Lab 12. Images with Thin Lenses

Goals

- To learn experimental techniques for determining the focal lengths of positive (converging) and negative (diverging) lenses in conjunction with the thin-lens equation.
- To learn how to make a scale “ray diagram” for a combination of a positive and negative lens using three principle rays for each lens and interpret it.
- To understand the specific meaning of the term “magnification” as applied to optical systems and to determine its value by three methods: (a) direct measurement, (b) calculation using the thin lens equation, and (c) using a ray diagram.

Introduction

For a simple focusing element with focal length $f$, it can be shown that

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$  \hspace{1cm} (12.1)

where $s$ and $s'$ are the object and image distances respectively. This is called the thin-lens equation. The object distance is measured from the light source to the center of the lens, and the image distance is measured from the viewing screen, where the real image is displayed, to the center of the lens.

An optical bench with a metric length scale attached to it, two lenses and holders, a light source, and a viewing screen are provided. Some ray box light sources are provided with crossed arrows that serve as the object to be imaged. When one has a clear view the light bulb in the light source, the filament of the light bulb can also serve as the object to be imaged. For clearer view of the image, hang a clean sheet of paper over the glass viewing screen on the side facing toward the ray box.

**Caution:** Always secure (but not too tightly) the optical mounts on the optics bench so that the optical elements do not fall and break. Handle the lenses using the edges only. Your TA will demonstrate how to put a lens in the lens holder.
Determining the focal length of a converging lens

Use the optical bench with the light source and the viewing screen to determine the focal lengths of the two lenses provided, one a converging lens (positive focal length) and the other a diverging lens (negative focal length). You should be able to tell which is which by looking at their cross-sections. The focal length of the converging lens should be determined first. This can be done experimentally by finding pairs of object and image distances that give clear real images of the light source on the viewing screen. (A “real” image can be projected onto a screen.) Then use the thin lens equation to calculate the focal length. Repeat this several times using significantly different values of \( s \) and \( s' \).

Find the mean value of the focal length and compute its standard deviation. If you do not know how to compute a standard deviation, consult the Uncertainty/Graphical Analysis supplement to the lab manual.

What happens when you try the same procedure for the negative (diverging) lens?

Determining the focal length of a diverging lens

A diverging lens forms a real image only when used in conjunction with a converging lens. Using both lenses (place the converging lens nearest the light source), find lens and screen positions that yield clear images. In this configuration we can measure only the object distance of the converging lens and the image distance of the diverging lens. Knowing the focal length of the converging lens from your measurements above, the thin lens equation can be used to find the location of the image formed by the converging lens. Then treat the image of the converging lens as an object (be careful of the sign of the object distance) for the diverging lens. Apply the thin lens equation again to find the focal length of the diverging lens. Note that the sign conventions used in the thin lens equation demand that the focal length for a diverging lens be a negative number. Repeat this process for several significantly different lens and viewing screen positions. Calculate the mean focal length and the corresponding standard deviation.

Drawing a ray diagram for a two-lens system

Pick one configuration of lenses and viewing screen from your measurements on the diverging lens and draw a complete ray diagram to scale showing the formation of the intermediate image from the converging lens and the final image of the diverging lens. Ray diagrams for single converging and diverging lenses are shown in your textbook. Trace the rays for the lens closest to the light source first; then use the resulting image as the object for the second lens. Use your experimental values of focal lengths as given values on your diagram. Does your ray diagram predict the correct location for the final image? Compare the result to your experimental value using the diverging lens.
Magnification

Magnification is defined as the ratio of the size of the image to the size of the object being imaged. When the image is upside down, the magnification is negative. If the image is upright, having the same orientation as the object, the magnification is positive. Using ray diagrams, one can show that the magnification (sometimes called the transverse magnification), \( m \), is equal to \(-\frac{s'}{s}\) for both positive and negative lenses. Compare the heights of the object and image in your ray diagram to determine magnification of the two-lens combination. Compare this value with the magnification calculated using the thin-lens equation for the same lens configuration, knowing the focal lengths and positions of the lenses relative to the object and the final image.

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<thead>
<tr>
<th>Grading Rubric</th>
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<tbody>
<tr>
<td><strong>No Effort</strong></td>
</tr>
<tr>
<td><strong>AA</strong></td>
</tr>
<tr>
<td><strong>AB</strong></td>
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<td><strong>AC</strong></td>
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### No Effort

**AD**
Is able to use representations to solve problems

| Labs: | 3, 5, 8, 9, 11, 12 |

- No effort is made to solve the problem.
- The problem is solved correctly but no representations other than math were used.
- The problem is solved correctly but there are only two representations: math and words explaining the solution.
- The problem is solved correctly with at least three different representations (sketch, physics representation and math or sketch, words and math, or some other combination).

### Progressing

**AG**
Mathematical

| Labs: | 3, 4, 6, 8, 10-12 |

- No representation is constructed.
- Mathematical representation lacks the algebraic part (the student plugged the numbers right away) has the wrong concepts being applied, signs are incorrect, or progression is unclear.
- No error is found in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression.
- Mathematical representation contains no errors and it is easy to see progression of the first step to the last step in solving the equation. The solver evaluated the mathematical representation with comparison to physical reality.

**AH**
Ray diagram

| Labs: | 12 (Not included in Evaluation) |

- No representation is constructed.
- The rays that are drawn in the representation do not follow the correct paths. Object or image may be located at wrong position.
- Diagram is missing key features but contains no errors. One example could be the object is drawn with the correct lens/mirror but rays are not drawn to show image. Or the rays are too far from the main axis to have a small-angle approximation. Or the diagram is drawn without a ruler.
- Diagram has object and image located in the correct spot with the proper labels. Rays are correctly drawn with arrows and contain at least two rays. A ruler was used to draw the images.

### Expectation

**BA**
Is able to identify the phenomenon to be investigated

| Labs: | 1, 2, 4, 6, 7, 9, 11, 12 |

- No phenomenon is mentioned.
- The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest.
- The description of the phenomenon is vague or incomplete but can be understood in broader context.
- The phenomenon to be investigated is clearly stated.

**BE**
Is able to describe what is observed concisely, both in words and by means of a picture of the experimental setup.

| Labs: | 1, 2, 4, 6, 7, 9, 11, 12 |

- No description is mentioned.
- A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations.
- A description is complete, but mixed up with explanations or pattern. OR The sketch is present but relies upon description to understand.
- Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
### EXIT TICKET:

- Remove the lenses from the lens holders, place them in protective bags, and then place them in the plastic tray provided.
- Quit any software you have been using.
- Straighten up your lab station. Put all equipment where it was at start of lab.
- Report any problems or suggest improvements to your TA.
- Have TA validate Exit Ticket Complete.