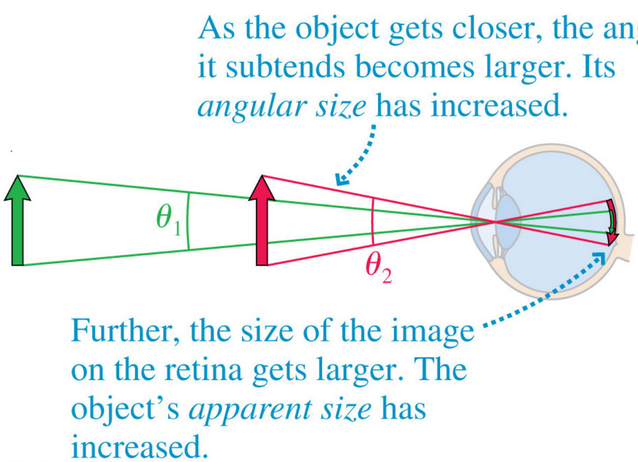
Physics 216 Laboratory 7, Spring 2018
Optical Instruments

Background

In this lab you will first investigate the formation of images by multi-lens systems. You'll then apply your knowledge of converging and diverging lenses to produce functional optical instruments using combinations of lenses, including different kinds of telescopes and a microscope.

With optical instruments such as microscopes and telescopes, in which an image is viewed from a particular vantage point, the lateral magnification $m = \frac{h'}{h} = -\frac{s'}{s}$ is less relevant than the angular magnification $M = \frac{\theta}{\theta_0}$ where θ is the angle subtended by the object as seen through a lens (or lenses) and θ_0 is the angle subtended by the object with no lens. The subtended angle is related to the apparent size of the object being viewed, as shown in the figure below (Fig. 35.11 from Knight).



The angular magnification of an optical instrument may be measured by comparing the size of a calibrated object (such as a ruler or piece of graph paper) as seen through the instrument to its size as seen with the unaided eye.

Investigation I: Combinations of lenses

Activity 1-1: Converging lenses

Place an object at 10 cm from the 20 cm focal length converging lens. Can you project a clear image on a screen? Why not?

Without changing the distance between the object and the 20 cm lens, place the 15 cm focal length converging lens about 15 cm from the original lens. Are you now able to find a screen location where you can obtain a real image? What is acting as the object for the second lens?

Is the image inverted? Does this make sense?

Record the positions on the optical bench for this configuration:

Object:

Lens 1:

Lens 2:

Screen:

Use these measurements, the given focal length of the original lens, and the thin lens equation to calculate the location of the image formed by the original lens alone:

Now use the position of the first image to calculate the location of the image formed by the second lens. Does the image position agree with your experimental result?

Next, replace the original converging lens (the one closer to the object) with a diverging lens, and move the screen to find the new image position. Are there any differences in the image compared to the previous exercise?

Again, record the positions for this configuration:

Object

Lens 1

Lens 2

Screen

Use these measurements, the given focal length of the diverging lens, and the thin lens equation to calculate the location of the image formed by the diverging lens alone:

Now use this to calculate the location of the image formed by the second lens. Does the image position agree reasonably well with your experimental result?

√ Checkpoint 1

Activity 2-2
Challenge: use two (and only two) lenses to make an upright, real image. Explain how you arrived at the solution to the challenge, and describe your solution.

√ Checkpoint 2

Investigation II: The eye and angular magnification
Measure the closest distance at which an object can be for you to easily see it in focus (if you wear glasses, keep them on). This is the near point distance of your eye (NP). Record the result:

Using the 10 cm converging lens, place a calibrated object just inside the focal length of the lens and look through the lens at the image of the object so that the image is magnified as much as possible (but still in focus). (This "instrument" is called a simple magnifier.) Estimate the angular magnification by comparing the size of the image viewed through the lens with the size of the object viewed without the lens. Compare your measured angular magnification to the theoretical value $M = \frac{NP}{f}$.

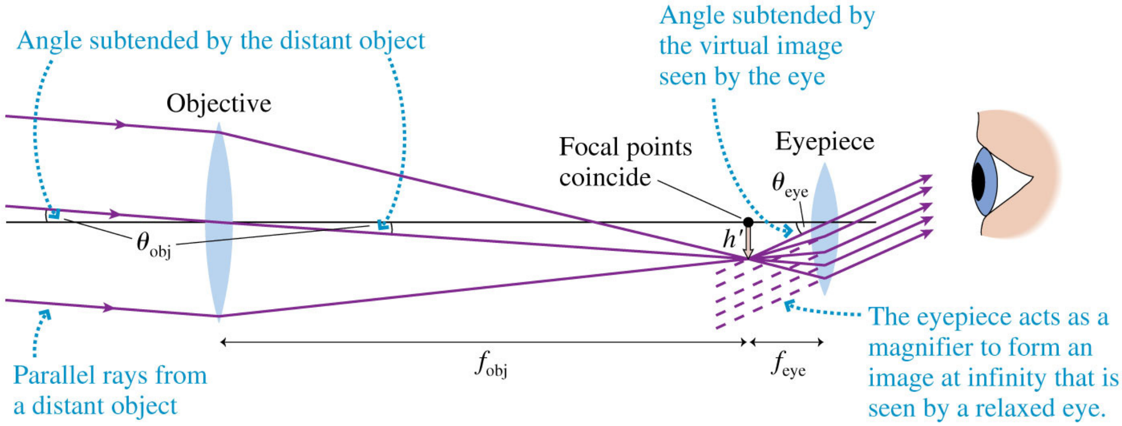
√ Checkpoint 3

Investigation III: Telescopes
Activity 3-1: Simple refracting (Keplerian) telescope
A common optical instrument is the two-lens astronomical telescope (see figure 35.15 in Knight, reproduced below), which produces a magnified, inverted image of a distant object (note that inverted images are perfectly acceptable for astronomical applications). In this type of instrument, the lens closest to the object (the "objective" lens) has a long focal length relative to the lens closest to the viewer (the "ocular" or "eyepiece"). Both the objective and the eyepiece are converging lenses.

The objective lens forms an image that is inspected using the eyepiece lens. Thus the image of the objective lens serves as the object of the eyepiece. The separation between the objective and eyepiece is approximately the sum of the focal lengths of the two lenses, and the angular magnification of the telescope is equal to the ratio of the focal length of the objective to the focal length of the eyepiece, $M = -\frac{f_o}{f_e}$.

Think about how you would use your lenses to construct an astronomical (inverting) telescope. To get as large a magnification as possible with the lenses you have, which lens would you use as the objective, and which as the eyepiece? Why?

Also estimate the required distance between the objective and the eyepiece for these two lenses, based on the discussion above and the figure below.



Now construct an inverting telescope using the two lenses you've chosen. Looking at a distant object, adjust the spacing between the objective and the eyepiece for the clearest image. Record the positions of the lenses. Determine the magnification of the telescope by viewing a (distant) calibrated object both through the telescope and with the unaided eye. Compare your measured magnification to the ratio of the focal lengths of the objective and eyepiece lenses.

Is the image inverted? Is that what you expect?

√ Checkpoint 4

Activity 3-2: Non-inverting telescope with three converging lenses
Although inverted views are fine for astronomical applications, for terrestrial viewing the ultimate image should be upright. One type of non-inverting telescope uses three converging lenses to make an image of a distant object. The objective has a focal length of f_1. A second lens is placed a distance $2f_2$ from the location of the image formed by the objective. Then the third lens (the eyepiece) is placed at a distance of just under f_3 from the image formed by lens 2 so that it serves as a magnifier for that image.

Construct a non-inverting telescope with your three lenses. Again, use the 20 cm lens as the objective (lens 1). Where does this lens form the image of a distant object? Place the 15 cm lens (lens 2) at a location twice its own focal length from the location of the image formed by the first lens. Where does this lens form an image? (Hint: the object for lens 2 is a distance $2f_2$ from the lens.) Now place the 10 cm lens (the eyepiece) at a distance of approximately f_3 from the image formed by lens 2. Adjust this third lens to produce a sharp, upright image of the distant object.

Estimate the magnification by viewing an object with and without the telescope.

Whereas the two-converging-lens telescope produced an inverted image, this three-lens combination produces an upright image. Explain why this is true using a sketch of the system showing the locations of the lenses and the images produced by lens 1 alone, lenses 1 and 2 together, and all three lenses together. Explain what the function of each lens is.

√ Checkpoint 5a

Activity 3-3: Galilean telescope (optional)
Another type of non-inverting telescope uses a diverging lens as the eyepiece and a relatively long focal-length converging lens as the objective. This is the kind of telescope Galileo used.

Use the longest focal length converging lens as the objective and your diverging lens as the eyepiece. Move the objective lens until a sharp focus is achieved. What is the separation between the two lenses in this case? What does this mean about the intermediate image (the image formed by the objective)?

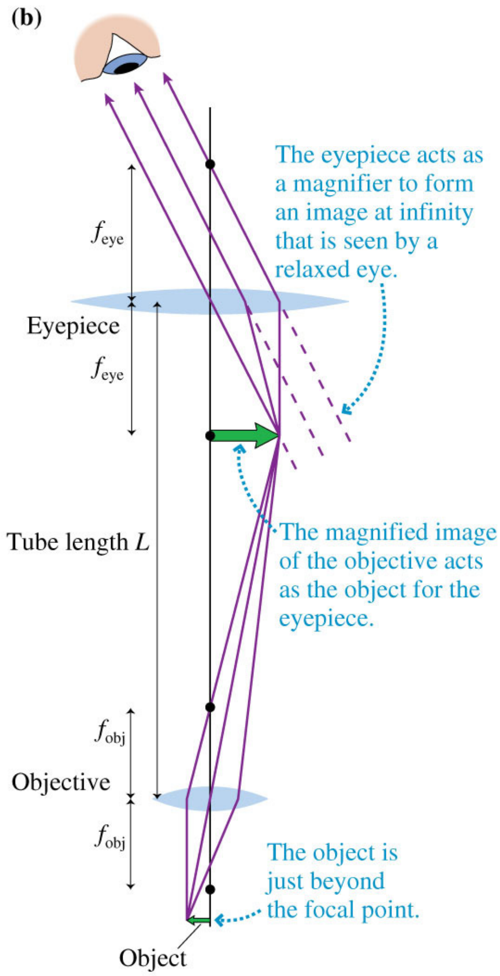
Is the image upright? Explain why this type of telescope produces an upright image.

Estimate the magnification.

Do you notice any other differences between this telescope and the telescope in the previous activity?

√ Checkpoint 5b

Part IV: Microscope
When the object to be studied is very close rather than very far away, a microscope rather than a telescope is employed. For this application, the objective and the eyepiece are normally two relatively short focal length converging lenses. The object to be viewed is placed a small distance beyond the focal length of the objective lens, and the eyepiece is used to inspect the image produced by the objective lens, as shown in the figure below from Knight. The eyepiece lens is typically placed a little less than its own focal length from the image produced by the objective lens.



An estimate of the angular magnification of a microscope is given by this equation, which is simply the product of the angular magnification of each of the lenses:

$$M = -\left(\frac{L}{f_o}\right)\left(\frac{25cm}{f_e}\right).$$

The 25 cm in the equation comes from the typical distance of the near point of the eye.

To construct a microscope, use a 10 cm focal length lens as the objective and a 20 cm focal length lens as the eyepiece. Use a piece of graph paper as the object to be viewed, placing it approximately 5 cm beyond the focal distance of the objective lens.

Calculate the position of the image produced by the objective alone:

Place the eyepiece lens a little less than its own focal length from the image produced by the objective.

Adjust the eyepiece to obtain a sharp image, and record the position of both lenses.

Is the image inverted or upright? Is this what you expect?

Estimate the magnification of your microscope by looking at the grid on the graph paper through the instrument and also with the unaided eye. Compare your measured value for magnification to the theoretical value.

Prediction: with the 10 cm lens as the eyepiece, do you expect a larger or smaller magnification? Explain your reasoning.

Check your prediction by using the 10 cm lens as the eyepiece. Adjust to get a sharp image and estimate the magnification. What difference(s) do you notice with this lens as the eyepiece?

What determines the “tube length” L of the microscope?

√ **Checkpoint 6**