Galileoscope Optics Activity Guide

Robert T. Sparks and Stephen M. Pompea
National Optical Astronomy Observatory
Tucson, Arizona USA
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Galileoscope Activity Guide
Table of Contents

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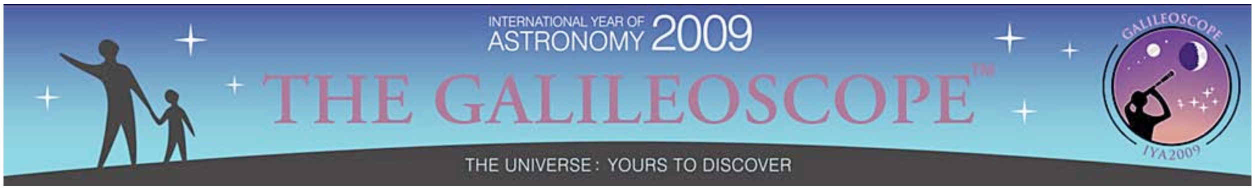
For Suggestions and Comments Please Contact:
Dr. S. Pompea
Manager of Science Education
U.S. Project Director, International Year of Astronomy 2009
Past Project Director and Co-PI, Hands-On Optics, Co-PI Astronomy from the Ground Up
NOAO, 950 N. Cherry Avenue, Tucson AZ 85719
spompea@noao.edu



Introduction to the Galileoscope

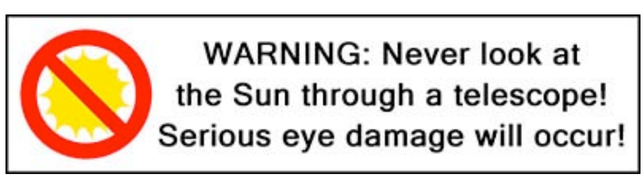
Four hundred years ago, Galileo turned his small telescope toward the heavens. His observations transformed our understanding of the universe.

Galileo saw craters on the Moon, phases of Venus, moons orbiting Jupiter, and "ears" on Saturn which we now know to be rings. His systematic observations challenged conventional scientific knowledge of the day.

The International Year of Astronomy celebrates Galileo's achievements. In order to help people appreciate what he accomplished, we have developed the Galileoscope. The Galileoscope is a low cost, high optical quality telescope similar in size to the ones used by Galileo to make his historic observations. The Galileoscope is capable of resolving craters on the Moon, the phases of Venus, the four Galilean Moons of Jupiter and the rings of Saturn. The Galileoscope also can be used to observe bright double stars, star clusters, nebular, and even some of the brighter galaxies.

The Galileoscope is designed as an educational kit. The Galileoscope requires some simple assembly so you can see the elements that go into making a small refracting telescope. This educational guide goes deeper into the optical principles behind telescopes. You will see how light bends when it enters different substances. You will get to learn about how lenses form images and measure their focal lengths. You will use lenses as magnifying glasses to learn how eyepieces work. And you will build the Galileoscope and use it to observe the heavens.

This guide contains a series of demonstrations and activities centered around how telescopes focus light. Each activity includes student learning goals, an equipment list, step-by-step directions, student worksheets, and background information for teachers. When you have finished these activities and have your own Galileoscope, you can go out and observe the night sky. You can find the Galileoscope Observing Guide at http://www.galileoscope.org.



Summary of Galileoscope Activity Guide

About These Activities
The activities in this manual were originally developed for the National Science Foundation sponsored Hands-On Optics program (www.hands-on-optics.org). The activities were adapted for another NSF project: Astronomy From the Ground Up. (www.astrosociety.org/afgu/) led by the Astronomical Society of the Pacific. A kit of materials was developed to go with these activities which included all the equipment needed to do these activities. Both the Hands-On Optics and Astronomy from the Ground Up projects were aimed at informal science educators such as museum educators and afterschool program leaders. The materials have been used very successfully by classroom teachers.

At the end of this manual is a list of vendors you can use to obtain materials to do these activities. Alternately, many of the activities can be done by substituting household items or using the lenses from the Galileoscope. See each individual activity for suggestions on what equipment to use. Note that the Galileoscope can be assembled, used for observations, and then disassembled to use the lens for various experiments. A summary of activities is given now.

Light Through an Acrylic Block: A Demonstration: 10-15 minutes
Starting with a laser pointer shining perpendicular (at what is called the normal incidence angle) to an acrylic block, the teacher will slowly increase the incident angle. The students will observe that the path of the light changes as the incident angle increases. This demonstrates that light can be bent or refracted by a material.

Light Passing Through a Convex Lens : A Demonstration : 15-20 minutes
When parallel light beams encounter an object such as a lens, its shape can cause different light rays to bend by different amounts. Students predict the path of the rays through an acrylic block and through a lens, then determine if they are correct by using a mister or chalk dust to expose the laser beams.

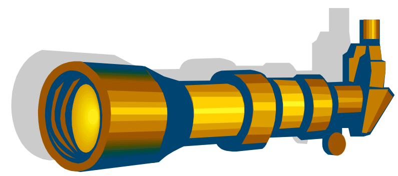
Finding the Focal Length Using a Distant Object: 30-40 minutes
When looking at a brightly colored lamp on one side of the room, students will measure the focal length of a lens by forming an image of the light on a screen and measuring the distance between the lens and the screen.

Simple Magnifiers: 30-40 minutes
In this activity, students will explore the magnifying properties of the lenses and notice the connection between how much the lens is curved and its ability to magnify. The students can also see how a juice bottle filled with water can bend light and magnify.

Build a Refracting Telescope I: 30-40 minutes
This is the first of several activities relating to refracting telescopes like the Galileoscope. Students will first determine how to arrange two lenses so that when they look though them they will see a magnified image of a distant object.

Build a Refracting Telescope II: 30-40 minutes
Using the configuration of lenses that they found previously, students will create a magnified image of a distant object. By placing the velum screen in varying locations, students will determine the function of each lens in a basic refracting telescope.

Build a Galileoscope: 20-30 minutes
The students in groups of two or three will build the refracting telescope from the kit. They will then look through the telescope at distant objects, making notes about their observations.



Light Through an Acrylic Block: A Demonstration

Overview
This demonstration introduces the concept of refraction. Refraction occurs when light changes its direction of travel when its speed changes as it moves from one medium to another. An example is when light travels from air to water or from air into an acrylic block.

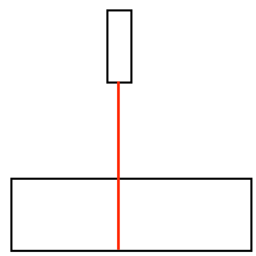
Students Will Learn…
- In a uniform medium, light will travel in a straight path.
- When light hits a boundary between two different substances, such as air and water, the path it follows can change.

TIP: You can use a clear plastic rectangular glass or plastic container filled with water instead of an acrylic block. Place a drop of milk in the container so you can see the laser beam.

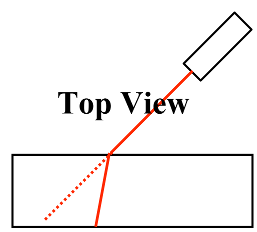
What You Need
For the class:
- ❑ 1 acrylic block
- ❑ 1 laser pointer

Getting Ready
Clear a space on a large table so everyone can see. Set up the laser and the acrylic block. Dimming the room lights (if practical) may make it easier to observe the demonstration.

GO: Light Through a Glass Block



1. Place an acrylic block on a table and have the students gather around. Shine a laser pointer so the beam hits the surface at a right angle. The beam of light should be perpendicular to the surface that it is shining through. Ask the students if they notice anything happening to the direction of the beam.



2. Now slowly turn the laser so it hits the surface at an oblique angle. Again ask the students if anything has happened to the direction of the beam.

3. Keep increasing the angle at which you are holding the laser. Ask the students what is happening to the amount that the beam is being bent as the angle changes.

What's Really Happening Here …

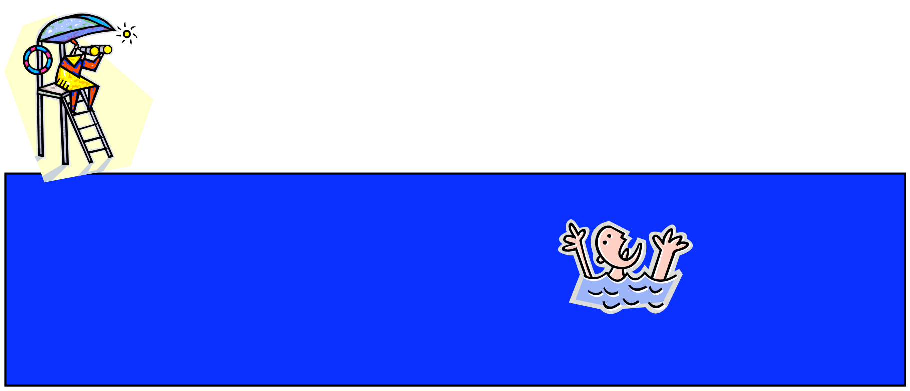
When light travels from air to glass, the speed of light will decrease. This change in speed causes the light to change its direction of travel at the boundary. Light follows Fermat's Principle. Fermat's Principle states that light will take the path between two points that is the shortest in time (i.e., light follows the quickest path). We usually think light travels in a straight line. In this case, however, a straight line is not the quickest path through the block due to the fact that the material that makes up the block slows the light down. So the light beam bends to find the path that would take the least amount of time. Students can do the **Kinesthetic Optics Activity** to learn why light bends when it encounters a boundary where it slows down.

Going Further

1. Examine the point where the laser leaves the block and returns to the air. What happens to the path of the beam at this point? You can use chalk dust or canned fog to make the beam more visible.

2. Get a clear plastic glass and partially fill it with water. Place a pencil in the glass and notice how it appears "bent" at the boundary between air and water. Have students explain what is happening using their knowledge of refraction.

3. Suppose a lifeguard is standing on the beach and sees a swimmer who needs help. The lifeguard wants to get to the swimmer as quickly as possible. What path should she take? How does this relate to refraction?



4. Have students get into groups and let them explore the refraction of light using other objects in the classroom, such as fish tanks or other large, clear objects. Please remind them of Laser Safety Rules.

5. Place a coin at the bottom of an opaque cup. Have the students back away from the cup. Tell them to stop as soon as they can't see the coin anymore (be sure they realize that they will not all stop at the same point due to the fact that they are different heights). Slowly pour water into the cup. Ask students to describe their observations and determine the cause of this effect.

Kinesthetic Optics

Overview
This activity allows students to pretend to be "wave fronts" of light (much like an ocean wave). As the students walk from "air" to another substance such as "plastic" where light slows down, they will observe how the light changes direction.

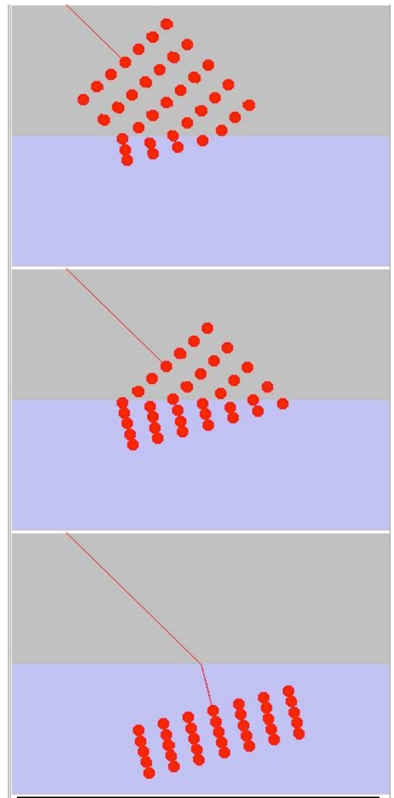
Students Will Learn…
- Light travels slower in substances such as plastic and glass than in air
- Light bends toward the normal if it slows down when it passes from one substance to another
- Light bends away from the normal if it speeds up when it passes from one substance to another

What You Need
For the class
- ❑ A large open space

Getting Ready
You will need a large open space where students can move about. You will need a line in the center of the area. If you are using a basketball court or athletic field, choose one of the lines on the court or field. You can also make a line in the center of the area using floor tape.

Go: Kinesthetic Optics
1. Tell the students they are going to learn why light bends when it passes from air to plastic. Show the students the line and tell them that one side of the line represents air and the other side of the line represents plastic.
2. Tell the students that light is a wave, similar to a water wave. They are going to represent a wavefront. A wavefront can be though of as the crest or top of a wave for our purposes.
3. Have the students line up next to each other and lock arms. Have the students practice walking at the same speed so the line stays straight as they walk. Tell the students this is how light moves in air, As long as light does not move to a different substance, all parts of the wavefront move at the same speed.
4. Have the students line up in the "air" facing the "plastic". Have the students line up in the "air" and lock arms. Make the wavefront parallel to the air-plastic boundary line. Tell the students that light moves slower in plastic than air. Ask them what they will do when the get to the air-plastic boundary. Make sure the students understand they will walk slower when they move into the plastic. Tell them to walk about half as fast in the plastic. Remind them that they will all walk at the same speed as everyone else. Practice this a few times. Ask the students if light changes direction when it encounters the plastic.
5. Now have the students line up in the air and lock arms. Have the students rotate the entire line so they will hit the plastic at an angle. Remind the students that they will slow down only when the cross the air-plastic boundary line. Remind students at the end of the line that they will keep walking fast until they hit the line, even though others may have slowed down earlier. Tell the students to keep walking after they are in the plastic but at the slower speed.

6. Ask the students if light changed direction when it hit the boundary. They should notice light changed direction. If your students are familiar with the term, you can tell them light bent toward the normal. Have the students practice this several times.
7. Tell the students they are going to look at what happens when light travels from plastic to air. Ask them how their speed will change when they encounter the boundary. Tell students that they will start walking slowly in the plastic and then speed up when they encounter the plastic-air boundary.
8. Have the students line up in the plastic and lock arms. Make the line parallel to the boundary. Have the students practice walking slowly in the plastic and speeding up when they encounter the air several times. The line should not change directions in this case.
9. Now have the students rotate the line so they will encounter the air at an angle. Ask the students what they think will happen. Remind the students not to speed up until the encounter the plastic-air boundary.
10. Ask the students what happened to the direction they were moving. They should notice they turned the opposite direction as before. If you students are familiar with the term, you can tell them that light bends away from the normal. Have the students practice moving from plastic to air several times.



This series shows a view from above of the students walking across the air-plastic

What's Really Happening Here …

This analogy uses the wave nature of light. Each part of the wavefront will travel at the same speed until in encounters a different substance. If the wavefront approaches a boundary at an angle, one part of the wavefront encounters the boundary first and slows down. The other parts of the wavefront keep traveling fast until they encounter the boundary. This causes the entire wavefront to rotate and change directions. If the wave slows down, it will bend toward the normal. If the wave speeds up, it will bend away from the normal.

Light Through a Convex Lens (Demonstration)

Overview
In this activity, students will see how we can use the property of refraction to focus parallel rays of light. Students will observe how a convex lens can cause parallel rays of light to converge.

Students Will Learn…
- A convex lens can cause parallel rays of light to converge.
- The point at which parallel light rays meet is called the focal point.
- The distance from the lens to the point where the light rays meet is called the focal length.

What You Need
For the class:
- 1 laser pointer
- 1 acrylic block
- 1 velum screen or a wall
- 1 large positive lens

Tip: Use a container of water instead of an acrylic block as mentioned in the previous activity. You can use the objective lens of the Galileoscope instead of the large positive lens. An index card can be used instead of velum.

For each student:
- Copy of "STUDENT HANDOUT: Which Laser Produced Which Spot?"

Getting Ready
1. Clear a space on a table. Set the laser on the table by rotating its legs until they are perpendicular to the laser body.
2. Set up a velum screen several feet away from the lasers (or alternately, have the lasers project onto a wall or other vertical surface).
3. Make a holder for the large positive lens. Cut the bottom off a Styrofoam cup so that the lens will sit in the cup. You may want to cut small notches in the side of the cup to make the lens more stable.

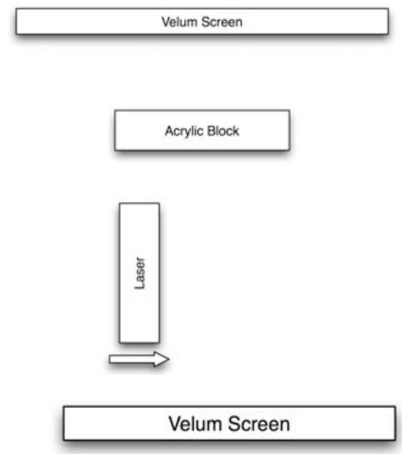
Lens holder made from a Styrofoam cup.

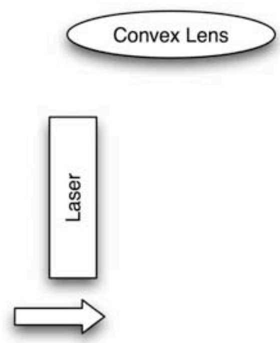
GO: Light Through a Convex Lens

1. Shine the laser through the block. Starting at the left side of the block, slowly slide the laser to the right. Have the students observe how the spot on the screen moves.

2. Now replace the glass block with the positive lens. Place the laser so the beam goes through the left side of the lens. Slowly move the laser to the right. Have the students observe the how the spot on the screen moves..

3. You can use a plant mister to spray water to reveal the path of the beam to the students. You can also show the path of the beam by using an index card to trace where the beam goes on a sheet of paper.





What's Really Happening Here …

A converging lens, sometimes called a positive lens (due to the fact that it has a positive focal length) is capable of focusing parallel light rays down to a single point, called the focal point. You will notice that a converging lens has a curved surface and is thick in the middle and thin at the edges. Light rays that pass through the center of the lens will not change direction. Light rays that hit away from the center of the lens have a different angle of incidence. Therefore, they are refracted and will change their direction of travel. The shape of a converging lens causes all incoming parallel light rays to converge to a single point.

The converging lens can focus incoming light rays that are not parallel as well. These light rays will not converge at the focal point. For more information, see "Finding the Focal Length Using a Distant Object: What's Really Happening Here…"

NOTE: This is a place in the module to make it clear to the students that the focal point of a lens is a property of the lens and it DOES NOT change. Images are formed where rays are in-focus, which is NOT necessarily where the focal point of the lens is.

Going Further

Can students find other materials in the classroom that can be used to create a focal point.

Finding the Focal Length Using a Distant Object

Overview
In this activity, students will learn how to focus images of a distant object onto a screen using a converging lens. By measuring the distance from the screen to the lens, students will determine the focal lengths of the lenses.

Students Will Learn…
- ♦ Converging lenses can be used to project an image onto a screen.
- ♦ A single converging lens will produce an inverted image on the screen.
- ♦ When focusing a distant object on the screen, the focal length of the lens is equal to the distance from the lens to the screen.

What You Need

For each group of students:
- ❑ 1 20-cm focal length lens
- ❑ 1 7.5-cm focal length lens
- ❑ 1 velum screen
- ❑ 3 Styrofoam cups
- ❑ ruler

> **Tip:** You can use the objective lens of the Galileoscope for the long focal length lens and assemble the eyepiece for the short focal length lens in this activity. The focal lengths will be different (50 cm and 2 cm respectively).

Getting Ready
1. You will need to have an object for the students to focus to produce an image. There are several objects you can use. If you have a large window in the classroom, you can dim the room lights and students can focus the image of objects outside such as trees or cars. You can buy small neon lamps at stores such as Wal-Mart or Walgreens for $10-$20 that also work well.

2. Remove the lenses from their boxes, because the focal lengths are printed on them. When cleaning up, remember that the thicker lens has the shorter focal length.

GO: Finding the Focal Length Using a Distant Object
1. Hand out the lenses, screens, and rulers to each group. Be sure to remove the lenses from their boxes since the focal length of each lens is printed on the box.

2. Have the students complete the worksheet, "STUDENT HANDOUT: Finding the Focal Length Using a Distant Object." Assist the students as necessary.

What's Really Happening Here …

When you look at a very distant object (very distant means the distance to the object is very large when compared to the focal length of the lens) an image will form at the focal point. This image will be upside down and much smaller than the object. A camera works based on this principle. A converging lens focuses an image on the film. To see the mathematical description of this phenomenon, see "More Background for the Interested Educator."

Going Further

Ask students to think about other optical devices that use a converging lens to focus an image on a screen. Ask students if they can think of a way to project an image onto a screen that is right side up.

STUDENT HANDOUT: Finding the Focal Length Using a Distant Object

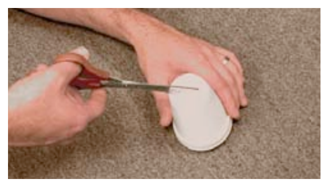
What You Need

- ❑ 1 thick convex lens (or Galileoscope eyepiece)
- ❑ 1 thin convex lens (or Galileoscope objective lens)
- ❑ 1 velum screen
- ❑ 3 Styrofoam cups
- ❑ ruler

What To Do

1. Examine the two lenses. How are they similar? How are they different?

2. Create a lens holder. Cut a slit in the bottom of the Styrofoam cup, like in the picture at right. Insert the thick lens into the slit. Hold the lens in place with tape as shown in the picture at far right. Cut a slit in the bottom of another Styrofoam cup. Insert the velum screen into this slit.



3. Your instructor will point out an object to use. It may be a tree outside or a light in the room. Place the screen holder on the table. Move the lens closer to and farther away from the screen until you see an image of the object on your screen. Move the lens until you see a well focused image.
   a. Is the image right side up or upside down? Is it larger (magnified) or smaller than the original object?

   b. Measure the distance from the thick lens to the velum screen. Record this distance. What is this distance called?

4. Repeat the procedure for question 3 for the thin lens.
   a. Is the image right side up or upside down? Is it bigger (magnified) or smaller than the original object?

b. Measure the distance from the thin lens to the velum screen. Record this distance.

5. The distances you measured in questions 3b and 4b are called focal length. Ask your teacher to tell you the focal length of the lenses. How do these numbers compare with what you measured?

6. Describe the differences between the shape of the long focal length lens and the short focal length lens.

7. Based on your observations, what can you conclude about the relationship between the focal length of a lens and the shape of a lens?

Simple Magnifiers

Overview
In the previous section, some fundamental properties of converging lenses were investigated. Students used a converging lens to project an image onto a screen. An image that can be projected onto a screen is called a real image. However, converging lenses can also produce images that cannot be projected onto a screen – these are called virtual images. For a converging lens, the virtual image is right side up and larger than the object. A converging lens used in this way is commonly called a magnifying glass.

Students Will Learn…
- ♦ Converging lenses can be used to magnify an object.
- ♦ The amount of magnification is related to the focal length of the lens.
- ♦ The point at which an image "flips" is the focal point.

What You Need

> **Tip:** You can use the objective lens of the Galileoscope for the long focal length lens and assemble the eyepiece for the short focal length lens in this activity. The focal lengths will be different (50cm and 2cm respectively).

For each group of 2-3 students:
- ❑ 1 20-cm focal length lens
- ❑ 1 7.5-cm focal length lens
- ❑ ruler
- ❑ drawing paper
- ❑ colored pencils or markers
- ❑ an assortment of tiny objects from the classroom

For each student:
- ❑ Copy of "STUDENT HANDOUT: Simple Magnifiers"

GO: Simple Magnifiers
1. Break the students into groups of two or three students and give each group the drawing materials and an assortment of tiny objects.

2. Have the students complete the worksheet, "STUDENT HANDOUT: Simple Magnifiers." Assist the students as needed.

What's Really Happening Here…

When a converging lens is less than one focal length away from an object, it produces a virtual image that is right side up and magnified. Recall that virtual images cannot be projected onto a screen. You can view a virtual image by looking through the lens at the object. The converging lens in your eye will project a real image onto your retina.

When an object is at the focal point of a converging lens, all the incoming light rays are parallel when they leave the lens. Therefore, an object at the focal point will not form an image. The focal point is the "flip point". If the lens is closer to the object than the focal point, the image is right side up. If the lens is farther away than the focal point, the image is upside down. You might notice a similar effect with a concave mirror such as a make up mirror.

Going Further

1. Have a table set up with the empty juice bottle (an empty soda bottle will work), container of water, and some small objects (i.e. coins, beads, text, etc.) Ask the students if they can make a magnifier out of the juice bottle (fill it with water). Then have them draw what they see looking through the bottle at the small objects.

2. How is the glass bottle filled with water similar and dissimilar to the lenses in the kit?

3. Can students find anything around the room or at home that could also be used as a magnifier?

STUDENT HANDOUT: Simple Magnifiers

What You Need

- 1 20-cm focal length (thinner) lens (or Galileoscope objective lens)
- 1 7.5-cm focal length (thicker) lens (or Galileoscope eyepiece)
- ruler
- drawing paper
- colored pencils or markers
- an assortment of tiny objects from the classroom

What To Do

1. Look at a tiny object with your eye. Make a sketch of a couple of the objects in the space below.

2. Your teacher will give you two lenses. Examine the tiny objects through the 20-cm focal length lens. Make a sketch of the objects as they appear through the lens in the space below.

3. Examine the tiny objects through the 7.5-cm focal length lens. Make a sketch of the objects as they appear through the lens in the space below.

4. Compare views through the two lenses. Which lens produces a larger magnification?

5. Move the 7.5-cm lens closer to and farther away from the objects. What is the relationship between the distance to the objects and the magnification?

6. Looking through the 7.5-cm lens at one of the objects, slowly move it farther away from the object. Keep moving the lens farther away until you see the image flip over and become upside down. What do you think is happening at this point?

7. Try this with the 20-cm focal length lens. Does it behave in the same way as the 7.5-cm lens?

8. Measure the distance from the object to the lens at the point where the object flips over. Record your distance for each of the two lenses. What do you notice about this distance?

Build a Refracting Telescope I

Overview
Now that we have explored what a single positive lens can do, we will investigate what happens when we use two positive lenses together. By doing so, students will, in effect, build a refracting telescope.

Students Will Learn…

- Focusing is done by adjusting the distance between the two lenses.
- To achieve the greatest magnification, the most curved lens (shortest focal length lens) is the one closest to the eye.
- The two-lens system will invert the image.

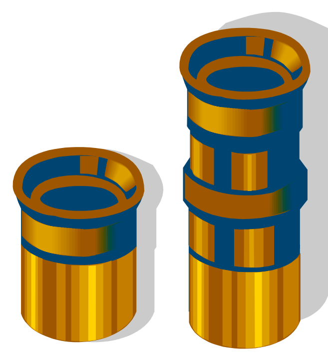
What You Need:
For the entire class:

- ❑ Colored lamp

For each group of 2-3 students:

- ❑ 1 20-cm focal length lens (or Galileoscope objective lens)
- ❑ 1 7.5-cm focal length lens (or Galileoscope eyepiece)
- ❑ ruler

Getting Ready
Place the colored lamp in a prominent position in the room where all students can easily see it. Make sure the lamp is several meters away from the closest group.



GO: Build a Refracting Telescope I

1. Ask your students about instruments or devices they can use to see far away. Binoculars and telescopes are good answers (binoculars are just two telescopes placed side by side). Ask students if they have ever visited a research telescope at an observatory. Tell the students that, over the next several activities, they will learn how telescopes collect light and form images of distant objects.

2. Divide the class into groups of 2-3 students. Each group should be given two converging lenses of differing focal lengths and a ruler.

3. Have the students complete the worksheet, “STUDENT HANDOUT: Build a Refracting Telescope I.” Assist the students as necessary.

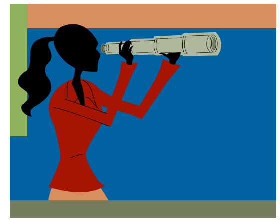
What's Really Happening Here…
Light from a source (such as our colored lamp or a star) will travel to the telescope and pass through the first (closets to the object) converging lens. This lens will create a real image of the object. This lens is also called the objective lens. The second converging lens is placed less than one focal length away from the image of the first lens. The second lens will magnify the image created by the first lens. The second lens is also known as the eyepiece and is located at the end of the telescope nearer to the eye.

For refracting telescopes, the objective lens has a larger diameter and a longer focal length than the eyepiece. The function of the objective lens is to collect a lot of light; a larger diameter lens will allow in more light than one with a smaller diameter. There are several reasons that the objective has a long focal length. First, a long focal length lens is thinner and lighter. If you have a large objective lens with a short focal length, you will have a very heavy lens at the front of your telescope. Since the lens can only be supported by the edges, a large lens will sag under its own weight and not maintain its shape, leading to a blurry image.

Another reason for a long focal length objective lens is to reduce chromatic aberration. Chromatic aberration occurs because short wavelength light is refracted more by a lens than long wavelength light. The result is color fringes in the image. Chromatic aberration is worse for large, short focal length lenses. Making the objective a long focal length lens reduces chromatic aberration. Even though the eyepiece has a short focal length, its diameter is small and chromatic aberration is not as severe for small diameter lenses.

The magnification of a telescope can be changed by using a different eyepiece lens. Recall that a shorter focal length lens gives a larger magnification when used as a magnifying glass. Similarly, a shorter focal length lens will yield a higher magnification when used as the eyepiece of a telescope.

STUDENT HANDOUT: Build a Refracting Telescope I



What You Need

- ❑ 1 20-cm focal length lens (or Galileoscope objective lens)
- ❑ 1 7.5-cm focal length lens (or Galileoscope eyepiece)
- ❑ ruler

What To Do

1. Hold the two lenses so that the 20-cm lens is in front of the 7.5-cm lens (in other words, so the 20-cm lens is closer to you). Look at a distant object through the lenses. Move the lenses closer together and farther apart.

    a. Can you create a focused, magnified image of the distant object?

    b. Describe what you see.

2. Now reverse the lenses – hold them so that the 7.5-cm lens is closer to you. Again look at the distant object through the lenses. Move the lenses closer together and farther apart.

    a. Can you create a focused, magnified image of the distant object?

    b. Describe what you see.

3. Draw the arrangement that is best for seeing the distant object. Be sure to label your diagram.

4. The lens closer to your eye is called the *eyepiece*. Which lens is your eyepiece?

5. The lens farther from your eye, and closer to the object you are viewing, is called the *objective*. Which lens is your objective?

6. Is there a relationship between the focal lengths of the lenses and the distance between the lenses when you look at a distant object? If so, what is that relationship?

7. Repeat questions #1 and 2, but this time look at a nearby object (something about 3 feet away from you). First put the 20-cm lens closer to you.

    a. Can you create a focused, magnified image of the nearby object?

    b. Describe what you see.

8. Now reverse the lenses – hold them so that the 7.5-cm lens is closer to you. Again look at the nearby object through the lenses. Move the lenses closer together and farther apart.

    a. Can you create a focused, magnified image of the nearby object?

    b. Describe what you see.

9. Which arrangement is best for seeing the nearby object?

10. With the best arrangement, again look at the nearby object and move the lenses until you get a focused image. Have your partner measure the distance between the lenses while you hold them steady. Record the distance here.

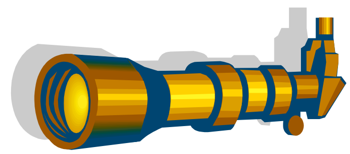
11. How does this distance change when you look at a nearby object?

Build a Refracting Telescope II

Overview
In this activity, students will learn about the functions of the two lenses in a refracting telescope. Students will use one lens, the objective, to project an image onto a screen. The second lens, the eyepiece, will then be used to magnify the image.

Students Will Learn…
- ♦ The first lens creates an inverted, real image on the screen.
- ♦ The second lens acts as a simple magnifier, making the image larger.

What You Need:
For the class:
- ❑ Colored lamp

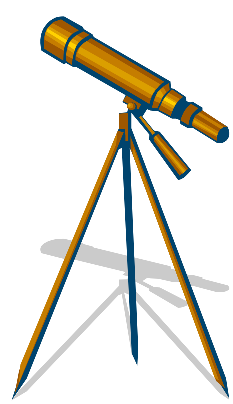


For each group of 2-3 students:
- ❑ 1 20-cm focal length lens (or Galileoscope objective lens)
- ❑ 1 7.5-cm focal length lens (or Galileoscope eyepiece)
- ❑ 1 velum screen
- ❑ 3 Styrofoam cups
- ❑ tape
- ❑ ruler

Getting Ready
Place the colored lamp in a prominent position in the room where all students can easily see it. Make sure the lamp is several meters away from the closest group. If you can, darken the room by turning off some lights and closing any blinds or curtains.

GO: Building a Refracting Telescope II
1. Distribute the materials to each group of 2-3 students.

2. Have the students complete the worksheet, "STUDENT HANDOUT: Build a Refracting Telescope II." Assist the students as needed.



What's Really Happening Here…
Students frequently have difficulty understanding the function of the lenses in a refracting telescope. This activity attempts to make the role of each lens clear. The front lens, or objective, is placed one focal length from the screen. The lens focuses the light and creates a smaller, inverted image. The use of the screen is meant to let students see this image. The second lens, or eyepiece, is held less than one focal length away from the screen. Recall that when a lens is held less than one focal length away from an object, the image is right side up and magnified. The eyepiece magnifies the image. In other words, the object for the eyepiece is really the image formed by the objective lens. A normal

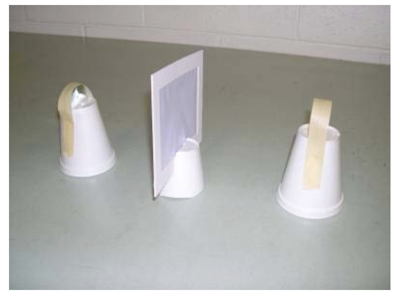
refracting telescope does not have a screen, of course. The lack of a screen makes it difficult for some students to visualize what is happening inside a telescope.

STUDENT HANDOUT: Build a Refracting Telescope II

What You Need

- ❑ 1 20-cm focal length lens (or Galileoscope objective lens)
- ❑ 1 7.5-cm focal length lens (or Galileoscope eyepiece)
- ❑ 1 velum screen
- ❑ 3 Styrofoam cups
- ❑ tape
- ❑ ruler

What To Do



1. Make lens holders and a holder for the velum screen following the same procedure you used in "Finding the Focal Length Using a Distant Object."

2. Recall from the last activity that the best arrangement of lenses to view a distant object was to have the shorter focal length (7.5-cm) lens as the eyepiece and the longer focal length (20-cm) lens as the objective. Use the objective to project an image of the light onto the velum screen.

3. Place the eyepiece behind the velum screen. Look through the eyepiece at the screen. Move the eyepiece until you see a focused, magnified image of the colored lamp.

4. Measure the distance from the objective to the screen. Measure the distance from the eyepiece to the screen. Is there a relationship between these distances and the focal lengths of the lenses?

5. Do you think the screen is necessary in this set up? Explain your reasoning.

6. Test your hypothesis by removing the screen and looking at the colored lamp again. Describe your observations.

Build a Galileoscope

Overview
The Galileoscope has been created for the International Year of Astronomy (IYA) to give students the opportunity to recreate the historic observations of Galileo. The Galileoscope is an inexpensive telescope with high optical quality and is easy to use for the beginning stargazer. The telescope requires some simple tools-free assembly allowing students to see the internal elements of a refracting telescope.

Students Will Learn…
- ♦ How to assemble a small telescope
- ♦ The layout of the optical elements in a small telescope.
- ♦ How to focus and use a telescope.

What You Need
- ❑ Galileoscopes for the class. You may wish to have each student build one or work in teams of two or three.

Getting Ready
Be sure to order Galileoscopes so they arrive on time. Galileoscopes can be ordered at http://www.galileoscope.org. Build a Galileoscope yourself and test it before attempting to do this activity with students. Be sure you can find the focus and can help the students find the focus as well.

Go: Building a Galileoscope
1. Tell the students they are going to build a small refracting telescope similar in size to the one Galileo used to make his historic observations.
2. Warn the students that this is **NOT A SOLAR TELESCOPE! IT SHOULD NEVER BE POINTED AT THE SUN!**

3. Pass out the Galileoscope kits to the students. The Galileoscope come with pictorial assembly instructions.
4. As the students complete their telescopes, have them attempt to focus on a distant object such as some trees outside. Help the students focus the telescopes. It can be difficult to find the focus point the first time. The telescope focuses by sliding the eyepiece holder forward and backward. Be sure the students are moving the focuser

slowly. If they slide the focuser quickly, they may go past the focus point without realizing it.
5. Show the students how to mount the telescope on a camera tripod. It will be necessary to mount the telescope to hold it steady enough to produce a pleasing image.

Troubleshooting The Galileoscope
Although it is deigned to be easy to assemble and use, there are a few common mistakes that can be made when assembling and using the Galileoscope.

1. Be sure the objective lens is oriented correctly. Check its orientation against the diagram in the directions.
2. Check the orientation of the eyepiece and its lenses. The grooves should help you get the eyepiece lenses oriented correctly.
3. Move the focuser SLOWLY throughout its entire range when looking for focus. If you move it too quickly, you may pass the focus point without realizing it. If you do not try the whole range, you may miss the focus point entirely.
4. If you are trying to focus on a nearby object, the focuser usually needs to be pulled farther out. Push the focuser in to focus on distant objects.
5. Try focusing on a very distant object. The Galileoscope (as all telescopes) has a near focus point. That means you cannot focus on objects very nearby (closer than a few meters). If you are looking at objects in the room, this may be your problem. Try going outside or to a very long hallway where you can focus on objects much farther away.

Going Further
1. Point out the eyepiece design of the Galileoscope to the students. Ask them how it differs from the eyepiece they used in **Build a Refracting Telescope I**. Ask students why they think we used four lenses instead of one. Have them research eyepieces to answer the question.
2. You may wish to explore the resolution of the telescope. A simple way to approximate resolution is by using an eye chart. Students know they should be able to read the 20 foot line from 20 feet away. How far away can they read the 20 foot line with the Galileoscope?
3. Have the students use the telescope at night. See the next section of the guide for suggestions on observing projects.
4. You can use the Galileoscope to observe the Moon during the day. Arrange a time to observe the Moon when it is visible during class.

Vendor Information

Below is a list of parts and vendors we have used in the past to obtain lenses and other items for the activities outlined in this manual.

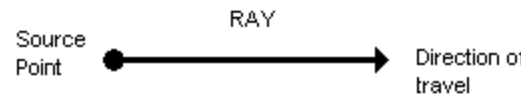
Item	Catalog or Part #	Vendor Information
Laser Level	TOL10206	Surplus Computers http://www.surpluscomputers.com
20 cm focal length double convex lens	# L1914D	Surplus Shed 8408 Allentown Pike Blandon, PA 19510 Phone 877-778-7758 http://www.surplusshed.com/
7.5cm focal length double convex lens	# L1912D	Surplus Shed 8408 Allentown Pike Blandon, PA 19510 Phone 877-778-7758 http://www.surplusshed.com/
100mm diameter 20cm focal length double convex lens	# L2006D	Surplus Shed 8408 Allentown Pike Blandon, PA 19510 Phone 877-778-7758 http://www.surplusshed.com/
Velum	Flat 5x7 cards (25)	Mountaincow P.O. Box 2702 Providence, RI 02906 Phone 800-797-6269 http://www.mountaincow.com/
Custom Matte Frames	#WV101	Worldview Pictures 373 Dawson Drive Camarillo, Ca 93012 Phone 1-800-543-9919 http://www.worldviewpic.com/
Galileoscope		http://www.galileoscope.org
Acrylic Block	HA001 Acrylic 3x5x1/2" block	Onyx Expressions 16827 Anna Green Houston, TX 77081 Phone: 800 252-0807

More Background for the Interested Educator

Ray Tracing

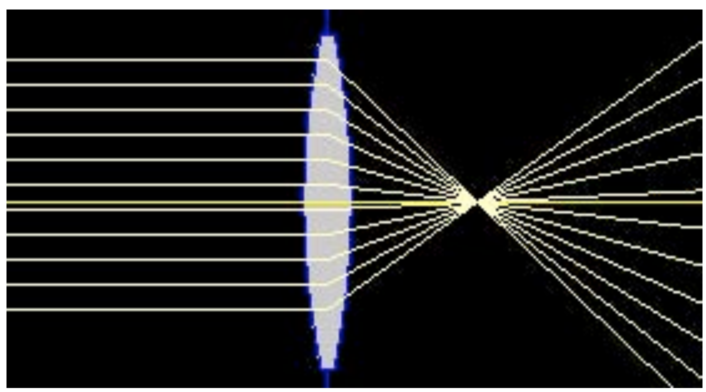
How is it that we can use a lens to magnify our thumb, and in other instances we can use the same lens to invert a distant image onto a screen? How do these images form?

To explain how an image is created, scientists use a model called *ray tracing*. Ray tracing describes the direction the light is heading. Light originates from a source. As long as light is in a uniform medium, we can think of light rays traveling in a straight line until the light encounters a boundary or barrier of some type.



Ray tracing can be used to find where the image forms when light rays from an object pass through an optical system consisting of one or more lenses or mirrors.

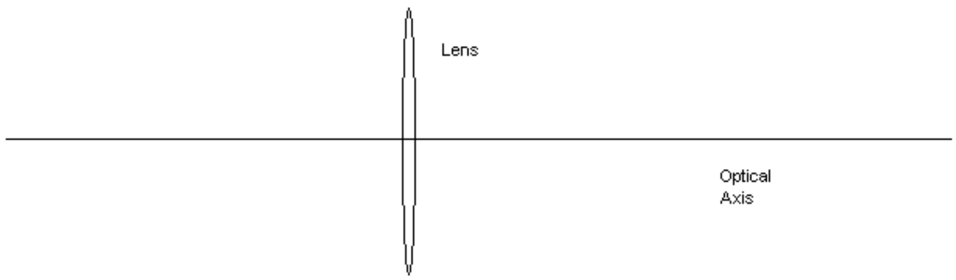
Recall the activity, "Finding the Focal Length Using a Distant Object," where we used a very distant object to create an image. When an object is very far away from the lens (much farther than the focal length), we consider the object to be infinitely far away. When you are very far away from the object, the light rays are spreading out so slowly they are difficult to distinguish from parallel light rays. A converging lens will focus all incoming parallel light rays to the focal point.



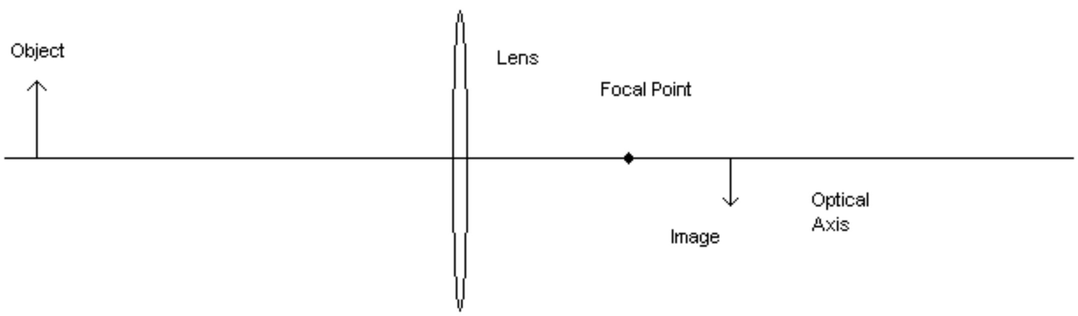
Ray Diagrams

Now with this basic understanding we can start to construct a ray diagram of our optical system.

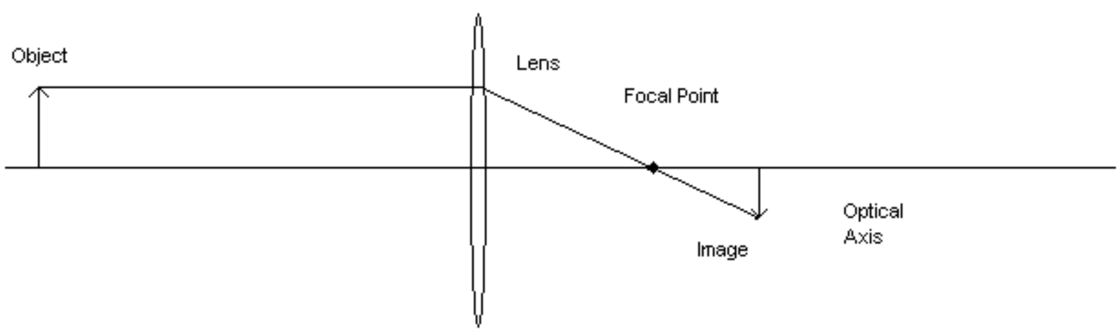
Step One: First draw the lens. Next draw a line through the center of the lens. This line is called the *optical axis*.



Step Two: Draw in the object and image locations and the location of the focal point. Make sure that you draw everything to scale.

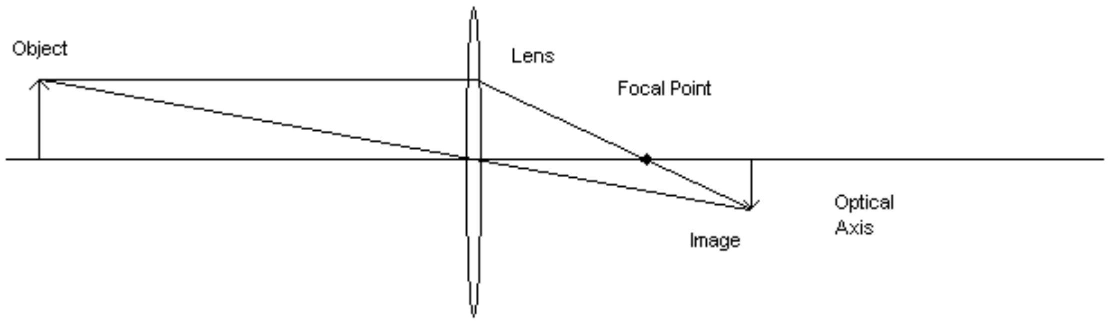


Step Three: Draw a ray parallel to the optical axis from the top of the object to where it meets the center of the lens. (Note: To simplify things, the lens can be drawn as a single vertical line.) This ray will go form the center of the lens, through the focal point, to the



top of the image.

Step Four: Draw a line from the top of the object through the center of the lens to the top of the image.



This is one of the most straightforward ways to create a ray diagram for a positive lens.

This method can be used to predict where an image is going to be. It also can be used to predict how big the image is going to be. Alternatively, if you know where the image is, you can find how big and how far away the object was.

How Light Travels

Light is composed of electromagnetic waves. These waves travel in a straight line that can be though of as a ray. A ray has an origin and direction. This ray of light will travel in a straight line until its path crosses into a different medium. Once the light ray enters the other medium, it is bent into another direction (either away from or closer to the surface normal). The amount that the ray of light is bent is determined by Snell's Law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

The subscripts denote which medium the light is coming from (medium 1) and is entering (medium 2). The angle θ_x is the angle that the ray makes with the surface normal within the given medium. The index of refraction of the medium is designated n_x. The index of refraction is the ratio of the speed of light in vacuum to the speed of light in the medium:

$$n = \frac{c}{v}$$

The letter c is the speed of light in vacuum ($3*10^8$ m/s) and the letter v is the speed of light in the medium. Common values for n are:

n = 1 for vacuum and air
n = 1.333 for water
$n \cong$ 1.5 for glass

Lenses

When you look at a very distant object (very distant is defined as the distance to the object is very large when compared to the focal length of the lens) an image will form at the focal point. This image will be upside down and much smaller than the object. A camera works based on this principle. A converging lens focuses an image on the film.

Positive Singlet

There are many different types of lenses, from single pieces of glass called singlets to complex multiple-element lenses found in expensive cameras. We use singlets in this module. Singlets can either have positive or negative power. Negative singlets can be used with positive powered lenses to create types of telescopes and other such devices.

Positive lenses are lenses that are thicker in the middle than on their edges. Their shape is what causes the light to bend and come to a focus. This module deals only with positive lenses.

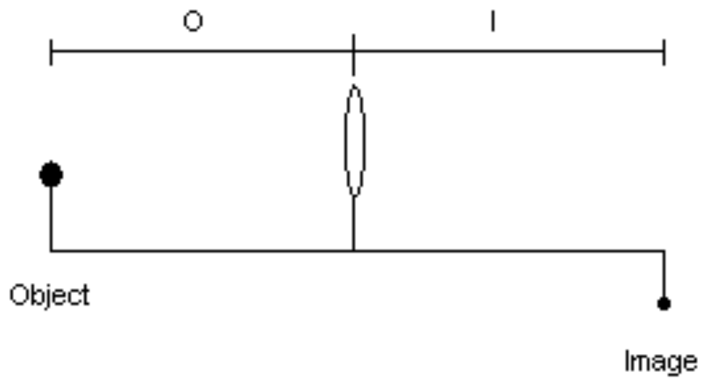
Positive lenses are used to create images. Light comes from an object and passes through the lens to form an image (see "Going Further: Ray Tracing and Diagrams"). There are two types of images that can be formed with positive lenses. A real image is one that can be projected onto a surface. A real image and its original object are always on opposite sides of the lens. An example of a real image is the image created by an overhead projector.

In contrast, a virtual image is one that cannot be focused onto a screen. It can only be seen by looking back at the object through the lens. An example of a virtual image is when you look through a magnifying glass.

Lenses are designed using the following equation called the Thin Lens Formula:

$$\frac{1}{O} + \frac{1}{I} = \frac{1}{F}$$

where O is the distance from the object to the lens, I is the distance from the lens to the image, and F is the focal length of the lens.



There are two common methods to measure the focal length of a positive lens. The simplest method is the “object at infinity” method. If you use an object that is very far away (many times longer than the focal length such as a distant building, light bulb, etc.), O becomes very large, so 1/O becomes very small. Assuming 1/O very close to zero, the equation above becomes I = F. In other words, the image forms at the focal point.

Two positive lenses can be put together to create refracting telescope. It is called a refracting telescope because it is made of lenses that bend or refract the light. There are two lenses used in the refracting telescope contained in the module. The lens that is held closest to the eye is called the eyepiece and the lens that is farthest away is called the objective (or objective lens). The objective creates a real image (see “Building a Refracting Telescope II”). This real image then becomes the object for the eyepiece and the eyepiece acts as a magnifier.

Lenses suffer from a problem called chromatic aberration. The index of refraction varies slightly for different colors of light. The index of refraction is slightly higher for blue light than for red light. Dispersion is the name given to the process of a lens spreading out different colors of light. If you try to focus and object with a single lens, you will see some color fringes. This effect is particularly noticeable for larger lenses and at higher magnification. Therefore, it is not a significant problem in the human eye.

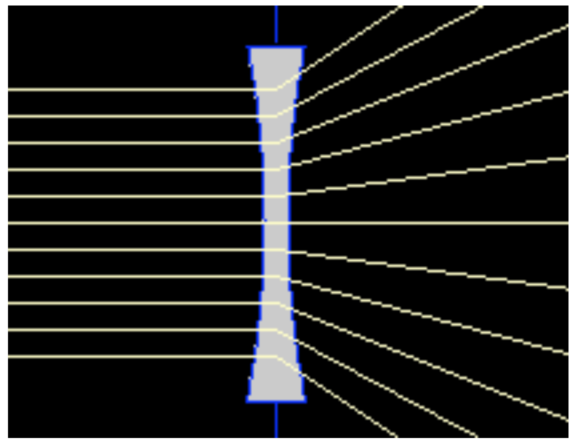
Compound Lens:

Chromatic aberration can be corrected by using compound lenses. Compound lenses consist of two or more singlets. The singlets can have air, oil or other substances in between them to help achieve the desired focal length and correct chromatic aberration.

The problem can be further reduced by using special low dispersion glass. Modern glass containing fluorite is frequently used in high quality refractor telescopes due to its low dispersion.

Lenses are not the only optical component that can create real images. A concave mirror can create real images as well. Like the positive lens, the concave mirror reflects light in such a way that it can come to a focus at a focal plane. Concave mirrors are important because they are used in many types of reflecting telescopes.

Diverging (Negative) Lenses



All of the lenses used in this module are converging lenses and have a positive focal length. It is also possible for lenses to spread light out. These lenses are called diverging lenses.

Diverging lenses are concave. Concave lenses take light rays that are parallel and spread them out. The rays spread out so they appear to be coming from a common point. The focal point of a diverging lens is on the same side of the lens as the light source. The focal length of a diverging lens is negative since it is on the opposite side of the lens as the focal point of a converging lens.

Eyeglasses

Most people's eyeglasses are negative lenses, as opposed to the positive lenses used in this module. Therefore using your or a student's glasses (those which correct for nearsightedness or farsightedness) for the experiments in this module will not usually work. For those individuals who have reading glasses, their glasses can be used in the experiments in the module. Reading glasses are composed of positive lenses.

The reason that people have glasses is that their eye either focuses light in front of or behind the retina. The retina is responsible for taking the image that is focused on it and turning it into an electrical signal that our brain can interpret. People who have images focusing in front of the retina are said to be nearsighted and have the condition called *myopia*. People who have images in focus behind the retina are said to be farsighted and have the condition called *hyperopia*. Most people who have eyesight problems are myopic; the condition results in blurry images. Negative lenses are used to correct myopia and positive lenses are used to correct hyperopia.

One way to check to see if you are myopic or hyperopic is to take off your glasses, hold them in front of you and look at a distant object. If that object appears bigger through your glasses than without you have hyperopia; if that object appears smaller you have myopia.

Another affliction that can affect a person's eyesight is astigmatism. Astigmatism occurs when the lens in the eye is not completely circularly symmetric, meaning that the curvature of the lens from top to bottom is different than the curvature from left to right.

Glasses and contact lenses can be made to correct for astigmatism. To test if your glasses are astigmatic, look at a distant object through one of the lenses in your glasses, like a clock on the wall. Then rotate your glasses. If the object does not change shape your eyes are not astigmatic. However, if the object appears to stretch as you rotate your glasses (Salvador Dali-like clocks), then your eye is astigmatic.

You may have one or both eyes that are astigmatic. To correct your vision properly, the astigmatic lens must be held in place to compensate for the astigmatism in your eye. This is easily done with the frames of glasses. Contact lenses are held in place by putting a small weight at the bottom of the lens causing gravity to hold it in the proper position.

One topic that is not discussed in the module is the power of a lens. The units for power of a lens are diopters. The Power of a lens is defined as $P=1/f$ where P is the power of the lens and f is the focal length. Power is measured in units called diopters. One diopter, or 1D, is equal to 1/meter. For a positive lens with a 100-mm focal length, its power is 10D. A negative lens would have a negative power. If we had a negative lens with a -50-mm focal length, its power would be -20D. The prescription that a doctor writes for glasses is given in diopters.

In this module we have found that lenses can be used to create images of objects and can be used to make objects appear larger. Have you ever wondered why, when you put on your glasses, the size of things does not change? The reason for this is that eyeglasses are set on the nose at a special distance away from the lens in the eye. The distance is equal to the focal length of the lens in the eye. The human eye has a power of about 60D, or a focal length of about 17 mm. We have explored combining two lenses in this module but we have not seen an equation that describes what happens when you combine two lenses.

Partial Lenses

What happens when you cover up part of a lens? Does part of the image go away? Does the image get brighter or dimmer?

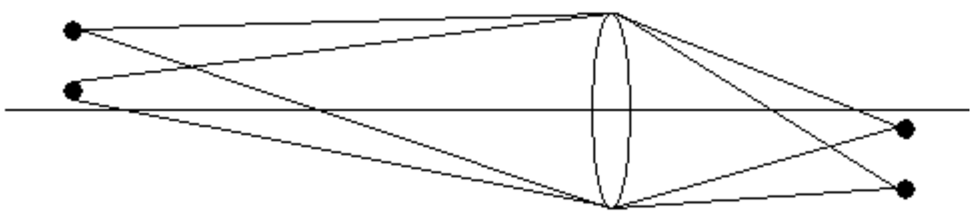
First off we have to revisit the ray model described earlier in this section. Three main points to remember are:

1. that light rays are emitted uniformly in all directions from a point source,
2. only the rays that enter the lens are focused at the image, and
3. points on the object map to points on the image.

Let's consider two points on an object that has limited extent (it is not considerably large when compared to the size of the lens) that are emitting light rays in all directions.

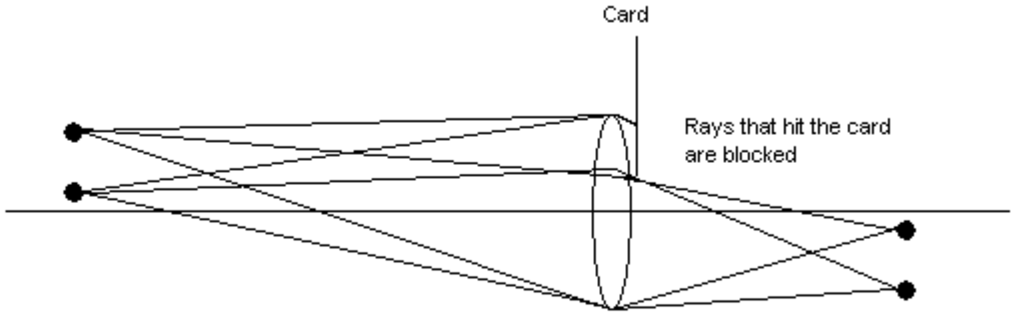
As the light rays travel farther from their source and closer to the lens they separate from each other. This is why light from a light bulb gets dimmer the farther away from it you get – the light is being spread out over a greater area. Since the points are close together and are about the same distance from the lens, the same amount of light from each of the point sources is incident on the lens. Also, since the point sources emit light in all directions, every bit of surface area on the lens has rays incident on it from both sources.

Once the light rays enter the lens they get bent and travel to where they cross each other and form images of each of the two point sources.

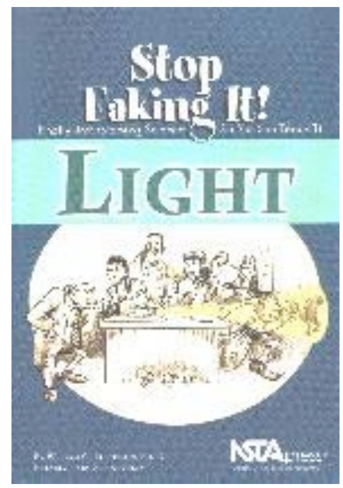


So to create the image of the point sources, the light from the top of the lens adds with the light from the middle of the lens, adds with the light from the left side of the lens and so on to create a bright image of the object. So now what happens if we cover part of the lens? Since light from each of the points is spread out over the entire lens we will not cut off part of the image, we simply just lose light! The larger the area of the lens that is blocked, the less light that can be collected, and the image gets dimmer.

Below is an experiment that can be tried in the classroom to test this discussion.
- Set up a single lens with a Styrofoam holder between a bright source and a velum screen.
- Turn off the lights in the classroom so the image is very bright.
- Adjust the spacing of the elements so that image is in focus.
- Now take a card and move it just behind or in front of the lens.
- Notice that the image gets dimmer as the card blocks more of the light.



For a more examples and a detailed explanation of how light works, consult the book *Stop Faking It!: Light* by William C. Robertson (NSTA Press). This book discusses reflection, refraction, and the nature of light.



Common Misconceptions About Light

Many people hold some common misconceptions about the nature of light and reflections. One of the biggest challenges teachers face is getting students to recognize these erroneous ideas and correct them.

In this section, we will attempt to address a few of the common misconceptions. You will find suggestions on how to bring out the student's misconceptions as well as demonstrations to help dispel them.

Myth: Light always travels in a straight line.

By now, students should be familiar with examples that show light does not always travel in a straight line. They have seen light reflect off mirrors and observed light refract when it passes from air to the acrylic block in a demonstration in Terrific Telescopes.

Light does travel in a straight line when it is traveling in a uniform medium. The direction light travels changes when the medium it travels through changes. This change in medium can cause reflection, refraction, or even absorption of the light.

Through these modules, students have only seen sudden changes in the direction of light, such as when light reflects off of a mirror or when it travels from air to plastic. The change in index of refraction can also be gradual, causing the path of light to gently curve. An example of this phenomenon is when sunlight encounters Earth's atmosphere. The upper layers of the atmosphere are very thin and have a lower index of refraction. The lower layers of the atmosphere are thicker and have a higher index of refraction. This changing index of refraction causes the path of the sunlight to curve.

An interesting consequence of this is that refraction slightly alters the time of sunrise and sunset. Refraction will make the Sun appear about half a degree higher in the sky than it really is (34 arc minutes on average). Therefore, the Sun appears to rise a few minutes earlier and set a few minutes later than it would if Earth had no atmosphere!

Myth: Light travels infinitely fast.

Light travels fast, but it has a finite speed just like everything else. Light in a vacuum travels at $3*10^8$ m/s. The speed of light in a vacuum is sometimes called the speed limit of the universe.

Direct evidence that light has a finite speed is difficult, but not impossible to illustrate. Remember that refraction occurs due to the fact that the speed of light changes when it passes from one substance into another.

Another interesting way to see the effect of the speed of light is using satellite television.

Set up two televisions side by side. Have one of the televisions connected to an antenna. Connect the other television to cable or a satellite dish. Tune them both to the same local channel. You will notice that the television connected to the antenna receives the signal first!

What's going on? Cable or satellite television bounces the signal to a satellite in geosynchronous orbit about 22,000 miles above the Earth's surface. The signal for cable or satellite television must travel to the satellite and back – meaning it gets to the television later due because it travels a greater distance.

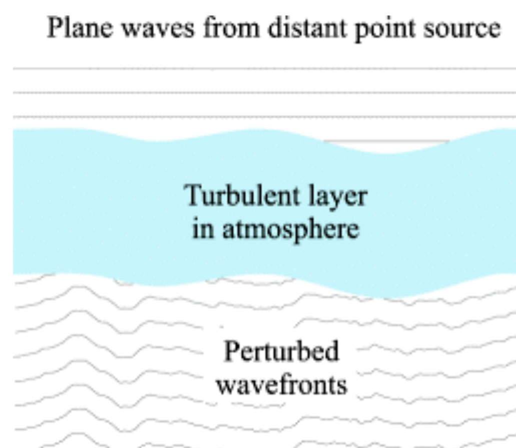
Myth: You can use a telescope to magnify objects as much as you desire.

Many people believe you can always increase the magnification of a telescope. It is not uncommon to see advertisements for telescopes with diameters as small as 2 inches that will advertise magnifications of 575x!

Small telescopes cannot achieve such large magnifications for a variety of reasons. Even assuming perfect optics, a telescope is limited by its resolution. Resolution is the ability of a telescope to see fine detail and separate closely spaced objects. Resolution depends primarily on the diameter of the telescope. If you try to magnify an object beyond the resolution of a telescope, you get a dim, fuzzy image.

A general rule of thumb for astronomers is that the maximum useful magnification for a telescope is about 50x per inch of aperture. Therefore, a 2 inch telescope generally cannot magnify more than about 100x. The 50x per inch of aperture assumes you have very good optics (not always the case in inexpensive telescopes) and that the atmospheric seeing is very good.

The atmospheric seeing is another limiting factor in telescope resolution. If you have ever looked at hot pavement on a summer day, you have probably seen "heat waves." The heat waves are due to the fact that the index of refraction of air is very temperature-dependent. As the pavement heats up, the hot air above the pavement rises and causes turbulence. As light passes through air of different temperatures, its path is changed, leading to the heat waves.



As light passes through turbulent layers in our atmosphere, the waves become distorted.

Earth's atmosphere has a similar effect on light at night from the stars and planets. You can see this effect in the twinkling of stars. Even on a relatively calm night, a telescope will magnify any distortion present in the atmosphere. The best observing sights in the world rarely have seeing better than one arcsecond (one arcsecond is 1/3600th of a degree). More common is 2 to 3 arcsecond seeing or worse.

The Hubble Space Telescope was launched to get above the Earth's atmosphere. Although the Hubble has a relatively modest sized 2.5 meter primary mirror, it does not have to look through Earth's atmosphere, yielding much sharper views. The Hubble Space Telescope has a resolution of about 0.1 arc seconds, 10 times sharper than is typically possible from the ground.

In recent years, great advances have been made in overcoming the effects of atmospheric seeing through a process called adaptive optics (AO). Adaptive optics systems work by observing a star to precisely measure the distortions caused by Earth's atmosphere. Once the distortions are measured, they can be removed by quickly and precisely changing the shape of a small, flexible mirror in the telescope. Ground-based telescopes may soon produce images as good as the Hubble Space Telescope using adaptive optics systems.

Myth: An image is always formed at the focal point of the lens.

The focal point of a lens is where light rays that start out parallel will converge and form an image. Many physics books state that light rays from a distant object are parallel. While the light rays are not truly parallel, they are moving apart very slowly and will converge very close to the focal point.

For an object that is close to a lens or mirror, the incoming light rays are traveling in very different directions. Since the light rays are not close to parallel, they will not converge at the focal point. You can find where they will converge through careful ray tracing or by using the equation $\frac{1}{f} = \frac{1}{O} + \frac{1}{I}$.

Glossary

Angle of incidence – The angle between the surface normal and the incoming ray.

Angle of refraction – The angle between the surface normal and the outgoing (refracted) ray.

Focal length – The distance between a lens and its focal point. The focal length remains fixed for a given lens.

Focal point – The point where the parallel light rays from an object placed at infinity are focused after passing through a lens. The focal point is determined by the curvature and index of refraction of the lens.

Image – Where the light rays emitted from an object cross.

Image distance – The distance between a lens and the plane where its image is formed.

Image plane – A plane in space where an image is formed.

Index of refraction –The ratio of the speed of light in a vacuum to the speed of light in the material, $n = \frac{c}{v}$

Lens – A piece of transparent material (e.g., plastic or glass) that is used to bend light rays.

Magnification (m) – The ratio between the size of an image and the size of the original object viewed with the naked eye, $m = \frac{h_{image}}{h_{object}}$, using the same units. Magnification can also be calculated from the focal lengths of the lenses: $m = \frac{f_{objective}}{f_{eyepiece}}$.

Medium – A substance through which a wave passes, such as air or water. Plural: media.

Object – Anything in an optical system that is used to create an image. Objects can either emit or reflect light.

Object distance – The distance between an object and the lens.

Optical system – A series of lenses, mirrors and/or other optical devices aligned in such a way as to perform a task, such as creating an image.

Refraction – The turning or bending of light as it passes between different media with differing optical properties.

Resolution – A measure of the amount of detail that can be distinguished, especially when using optical systems such as telescopes.

Snell's Law – The scientific law that describes how much light is bent when it passes from one medium to another, $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Surface normal – A line that is perpendicular to a plane surface, against which angles are measured. Also simply called the normal.

Appendix: Education Standards

National Science Education Standards (National Research Council, 1996), grades 5-8, supported by this module include:

- Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems (Unifying Concepts and Processes, p. 117).
- Use appropriate tools and techniques to gather, analyze, and interpret data (Standard A – Inquiry, p. 145).
- Develop descriptions, explanations, predictions, and models using evidence (Standard A – Inquiry, p. 145).
- Think critically and logically to make the relationships between evidence and explanations (Standard A – Inquiry, p. 145).
- Communicate scientific procedures and explanations (Standard A – Inquiry, p. 148).
- Use mathematics in all aspects of scientific inquiry (Standard A – Inquiry, p. 148).
- Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object – emitted by or scattered from it – must enter the eye (Standard B – Physical Science, p. 155).
- Design a solution or product (Standard E – Science and Technology, p. 165).
- Implement a proposed design (Standard E – Science and Technology, p. 165).

Principles and Standards for School Mathematics (National Council of Teachers of Mathematics, 2000) for grades 6-8 supported by this module include:

- Understand measurable attributes of objects and the units, systems, and processes of measurement (Measurement, p. 240).
- Apply appropriate techniques, tools, and formulas to determine measurements (Measurement, p. 240).
- Develop and evaluate inferences and predictions that are based on data (Data Analysis and Probability, p. 248).
- Organize and consolidate their mathematical thinking through communication (Communication, p. 268).
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others (Communication, p. 268).
- Use the language of mathematics to express mathematical ideas precisely (Communication, p. 268).
- Recognize and apply mathematics in contexts outside of mathematics (Connections, p. 274).
- Create and use representations to organize, record, and communicate mathematical ideas (Representation, p. 280).
- Use representations to model and interpret physical, social, and mathematical phenomena (Representation, p. 280).

Standards for Technological Literacy: Content for the Study of Technology (International Technology Education Association, 2000), grades 6-8, supported by this module include:

- Design involves a set of steps, which can be performed in different sequences and repeated as needed (Standard 9F, p. 103).
- Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions (Standard 9H, p. 103).
- Apply a design process to solve problems in and beyond the laboratory-classroom (Standard 11H, p. 120).
- Make two-dimensional and three-dimensional representations of the designed solution (Standard 11J, p. 121).
- Test and evaluate the design in relation to pre-established requirements, such as criteria and constraints, and refine as needed (Standard 11K, p. 121).
- Interpret and evaluate the accuracy of the information obtained and determine if it is useful (Standard 13I, p. 137).
- The use of symbols, measurements, and drawings promotes a clear communication by providing a common language to express ideas (Standard 17K, p. 171).

References

International Technology Education Association. 2000. *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA: ITEA.

National Council of Teachers of Mathematics. 2000. *Principles and Standards for School Mathematics*. Reston, VA: National Council of Teachers of Mathematics.

National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academies Press.