

## EXPERIMENT 6 DISPERSION OF A GLASS PRISM

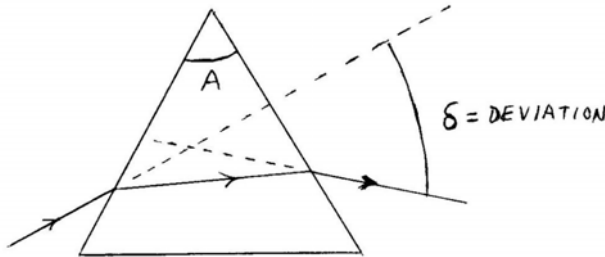
### I. THEORY

The deviation,  $\delta$ , of a ray of light as it passes through a prism is defined as the angle between the direction of the ray which enters the prism and the direction of the ray which leaves the prism after two refractions. This is shown in the diagram in section IV.

It is found experimentally that, as the prism is rotated, the deviation goes through a relative minimum. Using Snell's Law and differential calculus, it may be shown that the minimum deviation occurs when the ray passes symmetrically through the prism. This result provides a very precise way to measure the refractive index of the prism. Combining this result with Snell's Law and some trigonometry, we obtain the equation

$$n = \frac{\sin\left(\frac{1}{2}(A + \delta_m)\right)}{\sin\left(\frac{1}{2}A\right)}.$$

In this equation  $A$  is the apex angle as shown in the diagram in below, and  $\delta_m$  is the angle of minimum deviation. We will measure both of these angles to the nearest minute of arc.



The common observation that a prism separates white light into the spectrum of colors proves that the refractive index varies with wavelength. The mathematician Cauchy is credited with devising the following equation for the variation of the refractive index with wavelength in the visible region:

$$n = a + \frac{b}{\lambda^2}$$

The angles mentioned above are measured quite precisely with the help of a spectrometer, which is shown in a diagram in section IV. Rays of light from a source pass first through an adjustable slit, and then through a collimator tube containing a lens to render the rays parallel. Then they pass through the prism, which rests on the prism table. After being refracted by the prism, the rays enter the telescope. The experimenter, looking into the eyepiece of the telescope, sees an enlarged image of the slit, in the same plane as the crosshairs.

Both the prism table platform, which supports the prism table, and the telescope may be rotated about a vertical axis which passes through the center of the spectrometer. The collimator may not be rotated. Angles are measured, using either of the two windows, with a vernier scale, which is adjacent to the main scale. When the telescope is moved, the main scale moves with it; when the prism table platform is moved, the vernier scale moves with it. THEREFORE, WHEN MEASURING THE ANGLE OF ROTATION OF THE PRISM TABLE PLATFORM RELATIVE TO THE COLLIMATOR, THE TELESCOPE MUST NOT BE MOVED. ALSO, WHEN MEASURING THE ANGLE OF ROTATION OF THE TELESCOPE RELATIVE TO THE COLLIMATOR, THE PRISM TABLE PLATFORM MUST NOT BE MOVED.

## II. LABORATORY PROCEDURE

**WARNING:** Avoid touching the sides of the prism. If oil from your fingers gets on the sides of the prism, it will cause unwanted refraction. Handle the prism near the corners or by the top and bottom.

**WARNING:** The following precautions should be followed in the use of the spectrometer:

- Lift the spectrometer only by the base, never by the collimator, telescope, or prism table. Avoid jarring it.
  - Tighten the telescope and prism table platform locking screws only enough to ensure that no motion will occur; excess tightening may warp the metal parts.
1. Clamp the helium discharge tube in the spectrum tube power supply, so that the metal clamps contact the metal ends of the tube. Raise the tube to its highest level. (Any power supply with a round base must be raised by placing it on a small wooden box.) Place the tube and power supply near the middle of the laboratory table and plug it in. Do not touch the tube or terminals when the power supply is plugged in, because of HIGH VOLTAGE. Place the spectrometer on a large inverted wooden box. Look through the telescope at the discharge tube and adjust the eyepiece so that the crosshairs are in sharp focus.
  2. Orient the spectrometer so that the collimator points away from the edge of the laboratory table. Place the spectrum tube just beyond the slit of the collimator. Make sure that the slit is open. Loosen the telescope clamping screw, swing the telescope so that it points directly at the collimator, and clamp it. Rotate the knurled ring of the telescope to bring the slit into sharp focus. The crosshairs should remain in focus.
  3. Record the prism number. Place the prism on the prism table. Push side BC **against the post** and clamp the prism in place.
  4. Adjust the height of the prism table so that the center of the prism is at about the same height as the central axes of the collimator and telescope.

5. Move the telescope so that it is about  $90^\circ$  from the collimator, as estimated by eye, and clamp it in place. Orient the spectrometer so that the telescope eyepiece is near the edge of the table. Place the spectrum tube just beyond the collimator slit. Loosen the clamp of the prism table platform. While looking through the telescope, slowly rotate the prism table platform until the reflected image of the slit is seen, using light reflected from either of the two sides of the prism adjoining the apex angle A. Clamp the prism table platform in position. Narrow the slit. Focus the telescope on the slit image. Use the prism table platform tangent screw to place the slit image precisely on the intersection of the crosshairs. Check to see that both the telescope and the prism table platform are clamped in position. Choosing window A or window B to read, whichever is more convenient, determine where the zero mark of the vernier scale (NOT the negative one mark) is located, relative to the main scale. Record the number of degrees and half-degrees so indicated. Next, locate which division of the vernier scale is most nearly aligned with a division of the main scale. Record the number of minutes of arc so indicated. Combine the two readings, remembering that one degree equals 60 minutes. For example, 128.50 combined with 24' yields  $128^\circ 54'$ . To minimize reading errors, it is recommended that two or three people make each reading independently and silently, and then compare results. Give the final angle in degrees and minutes only, **with no decimal points**. Record which window, A or B, you read, and cover the other window with a piece of paper.
6. Keeping the telescope fixed in position, rotate the prism table platform until light from the slit reflects from the OTHER side of the prism adjoining the apex angle A. As in the previous step, place the image precisely on the intersection of the crosshairs. Read THE SAME window as in the previous step. The difference between the two readings should be  $120^\circ \pm 30'$ . If it is not, recheck both readings. (If the scale passed through zero while the prism was rotated, add  $360^\circ$  to the smaller reading before subtracting.)
7. Move the telescope to a position about  $130^\circ$  to  $140^\circ$  from the collimator. Move the entire spectrometer so that the telescope eyepiece is near the edge of the lab table. Rotate the prism table platform so that light from the slit is refracted through the prism, as in the diagram in section IV. The incident ray should make an angle of about  $50^\circ$  to  $55^\circ$  with the normal line, or about  $35^\circ$  to  $40^\circ$  with the face of the prism. (A spectrum may also be seen using light at normal incidence to the first face of the prism, but this light reflects internally from the base of the prism, and does not show minimum deviation.) Move the telescope until you see the spectral lines. Each line is an image of the slit formed by light of a particular wavelength.
8. Widen the slit so that both bright and faint lines of the spectrum can be seen. Compare the spectrum to the diagram in section IV. Identify each line of the spectrum by means of its color, its brightness, and its relative position. The three lines of shortest wavelength are near the ultraviolet boundary, and may not be seen by some students.
9. Move the telescope so that line 447.1 nm is near the center of the field of view. While looking at this line, rotate the prism table platform a small amount. If the deviation increases, rotate the platform in the opposite direction. Follow the line with the telescope and continue rotating the platform until minimum deviation is reached; that is, the line

reverses direction. Clamp the telescope and the prism table platform in position. Narrow the slit. Using the telescope tangent screw, set the crosshairs precisely on the line. Take the reading in window A or window B. Record which window you used, and cover the other window with a piece of paper.

10. Leaving the prism in place, move the telescope so that it is opposite the collimator.
  - a. If enough light goes around the prism to allow an image of the slit to be seen, proceed to step C.
  - b. If a slit image cannot be seen, remove the prism table with the prism clamped securely in place on the table.
  - c. Move the telescope to place the crosshairs precisely on the slit, and clamp it in place. Record the reading in the *same* window as in step 10.
  - d. If the prism table and prism were removed in step B, replace them.
11. Repeat the two preceding steps for lines 471.3, 501.6, 587.6 and 667.8 nm. Step 10 must follow step 9 for each line, since rotating the prism table platform changes the scale readings even if the telescope is not moved. Calculate the minimum deviation for each of the wavelengths. The minimum deviation should decrease continuously as the wavelength increases; redo any measurements where this is not the case. Return the prism to its box.
12. Store the spectrometer as follows: Clamp the prism table platform in place. Move the telescope in the CW direction, as seen from above, as far as it will go, and clamp it in place. Also rotate the knurled ring of the telescope to make the telescope as short as possible. Place the collimator and telescope into the storage case before the base.
13. Unplug the spectrum tube power supply and use a paper towel to remove the hot spectrum tube.

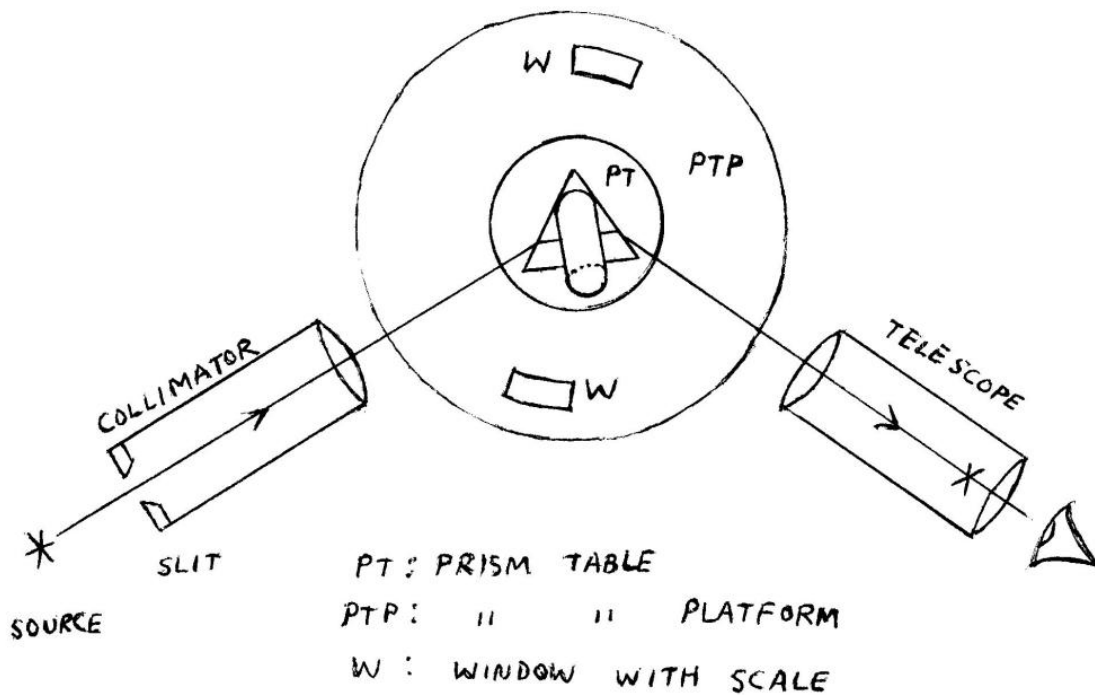
### III. CALCULATIONS

In your calculations, express all angles in degrees and minutes, do not use decimals.

1. Calculate the apex angle  $A$  of your prism.
2. Make a table containing the wavelength, the angle of minimum deviation, and the index of refraction. Through error analysis, the index of refraction can be shown to have 4 significant figures.
3. Plot a graph of refractive index versus wavelength. Draw a smooth curve through the points.
4. Convert the wavelengths to  $\mu\text{m}$ . Make a table containing the quantities wavelength, wavelength<sup>-2</sup>, and index of refraction.

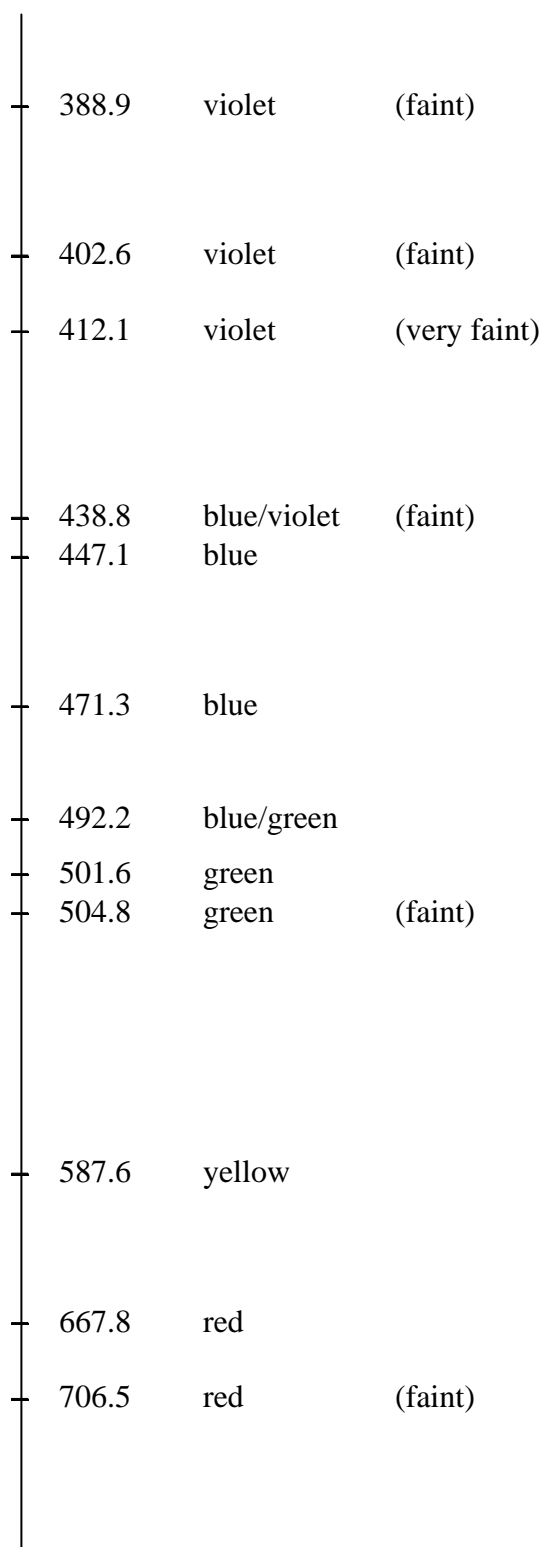
5. Plot a graph of index of refraction versus wavelength<sup>-2</sup>. Draw the straight line which best fits the plotted points. Does the graph appear linear?
6. Use the Method of Least Squares to determine the slope and intercept of the graph of step 5. Include a calculator or computer printout, or list the four sums of page I-10, observing the warning regarding rounding errors on that page.
7. From the slope and intercept of your line, what are the constants **a** and **b** for your prism?

#### IV. SPECTROMETER DIAGRAM



## HELIUM SPECTRUM

(wavelengths in nm)



388.9	violet	(faint)
402.6	violet	(faint)
412.1	violet	(very faint)
438.8	blue/violet	(faint)
447.1	blue	
471.3	blue	
492.2	blue/green	
501.6	green	
504.8	green	(faint)
587.6	yellow	
667.8	red	
706.5	red	(faint)