Lab 2: Optics

Part I: Real Images and the Thin Lens Equation

In this investigation, you will explore the formation of real images with convex lenses. You will have the opportunity to project images in various configurations, and explore the variables that affect the formation of a real image. After exploring the phenomena, you will formalize your explanations and learn mathematical relationships governing the behavior you have observed.

OBJECTIVES

- Use lenses to produce real images.
- Explore the appearance, orientation, and magnification of real images.
- Explore the relationship between object distance, image distance and focal length in real images produced by convex lenses.

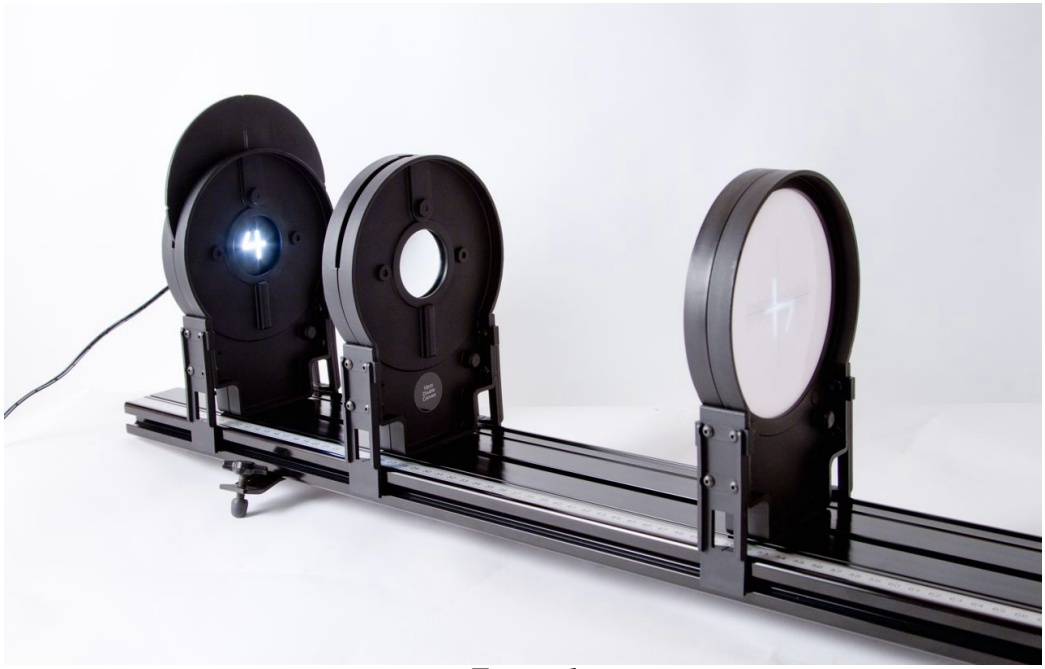


Figure 1

MATERIALS

Vernier data-collection interface
Logger *Pro* or LabQuest App
Vernier Dynamics System track
Vernier Optics Expansion Kit

PRELIMINARY INVESTIGATION

1. Place the screen at the 10 cm mark on the track. Then place the 10 cm double convex lens to the right of the screen, around 50 cm.

2. Aim the lens end of the track at a window to the outdoors to receive light from distant objects.

3. Adjust the position of the lens on the track until you see a clear image on the screen.

4. Describe the size, shape, color, and orientation of the image.

5. Repeat the above steps with the 20 cm double convex lens. How does the setup differ between the lenses?

PRELIMINARY QUESTIONS

1. How do you think a lens makes an image?

2. What factors might determine the size of an image?

3. What factors might determine whether an image is clear and in sharp focus?

4. What is special about the location where the lens projects a clear image for an object very far away? Is this location the same for other lenses?

PROCEDURE

1. Use the light source and a lens to project an image:
   a. Attach the light source from the Optics Expansion Kit to the Vernier Dynamics System near one end of the track at the 10 cm mark, facing toward the higher distance markings.
   b. Place the 10 cm double convex lens on the track, at about 50 cm.
   c. Attach the screen to the track and position it so that light from the light source passes through the lens and strikes the screen.
   c. Turn the light source wheel until the number "4" is visible in the opening. This will be your "object" for this investigation.
   d. Adjust the position of the lens and the screen until you see a clear image on the screen. This may require some trial-and-error.

2. Record the distance between the light source and the lens as "Object distance" and the distance between the lens and the screen as "Image distance" in the data table.

3. Is there anything about the image that surprises you? Describe the size, shape, and orientation of the image.

4. Continue adjusting the position of the lens and the screen to find different configurations that yield sharp images. Record 5 pairs of values for "Object distance" and "Image distance" in the table.

5. Under what conditions is the projected image largest? When is the image smallest?

6. Graph the data:

   Using Logger Pro

   a. Choose New from the File menu.
   b. Select the X column header to bring up the column options menu. Enter the name **d-o** to represent the object distance and select OK.
   c. Select the Y column header to bring up the column options menu. Enter the name **d-i** to represent the image distance and select OK.

d. Enter the data from the data table into the rows on the screen. (The Enter key will bring you to the next cell.)

Return to the graph view to see the illustration of distance versus object distance. It may be necessary to deselect Connect Points in the Graph Options menu.

7. Describe the relationship between object distance and image distance:

   a. As object distance increases, what is the trend in image distance?
   b. Does the graph appear to be linear? That is, does it resemble a straight line?

8. When a mathematical model doesn't fit the data well, it is often worthwhile to view the data a different way. Use calculated columns to graph the inverses of object distance and image distance:

   Using Logger *Pro*

   a. Choose New Calculated Column from the Data menu.
   b. Enter **1/do** for the Name.
   c. In Equation, enter **1/"d-o"** by typing **1/** then selecting **d-o** from the Variables (Columns) menu. Select OK.
   d. Repeat steps a-c with **1/di** for the column Name and **d-i** from the Variables (Columns) menu.

9. Perform a linear fit on the graph of the inverses of object distance and image distance:

   Using Logger *Pro*

   a. Choose Linear Fit from the Analyze menu.

10. Look at the linear fit for 1/do vs. 1/di. Identify the y-intercept, "b," in the equation. What is the significance of the value? (Hint: Examine the inverse, or 1 over the Y-intercept. What are the units of the Y-intercept?)

DATA AND CALCULATIONS

Object distance (cm)	Image distance (cm)

ANALYSIS

Real images

In this investigation, you worked with *real images*. Real images can be projected onto a screen or a card, and rays of light pass through the location of a real image. The other kind of image you'll study in Part II is a *virtual image*.

The relationships you have explored today are explained in a mathematical model known as the *thin-lens equation*. It shows the relationship between the object distance (d_o), the image distance (d_i), and the focal length (f).

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

This is why you found a linear relationship between $1/d_o$ and $1/d_i$.

It also explains why, when you increase the distance between the light source (object) and the lens, the distance to the screen (image distance) decreases.

The y-intercept you measured was the constant in the equation, $1/f$.

1. Using the graph of the inverses for the 10 cm double convex lens, predict where you would be able to find an image if you placed the light source 33 cm from the lens.

EXTENSIONS (OPTIONAL, ONLY IF YOU HAVE TIME)

1. Design a procedure to test the focal length of any converging (double convex) lens.

2) The ratio between the image distance and the object distance should be equal to the *magnification*, or the ratio between the heights of the image and the object. Add a calculated column to your table with the magnification for each configuration. Under what conditions is the magnification the greatest?

$$m = \frac{d_i}{d_o} = \frac{h_i}{h_o}$$

3) The "L" shape on the light source is 2 cm tall and 1 cm wide. Set up the light source, convex lens and screen to project an enlarged image. What is the magnification? Does the ratio of the distances match the ratio of the heights? (For convenience, you can use the width of the "L." The magnification is the same in each dimension. The screen has a horizontal rule with centimeters marked.)

Part II: Virtual Images and the Telescope

The telescope is an example of the usefulness of lenses in producing images. One of the many claims to fame of Galileo Galilei is his work refining the design of a refracting optical telescope. Telescopes use combinations of lenses to produce a magnified image.



Figure 1

OBJECTIVES

- Build a refracting optical telescope.
- Discuss the characteristics of real and virtual images.

MATERIALS

Vernier Dynamics System track

Optics Expansion Kit: 10 and 20 cm double convex lenses

PRELIMINARY QUESTIONS

1. You learned from Part I how to project a real image of a distant object using a double convex lens. How must you arrange an object, lens and screen to produce a real image?

2. What are the characteristics of a real image?

PROCEDURE

Part A: Investigating Virtual Images

1. Investigate the 15 cm double concave lens. Is it possible to project a real image as you did with the convex lenses?

2. Look “into” the lens. Is it possible to see an image this way? This is a *virtual image.* How does it differ from a real image?

Part B: The Magnifying Lens

Next, we will experiment with the use of a double convex lens as a magnifying glass.

1. Attach the screen to the track.

2. Attach the 10 cm double convex lens to the track.

3. Look through the double convex lens at the screen. Adjust the distance between the two until you clearly see a magnified image of the screen and its scale markers. Continue to adjust the distance to maximize the magnification of the image.

4. Is the image produced by a magnifying glass real or virtual? How do you know?

5. What is special about the position where the image has maximum magnification while remaining in focus?

Part C: The Telescope

Now we will make a telescope. In a previous activity, you projected the image of a distant object (the outdoors) on a screen. A telescope is a combination of this type of projection and a magnifying glass.

1. Set up the 10 cm double convex lens and the screen in the position from Part B that yielded maximum magnification. Be sure to leave space on the opposite side of the screen for steps that follow.

2. Use a 20 cm double convex lens to project the image of a distant object on the "back" side of the screen, as you did in Part I. Adjust the lens position until the projected image is in sharp focus. The final arrangement of the track should be: Window, 20 cm lens, Screen, 10 cm lens.

3. Now remove the screen. You've made a telescope. The lens that was a magnifying lens is now the eyepiece, and the lens producing the real image is the objective lens.

4. Describe the image you see when looking through the eyepiece. Is it upright or inverted? Magnified or reduced? Real or virtual? How do you know?

5. What is special about the distance between the two lenses?

6. Look through the lenses from the other direction. How does the image seen through the eyepiece compare?

7. Borrow a lens from a neighboring lab team so you have two lenses of the same focal length. Set up the two lenses at the special distance. Describe your results.

In a refracting optical telescope, a real image of a distant object is produced in the space between the lenses. A second lens produces a magnified virtual image. Below is a ray diagram of the two lenses, the real image, and the virtual image.

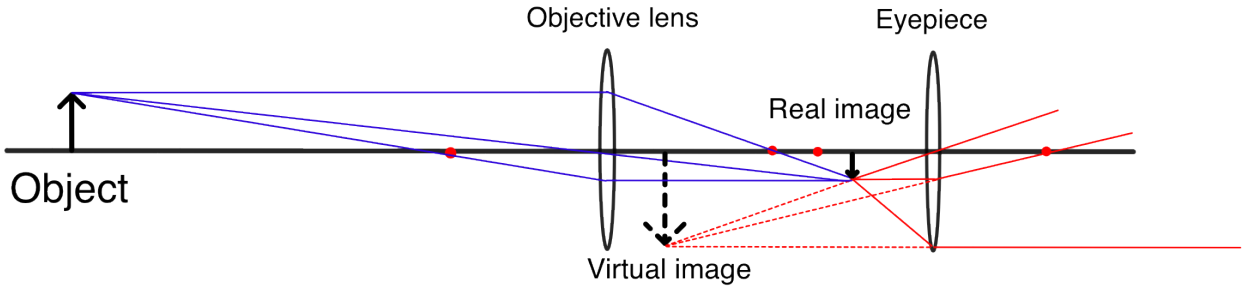


Figure 2: Ray Diagram of a Telescope

Part III: Aperture and Depth of Field

Lenses are used in a variety of everyday applications. In a camera, a real image is produced when light from a source passes through a lens and an opening, called the *aperture,* before striking film or a sensor. The size and shape of the aperture affects how much light strikes the film or sensor, and also affects some characteristics of the image. In this activity, you will investigate the role of the aperture in image formation.

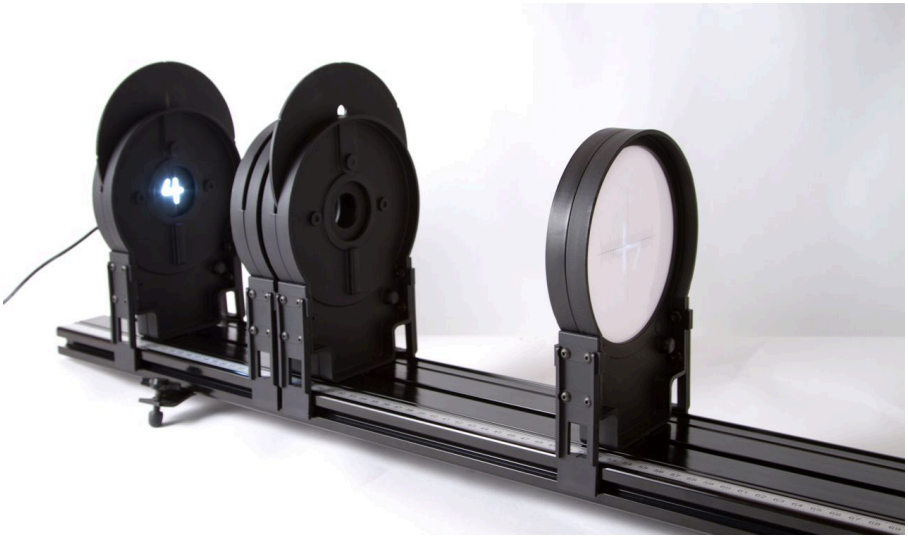


Figure 1

OBJECTIVES

- Predict and observe the effect of aperture adjustments real image formation.
- Observe the relationship between aperture and depth of field.

MATERIALS

Vernier Dynamics System track

Vernier Optics Expansion Kit: light source, aperture assembly, 20 cm double convex lens, screen

PART A: THE HALF-LENS

1. Set up the Optics Expansion Kit on the Dynamics System track with the light source at 10 cm, the 20 cm double convex lens at 40 cm, and the screen at 110 cm. (See Figure 1.)

2. Turn the disc on the light source to the numeral "4." Adjust the position of the components until a real image is projected in sharp focus on the screen.

3. Prepare the aperture assembly by turning it to the largest opening.

4. Place the aperture assembly on the track, immediately adjacent to the lens at around 40 cm. (Either side is OK.) Describe the image you see on the screen.

5. The aperture has a setting that covers half the lens vertically, so the opening is in the shape of a "D." Predict how the appearance of the image will change when half the lens is covered.

6. Adjust the aperture assembly to the D-shaped opening. What do you observe? How does that compare with your prediction?

7. Predict what will happen to the image as the round aperture is made smaller and smaller. Try it. What do you observe? How does that compare to your prediction? Why might this be happening?

PART B: APERTURE AND DEPTH OF FIELD

1. Using the same setup as in Part A, turn the aperture to one of the mid-sized openings. Move the screen toward and away from the screen. When is the image in focus? Is the image only in focus at a fixed location, or is there a range over which the image appears to be in focus? Over what distance can you move the screen while keeping the image in focus?

In photography, there is a term known as the depth of field. This refers to the range over which an image appears to be in focus. For example, in a photo with a large depth of field, you might see a person in the foreground with scenery in the background, and all of these subjects are in sharp focus. A narrow depth of field yields a single object in focus, while the scenery and background are out of focus. This is sometimes used to draw the viewer's attention to an object.

2. Predict: Look at the different openings on the aperture apparatus in your setup. Do you think the larger or smaller apertures will produce greater depths of field? Justify your answer.

4. Set the aperture to the largest setting. Beginning with the screen far away from the lens, move the screen closer until the image produced first appears to be in good focus. Record the distance.

5. Continue moving the screen toward the lens until the image just begins to lose focus. Record this second distance.

6. Find the difference between the two distances to calculate the range of focus. Record this value in the Data Table.

7. Repeat Steps 4 - 6 with each of the round apertures, with 5 being the largest, and 1 being the smallest. Which aperture has the greatest depth of field?

DATA TABLE

Aperture	Depth of field (cm)
5 (largest)	
4	
3	
2	
1 (smallest)	