Lab 10 Thin Lenses

What You Need To Know:

The Physics From last week's lab, Reflection and Refraction, you should already be familiar with the following terms: principle axis, focal point, focal length, **f**, converging lens (**f** → +), and diverging lens (**f** → –). If these concepts aren't fresh in your head, then review last week's lab. This lab will be using these concepts to show you how to form images with thin lenses.

When forming an image, there will always be an object that the lens is using to create the image. For example, glasses or contacts are lenses that form images that your eyes are able to focus on. The object would be anything in your field of view. Another example would be when you see a movie in a theater. You are looking at an image that is formed on a screen by a lens in the projector. (In fact, the first part of this lab you will be creating this exact situation.) For this situation, the object would be the film in the projector. In diagrams, like **Figure 1**, objects are drawn as arrows.

There are two ways in which you can gather information (such as the size or orientation) of the image. There is a light-ray diagram approach and an algebraic approach. **Figure 1** shows a light ray diagram for an object that is outside of the focal point of a converging lens. The method used to draw this diagram will be left to the lecture class to explain. This lab will only be concerned with the algebraic approach.

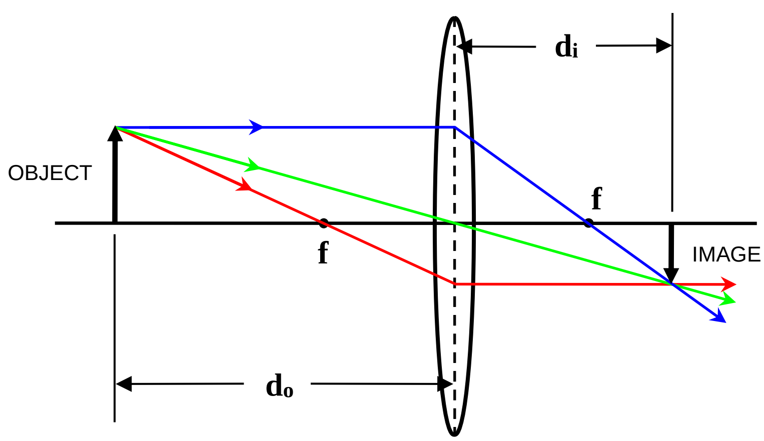

FIGURE 1 - Light ray diagram

There are two main equations that will tell you information about the image. The first is called the Thin Lens Equation. Refer to **Figure 1** on how the variables relate to the diagram.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f is the focal length of the lens (in cm)
d_o is the object distance (in cm)
d_i is the image distance (in cm)

Given a focal length and an object distance, you can use the Thin Lens Equation to calculate the image distance. The sign of the image distance can tell you additional information on the image. See the Sign Conventions chart below.

There are other ways in which you can tell if an image is real or virtual. If you can form an image on a screen or a wall then it is a real image. A good example of a real image is the image you see on a screen in a movie theater. On the other hand, if you have to look through a lens to see the image, then it is a virtual image. People who wear glasses or contacts are looking at virtual images.

The second equation you will use in this lab is the Magnification Equation …

$$m = -\frac{d_i}{d_o}$$

m is the magnification of the image (no units)
d_i is the image distance (in cm)
d_o is the object distance (in cm)

There are several things that the magnification can tell you about the image. See the **Sign Convention** chart below.

Sign Conventions for Lenses

- If d_i is **+** then the image is real.
- If d_i is **–** then the image is virtual.

- If **m** is **+** then the image is upright.
- If **m** is **–** then the image is inverted.

- If $|m|$ **> 1** then the image is larger than the object.
- If $|m|$ **< 1** then the image is smaller than the object.

So, in re-examining **Figure 1** and using the information in the chart above, you can tell that the magnification of the image must be *negative* and *less than 1*.

In today's lab you will be using all of the above information to calculate, in a variety of ways, the focal lengths for a converging lens and a diverging lens.

The Setup The main piece of equipment you will be using is an optical bench. See **Figure 3** on the next page. The bench will hold a light source, one or two lenses in lens mounts, and a screen. The light source is the same light box you used last week. However, this time you will use the opposite side of the box, which has a pattern, like **Figure 2**, on an opaque piece of plastic. Light will shine through the plastic and serve as the "object" for the optical system.

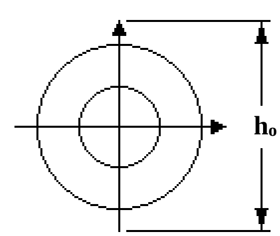

FIGURE 2 -
"Object" on light source

You are able to move the lens mounts and the screen back and forth on the track of the optical bench. This will allow you to form images on the screen. The arrows on the object in **Figure 2** will let you know if the image has changed its orientation with respect to the object. **NOTE: DO NOT WRITE ON THE SCREEN.**

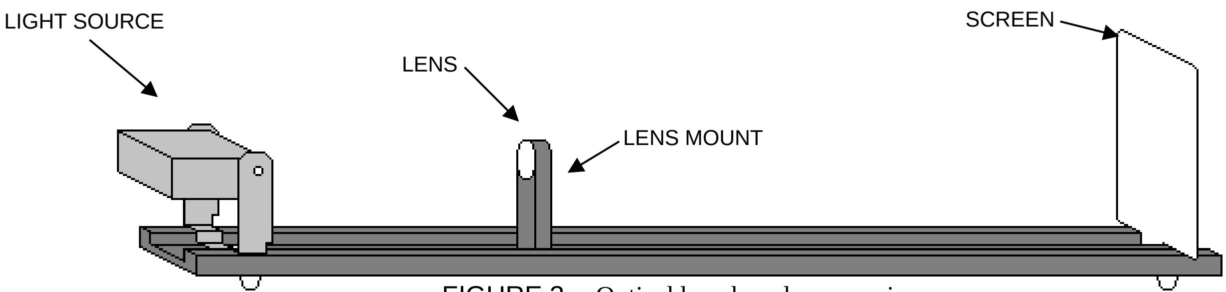

FIGURE 3 - Optical bench and accessories.

What You Need To Do:

Focal Length and Infinity For the first part of the lab, you will not be using the optical bench. Instead you will go to the wall near the rear door of the laboratory. Bring with you the mounted converging lens (the one with **+200 mm** on it) and a ruler. Your TA will raise the blinds of the window directly across from the wall. The light coming from the window will be your object. This light is considered to be coming from very "far away". Using the converging lens, try to focus an image of the trees outside of the window on the wall. You might be able to get your TA to wave their arms around (and maybe jump up and down) in front of the window so that you can see how this situation relates to a movie theater. Notice that this is a real image. When you have a focused image, use the ruler to measure the distance from the wall to the lens. The lens is positioned at the center of the mount so you should use that as a reference point when you make your measurement. The distance that you are measuring is the image distance, but in this specific situation it is also the focal length of the lens. This focal length is your first piece of data.

Question 1 Using an equation from the introduction of this lab, explain why the image distance is approximately equal to the focal length in this situation.

	d_o	d_i	f	$m = -\frac{d_i}{d_o}$	h_o	h_i	$m = \frac{h_i}{h_o}$	% diff for "m"
1st location								
2nd location								

Average focal length:

% error for focal lengths:

CHART 1

EQUATIONS

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$m = -\frac{d_i}{d_o}$$

The Optical Bench Make a copy of **Chart 1**. You are now going to use the optical bench to measure the focal length of the same lens you used at the wall. First, make sure that the light source is flush with **0 cm** on the optical bench. You should leave it that way for the entire lab. The screen should be placed at **110 cm**. Plug in the light source. Measure the height, $\mathbf{h_o}$, of the arrow (your "object"). See **Figure 2**. Place this value in both rows in the chart. Place the converging lens/mount on the optical bench in between the object and the screen. There are **two** locations for the lens along the optical bench that will focus an image on the screen. Find one of these locations. Once you have the image in **sharp** focus, take measurements for: the object distance, $\mathbf{d_o}$, the image distance, $\mathbf{d_i}$, and the height of the image, $\mathbf{h_i}$. NOTE: You will be able to focus a sharper image if you turn off the lamp at your table. Place these values in the chart. Repeat this procedure for the other location that forms an image.

A) Using the above data for both locations, calculate the focal length of the lens. Take the two focal lengths and average them. Compare, by calculating a percent error, this average value to the focal length you measured at the wall. Place all values in the chart.

B) Using the **d** values, calculate the magnification for each location. Place these values in the chart. Find the product of the two magnifications. NOTE: Ignore any negative signs. The value should be very close to 1.

Question 2 Why should the product of the magnifications be equal to 1?

Question 3 Discuss the state of the image for one of the locations. Comment on such things as real/virtual, upright/inverted, and bigger/smaller. Does the state of the image match with the calculated values? Explain!!! Discuss!!!

C) You can also calculate the magnification by dividing the image height by the object height, $\mathbf{m = h_i/h_o}$ … (no Seven Dwarfs jokes please). **NOTE:** There is no additional negative sign in this equation. Using this equation, calculate the magnification at each location. Calculate a percent difference with its sister measurement from **Part B**. NOTE: Take the absolute values of the magnifications before you do your percent difference. Place all values in the chart.

Diverging Lens Now you are going to measure the focal length of the diverging lens. You can't form a real image on a screen with just a diverging lens. Go ahead and try it. Remove the converging lens and put the diverging lens on the bench. (The diverging lens mount has brass screws on it.) Slide the lens back and forth to form an image. You can't. By itself, a diverging lens can only form virtual images. You can look through the lens and see a *virtual image* but you can't form a *real image* with it. In order to get a real image to form on the screen you have to use a combination of two lenses.

Put both lenses on the optical bench. The order of the mounts should be: OBJECT – CONVERGING LENS - DIVERGING LENS – SCREEN. There are many possible positions for the two lenses that will allow you to form an image on the screen. So, by trial and error, get an image to form on the screen. Just slide both mounts around until you get an image. If you can't get an image to form then grab your TA.

Now take the following data … [See **Figure 4** for reference. NOTE: Drawing is **not** to scale.]

- Measure the distance from the object to the converging lens, $\mathbf{d_{o1}}$.
- Measure the distance from the converging lens to the diverging lens, **d**.
- Measure the distance from the diverging lens to the screen, $\mathbf{d_{i2}}$.
- Measure the height of the image, $\mathbf{h_i}$.

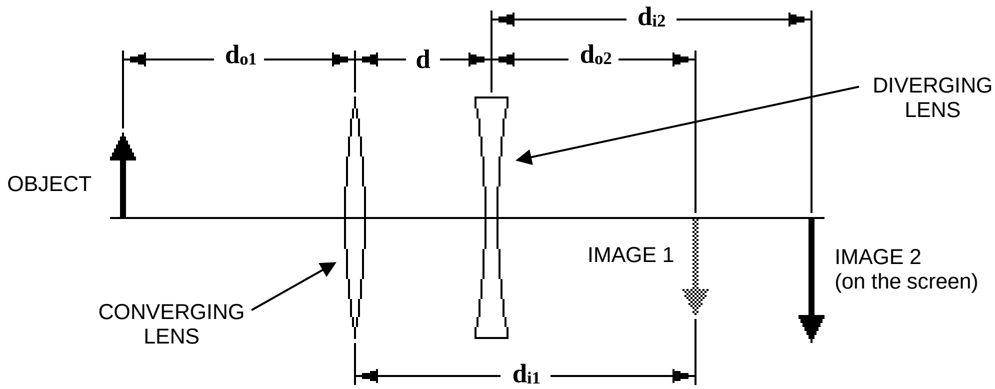

FIGURE 4 - Two lens set-up

EQUATIONS

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$m = -\frac{d_i}{d_o}$$

A) The first thing you need to do is calculate the image distance, $\mathbf{d_{i1}}$, for the converging lens. See **Image 1** in **Figure 4**. This is the image that would form if the diverging lens wasn't there, that's why it's grayed-out in **Figure 4**. Using your $\mathbf{d_{o1}}$ and the average focal length for the converging lens (from the first part of the lab), calculate $\mathbf{d_{i1}}$.

In order to do calculations for multiple lens systems you have to treat the *image* for the first lens as the *object* for the second lens. That's why $\mathbf{d_{o2}}$ is labeled the way it is in **Figure 4**. (The object distance is from **Image 1** to the second lens.)

B) Using the data you took, calculate $\mathbf{d_{o2}}$ based on the **Figure 4**.

OK, **Image 1** is now considered to be the object for the second lens (call it **Object 2**). The light that is trying to form **Image 1/Object 2** is entering the diverging lens from the left. Since **Object 2** is on the *opposite side* of the lens that the light is coming from, it is considered to be a *virtual* object. Any virtual object has a <u>negative</u> value so make sure you use a negative in the calculation below.

C) Using your data, calculate the focal length, $\mathbf{f_2}$, of the diverging lens. Compare this focal length to the one given on the lens mount. Use a percent error.

Question 4 Is the value you calculated in **Part C** consistent with what you know about the focal length for a diverging lens?

D) Each lens has its own $\mathbf{d_o}$-$\mathbf{d_i}$ pair of data. Using this data, calculate the magnification for each lens. Label them $\mathbf{m_1}$ and $\mathbf{m_2}$.

E) The *total magnification* for a multi-lens system is the product of the separate magnifications. Find the total magnification (include any negative signs).

Question 5 Is the total magnification of the system consistent with the orientation of the image (inverted or upright) on the screen? Explain.

F) We should also be able to calculate the total magnification of the system by using the equation, $\mathbf{m = h_i/h_o}$. Calculate the total magnification with this equation.

G) Calculate a percent difference, comparing the magnifications from **Part E** and **Part F**. **Note:** Take the absolute values of the magnifications before you do your percent difference.

What You Need To Turn In:

Make sure any measurements you made are in the appropriate sections where you were asked to measure them. Turn in your chart that has any measurements or calculations included in it. Make sure any calculations are done in the appropriate sections. You only have to do one sample calculation for each different type.

© Spring 2013 by Michael J. Dubuque