Thin Lenses

This laboratory will be performed in the discovery format. This handout is provided as a guide to the equipment and possible measurements but students are encouraged to develop their own techniques for exploring the phenomena and presenting results.

Introduction:

Figure 1: Convex lenses

Lens types in Figure 1 are from left to right are: double convex (DCX), planoconvex (PCX), and convex meniscus (CXM)

Thin lenses are optical components manufactured in configurations such that they bend light in very particular ways. We study thin lenses, such as those used in eyeglasses or the eye, as opposed to thick lenses, as used in many cameras, because image formation in thin lenses is governed by particularly simple equations, which we will investigate in this lab. Convex lenses (also called converging or positive lenses) are those with at least one convex surface (outwardly-bowed surface). See Figure 1. They all focus distant images at a point on the side of the lens opposite from the light source.

Concave lenses (also called diverging or negative lenses) are those, which have at least one concave surface (caved-in surface). See Figure 2. They all focus distant objects so that for a viewer on the side of the lens opposite that from which light is incident, the object appears to be at a point behind the lens (at its "negative" focal length). With the proper combination of these lenses, various instruments may be constructed (telescopes, microscopes) and light can be carefully focused for use in instruments of various types.

Figure 2: Concave lenses

Lens types in Figure 2 are from left to right are: double concave (DCV), planoconcave (PCV), and concave meniscus (CVM)
For spherical lenses (and for spherical mirrors as well), a general equation can be used to determine the location and magnification of an image. This equation is called the Thin Lens equation:

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]  

(1)

where \( f \) is the focal length of the lens, and \( d_o \) and \( d_i \) are the distance from the lens to the image and object respectively (see Figure 4). If \( h_0 \) and \( h_i \) are the object and image height respectively, then the magnification of the image is given by the equation:

\[ M = \frac{h_i}{h_0} = -\frac{d_i}{d_o}. \]  

(2)

For an upright image, the magnification is positive, and for an inverted image the magnification is negative. In this experiment, you will have an opportunity to test and apply these equations.

Sign Convention for Thin Lenses

<table>
<thead>
<tr>
<th></th>
<th>Lenses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focal Length (f)</strong></td>
<td>+ for a converging lens</td>
</tr>
<tr>
<td></td>
<td>- for a diverging lens</td>
</tr>
<tr>
<td><strong>Object Distance (S or d₀)</strong></td>
<td>+ if the object is to the left of the lens (real object)</td>
</tr>
<tr>
<td></td>
<td>- if the object is to the right of the lens (virtual object)</td>
</tr>
<tr>
<td><strong>Image Distance (S’ or dᵢ)</strong></td>
<td>+ for an image (real) formed to the right of the lens by a real object</td>
</tr>
<tr>
<td></td>
<td>- for an image (virtual) formed to the left of the lens by a real object</td>
</tr>
<tr>
<td><strong>Magnification (m)</strong></td>
<td>+ for an image that is upright with respect to the object</td>
</tr>
<tr>
<td></td>
<td>- for an image that is inverted with respect to the object.</td>
</tr>
<tr>
<td><strong>Height (hᵢ or h₀)</strong></td>
<td>+ for an image that is upright</td>
</tr>
<tr>
<td></td>
<td>- For an inverted image</td>
</tr>
</tbody>
</table>

* Optical instruments that use two or more lenses/ mirrors sometimes use the image formed by the first lens/mirror as the object for the second lens/mirror. For these cases, the object distance is negative and the object is said to be a virtual object.
Part 1: Focal Length and Magnification of Convex Lenses

In this experiment you will verify the focal length of two convex lenses and calculate their magnification for the selected object distance.

A) Convex Lens with a Focal Length of +100 mm

1. Place the light source with the object (the cross) at 0 cm on the optical rail. Then place the \( f = +100 \text{ mm} \) convex lens at an object distance of \( d_0 = 30 \text{ cm} \) (distance from the light source to the lens). Adjust the position of screen till you find a sharp image. Measure the distance between the lens and the screen and record it as the object distance \( d_i \).

2. Calculate the focal length using the lens equation to find experimental value of \( f \). Compare your result and find the percent error using the equation:

\[
\% \text{ Error} = \left(100 \text{ mm} - f \text{ (measured)}\right) \% 
\]

3. Measure the height of the object \( h_O \) and the height of the image \( h_I \). Calculate the magnification of the lens \( M_0 \) (heights) = \( \frac{h_I}{h_O} \). Calculate the magnification of the lens also using \( M_0 \) (distances) = \( -\frac{d_i}{d_0} \). Compare the two values and calculate the percent error: \%\text{Error} = 100\%\left[M_0(\text{heights}) - M_0(\text{distances})\right]/M_0(\text{heights}) \%.

B) Convex Lens with a Focal Length of +200 mm

4. Place the light source with the object (the cross) at 0 cm on the optical rail. Then place the \( f = +200 \text{ mm} \) convex lens at an object distance of \( d_0 = 30 \text{ cm} \) (distance from the light source to the lens). Adjust the position of screen till you find a sharp image. Measure the distance between the lens and the screen and record it as the object distance \( d_i \).

5. Calculate the focal length using the lens equation to find experimental value of \( f \). Compare your result and find the percent error using the equation:

\[
\% \text{ Error} = 0.5\%\left[200 \text{ mm} - f \text{ (measured)}\right] \% 
\]

6. Measure the height of the object \( h_O \) and the height of the image \( h_I \). Calculate the magnification of the lens \( M_1 \) (heights) = \( \frac{h_I}{h_O} \). Calculate the magnification of the lens also using \( M_1 \) (distances) = \( -\frac{d_i}{d_0} \). Compare the two values and calculate the percent error: \%\text{Error} = 100\%\left[M_1(\text{heights}) - M_1(\text{distances})\right]/M_1(\text{heights}) \%.
Part 2: Combination of Convex Lenses

1. In this experiment you will set the first convex lens with \( f_1 = +200 \text{ mm} \) at an object distance of \( d_{01} = 30 \text{ cm} \) and find the image on the screen. Verify that you get the same image distance \( d_{i1} \) as the found in part 1B.

2. Place the second convex lens with the focal length \( f_2 = +100 \text{ mm} \) at 60 cm (i.e. 30 cm away from the first lens). The goal of this experiment is to find the magnification \( M_2 \) of this lens. Then find the image position by adjusting the screen. Measure the height of the object \( h_0 \) and the height of the image \( h_i \) and calculate the magnification for the combination of lenses using

\[
M_C = \frac{h_i}{h_o}.
\]

3. Theoretically, the compound magnification is the product of the magnification of the two lenses, so \( M_C = M_1M_2 \).

4. Use the value of \( M_1 \) from part 1B and solve for \( M_2 = M_C/M_1 \).

Part 3: Combination of a Concave Lens and a Convex Lens

1. In this experiment, you will determine the compound magnification of a concave lens and a convex lens.

2. Place the concave lens with \( f = -150 \text{ mm} \) at an object distance of 30 cm. Place the convex lens with \( f = +200 \text{ mm} \) at 30 cm from the first lens.

3. Adjust the screen to find the image.

4. Measure the height of the object \( h_0 \) and the height of the image \( h_i \).

5. Calculate the compound magnification \( M_C = h_i/h_0 \).