

# Lab 9. Reflection and Refraction

## Goals

- To explore the reflection of a light ray from a shiny smooth surface.
- To observe and understand how a curved mirror focuses incoming parallel light rays to a single point.
- To explore the behavior of a light ray as it passes from one transparent medium into another transparent medium.
- To verify Snell's Law of refraction for light rays passing from air to PMMA [a plastic also known as Lucite, Plexiglass, or poly(methyl-methacrylate)] and from PMMA to air.
- To calculate the index of refraction for PMMA from the data.
- To observe the focusing of parallel rays of light by a semi-circular PMMA prism analogous to a simple lens.

## Introduction

The basic behavior of light reflecting off mirror surfaces or passing from one medium to another is to be investigated. A “ray box” produces one or more thin beams of light that behave much like the ideal rays used to describe reflection and refraction in the text. Tracing the paths of these rays as they interact with a mirror or an interface shows the behavior of light in these situations.

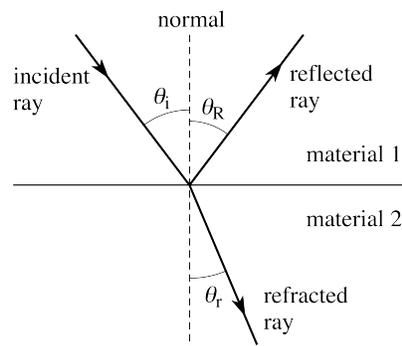


Figure 9.1. Angles of Reflection & Refraction

By convention the angle of incidence is defined as the angle between the incident ray and the surface normal—the direction perpendicular to the surface of the mirror or lens. When dealing with mirrors, the angle of reflection is the angle between the reflected ray and the normal to the

surface of the mirror. When dealing with refraction, the angle of transmission is defined as the angle between the transmitted ray and the surface normal at that point.

**Caution: Avoid putting fingerprints on the surfaces of the optical elements. Handle them by the edges.**

## Reflection from a plane mirror

By flipping or changing the plastic mask on the front of the ray box, single or multiple rays can be obtained. To investigate the reflection of a single ray of light, adjust the box to give a single ray of light. A piece of circular graph paper will be used to measure the angles of incidence and reflection.

Align the plane mirror with the  $0^\circ$ - $360^\circ$  line on a piece of circular graph paper, and direct the ray so that it strikes the mirror at the center of the circular graph paper. Without changing the position of the mirror, measure and record the angles of incidence and reflection as the incident angle of the ray is varied by  $10^\circ$  increments from  $10^\circ$  to  $80^\circ$ . You will have to move the ray box relative to the paper by carefully moving one or the other or both. Make sure that the ray always strikes the mirror at the center of the graph paper. Remember that incident and reflected angles are measured by convention from a line perpendicular to the mirror surface.

Present your results in a table. From your data, can you propose a general relationship between incident and reflected angles? How well is your generalization supported by the data?

## Reflection from two perpendicular plane mirrors

Place two plane mirrors at right angles to each other in a L-shaped formation near one corner of a piece of engineering paper. The back or non-reflective sides of the mirrors should face toward the edges of the paper.

Using the same ray box configuration as above, place the ray box so that the single ray impinges on the front of one of the mirrors near its middle at an incident angle of about  $45^\circ$ . You should observe a reflected ray from this mirror combination. Use a ruler to draw on your paper the paths of both the incident and reflected rays. Now vary the incident angle of the incoming ray, always making sure that the ray's path includes one reflection from each mirror surface, and again mark the paths of the incident and reflected rays from the mirror combination.

From your observations what general rule might you suggest for the relationship between the incoming and outgoing rays for this configuration? How well does your data support your generalization?

Note that radar is a form of electromagnetic radiation, like light, and so exhibits the same properties as light when it comes to reflection. Radar often works by sending out a beam from a point, and then looking to see what, if anything, gets reflected back to that same point. An aircraft has many parts that fit together so that the surfaces make angles with each other. What angles should be avoided when designing "stealthy" aircraft, that is, those hard to "see" with radar?

## Focal length of a concave cylindrical mirror

To determine the focal length of a curved mirror, it is useful to adjust the rear box so that it gives several parallel rays. Adjust the ray box to give five rays, and place a piece of engineering paper in front of the ray box. Place the reflective surface of the mirror toward the ray box with the center of the mirror surface perpendicular to the middle one of the five rays. Outline the position of the mirror on the paper. Then trace the path of each incident ray and its reflected ray.

The focal length of a mirror is defined to be the distance from the center of the mirror to the point where parallel incident rays intersect after reflecting from the surface. Determine the focal length for this concave mirror from your ray drawing. If all the rays don't quite meet at the same point, this is called "aberration." Does your mirror exhibit aberration? Do each of the five rays obey the simple rule of reflection you stated at the conclusion of part 1 from the mirror surface? Discuss and explain in each case.

## Refraction at the surface of a semicircular lens

When a ray of light enters a transparent material at any angle except  $90^\circ$ , the ray bends at the interface. To study the bending process, adjust the ray box so that it produces a single ray of light. Use the circular graph paper to measure the angles of the incoming incident ray and the outgoing refracted ray. To do this, orient the flat face of the semicircular PMMA lens on the circular graph paper so that it lies along the  $0^\circ$ - $360^\circ$  line. Then position the ray box so that the ray strikes the flat face of the lens at right angles. The point of intersection should lie at the center of the graph paper, so you can measure its angle.

Trace the path of the incoming ray from the ray box and the outgoing ray emanating from the curved side of the lens. Note that when the ray is perpendicular to the interface from air to lens or from lens to air, the ray does not deviate from its original direction. In this case, the incident and refracted angles are both zero. Now vary the angle of incidence from  $10^\circ$  to  $80^\circ$  in  $10^\circ$  increments. In each case trace the incoming and outgoing rays. It is imperative that the incoming ray strikes the PMMA at the center of the straight side of the semicircle each time. After refraction, rays striking the center of the straight edge of the semicircle will pass along a radius of the semicircle and will always strike the curved edge of the lens at right angles. Since the incident angle departing the PMMA lens is  $0^\circ$ , no additional refraction takes place. Care here will ensure the validity of your data.

To determine the relationship between the incident angle and the refracted angle for the air-PMMA interface. Make a graph of the incident angle on the vertical axis versus the refracted angle on the horizontal axis. Based on your graph, can you propose a simple relationship between the two angles?

Historically the relationship between the incident and refracted angles was not fully understood until the wave theory of light was proposed. It is now well understood and experimentally verified that light travels more slowly through materials than through empty space. Air is mostly empty space, so the slowing down of light in air is very small and can be ignored in many cases. The index of refraction of a material is defined as follows:

$$\text{index of refraction, } n = \frac{\text{speed of light in vacuum, } c}{\text{speed of light in material, } v} \quad (9.1)$$

Consequently, the index of refraction for air is essentially 1.00, while the index of refraction of PMMA is greater than one. It has been predicted and verified by careful experiments that the incident angle,  $\theta_i$  is related to the refracted angle,  $\theta_r$ , by:

$$n_i \sin \theta_i = n_r \sin \theta_r \quad (\text{Snell's Law}) \quad (9.2)$$

where  $n_i$  is the index of refraction of the material for the incident ray and  $n_r$  is the index of refraction of the material for the refracted ray. Now use Snell's Law to determine the index of refraction of the PMMA. A graph is a good way to do this.

The behavior of the light traveling from air into PMMA is characterized by Snell's Law, but is the behavior of light traveling from PMMA into air the same? To test this, put the ray box on the opposite side of the PMMA semicircle. The incoming ray should enter the PMMA through the curved side and pass along a radial line to the center (Important!) of the straight side. Here the ray leaves the PMMA and passes into the air. Again trace rays and measure incident (now in the PMMA) and refracted (now in the air) angles as before. Do you see any differences? For fairly large incident angles, what happens to the refracted ray? The effect that you observe is utilized in optical fiber transmission lines to keep the light from "leaking" out of the fiber. Determine the index of refraction of the PMMA from this data by plotting the angle of refraction versus the angle of incidence. Does the index of refraction agree with the value obtained when the ray was incident on the flat side of the lens?

## Determining the focal length of a lens

To determine the focal length of the PMMA lens, adjust the ray box to give five rays once again. Place the lens on a piece of engineering paper and orient the ray box so that the middle rays strike the center of one side of the lens at right angles. Trace the incoming and outgoing rays and determine the focal length of the lens. By convention, the focal length is measured from the center of the lens at its thickest point.

Rotate the lens by  $180^\circ$ . Does this change the focal length? Try rotating the lens, say,  $20$ - $30^\circ$ . Does this change the focal length? Is the focal point as well defined, that is do the rays intersect as closely to a single point? Discuss and explain in each case. Use diagrams liberally.

Block two of the incoming rays on one side of the lens. Does blocking two rays change how the remaining rays focus? If you were given just half a lens, would it focus light properly? Explain.

## Summary

Summarize your results and make any final conclusions.

	<b>No Effort</b>	<b>Progressing</b>	<b>Expectation</b>	<b>Scientific</b>
<p><b>SL.A.b</b></p> <p>Is able to identify the hypothesis for the experiment proposed</p> <p>Labs: 4-6, 9</p>	No deliberately identified hypothesis is present in the first half page or so of notes	An attempt is made to state a hypothesis, but no clearly defined dependent and independent variable, or lacking a statement of relationship between the two variables	A statement is made as a hypothesis, it contains a dependent and independent variable along with a statement of relationship between the two variables. This statement appears to be testable, but there are some minor omissions or vague details.	The hypothesis is clearly stated and the direct link to the experiment at hand is apparent to any reasonably informed reader.
<p><b>SL.A.c</b></p> <p>Is able to determine hypothesis validity</p> <p>Labs: 4-6, 9</p>	No deliberately identified attempt to use experimental results to validate hypothesis is present in the sections following data collection.	A statement about the hypothesis validity is made, but it is not consistent with the data analysis completed in the experiment	A statement about the hypothesis validity is made which is consistent with the data analysis completed in the experiment. Assumptions which informed the hypothesis and assumptions not validated during experimentation are not taken into account.	A statement about the hypothesis validity is made which is consistent with the data analysis and all assumptions are taken into account.
<p><b>SL.B.b</b></p> <p>Is able to explain patterns in data with physics principles</p> <p>Labs: 1-3, 5, 7-9, 12</p>	No attempt is made to explain the patterns in data	An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data.	An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles.	A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit.
<p><b>CT.A.b</b></p> <p>Is able to identify assumptions used to make predictions</p> <p>Labs: 4-6, 9</p>	No attempt is made to identify any assumptions necessary for making predictions	An attempt is made to identify assumptions, but the assumptions stated are irrelevant to the specific predicted values or apply to the broader hypothesis instead of the specific prediction	Relevant assumptions are identified regarding the specific predictions, but are not properly evaluated for significance in making the prediction.	Sufficient assumptions are correctly identified, and are noted to indicate significance to the prediction that is made.
<p><b>CT.A.c</b></p> <p>Is able to make predictions for each trial during experiment</p> <p>Labs: 4-6, 9</p>	Multiple experimental trials lack predictions specific to those individual trial runs.	Predictions made are too general and could be taken to apply to more than one trial run. OR Predictions are made without connection to the hypothesis identified for the experiment. OR Predictions are made in a manner inconsistent with the hypothesis being tested. OR Prediction is unrelated to the context of the experiment.	Predictions follow from hypothesis, but are flawed because relevant experimental assumptions are not considered and/or prediction is incomplete or somewhat inconsistent with hypothesis or experiment.	A prediction is made for each trial set in the experiment which follows from the hypothesis but is hyper-specific to the individual trial runs. The prediction accurately describes the expected outcome of the experiment and incorporates relevant assumptions.

	<b>No Effort</b>	<b>Progressing</b>	<b>Expectation</b>	<b>Scientific</b>
<p><b>CT.B.a</b></p> <p>Is able to describe physics concepts underlying experiment</p> <p>Labs: 1-3, 5, 7, 8-12</p>	No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words.	The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week.	The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab.	The physics concepts underlying the experiment are clearly stated.
<p><b>QR.B</b></p> <p>Is able to identify a pattern in the data graphically and mathematically</p> <p>Labs: 1-3, 5, 7-9, 12</p>	No attempt is made to search for a pattern, graphs may be present but lack fit lines	The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented.	The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality	The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit.
<p><b>IL.A</b></p> <p>Is able to record data and observations from the experiment</p> <p>Labs: 1-12</p>	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.

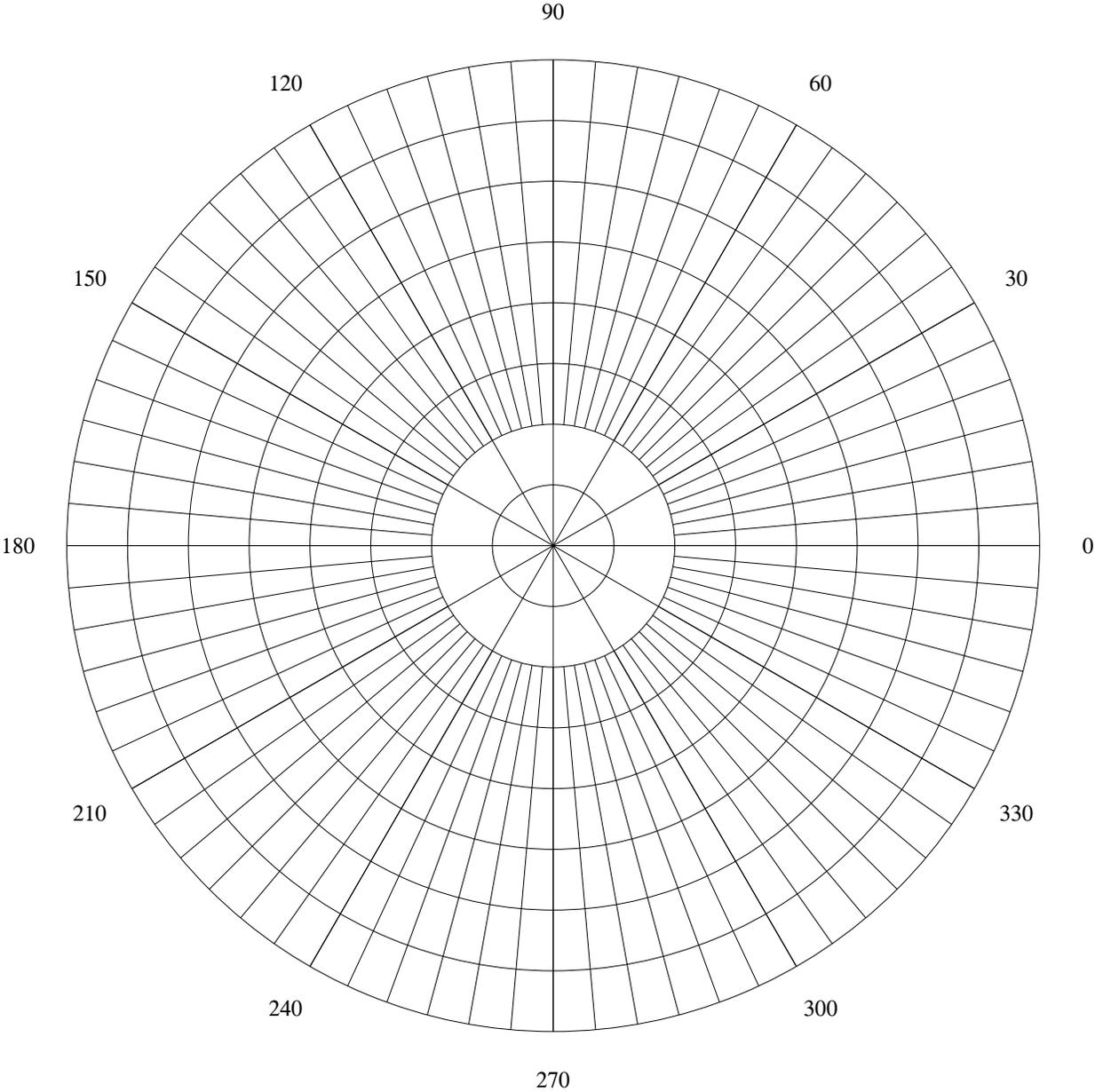


Figure 9.2. Polar Graph Paper



Figure 9.3. Cartesian Graph Paper "Engineering Paper"

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 9 Reflection and Refraction:

Name: \_\_\_\_\_ Lab Partner: \_\_\_\_\_

<b>EXIT TICKET:</b>	
<input type="checkbox"/> Quit any software you have been using.	
<input type="checkbox"/> Straighten up your lab station. Put all equipment where it was at start of lab.	
<input type="checkbox"/> Required Level of Effort.	
<input type="checkbox"/> Complete the pre-lab assignment	<input type="checkbox"/> Arrive on time
<input type="checkbox"/> Work well with your partner	<input type="checkbox"/> Complete the lab or run out of time

SL.A.b	
SL.A.c	
SL.B.b	

CT.A.b	
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