Lab 11. 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 rather simply by knowing 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 microscope or telescope 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.

Now determine by visual means the angular magnification, M, for the telescope. Your lab instructor will be able to explain the technique. Note: You will need to use both eyes to determine the angular magnification. If for any reason you do not have the use of both eyes, have your lab partner do the visual part of this determination. This holds true for the microscope as well. Wearing glasses or contacts does not usually pose any problems.

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 used 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 masking tape to mount a ruler on the back of the viewing screen 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 later 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, which equals one or two of the smallest metric divisions on the ruler. Your lab instructor can explain the visual method used to determine the angular magnification for the microscope. In principle it is similar to the technique used in the case of the telescope, but it does not require making any marks on a piece of paper. A wide range of angular magnification values is achievable. Choose a single configuration that yields an angular magnification between 6 and 12.

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 piece of engineering paper. 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.