Introduction

In this lab you will have the opportunity to use a variety of lenses to form images. The equipment you will use includes a light bulb as a source (object); cards and screens (and your eyes) to view images; several lenses and baffles to create images; and a ruler to measure lengths. The theory behind these experiments is covered in Serway and Faughn 6th Ed., Chapters 23 and 25.
You should perform this lab with the main lab lights off. Use the desk lamps for reading.

Pre-Lab Homework:

Your prelab homework requires you to work online. Visit this site:

    http://phet.colorado.edu/simulations/sims.php?sim=Geometric_Optics
    Click the *Run Now* button to start the web simulations, set the ***radius of curvature*** to 1.2 m, the ***refractive index*** to 1.75, and the ***diameter*** to 1.2 m. (1.19 works if 1.2 is hard to get)

1. Calculate the focal length of this lens using the lens makers' equation.
2. Select *principal rays*, turn on the *ruler* and *virtual image* (for later), with the *Change Object* button select the arrow as your object and position the arrow so its tail on the optical axis.

   a) Calculate the distance you need between the lens and the arrow so that its image is the same size as the object. What are your calculated values of *p* (object distance), and *q* (image distance)?
   b) Using the ruler move the arrow to your calculated position, and check that the image is the same size as the object. Is the image upright or inverted?
   c) Reproduce the ray diagram in your notebooks. Label object, image and focal points.
   d) Draw a diagram and explain the properties of "principal rays."

3. Switch to "*many rays*". What happens to the rays that do not go through the lens?
4. Now turn on the *screen*. This will give you a flashlight as the light source. Leave the flashlight fixed for now. Move the screen slowly from the extreme right hand side to the position of the lens. What happens to the light on the screen especially as you get close to the focus?
5. Move the object (flashlight) closer to the lens. What happens to the image? When the flashlight is at the focal point, where is the image? Make a drawing showing the rays.
6. Bring the flashlight closer to the lens than the focal point.

   a) What happens to the rays? Is an image formed? If so, describe this image.
   b) Where do you need to put the flashlight to get a virtual image that is three times the focal length distant from the lens? Draw the rays for this configuration.
   c) Where would you need to put your eye to see the image? Draw this on your diagram.
   d) What are *p*, *q* and the magnification for this setup?

7. What happens to the focal length of the lens if you increase the refractive index?
8. What happens to the focal length of the lens if you increase the radius of curvature of the lens surfaces?

Group Activity:

G1.   Suppose you are given a positive lens with focal length of $f = +100$ mm, and you need to make an inverted image that is exactly 80% of the size of the object.
  - Find, by calculation, what your image distance and object distance would be.
  - Record your calculation on your whiteboard and in your notebook.

G2.   Using the top half of the whiteboard, draw this arrangement exactly to scale. Draw the object, optical axis, lens and image in black. Use an object height of 6.0 cm and assume your lens has a diameter of 14.0 cm. Use a meter stick to draw straight lines for the rays. Put the object close to the left edge of the board.
  - Show the three principal rays from the top of the object through the lens to the image. Draw these three rays in RED. Draw arrows on your rays to show which way the light is traveling. Label the object, the image and the focal points of the lens.
  - Draw (in GREEN) three principal rays from the midpoint of the object to the midpoint of the image. Choose the rays the same way as for the red rays from the top of the object.
  - Finally draw (in BLUE) three rays from the foot of the object through the lens to the image. Choose one ray through the center of the lens and one to the extreme top and bottom of the lens.

G3.   Now try the experiment. You will need to darken the lab. Use the reading light for general illumination. Do this setup on the optical bench. Use the +100 mm lens for this activity.
  - Setup the PASCO light source which provides a uniform illumination of the "crossed arrow." Put the +100 mm lens onto the optical bench. Set the distance between object and lens to be what you calculated. Set the image screen at the position you expect to see an image.
  - Adjust the position of the screen until you see a sharp image of the arrows.
  - Measure your object and image distances. Do they agree with your calculation in G1?

G4.   Examine the image using a screen:
  - Is the image the same size as the object? How can you tell?
  - Is the image the same way up as the object, or is it inverted? How can you tell?
  - Compare your measured value of the magnification to the calculated value.

G5.   Examine the image using your eye:
  - Put your eye where the image is formed (have your collaborators help you find the right position). What do you see? Experiment, by moving your head, to find a place that you can see the image in focus directly with your eye. Where do you need to put your eye to do this?
  - Add your eye to the diagram on your whiteboard to show how the rays enter the eye.

G6.   On the lower half of the whiteboard draw the same object/lens/image setup, but draw an opaque screen over the top half of the lens. Draw only the rays that pass through the lower half of the lens. Decide as a group if you will, or will not be able to see the entire image. Write your prediction on the white board together with your justification.

G7.   Try the experiment described in G6. What do you observe? How can you explain this?

Experiment A: Measuring focal lengths of positive lenses

> You should have two lenses labeled 1 and 2 available on the lab bench (DO NOT MIX THEM UP; MAKE SURE THEY RETURN TO THEIR PROPER BAGS WHEN YOU ARE FINISHED WITH THE LAB).

- Examine each lens and describe its shape (e.g., biconcave, plano-convex etc). Which lenses are thinner in the middle than at the edge, and which are thicker at the middle?
- Which lenses are converging lenses and which are diverging lenses (if any)?

Clean the lens with a tissue after handling it. In this lab, our lenses are not expensive, high quality optical elements, and we do not mind them being handled and cleaned. But if you are working in a professional lab using optics, remember that handling an optical element with your fingers could harm it. Even cleaning a glass lens with a tissue makes fine scratch marks.

A1.   Measure the focal lengths of lens 1. Use a light source (this is the "object") at a large distance from the lens (such as the desk light from the lab table across the room). Find the position where you get an image on the screen as you did before in G3.

- Vary the distance between the lens and the screen until you see the sharpest image. Measure the lens to image distance (q).
- Now measure the distance from the object to the lens (p) with the two-meter stick provided. Calculate the focal length using the measured object and image distances.
- Student XYZ asserts that: *"The distance to the object is so much larger than the distance to the image, I can assume that object is at infinite distance. So it is not worth my time to measure the object distance, I can assume the object is at infinity"*. Follow this student's advice. Calculate the focal length using your measured value of q, and an object distance of infinity. What focal length would you get?
- By what percentage do these two measurements of the same quantity (the focal length) differ? Which is larger? Why?
- Can you evaluate the strength of student XYZ's advice? Suppose you make a 1 mm error in measuring q. What fractional error would this be in the value of q? What fractional error is this in the value of $(1/q)$?
- Is a 1 mm uncertainty in the measurement of q a reasonable assessment of the difficulty of the measurement? If it is not, use your own estimate of this uncertainty.
- If you make no error at all in measuring p (you can actually do this very precisely), then your fractional error in calculating the focal length is the same as your fractional error in measuring q. What is your fractional uncertainty in q and thus also in f? Using your calculated value of the focal length what is the uncertainty in the focal length in mm?
- Is student XYZ correct in her assumptions?

A2.   Repeat A1 to measure the focal length of lens 2. Do your results for lens 2 confirm your earlier assumption of the value of the focal length of this lens?

A3.   What is the orientation of the images (upright or inverted)?

A4.   What are the relative sizes of the images?

- Which lens made the larger image?
- Compare the focal lengths of these lenses. Explain why one makes a larger image than the other.

Experiment B: Measuring the focal length of a negative lens

In this section, you need a lens that has a negative focal length. You will pick this lens up from your TA. DO NOT MIX THIS LENS UP WITH THE ONES WITH POSITIVE FOCAL LENGTHS! Keep this negative lens separate from the positive lenses whenever possible. When you are done with this section, immediately return the lens with negative focal length to your TA. DO NOT LEAVE IT ON THE LAB BENCH NEXT TO THE POSITIVE LENSES WHEN YOU LEAVE LAB OR POINTS MAY BE TAKEN OFF YOUR IN-CLASS LAB GRADE!

In this exercise, you will measure the focal length of a combination of a positive lens and a negative lens. If you know the focal length of the positive lens you can then find the focal length of the negative lens.

If you place two thin lenses so close together that they touch each other, it is useful to know the effective focal length of the combination. The easiest way to calculate this is to use a concept called the "power" of a lens. This is measured in units called "diopters" which are the same units your optician uses for prescribing eye glasses or contact lenses. The power of a lens in diopters is the reciprocal of the focal length in meters. (Example if focal length of a lens is 333 mm, its power is 3.0 D). See p. 786 of your text for another example.

When you place two lenses close together so they touch, the power of the combination is the sum of the powers of each lens. (Example, two identical f = 333 mm lenses together make a 6.0 D combination).

B1. Calculate the powers of each of the positive lenses you measured in experiment A.

B2. What is the power of a negative lens of focal length f = −333 mm? If this lens is flat on one side what word do opticians use to describe its shape? Draw this shape of lens in your lab book.

B3. What is the power of the combination of a negative lens (f = −150 mm) and a positive lens with f = +500 mm? If the positive lens also is flat on one side how do opticians refer to its shape? Draw this type of positive lens in your lab book.

B4. Show the two lenses touching, curved sides together.

- What is the focal length (and "lens" power) of a sheet of glass with parallel sides?

- How is this related to your answer in B3? Does your answer make sense? Explain.

B5. Lenses 1 and 5 do not have equal and opposite focal lengths.

- Measure the focal length and the power of the combination of lenses 1 and 5. You can use the technique you perfected in experiment A.

- Using the technique from experiment A, calculate the power and focal length for lens 1. Then use this information to calculate the power and the focal length of lens 5.

Conclusion:

1. Please do a write-up for the section of the lab that your TAs specified. You can download an example off the class website.