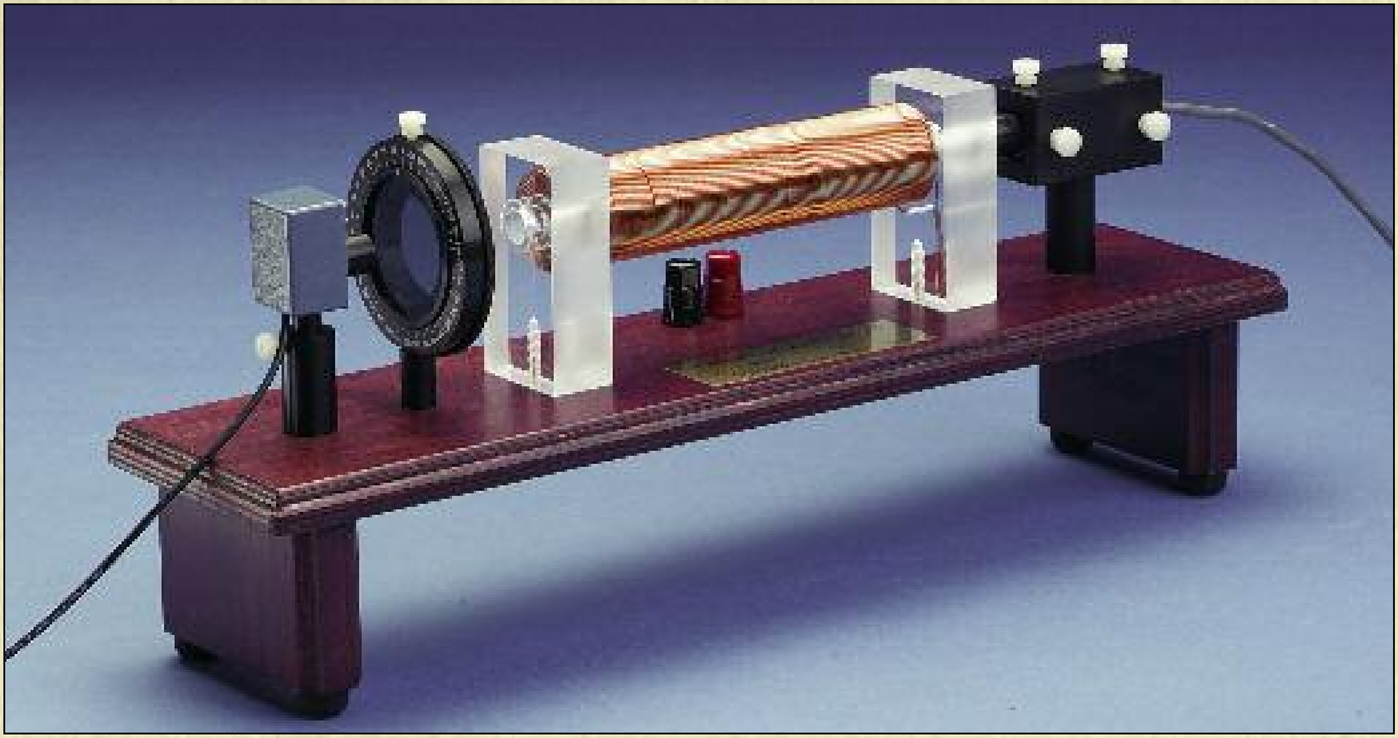
FARADAY ROTATION



Interaction of Light, Matter, and Magnetic Fields

While searching, in 1845, for experimental evidence that the forces in nature are all interconnected, Michael Faraday detected the rotation of the plane of polarization of light as it passed through transparent material placed in a static magnetic field. The effect he witnessed was extremely small, but as an exceptional experimenter, he was able to unambiguously identify the phenomenon which continues to bear his name, "Faraday Rotation."

TeachSpin decided to build the FR1-A for a number of reasons, not the least of which is the fact that this phenomenon was the first experimental evidence that light and magnetism were somehow connected. This is another of our "classic" experiments. Faraday rotation has important practical applications in modern optical communications. It is the basic physical phenomenon behind optical isolators. These devices allow light to propagate in only one direction, usually through an optical fiber, and thus attenuate unwanted reflections caused by impedance discontinuities. Isolators are also important when lasers are the light source, because light reflected back into the laser can cause havoc with the laser itself.

Faraday rotation also appealed to TeachSpin as an experiment to show off the capabilities of our Signal Processor/Lock-In Amplifier, SPLI-1A. For most materials, in reasonable laboratory magnetic fields created by a solenoid, there is only a tiny rotation of the plane of polarization. However, using SPLI1-A and AC lock-in detection, it is possible to measure polarization rotations as small as 10^{-5} radians.

The unit has a laser light source with an attached polarizer shown above on the right hand side. The four white thumb screws provide alignment adjustment for the laser. The optical detector, a photodiode with a 10k, 3k or 1k load resistor, is mounted in the blue metal box on the far left end. The analyzer is mounted in the calibrated rotation holder between the detector and solenoid. Calibration is in 5 degree increments.

THE INSTRUMENT

The apparatus, as described, consists of four basic parts; the light source, the solenoid (magnetic field source), the analyzer Polaroid and the optical detector.

The light source is a red laser diode operating at a nominal wavelength of 650 nm with an output power of about 3 mW. The laser requires a 4 volt, 40 mA regulated dc power supply which is not supplied with the unit. Although the laser output is about 60% polarized, the light is directed through a polarizing filter which increases its polarization to about 95%. The entire light source assembly is easily removed by releasing one thumb screw. This allows students to substitute other light sources to investigate the wavelength dependence of Faraday rotation.

The solenoid consists of 10 layers of #18 gauge double insulated wire with 140 turns/layer. The axial magnetic field at the center of the 15 centimeter long solenoid can be calculated from the expression:

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

where B is in mT and I in amperes. The sample provided with the unit is a 10 cm long, 5 mm diameter rod of special flint glass (Schott SF-59).

STUDENT EXPERIMENTS

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:

$$\alpha = vlB$$

where v is called the Verdet constant. For SF-59 at 650 nm, v = 23 rad/Tm.

The "standard" strategy for measuring this rotation is: with the magnetic field off, arrange the laser polarizer and the analyzer polarizer with their axes crossed at 90°, complete extinction; pass current through the solenoid; rotate the analyzer until extinction is again obtained; measure the angle of rotation.

Although finding the angle of Faraday rotation by "extinction" is conceptually obvious, it turns out to be a very poor experimental strategy. This fact can be discovered by the student, possibly with the help of some professorial prompting. For small angle Faraday rotation, $\Delta\theta$, students can theoretically demonstrate that the change in intensity of the light transmitted, ΔI, is given by

$$\Delta I = (constant)\,\Delta\theta \cos\theta \sin\theta$$

where θ is the angle, in radians, of the laser polarizer relative to the analyzer.

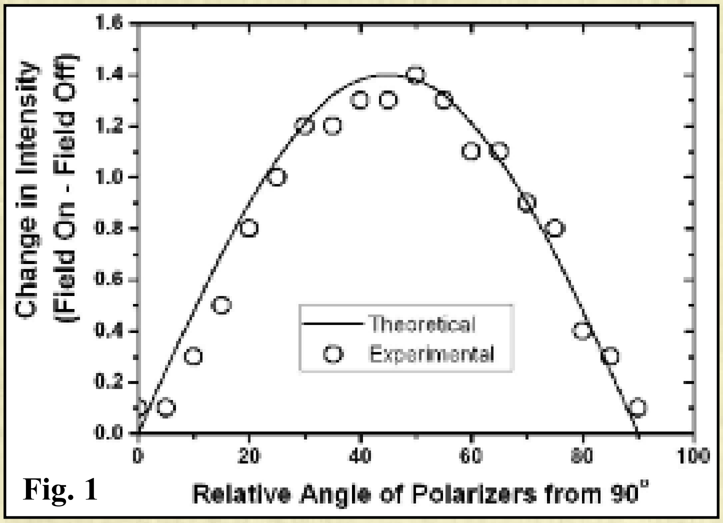


Fig. 1

A plot of this function, with the measured experimental points, is shown in Figure 1. Note that at extinction, there is no change in intensity for a small Faraday rotation. These measurements clearly show the optimum arrangement of the polarizers.

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 modulated at the AC frequency. Students can observe tiny rotations with this setup as well as determine the "best" relative angle of the two polarizers to observe the small rotation. They can compare these measurements with their theoretical analysis.

RECOMMENDED ACCESSORIES

Power/Audio Amplifier: to produce large AC magnetic fields and provide laser power
Signal Processor/Lock-In Amplifier: to observe rotations too small for direct observation
Glass Cell for Liquid Samples
Current Regulated Power Supply:
  Kenwood PR36, 3 amps, 36V DC

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