

LAB 9: OPTICAL MATERIALS AND DISPERSION I

Measuring the refractive index of a material is one of the most fundamental optical measurements, and one of the most practical. The refractive index of glass is a function of the wavelength of light, a property known as dispersion. A plot of refractive index vs. wavelength is called a dispersion curve. Different glass types exhibit different dispersion curves, as shown below.

Experiment: Dispersion

In this lab, you will determine the dispersion curve of a light flint optical glass, similar to LF6. Experimentally, you will use a spectrometer to measure the minimum angle of deviation for light at different wavelengths passing through an equilateral prism. From these angles, you can calculate the refractive index at each of these wavelengths, and plot the dispersion curve.

In the next lab, you will learn how to use the Abbe refractometer to identify unknown samples of glass. The Abbe refractometer is an instrument also routinely used in modern chemistry labs for identifying unknown chemical compounds.

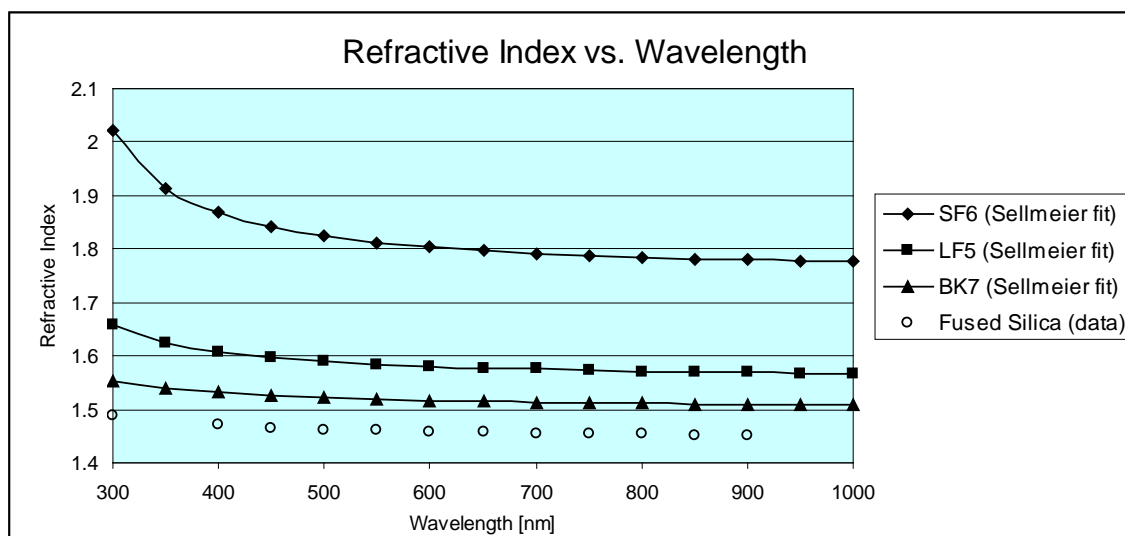
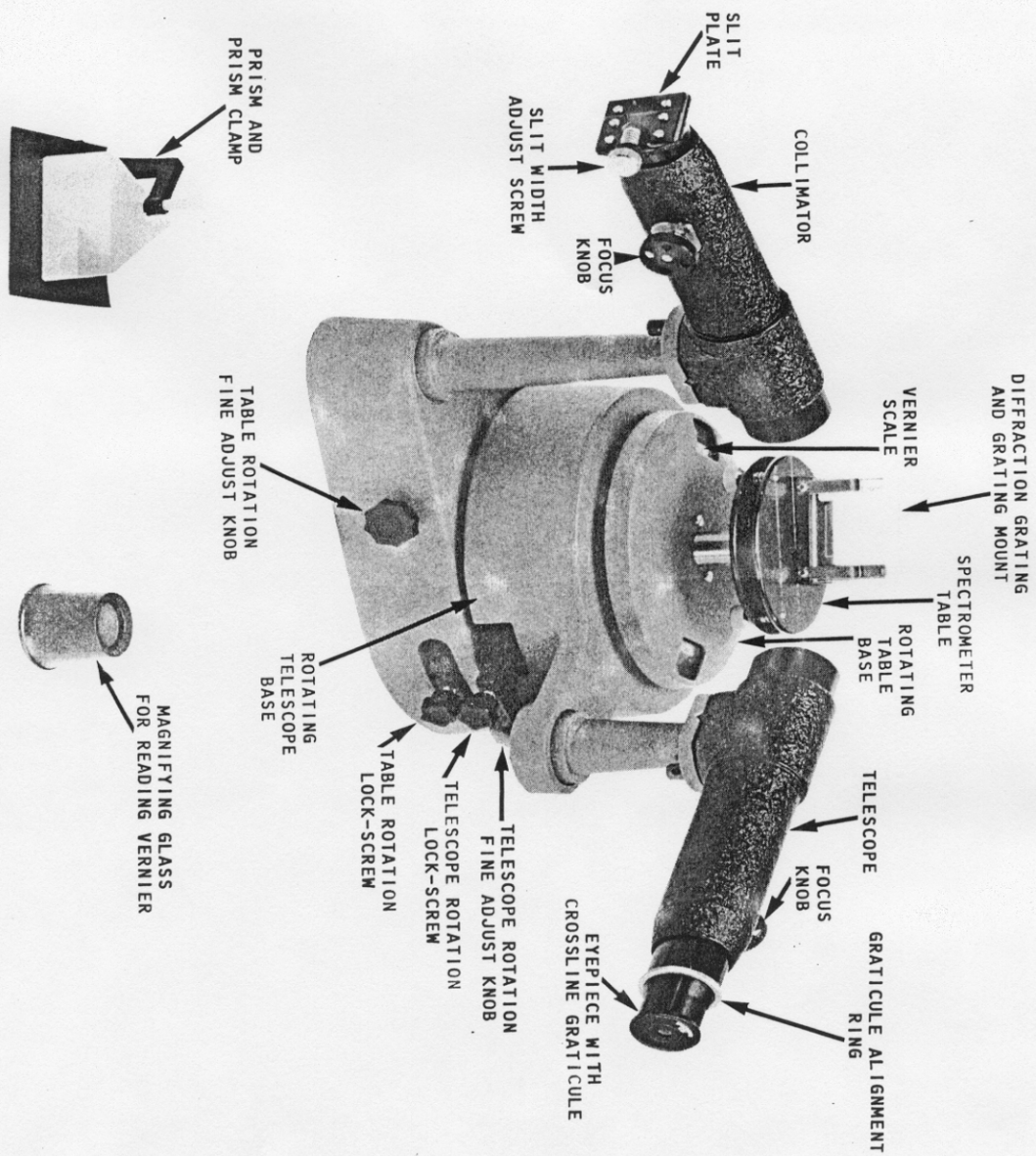


Figure 9.1. Refractive index vs. wavelength for various glass types.



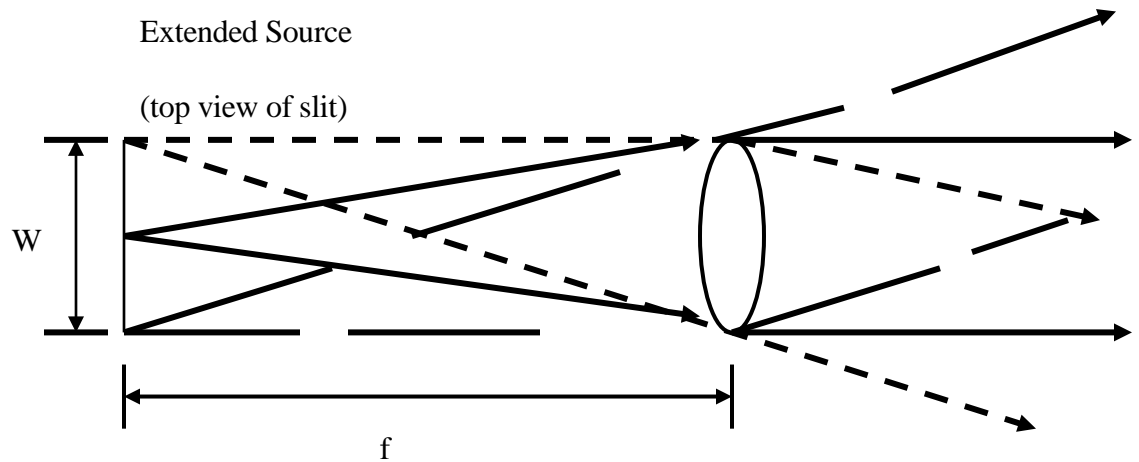


Figure 9.3. Rays from any object point emerge parallel to each other, but not parallel to rays from other object points.

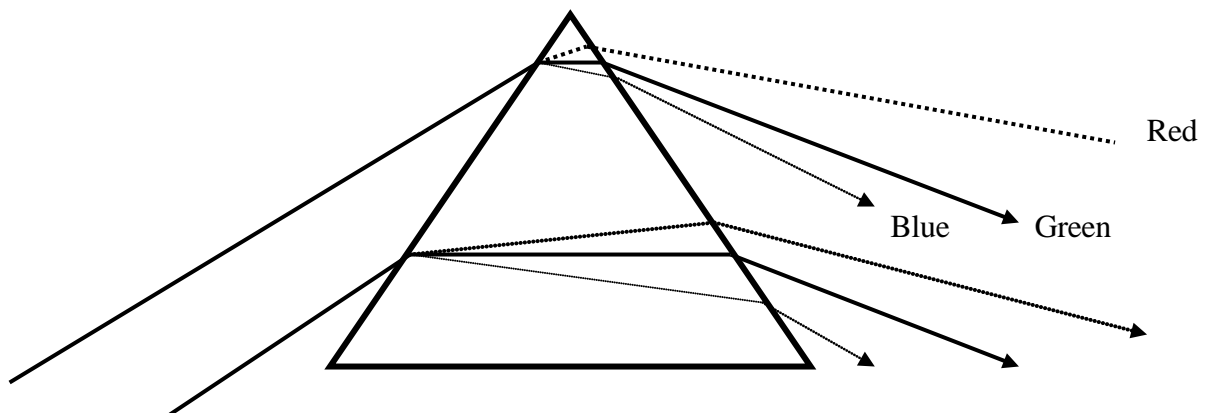


Figure 9.4. Refraction of collimated beams through a prism.

The Spectrometer and its Adjustment:

We wish to measure the angular deviation produced by a prism. The spectrometer is one convenient way to do this. The spectrometer consists of a slit, collimator, viewing telescope, arrangement for measuring the angle between collimator and scope, and a table for the prism. (Fig. 9.2). The slit and collimator produce parallel light. Rays from a point of an extended source at the front focal plane of a lens will emerge parallel to each other but not parallel to the rays from other object points (Fig. 9.3). By narrowing the slit the beam becomes more parallel, however, the intensity decreases. You will learn in physical optics how to calculate the optimum width of the slit. Here you need only adjust the slit so that it is as narrow as possible while the intensity is adequate. If this seems confusing, do not worry. It is an easy adjustment and will be obvious when you do the experiment.

With the slit well adjusted, an essentially parallel beam will emerge from the collimator. This will be deviated and dispersed by the prism (Fig. 9.4). All rays of a given wavelength exit the prism parallel to each other. However, each wavelength is deviated by a slightly different angle. The telescope is adjusted to image parallel rays. Rays parallel to the telescope's axis will image on the crosshair reticle. The ray bundle through a properly adjusted spectrometer is shown in Fig. 9.5.

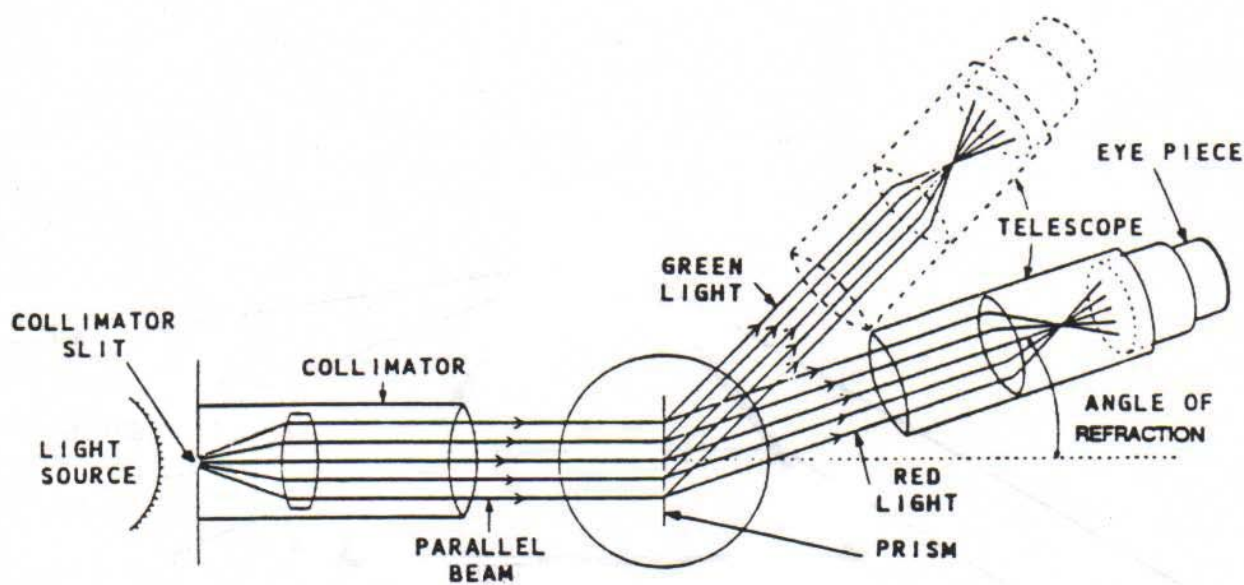


Figure 9.5. Collimated rays through the spectrometer.

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Minimum Angle of Deviation:

This is a very accurate and commonly used method. The angular deviation of a ray traversing a prism depends on the refractive index, prism apex angle A , and the angle of incidence I (Fig. 9.6).

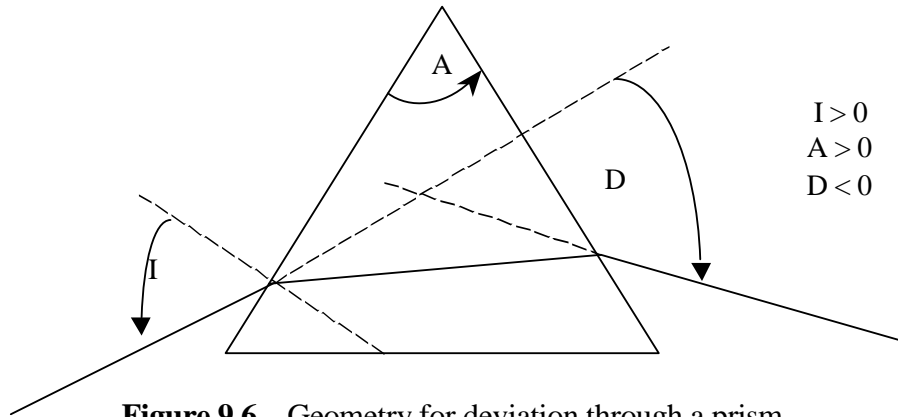


Figure 9.6. Geometry for deviation through a prism.

According to the following formula, corrected for our sign convention, (Hecht, *Optics* 2nd Ed. p. 164):

$$-D = I + \text{Arcsin}[(\sin A)(n^2 - \sin^2 I)^{1/2} - (\sin I)(\cos A)] - A \quad (9.1)$$

A graph of this equation for a given prism (i.e. a given n and A) is similar to a concave-up parabola. Thus, there is a point where the deviation angle D is a minimum. The minimum angle of deviation is related to the index by (see Hecht, p. 165):

$$n = \frac{\sin\left[\frac{(A - D_{\min})}{2}\right]}{\sin\left(\frac{A}{2}\right)} \quad \text{for } I > 0, A > 0, D < 0 \quad (9.2)$$

Note that because n is wavelength-dependent, so is the minimum angle of deviation. To use this technique, one makes a prism out of the material to be measured and aligns it on an autocollimating goniometer (an accurately divided rotation stage with collimated light source designed for alignment). Our spectrometers are essentially this type of instrument. By measuring the prism apex angle A and experimentally finding and measuring $D_{\min}(\lambda)$, $n(\lambda)$ may be calculated. In this lab, the prism tip and tilt angles have been pre-aligned to save time. The angle of incidence, I , is what is to be varied experimentally.

Procedure

You will align and use the spectrometer. There are several critical adjustments which have been preset to save time in this lab. Therefore, **DO NOT ADJUST ANYTHING ON THE SPECTROMETER UNLESS INSTRUCTED TO DO SO.**

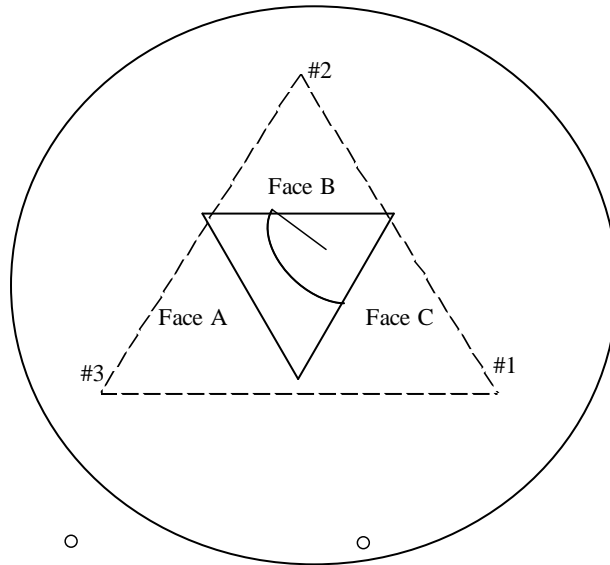


Figure 9.7 Prism table of the student spectrometer

Step 1--Focus the Eyepiece on the Crosshair Reticle

Plug in the Gaussian eyepiece. Adjust the eyepiece by sliding the eye lens until the crosshairs are in sharp focus. When the crosshairs appear sharp, move your head slightly back and forth. The image should not move. If it does, readjust until the crosshairs are stationary for small head movements (no parallax). *Each individual will adjust the eyepiece differently, so once you have done this the same person should proceed with the remaining steps.* Then let the next group member try.

Step 2—Focus the Telescope at Infinity (Autocollimation, or “AutoReflection”)

Refer to Fig. 9.7. Rotate the prism table (**NOT THE PRISM ITSELF**) until face A is perpendicular to the axis of the collimator. Gently **lock the prism table in place** with the locking screw. Rotate the telescope until it appears to be normal to one of the prism faces, either B or C. Look through the eyepiece and slowly rotate the telescope until you see an image of the crosshairs (light reflected from the prism). The crosshair reticle itself will appear illuminated, and the image reflected in the prism will appear black.

- Why?

Fine tune the focus of the telescope until the image of the crosshairs is in sharp focus. At this point the telescope is focused at infinity.

- Explain.

Step 3—Measure the Apex Angle of the Prism

Look through the eyepiece and slowly fine tune the telescope rotation until the vertical crosshair and its image overlap. At this point the axis of the telescope is normal to the face of the prism. DO NOT ADJUST OR CHANGE THE PRISM ANGLE IN DOING THIS. Record the position of the telescope using the scale readings in both windows.

Rotate the telescope around to the second face of the prism. As you just did, slowly rotate the telescope until the vertical crosshair and its image overlap. Again, record the position of the telescope using the scale readings in both windows.

Calculate the telescope rotation angle, T , as the difference in both sets of scale readings. Take the average of both values of T to compensate for (possible slight) machining errors in the prism rotation table. Calculate the prism apex angle A using the formula:

$$A = 180^\circ - T \quad (9.3)$$

Step 4—Find the Minimum Angle of Deviation

Turn off the Gaussian eyepiece and turn on the Argon source (labeled “A”). Unlock the prism table and rotate it until face A is roughly parallel to the axis of the collimator (position face A so it is on the right side of the collimator when looking along the collimator toward the source). Leave the prism table unlocked for the remainder of the experiment.

Rotate the telescope counterclockwise toward face A and look for the various spectral lines. They will appear as colored images of the vertical source slit. You will also have to rotate the prism table to see them. Find the brightest red line (696 nm) and position it in the center of the telescope’s field of view.

Slowly rotate the prism table so that the red line moves to the left in the field of view. At the same time move the telescope to track it, keeping the line in the center of the field of view. At the point of minimum angle of deviation, the red line will appear to stop moving left, remain stationary for a second, then begin moving to the right, similar to a planet moving in retrograde motion. This should all happen within a small enough angle so that the telescope will no longer have to be rotated. The prism is at minimum deviation when the image appears stationary. At this point, lock the prism table in place, so that it can’t move (before the next step). Fine tune the telescope rotation so that the red line and vertical crosshair coincide. Record one of the scale readings.

Step 5—Measure the Angular Position of the Source

Rotate the telescope so its axis is parallel to the axis of the collimator. At this point you should see the purple image of the vertical source slit in the field of view. Rotate the telescope until its vertical crosshair is centered on the purple image of the undeviated source. Record the angle using the same side of the scale as in the previous step.

Step 6—Calculate the Minimum Angle of Deviation

Take the difference in angle readings of the spectral line and the source to calculate the minimum angle of deviation. Use the equation for minimum angle of deviation to calculate the refractive index of the prism at 696 nm.

Step 7—Measure the Complete Dispersion Curve

Replace the Argon source with the Mercury source (labeled Hg). Unlock the prism table. Repeat steps 4, 5 and 6 for the following spectral lines:

SPECTRAL LINE COLOR	SOURCE	WAVELENGTH
violet	Hg	405 nm
blue	Hg	436 nm
green	Hg	546 nm
orange (doublet)	Hg	578 nm
red	Ar	696 nm

- Plot the refractive indices you measured vs. wavelength (in nm). This is known as a dispersion curve. Each glass type has its own characteristic dispersion curve, published in the form of coefficients to a curve-fit of the measured refractive index data. Assuming that the prism you measured is a type of flint glass, use the following dispersion information for LF5 glass to calculate the expected refractive index values at the wavelengths you used. Plot these data on the same graph with your measured values.

$$n^2(\lambda) - 1 = \frac{B_1\lambda^2}{(\lambda^2 - C_1)} + \frac{B_2\lambda^2}{(\lambda^2 - C_2)} + \frac{B_3\lambda^2}{(\lambda^2 - C_3)} \quad (9.4)$$

Coefficients: $B_1 = 1.280356$

$B_2 = 0.163505$

$B_3 = 0.893930$

$C_1 = 0.009298$

$C_2 = 0.044913$

$C_3 = 110.493685$

(**NOTE:** wavelengths must be entered in microns in this formula)

- How accurate would the measurement be if you could determine both A and D to 1 second of arc? HINT: See Lab #1 from 201L for the formula.