LAKE FOREST COLLEGE
Department of Physics

Physics 115 **Experiment #11: Lenses v2** Spring 2025

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Table:

Preliminary Instructions
Create a folder for you and your lab partner on Teams. Save a copy of these instructions for each student to that folder. Include your name in the filename. As you edit this document put your text in a different color. Save one copy of the Excel template with both your and your partner's name included in the filename.

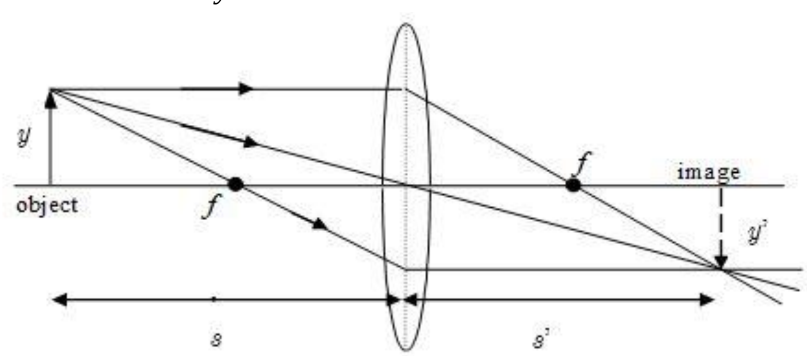
Experimental Purpose
The purpose of this week's experiment is to test the predictions of the thin lens equation and the magnification equation for a single converging lens and for a combination of a diverging and a converging lens.

Background
A lens is said to have a focal length *f*. For converging lenses, this focal length is positive; for diverging lenses, this focal length is negative. In the first part of the experiment, you will place an object at a distance *s* from a converging lens as shown below. If this object distance is larger than the focal length ($s > f$), then light from the object passing through the lens will form an inverted real image at some point on the far side of the lens. The distance between the lens and the image is denoted as s' and is related to the object distance and the focal length by the thin lens equation.

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad (1)$$

The magnification is defined to be the ratio of the image height to the object height. When the image is inverted, the image height is said to be negative. This magnification is equal to the negative of the ratio of the image distance to the object distance

$$m = \frac{y'}{y} = -\frac{s'}{s} \qquad (2)$$



Part I: Single lenses

1. Measure the size of the object.
   a. Locate the lighted object and observe the set of 11 green lights in the shape of an "F."
   b. Use a ruler to measure the distance between the two horizontal lines of lights in the "F." Measure from the center of the bulbs in one line to the center of the bulbs in the other line. Record this distance in the Excel table under object height.

2. Setup the optical system as shown in the above figure.
   a. Place the double convex lens (labeled +100 mm) in the lens holder. Note that this lens is thicker in its center and thinner near the edge.
   b. Place a meter stick on a table. Use drafting tape to secure the ends of the meterstick to the table. The lens holder, object, and screen all have a notch at the bottom that allows them to be placed directly over the meter stick. Place the lens holder with the center of the lens at the 60 cm mark of the meter stick. The bottom of the lens holder is approximately 6 mm wide, so one side of the holder should be at the 59.7 cm mark and the other side should be at the 60.3 cm mark.
   c. Turn on the lighted object and position it on the meter stick such that the front surface is at the 88 cm mark. This sets the object distance to be s = 28 cm.
   d. Position the viewing screen on the meter stick near the 40 cm mark.

3. Find real images
   a. Move the position of the viewing screen closer to the lens and farther away from the lens and observe the image of the inverted green dotted "F" formed on the screen.
   b. Adjust the position of the screen to achieve the sharpest focus. You want each green dot to have a sharp green circular ring.
   c. Take a picture of your setup and label the important pieces. **Paste that picture here. All tables, diagrams, and graphs must have captions.**

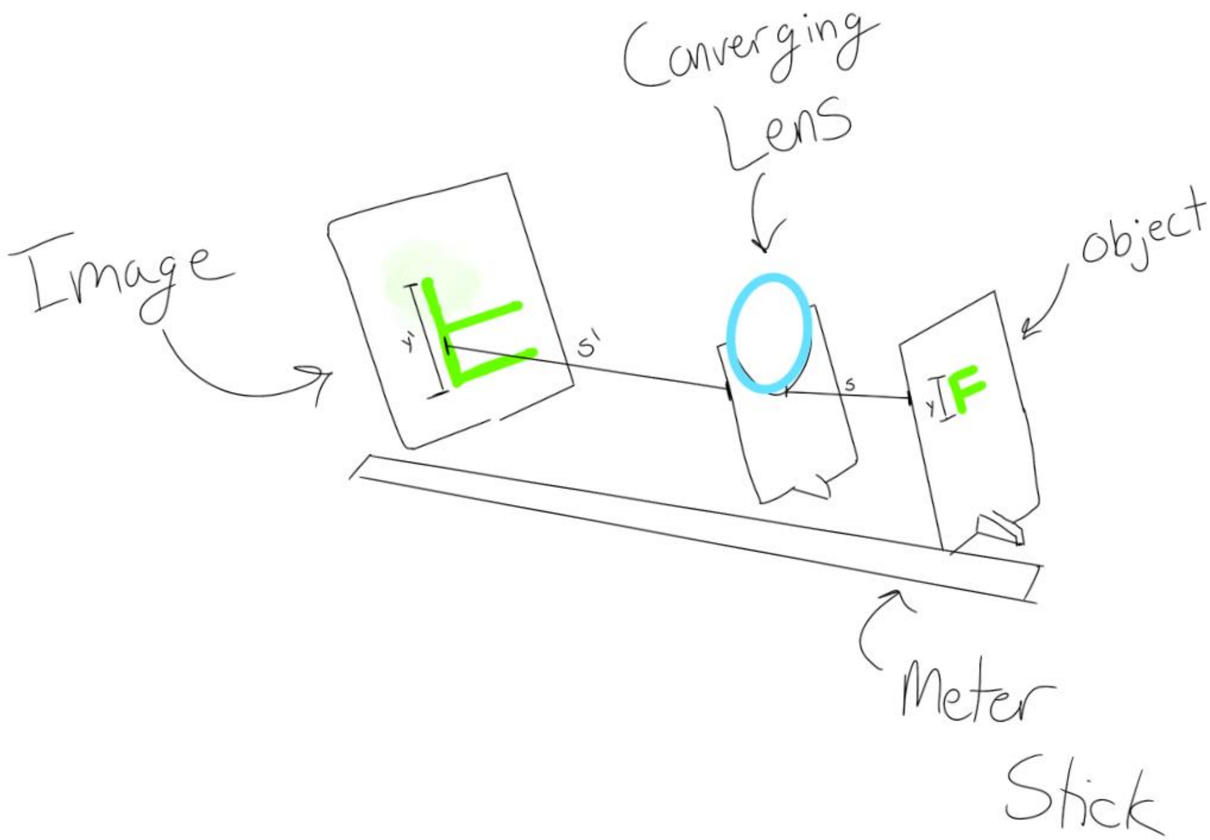


Figure 1. Single Lense Focal Length Measurement Apparatus. The object was a LED Object from Arbor Scientific. It was refracted through a converging lens in an Arbor Scientific Len Holder and onto an Arbor Scientific Viewing Screen. All object were placed along a meter stick so the distance between the object and the lense, s, and the distance between the image and the lens, s', could be measured.

d. Double check that the lens is still centered at 60 cm and that the front of the object is still positioned at 88 cm. Reposition them if necessary, then readjust the viewing screen to achieve the sharpest focus. Measure the distance from the center of the lens to the front of the viewing screen. Record this image distance in the Excel table.
e. Measure the image height as the distance on the viewing screen between the two horizontal rows of green dots. Measure from the center of one row of green dots to the center of the other row of green dots. Since the image is inverted, the image height is negative. Record this image height in the Excel table.
f. Calculate the measured magnification as the ratio of the image height to the object height.

$$m_{\text{measured}} = \frac{y'}{y}$$

g. Calculate the predicted magnification as the negative of the ratio of the image and object distances. $m_{\text{predicted}} = \frac{-s'}{s}$

h. Adjust the position of the lighted object and repeat steps a-g for each of the desired object distances given in the Excel table. Keep the center of the lens at 60 cm and move the object and the viewing screen for each trial.
i. Qualitatively compare the measured and predicted magnifications of each trial. You do not need to calculate a ratio test. **Instead, simply state here whether the predicted and measured magnifications seem "close."**

The predicted magnification was close to the measured magnification for all distances. Only the last values, -2.40 measured and -2.54 predicted, had a difference of more than 0.100.

j. Copy the image and object distances into LoggerPro and make a plot with image distance on the vertical axis and object distance on the horizontal axis.
k. Apply a curve fit. You will need to define a new functional form as $y = \dfrac{1}{\frac{1}{f} - \frac{1}{x}}$. Note that this is the form of the thin lens equation solved for the image distance *s*'.
l. Adjust the size and style of your data points to make them show up clearly. Adjust the font size and number of decimal places shown in the fit parameters box to make it easy to read. **Paste a copy of your graph here.**

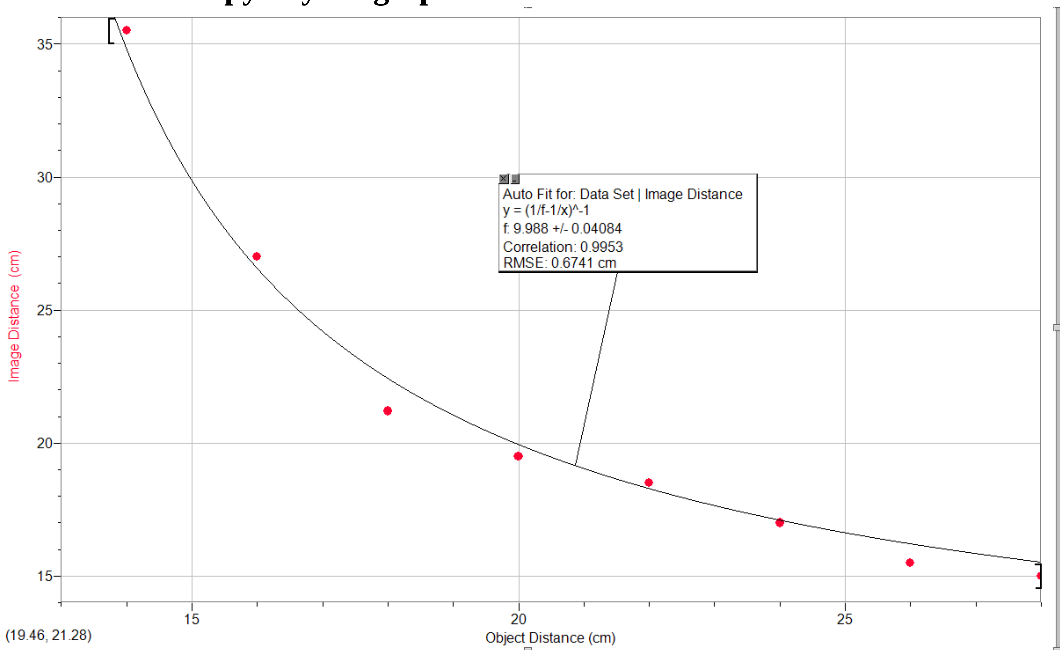


Figure 2. Focal Distance of a Single Lens Curve Fit. The object distance is the distance between the object and the lens. This value, measured in centimeters, is on the x-axis. The image distance is the distance between the image and the lens. This distance, in centimeters, is on the y-axis. The values were fitted using the equation y = ((1/f)-(1/x))^-1 where f is the focal length. The correlation of the fit was relatively high indicating that that values fit well to the curve.

m. Record the *f* fitting parameter in the Excel table as the measured focal length.

n. **Paste a copy your Excel Table 1 here.**

object height, *y* (cm)	object distance, *s* (cm)	image distance, *s*' (cm)	image height, *y*' (cm)	measured magni-fication	predicted magni-fication	nominal focal length (cm)	measured focal length (cm)
3.5	28.0	15.0	-1.90	-0.543	-0.536	10.0	9.988
	26.0	15.5	-2.30	-0.657	-0.596		
	24.0	17.0	-2.40	-0.686	-0.708		
	22.0	18.5	-2.80	-0.800	-0.841		
	20.0	19.5	-3.40	-0.971	-0.975		
	18.0	21.2	-4.20	-1.20	-1.18		
	16.0	27.0	-5.60	-1.60	-1.69		
	14.0	35.5	-8.4	-2.40	-2.54		

Table 1. Single Converging Lens Measurements. The object height, y, was measured from the top of the F LEDs to the bottoms of the F LEDs. The object distance, s, was measured from the front of the LEDs to the center of the lens. The image distance, s', was measured from the middle of the lens to the front of the viewing screen. The image height, y', was measured from the top of the F to the bottom of the F. Because the image was inverted, this measurement was negative. The measured magnification was calculated using the equation m = y'/y and the predicted magnification was calculated using the equation m = -s'/s.

o. **Qualitatively compare the nominal and measured focal lengths here.** You do not need to calculate a ratio test.

The nominal focal length is close to the measured focal length with a difference of only 0.012.

4. Observe a virtual image

When the distance between an object and a converging lens is less than the focal length, then an upright and enlarged virtual image is formed.

a. Lay the piece of graph paper flat on the table. Carefully hold the converging lens in its holder a few cm above the graph paper. Look through the lens and observe an enlarged virtual image of the graph paper. This is using the lens as a magnifying glass.
b. Adjust the distance between the lens and graph paper until the spacing between lines in the image (seen through the lens) is twice as large as the spacing between lines in the object (seen around the lens). There will be significant distortion.
c. Roughly measure the distance between the center of the lens and the graph paper that results in a magnification of two. Record this value in your Excel table.
d. Combine the thin lens equation (1) and the magnification equation (2) to show that, when the magnification is +2, the focal length is equal to twice the object distance. **Insert your derivation here.**

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} \qquad m = \frac{-s'}{s}$$

$$s' = -ms$$

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{-ms}$$

$$= \frac{1}{s}\left(1 - \frac{1}{m}\right)$$

$$f = s\left(\frac{1}{1-\frac{1}{m}}\right) = \frac{s}{1-\frac{1}{m}}$$

$$\text{if } m = 2$$

$$f = \frac{s}{1-\frac{1}{2}} = \frac{s}{\frac{1}{2}}$$

$$f = 2s$$

Figure 3. Using the thin lens equation 1/f = 1/s + 1/s' and the magnification equation m = -s'/s a relationship between focal length, magnification, and object distance f=s/(1-1/m) can be derived. f is the focal length, s is the object distance, s' is the image distance, and m is the magnification. When the magnification is 2 then the focal length is 2 times the object distance.

e. Use an Excel formula to calculate the focal length of the lens based on the derivation above.

f. Paste a copy of your Excel Table 2 here.

object distance that gives *m* = +2 (cm)	calculated focal length (cm)
4.80	9.60

Table 2. Calculated Focal Length of Converging Lens. The distance was measured by eye, looking through the lens at a grid. When one grid square inside the lens was equivalent to two squares outside the lens then the magnification was two and the distance between the lens and the page was measured. The focal length was calculated using the equation derived above.

g. Qualitatively compare this measurement of the focal length to the nominal value and to the value that you measured in step 3.

The measured focal length of 9.988, from the curve fit, and the calculated object distance of 9.60, from the magnification, are similar. They only have a difference of 0.388.

Both values are also similar to the nominal focal length of 10.0cm with a difference of 0.012cm and 0.400cm respectively.

5. Use a diverging lens
   a. Identify the double concave lens labeled –200 mm. The nominal focal length is $f_2 = -20.0\ \text{cm}$. Note that this lens is thinner in the center and thicker near the edge. Slide this lens into the black insert and insert it into the double lens holder.
   b. Lay the piece of graph paper flat on the table. Carefully hold the lens in its holder 15 - 25 cm above the graph paper. Look through the lens and observe a reduced virtual image of the graph paper.
   c. Adjust the distance between the lens and graph paper until the spacing between lines in the image (seen through the lens) is half as large as the spacing between lines in the object (seen around the lens). There will be significant distortion.
   d. Roughly measure the distance between the center of the lens and the graph paper that results in a magnification of +1/2. Record this value in Excel Table 3.
   e. Combine the thin lens equation (1) and the magnification equation (2) to show that, when the magnification is +1/2, the focal length is equal to the negative of the object distance. **Insert your derivation here**.

if $m = \frac{1}{2}$

$$f = \frac{s}{1 - \frac{1}{(1/2)}} = \frac{s}{1-2} = \frac{s}{-1}$$

$$f = -s$$

Figure 4. Diverging Len Focal Length Calculation Derivation. The start of the derivation using the thin lens equation and the magnification equation can be seen above in Figure 3. f is the focal

length, s is the object distance, s’ is the image distance, and m is the magnification. When the magnification is 0.5 then the focal length is the negative object distance.

f. Use an Excel formula to calculate the focal length of the lens based on the derivation above.

g. **Paste a copy of your Excel Table 3 here.**

Object distance that gives m = +0.5 (cm)	Calculated focal length (cm)
19.5	-19.5

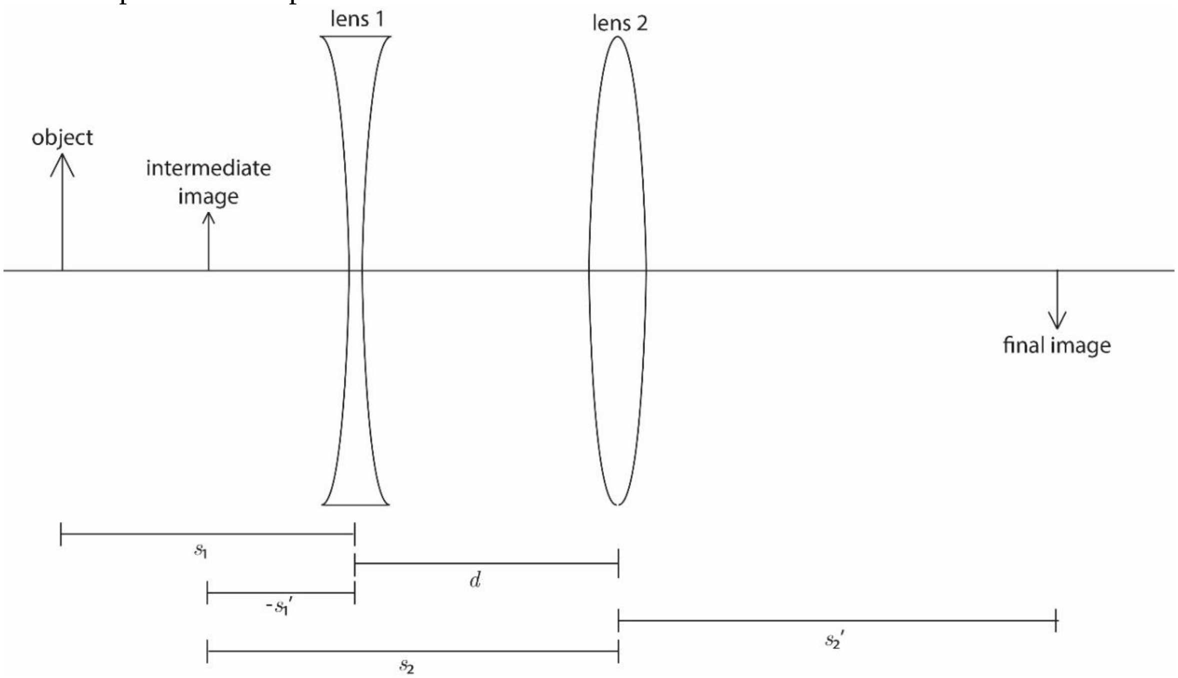
Table 3. calculated Focal Length of a Diverging Lens. The distance was measured by eye, looking through the lens at a grid. When two grid squares inside the lens were equal to one square outside the lens then the magnification was one half and the distance between the lens and the page was measured. The focal length was calculated using the equation derived above.

h. **Qualitatively compare this measurement of the focal length to the nominal value**.

The measured focal length of -19.5 is close to the nominal value of -20.0 with a difference of only 0.50.

Part II: Two-lens system

The second part of the experiment involves two lenses as shown below.



The components are arranged in a particular order from left to right: object, diverging lens (lens 1), converging lens (lens 2), and viewing screen. You will place lens 1 at a distance s_1 from the object. The image of a real object in a diverging lens is always virtual and difficult to locate directly. That virtual image will serve as the object of a converging lens (lens 2), which has a positive focal length (f_2). The converging lens will be placed a distance d from the diverging lens. Light from the object passing through the two lenses will form an inverted real image at some point on the far side of the converging lens. The distance between lens 2 and the final image is denoted as s_2'. The object and image distances are related by the thin lens equation for each lens. The diagram shows that the s_1', s_2, and d are also related.

$$s_2 = d - s_1' \qquad (3)$$

The product of the magnifications from each lens gives an overall magnification.

$$m_{\text{total}} = m_1 \cdot m_2 = \left(-\frac{s_1'}{s_1}\right)\left(-\frac{s_2'}{s_2}\right) \qquad (4)$$

6. Set up the optical components
   a. Place the object on the meter stick such that its front surface is at the 85.0 cm mark.
   b. Place lens 1 (The diverging lens that you used in step 5) a few cms in front of the object. Look through the lens. **Describe the image that you see. Is it upright or inverted? Is it enlarged or reduced? Is it real or virtual? Take a picture of the virtual image as seen through the diverging lens. Paste that picture here.**

Figure 5. Image of a Diverging Lens. The image created by the diverging lens was virtual as it was behind the lens. No image was projected onto the viewing screen. The image was upright and the size was slightly reduced from that of the original object. The image was only visible when looking though the lens from the front.

c. Place the center of lens 1 at the 80.0 cm mark of the meter stick. The bottom of the lens holder is approximately 16 mm wide, so one side of the holder should be at the 79.2 cm mark and the other side should be at the 80.8 cm mark. This sets $s_1 = 5.0$ cm.
d. Place the center of lens 2 (The converging lens that you used in steps 3 and 4) at the 60.0 cm mark of the meter stick. This sets the distance between the lenses, $d = 20.0$ cm.
e. Position the viewing screen on the meter stick near the 40.0 cm mark.
f. **Paste a labeled photograph of the setup here**.

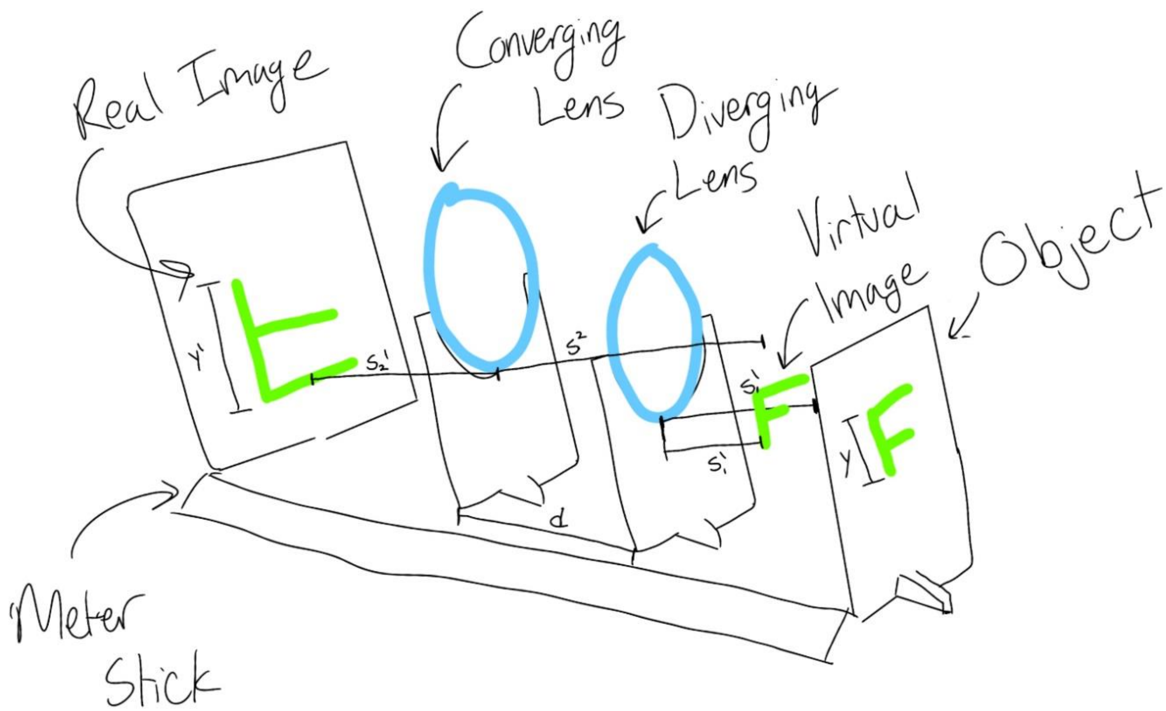


Figure 6. Dual Lens Focal Length Measurement Apparatus. The object was a LED Object from Arbor Scientific. It was refracted through a diverging lens in an Arbor Scientific Double Len Holder and created a virtual image behind the lens. The virtual image refracted though a converging lens in a Arbor Scientific Len Holder and onto an Arbor Scientific Viewing Screen. All object were placed along a meter stick so the distance between the object could be measured. Measured distances include the distance between the object and the diverging lens, s_1, between the diverging lens and the virtual image, s_1', between the virtual image and the converging lens, s_2, between the real image and the converging lens, s_2', and between the converging lens and the diverging lens, d.

7. Find real images
   a. Adjust the position of the viewing screen to achieve the sharpest focus.
   b. Double check that the object and both lens holders are still at their correct locations. Reposition them, if necessary, then readjust the viewing screen to achieve the sharpest focus.
   c. Measure the distance from the center of lens 2 to the front of the viewing screen. This is s_2'. Record this lens 2 image distance in the Excel Table 4.
   d. Use equation (1) for lens 2 to calculate the lens 2 object distance.
   e. Use equation (3) to calculate the lens 1 image distance.
   f. Adjust the positions of the lenses to achieve the values of s_1 and d listed in Table 4. For each case find the position of the viewing screen that gives the sharpest focus. Measure and record the lens 2 image distances.
   g. For the single trial where s_1 = 15.0 cm and d = 5.0 cm, measure the image height as the distance on the viewing screen between the two horizontal rows of green dots. The image

is inverted, so the image height is negative. Record this image height in the Excel Table 4. Calculate the predicted and measured magnifications. You do not need to do this part for the other trials. **Qualitatively compare the measured and predicted magnifications here.**

The measured magnification was like the predicted magnification with a difference of only 0.06.

h. Copy the seven s_1 and s_1' distances into LoggerPro and make a plot with image distance on the vertical axis and object distance on the horizontal axis.
i. Apply a curve fit as you did in step 3 and find the focal length of lens 1. **Paste a copy of your graph here.**

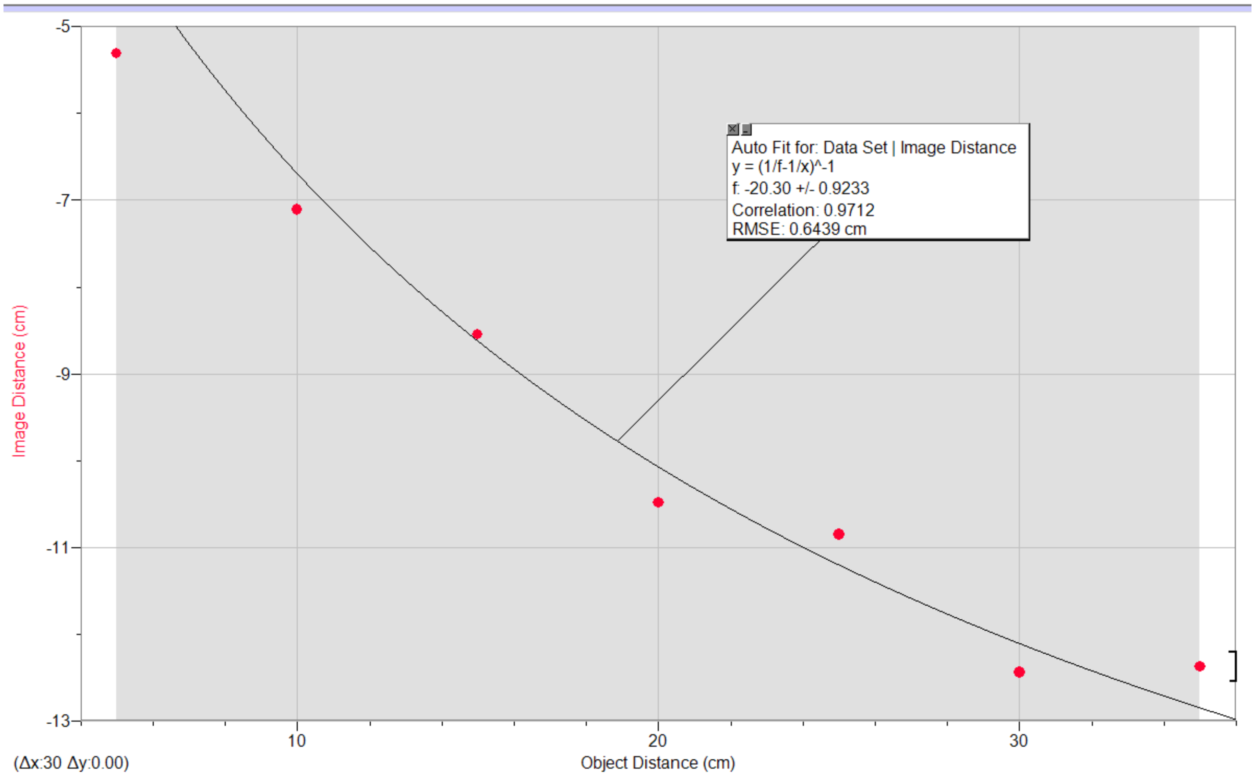


Figure 7. Focal Distance of Diverging Lens Line Fit. The object distance is the distance between the object and the diverging lens. This value, measured in centimeters, is on the x-axis. The image distance is the distance between the virtual image and the diverging lens. This distance, in centimeters, is on the y-axis. The values were fitted using the equation y = ((1/f)-(1/x))^-1 where f is the focal length. The correlation of the fit was relatively high indicating that that values fit well to the curve.

j. **Paste a copy your Excel Table 4 here**.

lens 2 focal length f_2 (cm) from Table 1	object height y_1 (cm) from Table 1	lens 1 object distance s_1 (cm)	distance between lenses d (cm)	lens 2 image distance s_2' (cm)	lens 2 object distance s_2 (cm)	lens 1 image distance s_1' (cm)	measured image height y_2' (cm)	measured magnification m_{meas}	predicted magnification m_{pred}	measured lens 1 focal length f_1 (cm)
9.988	3.5	5.0	20.0	16.5	25.31	-5.31				-20.3
		10.0	10.0	24.0	17.11	-7.11				
		15.0	5.0	38.0	13.55	-8.55	-5.4	-1.54	-1.60	
		20.0	10.0	19.5	20.48	-10.48				
		25.0	5.0	27	15.85	-10.85				
		30.0	10.0	18.0	22.44	-12.44				
		35.0	5.0	23.5	17.37	-12.37				

Table 4. Dual Lens Measurements. . Single Converging Lens Measurements. The object height and the focal length of the converging lens were taken from part one of this experiment. S_1 was measured from the front of the LEDs to the center of the diverging lens and d was measured from the center of the diverging lens to the center of the converging lens. S_2' was measured from the center of the converging lens to the front of the viewing screen. S_2 was calculated using the equation $1/s_2 = 1/f - 1/s_2'$. S_1' was calculated using the equation $s_1' = d - s_2$.

k. **Qualitatively compare the nominal and measured focal lengths of lens 1 here**.

The measured focal length of -20.3cm is very close to the nominal value of -20.0cm with a difference of only 0.3cm.

Conclusion

Summarize what you conclude from the results of your experiment. Do your measurements qualitatively agree with the predictions of the thin lens equation and the magnification equation?

The converging lens has a measured positive focal length of 9.988cm which is close to the given nominal value of 10.0cm. When the object is far enough from the lens then a real image is produced. The real image appears on the opposite side of the lens then the object. This allows it to be projected onto the viewing screen a measurable distance away.

The diverging lens has a measured negative focal length of -20.3cm which is close to the given nominal value of -20.0cm. The diverging lens produces a virtual image on the same side of the lens of the object. The virtual image is observable by looking though the diverging lens but hard to measured. Using a the virtual image as the object for a converging lens, the distance can be measured,

Final remarks

Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page. Double check that your Excel sheet, graphs, and Logger Pro files are saved in your folder on the Team. Clean up your lab station. Put the equipment back where you found it. Make sure that you logout of Moodle and your email, then log out of the computer. Check with the lab instructor to make sure that they received your submission before you leave.