Practical Lab 2
Thin Lenses

Objectives

1)   Use a converging lens to form an image on a screen.

2)   Measure the focal length of a converging lens.

Apparatus

A two-meter optical bench, a meter stick, a screen, a lighted object, and a converging lens will be used in this experiment.

Introduction

A converging lens will cause light rays passing through it to be bent toward each other and the principal axis of the lens. If parallel light rays are incident on a converging lens, the light rays will converge at the focal point, a distance f from the lens (see Figure 1). The distance f is called the focal length of the lens. For converging lenses, f is positive. In general, converging lenses are thicker in the middle than they are at the outer edge of the lens.
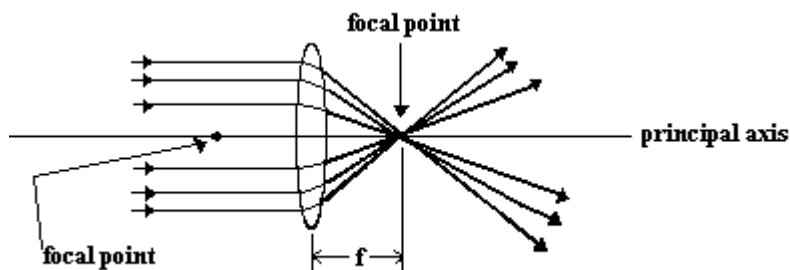

Figure 1: Parallel light rays passing through a converging lens

Ray diagrams can be a useful tool for analyzing the behavior of light rays passing through thin lenses. Here are some rules for drawing light rays in ray diagrams.

1. A light ray approaching the lens parallel to the principle axis will pass through the focal point on the opposite side of the lens for a converging lens (see Figure 1) or appear to diverge from the focal point on the same side of the lens for a diverging lens.
2. A light ray passing through the center of the lens will not change direction as it passes through the lens.
3. A light ray passing through the focal point will be parallel to the principal axis when it leaves the lens.

Consider the ray diagram shown in Figure 2 at the top of the next page. For clarity, only rays #1 and #2 (as described above) are shown. The image is formed where the rays intersect.
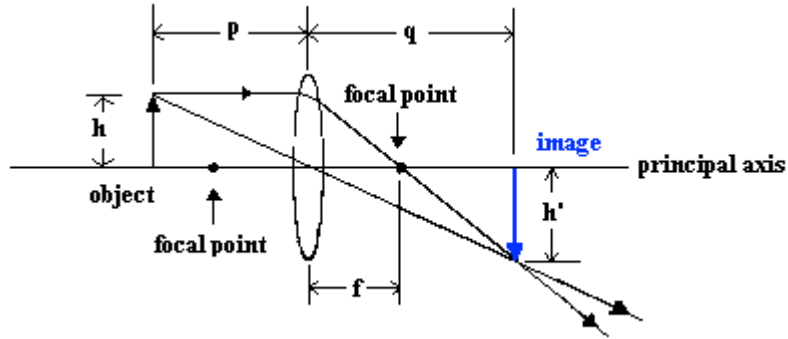
Figure 2: Real image formed by a converging lens

In Figure 2, h is the height of the object, h' is the height of the image, p is the object distance (measured from the lens) and q is the image distance (measured from the lens). There are two types of images: real and virtual. Real images occur when the light rays actually converge on a point and form an image. These types of images can be displayed on a screen. A virtual image is formed when the light rays appear to diverge from a point. Converging lenses can form both real and virtual images.

Sign conventions for lenses

The front side of the lens is defined as the side of the lens from which the light is traveling (in the diagrams above it is the left-hand side of the lens). The back side of the lens is defined as the side to which the light is traveling (in the diagrams above it is the right-hand side of the lens).

- The object distance is positive when the object is on the front side of the lens. The object distance is negative when it is on the back side of the lens.
- The image distance is positive when the image is on the back side of the lens. The image distance is negative when it is on the front side of the lens.
- Image height is negative when the image is inverted (compared to the object). The image height is positive when the image is upright.

For systems with a single optical element, a real image will always have a negative image height (inverted) and a positive image distance. In contrast, a virtual image will always have a positive image height (upright) and a negative image distance.

Focal length

The focal length of a thin lens is related to the object and image distances by the following expression:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \tag{3}$$

If we rearrange Equation (3) we obtain:

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$$\frac{1}{q} = -\frac{1}{p} + \frac{1}{f} \qquad (4)$$

Notice Equation (4) has the same form as the equation of a straight-line y = mx + b. With $\frac{1}{q}$ playing the role of y, $\frac{1}{p}$ playing the role of x and $\frac{1}{f}$ is the intercept. In this experiment, you will measure a series of object and corresponding image distances to calculate the focal length of a converging lens. You will do this by constructing a graph of $\frac{1}{q}$ vs $\frac{1}{p}$.

Procedure
Focal length of a converging lens

1. When you arrive to do this experiment, you will be told which converging lens to use. Record the given focal length of this lens in your Excel spreadsheet.
2. Place your converging lens a distance p = X_1 cm away from the object and adjust the screen until a clear image is formed (you will be given the distance X_1 when you do this experiment). Assign a reasonable uncertainty to your object distance p and record it in your Excel spreadsheet. You should notice as you move the screen back and forth that there is a range over which the image appears clear. You should place the screen in the center of this range and use half of this range as your uncertainty in the image distance q. Measure the image distance q and record it and its uncertainty in your spreadsheet.
3. Repeat step 2 for object distances p = X_2 cm, X_3 cm, X_4 cm, and X_5 cm (you will be given the distances X_2, X_3, X_4 and X_5 when you do this experiment).
4. Have Excel calculate $\frac{1}{p}$, $\frac{1}{q}$ and $\delta\left(\frac{1}{q}\right) = \frac{1}{q}\left(\frac{\delta q}{q}\right) = \frac{\delta q}{q^2}$. Import these data columns into Kaleidagraph and construct a graph of $\frac{1}{q}$ vs $\frac{1}{p}$. Include vertical error bars and have Kaleidagraph fit it with a best-fit line with relevant uncertainties.

Questions
1. What is the slope of your graph and its uncertainty? Is it consistent with what you expect from Equation (4)? Explain.
2. What is the intercept of your graph and its uncertainty?
3. From your graph, what is the focal length of the converging lens? Does it agree with the manufacturer's value? Explain.
4. If your lens is placed a distance of 15 cm in front of the object, where is the image? Is the image real or virtual? (To answer this question use the focal length you obtained from your graph).

CHECKLIST

1) the spreadsheet with your data and formula view of your spreadsheet

2) graph with best-fit line, error bars and equation of best-fit line and uncertainties

3) answers to the questions

4) other than needed to answer the questions, NO sample calculations are required

USING UNCERTAINTIES TO COMPARE DATA AND EXPECTATIONS

One important question is whether your results agree with what is expected. Let's denote the result by *r* and the expected value by *e*. The ideal situation would be $r = e$ or $r - e = 0$. We often use Δ (pronounced "Delta") to denote the difference between two quantities:

$$\Delta = r - e \qquad (1)$$

The standard form for comparison is always *result - expected*, so that your difference Δ will be negative if your value is lower than expected, and positive if it is higher than expected.

This comparison must take into account the uncertainty in the observation, and perhaps, in the expected value as well. The data value is $r \pm \delta r$ and the expected value is $e \pm \delta e$. Using the addition/subtraction rule for uncertainties, the uncertainty in $\Delta = r - e$ is just

$$\delta\Delta = \delta r + \delta e \qquad (2)$$

Our comparison becomes, "is zero within the uncertainties of the difference Δ?" Which is the same thing as asking if

$$|\Delta| \leq \delta\Delta \qquad (3)$$

Equation (2) and (3) express in algebra the statement "*r* and *e* are compatible if their error bars touch or overlap." The combined length of the error bars is given by (2). $|\Delta|$ is the magnitude of the separation of *r* and *e* . The error bars will overlap (or touch) if r and *e* are separated by less than (or equal to) the combined length of their error bars, which is what (3) says.

Copy of Spreadsheet:

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| Enter given value |
| Measured |
| Calculated |

| Manufacturer's focal length of lens: | | ± | cm |

δp =

p	1/p	q	δq	1/q	δ(1/q)
(cm)					