LAKE FOREST COLLEGE
Department of Physics

Physics 115 Experiment #3: Refraction and Reflection of Light v2 Spring 2025

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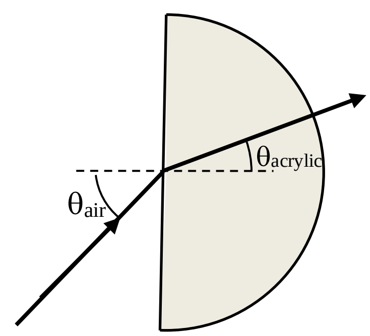
Table number:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Study the law of refraction and locate some reflected images.

Background
For many purposes, the behavior of light may be described in terms of *rays* (directed line segments). The laws of light rays involve the angles of the rays at surfaces. The *angles of incidence, reflection,* and *refraction* are measured from a *normal* (perpendicular) line to the surface.

Part I: Law of Refraction.



1. Place a transparent semicircular acrylic plastic disk in a horizontal position about 13-15 cm in front of the laser ray box (center beam only, $\lambda = 650$ nm), on top of a piece of polar graph paper. The point of incidence should be at the origin and at the center of the semicircle so the disk is concentric with the graph paper circles. **Take an overhead picture of your apparatus and paste it here. Label the important pieces. Include a caption.**

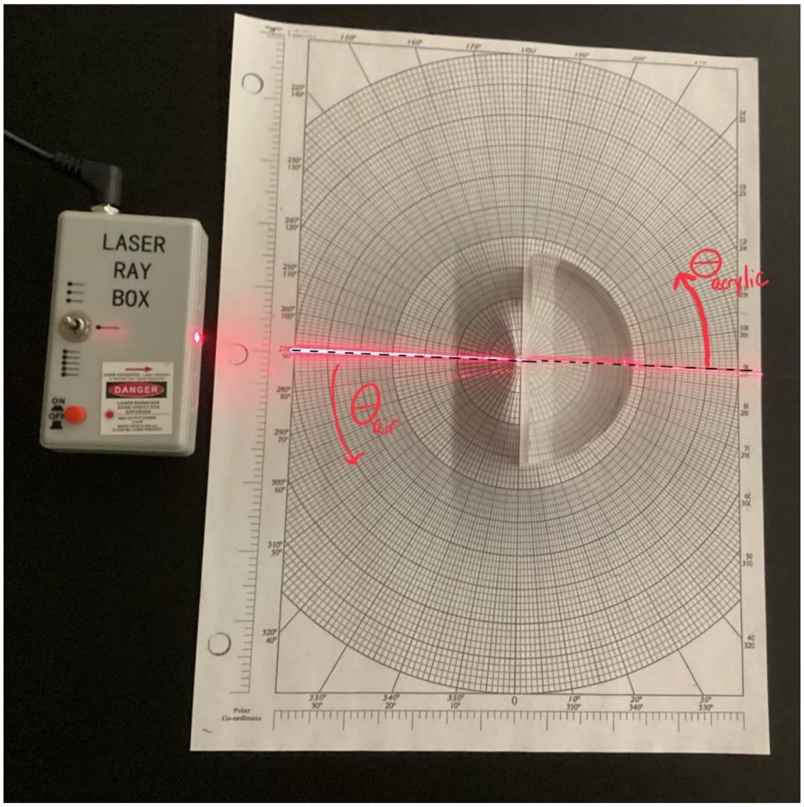


Figure 1. Refraction Apparatus. The laser is generated by an ASL Laser Ray Box. Θ_{air} is the angle between the laser and the flat face of the prism. In the example above Θ_{air} is 0°. $\Theta_{acrylic}$ is the angle of the laser coming out of the curved face of the prism. In the example above $\Theta_{acrylic}$ is 0°.

2. Mark the incident and transmitted ray for angles of incidence between 20° and 80° in steps of 10°. Record the angle of incidence (in air) and the corresponding angle of refraction (in acrylic) in the *Excel* table. In the corresponding columns, calculate the sine of the angle of incidence and the sine of the angle of refraction for each trial. Remember that when using the sine function in *Excel* the angles should be in radians. Use the RADIANS() function to convert from degrees to radians. **Place the data table here. Include a table caption.**

θ_{air} (°)	$\theta_{acrylic}$ (°)	$\sin(\theta_{air})$	$\sin(\theta_{acrylic})$
20	13.5	0.342	0.233
30	20	0.500	0.342
40	25.5	0.643	0.431
50	31	0.766	0.515
60	36	0.866	0.588
70	39.5	0.940	0.636
80	41.5	0.985	0.663

Table 1. Refraction Data. $\Theta_{acrylic}$ was measured at six different $\Theta_{air,}$ 20°, 40°, 50°, 60°, and 70°. The largest $\Theta_{acrylic,}$ of 39.5° coincided with the largest $\Theta_{air,}$ of 70°. The average difference between the Θ_{air} was 10° and the average difference between the $\Theta_{acrylic}$ was 4.7°. The sin values were calculated using sin(radian(value)).

3. Snell's Law predicts that the incident and refracted angles are related according to:

$$n_{\text{air}} \sin\theta_{\text{air}} = n_{\text{acrylic}} \sin\theta_{\text{acrylic}}$$

   where n is called the index of refraction of the material. For air, $n_{\text{air}} = 1.00$. Use Logger Pro to plot $\sin\theta_{\text{air}}$ (vertical axis) versus $\sin\theta_{\text{acrylic}}$ (horizontal axis).

4. Explain how a proportional fit ($y = Ax$, under "curve fit"— NOT a linear fit) of your data will yield n_{acrylic}. **Perform this fit and place a copy of the graph here. Include a caption.**

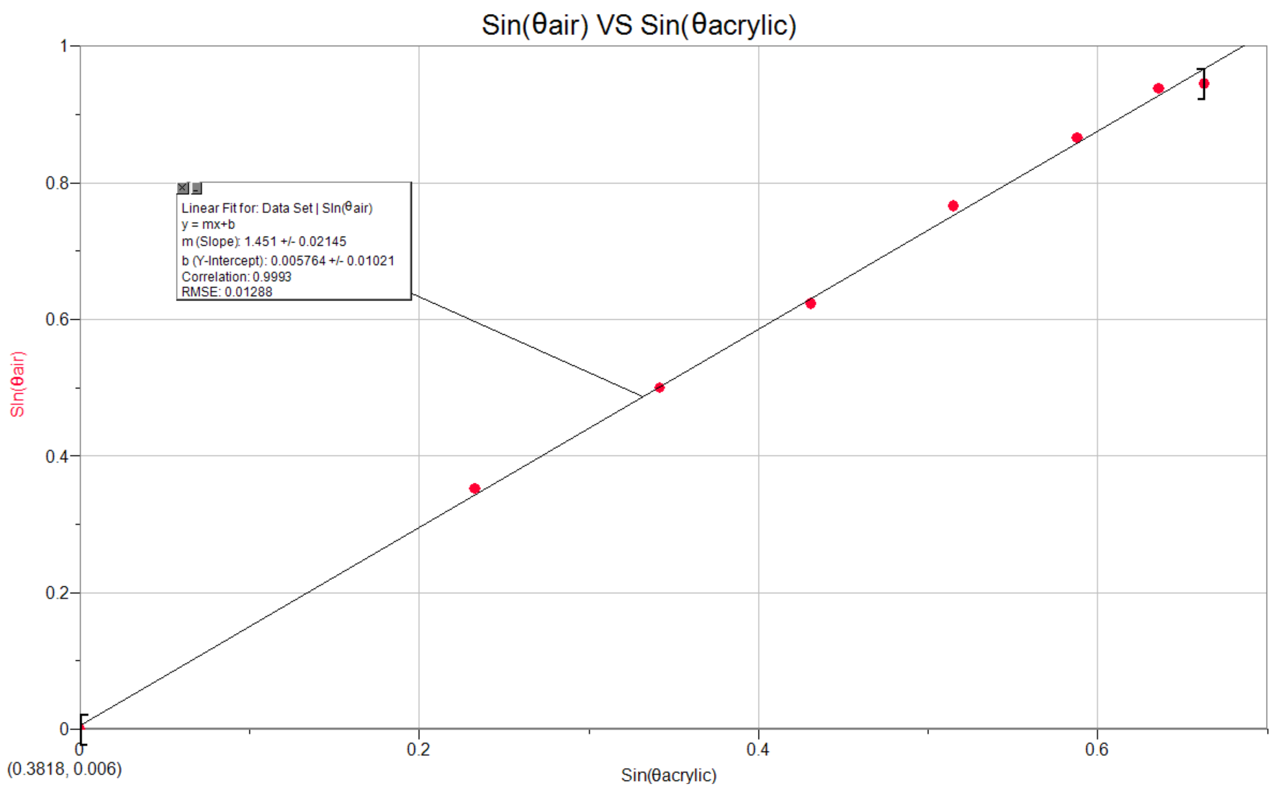


Figure 2. Refraction Graph. **Sin($\Theta_{acrylic}$)** is on the x axis and sin(Θ_{air}) is on the y axis. Since n_{air} is approximately one and n_{air} sin(Θ_{air}) = $n_{acrylic}$ ($\Theta_{acrylic}$), the slope of the line, 1.451 is equal to $n_{acrylic.}$ The uncertainty of the slope, 0.02145, is the absolute uncertainty of $n_{acrylic.}$

5. Record the uncertainty in the index o refraction of acrylic and calculate its relative uncertainty. Use the ratio test to compare your result to the accepted value of $n_{\text{acrylic}} = 1.49 \pm 0.01$. **Place the comparison table here. Include a caption.**

Experimental from graph		
$n_{acrylic}$	$\delta n_{acrylic}$	rel. unc.
1.451	0.021	1.45%
Accepted		
$n_{acrylic}$	$\delta n_{acrylic}$	rel. unc.
1.49	0.01	0.67%
	Ratio Test	
	1.26	

Table 2. Refraction Comparison Table. Accepted values were given in the experiment. The experimental from graph values were taken from a LoggerPro graph made with the sin of $\Theta_{acrylic}$ and Θ_{air}. The slope of the line and its uncertainty were the $n_{acrylic}$ and $\delta n_{acrylic}$. The calculated $n_{acrylic}$ agreed with the given accepted value according to the ratio test.

Part II: Critical Angle.

6. Place the transparent semicircular acrylic plastic disk in a horizontal position about 8-10 cm in front of the laser ray box (center beam only, $\lambda = 650$ nm), on top of a piece of polar graph paper. The point of incidence should be on the curved surface of the dish and the exit ray should be at the center of the flat surface, located at the origin of the graph paper. **Draw a schematic diagram and paste it here. Label the incident angle. Include a caption.**

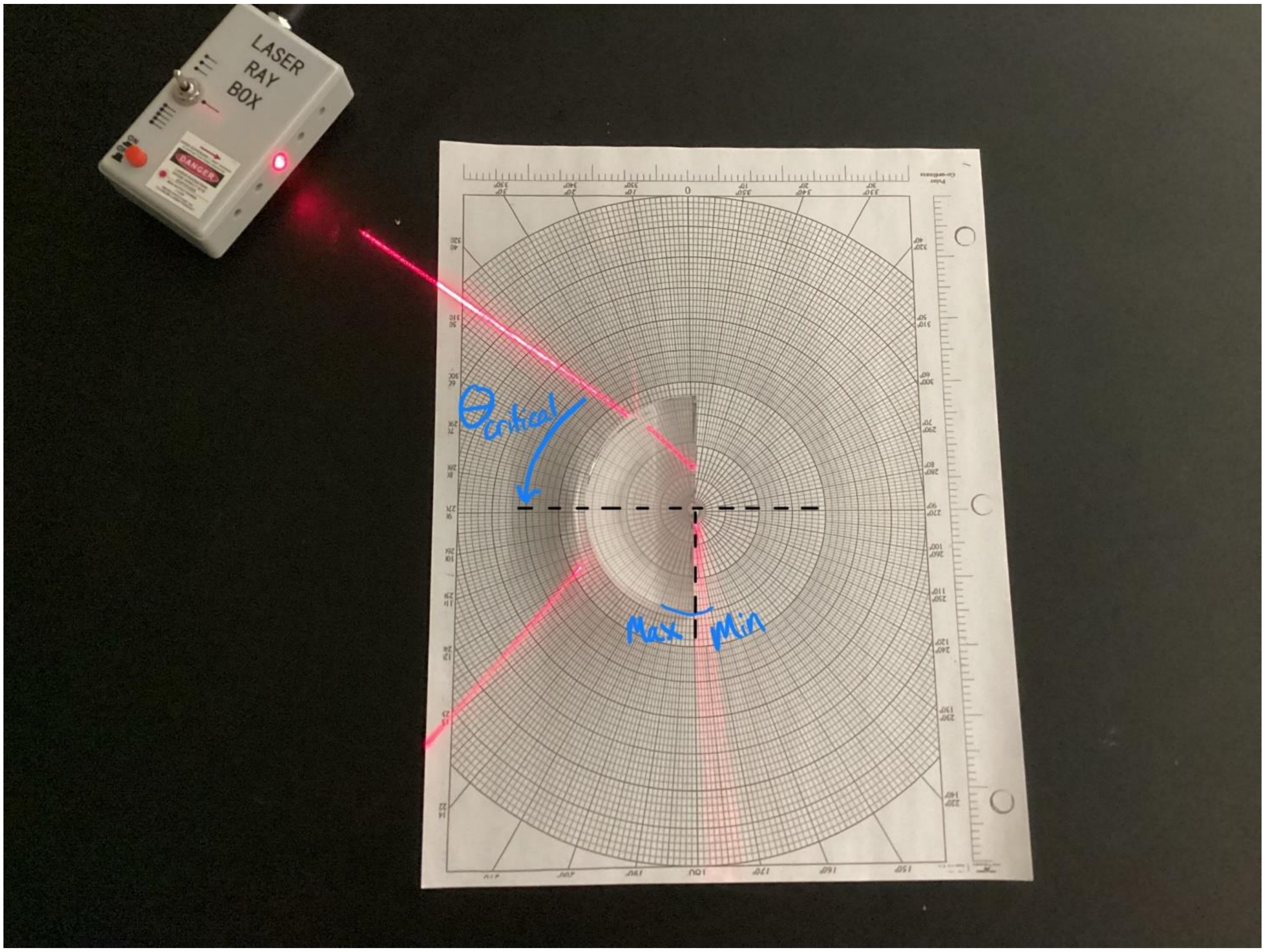


Figure 3. Critical Angle Diagram. The laser was generated by an ASL laser ray box. Θ_{critical} is the Θ_{acrylic} angle where Θ_{air} is 90°. This is measured by taking the average of $\Theta_{\text{critical min}}$, where the laser is barely visible outside the prism, and $\Theta_{\text{critical max}}$, where the laser disappears into the prism.

7. Find the *critical angle* of incidence, at which light is *just barely* not transmitted from the flat surface, but rather completely reflected internally. At this critical angle in acrylic, $\theta_{\text{air}} = 90°$ and $\theta_{\text{acrylic}} = \theta_{\text{critical}}$, so

$$n_{\text{air}} \sin\theta_{\text{air}} = n_{\text{acrylic}} \sin\theta_{\text{acrylic}} \Rightarrow (1.00)\sin 90° = n_{\text{acrylic}} \sin\theta_{\text{crit}} \Rightarrow n_{\text{acrylic}} = \frac{1}{\sin\theta_{\text{crit}}}$$

8. Near the critical angle, the exit beam will widen. Estimate the maximum and minimum critical angle. Record these values in the spreadsheet.

9. Calculate $n_{\text{acrylic max}}$ and $n_{\text{acrylic min}}$. Average $n_{\text{acrylic max}}$ and $n_{\text{acrylic min}}$ to obtain $n_{\text{acrylic avg}}$. Half the difference of $n_{\text{acrylic max}}$ and $n_{\text{acrylic min}}$ is an estimate of the uncertainty of $n_{\text{acrylic avg}}$.

10. Use the ratio test to compare your result for $n_{\text{acrylic avg}}$ to the accepted value of $n_{\text{acrylic}} = 1.49 \pm 0.01$. **Place the table here. Include a caption.**

Part II

Experimental				
$\theta_{crit\ max}$ (°)	$\theta_{crit\ min}$ (°)			
43	42.5			
$n_{acrylic\ min}$	$n_{acrylic\ max}$	$n_{acrylic\ avg}$	$\delta n_{acrylic}$	rel. unc.
1.466	1.480	1.473	0.010	0.67%
Accepted				
		$n_{acrylic}$	$\delta n_{acrylic}$	rel. unc.
		1.49	0.01	0.67%
		Ratio Test		
		0.845		

Table 3. Critical Angle Comparison. $n_{acrylic}$ is calculated using the equation $n_{acrylic} = \frac{1}{\sin(\theta_{critical})}$. The average is the average between the min and max $n_{acrylic}$ values. The accepted values were given in the experiment. The experimental and calculated values agree according to the ratio test.

Part III: Single Image.

11. Mount a plane mirror upright with the shorter side going up. Place the mirror on top of a piece of rectangular graph paper. Place a rod (on a transparent plastic base) vertically 5 cm in front of the mirror. Make sure that the object rod faces the <u>reflecting (silver)</u> surface of the mirror, not the glass side.

12. Locate the *virtual image* of the rod by the *method of parallax*. That is, place a second rod behind the mirror located at the position of the image so that the image and the rod behind the mirror always line up as you move your head from side to side. **Take a picture of your apparatus that shows at least part of the image in the mirror and the second rod behind it. Paste that picture here with a caption**.

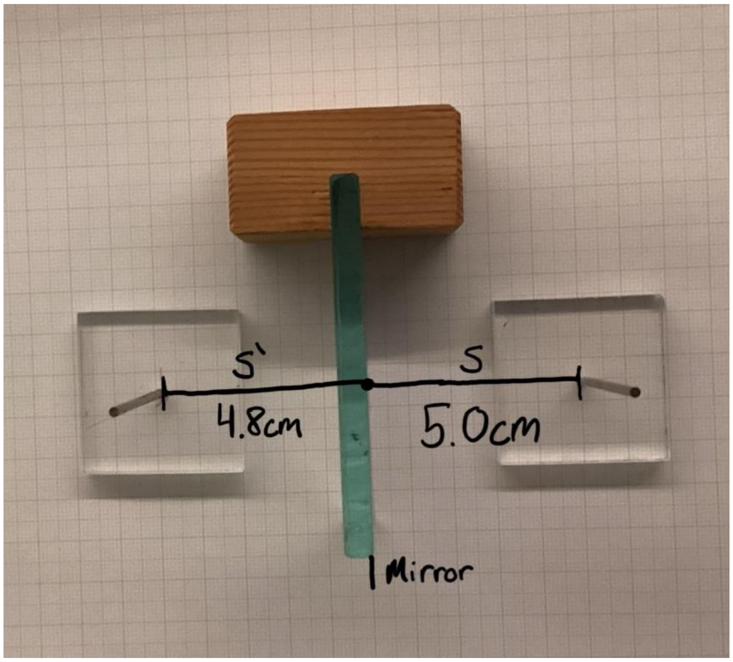


Figure 4. Single Image Apparatus. The Edmund Industrial Optics Surface Mirror was held by a wooden black. A pole was placed a distance, s, of 5cm away from the metallized side of the mirror. The location of the second poll was estimated distance, s', away from the metallized side of the mirror and visually lined up at all angles.

13. Carefully mark the object and image locations and the front surface of the mirror on your graph paper. **Place an image (photographed or scanned) of the graph paper here. Include a caption.**

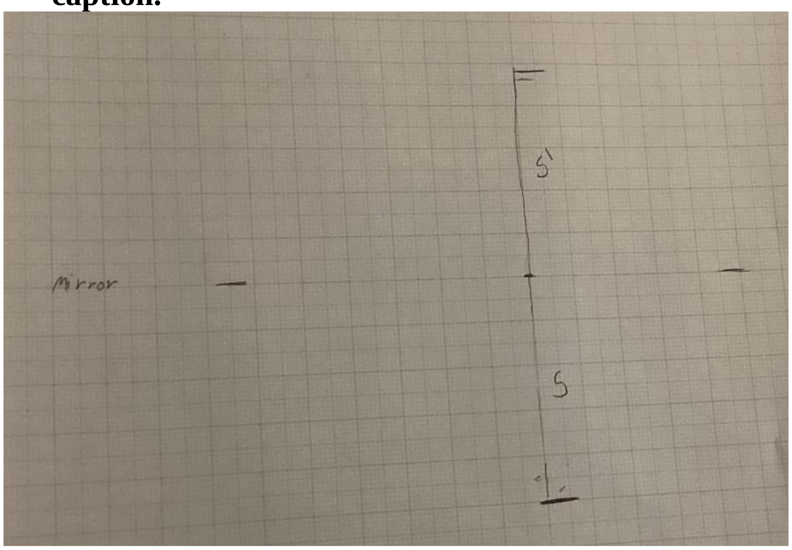


Figure 5. Single Image Graph Paper. S, 5.0cm, is the distance between the metallized mirror and the pole. S', 4.8cm is the distance between the metallized mirror and lined up pole.

14. Measure the distance from the object to the front reflecting surface (*s*) of the mirror and compare it to the distance from the image to the reflecting surface (*s'*) of the mirror. Try several nearby locations of the second rod to estimate the uncertainty in the image distance.

15. Compare *s* and *s'* by the ratio test. Also note the relative uncertainties. **Place the table here**. **Include a caption.**

Part III

s (mm)	δs (mm)	rel. unc.
50	2	4.00%
s' (mm)	δs' (mm)	rel. unc.
48	2	4.17%
	Ratio Test	
	0.5	

Table 4. Single Image Data. The s values were measured by eye from lining up poles. The absolute uncertainty came from the distance that the pole could be adjusted before the mirror image and the pole no longer lined up. The distances agreed according to the ratio test.

Part IV: Multiple Images.

16. Mount two plane mirrors upright with the short sides going up. Place the mirrors on top of a piece of rectangular graph paper. Make the mirrors adjacent and at right angles to each other.

17. Place a rod 3 cm in front of one mirror and 4 cm front of the other mirror.

18. Locate the <u>three images</u> by the method of parallax. Mark the object and image locations carefully. **Place an image (photographed or scanned) of the graph paper here. Include a caption.**

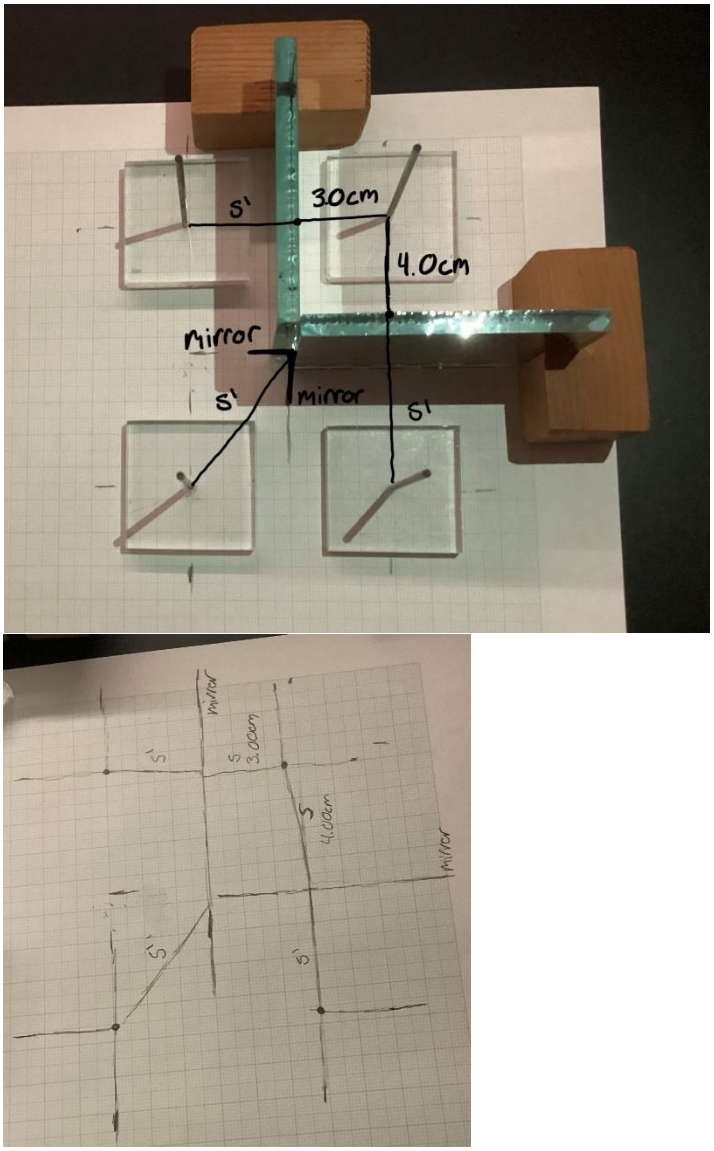


Figure 6. Multiple Image Graph Paper. Two Edmund Industrial Optical surface mirrors were lined up at a 90° angle. A pole was placed between the, 3.0cm away from the metallized one and 4.0cm away from the metallized surface of the other. Two poles were lined up to the mirror images from each image and one was lined up to the combined angle using parallax. The distances were equivalent to how far the original pole was from the mirror.

Analysis

19. **Write an analysis of the experiment here.** Make sure to include the following:
    - In part I, does Snell's law describe the data well? Does the measured index of refraction of acrylic agree with the accepted value? Estimate the uncertainty of your measured angles.
    - In part II did your measured index of refraction of acrylic agree with the accepted value?
    - In part III, did the image and object distances agree with each other? Estimate the uncertainty in the measured distance between the mirror and the image.

- In part IV, describe the location of the three images in relation to the two mirrors.

The ratio test between the experimental data and the accepted values agree, showing that Snell's law describes the data well because Snell's law was used to calculate the experimental values. If the law did not describe the data the experimental value of 1.45±0.02 would not agree with the accepted value of 1.49±0.01.

The experiment value of 1.47±0.01 agrees with the accepted value of 1.49±0.01 according to the ratio test.

The distance s, 50±2cm agreed with the distance s', of 48±2cm according to the ratio test. The uncertainty was estimated by determining the distance the pole could be moved before it became unaligned.

20. **Write a brief conclusion here.**

Different material refract light at different rates. This can be seen from the bending of the laser as it enters the acrylic prism. It would be interesting to see if different colors of light refract at different rates as well. Given that Snell's law does not account for color it might not but the refraction rate, n, could be different for different colors of light.

Reflections appear equal distance from the object that reflects them. The pole behind the mirror lines up with the mirror image when it is the same distance behind the reflecting surface as the reflected object is in front of the reflecting surface. The distance may have been slightly off because the glass coating the back of the mirror refracts the light differently than the air does.

Final remarks
Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Double check that your Excel sheet, graphs, and Logger Pro files are saved in your folder on the Team.

Clean up your lab station. Put the equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then log out of the computer. Ensure that the laptop is plugged in. Check with the lab instructor to make sure that they received your submission before you leave.