Chapter 10

Thin Lenses

Name:________________ **Lab Partner:**____________ **Section:**____

10.1 Purpose

In this experiment, the formation of images by concave and convex lenses will be explored. The application of the thin lens equation and the magnification equations to single and compound lens systems will be investigated.

10.2 Introduction

10.2.1 The Thin-Lens Equation

Lenses are common optical devices constructed of transparent material e.g. glass or plastic, which refract light in such a way that an image of the source of light is formed. Normally, one or both sides of the lens has a spherical curvature. When parallel light from a source impinges on a **converging lens**, the parallel rays are refracted so that all the light comes together at a **focal point**. The distance between the lens and the focal point is called the **focal length** of the lens. An imaginary line parallel to the light rays and through the center of the lens is called the **principal axis**. See Figure 10.1.

Another basic type of lens is the **diverging lens**. With a diverging lens, parallel rays are spread out by the lens. The focus of a diverging lenses is on the same side of the lens as the impinging parallel rays. See Figure 10.1.

The **thin-lens equation** relates the distance of the object from the lens, d_o, and the distance of the image from the lens, d_i, to the focal length of the lens, f. See Figure 10.2.

The thin lens equation is:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \tag{10.1}$$

The **magnification equation** is:

$$m = \frac{Image \;\; Height}{Object \;\; Height} = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \tag{10.2}$$

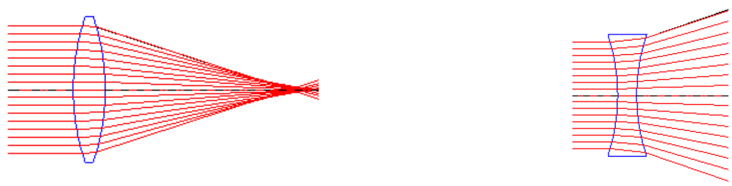

Figure 10.1: Converging lens (left) and diverging lens (right).

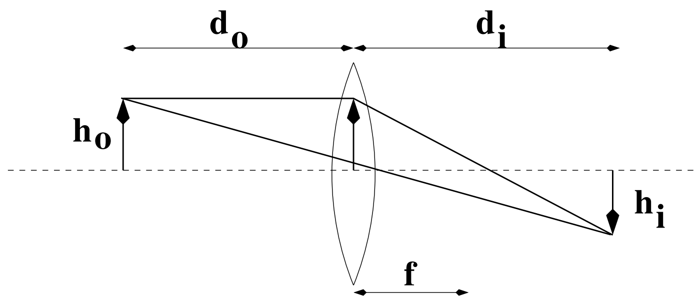

Figure 10.2: Geometry for the thin lens equation.

where h_o is the object height and h_i is the image height. The magnification, m, is the ratio of these heights. Since the triangle formed by the ray through the center of the lens and the object distance and height is a similar triangle to the triangle formed by the ray through the center of the lens and the image distance and height, the ratio of $\frac{h_i}{h_o} = -\frac{d_i}{d_o}$.

The following sign conventions are used with the thin-lens and magnification equations:

- f is positive (+) for a converging lens. f is negative (-) for a diverging lens.
- d_o is positive (+) when the object is to the left of the lens (real object). d_o is negative (-) for an object to the right of the lens (virtual object).
- d_i is positive (+) for an image formed to the right of the lens for a real object. d_i is negative (-) for an image formed to the left of the lens for a real object.
- m is positive (+) for an image that is upright with respect to the object. m is negative (-) for an image that is inverted with respect to the object.

When more than one lens is used, the thin lens equation can be applied to find the image location for the first lens. This location of the image from the first lens is then used as the **object** for the second lens and a second application of the thin lens equation. This process will be used in the last part of the experiment to investigate a concave lens. For the magnification equation for multiple lenses, the total magnification is the product of the magnifications of the individual lenses.

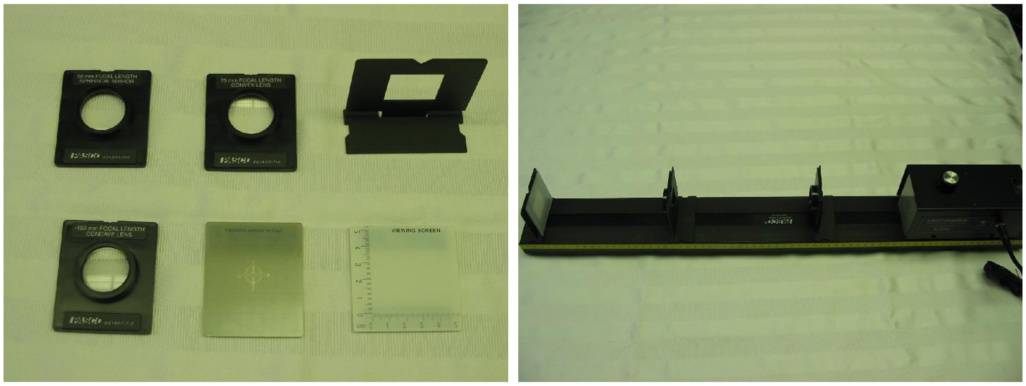

Figure 10.3: The left photo shows the lenses, viewing screen, cross arrow target and a component holder. The right photo shows the light source, lenses and viewing screens on the rail.

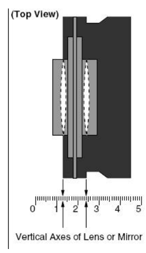

Figure 10.4: The position of the lens can be determined by reading the scale on the side of the rail. The position is different depending on how the lens is attached to the component holder.

10.3 Procedure

Figure 10.3 shows the equipment used in this experiment. The cross arrow target can be mounted on the incandescent light source. The equipment includes a viewing screen with a scale and lenses of various focal lengths. The lenses and other components have magnetic strips on the back so they attach easily to the component holders. Note the distance scale along the edge of the magnet rail. The position of the lens on the holder can be determined by the notches on the component holder (see Figure 10.4).
Special Cautions:

- **Do not drop the components or touch the optic surfaces.**
- **Be careful when moving around the darkened room.**

10.3.1 Procedure for Approximate Focal Length

The thin lens equation relates the object and image distances to the focal length of the lens. If the object distance can be made very large ($\frac{1}{d_0} \approx \frac{1}{\infty} = 0$) then the equation reduces to

Figure 10.5: Arrangement of components for the approximate focal length measurement for a single lens.

the image, which will be very small, being at the focal length of the lens.

- Place the white viewing screen at the far end of the magnetic optical rail. Place the cross arrow on the light source at the other end of the rail.
- Place the 75 mm (0.075 m) convex lens on a magnetic holder at the far end of the magnetic optical rail near the screen (see figure 10.5). The lens should be centered on the opening in the holder.
- Adjust the lens until a sharp very small image is formed. Since the object i.e. the cross arrow target is far away, the distance between the lens and the screen is approximately the focal length of the lens. Record the distance between the lens and the screen.

Distance between the lens and the screen (d_i) __________

- The distance between the object (cross arrow target) and lens ($\frac{1}{d_0}$) is not infinite. Measure and record the distance between the object and lens and record the value.

Object distance (d_0) __________

- Using the thin lens equation calculate the focal length of the lens. Show your calculation below and calculate the percentage error with the given focal length (75 mm) of the lens.

Focal length of lens __________
% error __________

10.3.2 Procedure for the Focal Length of a Single Convex Lens

The magnetic optics rail contains a measuring scale along the side. The optics components mount on magnetic component holders. Each holder has a small indicator position on the side to locate the position of the component on the rail side scale (see Figure 10.4). Each component should be centered on the holder.

- Attach the cross arrow target (CAT) to the front of the light source. Place the light source at one end of the rail. Place the 75 mm (0.075 m) focal length lens on a holder and position it 30 cm (.3 m) from the CAT. See Figure 10.6.

- Calculate the location of the image formed by the lens using the thin lens equation. Calculate the size and orientation of the image using the magnification equation. Show your calculations below and record the values.

Calculated image distance d_i ____________
Calculated magnification ____________
Orientation ____________

- Place the view screen on a holder and place it at the calculated image position. Make small changes to the screen position to get a good focus.

- Record the measured object and image positions for your lab report. Measure the image size and orientation. (The circle on the CAT is 1 cm in diameter. Slide the edge of viewing screen to the middle of the image to use the scale on the viewing screen for an accurate measurement of the size of the image.) Calculate the percentage difference between the calculated and measured values.

Measured image distance d_i ____________
% difference between calculated and measured d_i ____________
Measured magnification ____________
% difference between calculated and measured magnification ____________

- In the thin lens equation, the sum of the inverses of the object distance and image distance are equal to the inverse of the focal length. If the image and object distance are interchanged, another image should be observed on the screen assuming the total distance between object and image is not changed. Move the lens so the distance between the screen and the lens is 30 cm (.3 m). Is a sharp image formed by interchanging the object and image distance? What happens to the magnification?

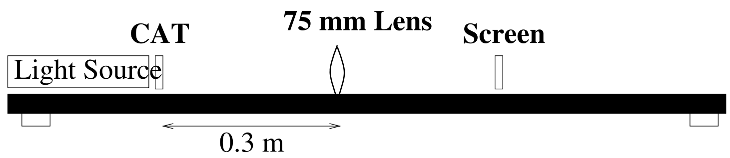

Figure 10.6: Arrangement of components for the focal length measurement for a single lens

10.3.3 Procedure for Compound Convex-Concave Lenses

The lens used above is convex and the focal length is positive. A concave lens has a negative focal length. The image formed is virtual. Visualizing a virtual image is possible but difficult. In this section of the experiment, we will use two lenses to form a real image of the virtual image from a concave (negative focal length) lens. Remember that when applying the thin lens equation, you must first calculate the image position for the first lens and use this position as the object for the second lens. The total magnification is the product of the magnification for each separate lens calculation.

- Place the cross arrow target (object) on the light source at one end of the rail. Place the -150 mm concave lens on a magnetic holder and position it .1 m (10 cm) from the CAT. Place the 75 mm convex lens on a holder and position it .1 m (10 cm) from the concave (diverging) lens. See Figure 10.7

- Calculate the position of the image for the concave lens. Using the virtual image position from the concave lens as the object, calculate the image position for the convex lens. Calculate the magnification for each separate lens and multiply the two magnifications values.

d_i for concave lens __________
d_o for convex lens __________
d_i for convex lens __________
Magnification for concave lens __________
Magnification for convex lens __________
Product of magnification for concave and convex lens __________

- Place the screen at the calculated position for the real image. Adjust the screen slightly for a good focus. Record the final image position. Record the size and orientation of the final image. Do the measured results agree with your calculated values?

Measured final image position __________
Size of final image __________
Orientation of final image __________

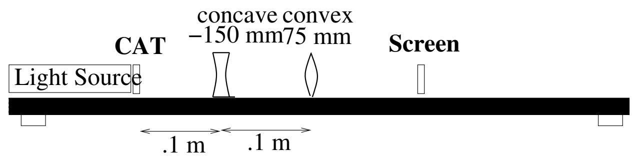

Figure 10.7: Compound lenses: The -150 mm focal length concave lens is placed in front of the 75 mm convex lens.

10.3.4 Questions

1. Explain why it is difficult to view a virtual image.

10.4 Conclusion

Write a detailed conclusion about what you have learned. Include all relevant numbers you have measured with errors. Sources of error should also be included.