Name: ________________________

Partner:______________________

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Date: ________________________

Geometric Optics

Purpose

The purpose of this lab is to become familiar with the simple geometric model of lenses and how ray tracings can be used for laying out optical instruments, such as the microscope and telescope.

Procedure

Part 1: Finding the focal length

Lenses can focus light ALMOST to a point, and so (although we really do know better) we will often refer to the focal point *as if* it were a mathematical point, as in Figure 1. The distance along the **optic axis** from the center of the lens to the focal point is known as the focal length, f.

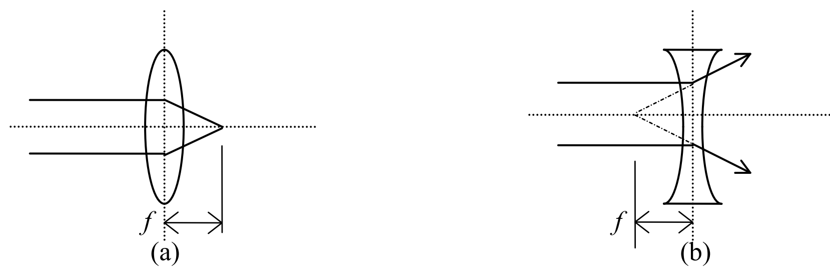

Figure 1: A lens in action. (a) A convex lens, where the image is formed on the transmission side of the lens and (b) A concave lens, where a virtual image is formed on the side of incidence. The dashed line of symmetry is called the optic axis.

According to the convention we will use today, if the image is formed on the transmission side of the lens, we will record the focal length as a positive number.

Technically, the focal length is properly found by having **parallel** light rays enter a lens and then measuring the distance to the point of greatest focus, as indicated in Figure 1. However, the light rays coming from our source would only (asymptotically) become parallel when the light source is moved infinitely far away. That said, in practice, keeping a *small* source a couple of meters away from the lens is enough to achieve the desired effect. So, with this goal in mind, you will work with a group across the room, using **their** light source and **your** lens. Turn the other group's light on and fix your lens in place on the optics bench at your station. Move your observing screen, until you find the distance where optimal focus is achieved. Record the distance from the lens to the screen and then repeat this measurement **ten times**. The <u>*mean*</u> of these measurements is taken to be the focal length of your lens. Do this for the lenses labeled as having a focal length (for some particular wavelength of light) of **127 mm** and **48 mm**. (You'll see later that the focal length depends on wavelength.) Your data can be recorded on the next page.

Reported Focal Length ________	
Measurement	Focal length ( )
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Mean Focal Length	________

Standard Deviation of the Mean:_________

Reported Focal Length ________	
Measurement	Focal length ( )
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Mean Focal Length	________

Standard Deviation of the Mean:_________

Which has the greater % uncertainty, the longer focal length or the shorter focal length?

Which has the greater % difference from the nominal focal length value reported on the lens holder?

Part 2: The Thin Lens Equation and Magnification

The technique used in Part 1 to find the focal length is somewhat cumbersome and time-consuming. Fortunately, there is a much simpler technique for thin lenses, which makes use of the so-called Thin-Lens Equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad (1)$$

where d_o is the distance from the object to the lens, d_i is the distance from the image to the lens and f is the focal length of the lens used. To examine the validity of the thin-lens equation, we use the setup seen in Figure 2.

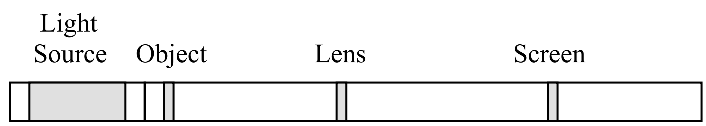

Figure 2

Using a lens from part 1 and slide 9121 (crossed arrow target) as your object, set-up the system shown in Figure 2. Set the object distance and move the screen until the image is clearly focused. Record the image and object distances and then repeat this process for nine other object distances. You should **also record the *heights***, both of the object (the arrow on the slide) and of the image formed (the arrow projected onto the screen); you'll need that info in a later section of this week's lab. Your data can be recorded below.

Focal Length ________________ Object Height ________________

Measurement	Object Distance ( )	Image Distance ( )	Image Height ( )
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Is the *thin*-lens equation valid for your data? As before, it is often useful to cleverly **plot your data and perform a fit** that is *suggested by your model* (in this case Equation 1) for the phenomena being examined. By carefully choosing your axes, your data should produce a simple curve, where a parameter from the curve fit is related to the focal length of the lens. What should your axes be? If the thin-lens equation is correct, what type of curve do you expect using these axes? What should constants of your curve fit be?
(*Huge hint*: It may be useful to plot the inverses of the image and object distances.
– At this point we really shouldn't have to give these sorts of hints anymore, should we?
– In all future labs, you will be expected to figure out for yourselves the connection between the equations supplied and sorts of plots and fits that you should make.)

Using your favorite graphing software, plot your data and perform the curve fit that you proposed above. Attach a copy of your plot and fit to the lab manual. Be sure to save your data for use in a later section of this week's lab. Based upon the results found in ***fitting*** your data, **how should you report** your experimental results on the focal length of your lens? Show any relevant calculations and explain what you did.

To what degree do these results agree with what you expected, based on your measurements from Part 1 of this lab? To what degree is your data consistent with the Thin-Lens Equation? If your data shows what you would argue to be significant disagreement with the model used, discuss why this may be.

You may have noticed that the size of the image was not constant. This leads us to a second important property of an optical system - magnification. **You should** construct a simple ray diagram and invoke the geometric rules regarding similar triangles to argue that the magnification should (according to this geometric **model** of light propagation) be given by Equation 2:

$$M \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o} \qquad (2)$$

where d_o is the distance from the object to the lens, d_i is the distance from the image to the lens and M is the magnification.

Let's take a look at the magnification **data** that you took. Does it support Equation 2? (There are many ways to use scientific language in answer to that question.) Support your argument using your data. Be sure to include and discuss any relevant analysis.

Part 3: Compound Lenses

So far you have examined the behavior and properties of *convex* lenses, which, according to the convention we are using today, have a positive focal length. Eventually, we will examine *concave* lenses (lenses that have a negative focal length). The (virtual) image formed by a single concave lens is located behind the lens, *i.e*. between the object and the lens. This is the physical meaning of the negative focal length. Because of where the image is formed, you can't measure the focal length as you did earlier. However, when two lenses are placed close together, they form what is called a doublet lens, as seen in Figure 3.

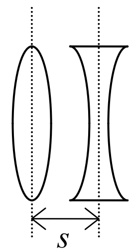

Figure 3: A doublet lens

The effective focal length of a doublet lens is given by Equation 3.

$$\frac{1}{f_{\text{doublet}}} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{s}{f_1 f_2} \tag{3}$$

where f_{doublet} is the focal length of the doublet lens, f_1 and f_2 are the focal lengths of the lenses used and s is the distance between the center of the two lenses.

Construct the setup seen in Figure 4. Let Lens 1 (the one closest to the object) be a concave lens – the (nominally) "-109 mm" focal length lens. For Lens 2, use one of the convex lenses from Part 1.

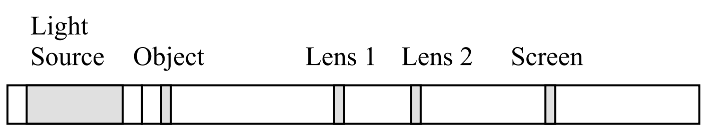

Figure 4

What effective focal length do you expect?

Although the effective focal length given by Equation (3) is a really good reality check to perform before doing any experiment with compound lenses, keep in mind that the Thin-Lens Formula measures all distances with respect to a *fictitious* plane. For your work with a single lens in Part 2, you naturally took this plane to be something like the middle of the lens, but as we start working with compound lenses, it becomes less intuitive **what plane to measure your distances from**!! If we were being really persnickety, we would define a plane called the "Second Principal Plane" that is located at a position relative to the second lens given by:

$$-\frac{f_{\text{doublet}}s}{f_1}$$

Instead, the *only* use we'll make of Equation (3) is just as a VERY rough guide to get you started. Once you have identified (at the bottom of the previous page) a lens separation that will give you a *reasonable* focal length, and **moved your imaging screen** until you find (experimentally) the approximate **location of the sharpest image**, we will now 'restart' our thinking about this compound lens as follows:

The input to the second lens is simply the output of the first lens. So, we consider the "object" seen by the second lens to be the "image" created by the first lens. However, since our first lens is a diverging lens, it will be simplest to work *backwards* to find the effective "object" position "seen by" the converging lens and to then use this as the expected image position of the diverging lens. (Trust me, and read on!)

The known values (besides the converging lens focal length f_{conv}) are the **coordinates, measured on your optical rail**, of the object, the two lenses, and the image, which we will call x_{obj}, x_{div}, x_{conv}, and x_{im}, respectively:

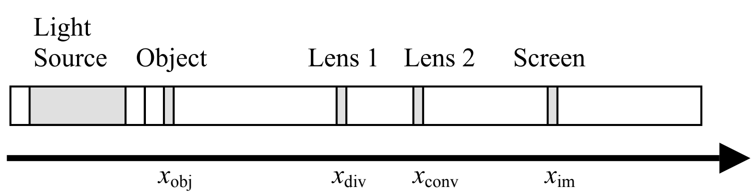

Figure 5

1. We first find the object distance relative to the position of the diverging lens and the image distance relative to the position of the converging lens:

$$d_{\text{o div}} = x_{\text{div}} - x_{\text{obj}}$$

$$d_{\text{i conv}} = x_{\text{im}} - x_{\text{conv}}$$

2. From observed imaged distance of the converging lens, we can use the Thin-Lens Equation, to find the position of the *effective object* seen by the converging lens:

$$d_{\text{o conv}} = \left(\frac{1}{f_{\text{conv}}} - \frac{1}{d_{\text{i conv}}}\right)^{-1}$$

3. Again, the "object" seen by the converging lens is taken to be the "image" created by the diverging lens. So, we now know the location of the (virtual) image created by the diverging lens. However, before we use that in our Thin-Lens Equation, we need to shift our coordinates by $s = x_{\text{conv}} - x_{\text{div}}$ so that this distance is now measured with respect to the position of the diverging lens:

$$d_{\text{i div}} = s - d_{\text{o conv}}$$

4. At last, because you already knew how far the object was from the diverging lens, and you now know how far the effective image is from the diverging lens, you can immediately find an experimental estimate of the focal length of the diverging lens, just by plugging these two values into the Thin-Film Equation. – **However**, there is enough experimental uncertainty in identifying the location of the sharpest image, that it is much more accurate to instead use the "**Method of Many Images**:" namely, find a bunch of values of $d_{\text{o div}}$ and $d_{\text{i div}}$ and then **plot** $1/d_{\text{i div}}$ *vs*. $1/d_{\text{o div}}$. The y-intercept gives $1/f_{\text{div}}$.

As before, you should take as many data points as you feel are necessary.

s __________

f_{convex} __________

Measurement	x_{obj}	x_{div}	x_{conv}	x_{im}

Experimental results for f_{div}: _______________

How do your reported experimental results compare with the nominal focal length written on the lens holder? What is the percent difference?

Part 4: Lens Errors

In the previous parts of this lab, we have treated the lenses as being, in a certain sense, ideal. Of course, there is no such thing as an ideal lens. Consequently, it is important to understand some of the errors, or "aberrations," which can arise. Today, we examine just one such aberration – ***chromatic* aberration**. Chromatic aberration involves the dependence on the focal length on the wavelength (color) of the light.

You will now repeat what you did in Part 2 of the lab, but with a color filter in front of the lens. You will first use a **red filter** and then replace that with a **blue filter**. Record your data below:

Focal Length ________

Filter ________

Measurement	d_o ( )	d_i ( )
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Focal Length ________

Filter ________

Measurement	d_o ( )	d_i ( )
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

A nice way to see the effect of this lens error to plot this data, **along with your original data from part 2**, all on the same set of axes. Do you notice anything? Are there differences in the observed focal lengths? What does your data suggest?

Initiative

<u>*Possible ideas:*</u>

1. If any part of the readings on optics in your text were confusing, the lab offers a real opportunity for you to sort things out!

2. The **pupil** of the human eye determines the amount of light that enters the eye. When it is bright, it contracts, allowing less light in and when it is bright, it widens, allowing more light into the eye. A variable diaphragm on the optics bench can simulate the effect. Try blocking half of the lens with a piece of paper taped onto the lens holder, and report What do you think would happen to the image formed if you

3. There are a couple of **ophthalmoscopes** (http://www.yorku.ca/eye/ophthal.htm) in the room and a chart on the next page that illustrates certain bodily impairments, such as glaucoma, diabetes and hypertension, which can be detected by observing the retina. You can try to use these devices on others in your group (trying not to blind each other in the process): http://www.yorku.ca/eye/retview.htm

Conclusions

http://cms.revoptom.com/index.asp?ArticleType=SiteSpec&Page=osc/3146/lesson.htm