Thin Lenses Physics 227 Lab

Introduction:

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 is +), and diverging lens (f is -). 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.
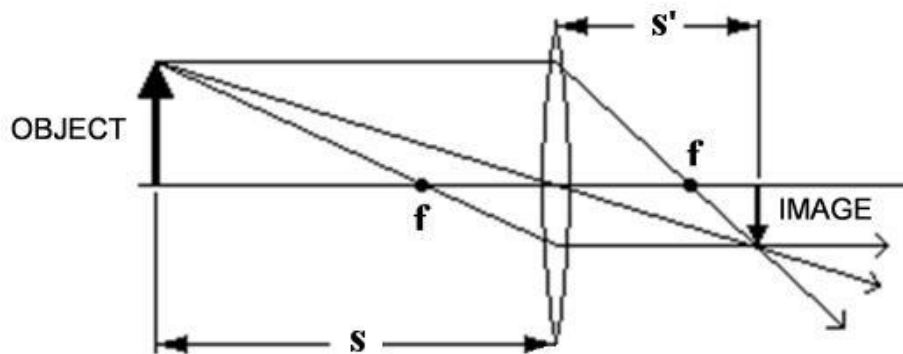

Figure 1 - Light ray diagram

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.

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.

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

 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 area below.

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Question 1: Using the Thin Lens Equation derive the two positions where the lens is in focus for a given distance $L = (s + s')$.
Extra: What happens if $L < 4f$?

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

$$m = \frac{h'}{h} = -\frac{s'}{s}$$

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

<u>Sign Conventions for Lenses</u>

- If s' is + then the image is real.
- If s' 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. 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.
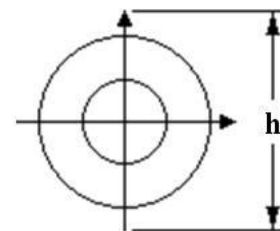

Figure 2: - "Object" on light source

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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.
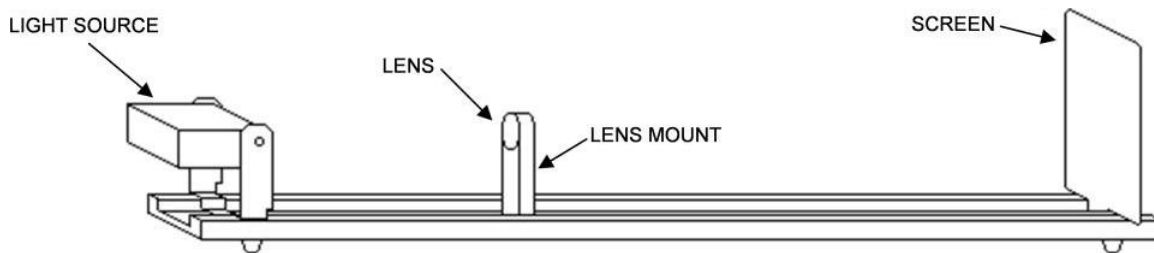

Figure 3: Optical bench and accessories

NOTE: Do not write on the screen.

Part I: Converging Lens

Table 1

	s	s'	f	$m = -\dfrac{s'}{s}$	h	h'	$m = \dfrac{h'}{h}$	% difference for "m"
1st location								
2nd location								

Average focal length:

%error for focal lengths:

Note: The height values h and h' are negative below the axis, and positive above, resulting in a negative magnification for inverted images.

Pay attention to the *direction* of the arrow, it should start pointing up, if the image points down h' is -

A.) Make a copy of Table 1 in your report. You are going to use the optical bench to measure the focal length of the lens marked with +200mm on it.

B.) First, make sure that the light source is flush with 0cm on the optical bench. You should leave it that way for the entire lab. The screen should be placed at 110cm. Plug in the light source.

C.) Measure the height, h, of the arrow (your "object"). See Figure 2. Place this value in both rows in the table.

D.) 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.

E.) Once you have the image in sharp focus, take measurements for the object distance, s, the image distance, s′ , and the height of the image, h′. *Again be sure to note the direction of the arrow when taking the sign for h'.* Place these values in the table.

NOTE: You will be able to focus a sharper image if you turn off the lamp at your table.

F.) Repeat step **E** for the other location that forms an image.

G.) Using the above data for both locations, calculate the focal length of the lens.

H.) Take the two focal lengths and average them.

I.) Compare, by calculating a percent error, this average value to the focal length given. Place all values in the table.

J.) Using the s, s′ values, calculate the magnification for each location. Place these values in the table.

K.) Find the product of the magnifications down the column (m 1st location * m 2nd location). The value should be very close to 1.

Question 2 Show algebraically that the product of magnifications should be equal to 1.
Hint: Try substitute Q1 solution into the general equation for magnification and use $L = (s + s')$.

Question 3 Discuss the state of the image for just one of the locations.
   a. Comment on real/virtual, upright/inverted, bigger/smaller.
   b. Does the state of the image match with the calculated values? Explain why or why not.

L.) Calculate the magnification by dividing the image height by the object height $m = \dfrac{h'}{h}$. Do this for both locations

M.)

NOTE: There is no additional negative sign in this equation.

N.) Calculate a percent difference with its sister measurement from before. In this case there is no "actual" or "theoretical" value, so compare their difference to their average as in the equation below. Place all values in the table.

$$\% \, Difference = \frac{|m_s - m_h|}{\left|\dfrac{m_s + m_h}{2}\right|}$$

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Part II: 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. 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. See Figure 4 below for reference.
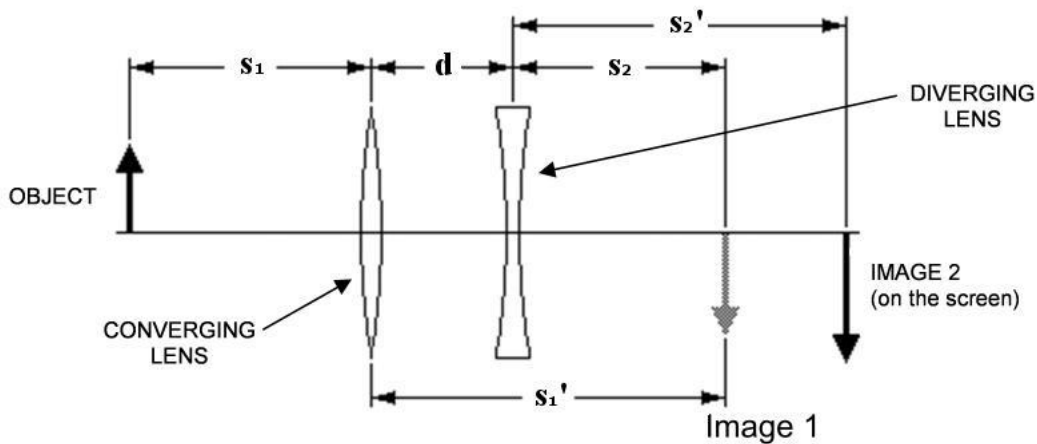

FIGURE 4 - Two lens set-up

A.) There are many possible positions of 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 or you're unsure if your image is focused then grab your instructor. Now the following steps will fill out Table 2

Table 2:

h_1	h_2'	s_1	f_c	s_1'	d	s_2	s_2'	f_d

B.) The shaded cells in table 2 can all be directly measured, do so now and record all values. You should have the values for h_1, h_2', s_1, d, s_2', see the diagram for help.

C.) Next fill in f_c , use your average focal length for the converging lens from part 1.

D.) The first thing you need to do is calculate the image distance, s_1'. This is the image that would form if the diverging lens weren't there, that's why it's grayed-out in Figure 4. Using your s_1 and f_c calculate s_1'.

E.) 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 s_2 is labeled the way it is in Figure 4. (The object distance is from Image 1 to the second lens). Using the data you took, calculate s_2 using d and s_1' based on the Figure 4.

F.) 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 negative value so now change the sign of s_2 to reflect this, make sure you use a negative in the calculation below.

G.) Using your data, calculate the focal length, f_d of the diverging lens.

H.) Compare this focal length to the one given on the lens mount. Use a percent error.

Question 4: Is this value you calculated for f_d consistent with what you know about the focal length for a diverging lens?

I.) Each lens has its own s, s' pair of data. Using this data, calculate the magnification for each lens. Label them m_c and m_d.

J.) The total magnification for a multi-lens system is the product of the separate magnifications. Find the total magnification $M = m_c * m_d$ (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.

K.) We should also be able to calculate the total magnification of the system by using the final height and the initial height, $M = \frac{h_2'}{h_1}$. Calculate the total magnification with this equation.

L.) Calculate a percent difference (same as earlier) for the magnification using the two results from above.
They should have the same sign, if they don't something went wrong, double check your work

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 tables that has any measurements or calculations included in it.
Make sure to show at least one sample for each calculation, write out the equation with measurement values and units substituted in. You only have to do one sample calculation for each different type.
Also of course include Intro, Analysis, Conclusion and all questions as always.