PHSX 222L **Lenses and Image Formation** **Name:**______________________

Object: (1) To measure the focal length of a converging lens. (2) To use this lens to form real images and to compare the measured position of each image with theory. (3) Also use the lens to observe a virtual image, estimate is magnifying power, and compare with theory.

Theory: The focal point of a converging lens is defined as that point where a beam of incoming parallel light rays will be brought to a focus. For a diverging lens, a beam of parallel light rays will be spread out such that it will appear to diverge from a focal point located in front of the lens.

Since lenses can bend light rays as stated above, it is therefore possible to form images using lenses. The location and nature of an image formed by a lens can be predicted either from a ray tracing diagram or by means of a lens equation.

To locate the image by diagram, three rays (known as the principal rays) are drawn:

1. A parallel ray is drawn from the top of the object parallel to the lens axis. When this ray passes through the lens it is bent so as to pass through the primary focal point.
2. A central ray is drawn from the top of the object toward the center of the lens. It passes through the lens undeviated.
3. A focal point ray is drawn from the top of the object through the secondary focal point. When it passes though the lens it will emerge traveling parallel to the lens axis.

The point at which these three rays converge gives the location and nature of the image. (The three principal rays are not the only rays coming from the object, but they are sufficient to determine the location of the image.)

The image location and nature can also be found using the thin-lens equation, which relates together the object distance x_o, the image distance x_i, and the lens focal length f:

$$\frac{1}{x_o} + \frac{1}{x_i} = \frac{1}{f}. \tag{1}$$

If the image is on the opposite side of the lens from the object, x_i is considered to be positive (real image); if on the same side, then negative (virtual image). Also, f is positive for a converging lens and negative for a diverging lens.

The magnification of the image is calculated from the ratio of the image distance to the object distance:

$$M = -\frac{x_i}{x_o} \tag{2}$$

M will be positive if the image is erect and negative if the image is inverted.

The *near point* of the eye is defined to be the closest distance for which the eye can accommodate to focus light on the retina. It increases with age, but averages about 25 cm for 20-year-olds.

When a converging lens is used as a magnifying glass, the lens is held next to the eye and the object to be viewed is placed just inside the focal point of the lens. The image will be a virtual image, upright, and further away from the lens than the object, and will be larger than the object. The *magnifying power* of such a lens is defined as the ratio of the angular size of the object when viewed through the lens (*i.e.,* the image) compared to the angular size of the object when viewed at the eye's near point without the lens. In the small-angle approximation, this is equal to the ratio of the eye's near point to the focal length of the lens.

$$M = \frac{\theta_{\text{image, lens}}}{\theta_{\text{near point, no lens}}} \approx \frac{25\ \text{cm}}{f} \tag{3}$$

Procedure:

1. Measure the focal length of your converging lens by placing a lighted object on one side of the lens, and a viewing screen on the other. Adjust the positions of the lens and screen until the object and the focused image are the same distance from the lens. Under these conditions the focal length will be one-half the object distance (or one-half the image distance since they are the same in this case). Measure f carefully for your upcoming predictions to be good.
2. Use equation 1 to calculate the image distance when $x_o = 50.0$ cm and when $x_o = 25.0$ cm.
3. Position a lighted object on the optical bench at each of the distances specified in procedure 2. Locate the image on a viewing screen and measure the image distance in each case. Compare your measured results with the results predicted in procedure 2.
4. Find the percent difference for each case.
5. Use your calculated x_i and x_o (from procedure 2) and equation 2 to calculate the image magnification when $x_o = 50.0$ cm and when $x_o = 25.0$ cm.
6. Use a ruler to measure the height of the object and image; record the measured magnification.
7. Find the percent difference for each case.
8. Predict (*pre* means before you do the experiment) what will happen to the image if you use a piece of opaque paper to cover the bottom half of the lens when $x_o = 25.0$ cm, and also if you cover the lens with an opaque paper with a 2 cm diameter hole cut in the center. Record your predictions. Then do the experiment and record what really happened.
9. Calculate the image distance when $x_o = 10.0$ cm. What will be the nature of this image?
10. Position the lighted object on the optical bench at $x_o = 10.0$ cm. Can you locate the image on a viewing screen? Explain your observations. How did you eventually see this image?
11. Place an object, such as your ruler, at a distance just less than the focal length from the lens. Place your eye close to the lens and look through the lens at the object. Also look at the object without the lens at your near point (25 cm if you are young) from your eye. Estimate the size of the image compared to the size of the object. How do your observations compare with the calculated magnifying power (given by equation 3) of this lens?

Results:

1. Focal length of the lens f: __________

	$x_o = 50.0$ cm	$x_o = 25.0$ cm
2. Predicted image distance x_i:	__________	__________
3. Measured image distance x_i:	__________	__________
4. Percent difference:	__________	__________
5. Predicted magnification of image:	__________	__________
6. Measured magnification of image:	__________	__________
7. Percent difference:	__________	__________

8. Prediction:

   What really happened:

9. Predicted image distance x_i when $x_o = 10.0$ cm: __________

   Nature of the image (real or virtual): __________

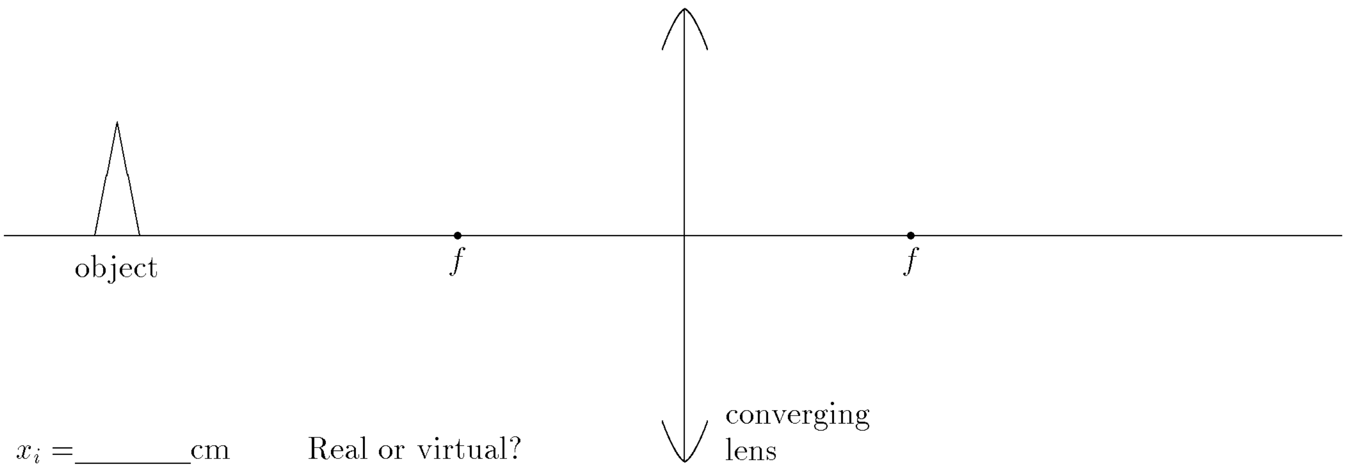
10. Explain observations and how you located the image:

11. Estimated size of image compared to size of object: __________

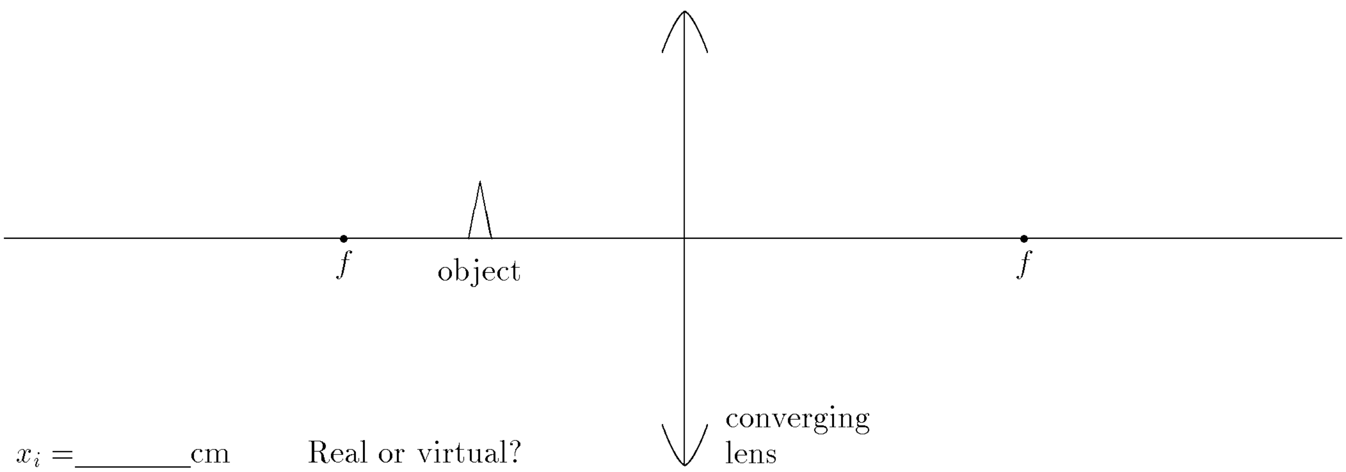
    Calculated magnifying power: __________

Conclusions:

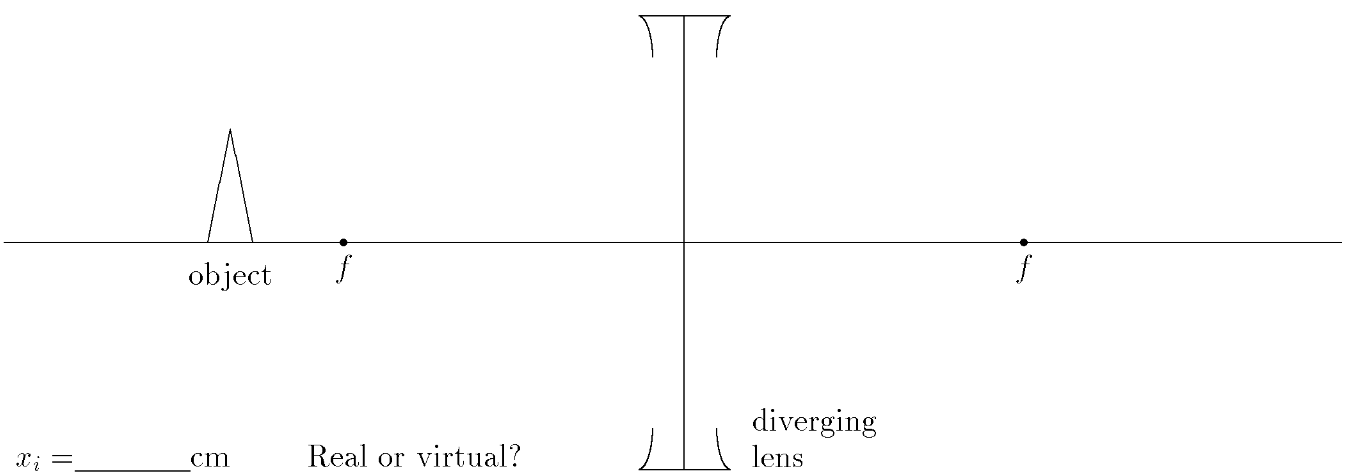
<u>Practice:</u> For each of the lenses shown below, use a straight edge to draw the three principal rays and locate and label the image. Measure the image distance with a ruler. Indicate virtual or real.



$x_i =$ ________ cm   Real or virtual?



$x_i =$ ________ cm   Real or virtual?



$x_i =$ ________ cm   Real or virtual?