FARADAY EFFECT ATTACHMENT
Cat. No. 79646

Assembly: Set up either electromagnet with the Tapered Pole Faces as shown in the photographs at left. The stationary Polaroid fits over one of the hollow bolts. It is fastened in position with the set screw. The hollow bolt with the shoulder is used to hold the analyzer dial in place on both magnets. The bent washer fits around the shoulder before the bolt is fixed in place. As shown in the photograph, the vernier on the Laboratory Electromagnet is held in place by inserting it in the slot at the top of the column and then tightening up the Allen head bolt. The vernier is already in place on the Research Aluminum Foil Electromagnet.

There are two glass samples included with the Faraday Effect Attachment: (1) One extra dense flint (marked EDF); (2) One light flint (marked LF). They are placed between the pole faces with the plastic support resting on the tapered portion of the pole faces. Any frosted incandescent lamp can be used as a light source. A bright light source is desirable since greater contrast of light levels is helpful in obtaining accurate data.

If the unmetered Variable *DC* Power Supply is used (cat. no. 79642), an accurate DC ammeter must be placed in series in the circuit. The metered DC Power Supply (cat. no. 79551) can be used without a meter, but for the best results, an accurate *DC* ammeter should also be placed in series with the circuit. If the Research Aluminum-Foil Electromagnet is used, no meter will be necessary since the meter included with the Solid State Filtered Power Supply is quite sufficient. It will be beneficial to use the AD Voltage Regulator with either of the small Power Supplies.

Procedure: Before beginning the experiment, turn the Power Supply to one half power **(note: the original power supply has been replaced with a slightly smaller power supply that only goes up to 2 Amp)** and let the magnet warm up for about half an hour. Then turn the power supply control back to zero and up to full power several times. Next with the power supply at full power and then at zero power, rotate the analyzer dial for most complete extinction of light passing through the sample. Check to see whether the ruled portion of the analyzer dial is adjacent to the Vernier scale in both cases. If the ruled portion of the analyzer dial is not adjacent to the Vernier scale at both the zero and 100 positions of the power supply dial, then the dial should be held fixed while the analyzer is rotated to a new orientation that will permit the ruled portion of the analyzer dial to be adjacent to the Vernier scale for light extinction at both the zero and 100 settings of the power supply dial.

In order to obtain the most accurate reading of the analyzer dial for extinction of light passing through the magnet, the analyzer dial should be rotated back and forth through the extinction position with decreasing amplitude until, in the opinion of the experimenter, the optimum position for light extinction has been attained. For monochromatic light the appearance of the light on both sides of the extinction position will be similar in hue. However, for a white light source the light transmitted by the sample will appear magenta on one side of the extinction position and blue on the other. At the extinction position the sample will appear to transmit either no light or a very dark midnight blue, depending on surrounding illumination conditions and the sensitivity of the eye of the observer. With care the analyzer dial readings for a given sample at a given value of the magnetic field can be reproduced with a probable error of six minutes of arc (or one-tenth of a degree).

Experiment 1: **Observation of the Faraday Effect; Determination of Verdet Constant for Light Flint Glass**

With the light flint glass sample in place set the current to its maximum allowed value. Record the current reading of the ammeter, Rotate the analyzer to the optimum position for light extinction and record the analyzer angle dial reading. Repeat this step several times. Performing this step five times enables one to arrive at a good average value. Again record the value of the current. If the current reading has changed by more than 5 milliamperes, the magnet was probably not sufficiently warmed up and the preceding steps should be repeated. In descending steps of about 100 milliamperes of current repeat the steps above, including obtaining analyzer angle dial readings with no current flowing through the magnet coil.

The amount of rotation of the plane of polarization of the light is expressed by the formula:

$$\theta = VH\ell$$

where V is the Verdet constant, θ is the angle of rotation of the plane of polarization, H is the magnetic field strength, and ℓ is the thickness of sample traversed. Typically θ is measured in minutes of arc, H in oersteds, and ℓ in centimeters.

Using the values of the angles measured, the values for the magnetic field at which these angles were measured as obtained from a sufficiently precise plot of magnetic field strength versus current in the electromagnet, and the value for the thickness of the sample as measured with a vernier caliper, values for the Verdet constant at the different current settings can be derived as follows:

$$\left(\theta_f - \theta_i\right) = V\ell\left(H_f - H_i\right)$$

Where θ_i is the angle measured from the analyzer angle dial with no current in the electromagnet, and H_i is the remanent field in the sample with no current in the electromagnet (H_i is taken as equal to zero if the sample is removed when θ_i is measured). θ_f is the angle measured at some current value and H_f is the magnetic field at the corresponding current value. Thus

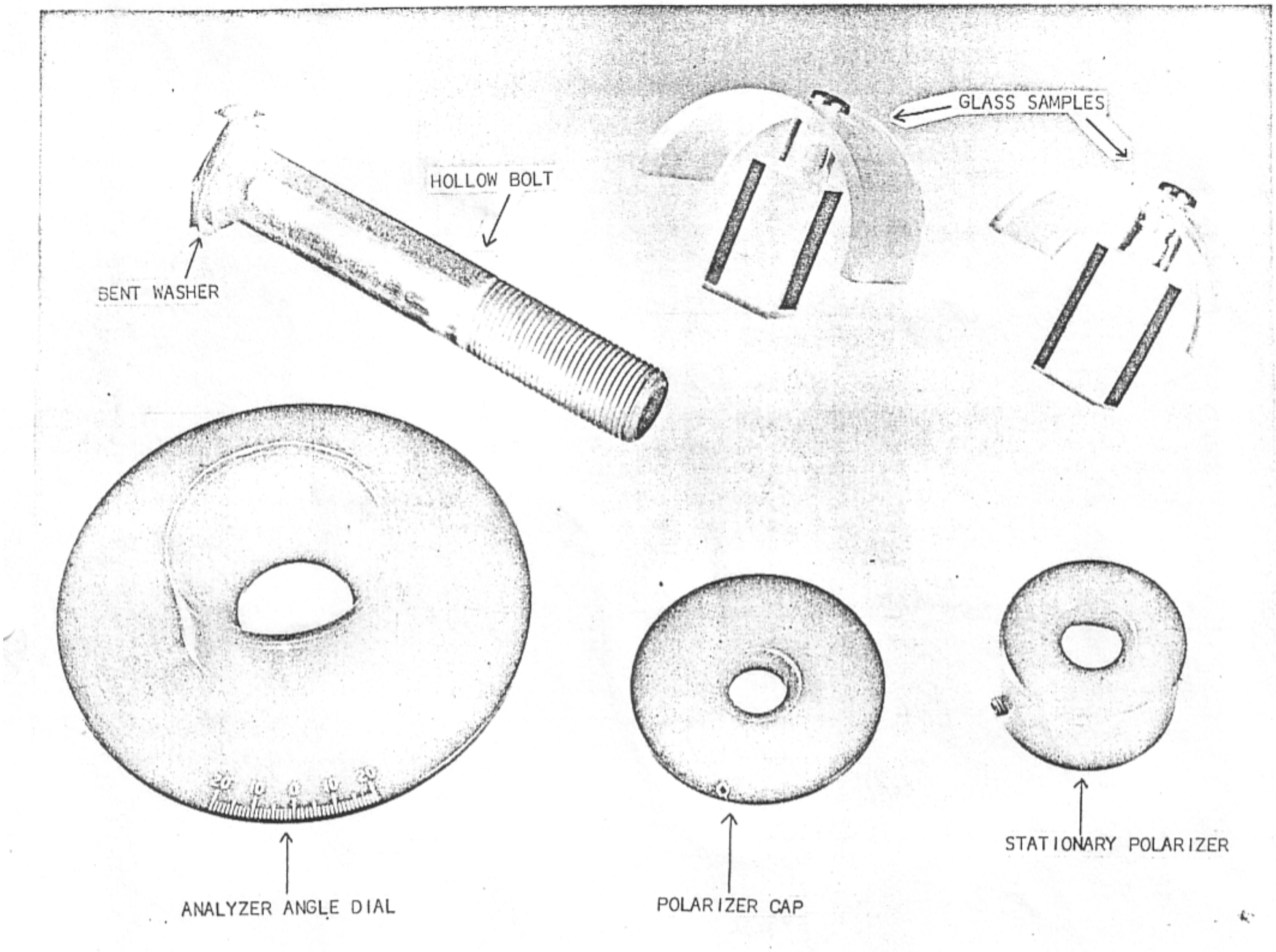
$$V = \frac{(\theta_f - \theta_i)}{\ell(H_f - H_i)}$$

Within the limits of error of the experiment V should be constant for the various values of θ_f and H_f derived from the experiment.

EXPERIMENT 2: **Observation of the Faraday Effect; Determination of Verdet Constant for Extra Dense Flint (Heavy Flint) Glass**

With the extra dense flint glass sample in place proceed as outlined in Experiment 1. A sample of data taken and its reduction is shown below for an extra dense flint glass sample using a white light source. Note: The old Atomic Laboratories Laboratory Electromagnet was used. This had a weaker field than the new Laboratory Electromagnet

I (amp)		1.616	1.428	1.240	1.050	0.880	0.702	0.520	0.350	0.160	0
H(oers.)		2950	2680	2380	2050	1735	1410	1070	760	405	110
Trial 1 θ (deg)		5.05	4.75	4.20	3.65	3 65	3.25	3.15	2.40	2.19	1.70
Trial 2		4.95	4.60	4.35	3.90	3.50	3.25	2.90	2.65	2.10	1.65
Trial 3		5.15	4.65	4.45	4.05	3.70	3.20	3.05	2.35	1.95	1.70
Trial 4		5.00	4.60	4.20	4.10	3.50	3.30	2.80	2.50	2.10	1.70
Trial 5		4.90	4.80	4 40	3.85	3.60	3.45	2.90	2.35	2.10	1.80
θ (deg) avg.		5.01	4.68	4.32	3 95	3.59	3.29	2.96	2.45	2.08	1.71



FARADAY EFFECT ATTACHMENT COMPONENTS

From the table above the remanent field H_i = 110 oersteds with an average angle dial reading at zero current θ_i = 1.71 degrees. The path length through the glass ℓ = 0.730 inches. A tabulation of the data analysis is as follows:

I (amp)	$(\theta_f - \theta_i)^\circ$	Probable Error in $(\theta_f - \theta_i)^\circ$	$(H_f - H_i)$ oersted	$V = \dfrac{(\theta_f - \theta_i)}{(H_f - H_i)}$ min/cm/oer.
1.616	3.30	0.031	2840	0.0376
1.428	2.97	0.033	2570	0.0374
1.240	2.61	0.044	2270	0.0372
1.050	2.24	0.052	1940	0.0374
0.880	1.88	0.052	1625	0.0376
0.702	1.58	0.065	1300	0.0395
0.520	1.25	0.105	960	0.0421
0.350	0.74	0.166	650	0.0369
0.160	0.37	0.119	295	0.0406

The weighted average value of the Verdet constant and its probable error are V = 0.0382 ± 0.0009 minutes per cm per oersted.

Discussion: Michael Faraday discovered in 1845 that when a transparent isotropic medium, liquid or solid, is subjected to a strong magnetic field, it becomes optically active, producing a rotation of the plane of polarization of a plane polarized light beam passing through the medium parallel to the direction of the magnetic field. Subsequently the phenomenon has been observed in many solids liquids and gases. Some typical values for solids and liquids are shown in the table below.

Value of Verdet Constant in Minutes of Arc per Oersted per Centimeter for λ = 5893 Å

Substance	Temp °C	V
Water	20	0.0131
Glass (phosphate crown)	18	0.0161
Glass (borium crown)	18	0.0220
Glass (light flint)	18	0.0317
Glass (extra dense flint)	18	0.0442
Glass (heavy flint)	18	0.0608
Glass (very heavy flint)	18	0.0888
Carbon Disulfide, CS_2	18	0.0430
Phosphorus, P	33	0.1326
Quartz (perpendicular to axis)	20	0.0166

For gases the density must also be specified. At S.T.P. the value at the Verdet constant is about one thousandth that for condensed substances.

NOTE: THE PREVIOUS THREE SETS OF FIGURES WERE OBTAINED BY USING AN OLD ATOMIC LABORATORIES MAGNET. THE NEW RESEARCH ALUMINUM-FOIL ELECTROMAGNET OR THE LABORATORY ELECTROMAGNET WILL PRODUCE DIFFERENT RESULTS DUE TO HIGHER FIELDS.

Theory

The Faraday effect is closely associated with the Zeeman effect. The rotation due to a magnetic field may be expressed in terms of e/m the ratio of the charge on the electron to its mass. The existence of two velocities, and hence of two indices of refraction, for the oppositely rotating circular components can be thought of as being due to the addition and subtraction of a small precession angular velocity ω_p to the large angular velocity ω of the components. This precession is due to the field's effect on the orbital motion of the electrons. According to the theory of Lorentz, an electron moving in its orbit about an atomic nucleus should suffer, when in an external magnetic field, a change $\pm\Delta\nu$ in its frequency of orbital motion. This change in frequency is given as

$$\Delta\nu = \frac{eH}{4\pi mc},$$

Where *e* is the charge on the electron in e.s.u. *H* is the field strength in oersteds, *m* the mass of the electron in gms, and c the velocity of light (cm/sec). Since $\omega = 2\pi\nu$ it follows that

$$\omega_p = \frac{e}{2mc}H \text{ (radians per sec.)}$$

Also

$$\omega = \frac{2\pi c}{\lambda}.$$

The time required for the faster component of velocity v_+ to traverse a centimeter of the medium is $1/v_+$ while that for the slower component is $1/v_-$ Hence the angle in radians through which the plane of vibration is turned is

$$\theta = \frac{1}{2}\omega\left(\frac{1}{v_+} - \frac{1}{v_-}\right).$$

But

$$v_+ = v + \omega_p \frac{dv}{d\omega} \text{ and } v_- = v - \omega_p \frac{dv}{d\omega}$$

so that

$$\theta = \frac{1}{2}\omega\left(\frac{1}{v + \omega_p \frac{dv}{d\omega}} - \frac{1}{v - \omega_p \frac{dv}{d\omega}}\right)$$

which reduces to

$$\theta = \frac{1}{2}\omega\left(\frac{-2\omega_p \frac{dv}{d\omega}}{v^2 - \omega_p{}^2\left(\frac{dv}{d\omega}\right)^2}\right)$$

Since both ω and $\frac{dv}{d\omega}$ are very small compared to v, to a good approximation

$$\theta = \frac{-\omega\omega_p}{v^2}\frac{dv}{d\omega}.$$

Substituting in this equation the values of ω, ω_p and $d\omega$ obtained from previous equations in this discussion, and the values of *v* and d*v* from *n* = *c*/*v*, where *n* is the index of refraction, it follows that

$$\theta = -\frac{e}{2mc^2}H\lambda\frac{dn}{d\lambda} \text{ radians per centimeter of medium traversed.}$$

Thus the Verdet constant is given by

$$V = \frac{e\lambda}{2mc^2}\frac{dn}{d\lambda} = \frac{1}{\ell}\frac{\partial\theta}{\partial H}$$

This relationship was originally deduced empirically by Becquerel. The derivation above is due to Larmor (J. J. Larmor, "Aether and Matter," Cambridge University Press 1900, p. 352).

For glass in the visible region of the spectrum generally the magnitude of $\frac{dn}{d\lambda}$, the derivative of the index of refraction with respect to wavelength, decreases with increasing values of the wavelength of light faster than λ, so that the Verdet constant decreases with increasing wavelength of light.

References:

pp 596 - 598, F. A. Jenkins and H. E. White, "Fundamentals of Optics," McGraw-Hill 1957

pp 312 - 315, G. S. Monk, "Light Principles and Experiments," McGraw-Hill 1937

pp 557 - 561, G. Bruhat "Optique, Masson at Cie, Paris 1959

part I, "Handbuch der Experimentalphysik Band 16 1 Tell," Akademische Verlagsgeselischaft M.B.H. 1936

FARADAY EFFECT NOTES:

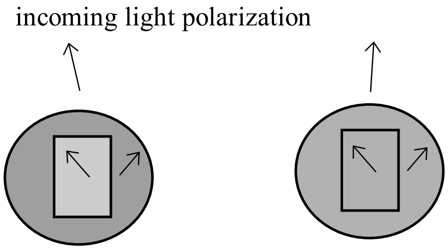
In the Faraday effect you have linearly polarized light traversing the specimen. After it has traversed the specimen, the light will have rotated its plane of polarization. (There is all the physics in what is happening to rotate the light. This note, however, is dealing with details of the experiment)

The chore is to measure the rotation of the plane of polarization. Note that for polarized light of intensity I_0, if it passes through a polarizer whose polarizing angle is at an angle t, then the intensity afterwards will be $I = I_0\cos^2(t)$. (And the light coming out will be polarized in the new direction, t). This leads to the effect that if the polarizer is at 90° to the polarization of the incoming beam, then no light will pass. (cos(90°)=0)

The analyzer in this system has two regions of polarizers, whose polarization rotations are not the same. For example, they could be a right angles to each other. If polarized light impinges on the analyzer, the intensity of the light that makes it through each section, will depend on the angle the incoming polarization vector makes with the angle of polarization of the region.

In the figure below, I am showing light coming towards your eye, (sort of) showing the direction of polarization of the incoming light, and the polarization angle of the regions in the analyzer.

If the incoming polarization angle has equal angles with respect to each region, then the intensity will be constant across the analyser. If there is ANY deviation from the exact middle, then one region will be lighter or darker than the other.



IF the incoming light changes its polarization vector, you will have to rotate the analyser by that same amount in order to get back to the condition that there is constant intensity across it. THEN the amount you rotate will be?? (the exact amount that the incoming light changed its polarization vector from previous measurement).

So, should you try to make the analyzer have the highest contrast between the two regions or the minimum contrast (constant intensity)? Highest contrast (assuming that you make the same region dark with respect to the other) would also give you the change in the polarization vector of the incoming beam.

However, your eye is very sensitive to the PRESENCE of contrast, and can tell the difference between when there is a teeny difference in contrast, and when there is none. However, you are much less sensitive to deciding the amount of contrast in two situtations that have contrast, but are similar. So, I would go for the situation that you are determining between no contrast, and some.

OTHER NOTES:

Although I don't just want you to blindly follow this set of directions. Please read first the Faraday effect handout, and think through the experiments. However, a way to proceed could be as follows.

Note that what you want in the end is the variation in polarization as a function of magnetic field (T(B)). However, you control a current on the magnet. So, if you need to know the magnetic field at each point, you either have to

a) measure the magnetic field each time you change the field
b) find how the magnetic field varies with current.

The positive point about a) is that you have a B measurement that is directly associated with the data point of the T. The disadvantage is that you have to keep taking the sample in and out., and turning the magnetometer off and on.

The positive point about b) is that you can do a calibration fairly quickly by measureing the magnetic field as you step through the current. The disadvantage is that you need to make sure that each time you step through the current, that the megnetic field generated is the same, (or at least close enough that you can feel confident that you know the magnetic field to withing a reasonable amount of error.

If you do a) then, the steps would probably be something like this.

i) Start at the highest current suggested (allow stabilization)
ii) Take sample out and measure the magnetic field with the magnetometer

iii) Put the sample in and measure T (try 5 times to measure T)
iv) Decrease current through magnet by an amp or two
v) go to step ii and repeat until get to low amperage

Your table might look like this

B(Kgauus)	Amp (magnet)	T (deg)try1	T try 2	Etc to try 5

Repeat for other samples.

For the b) option, the steps would probably be something like this.
i) Start at the highest current suggested (and wait to stabilize)
ii) Measure magnetic field with magnetometer
iii) Decrease current through magnet by an amp or two
iv) Go to step ii and repeat until get to low amps (maybe even 0)
the table for this might look lik

B (Kgauss)	Amp (magnet)

The steps above give you calibration that you can use later to determine magnetic field from current. Then you would measure T for sample
i) Start at the highest current suggested (and wait to stabilize)
ii) Measure T 4 or 5 times
iii) Decrease current through magnet by an amp or two
iv) Go to step ii and repeat
the table for this might look like

Amp (magnet)	T(deg)	T(deg)	T(deg)	T(deg)	T(deg)	T(deg)

Then, because you need to be able to prove that the magnetic field is similar even when you come to the same amp, repeat the calibration of the magnetic field.

Then go to the next sample…