Geometric Optics – II

Thin Lenses

Please look at the chapter on lenses in your text before this lab experiment. Please submit a short lab report which includes answers to the questions asked, and the ray diagrams requested.

Types of Lenses

There are two types of lenses, converging and diverging. Light rays parallel to the lens axis are bent toward the axis of a converging lens, and away from the axis of a diverging lens. A converging lens often doubly convex, i.e., thickest in the middle. A diverging lens is often doubly concave, i.e., thinnest in the middle. However, some lenses have one convex side and one concave side, e.g., the eyeglasses we wear. They may be converging or diverging depending on the relative curvatures of the two sides.

The Thin Lens Equation

When an object is placed a distance $s$ from the midplane of a thin lens of focal length $f$, an image of the object is formed at a distance $s'$ from the lens. The thin lens equation relate these distances: \[ \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \]

Consult your textbook for more information on this equation, including the sign conventions. You will also find there a more detailed discussion of the formation of images, and locating images by geometric ray tracing.

A. Converging Lenses

A1. Focal Point and Focal Length

Parallel rays emanating from a distance ($s = \infty$) incident on a convex lens will converge at a point, known as the focal point. The distance from the mid-plane of the lens to the focal point is the focal length $f$ of the lens.

Our light source will be an incandescent lamp with a cardboard shield. Illuminate the object (the bull’s eye target) with the light source and place the object at one end of the meter stick. Place the converging lens as far from the object as possible near the other end of the meter stick, and the viewing screen (white card or graph paper) behind the lens. Adjust the position of the screen until the image is sharp. Measure the distance from the center of the lens to the viewing screen. This is close to the focal length $f$ of the lens. Move the screen back and forth to estimate the uncertainty in $f$. Move also the object beyond the end of the meter stick to see if any readjustment of the screen position is necessary. This gives you an estimate of the
uncertainty in \( f \). This error is due to the fact that the object distance is not infinite. It is as large as you can achieve with the set up. You may bring the lens into the hallway outside the lab to see where a distant object forms an image behind the lens.

\[
\text{Light source and cover} \quad \text{Object} \quad \text{Lens} \quad \text{Image}
\]

**A2. Real Images**

If the distance \( s \) from the object to the lens is larger than the focal length \( f \), a real image is formed, i.e., one that can be projected on a screen. From the thin lens equation we can show that this corresponds to a positive value for \( s' \). The magnification is expected to be \( m = -s'/s \), where a negative magnification indicates that the image is inverted.

Start with the object between the lamp and the lens, a distance of about \( 2f \) from the lens. Look through the lens to view the image. Move the graph paper screen to obtain a sharp image on the screen. Record the object and image distances, \( s \) and \( s' \), and the image size. Also, record the object size, so you can calculate the magnification, the ratio of image size to object size. Is the image erect or inverted?

Repeat the above with two additional values of the object distance \( s \). Make a table of the distances \( s \) and \( s' \), and the image sizes.

For your lab report:
- Add to your table the values of \( 1/s \), \( 1/s' \), and the magnification \( m \).
- Make a graph of \( 1/s \), vs. \( 1/s' \).
- Determine the focal length \( f \) of the lens from the graph.
  - How does this agree with the first determination of the focal length?
- How well does the magnification \( m \) agree with expectations?
- For the smallest and largest object distances, draw ray diagrams (roughly to scale) to illustrate the image formation. Use the principal rays described below.

**A3. Image Location by Ray Tracing**

A light ray (1) parallel to the lens axis is refracted so that it passes through the far focal point of a converging lens. A ray (2) passing through the center of the lens is not refracted, and follows a straight line. A ray (3) passing through the focal point near the object is refracted so that it exits the converging lens parallel to the axis. These three
rays are known as the principal rays, and suffice to construct the image location and magnification for any object position.

A4. Image Location by Parallax

Again place the object a distance $2f$ from the lens, as before, and place the large pin a distance $2f$ on the other side of the lens. Looking through the lens, align the pin with the center of the image of the bull’s eye. Move your head slightly side-to-side. If the pin and image shift relative to each other, they are not at the same plane in space.

If the pin is closer to the eye than the image, as the eye is moved sideways the image will appear to shift in the direction of motion, relative to the pin. If the pin is farther from the eye than the image, the apparent shift is in the opposite direction. Move the pin until there is no shift due to parallax. The pin is now at the image position. Measure $s$ and $s'$, and add them to your table.

In your lab report:
• Add this data point to your graph, and compare with your earlier measurements.

A5. Virtual Image

If the distance $s$ from the object to the lens is less than the focal length $f$, a virtual image is formed, i.e., one that cannot be projected on a screen. From the thin lens equation we can show that this corresponds to a negative value for $s'$.

Place the object a distance of $f/2$ from the lens. Look through the lens and point to the image position. Where does the image appear to be? Estimate the magnification. Is the image erect or inverted? Notice that it is impossible to locate the image with the screen.
Place the pin behind the object, and locate the image by eliminating parallax as in part A4 above. You will have to concentrate on the image of the bull's eye, and view the pin above the lens. (Ignore the image of the pin in the lens.) Looking from somewhat above the lens axis may help, since the bull's eye will then appear near the top of the lens. Move the pin until there is no parallax. Record $s$ and $s'$. (Note that $s'$ is negative for virtual image.)

For your lab report:
- Calculate $f$ from this measurement, and compare with previous determinations.
- Calculate the expected magnification $m$ (with sign), and compare with your estimate.
- Draw a ray diagram showing the image formation for this case.

**B. Diverging Lenses**

Replace the convex lens with the concave lens. Place the object about 60 cm from the lens, and locate the image. You will find that it is a virtual image, which must be located by the method of parallax, as in A4 and A5. As before, sight above the lens, and ignore the image of the pin that appears in the lens. Record $s$ and $s'$. (Remember that $s'$ is negative.) Estimate the image size.

For your lab report:
- Calculate the focal length $f$ of the concave lens. Is $f$ positive or negative?
- Calculate the expected magnification $m$ (with sign) and compare with your estimate.
- Draw a ray diagram showing the image formation for this case.

**C. Lens Combinations as Optical Instruments**

**Microscope**

A microscope is used to view nearby small objects. Place the small, short focal length ($f = 5$ cm) convex lens in the lower lens holder on the vertical stand, and the convex lens you have been using in the upper holder. Adjust the lens positions to obtain an enlarged image of the small diagram. The image formed by the short focal length "objective" lens should fall just inside the first focal point of the longer focal length ocular ("eyepiece" lens). This real image plays the role of the object for the ocular and it forms a large virtual image far away from the ocular. When you look through the ocular, it is as if you are looking at a large object far away. This image subtends an angle that is much larger than the original object. Consult your textbook or lecture notes for more detailed explanation of the microscope. Record observations for your lab report.
For your lab report:
• Describe your observations of object and image location, size and orientation.

Telescope
A telescope is used to view large distant objects. The short focal length lens is used as the eyepiece, and the longer focal length lens is used as the objective. A distant object forms a real image on the focal plane of the objective. The ocular is positioned such that the image is also on its focal plane, i.e., the sum of focal lengths for the two lenses is equal to their separation. When you look through the ocular, you see a virtual image infinitely far away, but the angle subtended by the image is much larger than the angle subtended by the distant object. Pick up the stand with the lens holders, and look at a distant object with the small lens near the eye. (The opposite of the way it was used as a microscope, but small adjustments of the separation may help.)

Record your observations for your lab report.
For your lab report:
• Describe your observations of object and image location, size and orientation.