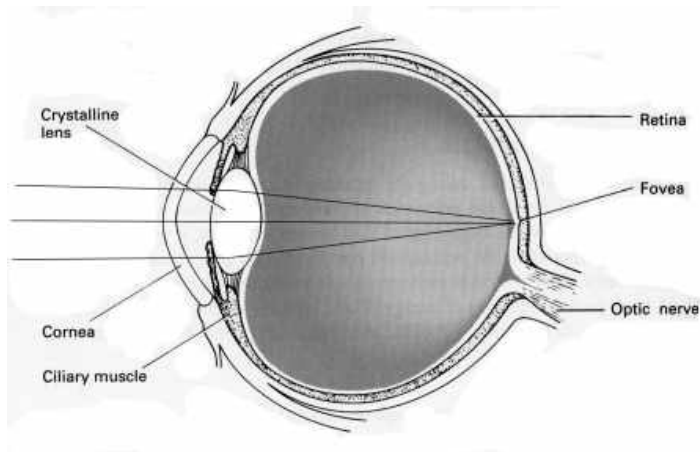## Introduction

Most of the subject material in this lab can be found in Chapter 25 of Serway and Faughn. In this lab, you will make images of images using lenses and the optical bench (Experiment A). **IT IS IMPERATIVE THAT YOU READ CHAPTER 25 BEFORE COMING TO LAB!** You will study your own eye as an optical instrument and measure the distance on your retina from the fovea to the "blind spot" (Experiment B). You will also study a model of the eye, and examine the ability of the lens to bring an object into focus at different distances. You will examine how an abnormal eyeball causes blurred vision and how to correct this (Experiment C). There is only one station with the model of the human eye. Whenever that station becomes available, take a few minutes at that station to perform Experiment C.

The Human Eye

The figure shows a cross section of a human eye. Light is refracted at the surface of the cornea, and is refracted again as it passes through the "crystalline" lens. In a normal eye, light is perfectly focused on the receptors in the retina where signals are generated in nerve fibers and transmitted to the brain. An inverted image is formed on the retina, but the brain "expects" this as normal and is wired to recognize this as normal. Unless you are studying details of the function of the eye, we can consider it to be a single lens (where the focal length can be varied), and a fixed distance from the lens to the retina where we would prefer to make sharply focused images. The table shows the optical power (diopters) of the various surfaces in the eye for a human aged about 20 years.

Refracting Structure	Relaxed eye (diopters)	Most converging eye (diopters)
Air-cornea interface	45	45
Lens	14	24
Entire eye	59	69

The relaxed eye focuses an object at infinity perfectly on the retina. These rays are shown in the figure. "Relaxed" means that the muscles controlling the lens are relaxed and the lens has its lowest power and longest focal length. If we struggle to focus on objects very close to our eyes the muscles controlling the lens tense, the lens gets fatter in the center, its power increases and its focal length decreases. This is the 'most converging eye". A "normal eye" has a far point (the maximum distance at which it can focus) of infinity, and a near point (closest distance at which the eye can focus) of 20 cm or less. The eye "accommodates" to these changes by flexing the muscles controlling the lens, ie changing the focal length. The image distance (between the lens and the retina) is fixed.

Pre-Lab Questions:

1. a) Measure your own "near point" and "far point." *(Hint: read Serway 25.2)* If you wear corrective lenses, do this with them on.

b) When your eye is relaxed, does the lens have its largest or shortest focal length? In this state, can you see more clearly at a distance or up close? Is the lens at its fattest or thinnest?

2. An optometrist measures the power of a lens in diopters (D). The formula defining diopters is:

lens power (in diopters) = 1 / focal length (in meters)

For example, if $f = -50$ cm, lens power $= -2.0$ D. Assume that the distance from the lens of your eye to the retina is exactly 1 inch (in effect, the image distance). Calculate the power of the lens in your eye (in diopters) for both your far point and near point. The difference between these two lens powers is called the "power of accommodation", and it decreases with age, as shown in the table below:

Age (years)	10	15	20	25	30	35	40	45	50	55	60	65
Accommodation (D)	14	12	10	8.5	7	5.5	4.5	3.5	2.5	1.7	1.0	0.5

Does your power of accommodation agree with the table?

3. (a) Draw ray diagrams for the following two situations involving converging lenses. Each ray tracing needs to have the three principal rays shown to the right. Also, draw the image on the ray diagram where the three principal rays converge. Refer to Section 23.6 of Serway & Faughn for further guidance on how to construct principal rays.

(b) Use a ruler to measure the object distances, image distances, and focal lengths for the two ray diagrams. Then, verify that your measurements are correct with the thin-lens equation.
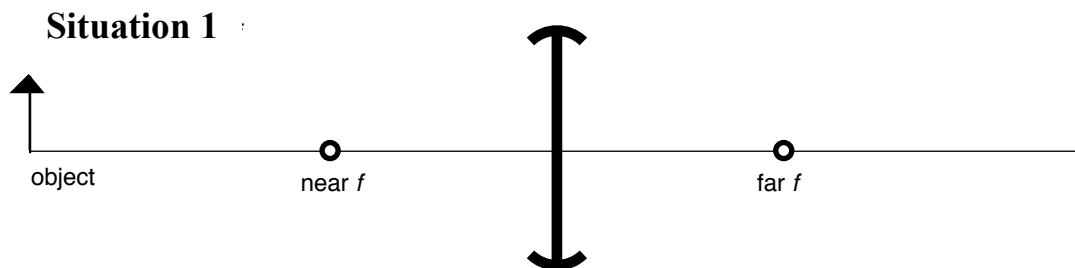
Situation 1

Situation 2
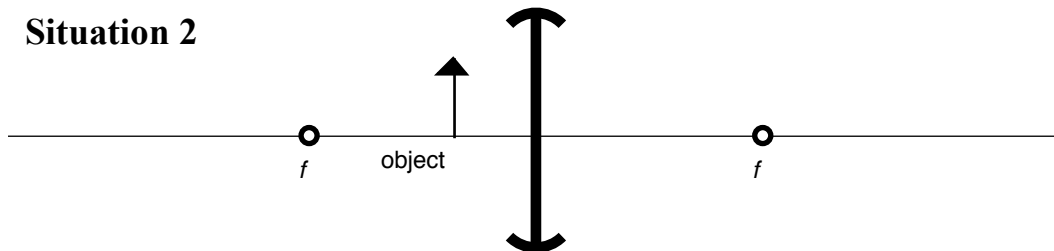
Group Activity

In the schematic of the eye shown, the distance between the lens and the retina is 17 mm.

1. Calculate the focal length of the lens to focus an object at infinity on the retina. Compare this to the table on page 1.

2. Calculate the focal length of the lens to focus an object at 20 cm on the retina. Compare this to the "converging eye" in the table on page 1. Could the eye described in the table focus on a point closer than 20 cm? If the object (at 20 cm) is a letter E on a page of writing where the E is 3 mm high, how large is the image?

3. At the fovea, where there is the densest packing of cones responsible for sharp color vision, the spacing of cones is about 3 μm. How many cones sense the straight back line of the letter E?

4. If the eye shown is nearsighted so that its far point is at 20 cm, what type and strength corrective lens should be prescibed?
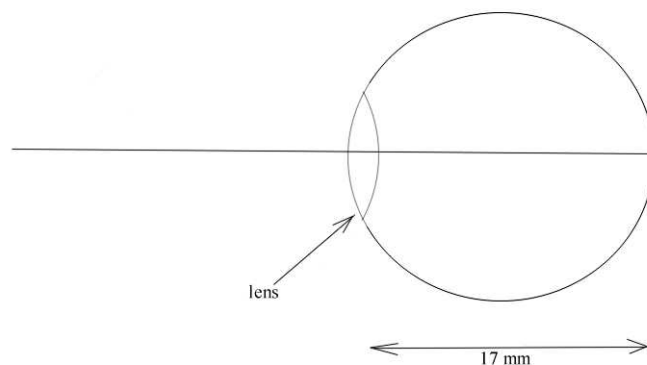
Experiment A: Images of Images

In this section you will explore how to make images of images using a two-lens system. You should have the following equipment available to you for this experiment: a +100 mm converging lens, a +200 mm converging lens, a –333mm diverging lens (labeled 2) placed in a holder, a luminous source of light with object, a screen, and an optical bench.

Consider the three following two-lens systems (lens 1 is always the lens nearest to the object):

(a)   Lens 1 makes a real image 1, of which lens 2 makes a real image 2.

(b)   Lens 1 makes a real image 1, of which lens 2 makes a virtual image 2.

(c)   Lens 1 makes a virtual image 1, of which lens 2 makes a real image 2.

For the three cases listed above you are free to use any two lenses that you wish, although you may want to ask your TA for suggestions if you are stuck.

Procedure:

For each case listed above first calculate using the thin-lens equation, where you need to position the first lens, the second lens, and the screen [for cases (a) and (c)] on the optical bench. Then experimentally verify each case using the equipment provided. It is a good practice to perform this experiment by first locating image 1 from the first lens and then placing the second lens once you know this location. Show your TA your result at the end of each case so that they may verify that your result is indeed correct.

- In your lab notebook, make a schematic drawing (not a ray tracing) for each case above. Do not do ray tracings, but instead use the thin lens equations to calculate all distances. Also, calculate the magnification of the final image and verify it experimentally.
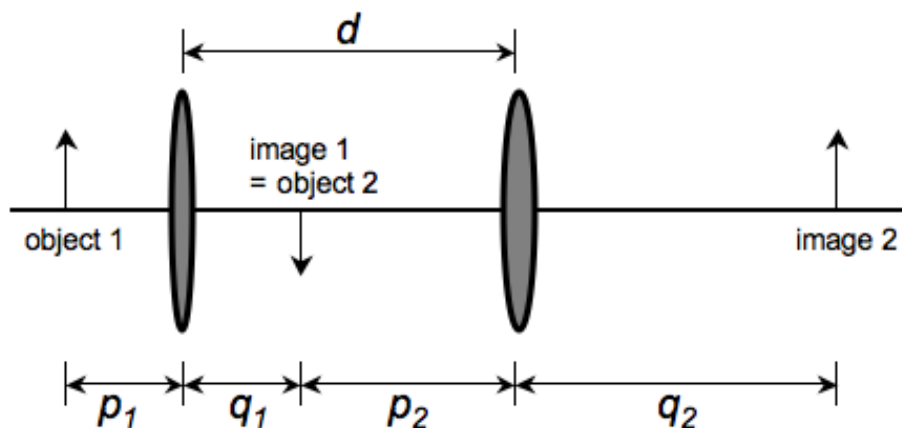
Questions:

A1. For case (a), (the real image of a real image):
- what is the orientation of the final image with respect to the original object (*i.e.* is it upright or inverted)?
- what is the magnification of the final image compared to the original object?
- could another combination of the lenses available to you in this lab create another real image of a real image?

A2. For case (b), (the virtual image of a real image),
- what is the orientation of the final image with respect to the original object (*i.e.* is it upright or inverted)?
- what is the magnification of the final image compared to the original object?
- could another combination of the lenses available to you in this lab create another virtual image of a real image?

A3. For case (c), (the real image of a virtual image),
- what is the orientation of the final image with respect to the original object (*i.e.* is it upright or inverted)?
- what is the magnification of the final image compared to the original object?
- could another combination of the lenses available to you in this lab create another real image of a virtual image?

Experiment B: Determining Your Blind Spot

At least one person in each group must measure his/her blind spot. Keep your eyeglasses or contacts on if you wear them.

1. Stand about 2-3 meters from the white board.
2. Have your lab partner make a 1-inch solid dot in the middle of the white board.
3. Cover your left eye with your hand and stare at the spot on the board with your right eye. (This puts the image of this point on the fovea where vision is most acute.)
4. Have another lab partner point the laser beam at the spot on the board. (Do not point the laser beam at anyone's eyes, ever!)
5. While continually staring straight ahead at the dot on the board, have the other lab partner slowly move the laser beam horizontally to the right. Do not move your eye to follow the laser beam. (This is cheating and will not help you find your blind spot.)
6. At a certain point, the laser beam will disappear from your field of vision. When this happens, have your lab partner mark this spot on the white board. This is because the image of laser beam falls on the blind spot of your eye. (The blind spot is where the optic nerve reaches the retina, and there are no receptor cells there.)
7. Have your partner continue to move the laser to the right and, eventually, the laser beam will reappear in your field of vision. Mark this spot on the white board as well.

Questions:

B1. Measure the distance from your eye to the board and the distance from the spot you were staring at to the beginning of your blind spot.
B2. Assume the focal length of your relaxed eye is 17 mm and that the distance from the lens to the fovea is also 17 mm. Using this model of the eye and similar triangles, calculate the distance on the retina between the fovea and the optic nerve.

Experiment C: The Human Eye Model

The eyeball model allows you to simulate and observe many of the functions of the eye on a large scale. The human eye varies the lens shape (and hence the focal length) to sharply focus the image on the fovea. The Human Eye Model consists of a sealed plastic tank shaped roughly like a horizontal cross section of an eyeball. A permanently mounted, plano-convex, glass lens on the front of the eye model acts as the cornea. The tank is filled with water, which models the aqueous and vitreous humors. The crystalline lens of the eye is modeled by a changeable lens behind the cornea. A movable screen at the back of the model represents the retina. The total length of the eye can be changed to simulate myopia and hyperopia.

Procedure and Questions:

The eyeball should be set up for a normal-shaped eye. In this experiment you will study how images are formed on the retina of the eye. Do not fill the eye model with water. Put the retina in the middle slot, marked NORMAL. Put the +400 mm lens in the slot labeled SEPTUM. Use the crossed arrows as the light source.

C1. Put the crossed arrow light source about 50 cm from the lens. Can you see an image on the retina screen? Is the image magnified or diminished compared to the original object? Is the image inverted or upright compared to the original object?

A person affected by myopia has images of a far-away object formed in front of the retina. Set the Human Eye Model to normal, near vision (put the +62 mm lens in the SEPTUM slot, remove other lenses, and put the retina screen in the NORMAL position). Use the crossed arrows as the light source. Adjust the distance between the eye and the source so that the image is in focus.

C2. Move the retina screen to the back slot, labeled NEAR. Describe what happens to the image.

C3. You will now correct the myopia by putting eyeglasses on the model. Find a lens that brings the image into focus when you place it in front of the eye in slot 1. Record the focal length of this lens. Calculate its power in diopters.

C4. To correct myopia, is it necessary to move the image formed by the eye closer to or farther from the eye's lens system? Does this require a convergent or divergent lens?

Conclusion:

1. Your TA will inform you which section of this lab you should write up.