SP212 Lab: Thin Lenses

January 8, 2024

Name Date

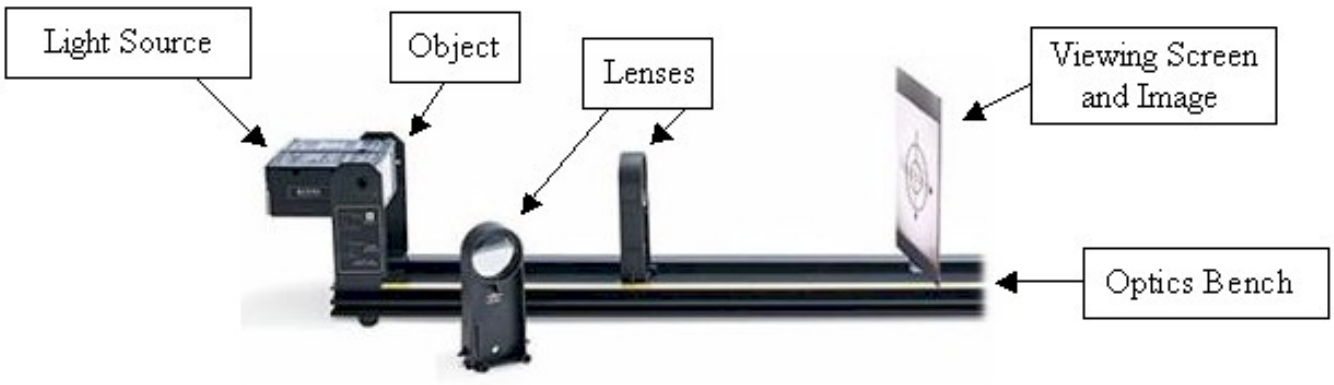


Introduction

Thin lenses have many applications. For example, they are used in microscopes, binoculars, eyeglasses, contact lenses, magnifying glasses, cameras, and refracting telescopes. Consequently we encounter them frequently in everyday life. The physics of a thin lens is relatively simple in how it forms an *image*. However, there are some subtleties involved since images can be *real* or *virtual*. Furthermore, the image formed by a thin lens can be either a real or a virtual object for another lens. Thus it is worthwhile spending some time firming up our understanding of thin lenses. The laboratory is an excellent place to do that since a real image can be displayed on a screen (such as a flat white surface). As a consequence, we can measure where the real image is relative to a lens and compare its position with that predicted by our equations. Also we can carry out experiments that involve virtual images. Although virtual images cannot be displayed on a screen, they still produce important effects. What we will do is study combinations of lenses where the role of the virtual image is important.

Equipment

The equipment consists of a light source, lenses, a viewing screen, and an optics bench (slotted aluminum track for fixing the light source, lenses, and screen in position). The "object" is the drawing (having concentric circles, perpendicular arrows, and a scale) on the front of the light source. An image of the object is visible on the screen in the next picture.



Theory

If an object is a distance s (object distance) from a thin lens of focal length f and forms an image at a distance s' (image distance) from the thin lens, the relationship between s, s', and f is

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

There is a sign convention for each of these quantities. For example, a *converging lens* has a positive focal length and is thus sometimes referred to as a *positive lens*. Next, if the object has a height h and the image has a height h', the lateral magnification is given by

$$m = \frac{y'}{y} = -\frac{s'}{s} \tag{2}$$

The *magnitude* of m has the usual meaning. For example, if $m = 2$, then the image is twice as large as the object. Also, the *sign* of m is meaningful. For example, if m is negative, then the image is inverted (flipped over and reversed right to left) relative to the object.

Lens Characteristics

Our first goal is to characterize the lenses.

1. Feel the shape of each of the lenses.

R1: Is the lens with the blue mark thicker or thinner in the middle?

R2: So is the lens with the blue mark diverging or converging?

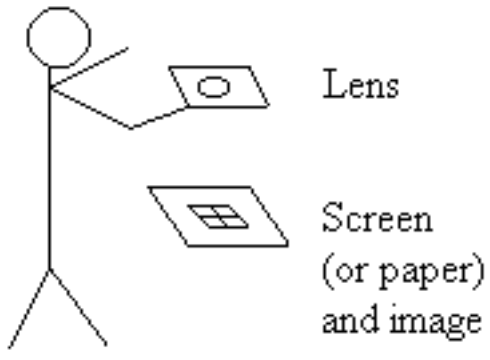
R3: Is the lens with a yellow mark thicker or thinner in the middle?

R4: So is the lens with a yellow mark diverging or converging?

R5: Is the lens with the red mark thicker or thinner in the middle?

R6: So is the lens with the red mark diverging or converging?

2. Let us confirm these predictions. *Only converging lenses can form real images of real objects* and we will use this fact to decide whether our predictions are correct. Using the technique shown in the next diagram, attempt to form an image of the ceiling lights (real objects) with each of the lenses.



R7: Does the lens with the blue mark form a real image?

R8: Is the lens with the blue mark diverging or converging?

R9: Does the lens with a yellow mark form a real image?

R10: Is the lens with a yellow mark diverging or converging?

R11: Does the lens with the red mark form a real image?

R12: Is the lens with the red mark diverging or converging?

Note: We have made the assumption that the object distance is greater than the focal length. As can be seen from eq. (1), converging lenses only form real images (positive *s'*) of real objects if the object distance (positive *s*) is greater than the focal length (positive *f*). If *s* is less than *f*, then a converging lens will form a virtual image (negative *s'*) that can't be displayed on a screen. Consequently, since the focal lengths of the lenses are fairly small, you will only have arrived at the correct conclusion if you kept the lens the expected (far) distance from the ceiling lights. However, if, for some strange reason, you stood on the table or whatever and placed any of the converging lenses near the ceiling lights, you would not have observed a real image and hence concluded incorrectly that the lens is diverging.

We will now determine the focal length of each of the lenses.

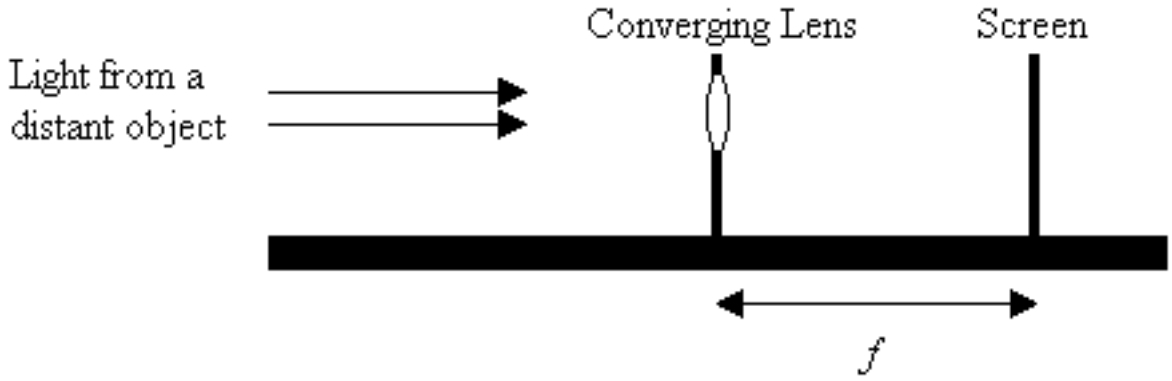
Converging Lens

For the *converging* lenses, there is a direct way to determine the focal length. Notice that when $s = \infty$ (object is very far) eq. (1) becomes

$$\frac{1}{\infty} + \frac{1}{s'} = \frac{1}{f} \tag{3}$$

In this case, *s' = f*. In other words, *when the object is very far away from the lens the image distance equals the focal length.* Let us carry out that experiment for each of the converging lenses.

1. If the light source is connected to the optics bench, carefully remove the light source from the bench. Arrange the equipment as shown in the next sketch . Be sure that the screen is perpendicular to the optics bench.



2. Our goal is to obtain an image (on the screen) of something (an object) very far away. The image will be easily visible if the object is brightly illuminated and the screen is darkened. One way to do that is to carry the equipment to the hallway outside the lab. Adjust the distance from the lens to the screen in an attempt to either get an image (on the screen) of the lights at the other end of the hall, or get an image (on the screen) of a distant object (such as a tree) by going to a stairwell and pointing the rail outside.

3. When the image is in focus, determine the distance from the lens to the screen. Record the distance from the lens to the screen as the focal length in the space provided. Be sure to add a plus sign (to indicate that the lens is converging) and estimate and record the uncertainty by noting how much you can move the lens and still get a reasonably sharp image.

4. Repeat steps 2 and 3 for the other converging lens. (Spaces are provided for all lenses. If the lens is diverging, leave the space blank.)

R13: $f_{\text{blue}} =$ _____ cm

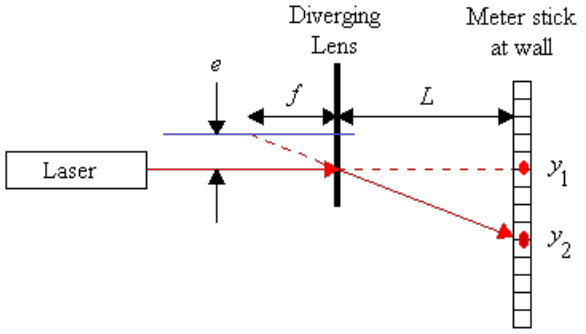
R14: $f_{\text{yellow}} =$ _____ cm

R15: $f_{\text{red}} =$ _____ cm

CHECKPOINT: _____

Diverging Lens

Since virtual images cannot be displayed on a screen, we need a different technique to determine the focal length of a *diverging* lens. The reason is that rather than converge the light from a distant object to a (focal) point, a diverging lens will diverge the light so that it appears to be coming *from* a (focal) point. This is shown in the sketch.



A ray from a distant object (indicated by the solid red laser beam) that enters a lens off-axis diverges from the axis. If the ray is extrapolated backward (as for the dashed line), it intersects the axis (thru center of the lens) at the focal point. The geometry makes it possible to calculate the magnitude of the focal length, $|f|$. The amount by which the laser beam diverges is y_2-y_1. The distance of the laser beam from the axis is e. The distance from the wall to the lens is L.

Then $|\,f\,|$ is calculated as

$$|f| = \frac{L\,e}{|y_2 - y_1|}. \tag{4}$$

In our experiment, we will use a laser beam to simulate light from a distant object. That is possible because *light from a distant object is parallel to the axis*, and it is easy to send a laser beam into a lens parallel to the axis. Proceed as follows.

1. Place the laser on the table about 2 m from a vertical 2-meter stick.

Record the reading on the meter stick where the laser beam strikes it in the space designated for y_1.

R16: $y_1 =$ _____ cm

2. *Place the lens in the laser beam so that the position of the middle of the beam at the meter stick does not change.* (The beam spot will spread out a little. Don't worry about that.) If the position of the beam is unaffected by the lens, the laser beam is striking the middle of the lens. You might need to turn the lens on its side. You need to find just the right height for the lens. Your lab station includes a lab jack that you may find helpful in setting heights.

3. Finally, raise the lens roughly 1 cm by using the lab jack or by placing an *additional shim* underneath the lens holder. (The jewel box for a Zip disk is a convenient thickness.) The thickness of the additional shim is e. (Yes, e is roughly 1 cm.) Measure the thickness of the *additional shim* and record the value as e in the space provided. (If the calipers that you are using are solar powered, there might not be enough ambient light for them to operate. After measuring, leave the calipers jaw spacing untouched and bring the calipers into the light to read the spacing.)

R17: $e =$ _____ cm

4. When the lens is raised by roughly 1 cm, the position of the beam on the meter stick at the wall will change by several cm. The new value of the position of the beam on the meter stick should be recorded as y_2 in the space provided.

R18: $y_2 =$ _____ cm

5. Finally, measure the distance from the lens to the stick, L, and record the value in the space provided.

R19: $L =$ _____ cm

6. Calculate the value of $|f|$ from eq. (4).

R20: Show your calculation.

Because it is a diverging lens, the value of the focal length must be negative. Consequently, record the value of $f_{\text{diverging lens}} = -|f|$ in the space provided.

R21: $f_{\text{diverging lens}} =$ _____ cm

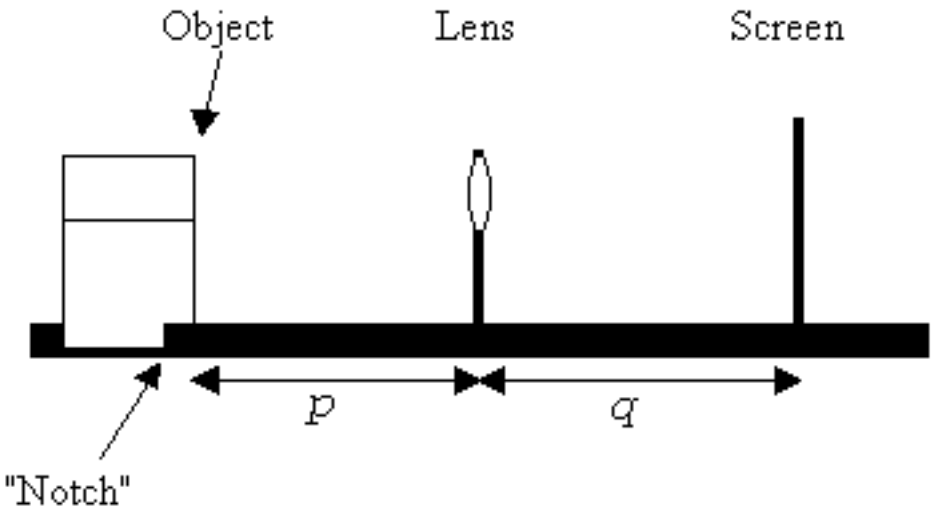
CHECKPOINT: _____

5-day section breakpoint

The Lens Equation

We want to verify eq. (1), the *lens equation*. What we will do is measure s' (the image distance) for a finite s (the object distance) and calculate f (the focal length of the lens). The focal length will then be compared with the value determined by "direct" measurement.

1. Arrange the light source/object, the converging lens with the *longest focal length* and the screen on the optics bench as shown in the next sketch.



Note: *Be sure that the source/object and bracket are configured exactly as shown in the* ***Equipment*** *section at the beginning of this write-up. There are several incorrect orientations that will cause problems. (The light source should be at the same level as the lens and the "notch" at the bottom of the bracket should be toward the lens.)*

Note: *Unplug the source/object (light) when it is not in use.*

Place the object close to one end of the optics bench (Consider placing the object at "0" on the yellow graduated scale.) and the screen at the far end of the bench. Be sure that the object and screen are perpendicular to the optics bench. Record the color of the mark on the lens holder and the positions of the object and screen.

R22: Color of Mark on Lens = ____

R23: Object Position = ____ cm

R24: Screen Position = ____ cm

3. Starting with the lens near the object, adjust the position of the lens until a focused image is formed on the screen. Record the position of the lens in the space provided.

R25: Lens Position = ____ cm

4. Determine the values of s and s' from the positions and record the values in the space provided.

R26: $s =$ ____ cm

R27: $s' =$ ____ cm

5. Use eq. (1) to calculate the focal length of the lens and record the value in the space provided.

R28: f (Calculated using s and s') = ____ cm

R29: Show your calculation.

R30: How does the value of the focal length compare with the value determined previously for this lens? Discuss.

Lateral Magnification

Our next goal is to verify eq. (2).

1. Use eq. (2) and the measured values of s and s' to calculate the magnification, m, of the lens. Record the value in the space provided.

R31: m (Calculated using s and s') =

2. Note that the object has a scale marked in mm. Choose a portion of the object to use as the object size and record that as y in the space provided. (For example, if you choose the diameter of the inner circle as the size of the object, you will record $y = 1.0$ cm.)

3. Devise a technique for measuring the size of the image. Measure the size of the image and, in the space provided, record the size of the image value as y'. (Note: If the image is inverted relative to the object, record the value of y' as negative.)

R32: $y =$ cm

R33: $y' =$ cm

R34: Describe your technique for measuring the size of the image.

4. Use eq. (2) and the measured values of y and y' to calculate the magnification of the lens. Record the value in the space provided.

R35: m (Calculated using y and y') =

R36: Compare the two values of m. Calculate a percentage difference. Discuss.

Combinations of Lenses

When light passes through more than one lens, the *image* created by the first lens becomes the *object* for the second lens. The final image is then the image formed by the second lens. These facts provide the opportunity for us to complete our study of a diverging lens. The reason is that while a diverging lens cannot form a real image of a real object, it can form a real image of a "virtual object." The "virtual object" is the image formed by the first lens. What we will do is use a converging lens to form an image, and then use that image as the object for a diverging lens.

1. Refer to the previous diagram and place the converging lens with the shortest focal length about 20 cm from the light source. We will refer to this lens as lens 1. Adjust the screen so that you have a clear image. Record the positions of the object, screen, and lens 1 in the spaces provided.

R37: Object Position = cm

R38: Screen Position = cm

R39: Position of Lens 1 = cm

2. Calculate the object and image distances, s_1 and s'_1, from the data and record the values in the spaces provided.

R40: $s_1 =$ cm

R41: $s'_1 =$ cm

3. Use eq. (1) and s_1 and s'_1 to calculate the focal length of lens 1, f_1, and record the value in the space provided.

R42: f_1 (Calculated using s_1 and s'_1) = _____ cm

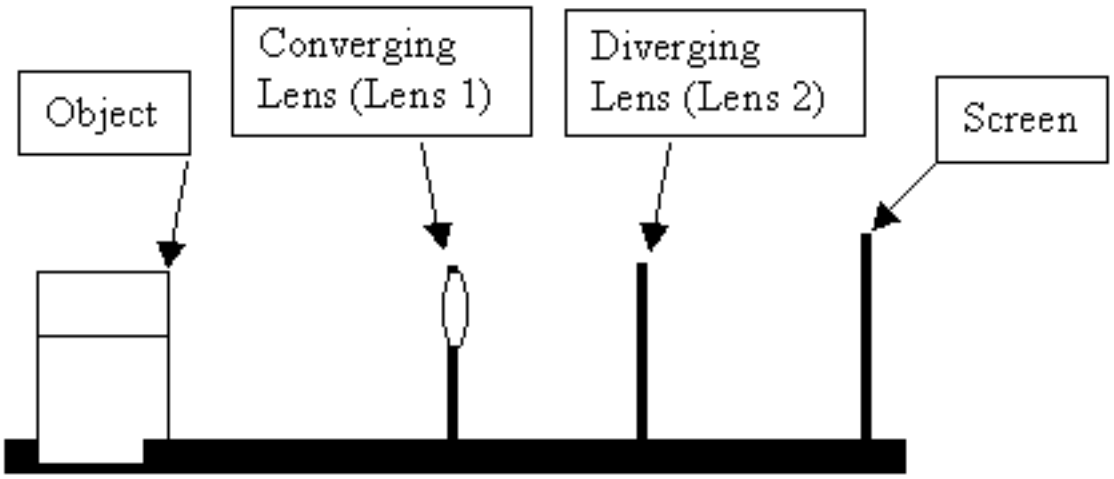
R43: How does the value of f_1 compare with that from the "direct" determination (value listed previously)? Calculate a percentage difference.

4. Use eq. (2) and the data to calculate the magnification caused by the lens 1, m_1, and record the value in the space provided.

R44: m_1 (Calculated using s_1 and s'_1) = _____

5. Place the diverging lens 2 about 10 cm to the right of the converging lens so that the new configuration is similar to that shown in the next sketch. In the space provided, record the position of lens 2. (Do ***not*** adjust the position of the screen yet.)

R45: Position of Lens 2 = _____ cm



6. Determine the object distance, s_2, for lens 2 and record the value in the space provided. (The magnitude of s_2 is the distance from lens 2 to the screen.) Explain clearly why s_2 must be negative.

R46: s_2 = _____ cm

7. Adjust the position of the screen to get a new real image. In the space provided, record the new (final) position of the screen.

R47: Final Position of the Screen = _____ cm

8. Determine the image distance, s'_2, for lens 2. (It is the distance from lens 2 to the final position of the screen.) Record the value in the space provided.

R48: s'_2 = _____ cm

9. Use eq. (1) and s_2 and s'_2 to calculate the focal length of lens 2, f_2, and record the value in the space provided.

R49: f_2 (Calculated using s_2 and s'_2) = _____ cm

R50: How does this value of the focal length compare with the value determined previously for the diverging lens? Calculate a percentage difference. Discuss.

10. Use eq. (2) and the data to calculate the magnification, m_2, caused by lens 2 and record the value in the space provided.

R51: m_2 (Calculated using s_2 and s'_2) =

The total magnification, m_T, of a combination of lenses is the product of the individual magnifications m_1 and m_2 i.e.

$$m_T = m_1\, m_2 \tag{5}$$

11. Use eq. (5) and the values of m_1 and m_2 to calculate m_T. In the space provided, record the value of m_T.

R52: m_T (Calculated using m_1 and m_2) =

12. Determine the size of the original object (the object at the light source). To avoid confusion, consider using the same portion of the object (y) that was used in the **Lateral Magnification** section of this lab. Record the value as y_O in the space provided.

R53: y_O = cm

13. Measure the size of the final image (the image on the screen) and record the value as y'_F in the space provided. (If the image is upright, the value of y'_F would be positive and if the image is inverted, the value of y'_F would be negative.)

R54: y'_F = cm

14. Calculate the total magnification using the following equation and record the value in the space provided.

$$m_T = \frac{y'_F}{y_O} \tag{6}$$

R55: m_T (Calculated using y_O and y'_F) =

R56: Explain why eq. (6) is correct. Use eqs. (5) and (2) in your answer.

R57: Compare the two values of the total magnification. Calculate a percentage difference. Discuss.

End of Lab Checkout

Tidy up the work station. Remember to slide your seats back under the lab bench to assist the lab staff.

CHECKPOINT:

Submit

RESPONSE FORM Name Date

R1:		**R26:**	
R2:		**R27:**	
R3:		**R28:**	
R4:		**R29:**	
R5:		**R30:**	
R6:		**R31:**	
R7:		**R32:**	
R8:		**R33:**	
R9:		**R34:**	
R10:		**R35:**	
R11:		**R36:**	
R12:		**R37:**	
R13:		**R38:**	
R14:		**R39:**	
R15:		**R40:**	
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R21:		**R46:**	
R22:		**R47:**	
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R24:		**R49:**	
R25:		**R50:**	