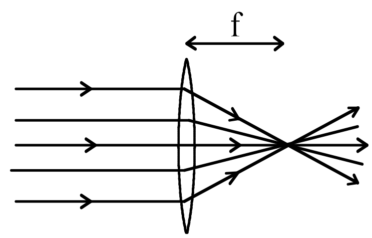
Circle your lab day and time.

Your name:	Mon	Tue	Wed	Thu	Fri
TA name:	8-10	10-12	12-2	2-4	4-6

Lab 10: Lenses & Telescopes

INTRODUCTION

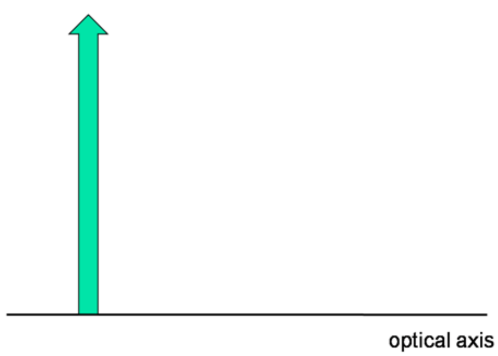


In this experiment, you will study **converging** lenses and the lens equation. You will make several measurements of the focal lengths of lenses and you will construct a simple astronomical telescope. There are a number of different types of converging lenses, but all of them are thicker in the middle than at the edges. A common converging lens shape, the double-convex lens (so called because both sides are curved outward), is shown to the right.

When a bundle of **parallel** light rays enters a converging lens, the rays are focused at a point in space at a distance **f**, the focal length, from the lens. The rays from a small source that is far away from the lens are approximately parallel and will satisfy this condition.

PART I: IMAGE FORMATION

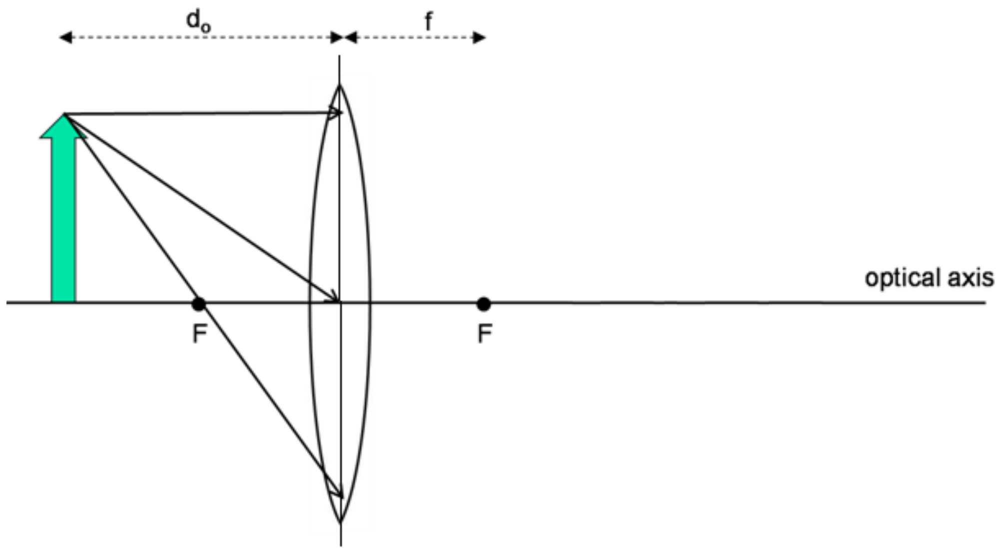
A. In the figure below, draw rays of light coming from the tip of the arrow-shaped **object** and going out in many directions. Next, draw rays of light coming from the middle of the object going out in many directions.



- If you were to expose a piece of photographic film to this mess of rays at some distance away, what would it look like?

- Would it form an image?

B. Now we put a lens in place. The points labeled **F** are the focal points (the distance from the center of the lens along the optical axis to either of the points **F**). Three different rays coming from the tip of the object to the lens are shown.



- Draw carefully how these rays continue after they go through the lens (Hint: The figure of the converging lens in the Introduction may help).
- Do the rays meet at one point on the other side of the lens?
- Draw another three rays coming from the middle of the object (one parallel to the optical axis, one through the center of the lens and one through the focal point on the same side of the lens as the object).
- Do these rays meet at one point?

Check your drawing with your TA.

C. All light rays that originate from a specific point on the object and then go through the lens are redirected to arrive at a single point. All these points together form the image of the object on the other side of the lens.

- Draw the image in the figure above.
- If you were to expose a piece of film to the rays that arrive at the image location, what would it look like?

PART II: MEASURING FOCAL LENGTH BY IMAGE FORMATION

The focal length f of a lens, the object distance from the lens d_o and the image location d_i are related by the lens equation:

$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$$

The object distance d_o and the focal length f are given in the figure from B on the previous page.

- Label the image distance in the same figure.
- How can you use the lens equation to determine the focal length (f) of a lens if you can measure d_o and d_i?

In the lab, you will use an optics bench, which is simply a rail on which lenses are placed, with a ruler on the side, for measuring distances. The other equipment includes a small bright light, which acts almost like a point source, and three converging lenses labeled A, B, and C. There is a frosted glass screen, labeled "I" on which you can view images. Finally, there is a metal plate with an aperture (a hole) in the shape of an arrow. The hole is covered with a frosted, translucent material (scotch tape). When this aperture is placed in front of the light source, it forms a convenient object for image-forming experiments.

Place the light source at the end of the optics bench and attach it with the thumbscrew in the slot. Place the arrow aperture on the front of the light source; there is a magnet to hold it in place. It will save a little trouble in your calculations if you position the source so that the object (the frosted arrow) is **exactly** beside an integer mark (e.g. 2.0 cm) on the scale of the bench.

- Gently tighten the thumbscrew to secure the source, and record the position of the object.

Turn on the light source. Place the frosted screen, I, at the far end of the bench. Again, it will save some trouble if you locate it a convenient integer mark, like 90.0 cm or 92.0 cm.

- Record its position, as indicated by the ring inscribed on the housing.

Now put lens B on the bench close to the object (the arrow) and move it slowly away from the source until you see a clear image on the screen. The image is most easily seen looking through the screen towards the light source, but it can also be seen from the other side. Adjust the position of the lens to give the sharpest image and record the position of the lens (as indicated by the ring on the housing).

- Draw a sketch of the setup, labeling the appropriate parts.

- Measure d_0 and d_i and record them below.

- From the lens equation, calculate the focal length *f*.

If the image is not centered on the screen, adjust the position of the object plate on the front of the light source until the image is centered.

- Measure h_0 and h_i, the heights of the object and image, and record them below.

- Compute the magnification $M = \left|\frac{h_i}{h_0}\right|$ and the value $\left|\frac{d_i}{d_0}\right|$.

- Are they the same? If not, why not?

What do you expect will happen to the image if you block half of the lens? Look at your diagram at page 2 and imaging blocking half of the rays that are going through the lens.

- Would you still form an image?

- Would there be any differences?

- Block half of the lens with a piece of paper. What happens to the image?

PART III: MEASURING FOCAL LENGTH WITH A COLLIMATED BEAM

A. If d_i was set to ∞ in the lens equation and we could measure d_0, how could we determine the focal length *f*? What would the rays of light look like near the lens if the rays converged to an image "at infinity"?

   - Make a diagram, indicating the lens, the rays which emerge from a point at a distance d_0 on the left side and then form an image "at infinity" on the other. Indicate focal length *f* on the figure.

The beam on the other side of the lens is called a collimated beam. Remove the frosted arrow plate from the light source. The source itself is very small and can be considered to be a point source. Readjust its position so that the source is at a convenient integer mark on your bench. Now place lens A close to the source and slide it away until it produces a parallel, collimated beam. A good way to check that it is parallel is this: point the beam at a nearby wall, where it will produce a disc of light.

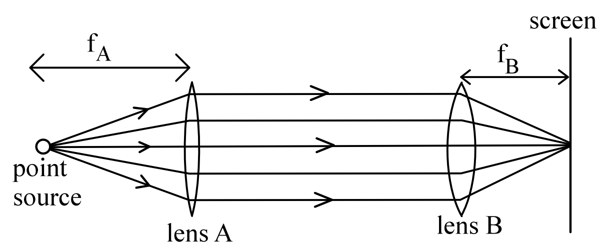
- Why does a collimated beam produce a disc of light?

Adjust the position of lens A until the diameter of the disc is exactly that of the lens opening.

- Now measure the distance from the point source to the lens; this is the focal length f_A.

- Compare your measurement of f_A with your previous value. Do you think this method is more or less accurate than the previous method? (Ask your TA for the focal length of lens A.)

B. If a point source and a lens have been set up to produce a collimated beam (i.e. parallel rays), then the focal length of another lens can be easily measured. The second lens (lens B) is placed in the collimated beam, and the place where the rays are brought to focus is measured. The distance from lens B to the focal point is f_B, the focal length of lens B.



- How is the lens equation used in this situation to determine f_B?

Now you will use this method to measure the focal lengths of lenses B and C. Without moving lens A, place lens B just beyond A, at a convenient integer mark, and put the frosted screen beyond B. Now move the screen until you get a sharp image of the **point source** on the screen. The distance from lens B to the screen is f_B.

- How would you compare the accuracy of this result with the accuracy of the results obtained using the other methods?

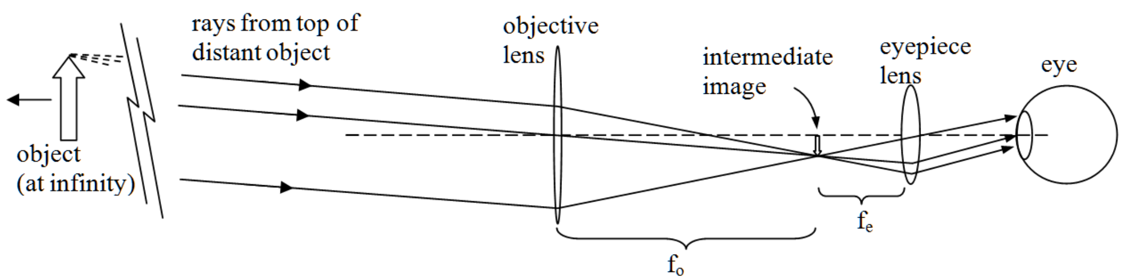
- Repeat the previous step with lens C in place of lens B. Record the focal length of lens C below.

PART IV: THE ASTRONOMICAL TELESCOPE

In the last part of this lab, you will construct a simple astronomical telescope. The astronomical telescope consists of two lenses: an *objective lens* with a long focal length f_0, and an *eyepiece lens* with a short focal length f_e. The objective lens forms an image of a distant object (an object "at infinity").

- By the lens equation, if the object distance is $d_0 = \infty$, what is the image distance?

This image, which appears a distance f_0 behind the objective lens, is called an **intermediate image**, because it is intermediate between the objective and eyepiece lens. The observer views *this* image through the eyepiece lens, which acts as a magnifying glass.



In this diagram, the rays entering the objective lens represent rays from the topmost point of the distant object. The rays exiting the eyepiece lens are parallel rays, which are about to enter the observer's eye.

- Show on the diagram how these rays enter the eye and proceed to the retina.
- What does the observer see as a result of just these rays?

- When you look through a telescope will you see things right side up or inverted? How does the diagram above help you answer this question?

The magnification of the telescope is given by the formula $M = f_0 / f_e$. (This is derived in the lecture notes.) Choose the lens with the longest focal length. This will be the objective lens with focal length f_0. Also choose the lens with the shortest focal length. This will be the eyepiece with focal length f_e. Place the eyepiece at one end of the optics rail and place the objective lens a distance $\ell = f_0 + f_e$ from the eyepiece. Aim the telescope towards the far end of the room, where there is an arrow and a graduated scale mounted on the wall, and adjust the telescope position until you can see the arrow through the telescope. It may be difficult to find the image since your telescope has a narrow field of view. Also, you may need to adjust the position of the eyepiece lens to get a sharp image.

- Is the final image you are looking at upright or inverted?

- Based on the telescope/lens configuration, calculate the theoretical value of the magnification M.