PHILIP
HARRIS

Foundation Physics

Optics Bench

Optics Bench

KIT CONTENTS

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Required Materials
12 V power supply
‘Foundation Physics Stand’
Laser pointer
Objects of various colors

OVERVIEW / SUGGESTIONS FOR USE

The Optics Bench allows students to investigate geometric optics as they apply to lenses and mirrors. Students can investigate the difference between real and virtual images and how an image can be magnified. With the included polarizing filters students can see how transverse waves can be filtered.

CLASS TIME REQUIRED

(1) 40 minute period

YEAR GROUP

Grades 7 - 11

NATIONAL CURRICULUM STANDARDS

Content Standard	Grades 8 - 12
B: Physics	• Vibration and waves • Reflection and Refraction

SAFETY

The lamp for the optics bench can become hot with extended use. Please use caution and do not touch the lamp when it is on and allow it to cool before storing.

TEACHER PREPARATION (PRIOR TO CLASS)

Read through the student activities and make copies of pages S1 - S18 if needed.

SUGGESTED ACTIVITIES

There are three major activities included in the Foundations of Physics Optics Bench Kit and two extensions to the activities. The extensions are intended for a more advanced treatment of optics during which the students must deal with the mathematical relationships of the optics variables when using the thin lens and mirror equations and the magnification equation. The teacher guide contains additional activities that may be helpful that are not in the student guide.

Activity 1. Converging Lenses (Student Guide pages 18 - 23) - KS3 and KS4

In this activity, students investigate the various characteristics of images associated with converging or convex lenses. Students will vary the distance between the object and the lens and observe how changing these distances affects the image. The object is a black plastic plate with the number “1” cut as a stencil into the plate. As the light shines through the stencil and through the lens, an image of the object “1” is projected onto a white plastic screen. *It is highly recommended that the students become familiar with ray diagrams and are proficient in drawing ray diagrams for lenses before the commencement of this activity.*

There are two data tables provided in this activity. **Data Table 1A** is for the *qualitative* observations about the images. It includes observations on the location, size and orientation of the image (upright or inverted), and whether the image is real or virtual. **Data Table 1B** is for the *quantitative* observations about the images. It includes observations on the exact distance between the object and the lens, d_o, the exact distance between the image and the lens, d_i, the size or height of the object, h_o, and the height of the image, h_i.

At the beginning of the activity, students are instructed to experimentally determine the focal length of their convex lens. In a darkened room with an outside window, they are instructed to select a *very distant* object and focus the light rays from that object through the lens onto the white screen. If the object is very far away, as far as visibly possible, then one may assume that the light rays from that object are arriving *parallel* to the principle axis of the lens. When this occurs, these parallel rays will converge through the focal point of the lens to produce a sharp image on the screen. The location of the screen will be the exact focal point of the lens, and measuring the distance between the lens and the screen will yield the determined focal length of the lens.

It is important that the students select a very distant object to find the focal length of their lenses. Selecting a nearby tree rather than some other more distant object could yield a focal length of considerable error.

Activity 2. Diverging Lenses (Student Guide pages 23 - 25) - KS3 and KS4

In this activity, the primary objective is to experimentally determine the focal length of a diverging concave lens. Since a concave lens does *not* focus (converge) light rays, the procedure to determine the focal length is much different than it is for a convex lens.

The activity requires the use of both a concave lens and a convex lens. A sharp image is focused onto the screen using the convex lens. The concave lens is then placed between the screen and the convex lens. Since the concave lens *diverges* the light rays, the image on the screen is no longer in focus. If the screen is moved farther back from the lenses, a new location for a sharp image will be found. The distance between the concave lens and the *original* screen location, d_o, and the distance between the concave lens and the new screen location, d_i, can be used in the thin lens equation to calculate the focal length of the concave lens.

To assist in the organization of the collected data, **Data Table 2** is included in this activity.

Activity 3. Spherical Mirrors (Student Guide pages 25 - 32) - KS4

In this activity, students investigate the various characteristics of images associated with spherical concave and convex mirrors. The students will vary the distance between the object and the mirror and observe how changing these distances affects the image. The object, again, is a black plastic plate with the number “1” cut as a stencil into the plate. As the light shines through the stencil and reflects off the surface of the mirror, an image of the object “1” is projected onto a white plastic screen. *It is highly recommended that the students be familiar with ray diagrams and proficient in drawing ray diagrams for mirrors before the commencement of this activity.*

Because the light reflects off of the concave mirror back towards the light source, and then focuses on a screen, the screen must be placed *between* the light source and the mirror. If the screen is placed *on* the optics bench, it will block the light from striking the mirror. Rather, it is placed very near the bench, close enough to pick up the reflected image, but far enough so as not to block the light from reaching the mirror. Students can tinker with the placement of the screen to get the best results. *By slightly rotating the mirror on its mount, the image can be easily directed towards the screen.*

There are two data tables provided in this activity. **Data Table 3A** is for the *qualitative* observations about the images. It includes observations on the location, size and orientation of the image (upright or inverted), and whether the image is real or virtual. **Data Table 3B** is for the *quantitative* observations about the images. It includes observations on the exact distance between the object and the mirror, d_o, the exact distance between the image and the mirror, d_i, the size or height of the object, h_o, and the height of the image, h_i.

At the beginning of the activity, the students are instructed to experimentally determine the focal length of their concave mirror. In a darkened room with an outside window, they are instructed to select a very distant object and collect the light rays from that object that reflect off of the concave mirror, then focus them onto the white screen. If the object is very far away, as far as visibly possible, then one may assume that the light rays from that object are arriving parallel to the principal axis of the mirror. When this occurs, these parallel rays will all reflect and converge at the focal point (principal focus) of the mirror to produce a sharp image on the screen. The location of the screen will be the exact focal point of the mirror, and measuring the distance between the mirror and the screen will yield the determined focal length of the mirror.

NOTE: It is important that the students select a very distant object to find the focal length of their mirrors. Selecting a nearby tree rather than some other more distant object could yield a focal length of considerable error.

General Information on the Activities

1. For all three activities, adequate background information is provided for the students in the Background section of the Student Guide. Much of the provided information should be covered during class, prior to the commencement of the activity. The provided information would then serve as a good review for the students.

2. Questions are provided in all three activities to assist students in summarizing the activities.

3. All the lenses and mirrors in the Foundations of Physics Optics Bench Kit are packaged in a plastic bag that is labeled with the focal length of the lens or mirror. Note that the actual focal length may differ from that on the label.

ACTIVITY EXTENSIONS

There are two activity extensions included in the Foundations of Physics Optics Bench Kit. Adequate background information is provided for the students in each extension. However, it is beneficial to expose students to the equations prior to the commencement of the extension activities. Students should have already had experience practicing using the equations. Assessment Questions for the students are included in each extension.

The following is a summary of the provided information for the Extension activities:

Thin Lens/Mirror Equation:

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

where
f = focal length
d_o = distance between object and lens/mirror
d_i = distance between image and lens/mirror

Magnification Equation:

$$m = \frac{\text{image size}}{\text{object size}} = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

where
m = magnification
h_o = height or size of the object
h_i = height or size of the image
d_o = distance between object and lens/mirror
d_i = distance between image and lens/mirror

Percent Error Equation:

$$\%\ \text{error} = \frac{|\text{accepted} - \text{experimental}|}{\text{accepted}} \text{ X } 100\%$$

Explanation for the numerical signs:

- For all real images, d_i is a positive (+) value; for a virtual image, d_i is negative ($-d_i$).
- h_i = positive (+) for a virtual image; $-h_i$ means the image is inverted, thus, a real image.
- Focal length: Convex lens/mirror = + f; Concave lens/mirror = -f
- For all real images, magnification has a negative sign (-m);
  for virtual images, magnification is positive (+m).
- A magnification value of >1 means that the image is larger than the object;
  values of m that are < 1 means that the image is smaller than the object.

Extension to Activity 1. Converging Lenses

In this extension, the students will use the *thin lens equation* and the *magnification equation* to mathematically determine the focal length and the magnification of their convex lens. The information contained in **Data Table 1B** of Activity 1 will be used to determine these values.

Extension to Activity 3. Spherical Mirrors

In this extension, the students will use the *mirror equation* and the *magnification equation* to mathematically determine the focal length and the magnification of their concave mirrors. The information contained in **Data Table 3B** of Activity 3 will be used to determine these values.

ADDITIONAL ACTIVITIES

A. Polarization - A-Level

Materials Needed:

2 Polarizers
Optics Bench
White Screen
Light Source

Light waves that vibrate in only one plane are said to be polarized. Included in the Foundations of Physics Optics Bench Kit are two mounted polarizing filters which can be rotated. When light passes through one of the polarizers, all planes of vibration except one, are knocked out. This will affect the intensity of the light. Either a demonstration or a student investigation of polarization can be performed on the optics bench.

1. Set up the light source at one end of the optics bench and the white screen at the other end.

2. Place one of the polarizing filters between the light and the screen. Place a convex (converging) lens in front of, and very close to, the polarizer. The lens should be between the light and the polarizer. Adjust all components so that there is a circular spotlight projected on the screen.

3. Remove the polarizer and examine the intensity of the spotlight on the screen. Now, replace the polarizer and ensure students have observed the change in the light's intensity.

4. Add the second polarizer on the screen side of the optics bench, near the first. This second polarizer can change the polarization direction of the light, and is known as the ***analyzer***. Note the change in intensity of the spotlight on the screen.

5. Rotate the analyzer and call attention to how this affects the intensity of the light.

6. Rotate the analyzer until maximum brightness is achieved. Using masking tape, a marker, or cellophane tape, put a mark on the rotating rim of the analyzer at the zero mark on the degree scale.

7. Now, rotate the analyzer until there is ***no light*** on the screen. At this position, the polarization directions of the polarizer and the analyzer are at **90°** to one another.

B. More with Polarization

Materials Needed:

Two Polarizing Filters
Cellophane tape
Light source

1. Set up the light source at one end of the optics bench and the white screen at the other end.

2. Place one of the polarizing filters between the light and the screen. Place a convex (converging) lens in front of, and very close to, the polarizer. The lens should be between the light and the polarizer. Adjust all components so that there is a circular spotlight projected on the screen.

3. Put strips of clear cellophane tape (wide cellophane packing tape works well) over the rim of the polarizer and place it on the optics bench. *Be careful not to stick the tape to the polarizing material.*

4. Place the analyzer on the bench so that the cellophane tape is *between* the polarizer and analyzer. Rotate the analyzer and note the different changing colors on the screen.

5. Add more layers of clear cellophane tape to the polarizer. Rotate the analyzer and note how the intensity of the colors has changed.

C. Color Filter Activity - KS4

Materials Needed:

Objects of various colors
Colored Filter
Light source

1. Set up the light source at one end of the optics bench with a colored filter in front of the lens.

2. Place objects in the light that differ in color from the filter top. Demonstrate how the color of the light affects the color we see on the object.

D. Double Slit Experiment - A-Level

Materials Needed:

Double slit slide
Laser pointer

1. Set up the double slit slide on a holder.

2. Project a laser pointer on the wall and note the size and shape of the pattern it creates.

3. Aim the laser pointer through the center of the double slit slide so its pattern appears on the wall.

4. Note the size and shape of the pattern it creates. Ask students why this pattern appears.

5. Move the set-up away from the wall and make note of any changes in the pattern.

TEACHER ANSWER GUIDE

The following answers are based on actual trials using the Foundations of Physics Optics Bench. These are not the only possible answers.

ACTIVITY 1: CONVERGING LENSES

The procedure for this part of the activity is explained to the students on pages S1 - S5 of the Student Guide. Sample data is provided below for answers to questions in the Student Guide.

Data Table 1A: Characteristics of Images

Determined Focal Length of Convex Lens = *17.2 cm*

Position of Object From Lens (in terms of F)	Position of Image From Lens (in terms of F)	Type of Image: Real or Virtual	Relative Size of Image Compared to Object:Larger or Smaller	Orientation of Image: Upright or Inverted
Beyond 2F	*Between 2F and F*	*Real*	*Smaller*	*Inverted*
At 2F	*About 2F*	*Real*	*About the same*	*Inverted*
Between 2F and F	*Beyond 2F*	*Real*	*Larger*	*Inverted*
At F	*No sharp image is obtainable*	*Fuzzy real*	*Fuzzy larger*	*Inverted*
Less than f	*On the same side as the object*	*Virtual*	*Larger*	*Upright*

Data Table 1B: Converging Lens Measurements

Determined Focal Length of Convex Lens = *17.2 cm*

Position of Object on Optics Bench Centimeter Scale (cm)	Position of Lens on Optics Bench Centimeter Scale (cm)	Position of Image on Optics Bench Centimeter Scale (cm)	Distance Between Object and Lens d_O (cm)	Distance Between Image and Lens d_i (cm)	Height (Size) of Object h_O (cm)	Height (Size) of Image h_i (cm)
(beyond 2F) 10.0 cm	*50.0*	*81.0*	*40.0*	*31.0*	*1.1*	*0.9*
(at 2F) 10.0 cm	*44.4*	*79.6*	*34.4*	*35.2*	*1.1*	*1.1*
(between F & 2F) 10.0 cm	*35.0*	*93.0*	*25.0*	*58.0*	*1.1*	*2.5*
(at F) 10.0 cm	*27.2*	*No clear image*	*17.2*	_______	*1.1*	_______
(less than f) 10.0 cm	*22.0*	*No clear image*	*12.0*	_______	*1.1*	_______

Questions:

1. When does a converging lens produce a virtual image?
   A virtual image is produced by a convex lens when the object's distance from the lens is less than the focal length of the lens.

2. List a practical use of a converging lens for:
   (a) Virtual image formation. *Magnifying glass, reading glasses*
   (b) Real image formation. *Movie projector*

3. Were you able to get a focused image when the object was placed exactly on the focal point? Explain.
   No focused image is possible because the light rays coming from the object and passing through the lens are refracted parallel to one another and can never converge to form a focused image.

4. When determining the focal length of the convex lens, suppose the distant object you selected was a nearby tree as opposed to a very far away building. How would this affect the determined focal length of the convex lens? Explain in some detail.
   In order for light rays to converge at the exact focal point of the lens they must enter the lens parallel to the principal axis. Only rays originating at "infinity" or very far away will do this. If a nearby object is selected, the rays coming in from that object will not be exactly parallel to the principal axis. This will cause the refracted rays to form a focused image beyond the focal point, somewhere between F and 2F. Thus, the determined focal length would be longer than the actual focal length.

5. Examine the qualitative results of the first four trials found on **Data Table 1A**. Describe the pattern for the location of the image as the object gets closer to the lens.
   As the object gets closer to the lens, the image moves farther away from the lens.

6. Examine the qualitative results of all trials found on **Data Table 1A**. Describe the pattern for the size of the image as the object gets closer to the lens.
   As the object gets closer to the lens the image gets larger.

7. When the object is placed exactly at 2F (twice the focal length from the lens), what do you notice about the location of the image and the size of the image?
   When the object is placed exactly at 2F, the image is also at distance 2F on the other side of the lens. The size of the object and the image are the same.

Extension for Activity 1: Converging Lenses

A. Calculate the Focal Length of the Convex Lens

1. Using the information on **Data Table 1B**, calculate the focal length of the convex lens for the first three trials when the distance between the object plate and the lens is:

Beyond **2F**

$$\frac{1}{f} = \frac{1}{40.0\text{cm}} + \frac{1}{31.0\text{cm}}$$

$$\frac{1}{f} = 0.0250\ \text{cm}^{-1} + 0.0323\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0573\ \text{cm}^{-1}$$

f = 17.5 cm

At **2F**

$$\frac{1}{f} = \frac{1}{34.4\text{cm}} + \frac{1}{35.2\text{cm}}$$

$$\frac{1}{f} = 0.0291\ \text{cm}^{-1} + 0.0284\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0575\ \text{cm}^{-1}$$

f = 17.4 cm

Between **F** and **2F**

$$\frac{1}{f} = \frac{1}{25.0\text{cm}} + \frac{1}{58.0\text{cm}}$$

$$\frac{1}{f} = 0.040\ \text{cm}^{-1} + 0.0172\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0572\ \text{cm}^{-1}$$

f = 17.5 cm

2. Compare the focal length determined in Part A of Activity 1 to the three focal lengths calculated by the above formula. Compute the average focal length for your lens using the three values obtained with the thin lens equation.
Average focal length = 17.5 cm
3. Using the focal length obtained in Part A of Activity 1 as the accepted value and the average focal length obtained using the thin lens equation as the experimental value, calculate the percent error for the calculated focal length.

$$\%\ \text{error} = \frac{|17.2\ \text{cm} - 17.5\ \text{cm}|}{17.2\ \text{cm}} \times 100\%$$

% error = 1.7 %

B. Calculate the Magnification of the Convex Lens

1. Using the information on your **Data Table 1B**, calculate the different magnifications of your convex lens for the first three trials when the distance between the object plate and the lens is:

Beyond **2F**

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

$$m = \frac{h_i}{h_o} = \frac{-0.9\ \text{cm}}{1.1\ \text{cm}} = -0.82$$

$$m = -\frac{d_i}{d_o} = -\frac{31.0\ \text{cm}}{40.0\ \text{cm}} = -0.78$$

At **2F**

$$m = \frac{h_i}{h_o} = \frac{-1.1\,\text{cm}}{1.1\,\text{cm}} = -1.0$$

$$m = -\frac{d_i}{d_o} = -\frac{35.2\,\text{cm}}{34.4\,\text{cm}} = -1.0$$

Between **F** and **2F**

$$m = \frac{h_i}{h_o} = \frac{-2.5\,\text{cm}}{1.1\,\text{cm}} = -2.3$$

$$m = -\frac{d_i}{d_o} = -\frac{58.0\,\text{cm}}{25.0\,\text{cm}} = -2.3$$

2. Compare the magnification values obtained by the height ratio to those obtained by the distance ratio for each trial. How similar are the two values for any given trial?
   For any given trial, the magnification value obtained from the height ratio is exactly the same or very close to the value from the distance ratio.

3. Do the magnification values, including the numerical signs, for your different trials support your observed qualitative results that are found in your **Data Table 1A**? Discuss
   The calculated magnification values all have a negative sign, which means the image is real. This is supported by ***Data Table 1A****. When m >1, the image is larger than the object. If m <1, the image is smaller than the object. When m=1, the object and image are the same size. The calculated values are all supported by* ***Data Table 1A****.*

ACTIVITY 2 - DIVERGING LENSES

Data Table 2: Observations of a Diverging Lens

TRIAL	Position of Diverging Lens on Optics Bench (cm)	Position of Image I_1 on Optics Bench (cm)	Position of Image I_2 on Optics Bench (cm)	Distance Between Object I_1 and Lens d_o (cm)	Distance Between Image I_2 and Lens d_i (cm)	Focal Length of Concave Lens f (cm)
1	*69.2*	*79.5*	*100.0*	*– 10.3*	*30.8*	*–15.5*
2	*75.5*	*83.0*	*89.3*	*–7.5*	*13.8*	*–16.5*
3	*83.0*	*89.5*	*94.0*	*–6.5*	*11.0*	*–15.8*

Average Focal Length of Diverging Concave Lens *-15.9 cm*

Calculations
Knowing the distances d_o and d_i, calculate the focal length (f) of the concave diverging lens for all three trials using the thin lens equation. Record this in the data table with the proper ± sign.

Trial 1

$$\frac{1}{f} = \frac{1}{-10.3\,\text{cm}} + \frac{1}{30.8\,\text{cm}} = -0.0971\,\text{cm}^{-1} + 0.0325\,\text{cm}^{-1}$$

$$\frac{1}{f} = -0.0646\,\text{cm}^{-1}$$

f = – 15.5 cm

Trial 2

$$\frac{1}{f} = \frac{1}{-\,7.5\text{cm}} + \frac{1}{13.8\text{cm}} \quad = \quad -\,0.133\ \text{cm}^{-1} \quad + \quad 0.0725\ \text{cm}^{-1}$$

$$\frac{1}{f} = \ -\,0.0605\ \text{cm}^{-1}$$

$f = -16.5$ *cm*

Trial 3

$$\frac{1}{f} = \frac{1}{-\,6.5\text{cm}} + \frac{1}{11.0\text{cm}} \quad = \quad -\,0.154\ \text{cm}^{-1} \quad + \quad 0.0909\ \text{cm}^{-1}$$

$$\frac{1}{f} = \ -\,0.0631\ \text{cm}^{-1}$$

$f = -15.8$ *cm*

Questions:

1. Compare and explain the two images observed when looking, at arm's length, through the convex lens and the concave lens. Why are the images so different?
   The image observed through the convex lens is a real image and is inverted. The image observed through the concave lens is an upright virtual image in which the objects appear to be much farther away than they are in actuality. The differences between these images can be explained by the fact that convex lenses converge light and concave lenses diverge light. The diverged light rays that enter our eyes make it appear that the objects are much farther away.

2. Explain why the location of the focused image from the converging convex lens is moved back farther from the lens when a diverging concave lens is placed between the convex lens and the original location of the image.
   The concave lens diverges the light rays, thereby changing the original angle of convergence by the convex lens. This causes the rays to converge at a different point farther away from the lens.
3. Which quantity was assigned a negative value in this activity? Explain.
   The distance between the virtual image and the concave lens, d_o, *has a negative value because it lies to the right of the lens, i.e., it lies between the lens and the screen. Real images always lie to the left of the lens so that the lens is between it and the screen. For real images,* d_o *is positive. For virtual images,* d_o *is negative. (Remember, we always assume that light rays are traveling from left to right.)*

ACTIVITY 3 – SPHERICAL MIRRORS

Data Table 3A: Characteristics of Images

Determined Focal Length of the Concave Mirror = *26.5 cm*

Position of Object From Mirror (in terms of F&C)	Position of Image From Mirror (in terms of F&C)	Type of Image: (Real or Virtual)	Relative Size of Image Compared to Object: (Larger or Smaller)	Orientation of Image: (Upright or Inverted)
Beyond C	*Between F & C*	*Real*	*Smaller*	*Inverted*
At C (2F)	*At C*	*Real*	*Same size*	*Inverted*
Between C and F	*Beyond C*	*Real*	*Larger*	*Inverted*
At F	*No clear image*	*Fuzzy real*	*Fuzzy larger*	*Inverted*
Less than f	*No image*	*No image*	*No image*	*No image*

Data Table 3B: Concave Mirror Measurements				
Determined Focal Length of Concave Mirror = *26.5 cm*				
Position of Object From Mirror (in terms of F&C)	Distance Between Object and Mirror d_O (cm)	Distance Between Image and Mirror d_i (cm)	Height (Size) of Object h_O (cm)	Height (Size) of Image h_i (cm)
Beyond C	*73*	*42*	*1.1*	*0.6*
At C (2F)	*53*	*53*	*1.1*	*1.1*
Between C and F	*40*	*78*	*1.1*	*2.1*
At F	*26.5*	*No image*	*1.1*	*No image*
Less than f	*19*	*No image*	*1.1*	*No image*

Questions

1. When the object plate "1" and the concave mirror were separated by the focal length of the mirror, were you able to get a focused image on the screen? Explain in some detail.
An image can be seen but it cannot be focused. It is a fuzzy, real image and larger than the object.

2. When the convex mirror was used on the optics bench, describe the type of image that was seen looking into the mirror. Refer to **Part B**: Procedure step 2.
The image was a virtual image with a wide, but distorted, field of view. In order for light rays to converge at the exact focal point of the lens, they must enter the lens parallel to the principal axis. Only rays originating at "infinity" or very far away will do this. If a nearby object was selected, the rays coming in from that object would not be exactly parallel to the principal axis. This would cause the refracted rays to form a focused image beyond the focal point, somewhere between F and 2F. Thus, the determined focal length would be longer than the actual focal length.

3. As the convex mirror was moved closer to the object plate, as described in **Part B** Procedure step 3, what changes in the image were observed?
The image became larger as the mirror neared the object plate, but it was always smaller than the object.

4. When determining the focal length of the concave mirror, suppose the distant object you selected was a nearby tree as opposed to a very far away building. How would this affect the determined focal length of the concave mirror? Explain in some detail.
In order for light rays to converge at the exact focal point of the mirror, they must strike the mirror parallel to the principal axis. Only rays originating at "infinity" or very far away will do this. If a nearby object is selected, the rays coming in from that object will not be exactly parallel to the principal axis. This will cause the reflected rays to form a focused image beyond the focal point, somewhere between F and 2F. Thus, the determined focal length would be longer than the actual focal length.

5. Convex mirrors are often used as security mirrors in stores and side-view mirrors on vehicles. Based on the characteristics of the images in convex mirrors, what are some advantages, and some disadvantages in using these mirrors for these purposes?
An advantage is that the convex mirror provides an upright virtual image with a wide field of view. The disadvantage is that the image is distorted, with objects appearing farther away than in reality.

Extension to Activity 3

Part A. Calculate the Focal Length of the Concave Mirror:

1. Using the information on **Data Table 3B**, calculate the focal length of the concave mirror for the first three trials when the distance between the object plate and the mirror is:

Beyond **C**

$$\frac{1}{f} = \frac{1}{73\text{cm}} + \frac{1}{42\text{cm}}$$

$$\frac{1}{f} = 0.0137\ \text{cm}^{-1} + 0.0238\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0375\ \text{cm}^{-1}$$

f = 26.7 cm

At **C**

$$\frac{1}{f} = \frac{1}{53\text{cm}} + \frac{1}{53\text{cm}}$$

$$\frac{1}{f} = 0.0189\ \text{cm}^{-1} + 0.0189\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0378\ \text{cm}^{-1}$$

f = 26.5 cm

Between **C** and **F**

$$\frac{1}{f} = \frac{1}{40\text{cm}} + \frac{1}{78\text{cm}}$$

$$\frac{1}{f} = 0.0250\ \text{cm}^{-1} + 0.0128\ \text{cm}^{-1}$$

$$\frac{1}{f} = 0.0378\ \text{cm}^{-1}$$

f = 26.5 cm

2. Compare the focal length determined in Activity 3 Part A step #4 to the three focal lengths calculated by the above formula. Compute the average focal length for your mirror, using the three values obtained with the mirror equation.
   Average focal length = 26.6 cm
3. Using the determined focal length obtained in Activity 3 Part A step #4 as the accepted value, and the average focal length obtained using the mirror equation as the experimental value (from #2 above), calculate the percent error for the calculated focal length.

$$\%\ \text{error} = \frac{|26.5\ \text{cm} - 26.6\ \text{cm}|}{26.5\ \text{cm}} \text{X } 100\%$$

% error = 0.38 %

Part B. Calculate the Magnification of the Concave Mirror:

1. Using the information on your **Data Table 3B**, calculate the different magnifications of the concave mirror for the first three trials when the distance between the object plate and the mirror is:

Beyond **C**

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

$$m = \frac{h_i}{h_o} = \frac{-0.6\text{ cm}}{1.1\text{ cm}} = -0.55$$

$$m = -\frac{d_i}{d_o} = -\frac{42\text{ cm}}{73\text{ cm}} = -0.58$$

At **C**

$$m = \frac{h_i}{h_o} = \frac{-1.1\text{ cm}}{1.1\text{ cm}} = -1.0$$

$$m = -\frac{d_i}{d_o} = -\frac{53\text{ cm}}{53\text{ cm}} = -1.0$$

Between **C** and **F**

$$m = \frac{h_i}{h_o} = \frac{-2.1\text{ cm}}{1.1\text{ cm}} = -1.9$$

$$m = -\frac{d_i}{d_o} = -\frac{78\text{ cm}}{40\text{ cm}} = -2.0$$

2. Compare the magnification values obtained by the height ratio to those obtained by the distance ratio for each trial. How similar are the two values for any given trial?
For any given trial, the magnification value obtained from the height ratio is exactly the same or very close to the value from the distance ratio.

3. Do the magnification values, including the numerical signs, for your different trials support your observed qualitative results that are found in your **Data Table 3A**? Discuss in some detail.
The calculated magnification values all have a negative sign which means the image is real. This is supported by ***Data Table 3A****. When m >1, the image is larger than the object. If m <1, the image is smaller than the object. When m = 1, the object and image are the same size. The calculated values are all supported by* ***Data Table 3A****.*

Optics Bench STUDENT GUIDE

BACKGROUND

Convex Lenses

A convex or converging lens is thicker in the middle of the lens than at the edges. The principal axis of symmetry of the lens is an imaginary line which is normal, i.e., perpendicular, to the center of the surface of the lens. On the principal axis at some distance from the lens is the focal point (F) of the lens. Light rays which strike and pass through the lens parallel to the principal axis converge at this point. The exact location of this focal point depends both on the shape of the lens and the index of refraction of the medium of which the lens is made. The distance between the optical center of the lens (C) and the focal point (F) is called the focal length (f) of the lens. Twice the focal length from the lens is an important position called 2F. It is the one point where the object height and image height are equal. If the lens is symmetrical, the focal point F, and the point 2F are located the same distance to the left of the lens as the corresponding points are located to the right. See **Figure A**.

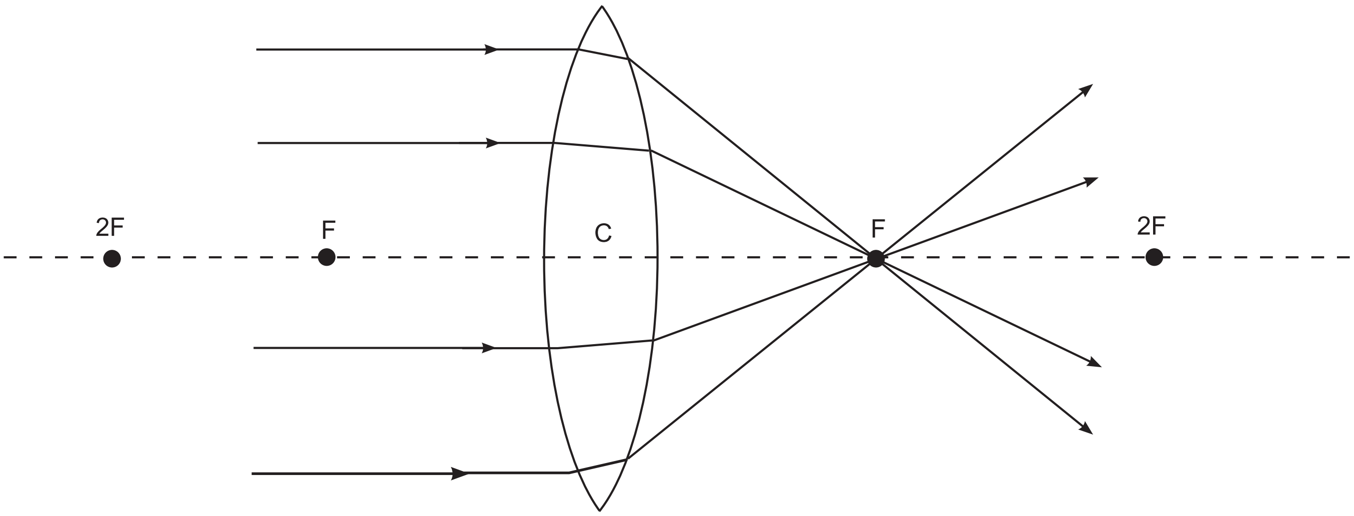

Figure A

There are two types of images, real images and virtual images. A real image forms when rays of light, which emanate from a point on an illuminated object, pass through a convex lens and converge at a point on the other side of the lens forming an image of that object point. The collective image points make up the real image. The image is called “real” because it can be projected onto a screen and, thus, really does exist. All real images are inverted.

If a converging lens is located from an object a distance less than the lens’s focal length, the refracted rays from the object do not converge and no real image is formed. Instead, the view through the lens renders a virtual image that appears in front of the lens. Even though the virtual image can be seen by the eye, it cannot be projected onto a screen, thus, it is not a real image. All virtual images are upright or erect.

Concave Lenses

A concave or diverging lens is thinner in the middle of the lens than at the edges. The principal axis of symmetry of the lens is an imaginary line which is normal to the center of the surface of the lens. Light rays traveling from left to right which strike and pass through the lens parallel to the principal axis will diverge and, thus, never come to a focus on the other side (right side) of the lens.

If the diverging light rays, however, which were parallel to the principal axis before entering the lens, are traced backwards through the lens as straight lines, they will appear to originate from a single point at the principal axis on the left side of the lens. This point is the focal point of the diverging lens. The distance between the optical center (C) of the lens, and the focal point (F) is called the focal length (-f) of the lens. Because the focal point lies on the left side of the lens, the same side as the incident rays, the focal length has a negative sign. All concave lenses have a negative focal length. See **Figure B**.

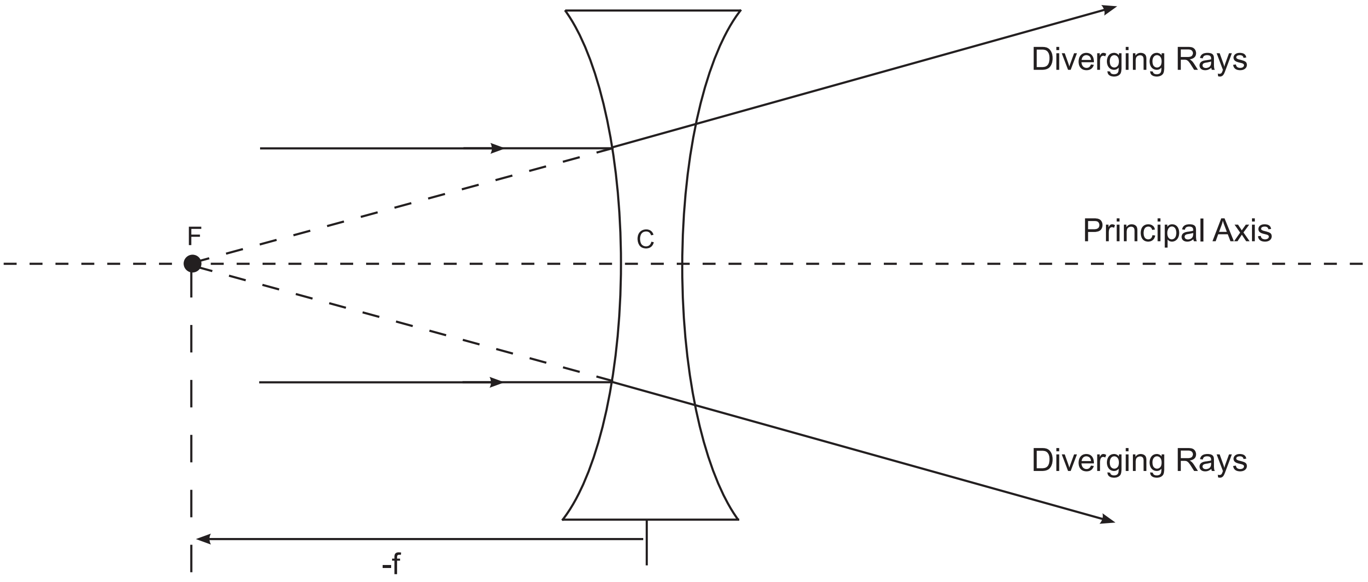

Figure B

There are two types of images, real images and virtual images. Since a concave lens can only diverge rays of light, it can never form a real image, which forms when rays of light converge.

Thin Lens Equation:

The relationship between the object distance from a lens (d_o), the image distance from the lens (d_i), and the focal length of the lens (f), is given by the Thin Lens Equation:

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

The object and image distances are measured from the optical center of the lens. Typically when drawing a lens diagram, the incident light rays travel from left to right. Numerical signs are used to distinguish when objects and images are on the left side or the right side of the lens. The following are the rules for assigning the numerical signs:

Object Distance
- d_o = positive (+) if object is to the left of the lens (real object)
- d_o = negative ($-d_o$) if the object is to the right of the lens (virtual object)

Image Distance
- d_i = positive (+) for a real image formed to the right of the lens
- d_i = negative ($-d_i$) for a virtual image formed to the left of the lens

Focal Length
- f = positive (+) for a converging convex lens (focal point on the right side of the lens)
- f = negative (-f) for a diverging concave lens (focal point on the left side of the lens)

Finding the Focal Length of a Diverging (Concave) Lens:

To find the focal length of a diverging lens it will be necessary to place a convex lens in front of the concave lens to converge the light rays before they enter the diverging lens. See **Figure C**.

If the converging (convex) lens would form a real image at I_1, the placement of a diverging lens between that image location and the convex lens will cause the image to be formed farther back at I_2. Using the distance between the diverging (concave) lens and position I_1 as the object distance, d_o (virtual object), and the distance between the diverging (concave) lens and position I_2 as the image distance, d_i (real image), the focal length (f) of the diverging lens can be calculated using the thin lens equation.

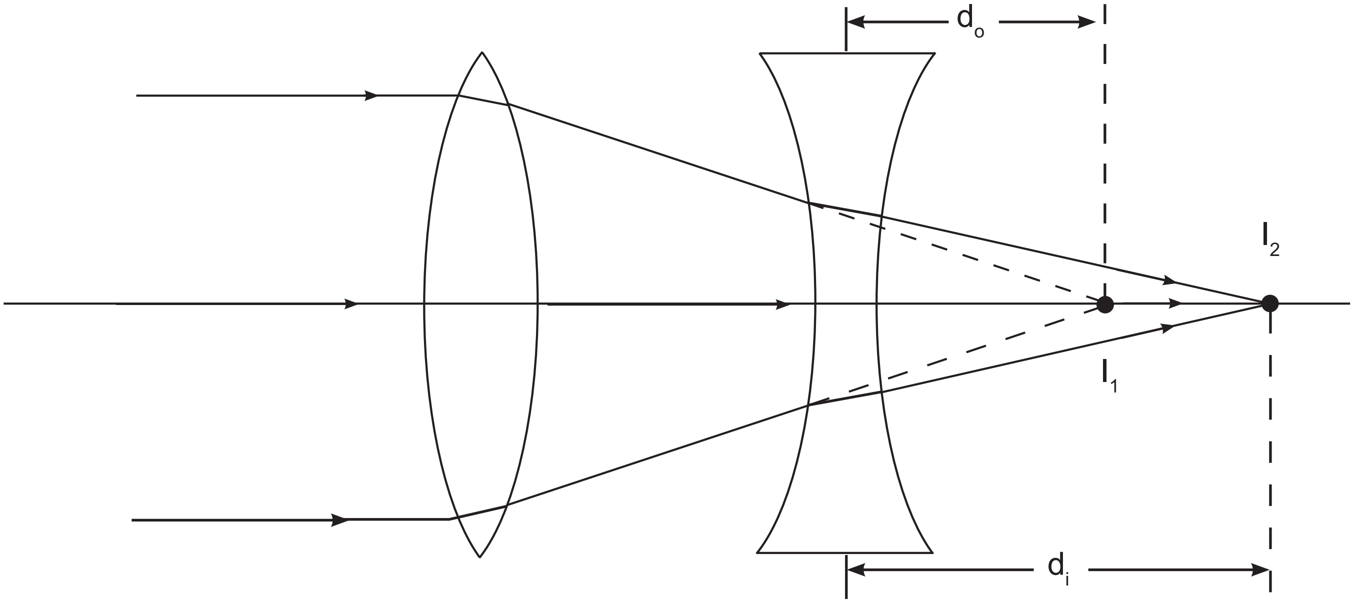

Figure C

ACTIVITY 1 CONVERGING LENSES

Objectives:

- To observe the optical properties of a convex lens.
- To study the types of images produced by a convex lens.

Materials Needed:

Optics bench
2 Double convex lenses
White screen
Light source
Holders for lens and screen
Object plate stencil cut “1”
Meter stick or centimeter ruler

Procedure:

Part A: Focal Length of Lens

1. Place one of the convex lenses into one of the lens holders provided in the Optics Bench Kit. Be certain to lock the lens into the holder using the plastic ring so that the lens does not slip out of the holder. You will now experimentally determine the focal length of that lens.
2. Place the white screen on the 50-cm mark of the optics bench and place the lens at some position between the screen and an outside window. Working in a semi-dark room (best if the room lights are off), select a distant object* outside the window and focus the image of the distant object on the screen by moving the lens until the image is clear and sharp. Be certain that the screen is perfectly perpendicular to the optics bench with the entire image in focus.

   ***The distant object you select, should be as far away as visually possible, so that the light rays reflecting off that object are arriving parallel to the principal axis of the lens. Only rays parallel to the principal axis will refract and converge at the focal point of the lens.*
3. Since the image on the screen comes from a very distant object outside the window, you may assume all the light rays from the object come into the lens parallel to each other. Because the rays come to a focus on the screen, the screen must now be at the focal point of the lens. Measure the distance from the lens to the screen to the nearest 0.1 centimeter. This is the determined focal length of the lens. Record it in **Data Table 1A**.

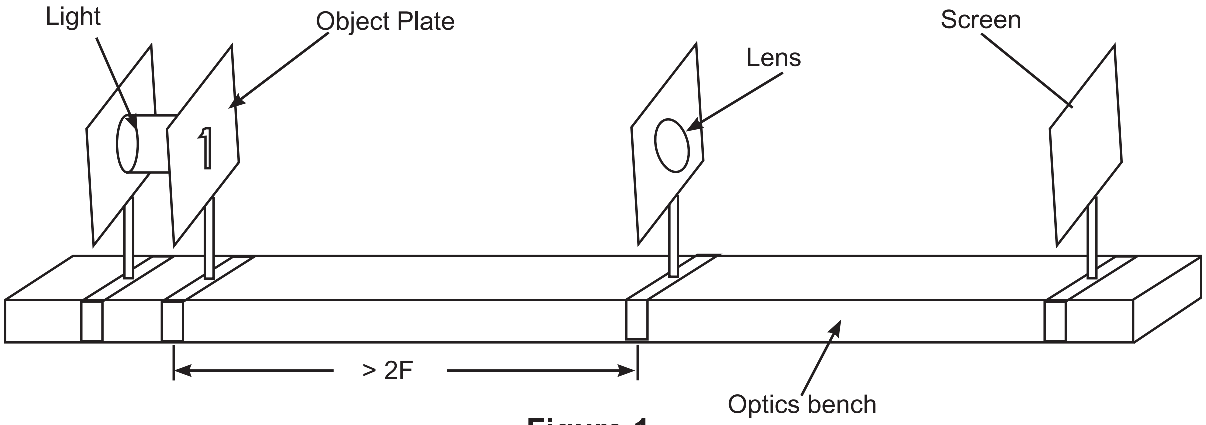

Figure 1

Part B: Real Images

1. Darken the room. Place the light source at one end of the optics bench and place the white screen at the opposite end of the optics bench. Put the object plate, the black plastic plate with a “1” stencil cut, into the plastic plate holder. Place this “object” directly in front of the light source on the optics bench so that it actually touches the front edge of the light source.

   WARNING: The light source can get extremely hot during use. Exercise caution and avoid getting burned.

2. Place one double convex lens on the optics bench far enough from the object plate “1” so that it will be at a distance greater than twice the focal length of the lens, i.e., the lens should be between the screen and the object plate/light source at some distance beyond 2F of the object plate “1” location. See **Figure 1**. Record this position as “>2F” in **Data Table 1A** under the heading “Position of Object from Lens”.
3. Move the screen along the optics bench until the image of the “1” is focused as sharply as possible on the screen. Study the image and record your observations for the location of the image in terms of F (focal point), i.e., image is at F, between F and 2F, or beyond 2F, in **Data Table 1A**.
4. In the same table, record the type of image (real or virtual), the relative size of the image compared to the object (larger or smaller), and whether the image is upright or inverted.

5 Note the positions of the object (plate), lens, and image (screen) on the optics bench centimeter scale and record these positions in **Data Table 1B**. Using the centimeter scale on the optics bench, measure the distance, to the nearest 0.1 centimeter, between the object plate and the lens. Record in **Data Table 1B** as d_o (distance of object).

6. Now measure the distance between the image (screen) and the lens. Record under d_i (distance of image).
7. Measure the size (height) of the object (the stencil cut “1”) and record under h_o in **Data Table 1B**. Measure, too, the height of the image on the screen and record in the data table as h_i. All measurements should be to the nearest 0.1 centimeter.
8. Now, move the lens closer to the light source/object plate so that they are separated exactly by distance 2F. Record this position as “2F” in **Data Table 1A** under the heading “Position of Object from Lens”. Focus the image of the object on the screen on the other side of the lens. As before, record the qualitative characteristics of the image in **Data Table 1A** and the quantitative measurements in **Data Table 1B**.
9. Position the lens closer to the light source/object plate so that they are now separated by a distance about the midpoint between F and 2F. Record this position as “Between F and 2F” in **Data Table 1A** under the heading “Position of Object from Lens”. Focus the image on the screen and record all observations as previously done, in **Data Tables 1A** and **1B**.
10. Move the lens closer to the object plate so that they are separated by the focal length f. The object is now exactly at the focal point F. Record this position as “F” in **Data Table 1A** under the heading “Position of Object from Lens”. Try to get a sharp focused image and record all observations as previously done, in **Data Tables 1A** and **1B**.

Part C. Virtual Images

1. Place the lens closer to the light source/object plate so that the distance separating them is *less* than f (the focal length of the lens). Record this position as "less than f" in **Data Table 1A**. Try to get an image on the screen.
2. Now remove the screen and, placing your eye close to the lens, look through the lens at the object stencil plate "1". The image of the "1" appears *on the same side of the lens* as the object but is quite different from the previously observed images. Study the image produced and record your qualitative observations in **Data Table 1A.** Since there is no real image, the image distance can not be measured or recorded.

Data Table 1A: Characteristics of Images

Determined Focal Length of Convex Lens = ______cm

Position of Object From Lens (in terms of F)	Position of Image From Lens (in terms of F)	Type of Image: Real or Virtual	Relative Size of Image Compared to Object:Larger or Smaller	Orientation of Image: Upright or Inverted

Data Table 1B: Converging Lens Measurements

Determined Focal Length of Convex Lens = _______ cm

Position of Object on Optics Bench Centimeter Scale (cm)	Position of Lens on Optics Bench Centimeter Scale (cm)	Position of Image on Optics Bench Centimeter Scale (cm)	Distance Between Object and Lens d_o (cm)	Distance Between Image and Lens d_i (cm)	Height (Size) of Object h_o (cm)	Height (Size) of Image h_i (cm)

Questions:

1. When does a converging lens produce a virtual image?

2. List a practical use of a converging lens for:

   (a) Virtual image formation.

   (b) Real image formation

3. Were you able to get a focused image when the object was placed exactly on the focal point? Explain.

4. When determining the focal length of the convex lens, suppose the distant object you selected was a nearby tree as opposed to a very far away building. How would this affect the determined focal length of the convex lens? Explain in some detail.

5. Examine the qualitative results of the first four trials found on **Data Table 1A**. Describe the pattern for the location of the image as the object gets closer to the lens.

6. Examine the qualitative results of all trials found on **Data Table 1A**. Describe the pattern for the size of the image as the object gets closer to the lens.

7. When the object is placed exactly at 2F (twice the focal length from the lens), what do you notice about the location of the image and the size of the image?

Extension to Activity 1: Converging Lenses

The following activity is designed for the more advanced treatment of optics. All calculations should be titled and neatly displayed, with units, on a calculation sheet.

A. Calculate the Focal Length of the Convex Lens:

1. Using the information on your **Data Table 1B**, calculate the focal length of your convex lens for the first three trials when the distance between the object plate and the lens is:
   - Beyond 2F
   - At 2F
   - Between F and 2F

   The focal length can be calculated using the **Thin Lens Equation** from page S2.

2. Compare the focal length determined in Part A of the procedure to the three focal lengths calculated by the given formula. Compute the average focal length for your lens using the three values obtained with the thin lens equation.
3. Using the focal length obtained in Part A of Activity 1 as the accepted value, and the average focal length obtained using the thin lens equation as the experimental value (from #2 above), calculate the percent error for the calculated focal length. Percent error can be calculated using the following:

$$\%\text{ error} = \frac{|\text{accepted- experimental}|}{\text{accepted}} \text{ X } 100\%$$

B. Calculate the Magnification of the Convex Lens:

1. Using the information on your **Data Table 1B**, calculate the different magnifications of your convex lens for the first three trials when the distance between the object plate and the lens is:
   - Beyond 2F
   - At 2F
   - Between F and 2F

   The magnification can be calculated using the Magnification Equation:

$$m = \frac{\text{image size}}{\text{object size}} = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

where m = magnification
h_O = height or size of the object
h_i = height or size of the image
d_O = distance between object and lens
d_i = distance between image and lens

Explanation for the numerical signs:

For all real images, d_i is a positive (+) value; for a virtual image, d_i is negative ($-d_i$).

h_i = positive (+) for a virtual image; $-h_i$ means the image is inverted, thus, a real image.

Focal length: Convex lens = + f; Concave lens = -f

For all real images, magnification has a negative sign (-m); for virtual images, magnification is positive (+m).

A magnification value of >1 means that the image is larger than the object; values of m that are < 1 means that the image is smaller than the object.

2. Compare the magnification values obtained by the height ratio to those obtained by the distance ratio for each trial. How similar are the two values for any given trial?

3. Do the magnification values, including the numerical signs, for your different trials support your observed qualitative results that are found in **Data Table 1A**? Discuss in some detail.

ACTIVITY 2 DIVERGING LENSES

Objectives:

- To observe the optical properties of a diverging concave lens
- To measure the focal length of a concave lens

Materials Needed:

Optics bench
Double convex lens
Double concave lens
White screen
Light source
Holders for lenses and screen
Object plate stencil cut "1"
Meter stick or centimeter ruler

Procedure:

1. Hold each lens at arm's length and look through them separately. Note the types of images you see. Question #1 will deal with your observations.

   Select one of the double convex lenses and one of the double concave lenses and place each lens into one of the lens holders provided in the Optics Bench Kit. Be certain to lock the lenses into the holder using the plastic ring so that the lenses do not slip out of the holders.
2. Darken the room. Place the light source at one end of the optics bench and place the white screen at the opposite end of the optics bench. Put the object plate (black plastic plate with a "1" stencil cut) into the plastic plate holder. Place this "object" directly in front of the light source on the optics bench so that it actually touches the front edge of the light source. See **Figure 1** on page S4.

   WARNING: The light source can get extremely hot during use. Exercise caution to avoid getting burned.

3. Place the converging (convex) lens on the optics bench somewhere between the light source/object plate and the white screen. Adjust the positions of the lens and screen until a sharp focused image is formed on the screen. Depending on the distance between the lens and object plate, the size of the image on the screen may be smaller or larger than the object stencil cut “1”. You can decide which size of the image you prefer.
4. When the image is sharp, note the position of the image (screen) and record it in the **Data Table 2**. This is position I_1.
5. Now place the diverging (concave) lens between the converging (convex) lens and the screen. You will note that the image is no longer in focus. Move the screen until a sharp image is again formed. Record the position of the diverging lens. Also record the new position of the screen as Image I_2 in **Data Table 2.**

Note: it may be helpful to refer to **Figure C** on page S3

6. To determine the virtual object distance (d_o), measure the distance between the position of the original image at I_1 and the position of the concave diverging lens. Record to the nearest 0.1 centimeter in the **Data Table 2**. Be sure to use the correct + or – signs in your recorded data.
7. Now measure the distance between the image I_2 and the (concave) diverging lens. This distance is the real image distance d_i. Record in the **Data Table 2** to the nearest 0.1 centimeter. Be sure to use the correct + or – signs in your recorded data.
8. Repeat steps 3-7 for two more trials using the same two lenses. Each trial should have different values for the object and image distances, d_o and d_i. Record all values in the data table with the proper ± sign.

Calculations:

Knowing the distances d_o and d_i , calculate the focal length (f) of the concave diverging lens for all three trials using the thin lens equation. Record this in **Data Table 2** with the proper ± sign.

Using the data from all three trials, determine the average focal length of your concave diverging lens. Enter this at the bottom of **Data Table 2** with the proper ± sign.

Data Table 2: Observations of a Diverging Lens

TRIAL	Position of Diverging Lens on Optics Bench (cm)	Position of Image I_1 on Optics Bench (cm)	Position of Image I_2 on Optics Bench (cm)	Distance Between Object I_1 and Lens d_o (cm)	Distance Between Image I_2 and Lens d_i (cm)	Focal Length of Concave Lens f (cm)
1						
2						
3						

Average Focal Length of Diverging Concave Lens _______ cm

Questions:

1. Compare and explain the two images seen when looking, at arm's length, through the convex lens and the concave lens. Why are the images so different?

2. Explain why the location of the focused image from the converging convex lens is moved back farther from the lens when a diverging concave lens is placed between the convex lens and the original location of the image.

3. Which quantity was assigned a negative value in this activity? Explain.

ACTIVITY 3 SPHERICAL MIRRORS

Spherical Mirrors:

Imagine a perfect hollow, thin-walled sphere that has a reflective mirror coating on both the inside surface and the outside surface. If a circular segment of this hollow sphere were to be cut away, it would be called a spherical mirror. A spherical mirror is, thus, just a segment of a sphere. All spheres have a center; a line connecting that center to any point on the surface of the sphere is a radius of the sphere. For a spherical mirror, the center of the sphere, of which the mirror is a segment, is called the center of curvature of the mirror and is symbolized by C. The principal axis of the mirror is a line perpendicular, or normal, to the center of the mirror. The center of curvature must lie on the principal axis. The distance between the center of curvature and the surface of the mirror, as measured along the principal axis, would naturally equal the radius of the sphere of which the mirror is a segment.

Concave Spherical Mirrors:

A segment of the sphere in which the inside surface has the reflective coating is called a concave spherical mirror. Light rays that are incident on the mirror and parallel to the principal axis will reflect in such a way that they all converge to a single point on the principal axis. This point is called the principal focus or focal point of the mirror and is symbolized by F. The distance from the principal focus to the center of the mirror is the focal length, f, of the mirror. See **Figure 3A**.

A relationship exists between the focal length of the mirror and the radius of the sphere of which the mirror is a segment: The focal length is one-half of the radius. As a consequence of this relationship, as measured along the principal axis, the distance from the surface of the mirror to the center of curvature is twice as long as the focal length of the mirror, i.e., the center of curvature, C, lies at a point equal to 2F.

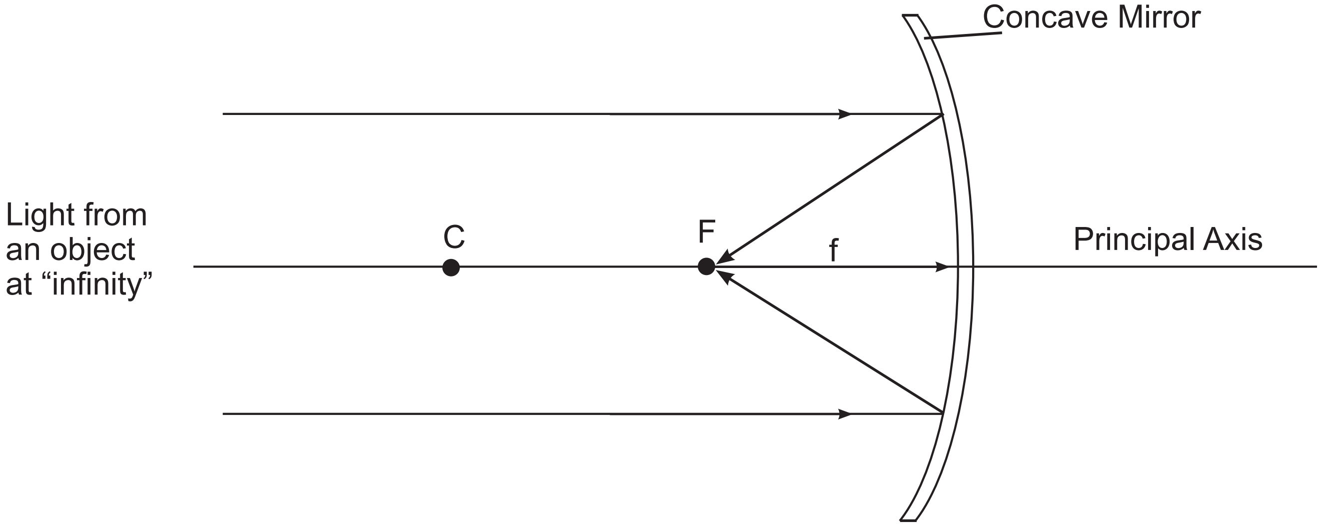

Figure 3A

Convex Spherical Mirrors:

A segment of the sphere in which the outside surface has the reflective coating is called a convex spherical mirror. Light rays which are incident on the mirror and parallel to the principal axis will reflect in such a way that they all diverge from the surface of the mirror. If the diverging rays are traced back behind the mirror, they would appear to meet at a single point on the principal axis on the opposite side of the mirror. This point is a virtual focal point of the mirror and is symbolized by -F. The negative sign indicates that it lies on the opposite side of the mirrored surface, i.e., behind the mirror. The distance between this virtual focal point and the center of the mirror is the same as the focal length of the concave backside of that mirror. The relationship between the center of curvature and the virtual focal point is the same as a concave mirror. See **Figure 3B**.

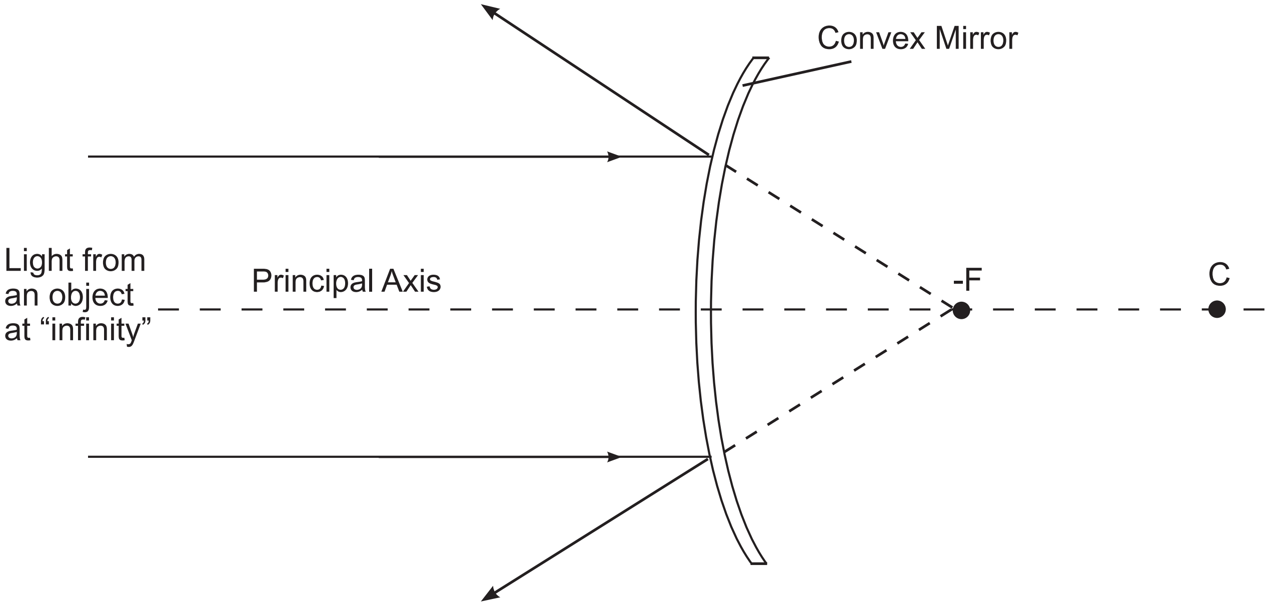

Figure 3B

Spherical Mirror Images:

Recall there are two types of images, real images and virtual images. A real image forms when rays of light converge and focus after reflecting off a concave mirror. Real images can be projected onto a screen and are always inverted. Depending on the location of the object, a concave mirror can also produce a virtual image.

Since a convex mirror can only diverge rays of light it can never form a real image. Instead, a virtual image can be seen by an eye that looks at the surface of the mirror. Even though the virtual image can be seen by the eye, it cannot be projected onto a screen, thus, it is not a real image. All virtual images are upright or erect. Convex mirrors can only produce virtual images.

Spherical Mirror Equation:

The relationship between the object distance from a mirror (d_o), the image distance from the mirror (d_i), and the focal length of the mirror (f), is given by the spherical mirror equation:

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

The object and image distances are measured from the center of the mirror. Typically when drawing a mirror diagram, the incident light rays travel from left to right. Numerical signs are used to distinguish when objects and images are on the left side or the right side of the mirror.

Rules for assigning the numerical signs:

Object Distance

- d_o is always positive (+) because the object must always be to the left of the mirror facing the reflective surface (real object)

Image Distance

- d_i = positive (+) for a real image formed to the left of the mirror
- $-d_i$ = negative ($-d_i$) for a virtual image formed to the right of the mirror (behind the mirror)

Focal Length

- f = positive (+) for a concave mirror (focal point on the left side of the mirror)
- -f = negative (- f) for a convex mirror (virtual focal point on the right side of the mirror)

Reflection Rules for Spherical Mirrors:

- Concave Mirror: Any light ray that passes through the center of curvature and strikes the mirror will reflect back through the center of curvature, i.e., the reflected ray will take the exact same path as the incident ray.

- Concave Mirror: Any incident light ray parallel to the principal axis will reflect off the mirror and pass through the focal point of the mirror.

- Concave Mirror: Any incident light ray that passes through the focal point F of the mirror will reflect off the mirror parallel to the principal axis

- Convex Mirror: Any incident light ray parallel to the principal axis will reflect off the mirror and diverge directly away from the virtual focal point behind the mirror.

Objectives:

- To examine the images formed by concave mirrors.
- To examine the images formed by convex mirrors.

Materials Needed:

Optics bench
Concave and convex spherical mirrors
White screen
Light source
Holders for mirrors and screen
Object plate stencil cut “1”
Meter stick or centimeter ruler

Procedure:

Part A: Concave Mirror

1. Select one of the concave mirrors and place it into one of the mirror holders provided in the Optics Bench Kit. Be certain to lock the mirror into the holder using the plastic ring so that the mirror does not slip out of the holder. You will now experimentally determine the focal length of the mirror.
2. Place the concave mirror on one end of the optics bench and orient the bench so that the mirror is facing an outside window. Place the white screen on the opposite end of the optics bench.
3. Working in a semi-dark room (best if the room lights are off), select a distant object***** outside the window and focus the image of the distant object on the screen by moving the mirror (or the screen) until the image on the screen is clear and sharp. Be certain that the screen is perfectly perpendicular to the optics bench with the entire image in focus.

   *****_The distant object you select should be as far away as possible so that the light rays reflecting off that object arrive parallel to the principal axis of the mirror. Only rays parallel to the principal axis will reflect and converge at the focal point (principal focus) of the mirror._
4. Since the image on the screen comes from a very distant object outside the window, you may assume all the light rays from the object that strike the mirror are parallel to each other. Because the rays come to a focus on the screen, the screen must now be at the focal point of the mirror. Measure the distance from the mirror to the screen to the nearest 0.1 centimeter. This is the determined focal length of the mirror. Record it in **Data Tables 3A** and **3B**
5. Place the light source at one end of the optics bench. Put the object plate into the plastic plate holder. The object plate is the black plastic plate with a “1” stencil cut. Place this “object” directly in front of the light source on the optics bench so that it actually touches the front edge of the light source. Now, place the concave mirror as far away as possible at the opposite end of the optics bench. This will ensure that the object is well beyond the center of curvature of the mirror.

   WARNING: The light source can get extremely hot during use. Exercise caution and avoid getting burned.

6. In order to get an image of the object “1” on the screen, light must travel from the source/object plate to the mirror, then reflect off the mirror onto the screen. If the screen is placed on the optics bench between the light source/object plate and the mirror, it will block the light from striking the mirror. A simple solution to surmount this problem is to place the screen very near the optics bench, but not on it. The screen should be just off to the side of the bench close enough to pick up the image but far enough to allow the light rays to strike the mirror. By slightly rotating the mirror on its mount, the image can be easily directed towards the screen.
7. Move the screen alongside the optics bench until the image of the “1” is focused as sharply as possible on the screen. Record the position of the image in terms of F (focal point) and C (center of curvature), i.e., image is at F, or between F and C, or beyond C, in **Data Table 3A**.
8. In the same table, record the type of image (real or virtual), the relative size of the image compared to the object (larger or smaller), and whether the image is upright or inverted.
9. Measure the distance, to the nearest 0.1 centimeter, between the object plate and the mirror. Record in **Data Table 3B** as d_o (distance of object). Now measure the distance between the image (screen) and the mirror. Record under d_i (distance of image).
10. Measure the size (height) of the object (the stencil cut “1” on the plastic plate) and record under h_o in **Data Table 3B**. Measure, too, the height of the image on the screen and record in the data table as h_i . All measurements should be to the nearest 0.1 centimeter.
11. Now, move the mirror closer to the light source/object plate so that they are separated exactly by distance C (or 2F), which is twice the focal length of the mirror. This means that the object “1” now lies at the center of curvature of the mirror. Focus the image of the object on the screen by moving the screen. As before, record the qualitative characteristics of the image in **Data Table 3A** and the quantitative measurements in **Data Table 3B**.
12. Position the mirror closer to the light source/object plate so that the location of the object/light source is about the midway point between F and C of the mirror. Focus the image on the screen and record all observations as previously done, in **Data Tables 3A** and **3B**.
13. Move the mirror closer to the object plate so that they are separated by the focal length (f). The object is now exactly at the focal point (F). Try to get a sharp focused image. Note your observations in **Data Tables 3A** and **3B**.
14. Place the mirror closer to the object plate so that the distance is less than the focal length of the mirror. Try to get a focused image on the screen. Note your observations in **Data Tables 3A** and **3B**.

Part B: Convex Mirror

1. Select one of the convex mirrors and place it into one of the mirror holders provided in the Optics Bench Kit. Be certain to lock the mirror into the holder using the plastic ring so that the mirror does not slip out of the holder.
2. Place the light source/object plate at one end of the optical bench. Place the convex mirror on the other end of the bench as far away as possible. Look into the convex mirror and examine the image you see. Note your observations to answer **Question #2**.
3. Now, move the mirror closer to the light source/object plate and observe the corresponding changes in the image. Note your observations to answer **Question #3**.

Data Table 3A: Characteristics of Images				
Determined Focal Length of the Concave Mirror = ______ cm				
Position of Object From Mirror (in terms of F&C)	Position of Image From Mirror (in terms of F&C)	Type of Image: (Real or Virtual)	Relative Size of Image Compared to Object: (Larger or Smaller)	Orientation of Image: (Upright or Inverted)
Beyond C				
At C (2F)				
Between C (2F) and F				
At F				
Less than f				

Data Table 3B: Concave Mirror Measurements				
Determined Focal Length of Concave Mirror = _____ cm				
Position of Object From Mirror (in terms of F&C)	Distance Between Object and Mirror d_o (cm)	Distance Between Image and Mirror d_i (cm)	Height (Size) of Object h_o (cm)	Height (Size) of Image h_i (cm)
Beyond C				
At C (2F)				
Between C (2F) and F				
At F				
Less than f				

Questions:

1. When the object plate “1” and the concave mirror were separated by the focal length of the mirror, were you able to get a focused image on the screen? Explain in some detail.

2. When the convex mirror was used on the optics bench, describe the type of image that was seen looking into the mirror. Refer to **Part B**: Procedure step 2.

3. As the convex mirror was moved closer to the object plate, as described in **Part B** Procedure step 3, what changes in the image were observed?

4. When determining the focal length of the concave mirror, suppose the distant object you selected was a nearby tree as opposed to a very far away building. How would this affect the determined focal length of the concave lens? Explain in some detail.

5. Convex mirrors are often used as security mirrors in stores and side-view mirrors on vehicles. Based on the characteristics of the images in convex mirrors, what are some advantages, and some disadvantages in using these mirrors for that purpose?

Extension To Activity 3: Spherical Mirrors

The following activity is designed for the more advanced treatment of mirror optics. All calculations should be titled and neatly displayed, with units, on a calculation sheet.

A. Calculate the Focal Length of the Concave Mirror:

1. Using the information on **Data Table 3B**, calculate the focal length of your concave mirror for the first three trials when the distance between the object plate and the mirror is:
   - Beyond C
   - At C
   - Between C and F

The focal length can be calculated using the Mirror Equation:

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

where

f = focal length of mirror

d_O = distance between object and mirror

d_i = distance between image and mirror

2. Compare the focal length determined in Activity 3 Part A: Concave Mirror step 4 to the three focal lengths calculated by the above formula. Compute the *average* focal length for your mirror using the three values obtained with the mirror equation.

3. Using the determined focal length from the top of **Data Table 3A** or **3B** as the *accepted value*, and the *average* focal length obtained using the mirror equation as the *experimental value* (from step 2 above), calculate the percent error for the calculated focal length. Percent error can be calculated using the following:

$$\% \text{ error} = \frac{|\text{accepted} - \text{experimental}|}{\text{accepted}} \text{X } 100\%$$

B. Calculate the Magnification of the Concave Mirror:

1. Using the information on **Data Table 3B**, calculate the different magnifications of the concave mirror for the first three trials when the distance between the object plate and the mirror is:
   - Beyond C
   - At C
   - Between F and C

   The magnification can be calculated using the Magnification Equation:

$$m = \frac{\text{image size}}{\text{object size}} = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

where

m = magnification

h_O = height or size of the object

h_i = height or size of the image

d_O = distance between object and lens

d_i = distance between image and lens

The following is an explanation for the numerical signs:

- For all real images, d_i is a positive (+) value; for a virtual image, d_i is negative ($-d_i$).
- h_i = positive (+) for a virtual image; $-h_i$ means the image is inverted, thus, a real image.
- Focal length: Concave mirror = $+f$; Convex mirror = $-f$
- For all real images, magnification has a negative sign ($-m$); for virtual images magnification is positive ($+m$).
- A magnification value of >1 means that the image is larger than the object; values of m that are < 1 means that the image is smaller than the object.

2. Compare the magnification values obtained by the height ratio to those obtained by the distance ratio for each trial. How similar are the two values for any given trial?

3. Do the magnification values, including the numerical signs, for your different trials support your observed qualitative results that are found in your **Data Table 3A**? Discuss in some detail.

PHILIP
HARRIS

0345 120 4521

techsupport@philipharris.co.uk

www.philipharris.co.uk

Philip Harris Education
2 Gregory Street, Hyde, Cheshire SK14 4TH