Geometric Optics

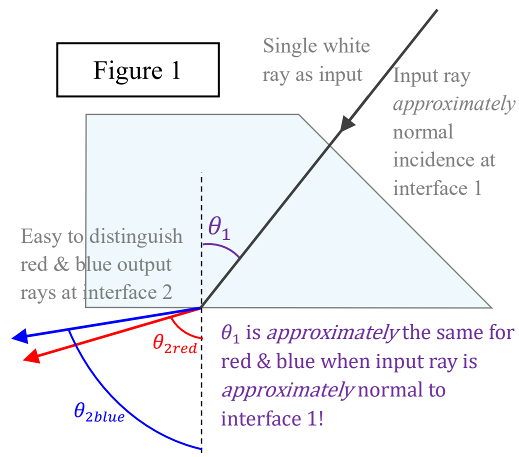
Apparatus: Ray Optics Kit, Basic Optics Light Source, Basic Optics Light Source Power Supplies, Basic Optics Tables & D-Shaped Lenses, rulers, protractors, desk lamps

WARNING: Be careful to handle all optics by the edges so you don't get smears on the surfaces. Do not attempt to clean optics unless you have been instructed in the proper technique (ask for assistance if optics are dirty).

Goal: The goal of this lab is to confirm the principles of refraction and reflection using lenses, mirrors, and prisms.

Use blank white or engineering paper (with printed lines on back).
On the first page, use your standard header (author name, partners names, early or late lab section, date).
Follow the instructions for each mini experiment described below.
Start each new section (each new experiment) on a new paper.
Each student (not each group) should produce each drawing, do all calculations, and submit a document.
Rotate which lab partner has to go first in each experiment so you each experience some of the struggles.

Experiment 1: Determine index of refraction for red & blue light
Place a light source and the trapezoid on a blank piece of paper. Engineering paper works fine (ensure lines are on the back side). Make the light source project *one ray* towards the trapezoid as shown in Figure 1. Ensure you can clearly distinguish the red and blue rays of the spectrum.



Once you have a nice set-up, gently press down *on the edges* of the trapezoid. *Without scratching the optics*, trace the trapezoid, input ray, red ray, & blue ray. Try to trace the *middle* of the red & blue output rays (not the outside edges). To trace rays, draw dots in the middle of each beam where they enter/exit the trapezoid. Draw a second dot in each beam far from the trapezoid. Use a ruler to connect the dots.

Once your trace is complete, label separate final angles for red and blue (θ_{2red} & θ_{2blue}).
Draw the normal to the surface at the SECOND interface only just like in Figure 1.
Use a protractor to ensure the normal is perpendicular to the surface (you may need to extend lines from your trace).
Measure θ_{red} & θ_{blue} with a protractor. You may need to extend the lines from your trace.
Lastly, measure the angle θ_1 as shown in Figure 1, extending lines from the trace as needed.

1a) Use Snell's law to determine the index of refraction of the acrylic trapezoid for both red light and blue light.
Show all work under your sketch.

2) Accepted values for the index of refraction of acrylic are $n_{red} = 1.489$ for $\lambda_{red} = 651$ nm and $n_{blue} = 1.497$ for $\lambda_{blue} = 486$ nm. Compute the percent difference between your experimentally determined values and the accepted values. Again, **show your work** below your sketch.

3) Assume the error in measuring each angle is about 2°.
Use this to determine the % precision in measuring each angle you used in Snell's law.
While only a crude estimate at best, assume the sum of these percent errors is your % precision.
Did your experimental results agree well with the predictions based on Snell's law for both red & blue rays?
Compare your % difference to your % precision in a sentence to support your answer.

Reminder: Start your notes for each experiment on a new page.

Experiment 2: Determine critical angle for TIR

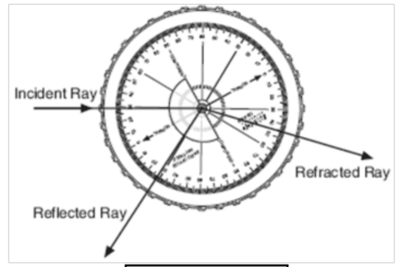


Figure 2

Now set the D-shaped lens on the rotating table so that the incident ray first strikes the *round* side of the D-shaped lens (see Figure 2).
Rotate the table while watching the *second* interface (going from acrylic into air).
The smallest angle to the normal with no *refracted* ray is the critical angle θ_c.

4) Determine $\theta_{c\ blue}$ experimentally.
Rotate the table until the blue ray is essentially parallel to the flat surface of the lens.
Many students find it is helpful to tape the bottom of the protractor table to the lab table.
Then you can rotate the top of the table (and the D-shaped lens) without messing up the alignment of the lens to the protractor table.
YOUR SKETCH SHOULD LOOK DIFFERENT THAN FIGURE 2!
You are supposed to rotate the lens until the blue refracted ray is parallel to the flat surface of the D-shaped lens.
Record the angles.
Make a sketch on paper by tracing the D-shaped lens.
Then use your measurements (along with a ruler and protractor) to sketch the incident, reflected, and refracted rays.

5) At the exact angle where the refracted ray first disappears it is essentially parallel to the flat surface.
When the refracted ray is parallel to the surface, what is the angle (of the refracted ray) from the normal?

6) Algebraically derive the condition for *theoretical* critical angle for acrylic by using Snell's Law.
In this case you should note that $n_1 = n_{blue}$ of acrylic while n_2 is that of air.

7) Using $n_{blue} = 1.497$ for $\lambda_{blue} = 486$ nm, determine a theoretical value of the critical angle (for blue).

8) Does the theoretical prediction match experiment? This would be a second verification of Snell's law.
Compare % difference to % precision.
Again, assume that errors in your angles are always 2°.
Find the percent error for each angle, then add up the percent errors to estimate % precision.
Show all your work below the sketch. Ensure it is painfully obvious so I can follow and grade quickly.

Reminder: Start your notes for each experiment on a new page.

Experiment 3: Determine focal length & radius of curvature of concave & convex spherical mirrors.

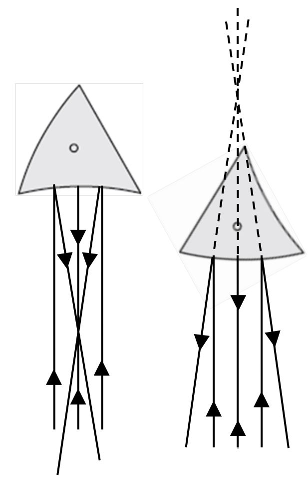
The factory specification states the radius of curvature for each curved mirror is ± 12.5 cm.
One is stated as a positive radius while the other is negative.

9) Which mirror (convex or concave) causes light rays to converge?
Should that mirror have a positive or negative focal length?
Should it have a positive or negative radius of curvature? Page 20 of Workbook Volume 5 may help.

10) Make two sketches as shown in Figure 3 by following the procedure below.

a) Make the light source produce *three* rays.
b) Ensure the middle ray hits the mirror at normal incidence for the *concave* mirror.
To do this, slowly rotate the mirror until the middle ray is reflected back on itself.
c) Trace the mirror, the incident rays, and the reflected rays for the *concave* mirror.
d) Move the mirror to a new spot on the page (as shown in Figure 3).
e) Repeat steps b & c procedure for the *convex* mirror.
f) Back extend the reflected rays from the *convex* mirror (dotted lines in Figure 3).
g) Determine the focal length of each mirror using the appropriate sign conventions.
h) Determine the experimental radii of curvature for each mirror from the focal length.
i) Get the % difference for each radius (compared to the factory spec of ±12.5 cm).
j) Estimate if the focal points are spread out over 1 mm, 2 mm, 5 mm, or 1 cm.
Call this the error in measuring each focal length (δf).
k) Estimate percent precision for each mirror using $\frac{\delta f}{f} \times 100\%$.
You may assume percent precision for your measurement of radius is the same since focal length and radius of curvature are related by the constant 2.

Ensure you show all work for *both* mirrors beneath each sketch.



Actual rays drawn with solid lines.
Back extensions shown with dotted lines.

Figure 3

11) Do your results agree with the manufacturer's specification?
Answer by comparing your percent precision to your percent difference.

Reminder: Start your notes for each experiment on a new page.

Experiment 4: Determine focal length of convex & concave lenses.

12) Determine the *experimental* focal lengths using the following procedure:

a) Use three rays to create the sketches shown in Figure 4.
b) Ensure the middle ray travels straight through each lens.
c) Notice the outgoing rays do *not* converge for the concave lens.
Back-extend the outgoing rays (dotted lines in Figure 4).
WATCH OUT! Ignore rays *reflecting* off the lenses. Pay attention.
d) Determine the focal length (including $\pm$ sign) for each lens.
Also state if each type of lens converges or diverges.
Page 26 of workbook volume 5 may help.

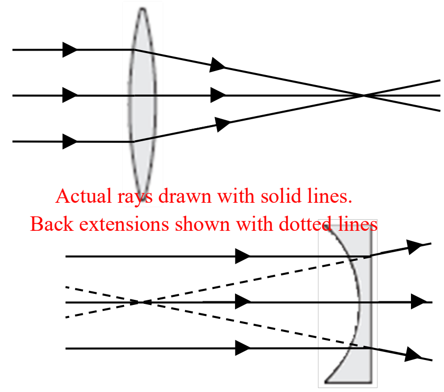


Figure 4a

13) Determine the theoretical focal lengths using manufacturer's specifications.

a) Make a new standalone sketch of the *biconvex* lens (no rays on it).
Label R_1 in this new sketch, clearly stating if $R_1 > 0$ or $R_1 < 0$.
Do the same for radius R_2.
b) Repeat the above step for the *concave* lens.
c) Use the lensmaker's equation to determine the focal length of each lens. Page 26 of workbook volume 5 may help.
Assume the index of acrylic is 1.49. The factory specification for each radius is ± 12.7 cm.

Figure 4b

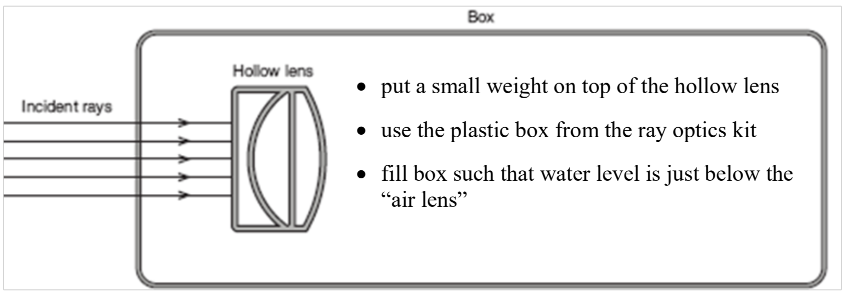
14) Compare your experimental measurements to those predicted by the manufacturer's specifications.

a) Get the % difference for each focal length.
b) Estimate if the focal points are spread out over 1 mm, 2 mm, 5 mm, or 1 cm.
Call this the error in measuring each focal length (δf).
c) Estimate percent precision for each mirror using $\frac{\delta f}{f} \times 100\%$.
d) State if your measurements are in good agreement with the manufacturer's specifications and support your claim using your % difference and % precision estimates.

This page is not required, but the experiments are fun.
I was thinking you would do the experiments without writing anything in your submission.
I'm hoping these will help you better understand some real-world applications.

A) Try making a beam expander.
To do this use the diverging and converging lenses spaced a small distance apart.
Shine the five rays on it (first the diverging lens, then the converging lens).
Slide the lenses back and forth and notice the spacing of the rays.
See if you can adjust the lenses until you see five parallel rays with a larger spacing between the rays!

B) Try making a lens out of air.
Notice what happens to the focusing properties concave/convex lenses.
In particular, a concave glass lens in air is diverging.
Is a concave air lens in water diverging or converging?

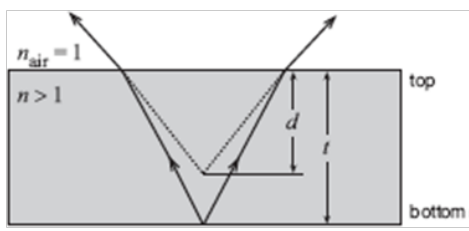


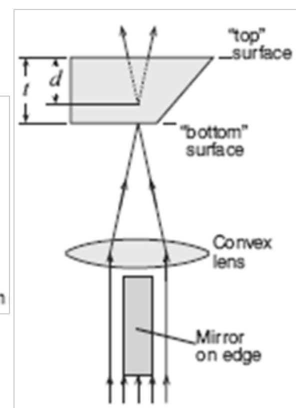
C) Experiment with apparent depth. Set up the system shown at right.

Notice that the "bottom" surface of the trapezoid is set at the point where the lens focuses.

Notice that you block the center three rays.

Trace the trapezoid and rays as before.





Back extend the exit rays with dotted lines.

Notice that from the perspective of someone above the "top" surface, the source of the rays "appears to be" inside the trapezoid. The actual source is the focal point at the bottom.

To compare to theory, apparent depth is given by $d = d_{apparent} = \frac{t}{n}$ where t is the actual depth (slab thickness in this case). Recall we are assuming $n = 1.49$ for acrylic.

Hopefully seeing this helps you understand the workbook problems on apparent depth.