

Geometric Optics

Purpose: Students will learn about refraction, lenses, and mirrors.

Introduction:

Few things are as basic as vision. If you are planning to go into a veterinary or medical field, you might be helping patients with eye problems. If not, maybe you just want to know a little more about your own eyeglasses or contact lenses. Or perhaps you'd like to know why objects in the mirror are closer than they appear. This lab will help you understand these things better.

TIME MANAGEMENT: Please avoid the rush! Do Experiment 7 at any time during the lab. Please do the other experiments in order. Experiment 7 is a brief observation.

Experiment 1: What is the index of refraction of the glass plate? (10 minutes)

The index of refraction is basic to all optical lenses and fiber optics. When a car drifts off of the edge of the road so that the passenger-side wheels are in sand or mud, the wheels slow down and the car jerks to the right. When light goes from air into glass, the light waves slow down. If the light enters the glass at an angle, this causes the light to change direction. The change in direction is described by Snell's Law.

$$\text{Snell's Law: } n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \text{Equation 1}$$

where n_1 and n_2 are the two indexes of refraction, and the θ 's are the angles between the rays and the normal line. Note that in optics, all angles are measured from the normal, meaning perpendicular, to the surface. The index of refraction n is a property of the material, which must be measured.

Procedure:

You have a cork board, a thick square of glass, a ruler, and some pins. Put a piece of paper on the cork board, then set up your apparatus on top of the paper as in Fig. 1 below.

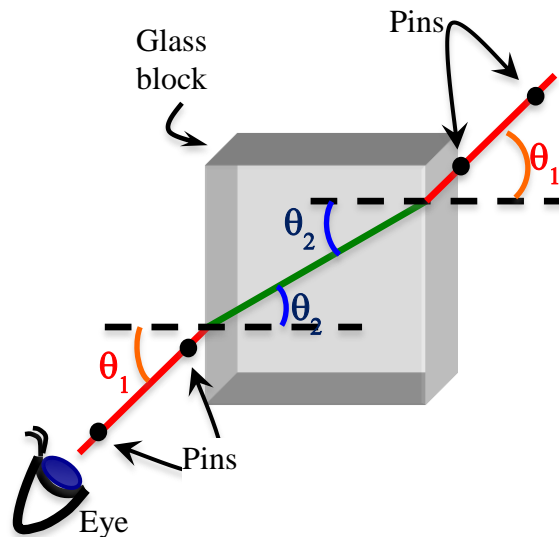


Fig. 1: Setup for measuring index of refraction

- Trace around the glass block with your pencil to mark its position.
- Get your head down to the table so you can look through the edges of the glass. **Please do not lift up the board**, as we do not want the glass to fall.
- Stick two pins on each side of the glass, as shown. When the pins are positioned correctly, all four pins will appear to line up in a row, one behind another so that they appear to be one pin.
- Remove the glass block. Use a ruler to draw the lines defined by the pins, both inside and outside the block.
- Use a protractor to construct the normal lines, as shown on Fig. 1. Measure the angles and calculate the index of refraction of the glass using Snell's Law. The index of refraction of air is $n_1 = 1.0003$. Record your work and results on the Data Sheet.

Experiment 2: Measuring the Focal Length of a Converging Lens (5 minutes)

If you've used a magnifying glass, you've used a converging lens. The focal length of the lens depends on its radius of curvature and its index of refraction. Fortunately, there's a very simple way to measure its focal length. If parallel rays enter the lens, they will come together at its focus. All you have to do is to measure the distance between the center of the lens and its focus with a ruler, as in Figure 2.

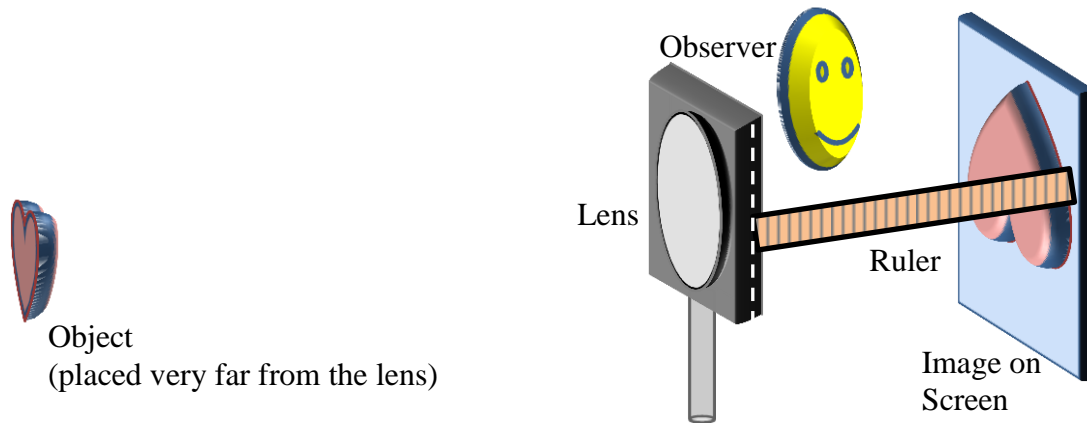


Fig. 2: Showing how to measure the focal length of a converging lens. If the object is very far from the lens, the focal length of the lens is the distance between the lens and the image on the screen.

- Use the "T" lens from your optics kit for this measurement.
- The object will be a set of lights at one end of the room. Perform this measurement from the other end of the room.
- This is a two-person measurement. One lab partner should hold the lens and the screen, while the other uses the ruler. Measure to the middle of the lens holder, not the surface of the lens.
- Record your work and your results on the Data Sheet at the end of the lab.
- If you like, you may repeat this measurement with any other convex/converging lenses that you have, including eyeglasses. Note that this method will NOT work for concave/diverging lenses. You can sometimes identify a lens by feel. If the lens is thicker in the middle, it's

converging. If it's thinner in the middle, it's diverging. If you use this method, please feel the lens through a piece of cloth or lens tissue to avoid putting fingerprints on the lens.

Experiment 3a: Optical Bench with a Converging Lens.

An optical bench lets you line up objects and lenses and move them around easily. Some of the benches have built-in meter sticks so that you can measure the positions of the optical elements.

- Mount the object light (with the arrows) on one end of the bench.
- Put the screen near the other end of the bench.
- Put the converging lens somewhere between the object and the screen. Its position is not critical, but it must be farther than one focal length (approx. 20 cm) from the object light.
- Make sure that the object light, lens, and screen are all at the same height. If you hold the meter stick horizontally, you can easily see whether things are lined up vertically.
- Turn on the object light. Slide the lens and the screen around until you get a clear and focused image of the object on the screen. Adjust the positions so that the image is not the same size as the object.

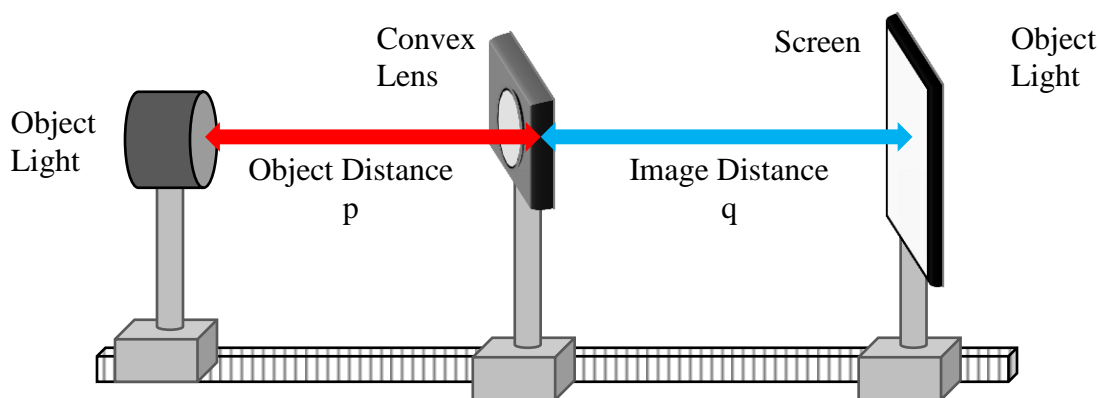


Fig. 3: Optical bench set up for a single convex lens.

You're now ready to make some observations and measurements.

- Record the **object distance** and **image distance** on the data sheet.
- Measure and record the **object size** (measured on the face of the lamp).
- Measure and record the **image size** (measured on the screen) and its orientation.
- Make a careful **ray diagram** of this situation, to scale, on a blank sheet of paper.
- Answer the **Analysis Questions** for this experiment.

How to draw a ray diagram:

- Draw a long horizontal line. This is the “principal axis,” also called the “optical axis.” It represents the center line of the optics system.
- Decide on a scale. It’s very common to draw the vertical distances two to five times larger than actual size, and the horizontal distances five to ten times smaller than actual size. Measure carefully! The success of your ray diagram depends on careful measurements.
- Draw a vertical arrow at the left of your drawing to represent the object. Pay attention to its height. Draw it to scale.
- Draw a vertical line at the location of the lens. Put a little picture of a lens on top so you remember what it is.
- Mark the focus of the lens on the principal axis.
- A parallel ray (shown in red below) hits the lens, then passes through the focus. Draw a ray between the the top of the object to the lens. This ray should be parallel to the principal axis. Then draw a ray from the point where the parallel ray hits the lens through the focus.
- A ray passing through the center of the lens (shown in blue below) is (in real life) nearly on the principal axis and is (to a very good approximation) not deflected. Construct a ray from the top of the object straight through the center of the lens.
- The point where the two rays intersect is the location of the top of the image. Note its position, orientation, and height.

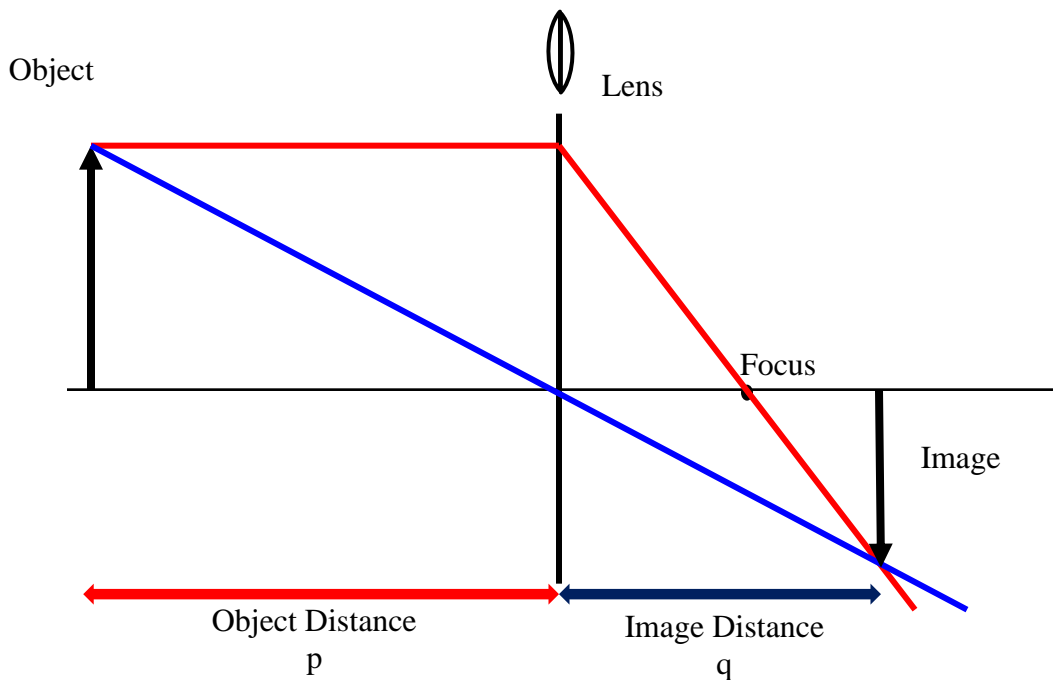


Fig. 4: Basic ray diagram for a single convex lens.

Your completed diagram should look similar to Fig. 4. Compare your drawing to what you see on your optical bench. If your drawing is way off, it may be that you have an incorrect focal length for the T lens. Don't panic. Answer the Analysis Questions. Turn your drawing in with your lab.

Experiment 3b: Convex Lens Again

- Use your setup from Experiment 3a.
- Make a new ray diagram, using your old image distance as the new object distance. Use your ray diagram to PREDICT what you will see on the screen. Record your predictions on the Data Sheet, and turn in the ray diagram with your lab report.
- Move the lens to its new position. Get a focused image on the screen, and measure everything as before. Compare the actual image distance and size to your prediction.

Experiment 4: Two-Lens System

- Take the convex "T Lens" off of the optical bench. Try using it as a magnifying glass. What do you see?
- Try the same thing with the "D Lens", which is a diverging lens. A diverging lens should make things look smaller than their actual size.
- Next, mount the lenses on the optical bench as in Fig. 5.

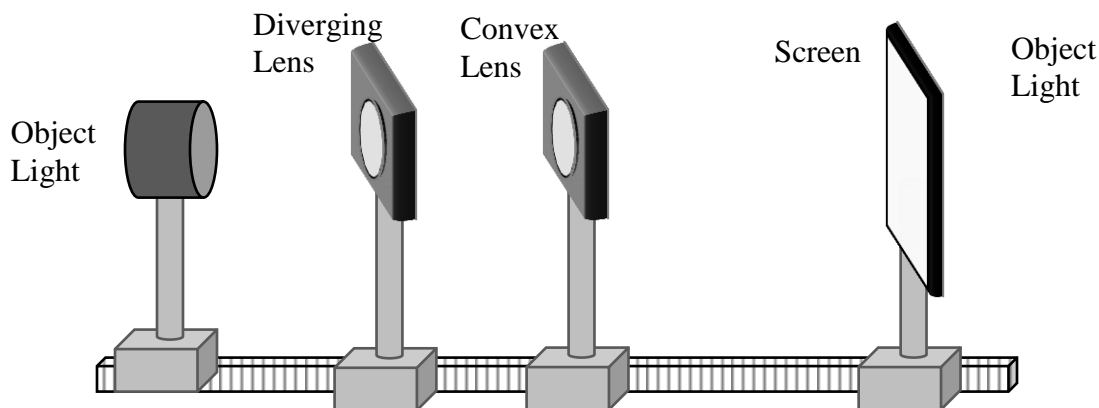


Fig. 5: Optical bench setup for the diverging and converging lens.

- Place the diverging lens approximately 25 cm from the object, and place the convex lens approximately 50 cm from the object. You may have to adjust these measurements slightly to get a good focused image on the screen.
- Make sure that everything is aligned vertically. If the image is too dim for you to see, replace the object light with the small light bulb and its holder.
- The focal length of a diverging lens can't be measured with the technique that you used in Experiment 1 in this lab. Normally, putting a real object in front of a diverging lens creates a virtual image that cannot be projected onto a screen. When you pair a diverging lens with a converging lens, the real image from the convex lens forms a virtual object

for the diverging lens. The diverging lens can then form a real image from this virtual object.

- Are you confused? Probably. The ray diagram shown below might help. It is not to scale.

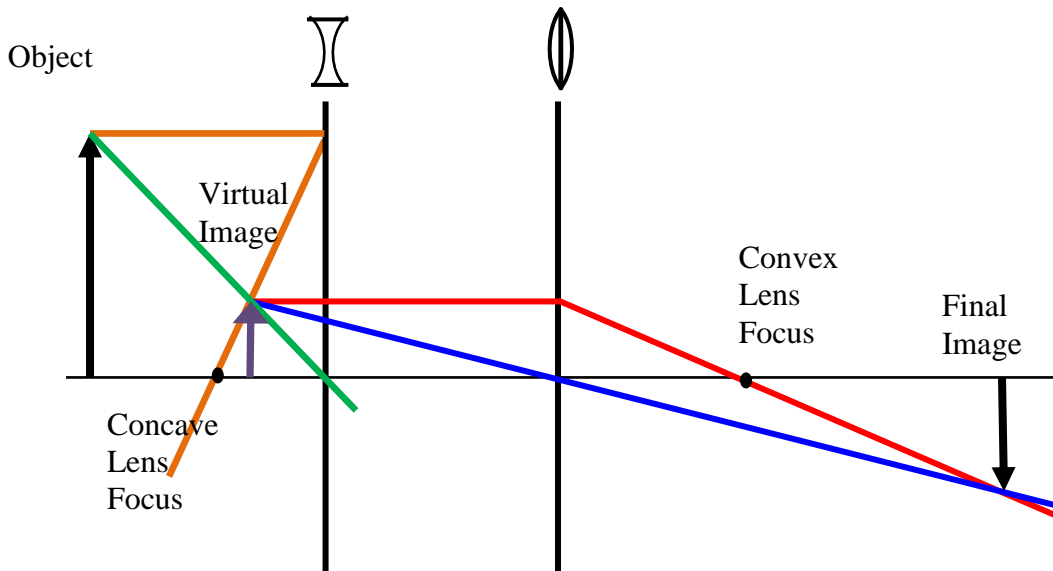


Fig. 6: Ray diagram for two-lens system. The focus of a diverging lens is to the left of the lens. The orange and green rays are for the diverging lens. (Parallel ray goes through the focus, ray through the center goes straight). The purple arrow is the virtual image formed by the diverging lens. The virtual image from the diverging lens is the object for the the converging lens. The red and blue rays show how the final image is formed.

- Record the optical element positions and the image data on the Data Sheet.
- Make a ray diagram for the two-lens system using the actual measurements from your optical bench. You know the focal length of the convex lens, the positions of the two lenses, the position of the object, and the actual size and position of the final image. Work backwards to figure out the location of the virtual image and the focal length of the diverging lens. Record your results on the Data Sheet and turn in your ray diagram.

The location of the virtual image is the distance between the virtual image and the diverging lens.

Experiment 5: Eyeglasses

The human eye is an optical instrument. Theoretically, light passing through the eye's cornea and lens is focused on the retina. Usually, however, the light doesn't quite focus on the retina. Hence the need for eyeglasses and contact lenses.

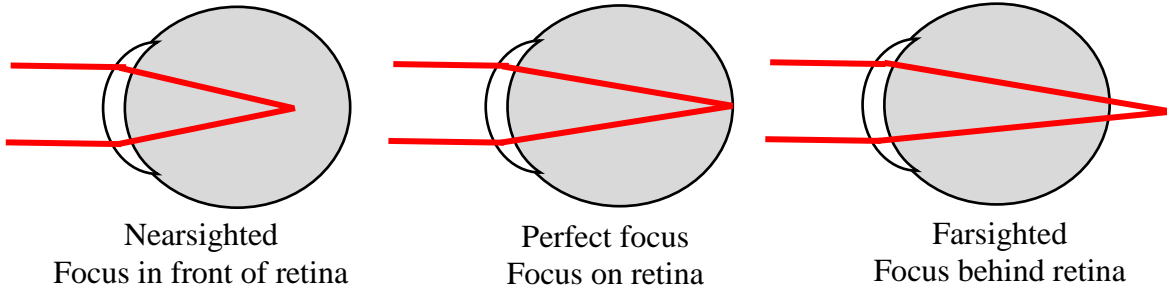


Fig. 7: How light is focused in the eye

We will use the “MU” lens to imitate the cornea of the eye. (The cornea does most of the focusing.) The screen will do an imitation of the retina of the eye.

- Remove the screen, diverging lens, and the converging “T” lens from the optical bench. Mount the converging “MU” lens so that it is located 7 or 8 cm from the object light. Hold the screen so that the “MU” lens forms a sharp image. The screen will be very close to the lens, so you will have to hold the screen in your hand.

If the light focuses in front of the retina, the person is near-sighted. This condition is corrected by a diverging lens.

- Hold the screen so that the “MU” lens forms a sharp image. Then put the diverging lens in front of, and in contact with, the “MU” lens. Just hold it there with your hand. Move the screen so that you have a sharp image again. Notice that when the diverging lens was inserted, you had to move the screen a little farther from the “MU” lens to achieve the focus.

If the light focuses in back of the retina, the person is far-sighted. This condition is corrected by a converging lens.

- Hold the screen so that the “MU” lens forms a sharp image. Then hold the “T” lens in front of, and in contact with, the “MU” lens. Move the screen so that you have a sharp image again. Notice that when the “T” lens was inserted, you had to move the screen closer to the “MU” lens.

Experiment 6: Spherical Mirror

You have a curved mirror in your optics kit. This is a two-sided mirror. Each PERSON in your group should try these observations.

Convex mirror:

You may have read somewhere that “objects in mirror are closer than they appear.”

- Look at your reflection in the convex side of the mirror. Notice that your reflection is very tiny. Also notice that the mirror gives a wide-angle view of your surroundings.
- Change the distance between the mirror and your face. Notice that your image is always tiny, erect, and virtual. The image appears to be behind the mirror.

Concave mirror:

Concave mirrors can do a lot of things. Different things happen depending on whether you are closer to the mirror than the focus, at the focus, or farther from the mirror than a focal length.

- Hold the concave side of the mirror very close to your face. Look at the reflection of your nose in the mirror. Notice that the image is erect, virtual, and magnified.
- Gradually move the mirror farther from your face. Keep looking at the reflection of your nose. At some point, the image will disappear. You’ve just found the focal length of the mirror.
- Keep moving the mirror away from your face. As you pass the focal length, the image of your nose will be upside down and smaller.
- Mount the mirror in its holder on the optical bench so that its concave side faces the object light. Put the mirror roughly (no, gently) in the middle of the bench. Turn the mirror so that the image gets thrown to the side of the bench.

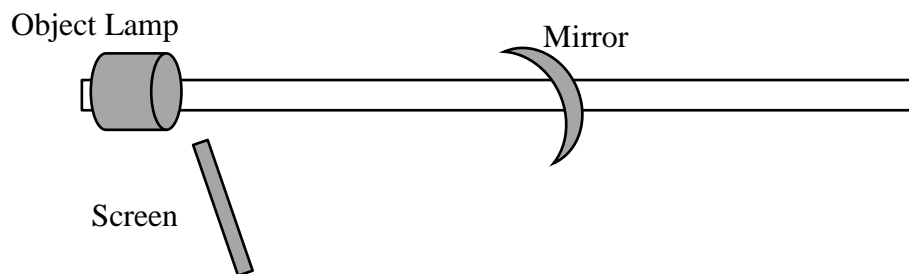


Fig. 8: Showing how to set up the optical bench with the mirror. Hold the screen by hand. You can use either the optics bench screen, the plastic box lid, or the cork board and a piece of paper. If you use the cork board (and even if you don't), **please don't lose the pins!**

- Play with the position of the mirror and its image. If you adjust things so that the image is at the location of the object, the screen is at the $2f$ (twice the focal length) point. The image is the same size as the object, but inverted.

Experiment 7: Full-Length Mirror (5 minutes)

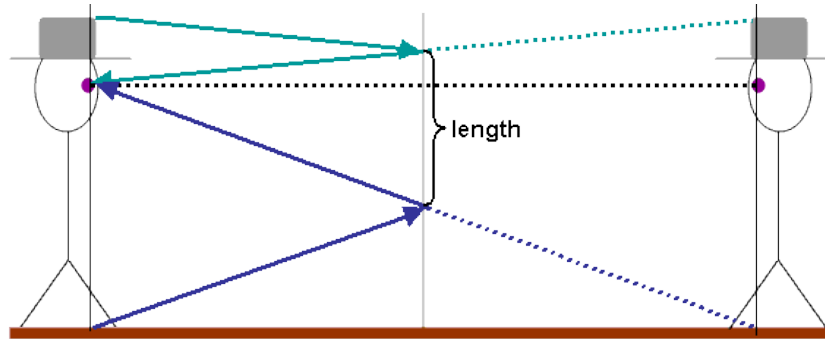


Fig. 9: Geometry for full-length mirror. The object is on the left, and the image on the right. Rays connect the eye to the hat and feet of the image.

How tall does a full-length mirror have to be? Proving that a full-length mirror only has to be half as tall as the person looking into the mirror is a standard homework problem in optics. Most people find it hard to believe that answer. Shouldn't the size of the mirror have something to do with the person's distance to the mirror?

Check it out! The entire lab group should go over to the mirror. One person should look at herself or himself in the mirror. The lab partners should, with the first person's help, mark and measure the size of the image in the mirror. To mark the top and bottom of the image, use your fingers or stick a bit of tape (provided in the lab) or a pair of sticky notes to the mirror. This measurement can be a bit sloppy. Compare the image size to the height of the person. Have the person take a few steps toward or away from the mirror and try again. What happens?

More Investigations:

1. Index of Refraction Applet: <http://phet.colorado.edu/en/simulation/bending-light>

Great applet for demonstrating how light bends when it crosses the boundary between two different materials. You can change both indexes of refraction. If you make the top one water and set the bottom one to air, you can observe total internal reflection.

2. Virtual optical bench applet: <http://webphysics.davidson.edu/applets/optics4/default.html>

Try setting up some of the situations that you did in this lab. Explore the effects of moving a lens or changing its focal length. You can use mirrors, too.

3. Check out this YouTube video:

<http://www.youtube.com/watch?feature=endscreen&v=zSqWHe0eVxg&NR=1>

This is easy to do at home. You can find the polyacrylate spheres where craft materials or floral supplies are sold.

Lab Section: _____ T.A.'s _____

Today's Lab Partners: _____

Data Sheet and Analysis Questions

Experiment 1:

 $n_{\text{air}} = 1.003$ $\theta_1 =$ _____ $\theta_2 =$ _____

1. Calculate the index of refraction of your piece of glass. $n_{\text{glass}} =$ _____
 Show your work below:

Experiment 2:

2. What is the measured focal length of your lens? _____ \pm _____ cm

Experiment 3a:

	Observed	From Ray Diagram
Object distance p		
Image distance q		
Object size:		
Image size:		
Magnification = $-\frac{\text{Image size}}{\text{Object size}}$		
Image orientation (erect or inverted)		

3. Discuss how well your ray diagram reproduced the observed image.

Lab Section: _____ T.A.'s _____

Today's Lab Partners: _____

4. The textbook relationship for lenses is: $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ where p is the object distance, q is the image distance, and f is the focal length of the lens. Calculate the focal length of the "T" lens, using your observed p and q. Show your results and work below.

"T" lens focal length from Exp. 2	
"T" lens focal length from Exp. 3a	
Percent difference	

Experiment 3b:

	Predicted from Ray Diagram	Observed
Object distance p (same as q in Exp. 3a)		
Image distance q (same as p in Exp. 3a)		
Object size:		
Image size:		
Magnification = $-\frac{\text{Image size}}{\text{Object size}}$		
Image orientation (erect or inverted)		

5. How well were you able to predict the characteristics of the image in Experiment 3b? (Hint: discuss what worked, what didn't work, how far you were off, etc.)

Lab Section: _____ T.A.'s _____

Today's Lab Partners: _____

6. The two positions of the lens in Experiments 3a and 3b are called “conjugate points.” Compare the image and drawing from Experiment 3a with the image and drawing from Experiment 3b. What did you notice about them?

Experiment 4:

	Measured
Location of diverging lens (measured from object)	
Location of converging lens (measured from diverging lens)	
Location of screen (measured from converging lens)	
Object size	
Final Image size:	
Magnification = $-\frac{\text{Image size}}{\text{Object size}}$	
Final Image orientation (erect or inverted)	
Virtual image position (from ray diagram; measured to diverging lens)	
Virtual image size (from ray diagram)	

Lab Section: _____ T.A.'s _____

Today's Lab Partners: _____

Experiment 5:

7. Were you able to see the effects of putting “glasses” on the “MU” lens? Discuss what happened at your lab station.

Experiment 6:

8. Were you able to see the effects listed for the spherical mirror? Discuss what happened at your lab station.

Experiment 7:

9. What happened? Can you explain it?

10. What are your overall impressions and thoughts about what you learned in lab today?

Drawings to turn in:

- Index of Refraction sheet from Experiment 1
- Ray Diagram for Experiment 3a
- Ray Diagram for Experiment 3b
- Ray Diagram for Experiment 4

Clean Up:

- Please refer to the list of items on the box lid and put the items in the box.
- Turn off all optical bench and desk lights.
- Report any missing or broken equipment to your TA.
- Please put trash and recyclables in their proper containers.
- Leave your lab station neat and tidy.