Physics 2310 Lab #5: Thin Lenses and Concave Mirrors

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Purpose: The purpose of this lab is to introduce students to some of the properties of thin lenses and mirrors. The primary goals are to understand the relationship between image distance, object distance, and image scale.

Theoretical Basis: You may be familiar with simple lenses and how they form images. The lens of your eye or a camera collects and focuses light and forms an image on retina or a piece of film or digital detector. A positive, convex glass lens works in much the same way to produce a real image. In contrast, a negative, concave lens can only produce virtual images. See the lecture notes of your textbook for a more complete description. Let's explore the properties of some simple lenses.

Begin by noting the equipment at each lab station. You will find a light source, a selection of lenses and mirrors, a white screen for viewing the images, and some sort of split-screen thing. We'll come back to it later. We will use the scale on the bench to measure the location of each component and compute the object and image distances. Note that there is a small offset between the light source support and the actual location of the illuminated screen that serves as the object. Your lab TA will give you the value of this correction. Note that the light source "object" has a mm scale and two arrows at right angles so that you can determine the size of the image and its orientation on the screen when imaged by the lens.

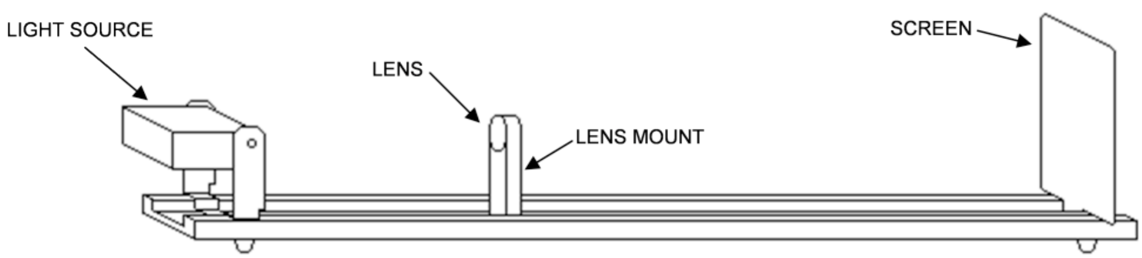


Figure 3: Optical bench and accessories

Procedure 1: Finding the image and focusing the lens.

Set up the light source and screen as far apart as possible on the optical bench. Turn on the light source. Now slide the lens holder back and forth along the bench until you find the point where the image formed by the lens comes into sharp focus. Use the scales on the optical bench to compute the *separation* between the lens and screen. Open up EXCEL and make columns for image distance, object distance, and image height (see below). Record the distance between the lens and the screen. *This is known as the image distance*. Next measure and record the distance between the light source and the lens. *This is known as the object distance*. Be sure to make any corrections that are needed. Estimate how accurately you can measure the position of best focus by carefully moving the lens. Each member of your lab group should try this and use these data as an estimate of your measurement error. Use the formula for the standard error (see Appendix of lab) for computing your measurement error.

Image formation by a lens

Draw a picture of the pattern on the light source and the appearance of the same pattern in the image formed by the lens. How do they compare? Now carefully measure the size of the light source pattern and its image using the mm scale provided. Record the image size as a column in your and add another for the image magnification (the ratio of measured image size to object size). Describe what you find.

Procedure 2: The relation between image distance and object distance

Now we want to examine the relation between the image distance and the object distance for the convex lens. In this case we will vary the object distance and then find where the lens forms and image. We will want to make a series of measurements of image and object distances for the lens. Recall that the thin lens equation predicts a hyperbolic relationship:

$$\frac{1}{s_o} + \frac{1}{s_i} = \frac{1}{f}$$

Verify that the light source is at the extreme end of the bench and the screen is at the other extreme. Now move the lens holder as before until the image is in sharp focus. Measure and record the image and object distance and measure the image size. Without moving the light source or screen see if you can find a second position where the lens focuses. Record the image and object distances and measure and record the image size. What did you find? Use the equation above to compute the focal length of the lens at both positions where you could find a focus.

Now we want to sample the functional relationship the equation above predicts. Repeat the above procedure by splitting the length of the optical bench into about 8-10 segments and adopt these positions as your set of object distances. Move the lens to each of these positions, one at a time, and then move the screen to focus the image. Make a measurement of the object and image distances and the image size at each location and record these in your spreadsheet. *Be sure to take turns with your measurements.*

Now use Excel to make a graph of the image vs. the object distance for the lens. Be sure and label the object and image distances on your graph. Identify the asymptotes on your graph. These correspond to the focal length of the lens. In your lab report, sketch these as horizontal and vertical lines on your graph. Describe what you find. Now insert two new columns and have EXCEL compute $1/s_o$ and $1/s_i$. Refer to the thin lens equation given above. What do expect to find when you use EXCEL to fit a trend line to $1/s_i$. vs. $1/s_o$? Try it and describe your results. Can you compute the focal length of the lens from this fit? If so, describe how you did it and what you find.

How well does the computed (theoretical) value of the focal length agree with what you infer from your measurements? Can you think of reasons why they might not precisely agree?

Magnification of Thin Lenses

Recall that the theoretical magnification of a thin lens is given by the ratio of image and object distances:

$$M = \frac{s_i}{s_o}$$

The empirical magnification is just the measured ratio of image size to object size. Add a column in EXCEL and compute this theoretical value from your image and object distances. Now add yet another column in which you compute the measured magnification from the ratio of the image size (your measurements) and the object size (a constant). Make a second graph showing the relation between the theoretical value and your measured value. Fit a trend line and report what you find. Are they in good agreement? If not can you think of why they might not be?

Procedure 3: The Imaging Properties of Concave Mirrors

Concave mirrors form images as well as lenses. To see this clearly we need to remove the screen and lens and place the concave mirror on the optical bench facing the light source and about 300mm away. Note that if we placed the screen in between the light source and mirror it would block the light. Now we know the purpose of the split screen. Place the split screen in between the concave mirror and the light source. Note how the light will pass through the open side but the "white screen section" can still be used to see the image reflected from the concave mirror. Clever huh? Move the screen until the image is in sharp focus. Start a new EXCEL spreadsheet similar to the one you constructed above for the lens. Measure the positions of the components and compute the image and object distances. Enter them into EXCEL. As before, use the mm scale to measure the image size. Enter these values into your column for magnification. Now sketch the appearance of the light source pattern formed by the mirror. Does it differ from that seen in the image formed by the lens?

The imaging properties of a concave mirror are similar to that of a lens so we can repeat our procedure for sampling the relation between image and object distance. Do this by repeating your measurements by placing the concave mirror at 8-10 locations along the bench. At each location (object distance) find the focus by moving the split screen until you have a clear image. Record the image and object distances as well as your measurement of the image size. Plot these data in graphs similar to the ones you made for the lens data (image vs. object and the inverse functions) and comment on any differences you find. Fit the trend lines to the inverse data and compare your measured value of the focal length (asymptotes) to the theoretical value obtained from the "thin lens equation".

Procedure 4: Visualizing Thin Lens Properties Through Graphical Ray Tracing

Now we want to solidify what we've learned through a set of graphical ray-tracing exercises. Recall that the principle planes of a thin lens are superimposed at the center of the lens. What follows are some drawings of thin lenses and mirrors where you can apply what you've learned to illustrate and reinforce what we've leaned in class and in lab.

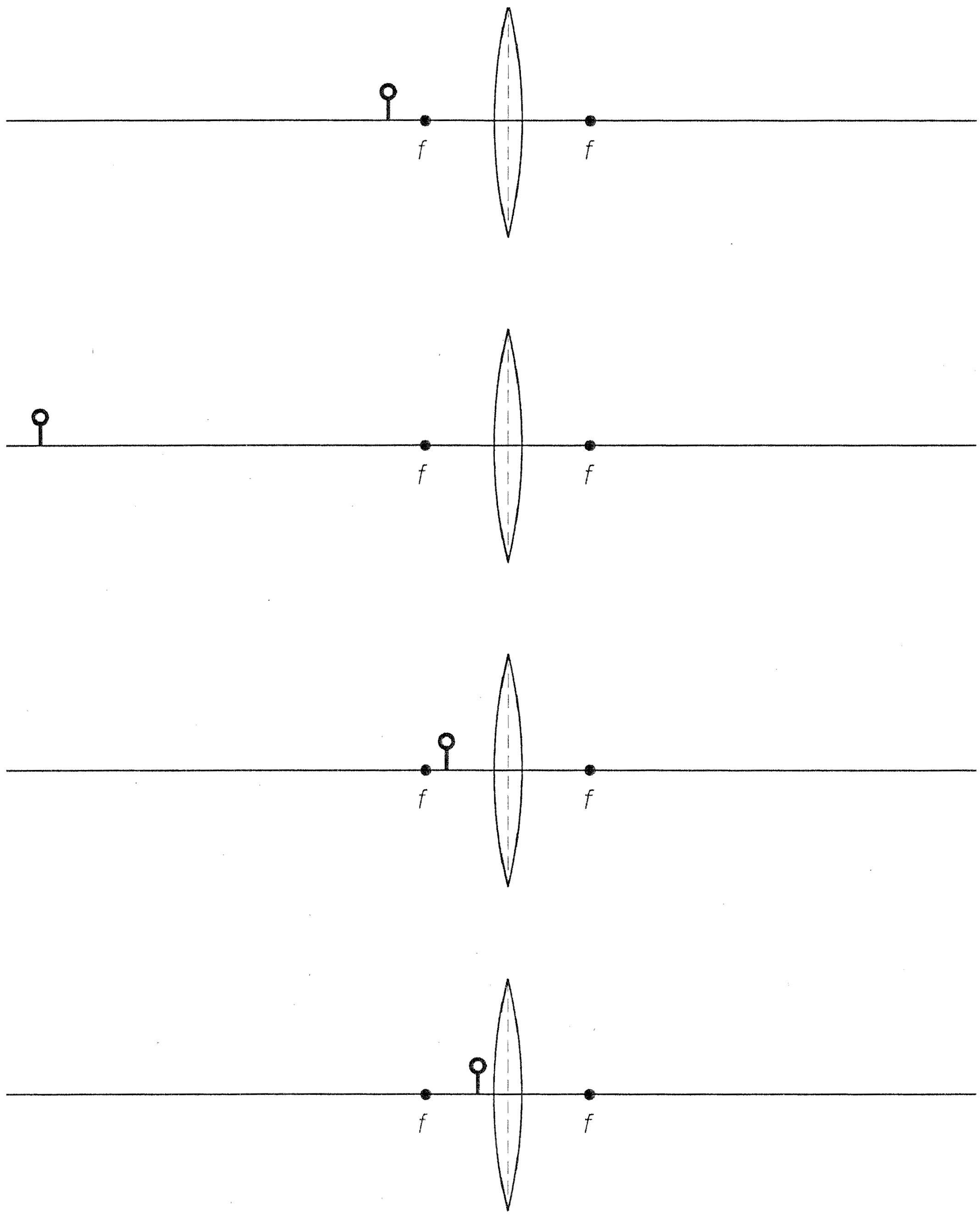
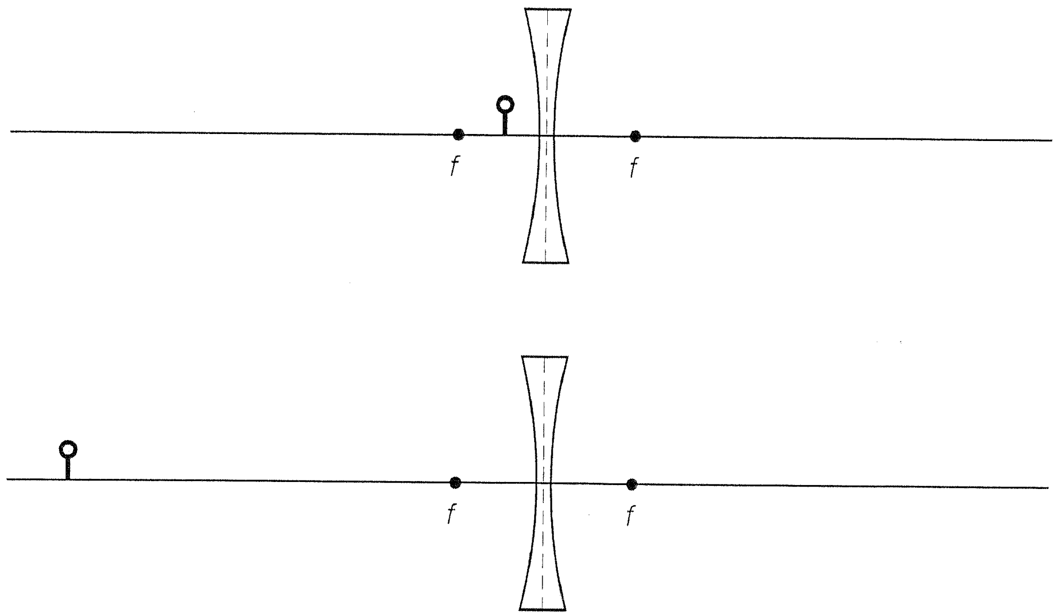


Figure 4: Graphical ray tracing with positive lenses.



Object at infinity

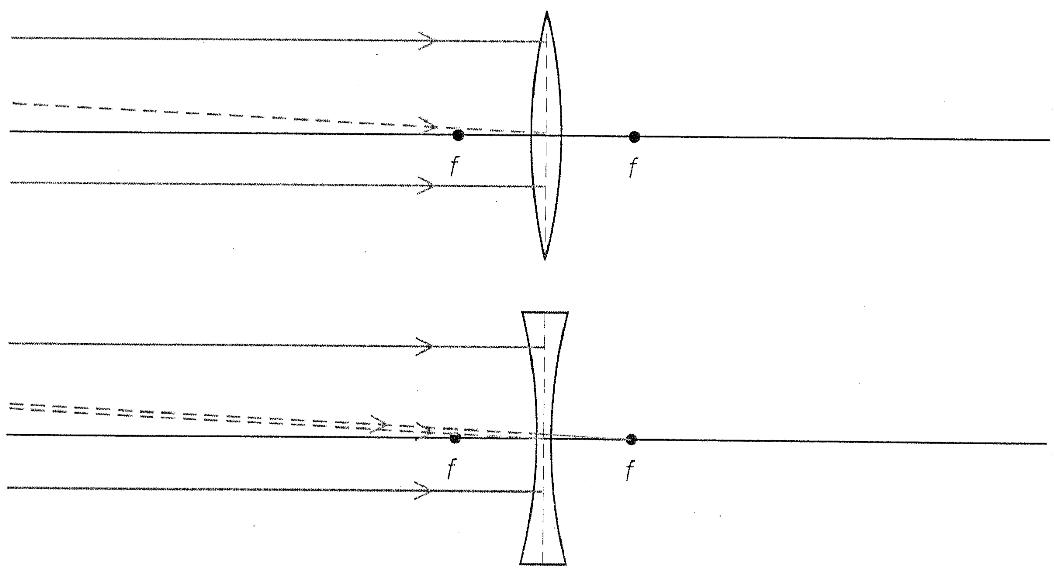


Figure 5: Graphical ray tracing with negative lenses and objects at infinity.

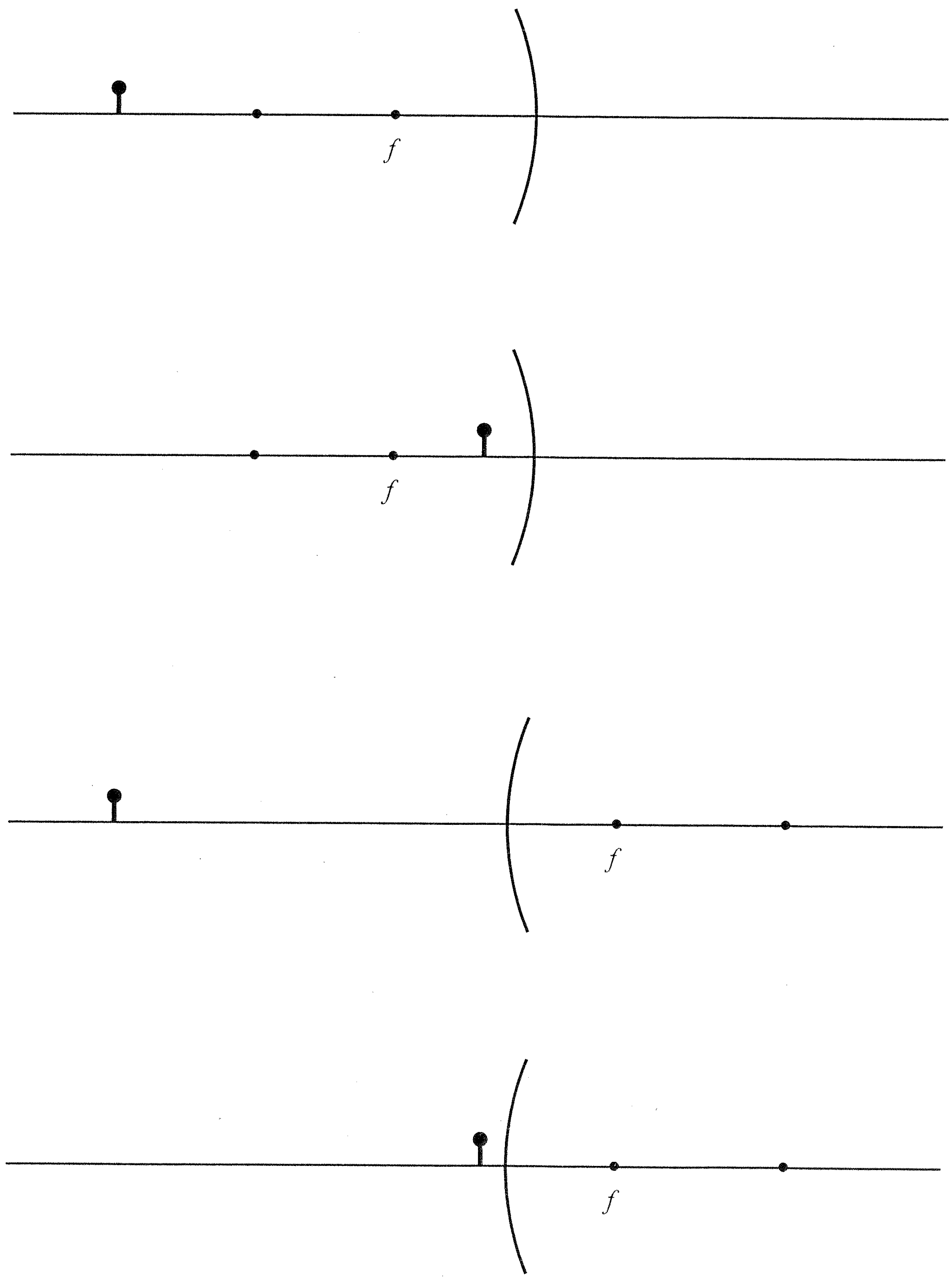


Figure 6: Graphical ray tracing with mirrors.

Appendix: The Standard Error

When you make several measurements of a quantity you can compute the error in your measurements from the deviations, or spread, from the average. For example, we could average various measurements of the focal length of a lens to find our best estimate of the focal length. We can also use these measurements to estimate how accurate our result is. One way to estimate the precision of such an average is to find the standard error of the estimate.

•Begin by subtracting the average focal length from each of the estimates to find the **residuals** and record them.

•Now square each of the residuals and record them.

•Add these up to find the sum of the residuals squared $\mathbf{S_r}$ and divide this by the number of points. This quantity is the average of the residuals squared and is called the variance.

If we take the square root of the variance we get the standard deviation, or standard error (σ). We might expect that our measurements would cluster around the correct value and that the average of the measurements would thus have a lower error than any given measurement. Thus, if we took more and more measurements the average would get closer to the "true" result. Measurement theory, i.e., statistics, predicts that unbiased measurements will follow a Gaussian distribution centered on the correct value. In this case, the standard error of our average will improve with the square root of the number of measurements.

standard error of average = (σ) / square root of (N-1)

In our case, N-1 is the number of measurements minus 1. If the standard error is typically about 1 mm, then about 68 percent of the measurements will fall within 1 mm of the average focal length.

•Rewrite the focal lengths with their standard errors in proper form, for example 48 $\pm$ 1.2 and adopt this error for all your remaining measurements.

Notice that the standard error gives us a measure of the precision of our observations but cannot warn us of **systematic errors** that affect all of our observations by the same amount. An example of this might be an error in our measurement scale or in our meter sticks. In this case, we have a systematic error and all bets are off! Not really, we just apply this systematic error to all of our measurements to correct for it.