Thin Lenses & Concave Spherical Mirrors

Equipment List

<table>
<thead>
<tr>
<th>Qty</th>
<th>Items</th>
<th>Part Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light Source, Basic Optics</td>
<td>OS-8517</td>
</tr>
<tr>
<td>1</td>
<td>Optics Bench, Basic Optics</td>
<td>OS-8518</td>
</tr>
<tr>
<td>1</td>
<td>Viewing Screen, Basic Optics</td>
<td>OS-8518</td>
</tr>
<tr>
<td>1</td>
<td>100 mm Convex Lens, Basic Optics</td>
<td>OS-8518</td>
</tr>
<tr>
<td>1</td>
<td>Concave Mirror Accessory</td>
<td>OS-8532</td>
</tr>
<tr>
<td>1</td>
<td>Vernier Caliper</td>
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</table>

Introduction to Thin Lenses

The purpose of this activity is to determine the relationship between object distance and image distance for a thin convex lens. A thin lens is one whose thickness is negligible in comparison to the image and object distance. A convex lens is thicker in the center than at the edges and can also be called a positive lens or converging lens. A concave lens is thinner at the center than at the edges and can also be called a negative lens or a diverging lens. Use a light source, optics bench, lens, and viewing screen to measure object distance, image distance, and image size. All of the technological pieces of equipment you see pictured here make use of lenses.

Background

When a light source, like a light bulb shine, it radiates light in all directions. A lens will alter the direction of those rays of light which strike it, resulting in either a real or virtual image to be formed. If the rays of light go from the source through the lens to form a single point in space, it will form a real image. However, a virtual image is formed if the projections from the rays of light form on the same side as the source. These can be seen in Figure 1 and Figure 2.

Fig. 1: Real Image Formation

Fig. 2: Virtual Image Formation
These distances and focal lengths are related by **The Thin Lens Equation:**

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

Object distances, image distances and focal lengths can be positive or negative. There is also a **Magnification Equation** to help predict how large or small the image will be compared to the size of the original object. This equation is:

\[
M_{\text{exp}} = \frac{h'}{h} = -\frac{q}{p}
\]

For multiple lenses, the magnification multiply; that is to say,

\[
M_T = \sum_i^n M_i = M_1M_2 ... = \frac{-q_1 \cdots -q_2 \cdots}{p_1 \cdot p_2 \cdots}
\]

This is the ratio of the image size \(h'\) to the object size \(h\). Note that if the image is inverted relative to the object then \(h'\) is negative making \(M\) negative.

**Setup**

1. Mount Object Source at the 0.0 cm mark of the Optics Bench. Connect the power supply.
2. Mount the Viewing Screen at the other end of the bench.
3. Make sure the crossed-arrow ‘object’ is illuminated and pointing toward the viewing screen.
4. Place the 100-mm Convex Lens on the Optics Bench at the 500 mm mark.

**Procedure for part 1: One Lens System**

1. With the lens positioned at the 500 mm position move the viewing screen so that a clear and focused image of the crossed arrow appears on the viewing screen.
2. Record, in Table 1, the distance from the lens to the viewing screen as the image distance for given object distance.

3. Using the Vernier Caliper measure the height of the image on the viewing screen, and then record that as the image height for the given object distance.

4. Repeat steps 1 – 3 for the rest of the listed object distances in Table 1.

Procedure for Part 2: Two Lens System \((f_1=10.0 \, \text{cm}, \, f_2=5.0 \, \text{cm})\)

1. Place the object source on one side of the track so that its front is at location 0.0 cm. Place lens 1 at 30.0 cm then place the lens 2 at 70.0 cm.

2. In the first row of Table 2 record the distance from the object to the first lens as \(p_1\).

3. In the first row of Table 2 record the distance between the two lenses as \(d\).

4. Place the screen behind the lens 2 and slide the screen until a clear image is formed. In the first row of Table 2 record the distance from the second lens to the screen as \(q_2\).

5. For the second row of Table 2 repeat steps 1 – 4, but with lens 1 at 5.0 cm, and lens 2 at 30.0 cm.

6. For the third row of Table 2 repeat steps 1 - 4, but with lens 1 at 30 cm, and lens 2 at 35.0 cm.

7. These are your experimental values for \(q_2\). Now for each configuration, using the thin lens equation, calculate the theoretical value of \(q_{cat}\), which we will label as \(q_{cat}\). Show the calculations in the space provided beneath Table 2.

8. Determine the percent error for each case. Show the calculations in the space provided beneath the Table 2.
Introduction to Spherical Concave Mirrors

The purpose of this activity is to measure the focal length of a concave mirror. Use a light source, concave mirror, and half screen accessory on an optics bench to measure the focal length of the concave mirror.

Background

Concave and convex mirrors are examples of spherical mirrors. Spherical mirrors can be thought of as a portion of a sphere which was sliced away and then silvered on one of the sides to form a reflecting surface. Concave mirrors are silvered on the inside of the sphere and convex mirrors are silvered on the outside of the sphere.

If a concave mirror is thought of as being a slice of a sphere, then there would be a line passing through the center of the sphere and attaching to the mirror in the exact center of the mirror. This line is known as the principal axis. The point in the center of sphere from which the mirror was sliced is known as the center of curvature and is denoted by the letter C in the diagram. The point on the mirror's surface where the principal axis meets the mirror is known as the vertex and is denoted by the letter A in the diagram. The vertex is the geometric center of the mirror. Midway between the vertex and the center of curvature is a point known as the focal point; the focal point is denoted by the letter F in the diagram. The distance from the vertex to the center of curvature is known as the radius of curvature (abbreviated by "R"). The radius of curvature is the radius of the sphere from which the mirror was cut. Finally, the distance from the mirror to the focal point is known as the focal length (abbreviated by "f").

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

\[
M_{\text{exp}} = \frac{h'}{h} = -\frac{q}{p}
\]

The focal point is the point in space at which light incident towards the mirror and traveling parallel to the principal axis will meet after reflection. The diagram at the right depicts this principle. In fact, if some light from the Sun was collected by a concave mirror, then it would converge at the focal point. Because the Sun is such a large distance from the Earth, any light rays from the Sun which strike the mirror will essentially be traveling parallel to the principal axis. As such, this light should reflect through the focal point.
Setup

1. Mount the Light Source at one end of the Optics Bench so its front is at location 0.0 cm. Turn on the Object Source.

2. Place the Concave Mirror at the 100.0 cm mark of the Optics Bench, with the mirror facing the image source.

3. Make sure the crossed-arrow ‘object’ is illuminated and pointing toward the mirror.

4. Place the Half-Screen on the Optics Bench between the Object Source, and the mirror.

5. With the Vernier Caliper measure the size of the crossed-arrowed object, and record this as the height of the object for Table 3.

Procedure for Part 3: Concave Mirror

1. With the Object Source, and mirror in their current locations move the Half-Screen closer to or farther from the Concave Mirror until the reflected image of the crossed arrow target on the white screen is focused.

2. Determine the distance between the position indicators on the Half-Screen and the Concave Mirror, and record that distance in Table 3 for q for position 100 cm.

3. Using the Vernier Caliper measure the size of the image and record it in Table 3 under h′.

4. Reposition the mirror to the next position listed in Table 3, and repeat procedure for all the listed object positions, p.

5. Preform calculations to complete Table 3. Show work in the space provided below Table 3.
**Analysis for Thin Lenses**

**Table 1: One Lens**

<table>
<thead>
<tr>
<th>Object Distance p (mm)</th>
<th>Image Distance q (mm)</th>
<th>Image Height h (mm)</th>
<th>Object Distance p (mm)</th>
<th>Image Distance q (mm)</th>
<th>Image Height h (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td></td>
<td>250</td>
<td></td>
<td></td>
<td></td>
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<td>475</td>
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<td>300</td>
<td></td>
<td>110</td>
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1. Using Excel, or some other graphing program, make a graph of Image Distance vs. Object Distance (q vs. p), then answer the following question about this graph.

2. What value does the image distance approach as the object distance becomes larger?

3. What value does the object distance approach as the image distance becomes larger?

4. How does the value of the answers to questions 1, and 2 relate to the lens used in part 1?

5. What is the relationship between image distance and object distance? (Directly related or inversely related?) Give evidence supporting your answer.

6. What is the relationship between object distance and image height? (Directly related or inversely related?) Give evidence supporting your answer.
7. Where would you place the object to obtain an image as far away from the lens as possible?

8. Where would you place the object to obtain an image located at the focal length of the lens (100 mm)?

<table>
<thead>
<tr>
<th>Table 2: Two Lenses</th>
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<tbody>
<tr>
<td>f₁</td>
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Table 3: Spherical Concave
Object Height, $h$  Mirror Focus Length

<table>
<thead>
<tr>
<th>$p$(cm)</th>
<th>$q$(cm)</th>
<th>$f = \frac{q \cdot p}{q - p}$</th>
<th>$h'$(cm)</th>
<th>$M = h'/h$</th>
<th>$M = -q/p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
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Average $f$
1. Calculate the % Error between the given focus length of the mirror and your average experimental value. Show work.

2. Using Excel, or some other graphing program, graph \( \frac{1}{q} \) vs. \( \frac{1}{p} \) from the data from Table 3.

3. What physical property of the mirror does the y-intercept represent?

4. Were the images, compared to the object, upright or inverted?

5. Would the image be upright or inverted if the object was placed ‘inside’ the focus length of the mirror?

6. Using Excel, or some other graphing program, graph M vs. p.

7. As the object position value gets larger what value does the magnification go to?