is also noise on the output of the photodiode, from stray light and other sources. The Preamplifier amplifies this noise just as much as it increases the signal, which is what you should see in this step.

Figure 2: The TeachSpin Signal Processor front panel. The Reference Oscillator, Preamplifier, and Filter modules are used in the AC measurement of the Faraday effect.

Set the gain of the Preamplifier to 10 and connect the photodetector output to the + Input, with the three-position switch at its middle position (AC coupling). Then connect the output of the preamplifier to the oscilloscope. Try a few different values for the gain; make observations about how the signal changes; and record the results in your logbook. Choose one value for the gain and then repeat Step 2. Make sure to note your chosen gain.

4. Now that you've seen the effect of the Preamplifier, it is time to try to filter out the noise so that you are left with only the amplified signal. Since the signal frequency is known, you can selectively remove some of the noise from the measurement by passing the preamplifier output through a bandpass filter, in the Filter module of the Signal Processor. The bandpass output is the ideal filter for this as it allows only the desired range of frequencies through. The filter frequency should be tuned to the signal frequency set by the Reference Oscillator. The behaviour of the bandpass filter is controlled by the numbered settings on the switch labelled Q, which refers to the quality factor of the filter. Increasing Q narrows the range of frequencies allowed through, which helps decrease the noise. After connecting the bandpass output to the oscilloscope, you should vary the Q value to see how the signal changes and record your observations. Again, choose a single value for Q and then repeat Step 2. Be sure to note what Q value you chose.

   To reduce systematic uncertainty in this portion of the experiment it is important to check for and reduce any background contributions to the signal that are unrelated to the Faraday effect, such as electrical crosstalk. Block the laser beam (you can use the index card) and see if the signal vanishes completely or not. If it does not vanish, you might need to reposition wires to reduce "parasitic" coupling (capacitive or inductive), and check for errors in your wiring that might be introducing a ground loop.

Analysis

Lab Book and Lab Report Evaluation

For this experiment you will be completing standard analysis in your lab book, where this will be evaluated under the standard "Lab Book" rubric. You will also be completing a "Full Lab Report", where this will be evaluated under the standard "Lab Report" rubric. The Full Lab Report is 12 pages maximum where the length limit **does NOT** include the Cover Page and Appendix.

Important Notes: Read carefully the Lab Book Guidelines to include In-Lab and Post-Lab Notes. Make sure you add your observations about the experiment and discussion/conclusion requested for each tasks. In addition, don't forget to include setup detail including diagram (with appropriate and clear labels/captions), uncertainties including apparatus uncertainty and justifications. The Post-Lab notes after the first afternoon must include preliminary analysis of the data your obtained during the first session, and a plan of work for the second afternoon session.

Required Analyses

1. Verify Malus' Law for the data you collected from the empty solenoid using Equation 2. Plot a linearized graph of V versus $cos^2(\theta - \theta_0)$ and compare the slope to the measured V_0.
2. Calculate the Verdet constant of the glass using graphing techniques and Equation 3 on the DC data. Evaluate whether the "maximizing extinction" (DC Verdet Constant Method 1) or "returning to a fixed intensity value" (DC Verdet Constant Method 2) procedure produces better results.
3. Calculate ΔV_{AC} and its uncertainty from the measurements taken in Steps 2, 3 and 4 for the AC Faraday Effect. Compare the voltage values as well as the uncertainties with each other.
4. Calculate the Verdet constant of the glass and its uncertainty using the measurements taken from Steps 2 and 3 for the AC Faraday Effect. Note that the voltage is amplified in Step 3 and be sure to take that gain into account when you are doing your calculation. Compare the AC and DC analyses.

Additional tasks you should address in the lab report

1. Discuss the effect of the different modules of the signal processor that you used.
2. Describe any effect the inclusion of a dielectric has on the light beam.
3. Discuss the effect of the magnetic field on the components of the apparatus, particularly the photodetector. Include a description of the effect of the polarity of the field in your discussion.

References

[1] D.A. Van Baak, "Resonant Faraday rotation as a probe of atomic dispersion." Am. J. Phys. 64 (6), June, 1996. This paper has an excellent set of references for both the historical story of this discovery and modem practical applications of the effect. The paper also contains references to student experiments and theoretical papers analyzing this phenomenon.

[2] See, for example, www.integratedphotonics.com

Appendix A

As stated in the AC theory section, $dV/d\theta$ is the derivative of V as defined in Equation 2, using the values you recorded with the glass rod inserted and no current supplied to the solenoid.

$$\begin{aligned}\frac{dV}{d\theta} &= \frac{d}{d\theta}(V_0 \cos^2(\theta - \theta_0)) \\ &= -V_0 \underbrace{2\cos(\theta - \theta_0)\sin(\theta - \theta_0)}_{\text{trig identity simplifies this to } \sin(2(\theta-\theta_0))} \\ &= -V_0 \sin(2(\theta - \theta_0))\end{aligned}$$

Since θ is 45° from the maximum, $\sin(2(\theta - \theta_0)) = -1$. So

$$\frac{dV}{d\theta} = V_0.$$

From there, it is just a matter of substituting Equation 3 and Equation 4 in for $\Delta\theta_{AC}$ to arrive at an equation whose only unknown is the Verdet constant.