OPTICS BENCH KIT
STUDY GUIDE

INTRODUCTION

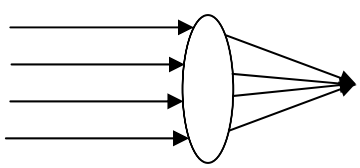
Visible light is a form of radiant energy and is a part of the electromagnetic spectrum, which includes x-rays and infrared light. Light behaves like a wave and can have different speeds and wavelengths. Light rays travel in a straight line and can be reflected and refracted.

Refraction of light is a common phenomenon in which the paths of light rays are bent as they travel through different media. Refraction is based on the principle that light travels at different speeds through different materials. For example, when light rays pass from air to water, their speed is slowed and the light rays are bent or refracted. (See "Teaching Tips for Younger Children" for an explanation of this.)

Lenses are made of transparent materials and use the principle of refraction to bend light and enhance an image for viewing. When light rays strike the surface of a lens, they are refracted as they pass from air through the material of the lens. When they emerge on the other side and pass from the lens to the air, they are refracted again.

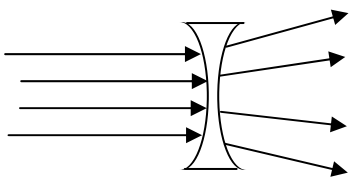
Convex lenses are curved so that the center of the lens is thicker than the sides. These lenses refract the light rays toward the center of the lens. For this reason, they are called **converging** lenses. A **plane convex** lens has one curved surface and one flat surface. A **double convex** lens has two curved surfaces.

Double Convex Lens (Converging)



Concave lenses curve the opposite way; the center of a concave lens is thinner than the sides. Light rays are spread apart, away from the center, as they pass through a concave lens and thus it is called a **diverging** lens. **Plane concave** lenses have one flat surface and one curved surface whereas **double concave** lenses have two curved surfaces.

Double Concave Lens (Diverging)



Light rays that are parallel to each other and pass through a convex lens will all be refracted to converge at a single point called the **focal point** (***f***) of the lens. Only light rays that come from an object that is very far or "infinitely" far away are parallel. When light rays come from an object that is closer than this, the rays are not parallel and do not converge at *f* but at some distance greater than *f* from the lens. Where the light rays converge, an **image** is formed. This image is either **erect** (right side up) or **inverted** (upside-down).

The following experiments will demonstrate the principle of refraction with a convex lens and a concave lens. An **optics bench** is used to align the lenses and objects in a straight line for better viewing. These activities will enhance the scientific skills of observing, measuring and controlling variables.

ASSEMBLY

Your kit contains the following items:

Optic bench holders, 2	Meterstick
Double convex lens	Lens holder
Double concave lens	Candle
Screen holder	Screen
Object marker	

1. Put the two bench holders onto the ends of the meter stick so that metric scale is right side up. This is the optic bench.
2. The screen holder, lens holder and object marker are designed to "sit" on the optic bench. The screen should be placed in its holder before being placed on the bench.
3. You may have to slightly open or close the fittings on the metal optics bench components so they slide easily on the meterstick without wobbling.

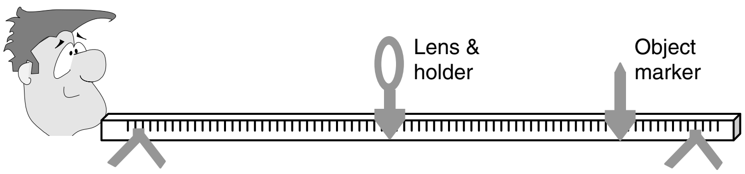
DETERMINE THE FOCAL LENGTH OF A CONVEX LENS, METHOD 1

Experiment 1

Although your convex lens may have the approximate focal length marked on the package, complete this experiment to determine the lens' actual focal length, *f*.

1. Put the convex lens in its holder and set this on the 50 cm mark of the optic bench.
2. Put the object marker on the bench a few centimeters away from the lens.

3. From the end of the optics bench that is opposite the object marker, look at the lens. You should see the object marker right side up through the lens. If you see the object marker upside down, move the object marker closer to the lens until it is right side up.



4. Ask a partner to slowly move the object marker away from the lens. At a certain distance from the lens, the image of the marker will invert and be upside down. Make a note of the distance of the object marker from the lens, in millimeters, just as the image begins to invert. This is the focal length (*f*) of the lens.
5. Repeat 4-5 times to make certain your measurements are very similar. Use the average value from the trials for the focal length.

DETERMINE THE FOCAL LENGTH OF A CONVEX LENS, METHOD 2

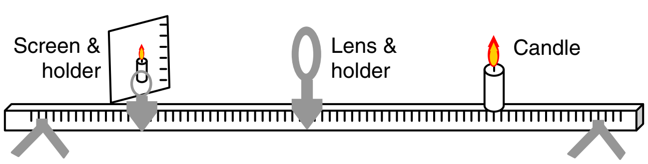
Experiment 2

1. Take the lens out in bright sunlight. Focus the sunlight at some point on the ground. When the focused light is the smallest pinpoint, measure the distance from the lens to the ground in millimeters.
2. Repeat 4-5 times. Take the average of the distance values you measure.
3. Your value for the focal length should be the same or very similar to the value found using the first method above.

IMAGES FORMED BY A CONVEX LENS

Experiment 3

1. Place the convex lens in its holder and set this on the 50 cm mark of the optics bench.



2. Place the screen in its holder so that the millimeter markings run vertically up the card. Place this on one end of the optic bench.
3. On the opposite side of the lens from the screen, place the object (either a candle or the object marker). If you use the object marker, you will need to shine a flashlight behind it to make the image appear on the white screen. If you use the candle, you may need to shorten it by a third to a half to make it the same height as the lens in its holder. (Make certain you use caution when moving the lighted candle on the optics bench so as not to burn yourself with wax!)
4. Place the object on the bench at a distance a little more than 2 times the focal length (*f*) from the lens. Then move the screen until the image is focused.
5. Record the following information in your data chart (see Table 1): What is the distance of the object from the lens? What is the distance of the screen from the lens? What is the height of the object? What is the height of the image? Is the image reduced, enlarged or the same size as the real object? Is the image erect (right side up) or inverted (upside-down)? If no image is formed, write "no image" in the table.
6. Move the object to a distance that is exactly 2*f* from the lens. Again record the data.
7. Move the object to the other distances given in the chart (between 2*f* and *f*, at *f*, and less than *f* from the lens.) Record the data for each point.

You should see that the image is inverted until the object is closer than *f* to the lens. When the distance of the object is *f* or less from the lens, you will not be able to focus the image on the screen. The farther away from *f* the object is, the smaller the image.

IMAGES FORMED BY A CONCAVE LENS

Experiment 4

1. Place the concave lens in its holder and set this on the 50 cm mark of the optics bench.
2. Place the object marker on the optic bench.
3. Look through the lens toward the object marker and move the object marker to different distances from the lens.
4. In your data table, record the orientation of the object (erect or inverted?) and the size of the object (is it reduced, the same size or enlarged?). Does the image enlarge or grow smaller as your move the object marker away from the lens?

The concave lens will produce erect images that are smaller than the original object.

TEACHING TIPS FOR YOUNG CHILDREN

Children see light refraction as soon as they take their first bath. They reach for an object under the water and are surprised to learn that it is not where their eyes tell them it should be. Thus, children are already familiar with this principle, even though they don't know its cause. Put a ruler half-submerged in a glass of water and ask the children to tell you what they see as they look at the ruler from different angles. Tell them that this is an example of refraction.

To explain this phenomenon, introduce the concept that light behaves like a wave. Children are familiar with waves on the shore of a lake or pond or ocean. They can see that the waves travel in fronts, which go in a straight line of direction. Light rays travel in a straight line too and they can pass through transparent objects like water, glass and air.

If you have some Jell-O and a pan of water, you can demonstrate that waves travel more slowly through Jell-O than through water. Make the Jell-O "jiggle" and watch the speed of these waves. Then, put your finger in the water pan and make a few waves. Compare the water waves to the Jell-O waves. Which is slower? Why?

Explain that refraction of light occurs because light travels at different speeds, depending on what material it is passing through. Some materials slow down the light, while others allow it to move more quickly. If you have some tall grass or a wading pool by your house, have your child walk through the tall grass or water and then walk on a flat surface like pavement. They will walk more slowly when going though the tall grass or water. Explain that light also slows down when it goes through glass and water compared to its speed through air.

You can further explain this principle by asking your child to imagine a group of several people in rows and columns marching toward an area of tall grass or water at an angle (you can use little "army men" toys for a visual aid). The first person to step in the grass or water slows down; he will be slower than the man next to him in his row. He will also be slower than the man behind him in his column. This happens to the next person to walk into the grass and so on. The straight rows of people will slowly "bend" as the grass slows each one down; the straight columns bend also. In the same way, light rays bends as they go from air to some other material like water or glass.

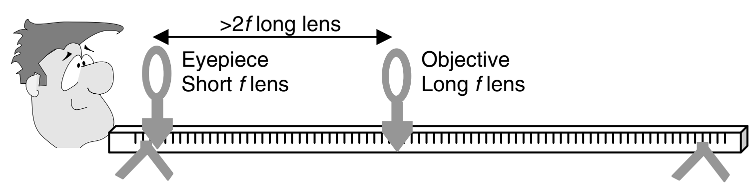
Have the children look through the convex and the concave lenses. Ask them which lens makes the image bigger? Which makes the image smaller? Explain that the convex lenses bend the light toward their center and are used in **magnifying lenses** and in **eyeglasses** to correct **farsightedness** (the inability to see near objects). Concave lenses bend the light away from the center and are used to correct **nearsightedness** (inability to see far objects).

FURTHER STUDY

Instead of looking through the lenses toward the objects, try putting the objects on the same side of the lens as your eye and look for an image of the object. (This works best with a candle in a darkened room.) Do this with both the convex and concave lenses. Is the image erect or inverted? Is the image larger or smaller than the object? **Refraction** *and* **reflection** are being demonstrated. Have the child research the property of light waves called reflection.

Experiment using the convex and concave lenses together. Set one lens in the holder with the object marker behind it. Look through the second lens and move it to a distance that brings the object into focus. What size is the image that results? Switch the lenses and try again. You may also need to move the object to bring its image into focus.

If you have another convex lens and lens holder, you can make a homemade telescope. Put the lens with the shortest focal length on one end of the optic bench. This is the eyepiece. Measure twice the focal length of the long *f* lens from the eyepiece. Put the long focal length lens, or objective, at the distance that is just beyond this distance (2*f* from the eyepiece). Look through the eyepiece and objective lenses at a distant object. You may need to slightly adjust the positions of the eyepiece to get a clear focus. Is the image inverted or erect?



To make a homemade microscope, place the candle or object marker on the optic bench slightly more than one focal length from the objective lens. Use the shortest focal length lens for the objective lens. Place the eyepiece (longest focal length lens) slightly more than the sum of the focal lengths of both lenses away from the eyepiece. Adjust the eyepiece to focus on the candle or other object.

If you have access to a physics book, you can do some further reading about how light rays converge through a convex lens. Draw your own diagrams of the path of the light rays through the lens for the various experiments given above. Include the original object, the refracted light rays, their path through the lens and their convergence to form the image.

Have your child research the history of telescopes, microscopes and eyeglasses. How did the discoveries of these instruments come about? If time permits, do a short biography on the early scientists who discovered how lenses could enhance images. How did scientists improve microscopes and telescopes over the years? What factors about the lenses that make up these instruments affect the quality of the images they produce?

TABLE 1.

LENS	Object Distance from Lens (mm)	Object Height (mm)	Image Distance from Lens (mm)	Image Height (mm)	Image Size: Reduced, Enlarged or Same Size	Image: Erect or Inverted
CONVERGING Distance from lens to object:						
Greater than 2*f*						
2*f*						
Between 2*f* and *f*						
f						
Less than *f*						
DIVERGING	N/A	N/A	N/A	N/A		