Image Formation

Safety and Equipment

- No special safety equipment is necessary for this lab.
- PASCO Optics Bench
- PASCO Basic Optics Components Kit (OS-8900)
  We use these components from the Kit:
  - Light Source with power adapter
  - Basic Optics Ray Table (round protractor)
  - Semicircular D-shaped Lens
  - Mirror (inside ray components kit)
  - Convex Lenses (+100 mm, +200 mm, +250 mm)
  - Concave Lens (-150 mm)
  - Viewing Screen

Introduction

Rays of light are generally straight lines, except when the light is refracted or reflected. Real objects emit light from every point. To make things easier, we usually consider one point at a time, so that the rays we trace are those from a point source called "the Object".

To form an image, the rays from the object reflect or refract and afterward they can be interpreted as passing (or appearing to pass) through a common source point. This common point shared by all of the rays after reflection or refraction is called "the Image".

Individual rays obey the reflection equation or Snell's Law:
$$\theta_1 = \theta_1' \qquad n_1 \sin \theta_1 = n_2 \sin \theta_2$$
where θ_1 is the angle of an incident (incoming) ray, θ_1' is the angle of a reflected ray, and θ_2 is the angle of a refracted ray. When dealing with reflection and refraction, angles are measured _from the normal_.
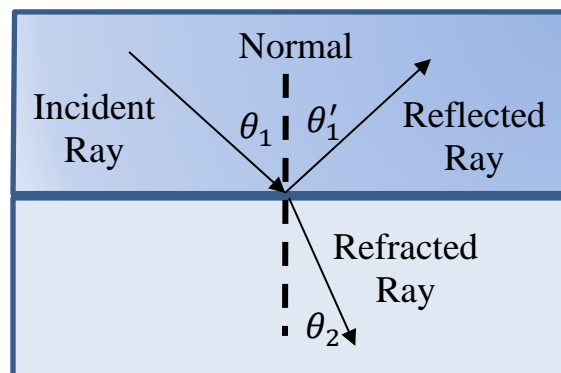

Figure 1. Refraction Geometry. Note the refracted angle could actually be larger than the incident angle, depending on the indices of refraction.

Images and objects obey the thin lens equations:
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad \frac{h_o}{h_i} = M = -\frac{d_o}{d_i}$$
where d_o (sometimes called p) is the object distance and d_i (sometimes called q) is the image distance. When dealing with lenses and mirrors, distances are measured _from the lens or mirror_. Negative distances are allowed and mean the image is on the "wrong side" of the lens or mirror. Instead of being where the rays are after the lens or mirror, the image is on the other side and the image is virtual.

Objectives:

- *To observe the rays formed from a flat mirror.*
- *To observe rays refracting from a prism.*
- *To verify the thin-lens equation.*

Part #1. Ray Reflection

1. Place the PASCO Light Source directly on the lab table, with the ray table just in front of it. Select the single beam of light, and align the ray table's Normal line with the ray. Place the flat mirror along the Component line of the ray table. The alignment is correct if the reflected ray is on top of the incident ray.
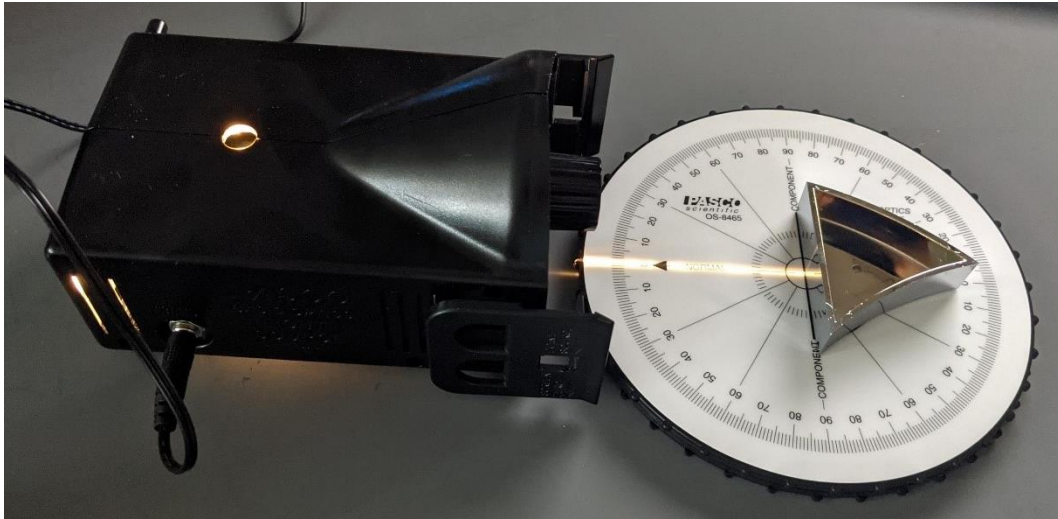

Figure 2. Reflection alignment with ray table and mirror.

2. Rotate the ray table in 10° increments to control the incident angle. Measure each reflected angle, calculate the % Error, and comment on the results in the caption.

Table 1. Reflection experiment data. (Comment on results.)

Incident angle θ_1 (°)	Reflected angle θ_1' (°)	% Error
10		
20		
30		
40		
50		
60		
70		
80		

Part #2. Ray Refraction

1. Replace the mirror with the semicircular D-shaped Lens. Align the lens with the outline that is drawn on the Ray Table. If the alignment is correct, the beam should exit along the 0° mark on the other side.
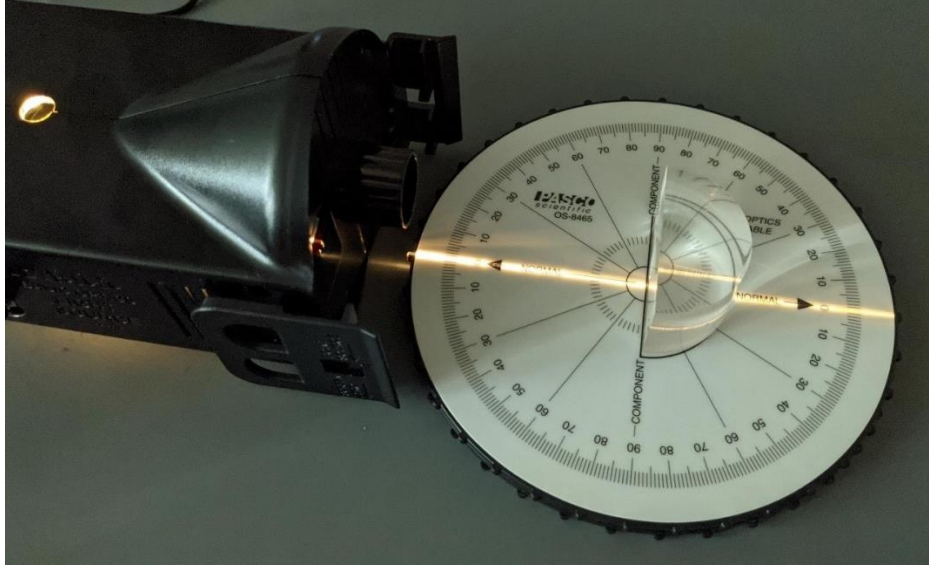

Figure 3. Alignment setup for the refraction experiment, using the D-shaped lens.

2. Turn the Ray Table to control the incident angle in 10° increments. Observe the ray exiting the lens. Notice that the ray exits perpendicular to the round surface, so that the light is not refracted at the round surface, only at the flat surface. Measure the angle of refraction, which is the direction of the beam inside the lens. Record this in Table 2 Refraction Data.

Table 2. Refraction Data.

incident angle θ_1 (°)	Refracted angle θ_2 (°)	$\sin\theta_1$	$\sin\theta_2$
10			
20			
30			
40			
50			
60			
70			
80			

3. Calculate the sine of each incident and refracted angle. (Reminder: In Excel, to take the sine of cell A3 measured in degrees, use `=sin(radians(A3))`.)

4. Make a plot of $\sin\theta_2$ vs. $\sin\theta_1$. The slope of this plot is $\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2}$. Assuming $n_1 = 1$, use the slope of the plot to calculate n_2. Include this information in Table 4 Analysis of Results of Refraction Experiment. Comment on the results in the caption.

5. Turn the Ray Table around so that the light is entering the round side of the lens. In this configuration, there are two beams that exit. One is the ray reflected from the flat side of the lens, and the other is the ray refracting from the lens into air.
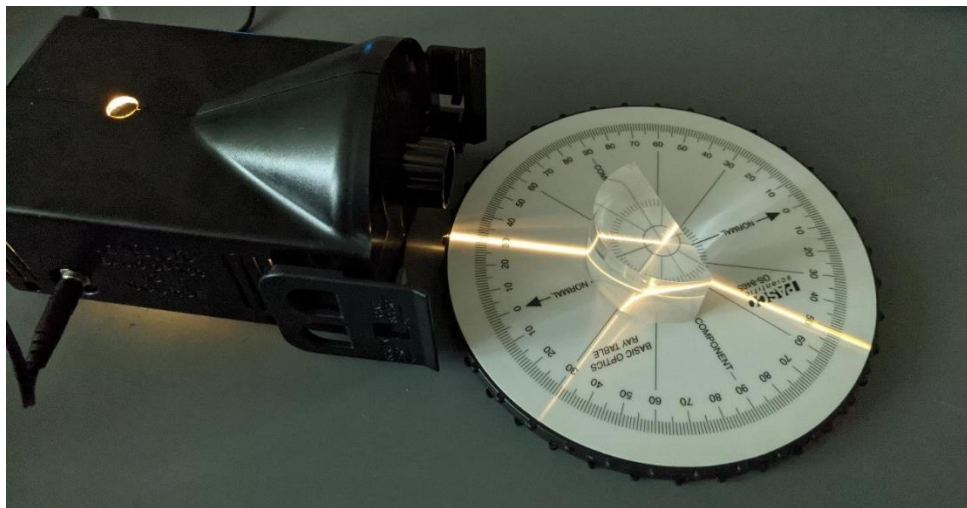

Figure 4. Setup for measuring refraction from the lens into air. Note that the beam enters the lens at the curved surface and does not bend there. Bending occurs only at the lens-to-air interface at the center of the Ray Table.

6. Control the incident angle in 10° increments. Measure each refracted angle, calculate the sines in Table 3, and Plot with a trendline. (You may not get data past 40°. Just don't include those points.) This time, $n_2 = 1$ and you should calculate n_1 from the data. Include the analysis in Table 4.

Table 3. Refraction Data for lens-to-air.

incident angle θ_1 (°)	Refracted angle θ_2 (°)	$\sin \theta_1$	$\sin \theta_2$
10			
20			
30			
40			

Table 4. Analysis of results of refraction experiments. (Comment on agreement.)

Experiment	Slope of graph $(\sin \theta_2 / \sin \theta_1)$	Known index	Unknown index	Value of Unknown
Air-to-Lens		$n_1 = 1$	n_2	
Lens-to-Air		$n_2 = 1$	n_1	

Part #3. Image Formation through Curved Lenses

Case 1: Object Very Far from Lens
1. Place the +100 mm lens on the optics track, perhaps at the 100 cm mark.
2. Place the observing screen on the optics track, about 10 cm from the lens.
3. "Point" the other end of the optics track at a bright, far-away object, such as the window.
4. Move the observing screen to focus the image.
5. Compare the lens-image distance to the focal length printed on the lens.

Table 5. Image formed of a very-far Object. (Comment on agreement.)

Image Distance (cm):	
Focal Length (cm):	
% Difference	

Case 2: Real images from a convex lens
6. Attach the PASCO Light Source to the optics track at the 0 cm mark. It should easily snap onto the top of the track. Later, to remove the Light Source, there is a little release lever that must be pressed.
7. Place the +250 mm lens on the optics track at the 75 cm mark.
8. Place the observing screen on the optics track, and move it around to obtain a focused image on the screen. (Hint: The screen should be near the 110 cm mark.) Record the object-lens distance and the image-lens distance. (Both are positive.)
9. Move the lens 5 cm closer to the object, and repeat. Stop when the image is further away than the end of the track.

Table 6. Real Image Data for a convex lens with expected focal length f = _____.

Object Distance, p or d_o (cm)	Image Distance, q or d_i (cm)	$1/d_o$ (cm^{-1})	$1/d_i$ (cm^{-1})

10. Calculate the inverses of the distances, and plot $1/d_i$ vs. $1/d_o$. Add a linear trendline and display the equation on the plot. The points should lie approximately along a line, with a slope of approximately -1 and an intercept of $1/f$. Calculate the experimental focal distance from the intercept and compare it to the label on the lens, presenting them in a Table 6, commenting on the results in the figure caption.

Table 7. Results of Real Image Experiment. (Comment on results.)

Intercept of Graph (1/cm):	
Experimental $f = 1/$intercept (cm):	
Focal Length (cm):	
% Difference	

Case 3: Virtual Images from Convex and Concave Lenses

11. Move the +250 mm lens closer to the lantern, to about the 20 cm mark. Look through the lens and observe the virtual image.
12. Replace the lens with the -150 mm concave lens. Compare the two virtual images. Record the image size as Reduced or Enlarged, and the Orientation as Upright or Inverted.

Table 8. Observations of Virtual Images.

Lens Focal Length	Object Distance	Image Size	Orientation
+250 mm			
−150 mm			

Report Requirements

This lab report must be turned in on the day of the lab. An Abstract is not required. Simply turn in the Excel file. There should be clearly visible areas of the file with each Table and Figure, with captions written in the cells above or below them.

- 8 Tables with captions.
- 3 Figures of graphs, with trendlines and equations, with captions.