

Geometric Optics

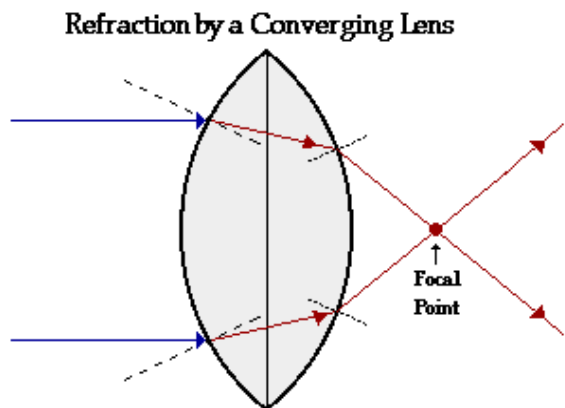
LBS 272L

Before you start:

- Read the LBS272 lecture material, chapter: mirror and lenses. Since the lab is somewhat ahead of the lectures, it is all the more important to read the material to understand the labs. It will also help you to get more out of the LBS272 lectures later when the material is covered in detail.
- Do labquiz 7.
- Read this manual.

Theory

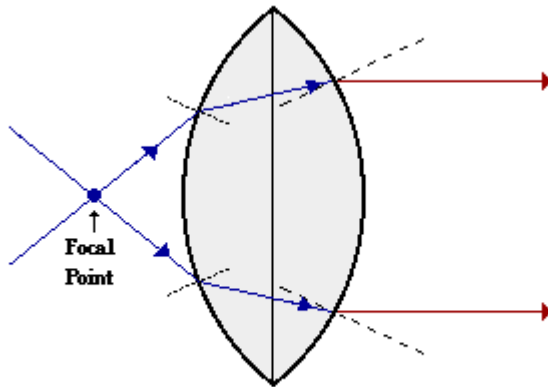
Spherical and cylindrical lenses bend light rays in a way that is consistent with *Snell's Law* of refraction. Light that is incident on the surface of a lens will deviate from its original path, **being bent towards the normal to the surface**. Light that emerges from the lens will be bent away from the normal to the surface of the lens. The degree to which light is bent, therefore, depends on the curvature of a lens. The *focal length* of a lens is a characteristic length that describes a lens's light-bending ability. The refraction rules for a **converging lens** are given below:



Incident rays which travel parallel to the principal axis will refract through the lens and converge to a point.

1. Any incident ray traveling parallel to the principal axis of a converging lens will refract through the lens and travel through the focal point on the opposite side of the lens.

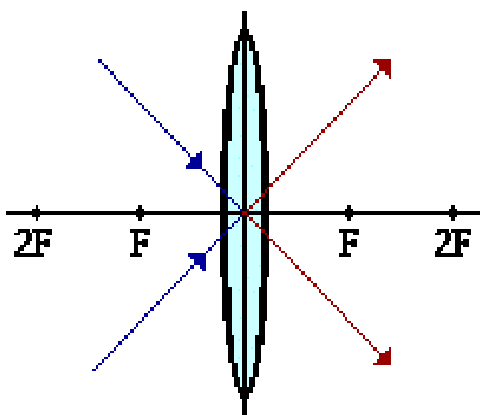
Refraction by a Converging Lens



Incident rays which travel through the focal point will refract through the lens and travel parallel to the principal axis.

2. Any incident ray traveling through the focal point on the way to the lens will refract through the lens and travel parallel to the principal axis.

Converging Lens

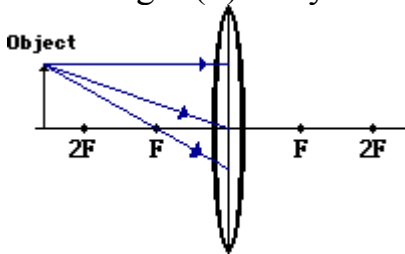


3. Any ray passing through the center of the lens will in effect continue in the same direction as it was going.

Note that the above rules in principle only apply for thin lenses (so that the path traveled within the lens contributes very little to the change in the direction of the light). This so-called ‘thin-lens approximation’ is already visually applied in figure 3, where instead of drawing the refraction of the light rays on each of the surfaces of the lenses, the refraction is only indicated on the vertical symmetry line of the lens.

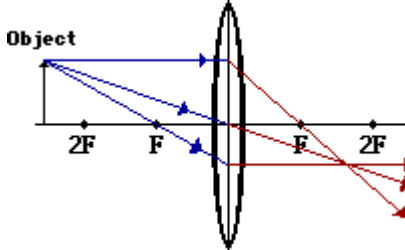
When you look at an object through a lens, the image is distorted. To visualize how an image will look, one can make use of so-called *ray diagrams*. Below, the method to construct such a ray diagram is given for

the case where an object (arrow) is put at a distance more than 2 times the focal length (F) away from the lens.



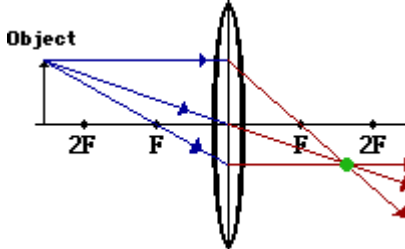
Step 1.

Draw three emerging rays from the top of the object: one ray parallel to the principal axis, one ray through the center of the lens and one ray passing through the focal point of the lens.



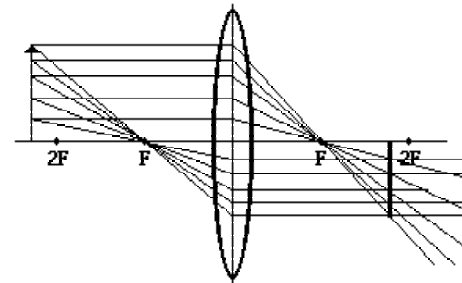
Step 2.

Using the rules of refraction described above, draw how the rays will be bend by the lens.



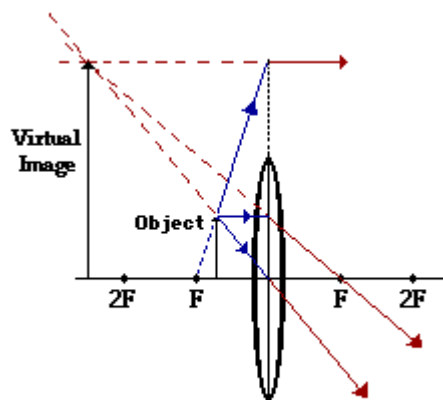
Step 3.

The rays will intersect at a point that corresponds to the location of the image of the top of the arrow.



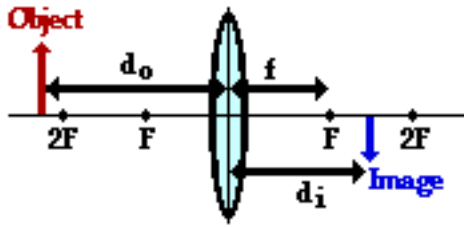
Step 4. Repeat the process for several point of the object. **A ray diagram should at least have the above three rays drawn from the top and bottom of the object.**

A special situation occurs when the object is placed at a distance from the lens smaller than the focal length, as shown below.



Applying exactly the same steps as above, you will find that the rays after the lens diverge and they will only intersect if you trace them backwards. A *virtual* image is then created before the lens. A virtual image cannot be seen (in reality this is not completely true: the lens will always reflect

some light and thus act as a mirror and create the image).



The relation between object (d_o) and image (d_i) position and the focal length (f) is given by:

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

Note that if the image is virtual, d_i will be negative. The magnification of the image is of course given by the ratio of the length of the image and object arrows:

$$M = \frac{h_i}{h_o}$$

By looking carefully at the above figure, you can also find:

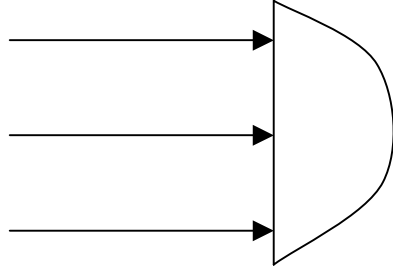
$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

The minus sign indicates that the image is inverted.

Part I.

Answer the following questions. If you like you can answer these questions at the end of the lab. You can test them with the equipment you are given!

- An object (say an arrow, just like above) is placed at a distance from a lens corresponding exactly to the focal length f of that lens. Make a ray-diagram for this situation (use a ruler and make a nice drawing!). Where is the image located?
- Consider a thick lens that has the following shape (you can find such a lens in the tools that you are given). First, consider rays of light coming from the left. By using the rules of light refracting at the surface of a lens given in the beginning of the theory chapter, draw how three rays of light (as indicated in the figure) will pass through the lens. Draw the normals to the lens surfaces where necessary. To make things easy, you can trace a line around the thick lens you are given on a piece of paper and do the drawing on there.



- c) Repeat the same for the case where the light rays hit the curved surface of the lens first.

Part II: Finding the Focal Length of a Convex Cylindrical Lens

In this section of the laboratory, you will determine the focal length of a convex cylindrical lens. When *parallel* light rays are incident on the surface of a convex lens, the rays are all bent in such a way that they converge at the *focal point*. The cylindrical lens that you will be using in this part of the experiment has a flat surface on one side, and a convex surface on the other (i.e. like the drawings above). This particular lens, then, will have two characteristic focal lengths, depending on which surface light rays are first incident upon.

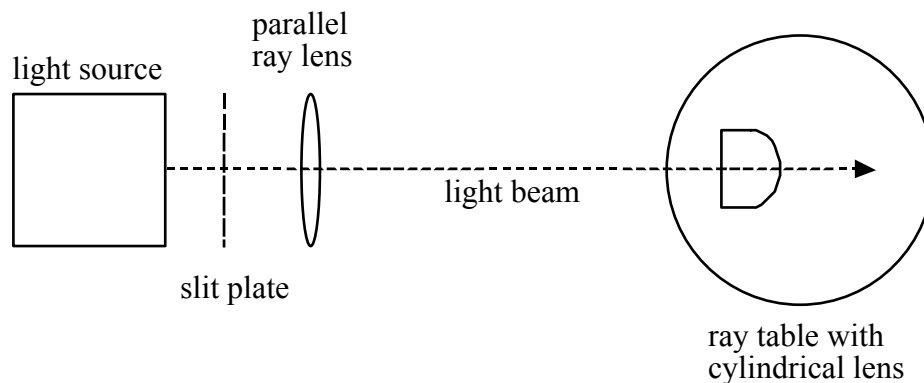
Equipment Needed

- PASCO Optical Bench with Light Source
- Ray Table (round) with Base, and Ray Table Component Holder
- 2 additional Component Holders
- Slit Plate
- Viewing Screen
- Cylindrical Lens
- Parallel Ray Lens

Setup

Set up the optical bench with the light source at the end from which the ruler begins measuring. You might want to move it as much as possible to the edge, without it toppling over. Attach the slit plate to one of the component holders and place the holder just in front of the light aperture (all of the components are magnetized which makes this very simple!). Attach the parallel ray lens to the other component holder, and then attach this holder to the bench. Now attach the ray table (quadrille side up is best) to its base and place this on the bench, sloping upwards. The parallel ray lens should be between the ray table and the slit plate. Using the ray table component holder, attach the viewing screen to the far end of the ray table. (see also the below figure).

Parallel rays from the light source are best established by adjusting the positions of both the slit plate and parallel ray lens, while at the same time observing the projections of the rays on the surface of the ray table. Make sure that at least 4 light rays are incident on the view screen. The “parallelness” of your rays can be fine-tuned by measuring the width of the light pattern that appears on the screen, and then sliding the ray table along the beam axis to see that this distance remains invariant.



Now, find focal length f_1 , by placing the cylindrical lens “flat side first” on the “upstream” side of the ray table, making sure that the flat surface is perpendicular to the light beams. (You may remove the view screen from the ray table.) The light rays will converge at the focal point. (Notice the spherical aberration - the focal point is not precisely defined?) f_1 is found by measuring the distance from the convex surface of the lens to this focal point (the ray table is ruled). f_2 is found by rotating the lens by

180 degrees, this time measuring to the focal point from the (downstream) flat surface. Record f_1 and f_2 .

Question

a) Why is one focal length shorter than the other is? (Hint: consider the refraction of the light rays at both surfaces of the lens, i.e. answer the questions b) and c) of part I now.)

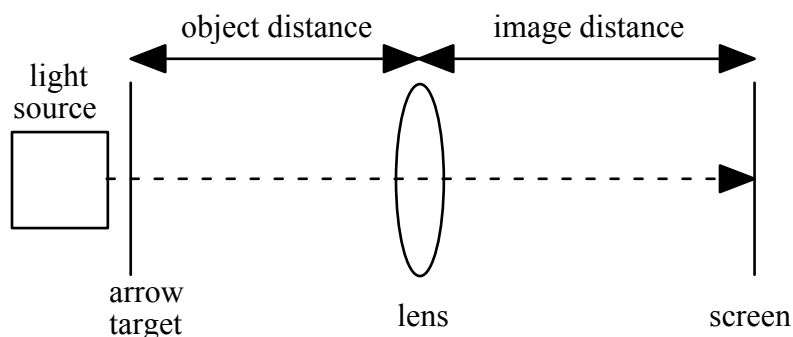
Part III: Image and Object Relationships for a Converging Lens.

In this segment of the experiment, you will use converging lenses of two different focal lengths to explore the relationship between object placement and image location as discussed in the theory.

Equipment Needed

- PASCO Optical Bench with Light Source
- 2 Component Holders
- Crossed Arrow Target
- Viewing Screen
- 75 mm focal length Convex Lens
- ??? mm focal length Convex Lens

Setup



Attach the crossed arrow target directly to the light source aperture (make sure that you don't leave the light source on for excessive periods of

time, as the target may experience heat damage!). Carefully adjust the placement of the light source on the bench so that the crossed arrow target is located at (no greater than) the 10 cm mark on the bench ruler. Now, attach the 75-mm focal length convex lens to one of the component holders and place it on the bench. Next, attach the viewing screen to the remaining component holder and place it downstream from the lens.

With the light source on and the object (crossed arrow target) placed at least 10 cm away from the lens, focus the resulting image onto the viewing screen. It helps in the focusing process if you adjust the light within the light source box (dial on top) so that it's as far left or right as it will go. Describe in your report what you see. Is the object inverted? Magnified? To familiarize yourself with the setup, experiment a bit with the object distance and see what effect this has on the image distance, orientation and magnification.

Note: be sure to place the target, lens and screen on the side of the component holder in the direction that the bottom of the holder is bent. A notch on the base of each component holder shows where the center of each component is. If you place components on the other side of the holder, your measurements may be off by as much as a centimeter.

Data taking and Analysis

Using at least 5 object distances between 10 and 25 cm, create a data table in Excel that contains object distances and the corresponding image distances. You will need to move the screen each time to focus the image and find the image distance. From this information, have your spreadsheet calculate a value for the focal length at each object position. Also, have Excel calculate the **expected** magnification at each object position. Using the ruler on the viewing screen along with the mm scale on the crossed arrow target, verify the magnification values that you just calculated. Next, calculate the average focal length over the 5 object positions. Find the error in the average so that you have a complete measurement with error bar. How does it compare with the given value? For each of the five cases, draw a scaled ray diagram and add them to your report. You can check the diagrams by looking at your measurements

Replacing the 75-mm focal length lens with lens with unknown focal length. Repeat the above procedure and determine the focal length. Hint: You might have to place the light source off the edge of the optical bench in order to fit all the component holders on the bench. Groups that find a focal length close to the real value and determine the error bar correctly, will receive a half a bonus point.

Questions

a) What would happen to the image distance if the object distance, is *very* large (i.e. infinite)?

b) Using the same setup as you used for finding focal lengths, position the object inside the focal length of the lens but still on the opposite side of the lens from the screen. Are you able to resolve an image? If so, what is its position and orientation? If not, why?