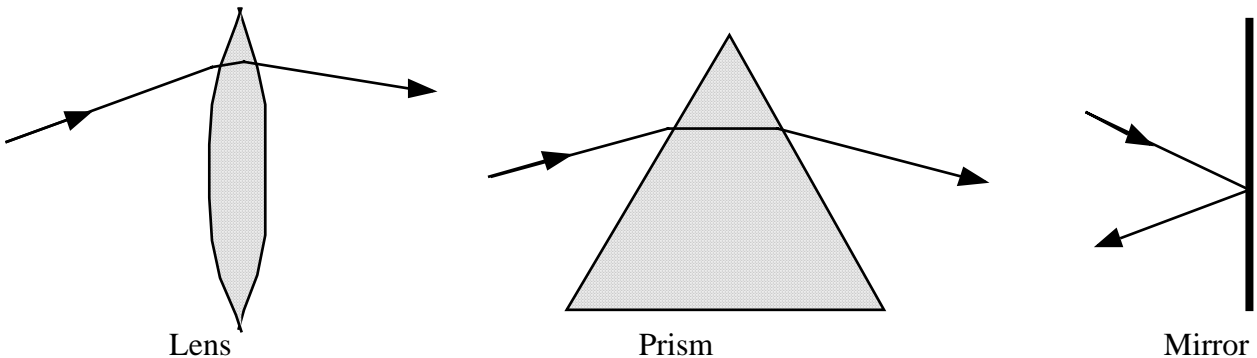


## GEOMETRICAL OPTICS

Geometrical optics is the treatment of the passage of light through lenses, prisms, etc. by representing the light as rays. A light ray from a source goes in a straight line through the air, but when it encounters a lens, prism, or mirror it bends or changes direction.



There are formulas and rules that tell how much the change in direction will be for any circumstance of a ray passing into or out of a medium, lens, prism, etc. With these rules and a little geometry, one can construct the whole path of a ray, hence the name *Geometrical Optics*.

The method of geometrical optics will not solve all problems that involve light. There are problems in which light must be treated as a wave with interference effects; this is called *physical optics* and is the subject of the experiment, Diffraction and Interference. Many situations can be treated by either method, but where there is a choice, the method of geometrical optics is usually simpler.

The statements below about lenses are accurate for *thin* lenses, i.e., those having a thickness at the center that is small compared to the distance between the lens and the image or object. The lenses in this experiment can be considered *thin*. There are two types of lenses used in this lab: *convex* (*vexed* or bowed outward) and *concave* (*caved* or bowed inward). Lenses in this write-up are pictorially represented by their cross-sections.

## LENS CHARACTERISTICS

**Bending of rays:** Figure 1 shows a light ray bending as it passes through a glass lens. The angle between the new and old directions,  $\theta$ , is proportional to the angle,  $\phi$ , between the surfaces of the glass *at the place where the light goes through*.  $\theta$  is proportional to  $\phi$ .

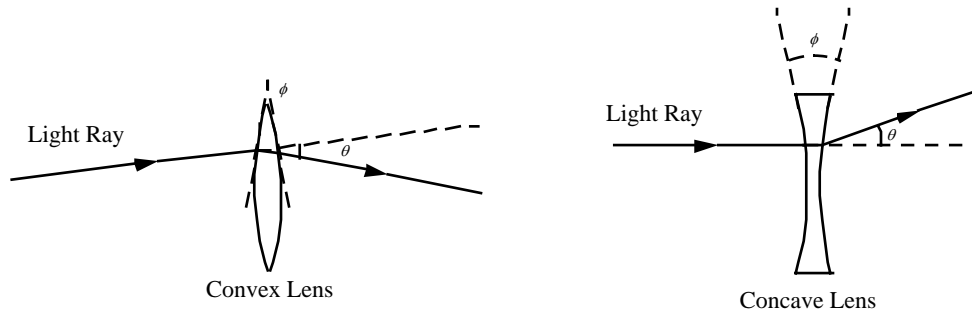


Figure 1

**Focus:** A focus exists when rays from a given point on an object, go through various parts of a lens, and converge after a certain distance forming an image. Light from every point on the object goes to a corresponding point on the image. The figure below shows rays from two points on an object focused onto corresponding points on the image. You could place a screen at the image position and see a *real* image. Sometimes, rays only appear to converge at the image but are not actually passing through it; this is called a *virtual* image (discussed further below).

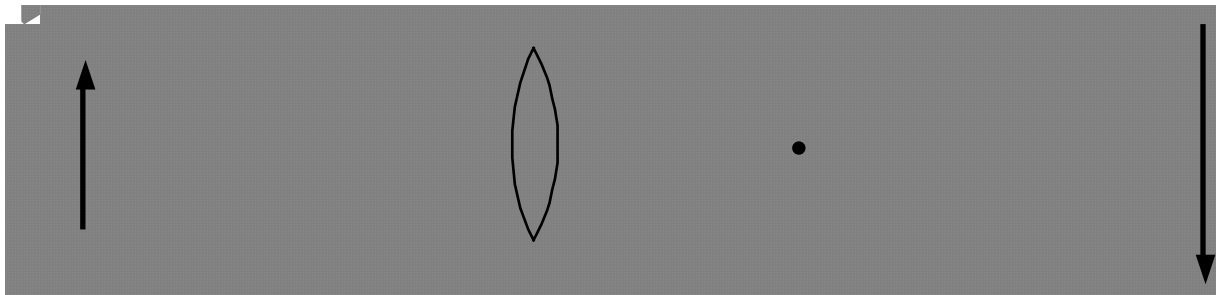


Figure 2

**Focal Length and Object-Image Distances:** The focal length,  $f$ , of a lens is related to the radius of curvature,  $R$ , and inversely proportional to the index of refraction of the material. For our *thin* lenses,  $f = 2R$ . Doubly convex or doubly concave thin lenses will have a focal point on each side of the lens at a distance,  $f$ , measured from the center of the lens along the axis to the *focal point*. The *object distance*,  $O$ , is the distance from the object location along the axis to the center of the lens. Similarly, the distance from the center of the lens along the axis to the image location is called the *image distance*,  $I$ . The relation between these three distances is given by the *thin lens formula*

$$\frac{1}{O} + \frac{1}{I} = \frac{1}{f} \quad (1)$$

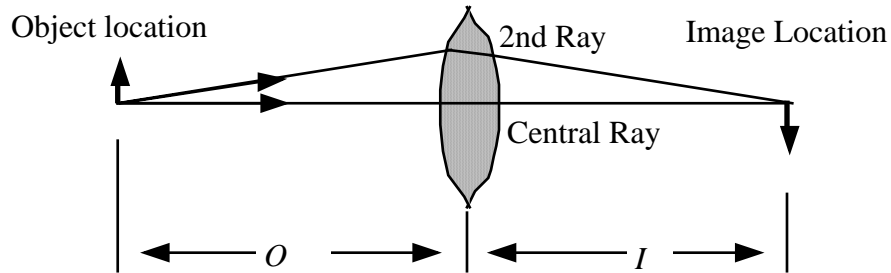


Figure 3

In using the lens formula the following sign convention should be applied. A lens has an object side, defined by the location of a real object, where object distances are positive (+) numbers. The other side of the lens is the image side, where image distances are positive (+) numbers. Whenever an image falls on the object side of a lens, the image distance is a negative (-) number. Likewise, if an object falls on the image side of a lens, the object distance would be negative (-). This latter situation can occur if you use combinations of two or more lenses. Convex or converging lenses have positive (+) focal lengths while concave or diverging lenses have negative (-) focal lengths.

**Virtual Images:** If an object distance is less than the focal length of a convex (converging) lens, the light rays on the image side of the lens will diverge. You will see no *real* image on a screen. By extending the diverging rays backward as indicated by gray lines in the figure below, a *virtual* image is found and the image distance,  $I$ , is negative since it falls on the object side of the lens.

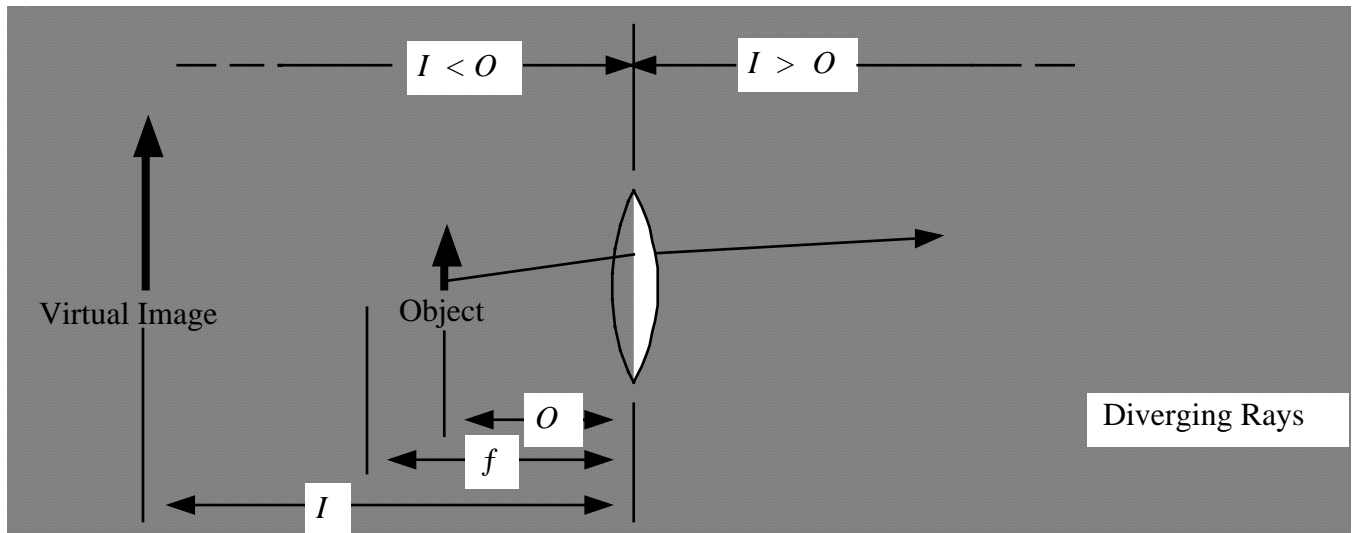


Figure 4

For an object placed inside the focal length of a converging lens, an image cannot be focused on a screen. However, you can see the image, since the lens of the eye can take the

diverging rays and converge them to form a real image on your retina. Here, the virtual image of the first lens becomes the object for the lens of the eye. You would see the virtual image through the lens as shown below.

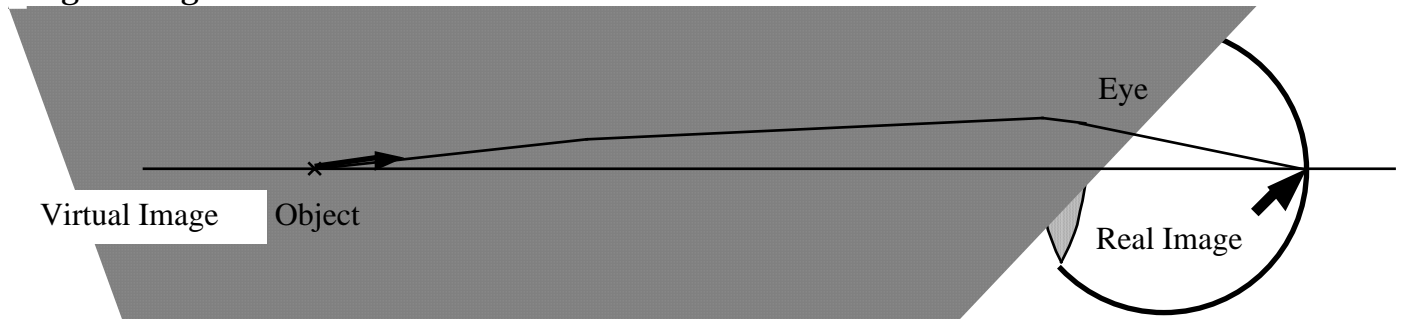


Figure 5

A concave or diverging lens will *only* produce a virtual image. If the object is infinitely far away, the parallel rays from it will form an image at the focal point. Recall that the focal length is negative for a diverging lens.

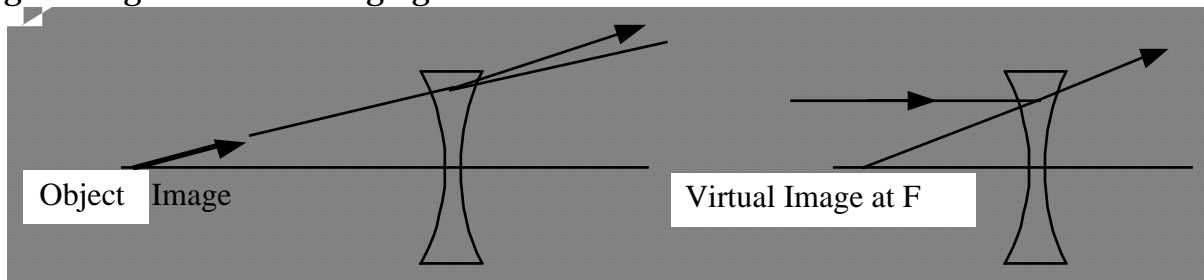


Figure 6

### APPARATUS

- Optical bench with 4 rod holders
- Object (black rod)
- 2 Lens clamps
- Object light source
- Rod mounted lamp
- Ground glass screen
- Meterstick
- Paper
- Rod Stand
- Prism
- 5 cm convex lens
- 10 cm convex lens
- 20 cm convex lens
- 20 cm concave lens
- Red and blue filters
- Knitting needle
- Masking tape

## EXPERIMENT 1: RAY DIAGRAMS

This experiment may be done at home and included with your lab report. The objective of this experiment is to learn how to draw principal ray diagrams and apply them to configurations like those in the following experiments. These useful definitions apply to images you will find:

Inverted Image: An image that is upside down as compared to its source.

Upright Image: An image that is right side up as compared to its source.

Magnified Image: The magnification of a lens is the ratio of the image size to object size, i.e.,  $M = -(\text{image size})/(\text{object size})$ . Use the object-image distance sign convention discussed before. Note that  $M$  can be greater than one (magnified image) or less than one (diminished image). A negative number indicates an inverted image while a positive number denotes an upright image.

### REAL IMAGES

A *principal ray diagram* is a graphical method used to locate the image of an object. We will demonstrate ray tracing rules by first considering a converging (convex) lens with the object distance,  $O$ , greater than the focal length,  $f$ , of the lens. To construct the location of an image, you can draw the rays shown in the Figure 7:

Ray 1: Any ray that comes into the lens parallel to the axis of the lens will pass through the focal point on the other side of the lens.

Ray 2: Any ray that passes through the optical center of the lens is undeflected.

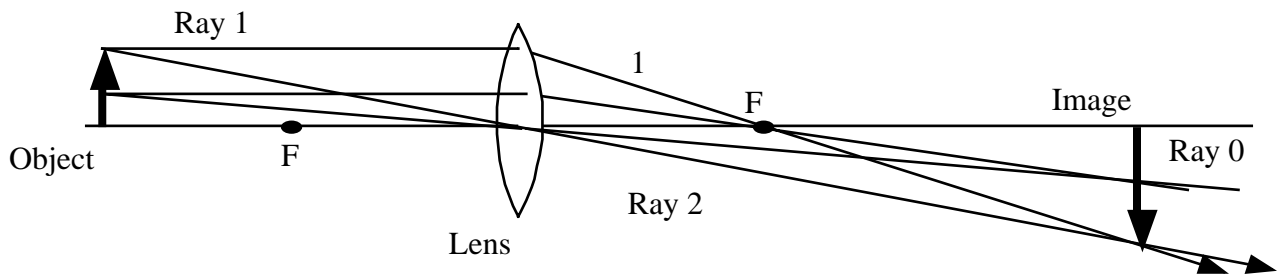


Figure 7

As part of Experiment 1, include the following in your lab report:

1. In Figure 7, is the image upright or inverted? Is the magnification greater or less than one? Explain.

- Use Ray 1 and Ray 2 rules to make a principal ray diagram showing that an object at infinite distance will create an image at the focal point. Use graph paper and a ruler to make an accurate ray diagram.

## VIRTUAL IMAGES

### CONVEX LENSES

Consider the situation in which the object distance is less than the focal length of a converging (convex) lens. In finding the image location, the same ray tracing rules listed above apply. Note that on the right-hand side of the lens the rays diverge; therefore, an image is never formed on a screen. However, to an eye placed on the right-hand side of the lens it appears that the rays meet on the left side of the lens. Since the image falls on the object side of the lens, the image distance is *negative* and the image is said to be *virtual*.

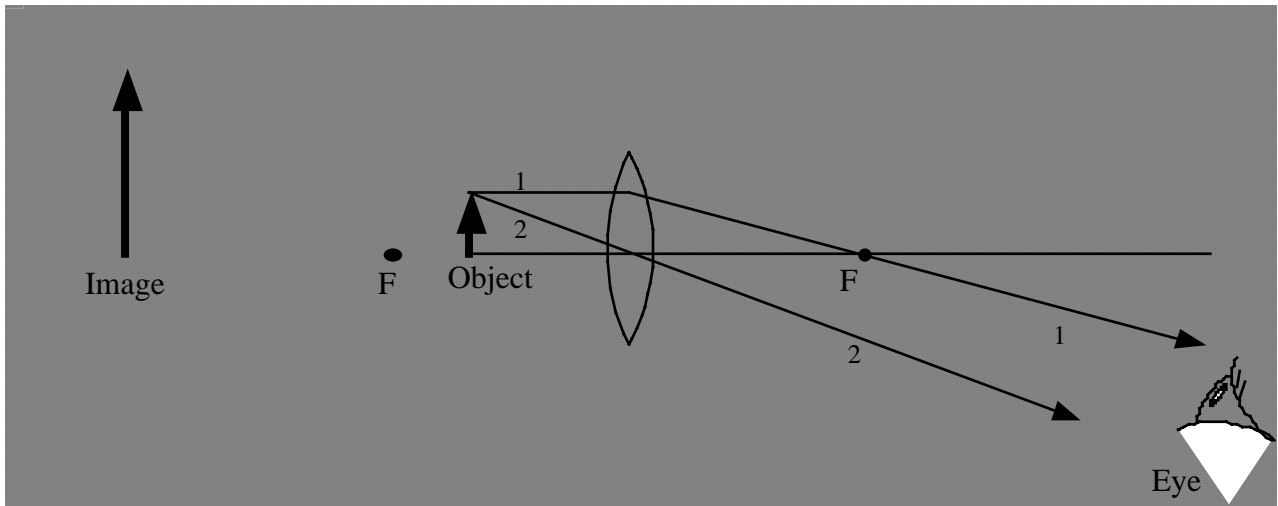


Figure 8

- Redraw Figure 8, for your lab report to practice the ray tracing rules.
- Is the image upright or inverted? Is the magnification greater or less than one? Describe the image.

## CONCAVE LENSES

Next, we illustrate the method of finding the image location for a *diverging* (concave) lens. Draw the same rays as before, except that now Ray 1 bends so that it goes directly away from the *near* focal point.

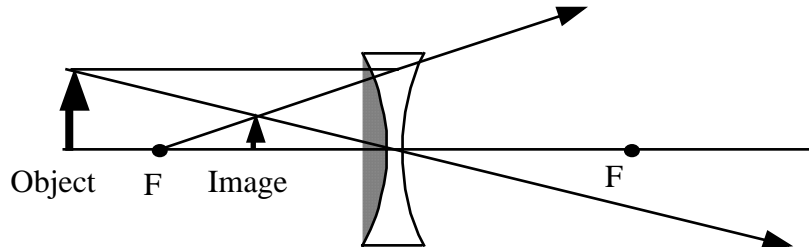


Figure 9

5. Redraw Figure 9 for your lab report to practice ray tracing .
6. Is the image upright or inverted? Is the magnification greater or less than one? Describe the image.

Also include the following in your lab report as part of Experiment 1:

7. Make a ray diagram for an object placed closer to a diverging (concave) lens than the focal point. Is the magnification greater or less than 1? Can the magnification for a diverging lens ever be greater than 1? Explain.
8. Show by making ray diagrams that for any image, the magnification,  $M$ , is the ratio of image to object distances:

$$M = -I/O. \quad (2)$$

9. What is the magnification for the limiting case of infinite object distance?

## EXPERIMENT 2. MEASUREMENT OF FOCAL LENGTHS

In this experiment you will measure the focal length of lenses. Use the data sheet provided to record focal lengths.

You will measure the focal length of a convex lens by placing the object relatively close to the lens so that all three terms in Equation (1) are significant. Use the optical bench arrangement in Figure 10:

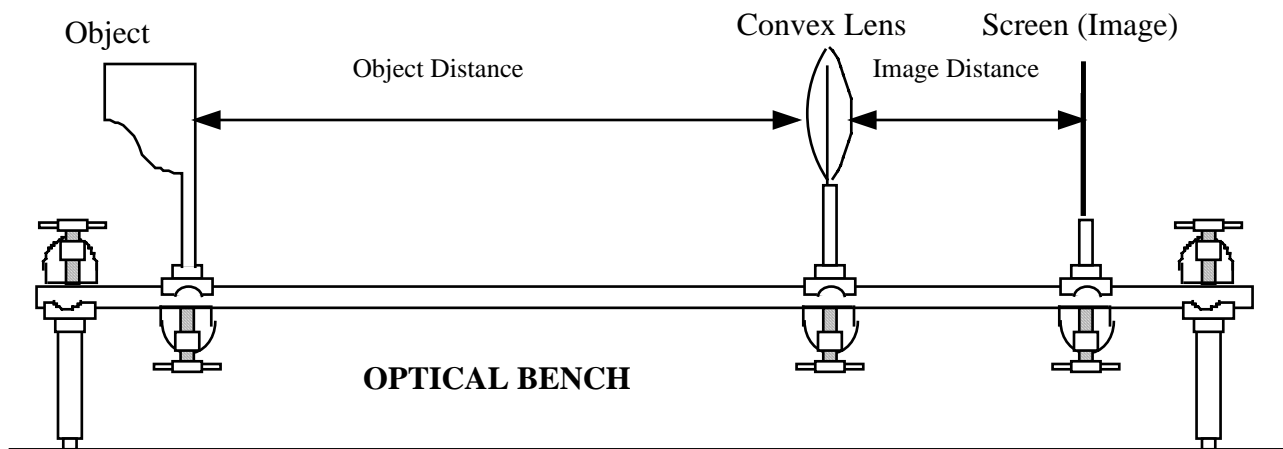


Figure 10

Adjust the position of the lens and screen until you see a sharp image. The best place to view the image is from *behind* the screen, especially if any room lights are on. Start with the screen as far from the light as possible and make measurements of object distance, image distance, and image size. Repeat these measurements for at least two more separations to check the magnification relation (Equation 2). Estimate your measuring error. Use a meter stick to extend the scale if the image forms beyond the optical bench. Make the same measurements for a second convex lens.

The same setup can be used to measure the focal length of a *diverging* (concave) lens if a sufficiently strong convex lens is also placed in the light path. For two thin lenses in contact (focal lengths  $f_1$  and  $f_2$ ), the focal length  $f$  of the combination is given by:

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} \quad (3)$$

With the smallest focal length converging lens and the diverging lens taped together (touching), find  $f$  for the combination. Use the focal length of the converging lens measured previously and Equation 3 to calculate the focal length of the diverging lens. In order for the light from the pair to form a real image, the converging lens must be stronger than the diverging lens; that is,  $f_c < f_d$ .



### EXPERIMENT 3. VIRTUAL IMAGES

There is a procedure that uses *parallax* to locate a virtual image. Before trying it with a lens, try it with two objects. With one eye closed, hold a pencil or similar object in each hand so that the two are nearly in line but one is a few inches farther away. If you move your eye from side to side it is easy to tell they are at different distances from the eye because their relative separation varies. If the objects are at the same distance, their apparent separation does not vary as you move your head from side to side.

Use the converging lens and arrange your optical bench as shown below in Figure 11. Put the lens near the farthest end from the lamp so you can observe comfortably.

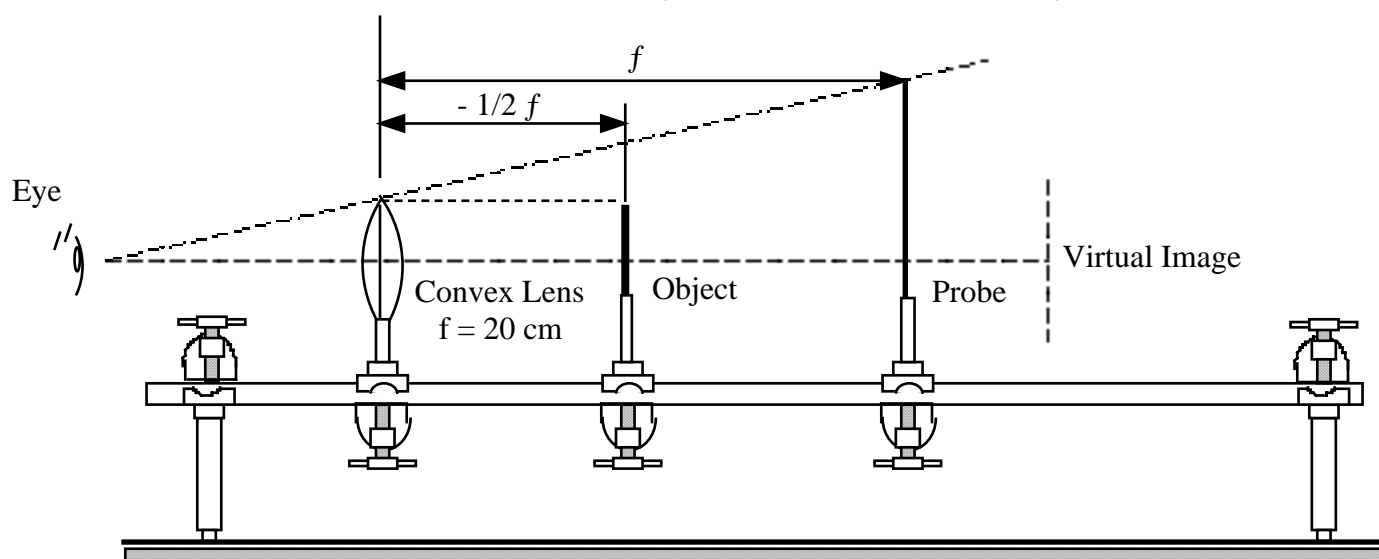


Figure 11

Place your eye and the object such that the image appears in the center of the lens. Mount a knitting needle as a probe with its tip slightly higher than the object's tip. Look *through* the lens at the *image*, and *over* the lens at the tip of the *probe*. Move your head slightly to the left and right. If the tip of the probe always appears stationary relative to the image, you have the probe at the location of the image. If the probe appears to move relative to the image, move the probe closer or farther until you find the image location. This may take some practice. Measure the lens-object and lens-image distances and record your results. Repeat each measurement twice to find the uncertainty in the image distance. Don't look at the probe **through** the lens; look at it **over** the lens. Ignore the image **in** the lens.

Use the same setup and the parallax method to find the focal point of the *diverging* (concave) lens. Put the object about 30 cm beyond the lens. The image and the probe should be between the lens and the object. Also, observe the range of magnification possible by

sliding the object back and forth. Is it possible to measure the magnification? Record all your observations.

## QUESTIONS

1. Explain briefly the principle of the parallax method, i.e., how does it work? Why does it give you the image distance for a virtual image? Can you suggest another way to find a virtual image?
2. Draw ray diagrams to scale for each case:
  - (a)  $f = +10$  cm,  $O = 30$  cm
  - (b)  $f = +10$  cm,  $O = 5$  cm
  - (c)  $f = -10$  cm,  $O = 7.5$  cm

Determine the image distance and magnification from your diagrams.

# DATA SHEET — GEOMETRICAL OPTICS TA [ ]

NAME: \_\_\_\_\_ INSTRUCTOR: \_\_\_\_\_

PARTNER: \_\_\_\_\_ SECTION: \_\_\_\_\_ DATE: \_\_\_\_\_

## EXPERIMENT 2

Lens	f (method 1)	distance <i>O</i>	distance <i>I</i>	f (method 2)	Mag. <i>m<sub>meas</sub></i>	Ave. f	<i>m<sub>calc</sub> = I/O</i>
						...	
	...					...	
	...					...	
	...					±	
						...	
	...					...	
	...					...	
	...					±	
						...	
	...					...	
	...					...	
	...					±	

<i>f<sub>conv</sub></i>	<i>f<sub>comb</sub></i>	<i>f<sub>div</sub></i>

### EXPERIMENT 3

Lens	trial #	$O$	$I$	$f$
converging				
converging				
converging				
Avg. $\pm$ error	•••	•••	•••	$\pm$
diverging				
diverging				
diverging				
diverging				
Avg. $\pm$ error	•••	•••	•••	$\pm$