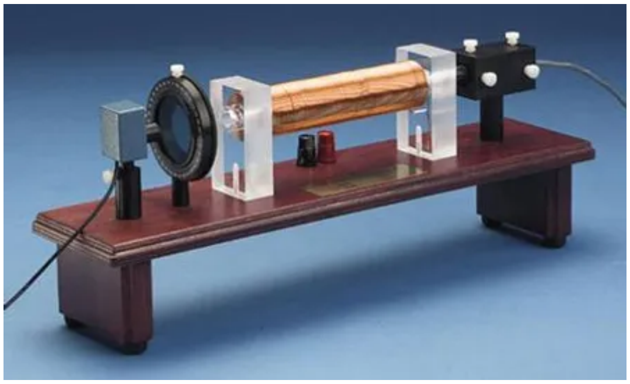
Faraday Rotation



In 1845, Michael Faraday was searching for experimental evidence that the forces in nature were all interconnected. He made a remarkable discovery by carefully examining the polarization of light as it passed through a transparent material in the presence of a magnetic field. He observed that linearly polarized light propagating through matter parallel to a static magnetic field, experiences a rotation of the plane of polarization. The effect is small, but he was an exceptional experimenter and he unambiguously identified the phenomenon. The rotation of the plane of polarization is still called the "Faraday Rotation."

Introduction | Instrument | Experiments | Additional Resources | Specs/Accessories

Introduction

The Faraday rotation experiment appealed to TeachSpin as a "real" physics experiment to dramatically "show off" the capabilities of the Signal Processor/Lock-In Amplifier (SPLIA1-A). Faraday rotation seemed ideal because, in the presence of a magnetic field reasonably obtained with a laboratory power supply and a solenoid, there is only a small rotation of the plane of polarization.

Faraday rotation has a practical application in optical isolators. An optical isolator is a device that allows light to go through in one direction but severely attenuates reflected light propagating in the opposite direction. Modern ultra-high field permanent magnets and special paramagnetic glasses have made these devices quite small, but not cheap (about $2K). The configuration of the components is essentially the same as in FR1-A. The polarizers are set at 45°. The combined effect of the special glass and the large magnetic field rotates the polarization plane of the light 45° on each passage. A simple sketch will show how this works as an optical isolator.

Optical isolators have important applications in telecommunications preventing reflected signals on fiber optic cables from producing unwanted signals. Isolators are important when lasers are used because reflected light can cause havoc with the operation of the laser itself.

Although Michael Faraday discovered this effect in 1845, it wasn't modeled quantum mechanically until the 1960's. These theoretical calculations are too sophisticated for the undergraduate student, but an excellent simplified QM model is carefully presented in David Van Baak's AJP paper. (D.A. Van Baak, Resonant Faraday Rotation as a Probe of Atomic Dispersion, Am. J. Phys.64 (6) June 1996)

Instrument

TeachSpin's Faraday Rotation Apparatus, FR1-A, Includes:

- The Light Source
- The Solenoid (magnetic field source)
- The Analyzer Polaroid
- The Optical Detector

The Light Source
The light source is a red laser pointer operating at a nominal wavelength of approximately 650 nm with a power output of about 3 mw. It requires a voltage regulated supply of 4 volts and 40 mA. TeachSpin’s Power Audio Amplifier PAA1-A has a voltage regulated (4V) supply

output specifically designed for this laser diode light source.

Although the output is approximately 60% polarized, the laser light is directed through a polarizing filter which increases its polarization to about 95%.
Before the sample is installed, four nylon thumb screws on the laser mount are used to aim the laser beam along the central axis of the solenoid.

The entire laser mount is removable so that an experimenter could use other light sources to study the frequency dependence of Faraday rotation. If any other sources are used, however, it is important that the intensity be stable. Small modulations in the frequency will not be as important.

The Solenoid
The solenoid is a 15 cm coil of #18 double insulated wire with DC resistance of 2.6 ohms. The approximate calibration at its center is:

$$B = (11.1 \mathrm{mT/A})\, I$$

where I is in amperes and B is in millitesla.

The magnetic field does vary along the axis of the solenoid. Such variation may be significant for certain samples, particularly those which extend outside the coils. We recommend that the students measure the axial magnetic field profile using TeachSpin's Hall Effect Probe HE1-A , or other equivalent field measuring apparatus.

The maximum continuous current through the unit is 3 amperes. For times of the order of 30 seconds, however, 10 amperes can be used without damaging the solenoid or its supports.

Since Faraday rotation measurements can easily be performed in 10-15 seconds by a student familiar with the equipment, it is possible to use these larger solenoid currents and thus obtain larger rotations.

The Analyzer Polaroid
The unit is equipped with a rotatable Polaroid film in a calibrated mount. The decal is marked in 5° increments. This limits the accuracy of an angular measurement to about 2°.

The Detector
The detector is simply a photodiode connected in series to one of three resistors; 10K, 3K, 1K. The photodiode is a current source and is a linear photonic detector, as long as the voltage across it is less than about 0.3 volt. Saturation begins to occur when this bias voltage appears across the diode. This makes the detector nonlinear. Varying the load resistor keeps the bias voltage below the 0.3 volt value.

The Sample
FR1-A comes with one sample, a 10 cm long SF-57 glass rod with a diameter of 5 mm.
The sample is easily removed so that the optics can be aligned.

Experiments

This experiment is appropriate for sophomore, junior, or senior students taking physics. The more advanced students can be challenged to measure small Verdet constants in liquid as well as solid samples. They can also study the theoretical model that Van Baak presents. This "simple" experiment has some wonderful surprises. We guarantee that!

The angle of rotation (α) of the plane of polarization of a light wave for a transparent material of length l in a magnetic field B is given by: $\alpha = \nu l B$

The symbol ν is defined as the Verdet constant. For the SF-57 glass rod sold with the TeachSpin apparatus, the Verdet constant for 650 nm light is 23 rad/Tm.

The "standard" strategy for measuring this rotation is to place a linear polarizer on each end of the solenoid containing the transparent material and cross them at 90°. The light source (laser in our case) is at one end and a detector is at the opposite end. With the magnetic field off and the polarizers "crossed" (at 90° to one another) there is "extinction," giving no (or very small) signal output from the detector. Putting current through the solenoid creates a magnetic field parallel to the light beam. This field produces a rotation of the polarization of the light which increases the light at the detector.

The polarizer in front of the detector is now rotated until extinction is again achieved. The angle of rotation of the polarizer is measured. This rotation angle can be measured as a function of magnetic field, length of sample, and wavelength of light. It depends on all three.

Although finding the angle of rotation by recreating “extinction” is conceptually straight forward, it is a very poor experimental strategy (as the student can discover and as we realized when developing this unit). First of all, for small angle Faraday rotation, the change in optical transmissions is zero to the first order when the polarizers are set at 90°. The maximum change in transmission, for a given small change in the angle of polarization, occurs when the polarizers are arranged at 45°. It is therefore more effective to set the polarizers at 45°, determine the transmission, apply the magnetic field and rotate the polarizers to return the transmission to the initial level. The analysis and experimental measurement of the optimum arrangement of the polarizers is a good exercise for the students. It will give them better insights into both these measurements and the calculus of differentials.

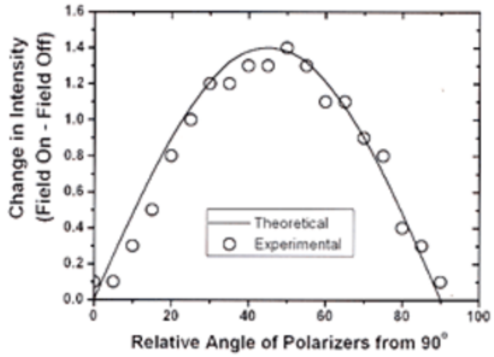


Fig. 2: Intensity Change as a function of angle for a coil current of 1 ampere.

TeachSpin’s Signal Processor / Lock-In Amplifier (or any commercial lock-in) can be used with the FR1-A to measure extremely small Faraday Rotations in a variety of materials. In these experiments an AC magnetic field is used so that the Faraday rotation is “coded” (modulated) at the AC frequency. Students can easily observe tiny rotations with this setup as well as easily determine the “best” relative angle of the two polarizers to observe the small rotation. They can compare these measurements with their theoretical analysis.

Additional Resources

- Faraday Rotation Brochure
- Learn about Signal Processor/Lock-In Amplifier (SPLIA1-A)
- Learn about Power Audio Amplifier PAA1-A

Specifications

Includes:
- solenoid
- laser
- detector
- Linear Polarizer in 360° Rotation Mount, 5° calibration
- Sample

Solenoid:
- #18 Gauge double insulated wire
- 10 layers
- 140 turns/layer
- Length = 15 cm
- DC resistance = 2.6 ohm
- Maximum Sustained Current = 3 A
- Approximate calibration at center of solenoid - B = 11.1 (mT/A I

Optics:
- Removable linear polarizer mounted on laser
- Linear Polarizer in 360° Rotation Mount, 5° calibration

Laser:
- red laser pointer
- nominal wave length - 650 nm
- power output - mw

Detector:
- Photodiode with 10 K, 3 K, and 1 K resistors

Sample:
- Material - Glass rod, SF – 59
- Diameter = 5 mm
- Length = 10 cm

Dimensions:
- Approx. 18” x 4 1/2 “ x 8”

Accessories

Digital Voltmeter for DC measurements

Power Supply for Solenoid
Current Regulated Polarizing Power Supply (At least 3 A)

Power Supply for Laser
TeachSpin’s Power Audio Amplifier (Voltage regulated 4V, 40 mA)
Learn about Power Audio Amplifier PAA1-A.

Signal Supply for AC Measurement
Signal Processor/Lock-In Amplifier (such as TeachSpin's SPLIA1-A)
Learn about Signal Processor/Lock-In Amplifier (SPLIA1-A).

Hall Effect Probe
This Low Field Probe allows the students to determine experimentally the magnetic field inside the solenoid.

Liquid Cell (Pair)

Additional Glass Rod

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