



Lab Sim 06: Geometric Optics

INTRODUCTION

If you wear glasses or contact lenses, you are already familiar with the science of optics. Whether you realize it or not, you understand the idea of a focal point. You are very aware when an image is out of focus (no glasses) or in focus (put your glasses back on). You even know the difference between a real and a virtual image, although you have probably never said to yourself, “I wish that the real image formed by the lens in my eye was better focused on my retina!” Or maybe you have...

OBJECTIVES

- Compare the behaviors of converging and diverging lenses
- Measure the focal lengths of converging and diverging lenses
- Identify the differences between real and virtual images
- Construct ray diagrams to accurately show how an image is formed
- Verify the lens equation for predicting the focal length of a convex lens
- Demonstrate the difference between a near- and far-sighted eye, and show how each vision problem can be corrected

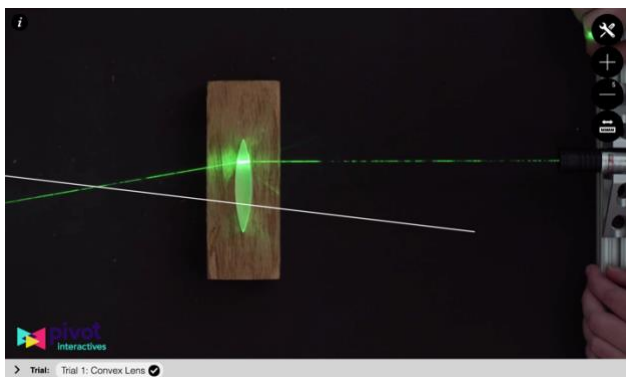
PIVOT INTERACTIVES

This exercise requires the online simulation (Lab 06: Geometric Optics). You should sign in to your Pivot account and choose the correct Interactive from the PHYS 1420 selection.

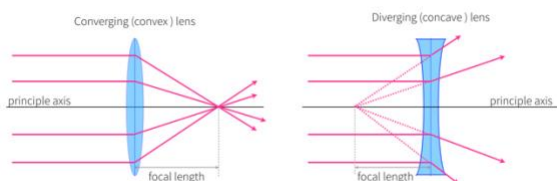
CONVERGING AND DIVERGING LENSES

The first video shows a laser aimed at different types of lenses. The laser is directed parallel to the principal axis of the lens. Use the tools to analyze how the laser beam changes direction as it passes through the lens.

Note: You have six lines that you can place over the video. You can change the direction of these lines by double-click-and-hold, then drag to rotate the image.



Observe both concave (inward-curving) and convex (outward-curving) lenses.



- 1) (2 points) Briefly describe how you will use the tools provided to measure the focal length of each lens.
- 2) (1 point) Determine the focal length of the convex (converging) lens. What is the uncertainty in your

measurement? Express your answer as $f \pm \Delta f$, where f is your measured focal length, and Δf is the uncertainty, measured in centimeters.

- 3) (1 point) Determine the focal length of the concave (diverging) lens. What is the uncertainty in your measurement? Express your answer as $f \pm \Delta f$, where f is your measured focal length, and Δf is the uncertainty, measured in centimeters.

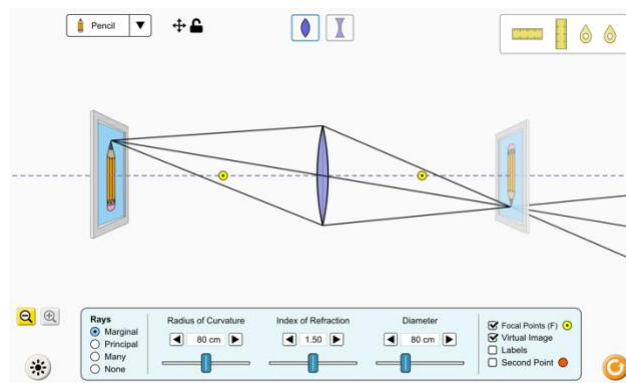
REAL AND VIRTUAL IMAGES

The simplest way to identify whether an image is real or virtual is to check its orientation. A real image will always appear inverted (upside down), and a virtual image will always appear upright (right-side up).

Let’s examine some images and determine what exactly makes a real image ‘real’ and a virtual image ‘virtual.’

If the frame in the Pivot window does not open properly, please [click here to open it in a new window](#). Choose Lens (not Mirror) to proceed.

The simulation lets us view how an image is formed by either a convex (converging) or concave (diverging) lens. We can adjust the type of lens, its focal length, and the position and height of the object.



Notice that the light is always incident from the left, traveling through the lens left-to-right. Pay attention to the sign conventions on the display.

- 4) (1 point) The default setting is a convex lens with a radius of curvature $R = 80\text{cm}$. Use the horizontal ruler tool to measure the focal length of the lens. What is the relationship between R and f ? Is this the same relationship as for spherical mirrors?

Notice that you can toggle on Marginal Rays or Principal Rays. Choose Principal Rays.

- 5) (2 points) Adjust the focal length, play around with the image distance, even change the lens from converging to diverging. Pay attention to how the Principal Rays are formed. Does changing any of the parameters affect the way in which the rays are constructed?
 - A. Yes. The rules for ray tracing change when you change the focal length of a lens.
 - B. Yes. If you change either the object distance or the object height, the rules for ray tracing change.
 - C. Yes. Changing the lens from converging to diverging results in a completely different set of rules for ray tracing.
 - D. No. The rules for ray tracing remain the same, no matter which parameter you change.

Return the simulation to the original parameters by hitting the orange reset button. Swap the converging (convex) lens for the diverging (concave) lens.

- 6) (1 point) Compare the images formed by the converging and diverging lenses.
 - A. Converging lens: Real image. Diverging lens: Real image.
 - B. Converging lens: Real image. Diverging lens: Virtual image.
 - C. Converging lens: Virtual image. Diverging lens: Real image.
 - D. Converging lens: Virtual image. Diverging lens: Virtual image.
- 7) (1 point) Using the converging lens, can you position the object to create a virtual image?
- 8) (1 point) Using the diverging lens, can you position the object to create a real image?

The magnification of an image is defined as $M = \frac{h_i}{h_o}$, where h_i and h_o are the image and object heights, respectively. According to sign convention, right-side-up is positive, and upside-down is negative, so $M < 0$ for real images and $M > 0$ for virtual.

- 9) (4 points) Select all of the true statements:
 - A. A converging lens could be used to create an image with $M = -2$.
 - B. A diverging lens could be used to create an image with $M = -2$.
 - C. A converging lens could be used to create an image with $M = +2$.
 - D. A diverging lens could be used to create an image with $M = +2$.
 - E. A converging lens could be used to create an image with $M = +\frac{1}{2}$.

- F. A diverging lens could be used to create an image with $M = +\frac{1}{2}$.
- G. A converging lens could be used to create an image with $M = -\frac{1}{2}$.
- H. A diverging lens could be used to create an image with $M = -\frac{1}{2}$.

THE THIN LENS EQUATION

The same equation can be applied to thin lenses regardless of curvature (concave or convex):

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

and the magnification M can be written as the ratio of distances as well:

$$M = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

Both of these equations require you to carefully apply the appropriate sign conventions!

If you start with the assumption that the object distance d_o is positive, then:

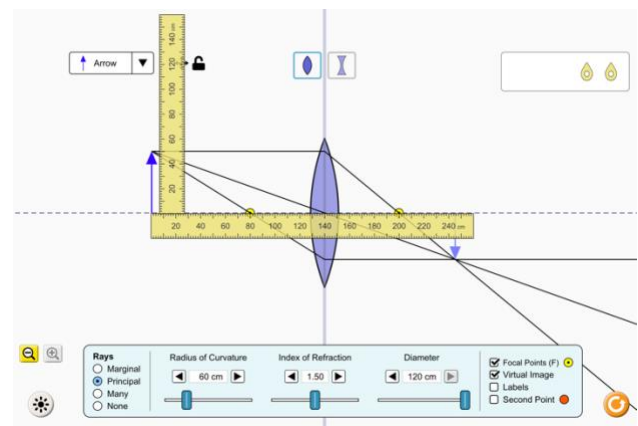
$d_i > 0$ when the image is on the opposite side of the lens as the object, and

$d_i < 0$ when the image is on the same side of the lens as the object.

Also, if you start with the assumption that the object is upright and the height h_o is positive, then:

$h_i > 0$ when the image is also upright, and $h_i < 0$ when the image is inverted (upside down).

Using the convex lens, adjust the radius to **60cm** and the lens diameter to **120cm**. Swap the pencil for the arrow. You can adjust the height of the arrow by dragging the tip.



Use the vertical ruler to make the arrow **50cm** tall. Position the arrow **140cm** from the center of the lens.

LENS	FOCAL LENGTH f (CM)	OBJECT DISTANCE d_o (CM)	OBJECT HEIGHT h_o (CM)
Convex		140	50
Concave		140	50

Add columns to your data table for **Predicted Image Distance, Magnification, and Predicted Image Height.**

- (10 points) Apply the lens equations to predict where an image will form and what its magnification will be. Use the magnification and object height to predict the image height.

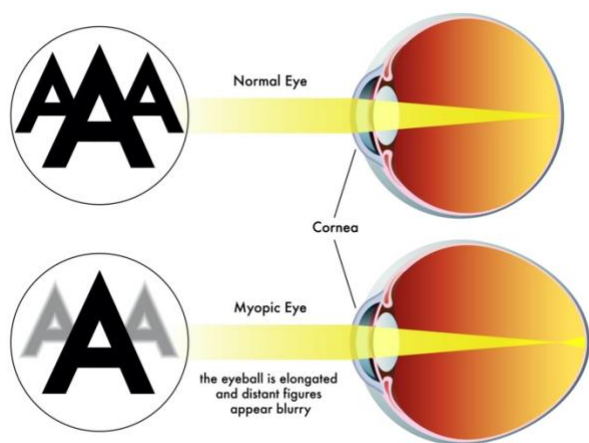
Use the ruler tools to measure the actual image distance and image height. Compare your predicted values with experimental values by adding them to your table. Create new columns for **Measured Image Distance** and **Measured Image Height**.

Now replace the converging with the diverging lens and repeat the process. Add a row to your data table and keep letting the table perform the calculations! Mind your signs!!

- (2 points) What is the uncertainty δx in your ruler tool? Do your uncertainties overlap with your predictions (for example, is your predicted d_i within the measured range $d_i \pm \delta x$)?
- (2 points) Using the converging lens, determine experimentally where you should position the object arrow to create a real image with $M = -2$.

VISION CORRECTION

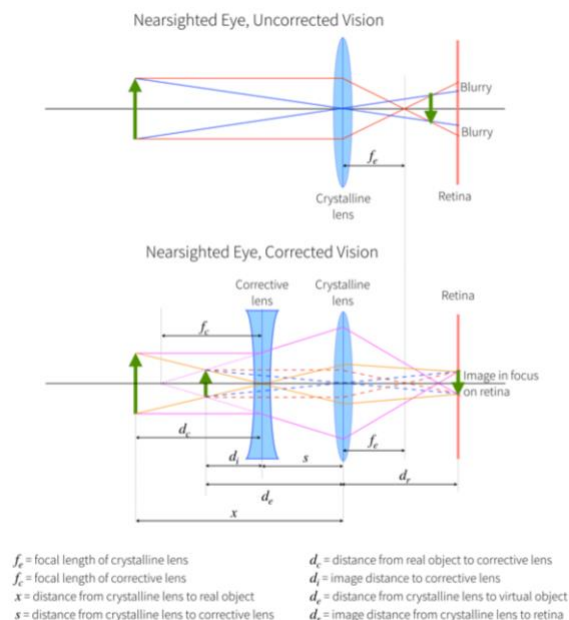
Are you nearsighted? If you don't have perfect vision, chances are you are nearsighted (near = clear, far = fuzzy). This is the most common vision defect and is typically the result of your eyeball having a slightly elongated shape.



If you wear glasses, you are familiar with the optician checking (and re-checking) lens combinations to make sure you get the best possible vision. It can get complicated (you might have astigmatism in addition to myopia, for example), but we can use the basic thin lens equation to get a pretty good idea of how to prescribe a pair of glasses.

Start with the uncorrected eye. Notice that the image forms too soon. You need a pair of glasses that will 'push' that image back onto your retina. A diverging lens will bend that light away from the principal axis, which is what needs to happen, but it has to be bent by just the right amount so that the image falls onto your retina.

So, look at the corrected vision. Just follow the ray diagram to begin with.



First step: The corrective lens forms an image. Follow the pink and orange rays, which locate the position of the virtual image. When you extend those real rays through the corrective lens, they hit the crystalline lens—but they aren't easy rays to trace because they aren't parallel to the principal axis!

Second step: Take the image formed by the corrective lens, and treat it like the object for the crystalline lens. Basically, form an image of an image. The red and blue rays are dashed because they are virtual rays, but they follow the ray tracing rules as if the concave lens isn't even there.

When your glasses are prescribed correctly, the final image falls properly on your retina. But notice what else you need to know: you need to know how long your eyeball is (distance from the lens to the retina), and you're gonna need to know where the corrective lenses will sit. Contact lenses that rest on your cornea will be about 5mm in front of the crystalline lens, while a pair of spectacles might sit 15-25mm in front of it.

Let's make some reasonable estimates and work out a prescription for a pair of glasses.

Let's create a table to solve the problem automatically. Once we have the formulae figured out, we can show that the prescription process works for a far-sighted eye as well as a near-sighted one!

Mathematically, start with the uncorrected eye: $f_e = 25\text{mm} = 2.5\text{cm}$ is about average for the human eye $d_r > 2.5\text{cm}$ means the eye is nearsighted. Choose a value a few tenths bigger. $x = 200\text{cm}$, which is two meters—this is about how far the wall chart is from the chair when you're at the optician. We simply need x to be very large compared to f_e and d_r .

You should be creating the columns of your table and filling them in as we go.

f_e (CM)	d_r (CM)	x (CM)	s (CM)

Now decide: Glasses or contact lenses?

$s = 0.5\text{cm}$ is about right for contacts, and

$s \approx 2.0\text{cm}$ is about where your glasses sit.

Pick a value and enter it into your table.

Here's where it starts to get...not exactly tricky, but a little *fussy* because we have to work the problem backward.

To calculate d_e , we are ignoring the corrective lens and assuming that the upright image is the virtual object for the crystalline lens (red and blue dashed rays!):

$$\frac{1}{d_e} + \frac{1}{d_r} = \frac{1}{f_e}$$

Solve for d_e :

$$d_e = \frac{(f_e \cdot d_r)}{(d_r - f_e)}$$

Add this column to your table and enter the formula to calculate it automatically.

Refer back to the ray diagram notice that you now have all you need to calculate the values of d_c and d_i . But pay *very careful attention* to sign convention! Add these columns and enter the formulae to calculate their values.

Almost done!

When you have completed this lab exercise in Pivot, please be sure to submit your responses. This lab is due no later than Thursday, 28 July 2022, at 11:59 PM CDT.

Now that you have the object and image distances for the corrective lens, we just apply the lens equation one last time to get the focal length:

$$\frac{1}{d_c} + \frac{1}{d_i} = \frac{1}{f_c}$$

Solve for f_c :

$$f_c = \frac{(d_c \cdot d_i)}{(d_c + d_i)}$$

- 13) (4 points) Add all the information to your table! Please be sure to use the same notation as on the figure.

If you need corrective lenses, do you know what your prescription is? The optometrist will express this using the **lens power**, which is defined as $p = \frac{1}{f}$, where the focal length is in meters. The lens power has units called diopters, which is just m^{-1} . A diverging lens will have a negative power, and a converging lens will have a positive power.

- 14) (1 point) For the near-sighted eye you created above, what is the power p of the corrective lens?

Go back to your table and add a second row of values. Use the values:

$$f_e = 25\text{mm} = 2.5\text{cm},$$

$$s = 0.5\text{cm}, \text{ and}$$

$$x = 200\text{cm},$$

but this time, assume that the eye is far-sighted. This means that the eyeball is shortened, not elongated, and

$$d_r < f_e.$$

- 15) (2 points) Set $d_r = 2.4\text{cm}$. What type of lens is prescribed? Remember, $f_c < 0$ is a diverging lens! What is the power p of this lens?