Lab 12. Optical Instruments

Goals

- To construct a simple telescope with two positive lenses having known focal lengths, and to determine the angular magnification (analogous to the magnifying power of a camera or a pair of binoculars) with the aid of some naked eye observations.
- To construct a simple microscope with two positive lenses having known focal lengths, and to determine the angular magnification with the aid of some naked eye observations.
- To draw a complete, to-scale ray diagram for your microscope configuration.
- To use the thin-lens equation along with the magnification to calculate the angular magnification values for the telescope and microscope that you constructed, and to compare your calculated values of angular magnification with those determined previously by visual techniques.

Introduction

The thin-lens equation relates the object and image distances to the focal length of a lens. Knowing any two of these parameters allows us to calculate the third one. You are provided with an optical bench, three lenses (Handle them only by the edges!), a light source, a viewing screen, and a ruler. Experimentally determine the focal length of the three lenses that you have. Take enough data so that at least one of your focal length measurements is within a few percent of the mean value.

Simple telescope

Telescope construction

Using the longest focal length lens of the three as the objective lens and the shortest focal length lens as the eyepiece, construct a telescope using two lenses. Keep your eye as close to the eyepiece as possible. (Your nose is the limiting factor!) Your lab partner should measure the actual distance from your eye to the center of the eyepiece lens with a ruler or meter stick. Remember that telescopes are used to magnify distant objects. We will compromise a little here and use two parallel vertical lines, 3 cm apart, as the object to be viewed with our telescope. These lines can be drawn on a plain piece of white paper taped to the wall at the end of your lab table and should
be at least 2.5 m away from your naked eye. Is the image formed by the telescope real or virtual? How do you know?

**Angular magnification from visual image sizes**

Although the magnification, $m$, of a lens system can be calculated if you know all the image and object distances, the angular magnification, $M$, is of more practical interest, since it tells us how much larger an object will look to us when viewed through the instrument than when viewed directly with our naked eye. The angular magnification is defined as the ratio of the angle subtended by the final optical image in our field of view divided by the angle subtended by the object itself as we look at it with our naked eye. Thus $M$ takes into account not only the sizes of the object and image but also how far the object or image is from our eye. For example, we could devise a lens system that forms a large image located so far from our eye that the image would look small to us. In this case, the magnitude of $m$ would be large, but $M$ would be small, meaning that we were unsuccessful in making the object of interest appear larger.

The angular magnification, $M$, of the telescope can be determined by visual means. Draw two vertical lines, about 1 inch apart, on a blank piece of paper. Use blue tape to post the paper on the wall (or other surface) in front of the telescope. One lab partner (the viewer) views the lines through the telescope, while the other lab partner (the recorder) stands by the paper with a pencil. The procedure is outlined in Figure 12.1. Note that the image of the lines viewed through the telescope is inverted (upside down).

The viewer points the telescope so that the leftmost line of the image (viewed through the lens with one eye) lines up with the leftmost line of the object (viewed by looking around the lens with the other eye). This is easier if the viewers eyes are a few inches behind the eyepiece (not very close to the lens). The viewer then directs the recorder to move the pencil until it lies directly over the rightmost line of the image. When the viewer is satisfied with the position of the pencil, the recorder marks the position of the pencil on the paper.

The angular magnification of the telescope is $L_i/L_o$, where $L_i$ is the distance between the lines as viewed through the lens (the image), and $L_o$ is the distance between the lines as viewed around the lens (the object).

Note: The viewer needs both eyes to determine the angular magnification. If for any reason you do not have the use of both eyes, your lab partner should be the viewer. Wearing glasses or contacts does not usually pose a problem.

**Angular magnification from the thin-lens equation**

Before moving the lenses or the optical bench, measure (a) the distance from the sheet of paper with the vertical lines to the objective lens, (b) the distance between the two lenses, and (c) the distance from the eyepiece lens to your eye. With the thin-lens equation and some trigonometry, calculate the locations and sizes of the final images using the thin lens equation. Then calculate the angle that each final image subtends from the position of the eye. Remember that $M$ is just the image angle divided by the corresponding object angle. Don’t hesitate to ask for some help! Do not use the equation given in your textbook for the angular magnification of a telescope. Your
textbook assumes that the object is located at infinity, which is not true for the object here. Estimate the uncertainties in your visual determination of $M$ and your calculated value. Do the two results agree within the expected uncertainties? Discuss.

**Simple microscope**

**Microscope construction**

Using the shortest focal length lens of the three as the objective lens (i.e., the lens closest to the object to be observed) and the intermediate focal length lens for the eyepiece (i.e., the lens closest to your eye), build a simple microscope using just the two lenses. Use blue tape to attach a piece of graph paper to the back of the viewing screen to serve as the object to be observed with your microscope. Remember that microscopes are used to magnify things that are relatively close to us.

Microscopes are used with your eye in a fixed location, close to the eyepiece. It can help to put your eye as close to the eyepiece as possible; touching the eyepiece lens holder with your nose will provide a reproducible location for your eye. Have your lab partner measure the actual distance from your eye to the center of the eyepiece lens for use in your calculations. Make sure that the final image seen when looking through the eyepiece is in clear focus. Continue adjusting the positions of the lenses until this is achieved. When you have achieved a configuration giving a clear magnified image, move just the eyepiece lens (and your eye!) as close to the objective lens as possible while still maintaining the clear image. The adjustability of the lens of your eye makes this range of positions possible. Is the image formed by the microscope real or virtual? How do you know?
Angular magnification from visual image sizes

It is convenient to use an object 1 or 2 mm long, that is, one or two of the smallest divisions on the graph paper. The magnification can be determined visually by viewing the graph paper through the lenses with one eye and directly (not through the lenses) using the other eye. Alternatively, one can take a picture of the graph paper centered on the edge of the lens, so that the graph paper is viewed through both lenses in part of the image and viewed directly (not through the lenses) in another part, as shown in Figure 12.2. A wide range of angular magnification values is achievable. Choose a single configuration that yields an angular magnification between 6 and 12.

Figure 12.2. Magnified image of square grid viewed through a two lens microscope. An unmagnified image of a corner of the grid is visible in the lower left. The angular magnification $M$ of the microscope can be estimated by comparing the size of squares in the magnified image to the the size of the squares in the unmagnified image. The angular magnification of this microscope is about 13. Image provide by Kamrul Ome.

Angular magnification from the thin-lens equation

When you have achieved an angular magnification within the acceptable range, record the positions of all the lenses as well as the position of the ruler and your eye. To get a better number for the distance from the ruler (object) to the center of the objective lens, measure this distance directly with a meter stick rather than using the readings on the optical bench itself. The reading on the optical bench actually marks the position of the center, thickness-wise, of the plastic viewing screen. The ruler (object) has been placed “off-center” on the surface of the viewing screen. It is usually a small difference, but it can be significant in your calculations!

With the thin-lens equation and some trigonometry, calculate the locations and sizes of the final image using the thin lens equation. Then calculate the angle that the object and the final image subtends from the position of the eye. Remember that $M$ is just the image angle divided by the
corresponding object angle.

**Ray diagram for the simple microscope**

Draw a complete ray diagram for the chosen configuration of your microscope. Include all three principal rays for each lens. This diagram must be drawn to-scale on a page in your lab notebook. Be sure to indicate the distance represented by each division on the paper. (We have not asked for a scale diagram of the telescope because the object is so far away from the telescope objective lens. With any reasonable choice of scale distance, the distance between the objective lens and the eyepiece lens is too small for useful measurements.)

Quantitatively compare the experimental (visual determination) of $M$, the theoretical (calculated) value of $M$, and the value of $M$ determined from the appropriate angles on your ray diagram. Do the angular magnification values agree within the expected errors of the methods used? Address this issue quantitatively.

**Summary**

Briefly summarize your results.

---

**Before you leave the lab please:**
- Remove the lenses from the lens holders and return them to the plastic bags.
- Remove rulers taped to viewing screens, paper sheets taped to walls, etc.
- Place the light source and viewing screen at opposite ends of the optical bench.
- Straighten up your lab station.
- Report any problems or suggest improvements to your TA.