Geometrical Optics

1 Experiment

In this section, we will see how a converging lens can produce a real image of an object. Using a lens holder, place a converging lens at the 50 cm mark of the optical bench. We will call 50 cm the *location* of the lens.

Next, make an *object* by drawing a picture on an index card. Use bold, dark ink so that we can produce a nice image. Place the object at a location somewhere between 0 cm and 50 cm on the optical bench. (You could use one of the lens holders for this as well, or come up with some clever way of holding it in place.) I want to distinguish between *object location* and *object distance*. The *object location* is just the mark on the optical bench where you place the object. The *object distance* is the distance of the object from the lens. It is the object distance that you use in the thin lens equation.

Measure the *height* of your object (from top to bottom) and record it.

Object Height	

Place a blank index card, or one of the glass plates, at a location somewhere between 50 cm and 100 cm on the optical bench, to be used as a screen. This location is the image location. (Again, I want to distinguish between *image location* and *image distance*.)

Illuminate the object with a lamp. The room should be reasonably dark so that most of the light that hits your screen is coming from the object and not from other sources in the room. Move the image screen around until you get the sharpest image that you can get. Record your locations in the first line of the table below. Also, measure the height of the image (from top to bottom). If the image is upside down, call the height negative.

Object Location	Lens Location	Image Location	Object Distance	Image Distance	Image Height	Focal Length

Use two other object locations and find the corresponding image locations. Record these data in the table. Then calculate the object and image distances. Finally, using the thin lens equation, calculate the focal length.

If your three calculations for focal length do not agree well, now is a good time to try to figure out why that is. If they do agree reasonably well, take the average of the three and record it here.

Focal Length	

2 Ray Diagram for the Experiment

Choose a single object distance corresponding to one of your data points above. Using this object distance and the value of the focal length obtained above (the average value), construct a ray diagram for the situation as follows.

1. Draw your lens in the middle of the page. You don't need to draw it carefully; you could draw the lens as a vertical line with a dot at the center. (But somewhere on the ray diagram you should indicate that this diagram is for a converging lens, either with a picture of a converging lens, or by writing "Converging Lens".)

2. Choose an appropriate scale for the diagram. Make your best guess. You want the diagram to fill most of the page, without flowing off the page. If your guess turns out to be poor (either because the diagram doesn't fit on the page, or because your diagram is contained in two square inches in the middle of the page), start over with a better guess. Write down your scale on your diagram.

3. Draw (or just imagine) a horizontal line through the center of the lens. Let's call this the *axis* of the lens. The *plane* of the lens will be the plane perpendicular to the lens axis going through the center of the lens. On our diagram, the plane of the lens is represented by a vertical line through the center of the lens.

4. Put dots at the (two) focal points of the lens. These should be on the axis.

5. Draw your object (traditionally an arrow pointing upward) at the object distance (on the left side of the lens). Choose the height of the object with moderation (not too big and not too small). Put the tail of the arrow on the lens axis.

6. Draw one ray parallel to the lens axis (in other words, horizontal) from the tip of the object to the plane of the lens. Since rays parallel to the axis pass through the focal point, continue this ray by drawing a line from the plane of the lens through the focal point.

7. Draw a second ray straight through the center of the lens. With the two rays you've drawn, you can locate the image. Draw the image as an arrow (since the object was an arrow).

8. You really only need two rays to locate the image. But draw in this third one just to check. Draw a ray from the tip of the object through the left focal point to the plane of the lens. Since rays parallel to the axis pass through the focal point, rays that pass through the focal point must exit parallel to the axis of the lens. This third ray should pass through the tip of the image.

9. From your ray diagram, find the image distance and write it down. Compare this image distance to your measured image distance for this object distance. Also calculate the image distance with the thin lens equation based on the object distance and focal length you used to construct the ray diagram.

Image Distance (ray diagram)	
Image Distance (experiment)	
Image Distance (thin lens equation)	

Answer the following questions.

Real Image or Virtual Image?	
Upright Image or Inverted Image?	
Magnification (ray diagram)	
Magnification (experiment)	
Magnification (thin lens equation)	

3 Other Ray Diagrams

In the previous section, you made a ray diagram for a converging lens that produced a real image. Now we will make ray diagrams for some other situations.

3.1 Converging Lens, Virtual Image

Consider a converging lens with a focal length of 20 cm. The object distance is 10 cm (the object is 10 cm in front of the lens).

Make a ray diagram for this situation. Fill in the table below. Remember our convention that the image distance for a virtual image is negative.

Image Distance (ray diagram)	
Magnification (ray diagram)	
Real Image or Virtual Image?	
Upright Image or Inverted Image?	

Now use the thin lens equation for the table below.

Image Distance (thin lens equation)	
Magnification (thin lens equation)	

3.2 Diverging Lens

Consider a diverging lens with a focal length of −20 cm. The object distance is 30 cm (the object is 30 cm in front of the lens).

Make a ray diagram for this situation. Fill in the table below.

Image Distance (ray diagram)	
Magnification (ray diagram)	
Real Image or Virtual Image?	
Upright Image or Inverted Image?	

Now use the thin lens equation for the table below.

Image Distance (thin lens equation)	
Magnification (thin lens equation)	