LAB 9: Lenses & Mirrors

Purpose

In this lab we will observe the images formed by lenses and mirrors and use the thin lens equation to calculate their focal lengths. We will also set up a simple refracting telescope and a microscope and compare their calculated and observed magnifications.

Equipment

- Optics bench
- Object lamp
- Screen
- Long and short converging lenses
- Long converging mirror
- Table lamp
- Object rods (2)
- Index card
- Light source at “infinity”

Principles

Thin, spherical lenses and mirrors can both be used to form images. This is because they have the ability to bring light rays from distant objects to a focus (see diagrams below).

Light rays from an object an infinite distance away will be parallel. When parallel rays pass through a lens, they will be refracted to a single point on the other side of the lens. This point is called the focal point, and the distance between the center of the lens and the focal point is called the focal length $f$ of the lens.

Parallel rays striking a mirror will be reflected to a point: the focal point of the mirror. The distance from the mirror to the focal point is the focal length of the mirror. It is found that a mirror’s focal length is one-half its radius of curvature: $R = 2f$.

Light rays from nearby objects will not be parallel, but they will be refracted or reflected in such a way as to form an image near the focal point.

The Thin Lens Equation

Both lenses and mirrors obey the thin lens equation:

\[
\left(1\right) \quad \frac{1}{f} = \frac{1}{s} + \frac{1}{i}
\]
where

- $f$ is the focal length
- $s$ is the distance from the object emitting the light to the center of the lens;
- $i$ is the distance from the lens to the image formed.

For converging lenses and mirrors, $f$ is a positive number. Converging lenses and mirrors cause light rays to converge to a point. (Diverging lenses and mirrors cause light rays to appear to diverge from a point. Their focal lengths are considered negative. We will not consider diverging lenses or mirrors in this lab.)

The image distance, $i$, can be positive or negative depending on where the image forms. When the object is located outside its focal length, the converging lens will form an image beyond the focal point on the other side of the lens. This is called a real image, since it occupies a real position in space. (For instance, the image can be observed on a screen placed at the image distance.) In this case the image distance is considered positive.
In the limiting case where the object is located at infinity (or far enough away to be considered at infinity), the image forms at the focal point. That is,

\[ f = i \] (object at infinity)

as is evident from the thin lens equation, with \( s \) very large.

As the object moves closer to the lens, the image moves farther away on the other side, as is also evident from the thin lens equation. When the object moves inside the focal length of the lens, the image forms on the same side of the lens as the object. The image distance is considered a negative number, and the image is called a virtual image.

A virtual image is one that can be seen only by looking through the lens. It cannot be projected on a screen and its position cannot be directly measured. Instead, we must measure the image distance by an indirect method (see the method of parallax, below).

Converging mirrors also form real and virtual images. The image will be real and \( i \) a positive number when the object is located outside the focal length of the mirror. The image will form on the same side of the mirror as the object, outside its focal point. An object at infinity will form a real image at the focal point.

When the object moves inside the focal distance of the mirror, the image becomes virtual – we have to look into the mirror to see it – and it appears to form on the other side of the mirror from the object. In this case, the image distance \( i \) is considered to be a negative number.

**Magnification**

The magnification of an image can be calculated in two ways:

\[
(2) \quad m = \frac{h_i}{h} \quad \text{or} \quad (3) \quad m = \frac{-i}{s}
\]

where \( m \) is the magnification, \( h \) is the height of the object and \( h_i \) is the height of the image, and \( i \) and \( s \) are the image and object distances, respectively. A negative magnification signifies an inverted image.

**The Method of Parallax**

To determine the image distance for a virtual image, we use the method of parallax, since the distance cannot be measured directly. Parallax is the apparent shift in position an object (or image) undergoes as the observer shifts his or her point of view. Near-by objects appear to shift greatly as the observer moves while distant objects don’t appear to shift much. Much of our depth perception is simply the phenomenon of parallax.
To use this to determine the apparent position of a virtual image, we place an upright rod where we can see both the image and the rod. (The image is the image of some other object, not the rod. We use the rod to locate the image.) As we shift our point of view – for instance by rocking our heads back and forth – the image and the rod will appear to move relative to each other, and relative to a distant background. When the image and the rod appear to move together, the rod is at the same distance as the image. The image distance for the virtual image is then the distance from the lens or mirror to the rod.

**Telescope**

We will also set up and observe a distant object through a simple refracting telescope. This consists of a long focal-length lens – called the *objective lens* – and a short focal length lens – called the *eyepiece*. The short lens is placed near the focal point of the objective.

When pointed at a distant object, the objective lens forms a real image near its focal point. This image serves as the object for the eyepiece. The virtual image seen through the eyepiece will be a magnified image of the distant object.

The magnification of a telescope is given by

\[ M = \frac{-f_o}{f_e} \]

where \( f_o \) is the focal length of the objective and \( f_e \) is the focal length of the eyepiece.

**Microscope**

A microscope uses a short focal length objective lens and a long focal length eyepiece – the reverse of a telescope. An object outside the focal length of the objective forms a real image near the objective’s focal point. If the eyepiece is placed so that the image formed by the objective is slightly inside its focal length, an enlarged, virtual image can be observed.

The magnification of a microscope is defined as the ratio of the angles subtended at the observer’s eye by the image and the object. It is given by

\[ M = \frac{-25L}{f_0 f_e} \]

where \( M \) is the magnification and \( L \) is the distance between the objective and the eyepiece.
Procedures

In each of the procedures below, record the positions of the object, the image, and the lens or mirror. Measure to the nearest millimeter.

Most of the lenses and mirrors we will use are marked with a nominal value for their focal lengths. Your job will be to determine the exact values by measurement.

In the following, “long lens” means the lens with the longer focal length. “Short lens” means the lens with the shorter focal length. Likewise for “long” and “short” mirrors.

   - Set up the optics bench at the end of a lab table. Insert the long lens into the grooves of the bench and slide the lens to the middle of the bench.
   - Point the bench and lens at a distant light source – at least 5 meters away. If a light source has not been set up for you, you can use a table lamp or any bright object. You could also use a light source outside the room, such as a tree in sunlight in the daytime or a streetlight at night.
   - Slide the metal screen onto the optics bench so that the lens is between the object and the screen. Slide the screen on the bench until you find the image of the distant object. Adjust the screen’s position until the image is as sharp as possible.
   - Record the object’s position as infinity. Record the image and lens positions. Calculate and record the object and image distances and the focal length.
   - Characterize the image as real or virtual, upright or inverted, enlarged or reduced.

2. Converging Lens – Nearby Object.
   a) First image
      - Slide the object lamp onto the optics bench on the opposite side of the lens from the screen. Plug the adaptor into an AC outlet and into the lamp. Tilt the lamp so that the arrows point toward the screen and position it at the end of the bench.
      - Position the converging lens so that the object lamp is about 10 cm outside the focal point of the lens.
      - Slide the screen until a sharp image is formed. Record the object, image and lens positions and calculate the object and image distances.
      - Measure one of the arrows on the object lamp and measure the corresponding arrow on the image. Record this.
      - Calculate the focal length using the thin lens equation. Take the percent difference between the two methods for finding the focal length.
      - Calculate the magnification using both formulas (2 and 3 above). Find the percent difference between them.
• Characterize the image as real or virtual, upright or inverted, enlarged or reduced.

b) Second image

• Now slide the lens toward the screen until a second image comes into focus. Leave the object lamp and the screen as they were.
• Record the object, image and lens positions and calculate the object and image distances.
• Measure one of the arrows on the object lamp and measure the corresponding arrow on the image. Record this.
• Calculate the focal length using the thin lens equation. Take the percent difference between this and that for the first image.
• Calculate the magnification using both formulas (2 and 3 above). Find the percent difference between them.
• Characterize the image as real or virtual, upright or inverted, enlarged or reduced.


• Take the screen and object lamp off the bench. Place the lens at the center.
• Place an upright rod on the optics bench inside the focal point of the lens, about halfway between the lens and the focal point. This rod will be the object in this experiment.
• Place another upright rod on the same side of the lens, well outside the focal point. This rod will be used to locate the position of the image of the first rod. We’ll call it “the image rod,” but don’t confuse the image rod with the image of the object rod.
• Look at the object through the lens. In this configuration, the converging lens becomes a magnifier and it forms a virtual image. Estimate the magnification of the object by the lens.
• Look at the image rod over the top of the lens – without looking through the lens. Find the image distance by the method of parallax. That is, slide the image rod back and forth until there is no parallax between it and the image of the object rod. When the correct distance is found, the image rod and the image will move together as you shift your point of view.
• This will take some practice. Don’t be discouraged if you don’t get it at first. If, after trying, you still can’t find it, shift the position of the object rod. The method is most difficult when the image distance is too close to the lens.
• Record the object, image and lens positions and calculate the object and image distances. Remember that the image distance is negative in this case.
• Calculate the focal length of the lens. Take the percent difference between this value and the value from the object at infinity.
• Calculate the magnification of the image using equation 3 and compare the result to your estimate. Remember that in this case the image distance is negative.
• Characterize the image.
4. **Converging Mirror – Distant Object**

- Mount the concave mirror on one end of the optics bench, on the side away from the distant object you used for the converging lens.
- Using an index card, find the image of the distant object. In order not to block the light, position the bench at a slight angle. The image will form slightly to the side of the bench.
- Record the object, image and mirror positions. Calculate and record the object and image distances and the focal length.
- Calculate the radius of curvature $R$ of the mirror.
- Characterize the image as real or virtual, upright or inverted, enlarged or reduced.

5. **Converging Mirror – Nearby Object.**

- Slide the object lamp onto the optics bench on the side away from the mirror. Plug the adaptor into an AC outlet and into the lamp. Tilt the lamp so that the arrows point toward the mirror.
- Position the object lamp outside the radius of curvature of the mirror.
- Find the image using the index card. Record the object, image and mirror positions and calculate the object and image distances.
- Measure one of the arrows on the object lamp and measure the corresponding arrow on the image.
- Calculate the focal length using the thin lens equation. Take the percent difference between the two methods for finding the focal length.
- Calculate the magnification using both formulas (2 and 3 above). Find the percent difference between them.
- Characterize the image as real or virtual, upright or inverted, enlarged or reduced.

6. **Refracting Telescope**

- Place a long and a short focal length lens on the optics bench. The short lens should be approximately at the focal point of the long lens. The long lens will be the objective lens of the telescope and the short lens will be the eyepiece. Record the focal lengths of the lenses.
- Look through the eyepiece at an object 8-10 meters away. Slide the eyepiece back and forth until the image is sharp and at its greatest magnification. Keep your eye at the same distance from the eyepiece as you attempt to focus it.
- Estimate the magnification of the image. Do this by looking at the image with one eye and the actual object with the other. In this way you can superimpose the two views of the object.
- Calculate the magnification using equation 4.
- Characterize the image.
6. Microscope

- Cut a square of graph paper and tape it to the screen on the optical bench.
- Place the screen outside the focal point of the short converging lens.
- Place the long lens on the other side of the objective, near the objective’s focal point.
- Look through both lenses until you get a sharp, magnified image of the graph paper.
- Estimate the magnification of the graph paper.
- Calculate the magnification of the microscope and take the percent difference with your estimate.
Data & Analysis: Lenses & Mirrors

1. Converging lens - distant object

<table>
<thead>
<tr>
<th>Position</th>
<th>Distance</th>
<th>Focal length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object</td>
<td>Lens</td>
<td>Image</td>
</tr>
<tr>
<td>Object</td>
<td>Image</td>
<td>Focal length</td>
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</tbody>
</table>

Characterize the image:

2. Converging lens – nearby object

a) First image

<table>
<thead>
<tr>
<th>Position</th>
<th>Distance</th>
<th>Focal length</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object</td>
<td>Lens</td>
<td>Image</td>
<td></td>
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<tr>
<td>Object</td>
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<table>
<thead>
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<th>Object Size</th>
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<th>Magnification</th>
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<td>By height</td>
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<tr>
<td>By distance</td>
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</table>

Characterize the image:
### Data & Analysis: Lenses & Mirrors

b) Second image

| Position | | | | | |
|----------|----------|----------|----------|----------|
| Object   | Lens     | Image    | Distance | Object   | Image    | Focal length | % diff |
|          |          |          |          |          |          |              |        |

<table>
<thead>
<tr>
<th>Image Size</th>
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<td>By distance</td>
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Characterize the image:
Data & Analysis: Lenses & Mirrors

3. Converging lens – object inside focal point

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<th>Focal length</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object</td>
<td>Lens</td>
<td>Image</td>
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<table>
<thead>
<tr>
<th>Magnification</th>
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</thead>
<tbody>
<tr>
<td>Estimate</td>
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Characterize the image:

4. Converging Mirror – distant object

<table>
<thead>
<tr>
<th>Position</th>
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<th>Focal length</th>
<th>Radius (R)</th>
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</thead>
<tbody>
<tr>
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<td>Lens</td>
<td>Image</td>
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<table>
<thead>
<tr>
<th>Focal length</th>
<th>Radius (R)</th>
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Characterize the image:
Data & Analysis: Lenses & Mirrors

5. Converging mirror – nearby object

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<th>% diff</th>
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Characterize the image:

6. Telescope

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<th>Magnification</th>
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<tbody>
<tr>
<td>Objective</td>
<td>Eyepiece</td>
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Characterize the image:

7. Microscope

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<td>Eyepiece</td>
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Characterize the image: