Lens Optics
Fall 2023

Introduction

In this experiment, you will examine the optical properties of thin lenses using an optical bench and by calculation from theory. *Please don't touch the lenses; samples will be provided for closer examination!*

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 (**Figure 1**). 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.

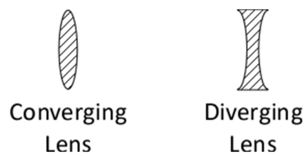

Figure 1: Lens types

I. Images of distant objects

1. *Converging lens observations*:

   a. Remove all lenses from the optical bench. Take lens B, hold it at arm's length (**Figure 2a**), and use one eye to look at a distant object outside the window or at the clock on the wall. Briefly describe and draw what you see through the lens, noting the difference in the magnification and orientation of the images.

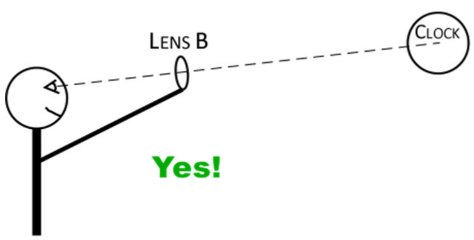

Figure 2a: Correct viewing of distant object

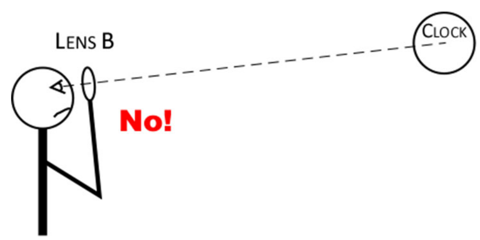

Figure 2b: Incorrect viewing of distant object

   b. Now, hold this lens about 10 *cm* from your hand or these instructions (**Figure 3a**); *don't hold the lens close to your eye!* Briefly describe and draw what you see through the lens.

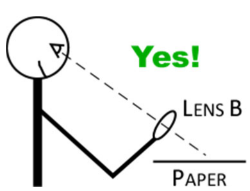

Figure 3a: Correct viewing of close object

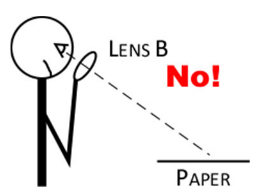

Figure 3b: Incorrect viewing of close object

2. *Measurement of focal length*:
   a. Remove the light box from the optical bench and aim the bench toward the window and place lens A at the 50 *cm* mark. Position the screen close to the lens and on the side of the lens opposite the window (**Figure 4**).
   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 pointer on the lens holder and the ***front*** of the screen, then calculate the distance between them.
      - *Check with your instructor that you have a reasonable value for the focal length*.

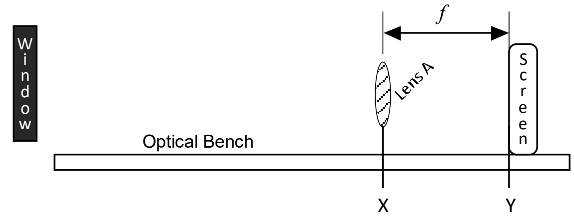

Figure 4: Measurement of focal length from lens to *front* of screen.

   c. Repeat this procedure to measure the focal length of lenses B and C. Distances should be measured to one-tenth of a centimeter.

3. *Diverging lens observations*:
   a. Repeat steps (1a) and (1b) 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 journal like the one below. You will fill it in with measurements and calculations for lens A as you follow through the next steps:

Object distance, p (cm)	Lens Position, X (cm)	Screen Position, Y (cm)	Measured image distance, q = Y – X (cm)	Calculated image distance, q (cm)	% Difference
60.0					
40.0					
30.0					
20.0					
10.0					

   b. Put the object/light box on the 10 *cm* mark of the optical bench. Place lens A at a distance p from the object as indicated in the table above (**Figure 5**). Record the lens position in the **X** column of the table. *Note that you will measure from the front edge of the object/light box to the center of the lens*.

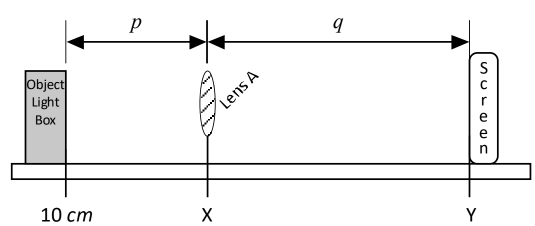

Figure 5: Object (p) and Image (q) distances

   c. Adjust the screen until you have a sharp image, and then record the screen position **Y** in the table. Calculate q, the measured image distance, as the difference between **Y** and **X** and record in the table.
   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*.
   e. The last object distance listed in the table is less than the focal length of the lens, so it will produce a *virtual image*, which cannot be projected on a screen. <u>That means you won't yet have a table entry for</u>

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:

Figure 6a

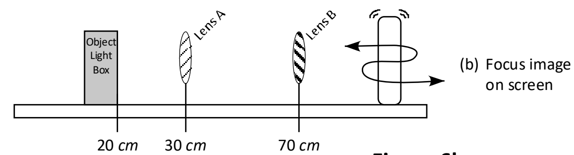

Figure 6b

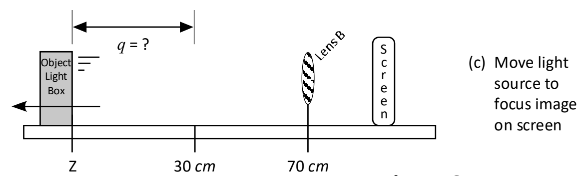

Figure 6c

f. Since a virtual image cannot be projected on the screen, we will need to use a second lens to determine where the virtual image is located. Position the object/light box at the 20 *cm* mark of the optical bench for the last object distance in the table. Then place lens A at 10 *cm* from the object and note its position on the optical bench (**Figure 6a**).

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 6b**).

   The *real image* you now see on the screen is created by lens B looking at the *virtual image* created by lens A! You will find the location of this virtual image in the following steps.

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 6c**). 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. *A graphical calculation of focal length:*

   a. Use KaleidaGraph to plot $1/p$ (the inverse of the *actual* object distance on the optical bench) vs. $1/q$ (the inverse of the ***measured*** image distance). Note that you won't have an entry for *p* = 20 *cm*! Print your completed graph.

      ✓ *Be sure to label the data columns before plotting!*

b. Calculate the focal length of lens A from the parameters of the best-fit line. Be sure to record the SSR.

c. How is the *uncertainty* in the focal length calculated? The focal length was calculated from the reciprocal of the intercept, but the uncertainty in the intercept is *not* the same as the uncertainty in its reciprocal. Therefore, we will use a different procedure to calculate uncertainty, as outlined below (follow along with the example):

First, we will calculate the *% uncertainty* of the intercept. The % uncertainty *is the same* for the intercept and its reciprocal, so it will be used to calculate the % uncertainty of the focal length, *f*:

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

For example, with the following values of the intercept and its uncertainty (recall that the uncertainty in the intercept is *twice* the standard error), we have:

Intercept = 0.0251 cm^{-1}; Uncertainty = 0.0001 cm^{-1}

$$\%\text{ uncertainty of slope} = \frac{0.0001}{0.0251} \times 100 = 0.4\%$$

Since the focal length is the inverse of the intercept, we now have:

$$f = \frac{1}{\text{intercept}} \pm (\%\text{ uncertainty}) = \frac{1}{0.0251} \pm 0.4\% = 39.8\ cm \pm 0.4\%$$

Now use this % uncertainty to calculate the uncertainty of the focal length:

$$\text{uncertainty} = 39.8\ cm \times 0.4\% = 39.8 \times 0.004 = 0.2\ cm$$

Therefore, the focal length and its uncertainty is $f = 39.8 \pm 0.2\ cm$. Follow this procedure to calculate the focal length and its uncertainty for your lens.

Discussion:

- Restate the focal length and uncertainty you calculated from KaleidaGraph, as well as the focal length from your optical bench measurements. Do these values agree with each other?
- 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 ($p = \infty$). Substitute $p = \infty$ into the Thin Lens equation; what is the relationship between q and f? How does this explain what you did in part I, step 2? (*Hint: what happens to a fraction when the denominator becomes very large?*)
- Again, use the Thin Lens equation, this time setting $p = f$ (this would place the object on the focal point of a converging lens). *Algebraically* solve for the image distance, q. Does this explain any of the observations you made today? Be specific. (*Hint: what is the value of a fraction when the denominator is zero?*)