## INSTRUCTIONAL GUIDE

Contents

Introductory Optical System:
- Single Lens Holder
- Double Lens Holder
- LED Object (AAA batteries included)
- Lens: Dia. 50mm, +100mm Double Convex
- Lens: Dia. 50mm, +200mm Double Convex
- Lens: Dia. 50mm, -100mm Double Concave
- Lens: Dia. 50mm, -200mm Double Concave
- Viewing Screen, Double Sided
- Pinhole Configuration Cards, Pair
- Instructional Guide and Activities

Required for Activity:
- **Meter Stick (P1-7072)**
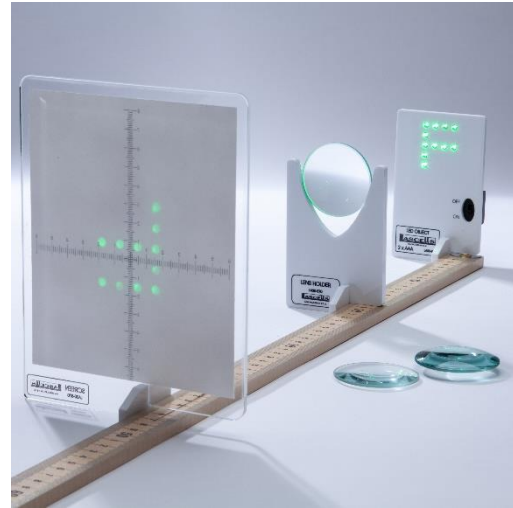
Introduction

Over 90 per cent of our brain processing is related to vision. We are constantly aware of the objects around us and the motion of these objects. This awareness is essential to our survival.

Many people use eyeglasses or contact lenses to improve their vision. Professional photographers use sophisticated cameras and almost all smart phones have lenses to capture images. Lenses are ubiquitous yet most students and many teachers have a limited understanding of how they work. The innovative materials in the optics kit will make the activities safer. No more cords for students to trip on and no more breaking of 100-watt bulbs. **Traditional instruction and pedagogy of image formation is ineffective, often creating and reinforcing many misconceptions. The improved pedagogy in these non-traditional activities will demonstrate how pinholes and lenses improve our vision and produce precise photos.**

The new equipment in the Introductory Optical System is vastly superior to previous options. The object is a bright 'F' shape that consists of 11 green LEDs. This object is powered by batteries so that we can forget about students tripping over cords and smashing 110-volt bulbs. Further, this object is bright enough so that the activities can be conducted with the room lights on! The unique screen includes a built-in scale and can also be **viewed from both sides!** Newly designed holders are engineered for converging and diverging lenses and pinhole arrangements. A large surface area Fresnel lens will gather plenty of pinhole images to produce both virtual and **real images that are visible without being projected onto screens**. Here is a brief summary of the activities. The suggested grade level(s) are listed: **MS** = Middle School, **HS** = High School, **PS** = Post-Secondary.

The Pinhole Camera (MS, HS, PS) activity will provide the basics of image formation. The concepts developed from this activity will then be applied to provide students a much-improved understanding of how lenses create images. This particular activity will clearly provide students an understanding of one of the key equations that are applied to lenses and images. This activity is largely conceptual, however one of the key equations related to images will be developed.

Images from Lenses (MS, HS, PS) is a unique activity that has been student tested in a high school classroom over several decades. Students will participate in a simple method to measure the focal length of converging lenses. This activity will demonstrate that each part of a lens acts as a pinhole camera and the converging lens forms an image by superimposing the individual pinhole images at a specific distance from the lens. The questions in **Part 5** require a deep understanding of images. Extensive studies in Physics Education Research (PER) have shown that HS and university students are NOT able to correctly answer these questions. The improved pedagogy in the first 2 activities should give your students much deeper understanding about how the lens works!

The Mathematical Model of Images (HS, PS) provides students data to reinforce the lens equation. Additionally, the concepts of symmetry and limits are included. A variation of the lens equation is shown that predicts the results for 2 lenses.

Eyes and Cameras (**MS, HS**) is unique and relevant to students. They all have eyes and also cameras in their smart phones. A large percentage of students wear eyeglasses or contact lenses. This is mostly background reading, but includes two quick, but memorable adventures.

Ray Drawings for Lenses (Visual Model) (**HS, PS**) prevents many misconceptions. This activity is an improved model for making "ray diagrams." Students will discover that the "pinhole model" is still useful for understanding the size and location of images. Students will learn that the object does NOT have to be directly in front of the lens. Students will appreciate that the lens does NOT have to be larger than the object! Students will also discover the required viewing position to locate virtual images.

Virtual Images (**HS, PS**) provides a unique and effective method to measure the position and size of virtual images. Students can apply their data to calculate the focal length of a diverging lens. Most teachers have never realized that it is possible to measure the d_i and h_i for diverging lenses. Ask an experienced teacher how to find the focal length of a diverging lens and he/she will either look puzzled, answer "look on the lens box", or suggest "maybe use lasers?".

Fresnel Lens (**MS, HS, PS**) is a rather quick, but highly effective activity that will surprise everyone that real images do NOT require a screen to be seen and also that the images from lenses are actually 3-D.

Background

The camera obscura (pinhole camera) has a rich history. Ancient records suggest that Aristotle and Leonardo DaVinci were aware of the value of this process. Artists from the Renaissance period used the camera obscura (pinhole camera) as a method to show them the correct proportions for their subjects. The artists would trace the outlines onto their canvasses and later add the pigments to bring the paintings to life.

Simple lenses have provided scientists a useful tool for examining very small objects (water drop microscopes) and later glass was cut and polished for eyeglasses. Hans Lippershey invented the spyglass (telescope) in 1608, but this invention inspired Galileo to create a 10-power telescope that he pointed skyward. His telescope allowed him to discover the ears (rings) of Saturn, the moons of Jupiter, and to draw accurate maps of the lunar surface.
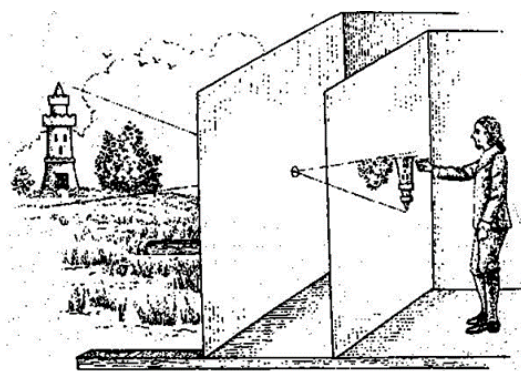
Pinhole Cameras

When light from an object passes through a pin hole, the light forms an image on a screen. Place the lighted "F" object at the 0 cm position and the screen at the 40 cm position on the meter stick as shown in the figure below. Use the **Pinhole Configuration Cards (92-7700-04)** Place the pinhole at the 20 cm position and notice the light pattern on the screen. The pattern on the screen is called an image. Describe the image on the screen.

Next, use a straight edge to draw the light rays from the bottom of the object through the pinhole and the light ray from the top of the object through the pinhole to show why the image is inverted (upside down).
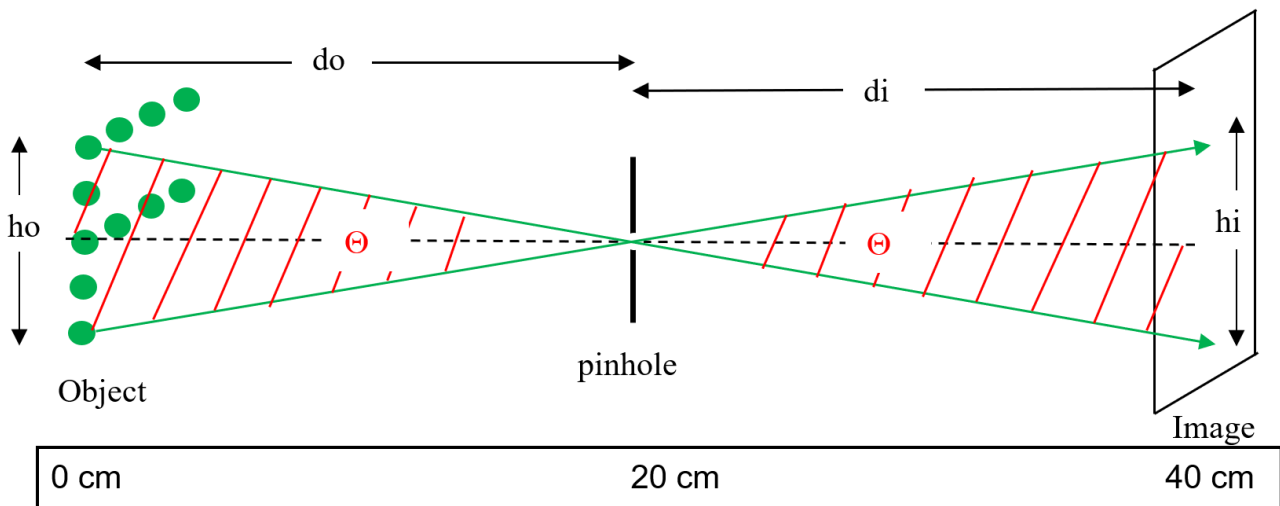
Now slowly move the screen toward the pinhole and describe the changes in the image.

Leave the object and pinhole in the same position, but move the screen to the 30 cm position.

Measure h_o, h_i, and d_o and d_i. Label these values on the sketch above.

h_i = _____ h_o = _____ d_o = _____ d_i = _____

Write a possible equation between h_o, h_i, d_o and d_i.

Next, Next, would your equation work when the image distance (d_i) is greater than the object distance (d_o)? Why or why not?

Go ahead and move the screen farther away (to the 50 cm position) and measure the new values of h_o, h_i, d_o and d_i. Put these new values into your equation. Is it still okay?

Predict what might happen to the image if the pinhole was half the diameter. Predict how the image will be similar. Predict how it will be different.

Uncover the large diameter pinhole. Compare this image to the image from the smaller pinhole.

Did you know that a pinhole can help you to see very small objects and also very close objects?

Do you normally wear glasses (or contacts) to read?   ___ yes   __ no

At the bottom of this page, you will see a note in a very small font. With one eye closed, move the paper to the smallest distance that you can read the message. This called the near point of your vision. Have your lab partner measure this distance.

What is your near point?
     distance = _____ cm

Repeat this experiment with the other eye. Record your results.
     near point distance = _____ cm

Now hold the larger pinhole next to your eye and repeat the experiment. Again, have your lab partner measure the distance. What is the near point with the pinhole?
     near point distance = _____ cm

Predict what will happen with the smaller pinhole:

Try it and describe what really happens. Explain your results.

Find someone in class who wears eyeglasses for reading. Compare the near point with glasses to the near point without glasses. Write a summary sentence of your results:

Can you read this?

Images from Lenses

Part 1: Intro to Lenses

You should have 4 different lenses. Try using each as a magnifying glass and describe your results.

Lens A   f = _____ cm

Lens B   f = _____ cm

Lens C   f = _____ cm

Lens D   f = _____ cm

### Part 2: Estimating the focal length of each lens.

Use the view out an open window as your object. Place the lens into the lens holder and slowly move the screen away until a bright image appears on your screen. The distance from the lens to the screen is approximately the focal length of the lens. Record the values on the sketch above

Write a statement that describes the relation between the curvature of the lens to the focal length.

Place lens A and B next to each other as show here.

Predict the combined focal length and explain your prediction.

What is the measured combination focal length?
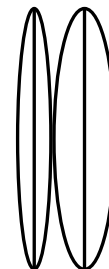
Part 3: Measuring Real Images

Select Lens A or Lens B for this part.

Place the "F" shaped object at the 0 cm position and the lens at the 25 cm position as shown below. (d_o = 25 cm)

Start the screen next to the lens and slowly move the screen away until a bright and sharp image appears on the screen. Measure d_i and also h_i and record in the data table below. Repeat this procedure to complete the data table below.
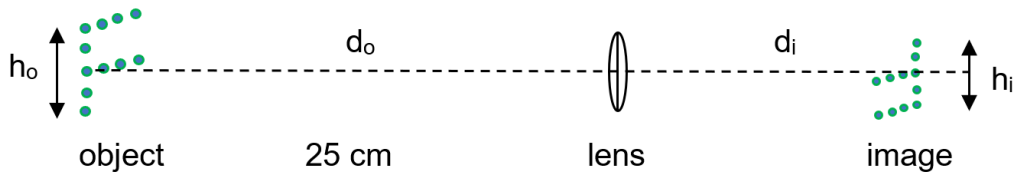
h$_o$ = _____ cm

d$_o$ (cm)	d$_i$ (cm)	h$_i$ (cm)
25		
35		
45		
55		

Write a statement that describes how the image distance (**d$_i$**) depends on the value of **d$_o$**.

Write a statement that describes how the height of the image (**h$_i$**) depends on the image distance (**d$_i$**).

Recall the pinhole image equation:

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

Substitute the values from one trial to see if this pinhole equation is valid for your lens.

Part 4: How Lenses Produce Images

Keep the object at 0 cm and the lens holder at the 25 cm position. Now **remove the lens and replace it with a notecard with 3 holes (card A)**.

Place the screen next to card A and slowly move the screen away from the card. Describe what happens on the screen:

Return the screen next to the card. Now return the lens to its holder. Slowly move the screen away from the lens/card A and observe the screen. Describe what you see.

Watch the screen closely as you remove card A from the holder. What do you see?

Does the lens produce a taller image than the pinholes? Explain.

What would happen if the notecard had 10 times as many holes?

Watch closely as you continue to move the screen farther from the lens. Describe your results:

Part 5: Predictions and Conclusions

Suppose that a converging lens produces a bright, focused image on a screen.
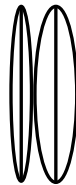Suppose that you now used your hand to block the top half of the lens.

Predict all of the changes in the image and explain each change.

Mathematical Model of Images from Lenses

Part 1: In the previous activity, you discovered that placing Lens A and Lens B together created a shorter focal length.

f_A = 20 cm f_B = 10 cm

The equation to predict the combined focal length is:

$$\frac{1}{f_{combined}} = \frac{1}{f_A} + \frac{1}{f_B}$$

Substitute your focal lengths into this equation to predict the combined focal length.

Now use the equipment to measure the combined focal length. Show your results.

f = _____ cm

The equation that describes the relation between focal length (**f**), the object distance (**d$_o$**), and the image distance (**d$_i$**) is:

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

Place the "F" object at 0 cm and the screen at the 100 cm position. Adjust the position of your lens so that a sharp image appears on the screen. Record the values into the data table below. Keep the "F" object and screen in the same positions and **move the lens** to find another position for a sharp image. Record the new values into the data table. Keep the object at 0 cm and move the screen to the 80 cm position. Repeat this process to complete the data table below.

move ⬍ lens

0 cm   100 cm
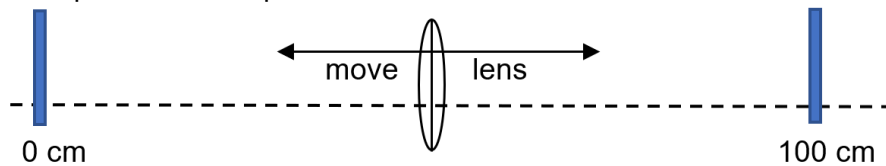
	d_o (cm)	d_i (cm)
d_o + d_i = 100 cm		
d_o + d_i = 100 cm		
d_o + d_i = 80 cm		
d_o + d_i = 80 cm		
d_o + d_i = 60 cm		
d_o + d_i = 60 cm		
d_o + d_i = 40 cm		
d_o + d_i = 40 cm		

d_i (cm)

d_o (cm)
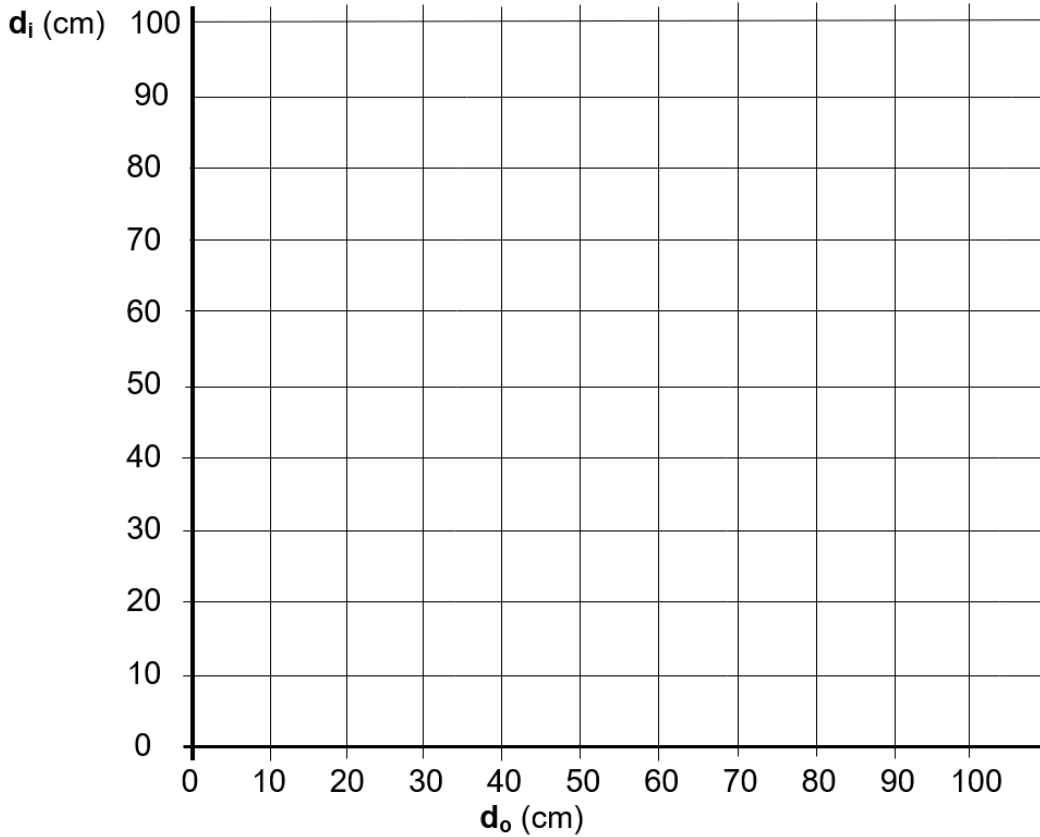
Plot your data points on the graph above.
Draw a smooth curve to connect the points.

Look closely at the curve. Does the increasing value of d_i seem to be approaching a limit as the value of d_o keeps increasing? Estimate the value of d_i Draw this horizontal line (called an asymptote).
   Predicted minimum: d_i = _____ cm

Now use the equation above to calculate d_i when d_o = 5000 cm.

d_i = _____ cm

Look closely at the curve above. Do you see a line of reflection symmetry? Draw it!

Draw this straight line on the curve.

Conclusions

Suppose that a different lab team had a different focal length for their experiment. How would their graph be similar to your graph? How would it be different?

Eyes and Cameras

Over 90 per cent of our brain processing is related to vision. We are constantly aware of the objects around us and the motion of these objects. This awareness is essential to our survival.

How do our eyes capture information? How are they similar to the operation of cameras?
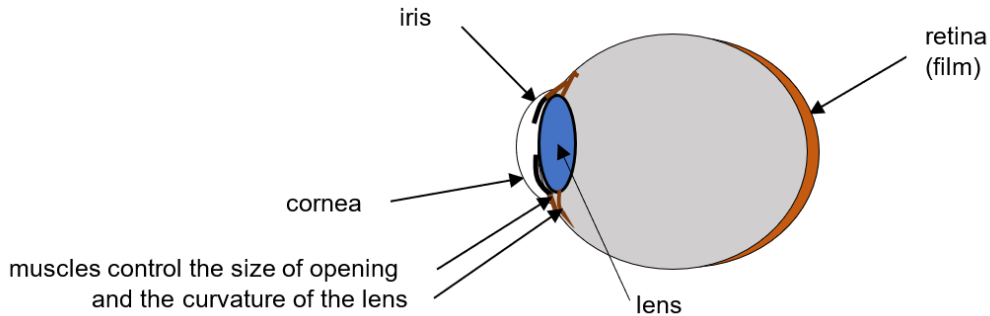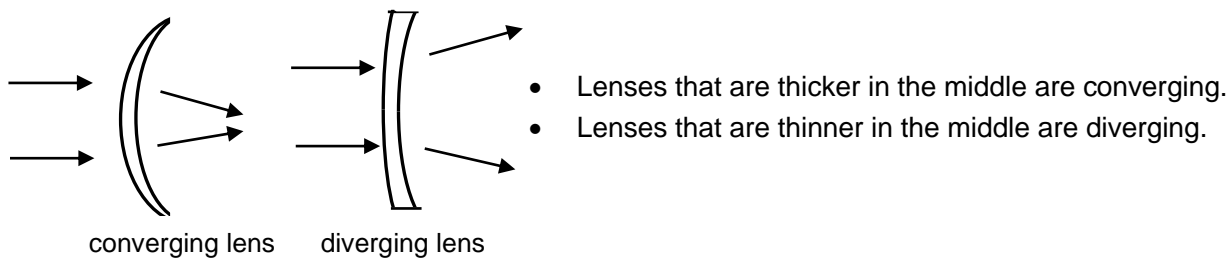

Your eyes have several "automatic" features. First, the eyelid automatically closes when the brain predicts a possible collision with objects. Second, the opening in the eye will be large when the light is low. As the light level increases, the muscles will pull and the opening will get smaller. The black spot in the eye is called the "pupil." This circle appears black because the light entering the eye is absorbed in the retina at the back of the eye.

Try this activity: Sit close to a classmate and look directly into her eyes as she looks into your eyes at a close distance (30 cm.). Have the teacher pull the window blinds and turn off the room lights. After 2 minutes, the teacher should give a loud count-down: 5,4, 3, 2, 1, "now" as she turns on the overhead lights. Notice what happens to the size of your classmate's pupils!

When you gaze at distant objects, the muscles that pull on your lenses will be relaxed. As you concentrate on closer objects, the muscles will automatically pull on the lens in your eye to give it more curvature and bring the objects into focus. Reading for a long period may cause these muscles to become stressed and you may notice tiredness or even a headache. (In a camera system, the lens does NOT change shape, but moves farther from the film (or CCD.)

The adult human eye is about 2.4 cm long and the lens is about the same size as an M&M candy. The length of your eyeball has a lot to do with whether you're nearsighted or farsighted. People who are nearsighted have a longer-than-normal eyeball, while people who are farsighted have a shorter-than-normal eyeball. Just a millimeter change in the length of your eye will change the prescription for that eye. You can wear eyeglasses or contact lenses as shown below to correct these problems.

converging lens   diverging lens

- Lenses that are thicker in the middle are converging.
- Lenses that are thinner in the middle are diverging.

Find someone in your class who wears eyeglasses. Try to use the glasses as a magnifying glass. Do they make objects look larger? If so, then the glasses are converging.

Student name: _____   Converging: _____   Diverging: _____

Let's assume that the distance from the cornea to the eye is 2.4 cm. When looking at distant objects the images form at the focal length, so that the "f" for your relaxed eye is also 2.4 cm. Now suppose that you look at a 30 cm tall tulip at a distance of 50 cm from your eye. What happens in your eye? First of all, the muscles pull on your lens to make it more curved which also increases the curvature of the cornea. This causes the focal length to decrease. Now the image will be focused at the retina so the d_i = 2.4 cm. Use the lens equation to calculate the new focal length:

Now use the pinhole equation to calculate the height of the image on the retina:

Professional photographers use digital cameras to focus the images at the back of the camera. The lenses in the camera are glass so that they cannot change shape. The images are focused by changing the distance between the lens and screen. The focal length of a certain camera is 8.0 cm. The 30 cm tall tulip is 50 cm from the camera lens. Use the lens equation to calculate the value of d_i:

Now use the pinhole equation to calculate the height of the image:

Ray Drawings for Images

The size and position of images created by lenses can be predicted by making a scale model of the object and lens. Here are the rules:

1. Select a scale factor: for example, let 1 cm = 10 cm
2. Draw the lens and the object to scale.
3. Draw lines from the top and bottom of the object through the center of the lens.
4. Extend the lens line up or down as needed.
5. Draw a ray from the top (or bottom) of the object so that the ray is parallel to the axis and intersects the lens line.
6. From this intersection point, draw the ray through the focal point of the lens so that it crosses the pinhole lines. Locate the intersection of the lines from the top of object.
7. Draw the top of the image at the intersection of lines 3 & 6.
8. Measure and label the h_i and with the scale factor!

Example:
Scale: Let 1.0 cm = 10 cm
d_o = 45 cm, h_o = 20 cm, f = 24 cm
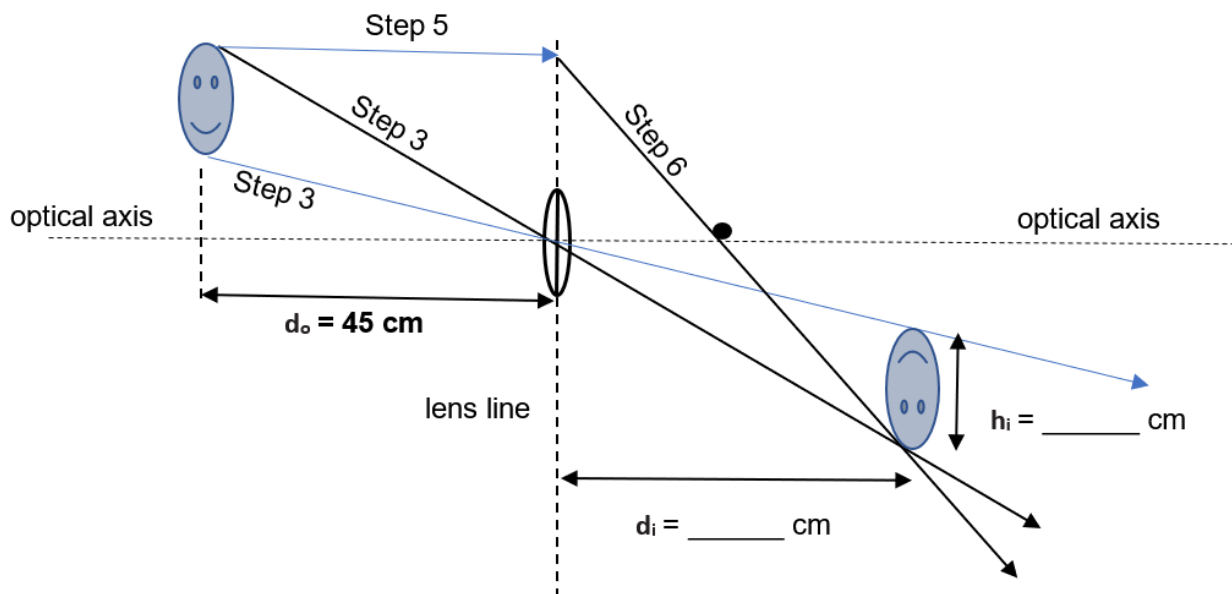
Note that the image is upside down and taller than the object.

Measure and label the values of h_i and d_i.

Note: when the object is outside the focal point of a converging lens, the lens will always form a REAL, upside down image on the opposite side of the lens. This image can be seen on a screen.

Here is the drawing when the object is **inside the focal length of a converging lens**:
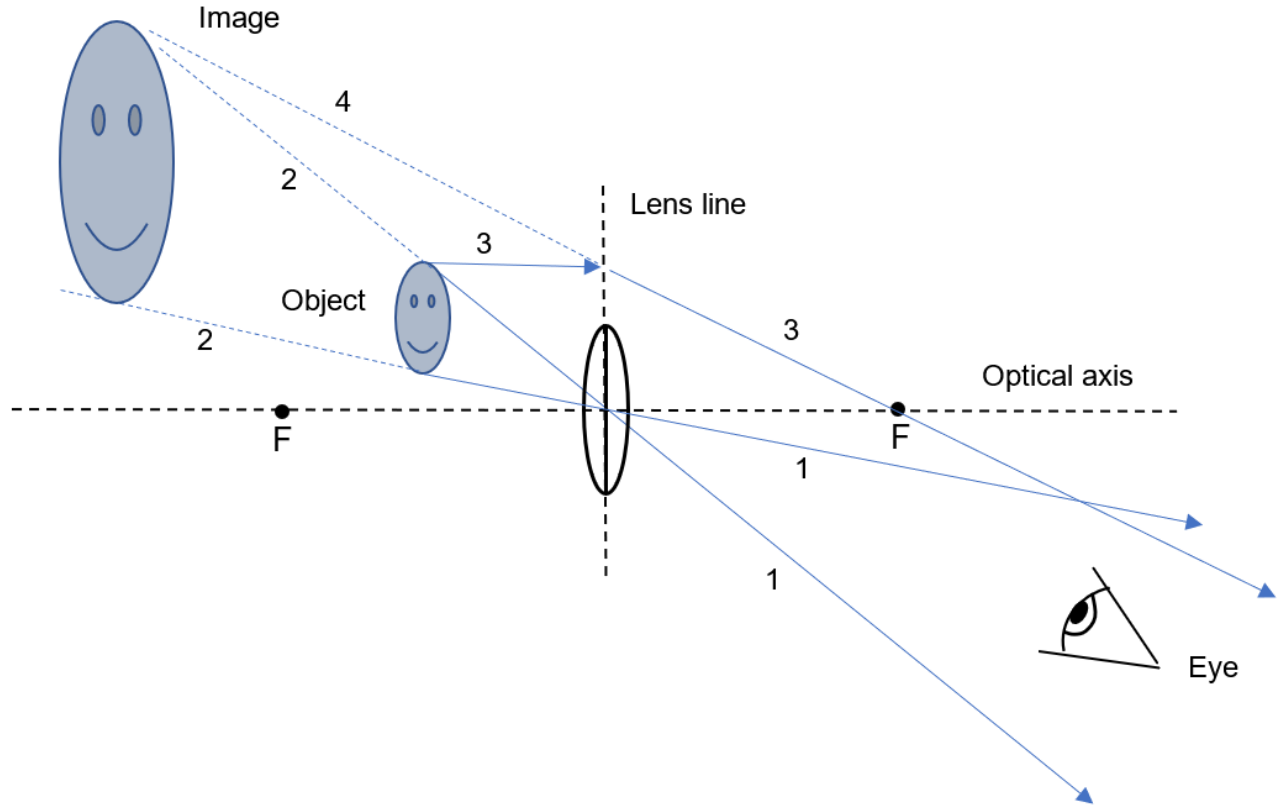
This is an example of a **magnifying glass**.
The object must be inside the focal length:
A **LARGER image** will be seen on the **same side of the lens**. This image will be **right-side up and farther from the lens**.

1. Draw the lines from the top and bottom of the object through the center of the lens. (1)
2. Extend these lines backwards away from the lens (see dashed lines.) (2)
3. Draw a from the top of the object to the lens and then through the far focal length. (3)
4. Extend this line backwards. (4)

The top of the image will be located where these construction lines cross. (2 & 4)
Look **through the lens to see this magnified image**. This is named a VIRTUAL image. Virtual images are always right side up and on the same side of the lens as the object.

Note: The object is too close to the lens to make a real image.

Virtual Images

Virtual Image for a Diverging Lens:

You have discovered that **diverging lenses cannot** make real images. Diverging lenses can only create virtual images. These images are **always right-side up and on the same side of the lens** as the object, so you must look **through the lens** to see this type of image. Use the diverging lens (f=-10 cm). Place the object near the lens and adjust the position so that the image (through the lens) appears about ½ the size (**width**) of the object. (Look over the top of the lens to see the object!) Record the distance of the object to the lens.

d_o = _____ cm
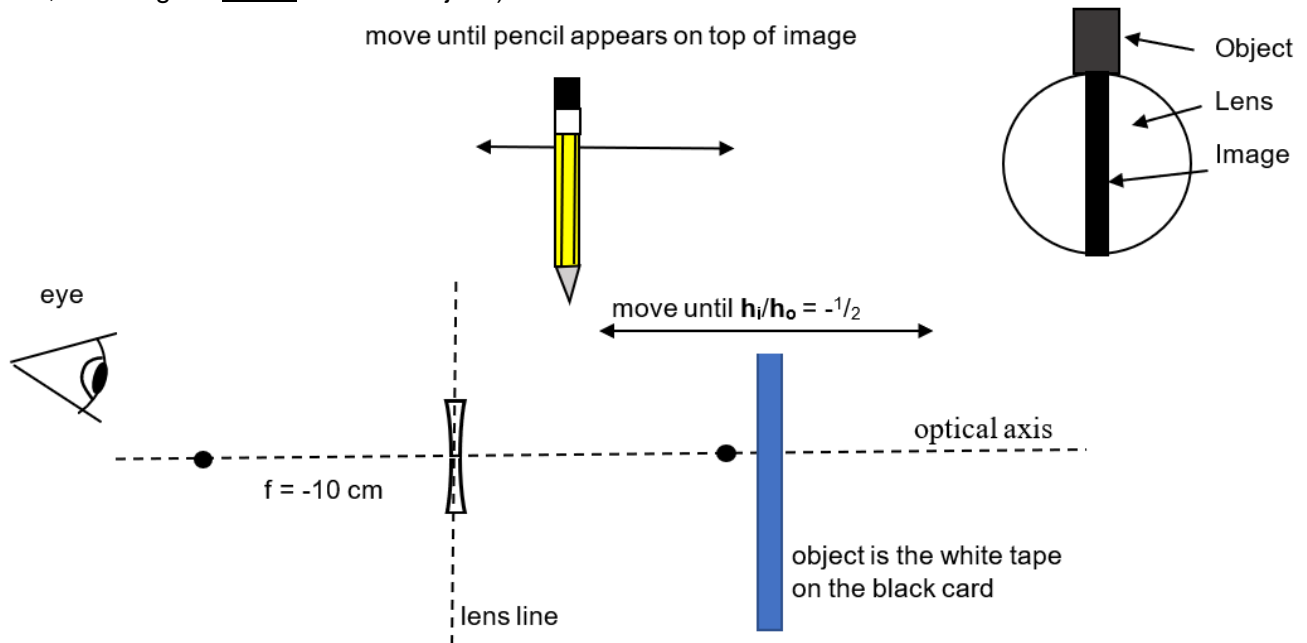
Now try to hold a pencil at the correct distance so that it seems to be directly over the image. Move your viewing position left and right and adjust the pencil so that it **stays over the image**.

Have your lab partner record the distance from the lens.

d_i = _____ cm

(Yes, the image is <u>closer</u> than the object!)

Since the image is ½ the size of the object, and $\frac{h_i}{h_o} = \frac{d_i}{d_o}$ then $\frac{d_i}{d_o}$ should equal -½.

Show the calculation for your values:

Substitute your measured values of d_o and d_i into the lens equation to calculate focal length:

Virtual Image for Converging Lenses:

When the object is inside the focal point of a converging lens, the lens is used as a magnifying glass. You will have to look through the lens to see this larger, right-side up image (on the same side of the lens as the object).

Place the object near the lens and adjust the position so that the image (through the lens) appears about 2 times the size (**width**) of the object. (Look over the top of the lens to see the object!)
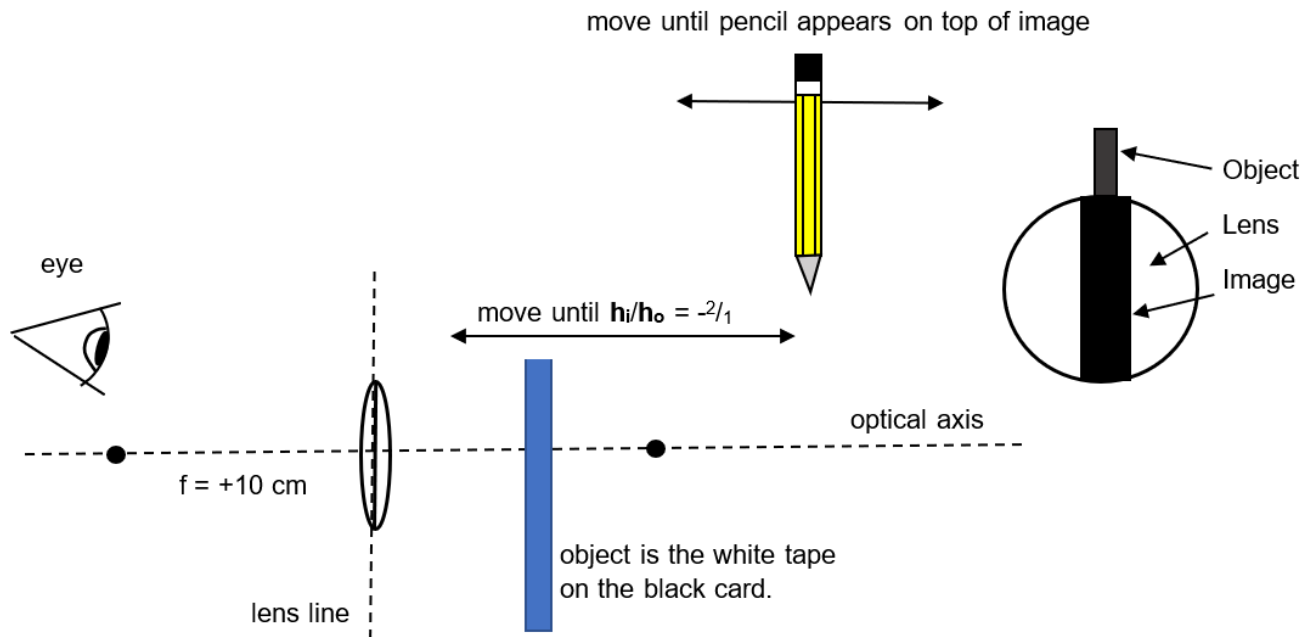
d_o = _____ cm

Now try to hold a pencil at the correct distance so that it seems to be directly over the image. Move your viewing position left and right and adjust the pencil so that it stays over the image.

Have your lab partner record the distance from the lens.

d_i = _____ cm

(Yes, the image is <u>farther</u> than the object!)

move until pencil appears on top of image

Object

Lens

Image

eye

move until h_i/h_o = $-2/1$

optical axis

f = +10 cm

object is the white tape on the black card.

lens line

Since the image is 2 times the size of the object, and $\frac{h_i}{h_o} = \frac{d_i}{d_o}$ then $\frac{d_i}{d_o}$ should equal $-2/1$.

Show the calculation for your values:

Substitute your measured values of d_o and d_i into the lens equation to calculate focal length:

The Fresnel Lens

The light that hits any lens changes direction at the front and back surfaces. The light travels in a straight line inside the glass, so that this material could be removed. A very clever Frenchman, Augustin Jean Fresnel (fra-NEL), decided to design a skinny, groovy lens. One of the first applications was for lighthouses. These new Fresnel lenses were extremely effective and revolutionized the design of glass lenses for lighthouses. Today, inexpensive, plastic, flat lenses are popular as hand-size or page-size magnifying glasses.

Left: This lighthouse lens system contains many Fresnel lenses. This design is both an exquisite piece of art and highly effective.

Right: Notice that the angles of the Fresnel cross-section match the angles of the typical lens.
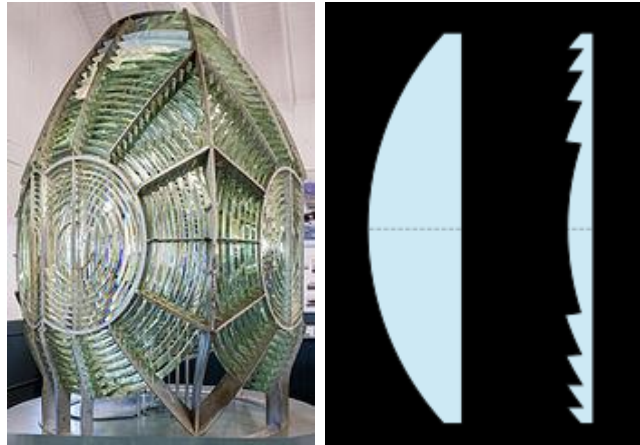
This groovy, skinny lens has concentric circles, where the angle of each circle matches the angle of the curved surface of the converging lens (see sketch above!). The light still changes direction at the front and back of the lens. The advantage of the Fresnel is that it uses much less material than the typical, fat, glass lens. The (skinny) Fresnel lens offers a very large surface at a much lower cost. A large surface area allows the lens to **gather more pinhole images** to produce **brighter images**. The pinhole equation and lens equation are still valid.

$$\text{Pinhole Equation: } \frac{h_i}{h_o} = \frac{d_i}{d_o} \qquad \text{Lens Equation: } \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Real Images from a Fresnel Lens

Use the 2 large clips to hold the Fresnel lens in a vertical position (Note—images will be slightly sharper when the flat side of the lens faces the object). Estimate the focal length by using the lens to form an image of a distant object (Hint—try using a distant tree, etc. as your object). When the d_o is huge, then the value of d_i is the focal length. Record the value.

f = _____ cm

Now use the "F" object and the suggested do values. For each d_o, measure the values of d_i and h_i and record in the data table.

Then, use the lens equation to calculate the predicted value of d_i. Record in the data table.

Next, use the pinhole equation to calculate the value of h_i and record into the table below.

d_o (cm)	measured d_i (cm)	measured h_i (cm)	calculated d_i (cm)	calculated h_i (cm)
50				
70				
90				

So far, you have used the screen to capture the images, but is the screen actually necessary? Leave the lens at the 90 cm position and place the screen so that the image is clear and bright on the screen.

Now position yourself about 100 cm farther than the screen and **your eyes directly in line with the object, lens, and image.** Next have your lab partner slowly remove the screen. Can you still see the image (floating in space!)? Reach out to verify that the image is still the same distance from the lens.

You should see a sharp image, even when the LED lamps are turned off!

Repeat this procedure for each student in your lab group.

Virtual Images

Place your hand 20 cm behind the Fresnel lens and look through the Fresnel lens to see the image. Slowly move your hand away from the lens. Describe your results:

Next, place your hand 20 cm behind the Fresnel lens, palm facing the lens. Now slowly curl your fingers into a fist. Is the image of your hand 2 dimensional or 3-D? Describe your results.

Resources

More information on Fresnel Lenses: https://www.edmundoptics.com/knowledge-center/application-notes/optics/advantages-of-fresnel-lenses/

More information on Pinhole Cameras: https://www.howtogeek.com/63409/htg-explains-cameras-lenses-and-how-photography-works/

Related Products

Laser Ray Box (P2-7680) Complete Optics Set uses 1, 3, or 5 Laser Beams! The most complete, economical optics kit you'll find!

Pair of Mega Mirrors (P2-7150) These extra-large parabolic mirrors make dramatic demonstrations of optical principles a snap. Each aluminized mirror measures 24" in diameter and is supplied with an aluminum frame, mounting bracket, and base.

Concave Convex Lens Set (P2-1200) These crown glass lenses packed in lined wood storage box are perfect for optical benches or basic optics demonstrations. Each set includes double convex, plano-convex, concavo-convex, double concave, plano-concave, and convexo-concave lenses.