**Physics 216 Laboratory 6, Spring 2018**
**Lenses**

## Background

The objective of this experiment is to explore the behavior of lenses of various shapes and to investigate the thin lens equation relating object distance, image distance, and focal length. A *thin* lens is one for which the thickness of the lens is small relative to the radius of curvature. The two basic types of lenses are *converging* and *diverging*. As implied by their names, converging lenses bring rays of light together, while diverging lenses cause rays to spread apart. Converging lenses are thickest in the middle, while diverging lenses are thickest at the edges.

The primary equation for describing the lenses used in this lab is the thin lens equation, which relates the distance from the object to the lens (s), the distance of the image from the lens (s′), and the focal length of the lens (f):

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

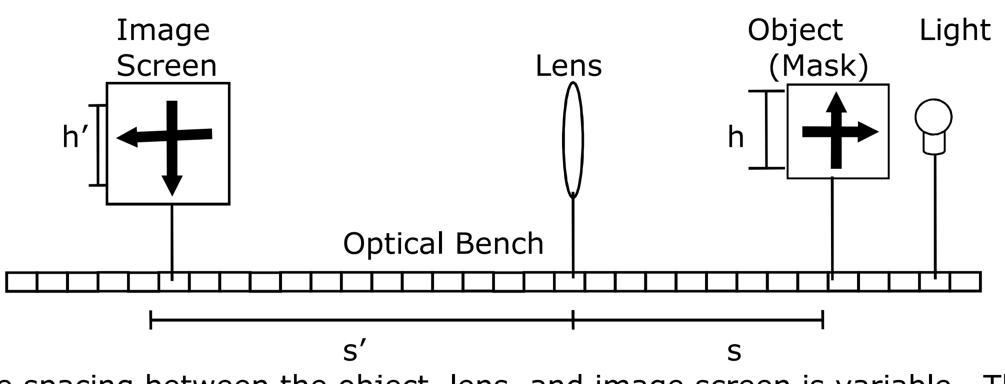
By convention, s is considered positive if the object is in front of the lens (i.e. on the same side as the incident light), while s′ is considered positive if the image forms on the other side of the lens. The focal length f is considered positive for converging lenses and negative for diverging lenses.

The *magnification* is the ratio of the image height (h′) to the object height (h), which is also the negative of the ratio of the image distance to the object distance, or

$$m = \frac{h'}{h} = -\frac{s'}{s}$$

## Apparatus

To perform this series of experiments, you will use a light bulb, a mask, a screen, a ruler, two double convex (converging) lenses, a double concave (diverging) lens, and an optical bench with associated clamps and holders, as shown below.




The spacing between the object, lens, and image screen is variable. The image screen contains markings to help you determine the height of the image (h′).

**Investigation I: Exploration: converging and diverging lenses, image formation**
**Activity 1-1: Converging lenses**
Hold a lens a few centimeters in front of your eye and look through it at a nearby printed page. Is the print enlarged (magnified) and upright, or smaller (minified) and upright, as seen through the lens? If the former, then the lens is a converging lens ($f > 0$); if the latter, it is diverging ($f < 0$). Try this with several lenses until you can make the identification of type of lens quickly and reliably.

The thin lens equation tells us that when the object distance (s) is infinity, the image distance s' is equal to the focal length (f) of the lens. In this case, parallel rays (such as those from an infinitely distant object) entering a converging lens from one side are brought together on the other side at the focal distance. So, for an object very far away from a converging lens, a real image will be formed at a distance close to the focal length of the lens. Use this definition to estimate and record below the focal lengths of the two converging lenses you have. (Consider using one of the ceiling lights, or a light bulb at the other side of the room, as the object.)

Note the physical characteristics of the shorter and longer focal length lenses. How would you design a lens with a very short focal length?

Look through one of the converging lenses at an object that is very far from the lens. Position your eye so that you can see a clear image. Now walk toward the object slowly and observe how the image changes. (You may have to move the position of your eye relative to the lens to see a clear image.) Describe what you see as you walk, using the terminology: upright/inverted, enlarged/reduced. What types of images can a single converging lens produce?

**Activity 1-2: Diverging lenses**
Unlike for a converging lens, for a diverging lens the focal length cannot be estimated by forming a real image of a faraway object, because a single diverging lens cannot produce a real image from a real object. One way to estimate the focal length of a diverging lens relies on the fact that when the object is at the focal point of a diverging lens, the image distance is half the object distance and so the magnification is equal to ½. Using quadrille-ruled paper as the object, make a rough estimate of the focal length of your diverging lens by this method and record it below.

Look through the diverging lens at an object that is very far from the lens. Position your eye so that you can see a clear image. Now walk toward the object slowly and observe how the image changes. Describe what you see as you walk, using the terminology we've developed: upright/inverted, enlarged/reduced. What types of images can a single diverging lens produce?

√ **Checkpoint 1**
(Your instructor will give you an "unknown" lens for you to identify as either a converging or a diverging lens and estimate the focal length.)

**Investigation II: Real images**
**Activity 2-1: Converging lenses and real images**

Place the light and crossed-arrow mask near one end of the optical bench and turn on the light. Place the image screen on the bench several dozen centimeters away from the mask. Place the shorter focal length converging lens between the object and the image screen, and then move it around until a sharp image is formed on the screen.

Investigate the image. Is the image erect or inverted? Is the image still present when the screen is removed from its holder? What happens to the image if a portion of the lens is covered with a piece of cardboard? Document and explain your results.

**Activity 2-2: Thin lens equation and magnification**
Obtain a sharp image with the smaller focal length converging lens. Open an Excel spreadsheet and make the columns below. Record the object location, the lens location, and the image location in the appropriate columns. Also record the object height h and the image height h' in the appropriate columns. Then fill in the other columns using spreadsheet calculations.

| Object location (cm) | Lens location (cm) | Image location (cm) | Object Distance s (cm) | Image Distance s' (cm) | 1/s (1/cm) | 1/s' (1/cm) | s'/s | Object Height h (cm) | Image Height h' (cm) | h'/h |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |

Repeat your measurements for four widely different image and object positions. (If the object height (h) is varying from trial to trial, something is very wrong.) In addition to your measured values, fill in the remaining columns of the table.

You should see a relationship between columns 6 and 7—what is it? Use this to find the mean focal length of the lens and its uncertainty (standard deviation of the mean).

f =

df=

How good is the agreement with your rough estimate of the focal length in Activity 1-1?

Next we'll use a graphical method that will allow us not only to get a numerical value for the focal length, but also to look explicitly at the functional relationship between object and image distances and the focal length.

Do you expect a graph of s' vs. s to produce a straight line? What if you plot 1/s' (y-axis) vs. 1/s (x-axis)? Hint: consider the lens equation.

Open LoggerPro and copy the two appropriate columns of your data into a LoggerPro table. (Don't close the spreadsheet yet!) Use the lens equation and your knowledge of the equation of a straight line ($y = mx + b$) to explain your graph of 1/s' vs. 1/s. What physical quantity does the slope of your graph represent? What about the y intercept?

Carry out a fit to your data and record the slope and y-intercept along with their uncertainties. Then use the results of the fit to find the focal length of the lens (along with uncertainty). Hint: since 1/f involves division, the relative uncertainty in f is the same as the relative uncertainty in 1/f.

f =

df =

Does this agree with the value for f that you found in the first part of this activity?

Finally, let's look at the magnification. What is the relationship between columns 8 and 11 of the table? Do you see any systematic differences in the magnitude of the magnification as measured directly (h'/h) and the magnification as predicted from the image and object distances (s'/s)?

**√ Checkpoint 2**

**Activity 2-3: Another relationship involving the focal length**
You saw earlier that there is a configuration for which the image distance and the object distance are equal. This occurs when s and s' are each equal to twice the focal length of the lens. Using what you regard as the best measurement of the focal length of the smaller focal length lens, set up the object at 2f from the lens and check the image location. Does it agree with what you expect? Draw a ray diagram (roughly to scale) of this situation.

Now replace the lens with the other converging lens (the one with the longer focal length). Measure the distance at which the object distance and the image distance are the same and use this measurement to determine the focal length of this lens. Does it agree with your earlier estimate for f in Activity 1-1?

f =

df =

**Activity 2-4: Challenge**
Choose one of the converging lenses and place the mask and the screen about 4f apart. *Prediction:* How many places can you put the lens so that the image is well focused on the screen?

Test your prediction experimentally. (Don't move the object or the screen, just the lens.) How many such locations are there? For each location, what are the characteristics of the image? Draw a ray diagram (roughly to scale) of this situation.

**√ Checkpoint 3**
**Investigation III: Virtual images**

**Activity 3-1:** Using the converging lens of longer focal length, observe what happens if you attempt to obtain a clear image on the screen with an object distance of less than the focal length. Does this make sense?

Use the measured object distance and the focal length you measured for this lens in the previous activity to predict where the image is. Experimentally locate the image using parallax. Does the image location agree with where you predicted it to be? Resolve any discrepancies. Draw a ray diagram (roughly to scale) of this situation.

**Activity 3-2:** Using the diverging lens, place the object about 30 cm from the lens and observe what happens if you attempt to obtain a clear image on the screen. Does this make sense?

Use the measured object distance and the focal length you estimated for this lens in Activity 1-2 to predict where the image is. Experimentally locate the image using parallax. Does the image location agree with where you predicted it to be? Resolve any discrepancies. Draw a ray diagram (roughly to scale) of this situation.

√ **Checkpoint 4**