



## Thin Lens Equation

### Introduction

Are you nearsighted or farsighted? If you are not, the odds are that, if you live long enough, you will develop one or both of these conditions. When you do, you will have to make one of three decisions. You can try to get by without any actions, which means that you will squint a lot, lose your driver's license, and possibly your ability to read if your arms are not 5 feet long. You can be fitted with corrected lenses, either placing directly on your eyeballs (contacts) or balancing on your nose (glasses). Or, you can now consider having surgery to have the shape of the lens on your eyeball changed so that you have perfect vision.

Why will you develop such a condition? Over time the shape of our eyeball changes for one reason or another. Sometimes, it is the lens at the front of the eyeball that changes. When this happens, the focal length, the distance at which objects are brought into focus behind the lens, will either shorten or lengthen. If the eyeball does not change shape to meet this, then objects will be out of focus. Sometimes, it is the eyeball itself that changes shape, which might change the distance between the lens and the back of the eyeball. If the lens does not change shape to change the focal length, then once again, images will be out of focus.

### Theory

In our last experiment, we saw that light waves are bent, or refracted, upon entering a medium in which the speed of light is different from that of air. Looking at a simple lens, we could guess that the light will be refracted upon entering the lens, travel in a straight line within the lens, and then be refracted again upon leaving the lens. Since the sides of the lens are not necessarily parallel, the light will leave the lens at a different angle from which it entered.

In class, we showed that, depending on the concavity of the lens, the light is either focused or defocused. Let us approximate both sides of the lens as spherical with radii of curvature  $r_1$  and  $r_2$  (see Figure 1), where  $r_1$  is positive if the center of the sphere is to the right of the lens and  $r_2$  is positive if the center of the sphere is to the left. If the index of refraction of the lens is  $n$ , and if air is surrounding the lens, then the focal length of the lens will be

$$\frac{1}{f} = (n - 1) \left( \frac{1}{r_1} + \frac{1}{r_2} \right)$$

While this formula is extremely useful for creating a lens, it is not very useful for determining the focal length of a lens that has already been created. This would require some way of measuring the radius of curvature of both sides of the lens, which would normally mean the use of some fairly sophisticated equipment found in an optometrist's office.

A much more practical method for finding the focal length of a lens uses the thin lens equation

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

where  $p$  is the distance the source is away from the lens,  $q$  is distance the image is behind the lens, and  $f$  is the focal length. To do this with a converging lens is quite simple, requiring only a bright object, a meter stick/ruler, a piece of paper, and a good set of eyes. Place the object a known distance away from the lens, and then move the paper on the opposite side until the object is in focus on the paper. Measure the distance between the lens and the paper, substitute these values into the equation, and solve for  $f$ . This procedure will not work for a diverging lens, which will require the use of converging lens in conjunction with it to focus the object.

### Procedure

In lab, we will use two slightly different methods for find the focal length. The first of these is to place the bright object an infinite distance from the lens which leaves you with the focal length equaling the image distance behind the lens. Finding a light source that is an infinite distance away will take some doing. However, we will approximate an infinite source by using a laser beam that is deflected translationally by a transparent slab of material. Figure 2 shows the setup. By pivoting the slab about the axis, the laser beam passing through it will be shifted translationally across the surface of the lens. If the screen is at the focal length of the lens, the laser beam should not move as the slab is pivoted.

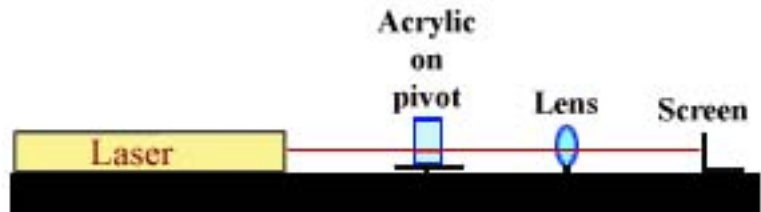


Fig: 2: Set up for Part 1

The other way to find the focal length is to place an object a finite distance away. This will be done with a light source attached to the optics bench at some distance from the lens, which is also attached to the optics bench. The screen on the optics bench is moved until it comes into focus. The distances are measured by subtracting the position of each object on the bench from the others. of the to use a light source that is a known



Fig: 3: Set up for Part 2

In the lab,

1. Set up the optical bench as in the Figure 2 above. Turn on the laser. Move the screen very near the lens and observe the spot on the screen as the laser beam is moved from the axis of the lens to the edge. Note the direction of movement.
2. Move the screen far away. Again, pivot the transparent slab and note how the spot moves.
3. Keep repeating this procedure at different spots between these two points until you find a position at which the spot does not move. Measure the distance from the lens to this spot. Record your results on the activity sheet.
4. Repeat with two more lenses.
5. Remove the laser and transparent slab, and place an incandescently lit source on the bench outside the focal length of the lens (Figure 3). Move the screen until an image is focused on it. Measure the distance from the source to the lens and from the screen to the lens. Record this data on the activity sheet and calculate the focal length.
6. Repeat this with the incandescent source at 4 other locations outside of the focal length of the lens.
7. Repeat this with two more lenses.
8. Answer the questions on the activity sheet.

