Introduction

In this experiment, you will examine the optical properties of thin lenses using an optical bench and calculated from theory.

You will use an optical bench that has a light box (which contains an arrow-object), a white plastic screen, and four lenses. Lenses A, B and C are converging (also known as positive) lenses, and lens D is a diverging (negative) lens. The distance between a lens and the focal point, where the image of a distant object is formed, is known as the focal length, \( f \). Converging lenses have a positive value for the focal length, while diverging lenses have a negative value. When a lens is used to examine close objects, the letter \( p \) is used to denote the distance between the lens and the object; \( q \) is the distance between the lens and the point where the image is formed.

I. Images of distant objects

1. **Converging lens observations**:
   a. Remove all of the lenses from the optical bench. Take lens A, hold it at arm’s length, and use one eye to look at a distant object outside the window or at the clock on the wall. Now, hold this lens close (about 10 cm) to your hand or these instructions (don’t hold the lens close to your eye!) Briefly describe and draw what you see through the lens in each case, noting the difference in the magnification and orientation of the images.
   
   b. Remove the light box and plastic screen from the optical bench, and aim the bench toward the window. Place lens A at the 50 cm mark, and lens D right up against lens A. Lens A should be closest to the window, as shown at right.
   
   c. While looking through lens D, slowly pull back on lens D, increasing the separation between the two no more than 5 cm; don’t pull the lenses too far apart or the image will become blurry. What happens to the magnification of the image as you increase the separation between the lenses? Briefly sketch the appearance of a distant object through the window as viewed through your simple telescope, again noting the orientation and magnification.

2. **Measurement of focal length**:
   a. Remove lens D from the bench, leaving lens A in place at the 50 cm mark. Place the screen back on the bench, close to the lens and on the side of the lens opposite the window.
   
   b. Move the screen until you see a sharp image of a distant object; at this point the screen is located at the focal point of the lens. Record the positions of the lens center and front of the screen, then calculate the distance between them; note that there is a pointer on the lens holder that marks the center of the lens.
   
   c. Repeat this procedure to measure the focal length of lenses B and C.

3. **Diverging lens observations**:
   a. Repeat step (1a) using lens D. Sketch the appearance of a distant and close object, and compare these images to those seen using the converging lens.
   
   b. Explain why you can’t measure the focal length of lens D using the procedure in step 2.
II. Image distances: Measurement vs. Calculation

1. Measurement of the image location:
   a. Set up a table in your report like the one below. You will fill it in with measurements and calculations for lens A as you follow through the next steps:

<table>
<thead>
<tr>
<th>Object distance, ( p ) (cm)</th>
<th>Lens Position, ( X ) (cm)</th>
<th>Screen Position, ( Y ) (cm)</th>
<th>Measured image distance, ( q = Y - X ) (cm)</th>
<th>Calculated image distance, ( q ) (cm)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>60.0</td>
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<td></td>
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<tr>
<td>40.0</td>
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<td>30.0</td>
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<tr>
<td>20.0</td>
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<tr>
<td>10.0</td>
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</tbody>
</table>

b. Put the object/light box on the 10 cm mark of the optical bench. Place lens A at position \( X \), a distance \( p \) from the object as indicated in the table above (note that you will measure from the front edge of the object/light box to the center of the lens).

c. Adjust the screen until you have a sharp image, and record the position \( Y \) and calculate \( q \), the measured image distance.

d. Repeat the measurements for the second and third object distance, recording all measurements to 0.1 cm.

The fourth object distance in the table gives interesting results. Briefly describe what happens when you try to find the image at \( p = 20.0 \) cm. Why do you think this happened?

e. The last object distance is less than the focal length of the lens, so it will produce a virtual image, which cannot be projected on a screen. That means you won’t yet have a table entry for the screen position, \( Y \) and the measured image distance, \( q \). You will now see how you can measure the location of this virtual image to complete the table.

Measuring the location of a virtual image:

f. Since a virtual image cannot be projected on the screen, we will have to use a second lens to determine where the virtual image is located. For the last object distance in the table, position the object/light box at the 20 cm mark of the optical bench; place lens A 10 cm from the object, and note its position on the optical bench – Figure (a) at right.

g. Move the screen back and forth. Is any image formed?

h. Look through the lens at the object/light box. Briefly describe the appearance of this virtual image.

i. Place lens B at the 70 cm mark of the optical bench (don’t move the other lens or the light box). Adjust the screen until a sharp image is formed – Figure (b).

The real image you now see on the screen is created by lens B looking at the virtual image created by lens A! Now you need to find the location of the virtual image.

j. Remove lens A, leaving the other lens, light box and screen in position. What happens to the image on the screen?
k. Now adjust the position of the light box until you again get a sharp image on the screen (figure c). The object/light box will now be located at the position of the virtual image created by lens A. Measure the distance between the light box and the 30 cm mark (the former position of lens A) to determine the image distance, and enter it as the measured image distance in the table. What should the sign be for this image distance?

2. Theoretical location of an image:
   a. Now calculate \( q \) for each \( p \) value using the Thin Lens equation below, and record your results in the table. Use your measured value of \( f \) for lens A from part I:

   \[
   \frac{1}{f} = \frac{1}{p} + \frac{1}{q}
   \]

   b. You may note that there seems to be a problem with your calculations when the object is 20 cm away. What do you suppose your calculations are telling you about the image in this case? What did you notice when you tried this object distance on the optical bench?

   c. Find the % difference between the calculated and measured values for \( q \) and record in the table.

3. Calculation of focal length:
   a. Use KaleidaGraph to plot \( \frac{1}{p} \) (the actual object distance on the optical bench) vs. \( \frac{1}{q} \) (the measured image distance). Calculate the focal length of lens A from the parameters of the best-fit line, and record the SSR.

   b. Since the focal length is calculated from the reciprocal of the intercept, we must follow the same procedure as used in the “Ohm’s Law” experiment to calculate the uncertainty in the focal length (recall that the uncertainty in a parameter is not equal to the uncertainty in its reciprocal).

   Since the % uncertainty is the same for the intercept and its reciprocal, it must be calculated first:

   \[
   \% \text{ uncertainty of intercept} = \frac{\text{uncertainty of intercept}}{\text{intercept}} \times 100\% 
   \]

   c. Now use the % uncertainty to calculate the uncertainty in the focal length.

Discussion:

- Summarize what you have learned about the difference between converging and diverging lenses.
- In part I, step 2 you determined the focal length of a lens by finding the location of an image \( (q) \) produced by a distant object \( (p = \infty) \). Look at the Thin Lens equation above and explain why your image distance was equal to the focal length when observing a distant object.
- Where is the image located when the object is placed at the focal point of a converging lens?