# PHYSICS 202 LAB 8: THE THIN LENS FORMULA
## DR. TIMOTHY C. BLACK

### THEORETICAL DISCUSSION

Lenses focus images by refracting (bending) the light rays emanating from the source in such a way that all rays leaving a given point that are able to pass through the lens will re-combine at a single point. Figure 1 shows the paths several representative rays may take as they traverse the lens. The points marked *f* in the figure are the *focal points* of the lens. The focal points are defined by the following rules:

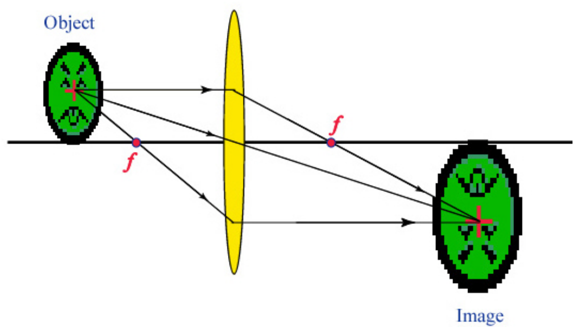


**Fig. 1: Ray trajectories for a convex lens**

1. A ray parallel to the axis and falling on the lens passes through a focal point *f*.
2. A ray falling on the lens after passing through a focal point will emerge from the lens parallel to the axis.

The second rule is really the same as the first, if the roles of the object and image are reversed.

The distance from the object (source of light rays) to the center of the lens is called the object length *o*. The distance from the image formed by the lens to the center of the lens is called the image length *i*. The distance from the center of the lens to the focal point is called the focal length. It is usually denoted by *f*, (as in *f*-stop on a camera), but we will call it $l_f$ to avoid confusion with the focal point. Figure 2 shows these experimental parameters.

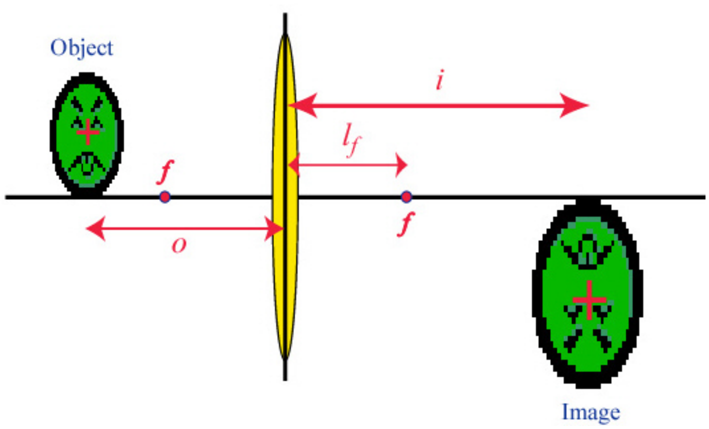


**Fig. 2: Experimental parameters in the thin lens formula**

For *paraxial rays* (rays lying close to the principal axis—a line which runs through the center of the lens and is perpendicular to the lens surface), the object distance *o*, image distance *i* and focal length $l_f$ are related by the *thin lens formula*:

$$\frac{1}{l_f} = \frac{1}{i} + \frac{1}{o} \qquad \textbf{Eqn. 1}$$

For a given object distance, the longer the focal length, the farther from the lens the image will be located. In today's experiment, you will measure the focal length of a particular lens in two different ways and numerically compare the results of your measurements.

## EXPERIMENTAL PROCEDURE

### Part I: Focal length for finite object distances

1. Repeat the following steps for (3) different values of the object distance $o$. Each value of $o$ should differ from the others by at least 2 cm.

   a. Record $o$.

   b. Find the image distance $i$ by bringing the viewing screen close to the lens and moving it away slowly. The image will decrease in size and come into focus. Adjust the distance until you get the sharpest possible focus. Record $i$.

   c. Determine $l_f$ from equation 1.

2. When you have three different measurements of $l_f$, calculate a mean value $\langle l_f^{(\mathrm{I})} \rangle$ and $rms$ (root-mean-square) uncertainty $\sigma_{rms}$ according to

$$\langle l_f^{(\mathrm{I})} \rangle = \frac{1}{n}\sum_{j=1}^{n} l_{f_j} = \frac{l_{f_1} + l_{f_2} + l_{f_3}}{3}$$

$$\sigma_{rms} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(l_{f_j} - \langle l_f^{(\mathrm{I})} \rangle)^2} = \sqrt{\frac{(l_{f_1} - \langle l_f^{(\mathrm{I})} \rangle)^2 + (l_{f_2} - \langle l_f^{(\mathrm{I})} \rangle)^2 + (l_{f_3} - \langle l_f^{(\mathrm{I})} \rangle)^2}{3}}$$

### Part II: Focal length for infinitely distant objects

In this case you will image an object "at infinity". Infinity is, of course, relative. In fact, the object distance must only be very large compared to the focal length. You might, for instance, attempt to form an image of an object that is outside, by positioning your lens table in front of one of the windows (making sure that the blinds are open). To the extent that the object is very far away,

$$\lim_{o \to \infty} \frac{1}{o} = 0$$

so that the thin lens equation becomes

$$\frac{1}{l_f^{(\mathrm{II})}} \approx \frac{1}{i} \quad \Rightarrow \quad l_f^{(\mathrm{II})} \approx i \qquad \textbf{Eqn. 2}$$

1. Locate the image distance $i_\infty$ for your infinitely distant object by following the method of Part I, section 1-b. Record $i_\infty$.

2. Calculate and record $l_f^{(\mathrm{II})}$ using the approximation of equation 2.

**Part III: Comparisons**

Numerically compare $\left\langle l_f^{(\mathrm{I})} \right\rangle$ and $l_f^{(\mathrm{II})}$ by taking the absolute value of their difference:

$$\delta = \left| \left\langle l_f^{(\mathrm{I})} \right\rangle - l_f^{(\mathrm{II})} \right|$$

Remember that the difference, unlike the fractional discrepancy, *does* have units. Does the difference between them lie within the *rms* uncertainty $\sigma_{rms}$, i.e., is $\delta \leq \sigma_{rms}$? If so, then you can conclude that methods I and II are equivalent means of determining the focal length. Otherwise, one of them (you don't know which) is superior to the other.