Image Formation

Safety and Equipment

- No special safety equipment is necessary for this lab.
- Meter Stick, Ruler
- Blank Paper
- Red Reflective Flat Mirror
- Two identical objects (soda cans or weights)
- Ray Box
- VWR Optics Kit (Curved Mirrors, 2-D Lenses)
- Light Lantern with arrow pattern
- Projection Screen (Fall 2016: a white box)
- Lens, Lens Holder, Stand

Introduction

Rays of light are generally straight lines, except when the light is refracted or reflected. Real objects emit light from every point. To make things easier, we usually consider one point at a time, so that the rays we trace are those from a point source called “the Object”.

To form an image, the rays from the object reflect or refract and afterward they can be interpreted as passing (or appearing to pass) through a common source point. This common point shared by all of the rays after reflection or refraction is called “the Image”.

Individual rays obey the reflection equation or Snell’s Law:

\[ \theta_1 = \theta_1' \quad n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

where \( \theta_1 \) is the angle of an incident (incoming) ray, \( \theta_1' \) is the angle of a reflected ray, and \( \theta_2 \) is the angle of a refracted ray. When dealing with reflection and refraction, angles are measured from the normal.

Images and objects obey the thin lens equations:

\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad \frac{h_o}{h_i} = M = -\frac{d_o}{d_i} \]

where \( d_o \) (sometimes called \( p \)) is the object distance and \( d_i \) (sometimes called \( q \)) is the image distance. When dealing with lenses and mirrors, distances are measured from the lens or mirror. Negative distances are allowed and mean the image is on the “wrong side” of the lens or mirror. Instead of being where the rays are after the lens or mirror, the image is on the other side and the image is virtual.

Objective:

- To observe the rays and image formed from a flat mirror.
- To observe rays refracting from a prism and a curved lens.
- To verify the thin-lens equation.
Part #1. Ray Reflection from a Flat Mirror

1. Place the small flat mirror on a sheet of white paper, near one edge, so that the reflective side faces the middle of the paper.
2. Trace a line along the edge of the mirror to record the location of the mirror. Mark a point near the middle of the mirror by drawing a dashed line normal to the mirror.
3. Install the single-slit diaphragm into the ray box. Place the ray box on the table and direct the ray to the intersection of the mirror and the normal line, at an angle.
4. Trace the incident and reflected rays with a ruler. (You may need to mark where you want the lines to be, then remove the ray box to use the ruler.)
5. Use a protractor to measure the incident and reflected angles.
6. Repeat the experiment two more times for different angles.
7. Comment on the agreement between the angles by calculating a % ratio of smallest value over largest.

<table>
<thead>
<tr>
<th>#</th>
<th>incident angle $\theta_1$ (°)</th>
<th>reflected angle $\theta'_1$ (°)</th>
<th>% Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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</tbody>
</table>

**Table 1**: Angles measured for rays reflecting from a flat mirror.

Part #2. Image Formed from a Flat Mirror

1. Put an object in front of the red reflective plane mirror.
2. Place another identical object behind the mirror exactly where you see the image of the first one.
3. Use a ruler to measure the distance from the mirror to the object in front of the mirror.
4. Measure the distance from the mirror to the object placed where the image of the first one appears. Be consistent with the measurements: measure the nearest distance between the mirror and an object.
5. Comment on the relationship between measured distance to the object and measured distance to the image.

<table>
<thead>
<tr>
<th>Distance to the object, $d_o$ (m)</th>
<th>Distance to the image, $d_i$ (m)</th>
<th>% Match</th>
</tr>
</thead>
</table>

**Table 2.** Measure values of distances for the flat mirror reflection
Part #3. Ray Refraction through a Rectangular Prism

1. Install the single-slit diaphragm into the ray box. Place the ray box and a prism on a sheet of paper.
2. Direct the light ray to a surface of the prism at an angle (approx 45°).
3. Observe the ray exiting the prism into the air out of the opposite surface (not the side, see the diagram).
4. Use a pencil to trace the edges of the prism.
5. Mark one point where the ray enters the prism and another where the ray comes out.
6. Mark two more points: one along the entering ray and another along the exiting ray.
7. Remove the ray box and the prism from the paper, and then connect the dots to retrace the light path.
8. Make sure to connect the point of entrance with the point of exit to trace the path inside the prism.
9. Draw one normal to the surface of the prism at the point of entrance and another normal at the point of exit. See Figure 3.
10. Using a protractor, measure two sets of angles (each between the normal and the ray):
   - Incident Ray from Air to Acryl and Refracted Ray in Acryl
   - Incident Ray from Acryl to Air and Refracted Ray in Air
11. Conclude about where the speed of light in Air is large than speed of light in Acryl. Include the statement in the abstract.
12. Using Snell’s Law, calculate refractive index of Acryl. Use the value of 1.0 as refractive index of air.
13. Average the results and compare it (% Diff) with the value that could be found on the Net.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Incident angle, $\theta_i$ (deg)</th>
<th>Refracted angle, $\theta_r$ (deg)</th>
<th>$n_{acryl}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air to Acryl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acryl to Air</td>
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</tbody>
</table>

**Table 3:** Angles measured for rays refracting in an acrylic prism.

**Figure 2.** Diagram of a ray of light refracting through an acrylic prism. The incoming ray (at the top) and the outgoing ray (at the bottom) are straightforward to record. Recording the middle ray requires connecting the rays from the incoming to the outgoing ray. The Normal lines are marked with dashes at the exact points where the incoming and outgoing rays are refracted.
Part #4. Ray Refraction through a Lens

1. Install the five-slit diaphragm into the ray box.
2. Place the ray box on the edge of a piece of plain paper, so that the light rays cross the paper.
3. Adjust the ray box so that the five rays are parallel.

**Convex Lens:**
4. Place a *convex lens from the VWR kit* in the middle of the paper.
5. Direct the light rays through the *convex lens* to observe the refracted rays.
6. Use a pencil to trace the edges of the lens, mark the focal point, and measure the focal length.

**Concave Lens:**
7. Set up the ray box on the edge of another piece of paper.
8. Place the *concave lens from the VWR kit* in the middle of the paper.
9. Direct the parallel light rays through the *concave lens* to observe the refracted rays.
10. Observe that the refracted rays are diverging. This makes it harder to find the focal point.
   - Use a pencil to trace the edges of the lens and the rays of light that you can see. (Ignore any light reflected off of the lens.)
   - With dashed lines, trace the refracted rays straight back toward the light source until they intercept.
   - Measure the focal length of the lens from the middle of the lens to the crossing point of the refracted rays.

<table>
<thead>
<tr>
<th>Type of Lens</th>
<th>Focal Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave</td>
<td></td>
</tr>
<tr>
<td>Convex</td>
<td></td>
</tr>
</tbody>
</table>

*Table 4. Comparison of refractive properties of different types of lens*
Part #5. Image Formation through Curved Lenses

**Case 1:** Object Very Far from Lens
1. Take any convex (converging) lens on the stand and determine its focal length by focusing light coming from a distant object (tree or building) to a screen. Measure the distance between the screen and the lens, and this is both the image distance and the focal length.

**Case 2:** Object sort-of Far from Lens
2. Shine the lantern through your lens, with the lens about fairly far from the lantern. (About 3 times the focal length apart works well.)
3. Place the screen out beyond the lens, and move it around until you see a sharp, focused image of the cross. (If you can’t find it, estimate the image distance using the lens equation.)
4. Measure and record the distance to the image and the distance to the object, and calculate the focal length using the thin lens equation.

**Case 3:** Object sort of close to Lens
5. Move the lens (not the screen, not the lantern) closer to the lantern until you again see a sharp, focused image.
6. Measure and record the distance to the image and the distance to the object, and calculate the focal length using the thin lens equation.

How consistent is your calculated focal length value? Use the average and standard deviation of your three measurements. Explain any inconsistency.

<table>
<thead>
<tr>
<th>Position of an object</th>
<th><strong>Object Very Far</strong> ((d_o \approx \infty))</th>
<th><strong>Beyond optical center</strong>, (d_o &gt; 2f)</th>
<th><strong>Between focal point and optical center</strong> (2f &gt; d_o &gt; f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to the object, (d_o) (cm)</td>
<td>(\infty)</td>
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</tr>
<tr>
<td>Distance to the image, (d_i) (cm)</td>
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</tr>
<tr>
<td>Calculated Focal length (f) (cm)</td>
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</tr>
<tr>
<td>Average Value of (f) (cm)</td>
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<tr>
<td>Standard Deviation of (f) (cm)</td>
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</table>

**Table 5:** Object and image distances for a single converging lens.