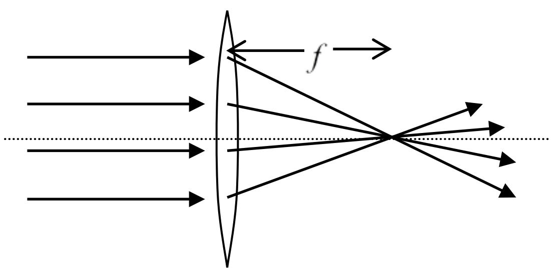
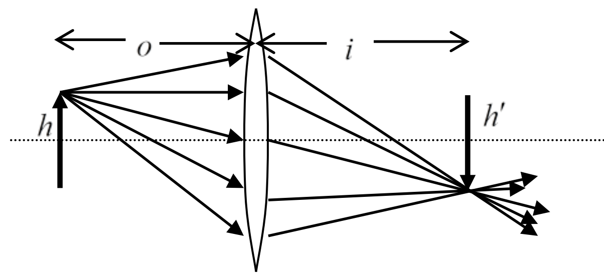
LENSES

We will assume in this lab that all the lenses we use are well-described as ideal thin lenses, so that the properties of the lens are described by a simple relationship involving the lens' focal length *f*, a parameter that depends on the curvature of the lens surfaces and the refractive index of the lens material. When light leaves an object and passes through a lens, an image of the object will be formed, and the characteristics of the image will depend on the lens' focal length. For an ideal thin lens, the relationship between the object distance *o*, image distance *i*, and focal length *f* is given by the **thin lens equation**:

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f}.$$

The meaning of these symbols is shown for a **converging lens** in the figures below:





The magnification of the image is theoretically expected to be

$$m=-\frac{i}{o},$$

and this can be compared with experimental measurements of the magnification,

$$m=\frac{h'}{h}.$$

A set of sign conventions apply:

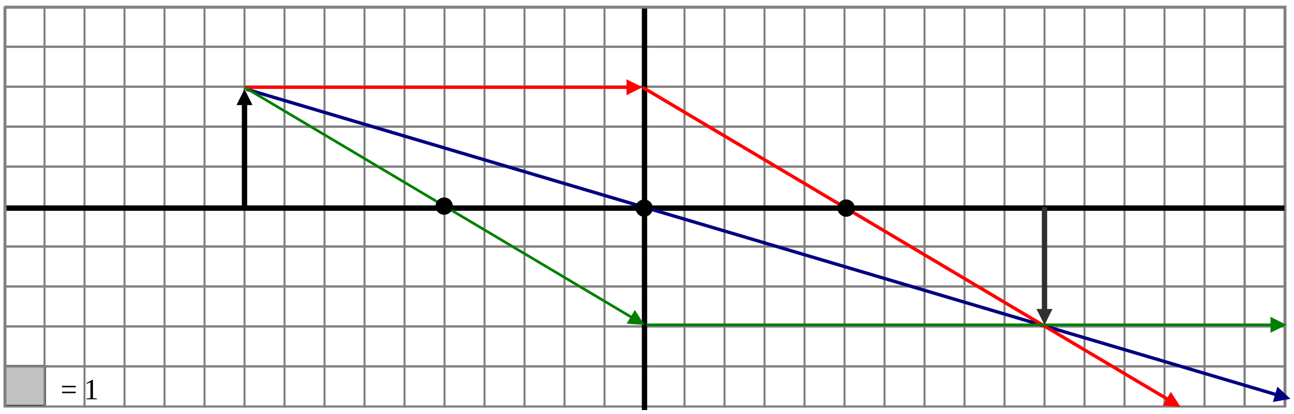
- Converging lenses have $f>0$. Diverging lenses have $f<0$.
- With only one lens, the object distance *o* is always positive. With multiple lenses, the object distance can be negative if the "object" is not on the "source side."
- The image distance *i* is negative when the image is on the “source side.” This is a virtual image.
- The image distance *i* is positive when the image is not on the “source side.” This is a real image.
- Inverted images have negative image heights h'.

We can also use geometric means to determine where the image produced by a lens will be located. This involves drawing the three **principle rays** (described below for a converging lens).

1. One of the principle rays is drawn from the object through the center of the lens.
2. Another principle ray relies on the definition of the focal point. Light parallel to the principle axis of the

lens is refracted by the lens to pass through the principal focal point.
3. And so does the third one. Light heading toward the secondary focal point (or appearing to come from the secondary focal point) is refracted by the lens to emerge parallel to the principle axis of the lens.

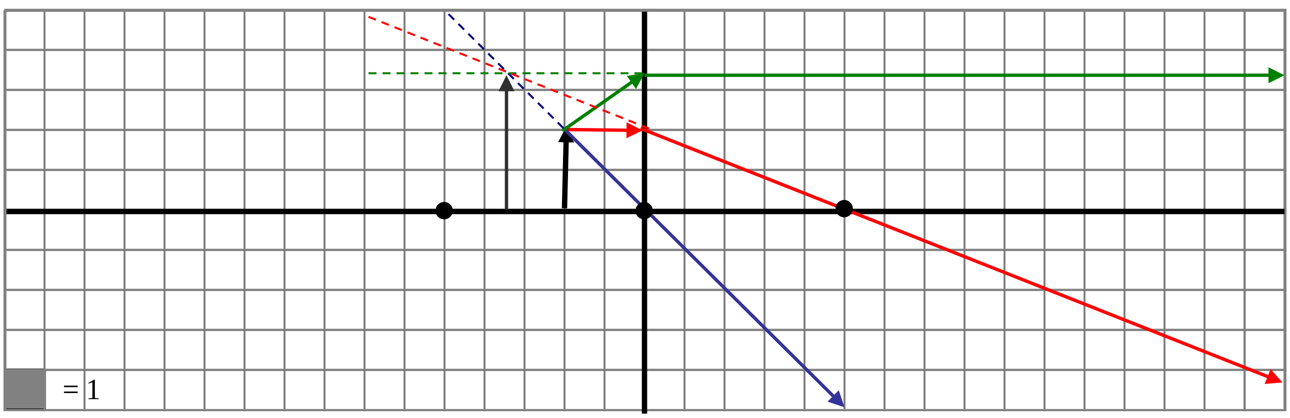
Illustration 1: Suppose we have a thin converging lens with a focal length of 5 cm on the vertical line below. An object is placed 10 cm in front of the lens. Where will the image of the object be located and what properties will the image have? We can use ray tracing to find out.



It is a real image. The image is inverted. The image is the same size as the object.

Use the thin lens equation and the magnification formula to check this result algebraically.

Illustration 2: Suppose we use the same lens, but place an object only 2 cm in front of the lens. Now where will the image of the object be located and what properties will the image have?



It is a virtual image. The image is upright. The image is larger than the object by a factor of ~1.7.

Use the thin lens equation and the magnification formula to check this result algebraically.

Measuring focal length using distant objects.

NOTE: When taking data in this lab, always record positions of the various optical components on the rail. Then calculate distances from those positions. Use drawings labeled with positions to record the data.

Use converging lens #2 to focus the image of a distant object on the viewing screen. You'll need to adjust the distance between the lens and the screen to achieve a sharp image. We will probably use distant tower (seen from the roof of Hoyt) as our distant object. Draw a diagram showing the arrangement of object, lens, and image (with positions labeled) when the image is sharp.

If the object is at a **very great distance**, what does the thin lens equation predict for the location of the image formed by a lens?

So, you should be able to "calculate" the focal length of converging lens #2 from your measurements.

Measuring focal length using nearby objects.

In this section we will use the electric light source as our object. Position the light near one end of the rail, and place the lens around 38 cm away from the light.

Given the focal length you calculated in the previous section, predict where the image of this object should appear.

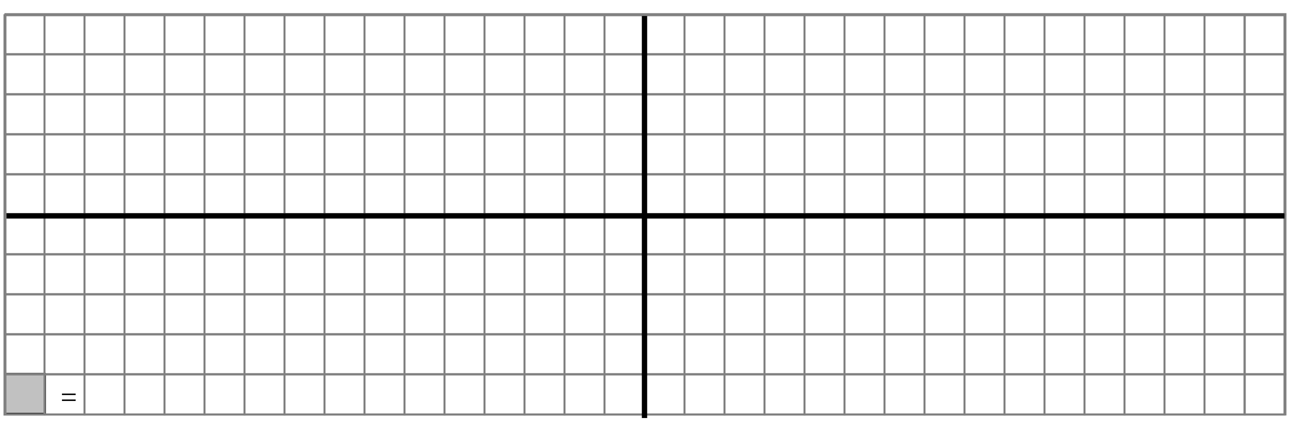
Place the screen on the rail, and move it until the image is sharp. Sketch the positions of object, lens, and image below.

Is the image inverted or upright? Is it reversed left-right? Is it larger or smaller than the object?

What is the image distance? How does it compare with your prediction?

Use your experimental image distance to calculate a revised value for the focal length of the lens.

Draw a to-scale ray diagram of the situation (using your revised value of *f*).



The characteristics of the image in your drawing (magnification, orientation, location) should agree with the experiment.

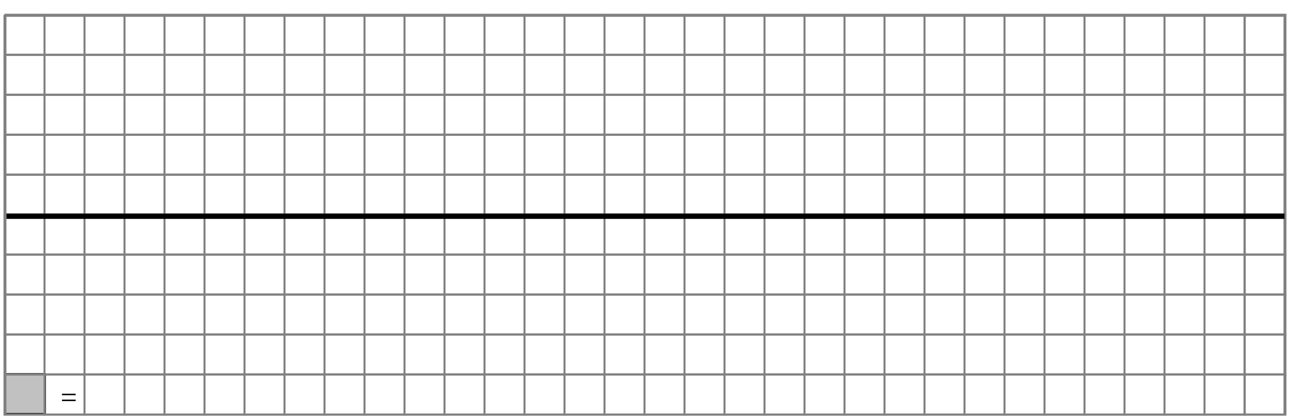
Two lens system-diverging and converging lenses.

Assemble the system by placing the light source near one end of the rail, the diverging lens 30 cm away from the light source and converging lens #2 another 10 cm beyond that. Adjust the screen position until the image produced by light passing through both lenses appears sharp. Sketch the positions of object, lenses, and image below.

We're going to approach the formation of an image due to a two-lens system by treating the image of the first lens as the object of the second lens. Using your measurements and starting from the final image, compute the position of the second object.

Now you have the information needed to determine the focal length of the diverging lens. Do so.

Draw a to-scale ray diagram of the situation, showing the images produced by both lenses.



Two lens system-both converging lenses.

In this system the object for the second lens is on the wrong side of the lens. We deal with this by assigning the object distance as negative value. In this section we will analyze this section in detail.

First we need to measure the actual focal length of the other lens. Determine the focal length of the converging lens that is nominally “10 cm”.

Now assemble the system. Place the light source near one end of the rail, the converging lens with a nominal focal length of 10 cm at a position 12 cm away from the light source, and converging lens #2 another 8 cm beyond that. Note that the screen is missing, you will predict its place it in the next step. Sketch the positions of object and lenses below.

Predict the final image location use the thin lens equation (twice).

Place the screen at the position you predicted. Adjust its position until the image produced by light passing through both lenses appears sharp. How does the actual position of the image compare to your prediction?