

TeachSpin's Faraday Rotation A Conceptual Introduction to the Experiment

Nowadays students are told at an early age that light is an electromagnetic wave, but there was once a time when there was *zero* experimental evidence that light had anything to do with either electricity or magnetism. And the first wave theories of light (such as Fresnel's displacement theory) were in fact mechanical, rather than electrical, in character. It took the genius of Michael Faraday to find empirical evidence proving that light and magnetism were connected; this fact helped lead to the 19th century's 'grand unification' of electricity, magnetism, and light into our modern electromagnetic theory of radiation.

What did it take for Faraday to make his 1845 observations? It took his philosophical conviction of the 'unity of the forces of nature', which provided him a motivation for looking. It took a sample of high-lead-content optical glass that Faraday himself had synthesized years earlier. It took the right geometry: sending light through that glass propagating *parallel* to a static magnetic field. And it took the right diagnostic technique: detecting not a deflection or attenuation of the light, but instead a *rotation of the plane of polarization* of linearly-polarized light.

So nowadays, Faraday rotation is relatively easy to demonstrate. Since the polarization-rotation is observed to scale linearly with sample length and with magnetic field, there is the motivation to use a rather long sample, and such a sample fits neatly into a solenoidal geometry that can give a modestly large field over a considerable length. Since there are important industrial applications of Faraday rotation, there are also commercially-available glasses which exhibit much more Faraday rotation than would be seen in ordinary soda-lime or optical glass. And the use of a laser source automatically produces the collimated, and linearly-polarized, light beam that gets sent through the sample.

TeachSpin's version of a Faraday-rotation demonstration uses a red diode-laser source (of wavelength near 650 nm, and output power < 1 mW) which offers a mm-wide beam of pure linear polarization. It comes with a sample of SF-57 optical glass of 10 cm length, which fits into a solenoid about 15 cm long. It also has a Polaroid serving as 'analyzer' to detect the polarization rotation that occurs. Finally, it includes a photodetector, which makes possible some detection techniques more subtle, and more sensitive, than the mere use of the 'extinction condition' for detecting the rotation of polarization.

Here are some things that you can accomplish using this apparatus:

1. You can demonstrate that Faraday rotation occurs – using a 0-3 A dc power supply, you can show that the 'extinction position' for the Polaroid analyzer rotates, by order 4°, upon application of the current. You can show that reversing the current reverses the rotation.
2. You can send the light beam to the photodetector rather than a screen, and test the Law of Malus over a full 360° rotation, first without, then with, the current flowing in the solenoid.

3. From such results, you can show why you will get the greatest sensitivity to small Faraday rotations by operating not right at, but instead at 45° away from, the extinction condition.
4. Having seen this, you can use rather modest *alternating* currents in the solenoid to create at the photodetector an *ac* signal, quantifiably related to Faraday rotation. This makes possible a rather sensitive detection technique of oscilloscope detection.
5. If you have access to a lock-in amplifier, you can detect such ac-signal evidence of Faraday rotation with superb sensitivity and noise-rejection, providing a fine example of the use, and usefulness, of lock-in detection techniques.
6. With guidance from TeachSpin documentation, you can relate the Faraday rotation you have observed to the 'Verdet constant' for your glass sample, and (better still) you can learn how such a Verdet constant can be derived from the dispersion (the wavelength dependence of the index of refraction) of the optical glass you're using.
7. You can use the 'liquid cell' available from TeachSpin, and your choice of techniques 4. or 5. above, to detect the much smaller Faraday rotation exhibited by a *water* sample.

Faraday rotation is not just a theoretical curiosity or an electromagnetism demonstration; it is also the basis of Faraday modulators and Faraday isolators. You can discuss it in the context of the optical rotation that is exhibited by samples made with chiral molecules (sugar water, for example). That, in turn, could let you talk about molecular handedness or parity inversion, or instead the curious time-reversal properties exhibited by optical rotation vs. Faraday rotation. Or perhaps your students would prefer to indulge in some applied physics, by transmitting music optically, via Faraday-modulation of a laser beam. However you use this apparatus, you are sure to enrich your students' experience of physics by introducing them to the tactile and visual reality of a demonstration of a famous effect of such historical significance.