Hands-On Optics
Making an Impact with Light
An educational collaboration
of SPIE, OSA and NOAO
Sponsored by the National Science Foundation

Hands-On Optics Mini-Kit

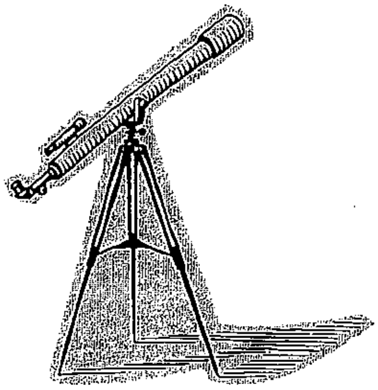
Terrific Telescopes

Hands-On Optics (HOO), an educational collaboration of The International Society for Optical Engineering (SPIE), the Optical Society of America (OSA), and the Association of Universities for Research in Astronomy, Inc. (AURA), is sponsored by a grant from the National Science Foundation.

Contents

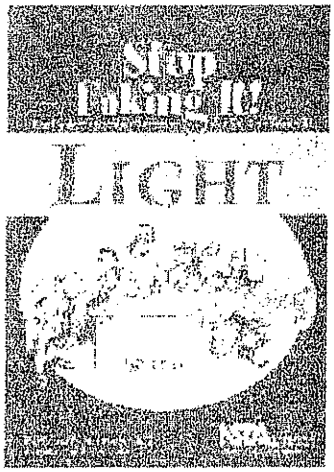
Overview : Terrific Telescopes

In *Terrific Telescopes*, students will explore basic properties of positive lenses. Positive lenses are used to focus rays of light to create images. Through the use of hands-on activities, exciting experiments, and teacher-lead demonstrations, the students will find properties of lenses such as the focal length and the "flip-point". Students will also learn how to use a single lens and other household objects as simple magnifiers. Then the students will discover how to combine two lenses together to create a simple refracting telescope. Throughout the module are teacher lead demonstrations showing how light bends and how lenses are used to create colorful images.

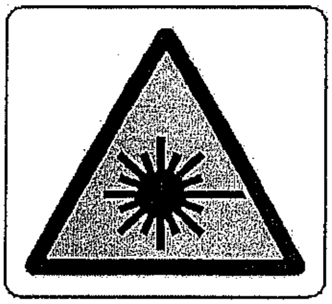


This kit has been prepared for Astronomy From the Ground Up. It is based on the Hands-On Optics program. This manual begins with a "Summary of Activities" that describes the basics of each activity as well as the approximate time required. "Learning Goals, Standards and Assessment" will help you understand what the students are expected to understand from this module and how you can determine their understanding. Next a "Materials: Master List" is provided; more details are provided within each activity, the descriptions of which follow this list. Many of the demonstrations and activities can be set up in advance. Although the demonstrations and activities do not require extensive knowledge of optics, it would benefit you to read the entire module and do all the activities on your own before presenting them to your class. Finally, additional background information on the relevant concepts and a description of common misconceptions are provided near the end of the module. It is also recommended that you read *Stop Faking It: Light*, by William C. Robertson (NSTA Press), which will help you understand the basic science concepts in an entertaining and insightful manner.

Six Basic Science Process Skills:
- Observation
- Communication
- Classification
- Measurement
- Inference
- Prediction



Summary of Terrific Telescopes Activities



Light Through an Acrylic Block: A Demonstration: 10-15 minutes

Starting with a laser shining at normal incidence 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.

Light Passing Through a Convex Lens : A Demonstration : 15-20 minutes

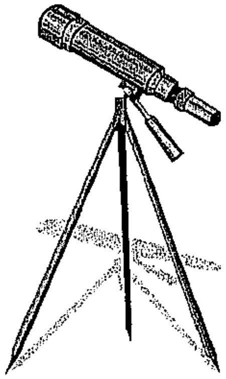
When parallel light beams encounter an object such as a lens, its shape can cause different light rays to bend by different amounts. Students predict the path of the rays through an acrylic block and through a lens, then determine if they are correct by using a mister or chalk dust to expose the laser 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 be used as a magnifier as well.



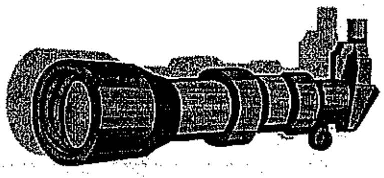
Build a Refracting Telescope I: 30-40 minutes

This is the first of several activities relating to refracting telescopes. 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 Refracting Telescope III: 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.



A Measure of Resolution: 30-40 minutes
Using the telescopes from the previous activity, students will make and graph measurements to compare the telescope's resolution with that of their eye. Additional options include the comparison of the telescope's measured resolution to its theoretical resolution.

Build a Three-Lens Refracting Telescope: An Activity for Student Assessment: 50-60 minutes
What happens to a telescope's image when a third lens is added to the system? Students will find that a third lens creates an upright image and will draw the optical layout of such a system.

Introudction to Ultraviolet Light
Using a black light and some ultraviolet sensitive beads, you students will learn about ultraviolet light.

Learning Goals, Standards, and Assessment

This module starts off with a demonstration to start students' investigating how light bends. Students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe. Through multiple activities they build a refracting telescope and measure its resolution. There are formative assessment opportunities throughout the module to gauge student comprehension. This module follows a "Learning Cycle" framework (exploration, concept introduction, concept application); however, it can be adjusted to follow the learning style framework that best fits your group.

Essential Features of Inquiry

- Learners are engaged by scientifically oriented questions
- Learners give priority to evidence
- Learners formulate explanations
- Learners evaluate their explanations based on scientific knowledge
- Learners communicate and justify explanations

The goals for this module are that 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.
- A convex lens can cause parallel rays of light to converge.
- The point at which parallel light rays meet after passing through a lens is called the focal point.
- The distance from the lens to the point where the light rays meet is called the focal length.
- Converging lenses can be used to project an inverted image onto a screen.
- 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.
- 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.
- The first lens creates an inverted, real image on the screen.
- The second lens acts as a simple magnifier, making the image larger.
- How to assemble a simple refracting telescope.
- How to estimate the magnification of a refracting telescope.
- Resolution is a measure of how much detail can be observed.
- How to determine the resolution of objects.

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).

Information about state standards will be available on the *Hands-On Optics* website, http://www.hands-on-optics.org/.

Embedded Assessment Opportunities

Light Through a Glass Block: A Demonstration and Three Lasers Converging at a Focal Point (Demonstration)

In both of these activities, students have the opportunity to make predictions about how light will travel as it moves from one substance to another with a non-zero angle of incidence. In the "Three Lasers" activity, they should indicate on their handouts that the beams travel in a straight line (and therefore do not cross) when the beams go through an acrylic block, but will cross one another when going through the large positive lens.

Finding the Focal Length Using a Distant Object

Teacher observations of students' measurements during this activity should allow you to gauge their understanding of focusing an image on a screen and finding the focal lengths of the lenses. The focal lengths of the lenses are 7.5-cm and 20-cm, as indicated on the lens boxes. Students' findings ideally should be as close to these numbers as possible. Students should also indicate that the focused image is inverted.

Simple Magnifiers

The worksheet for this activity serves as an assessment for student understanding of the lessons thus far. As they look at various objects with the lenses, students should determine that the magnification of the 20-cm lens is less than that of the 7.5-cm lens. They should notice that the magnification increases as the distance to the object increases, until the flip point is reached Finally, students should find that the flip point of the lens is located at the focal point and so the distance to the object at the flip point is approximately equal to the focal length.

Build a Refracting Telescope I

Observing students' manipulation of the lenses should give you an idea of whether or not they understand the ideal arrangement of the lenses in a telescope. Ultimately they should determine that a greater magnification can be achieved by using the shorter focal length lens as the eyepiece and the longer focal length lens as the objective.

Build a Refracting Telescope II

As students manipulate the lenses, they should discover that the distance between the lenses is slightly less than the sum of the focal lengths. This question is addressed at the end of "Build a Refracting Telescope I" and reinforced here. They should also recognize that it is not necessary to have a screen and that it can be removed.

Build a Refracting Telescope III

The telescope in the kit should be built and should function properly (i.e., students should be able to get focused images of distant objects through the telescope).

A Measure of Resolution

The calculations of resolution should show that the telescope's resolution is on the order of .002 radians while that of a "normal" eye (this could be with corrective lenses) is approximately .02 radians. You should note that the actual resolution of the telescopes could be quite different from the theoretical resolution because of the low-quality optical components; the resolutions of different telescopes may also vary across the class.

Build a Three-Lens Refracting Telescope: An Activity for Student Assessment

In this culminating activity, students should be able to determine that by adding a third lens to a refracting telescope, the image will invert a second time and so the image will appear upright. A drawing of the optical layout can be used to determine students' understanding of the light path.

Additional Assessment Ideas

Students could keep a science journal to document the key objectives they learned from each activity. They could record what they did, what science process skills they used, and possible applications.

Have the students make a KWL chart. A KWL chart consists of three columns. The K is for what the student knows about the topic (or think they know). W is for what the student wants to learn. The L column is where the student records what was learned.
Following this module, ask your students to write about various cultural views of light and mirrors. They can either write a story from their cultural background, or they can research another.

Students could write a letter to another student who doesn't know about optics explaining how light refracts.

Students could go to the library and research the nature of light online. They could look at lenses, telescopes, eyeglasses, and ray diagrams for a whole new understanding of refraction and magnification.

Choose a common misconception from the provided list and hold a debate with each side proving evidence to support their perspective on this topic. See if the students could design an experiment to establish the truth or falsity of an item.

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.

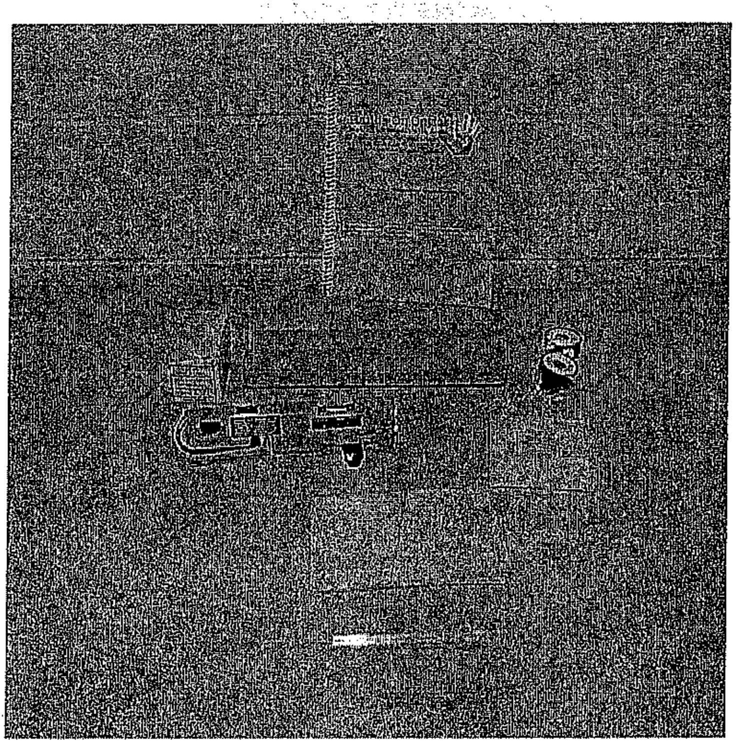
Materials: Master List

Materials provided in the Hands-On Optics Kit

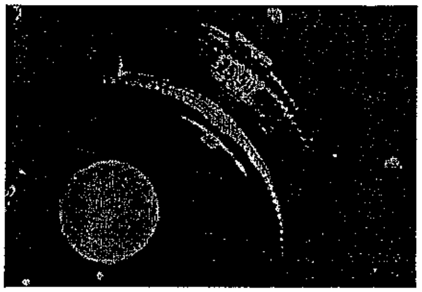
- ☐ 5 short focal length (7.5-cm) positive lenses
- ☐ 5 long focal length (20-cm) positive lenses
- ☐ 5 velum screens
- ☐ 5 telescope kits
- ☐ 1 laser pointer
- ☐ 1 large positive lens
- ☐ 1 acrylic block
- ☐ 3 resolution charts (labeled Figure 8.1)
- ☐ 1 Avon Derma Spec light
- ☐ 1 bag of ultraviolet sensitive beads

Materials to be supplied by educator

- ☐ Flashlight
- ☐ Scissors
- ☐ Styrofoam cups (to serve as lens holders)
- ☐ masking tape
- ☐ rulers

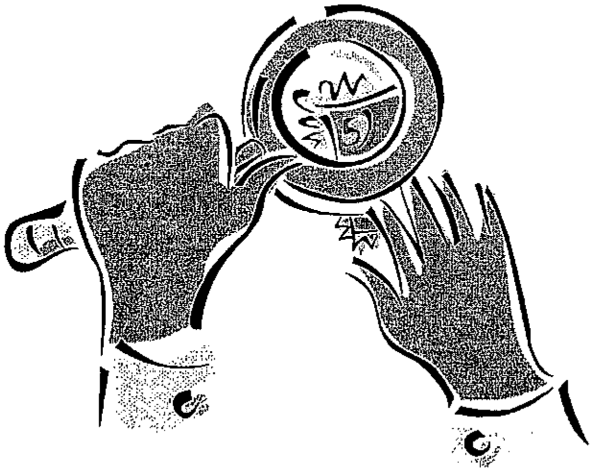


Introduction to Lenses



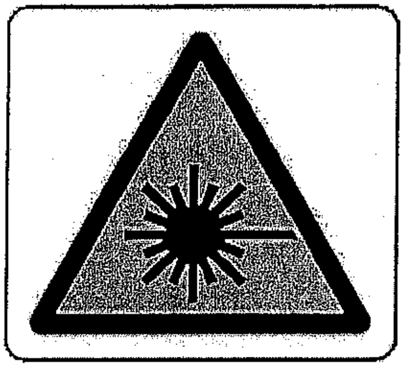
For centuries people have shaped and polished glass to make lenses for eyeglasses, telescopes, and cameras. Today, other materials such as plastics are molded and manufactured to make contact lenses, toy binoculars, and disposable cameras. Everyday people use lenses to harness and control light to perform a multitude of tasks ranging from the ordinary to mystifying.

All of the great inventions mentioned above are based on the same fundamental instrument: the lens. The lens is called an instrument here because it is a tool that can be used to shape and manipulate light. In this module, you will investigate the basic uses of positive lenses. You will learn how they create images and how they can magnify objects. You will also learn how combinations of lenses can be used to make telescopes and binoculars.



LASER SAFETY

Laser safety is important!



Never look into the laser. Be aware of where the beam is aimed at all times. Never look into the beam to see if it is on. Point the laser at a wall or at the floor to see if the beam can be seen.

Only turn the laser on when it is aimed in a safe direction, away from people.

Always keep your head away from and above the laser beam.

Do not wave the laser around the room or shine it on other people. Do not move the beam when it is on, if possible.

Do not allow the beam to inadvertently reflect from metal or glass surfaces. Take off any shiny jewelry such as watches, rings, or bracelets that may reflect the laser light into your or someone else's eyes. Be aware of reflective surfaces that are near the path of the beam.

Do not turn the laser on until you are aware of where it will go and are convinced that it will not shine in someone's eyes directly or through a reflection.

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.

What You Need

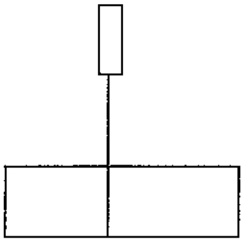
For the class:

☐ 1 acrylic block
☐ 1 laser pointer

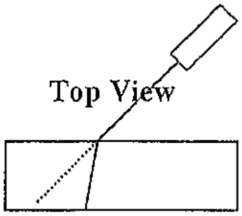
Getting Ready

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...

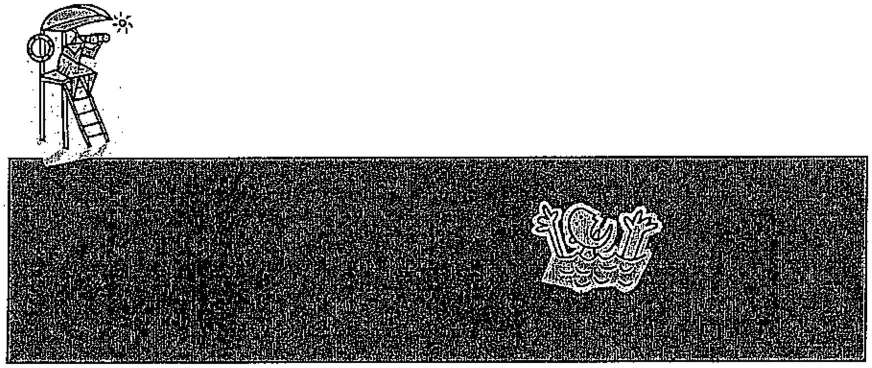
When light travels from air to glass, the speed of light will decrease. This change in speed causes the light to change its direction of travel at the boundary. Light follows Fermat's Principle. Fermat's Principle states that light will take the path between two points that is the shortest in time (i.e., 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.

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.

6. You can simulate what happens when light hits a boundary by having your students represent a wavefront.

   You will need a large area in which to do this activity. Have your students stand in a line and hold hands. Draw a line on the floor or use a pre-defined boundary. If you are in the gym, use a line on the court. If you go outside, use a boundary such as where pavement and grass meet. Make sure the line of students is not parallel to your boundary (remember, refraction only occurs if the angle of incidence is not zero degrees!)

   Tell your students to walk toward the boundary taking large steps. Instruct your students to take baby steps as soon as they cross the boundary but not before. Since you approach the boundary at an angle, some students will start taking baby steps before others. Due to this, the line of students will change direction when they encounter the boundary, similar to how light changes direction when it encounters a boundary. In this case, the direction they are traveling will bend toward the normal.

   You can also simulate what happens when light speeds up. Repeat the demonstration, but have the students start out taking baby steps. When they encounter the boundary, have the students start taking large steps again. Notice that the direction the students are traveling bends away from the normal in this case.

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:

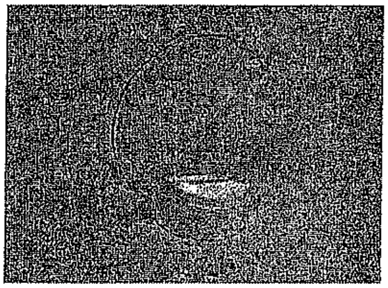
- ☐ 1 laser pointer
- ☐ 1 acrylic block
- ☐ 1 velum screen or a wall
- ☐ 1 large positive lens

For each student:

- ☐ Copy of "STUDENT HANDOUT: Which Laser Produced Which Spot?"

Getting Ready

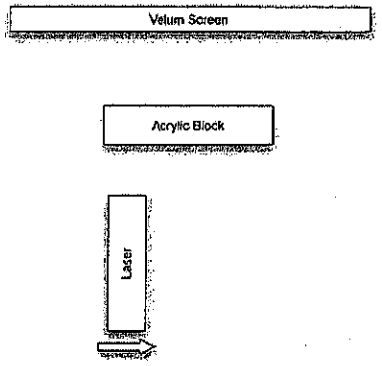
1. Clear a space on a table. Set the laser on the table by rotating its legs until the are perpindicular to the laser body.
2. Set up a velum screen several feet away from the lasers (or alternately, have the lasers project onto a wall or other vertical surface).
3. Make a holder for the large positive 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.



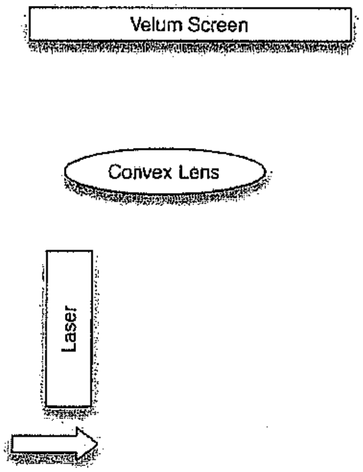
Lens holder made from a Styrofoam cup.

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.
4.

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.

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.

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…"

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

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

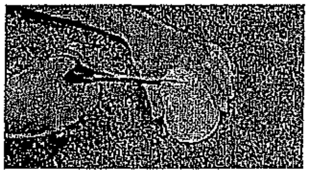
What You Need

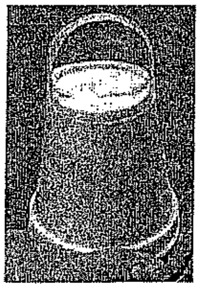
- ☐ 1 thick convex lens
- ☐ 1 thin convex lens
- ☐ 1 velum screen
- ☐ 3 Styrofoam cups
- ☐ ruler

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

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

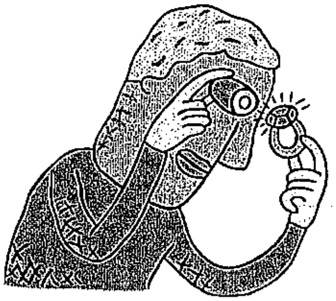
For each student:

☐ 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.

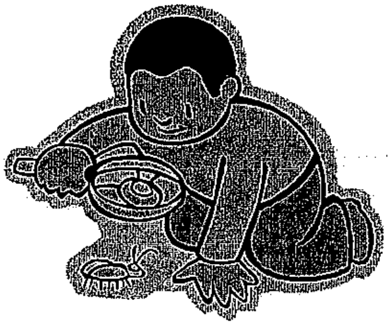
Going Further

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
- ☐ 1 7.5-cm focal length (thicker) lens
- ☐ 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.

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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:

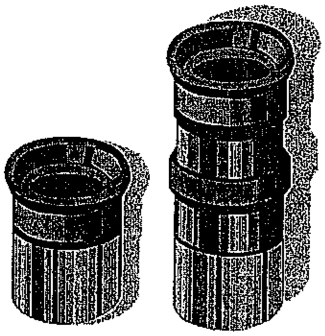
☐ Colored lamp (optional) or open window

For each group of 2-3 students:

☐ 1 20-cm focal length lens
☐ 1 7.5-cm focal length lens
☐ ruler

Getting Ready

Select an object that is several meters away from all the students for them to focus on. The object can be a car or tree outside of a window or you can buy a small neon lamp and place it in the corner of the room.



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...

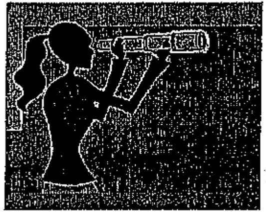
Light from a source (such as our colored lamp or a star) will travel to the telescope and pass through the first (closets to the object) converging lens. This lens will create a real image of the object. This lens is also called the objective lens. The second converging lens is placed less than one focal 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
- ☐ 1 7.5-cm focal length lens
- ☐ 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?

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6. With your best arrangement, again look at the distant 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.

7. 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?

8. 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.

9. 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.

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

11. 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.

12. 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.

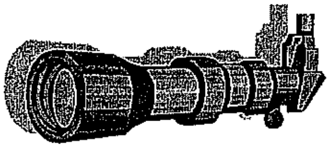
Students Will Learn...

- 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
☐ 1 7.5-cm focal length lens
☐ 1 velum screen
☐ 3 Styrofoam cups
☐ tape
☐ ruler

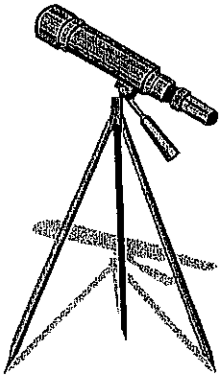
Getting Ready

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...

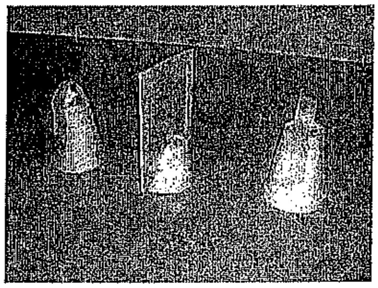
Students frequently have difficulty understanding the function of the lenses in a refracting telescope. This activity attempts to make the role of each lens clear. The front lens, or objective, is placed one focal length from the screen. The lens focuses the light and creates a smaller, inverted image. 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
- ☐ 1 7.5-cm focal length lens
- ☐ 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 object 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 Refracting Telescope III

Overview

Students will build a small refracting telescope. The lenses will be held in place inside two telescoping cardboard tubes. By sliding the tubes, students can focus the telescope on objects at different distances.

Students Will Learn...

- How to assemble a simple refracting telescope.
- How to focus a refracting telescope.
- How to estimate the magnification of a refracting telescope.

What You Need:

For each group of 2-3 students:

- ☐ 1 telescope kit for each group which includes:
  - ☐ a foam lens holder
  - ☐ a lens (43mm diameter)
  - ☐ a lens (17.5-mm diameter)
  - ☐ a pair of telescoping tubes
  - ☐ an eyepiece spacer
  - ☐ a cardboard washer
  - ☐ a plastic cap

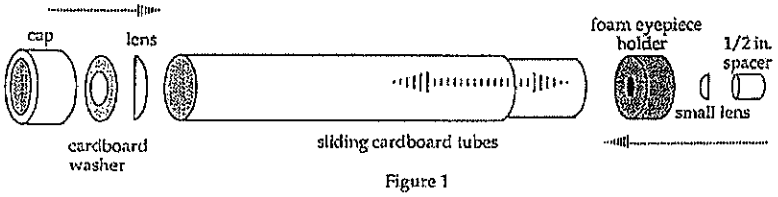


Figure 1

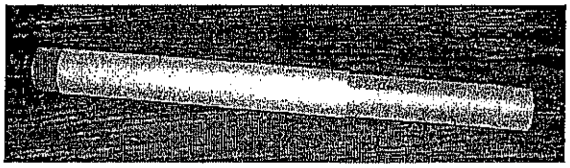
Getting Ready

Check the kit to be sure each group will have the required items. Provide a soft cloth to each group so they will be able to handle the lenses without getting fingerprints on them.

GO: Build a Refracting Telescope III

1. Distribute the telescope kits to the students.

2. Have the students assemble the telescopes using the directions in "STUDENT HANDOUT: Build a Refracting Telescope III."



3. Have the students complete the worksheet.

4. Have the students begin the next activity, "A Measure of Resolution," after their telescopes are complete. If you need to reuse the telescopes with different classes, have students complete the Resolution activity prior to disassembling the telescopes.

What's Really Happening Here...

The students have fixed the lenses in place. The configuration is the same as the previous two activities, although different lenses are used. The longer focal length objective lens creates a small, inverted image which is then magnified by the eyepiece. The lenses have focal lengths of 400mm and 25mm respectively, yielding a telescope that will magnify objects sixteen times.

Going Further

Consult activities (mostly on angular resolution) from *Telescope Kit Teacher's Notes and Activities* in the Project STAR book, "Where We Are in Space and Time." This book and more telescope kits are available from Learning Technologies, Inc. at 800-537-8703.

An inexpensive and fun option for having students build take-home telescopes uses the lenses from disposable cameras. This project is described by Byrd & Graham in "Camera and Telescope Free-for-All!" *The Physics Teacher*, 37 (December 1999), pp.547-550.

STUDENT HANDOUT: Build a Refracting Telescope III

What You Need

- ☐ 1 telescope kit that includes:
  - ☐ a foam eyepiece holder
  - ☐ a lens (43 mm diameter)
  - ☐ a lens (17.5 mm diameter)
  - ☐ a pair of telescoping tubes
  - ☐ an eyepiece spacer
  - ☐ a cardboard washer
  - ☐ a plastic cap

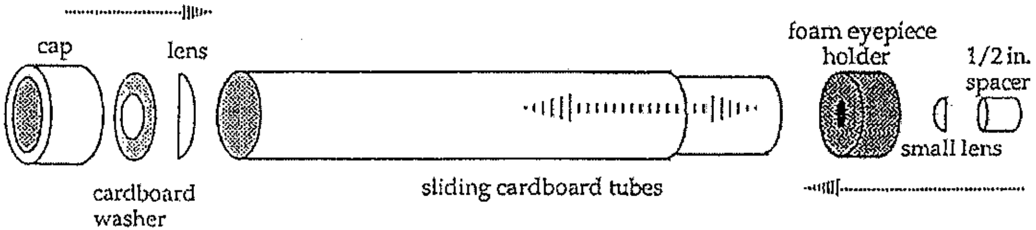


Figure 1

What To Do

1. Pick up the large lens, being careful not to smudge it with your fingers. Fit the curved side of the lens snuggly against the front of the outer tube, making sure it is positioned perpendicular to and centered in the tube. Slip the plastic cap over this end of the tube so that the lens is firmly held in place.

2. Using the small piece of cloth or tissue to prevent smudging, push the small lens into the foam lens holder, flat side in.

3. Slide the cardboard washer into the foam holder such that it pushes against the flat part of the lens. Push the washer into the holder just far enough so the end of the spacer is flat with the end of the foam holder.

4. With the curved side of the lens facing toward the large lens, slide the foam holder into the end of the smaller of the sliding tubes. The foam holder should be flat with the end of the tube.

5. You should now have a working telescope. You can focus the telescope by changing its length. Look at several objects and try to estimate the magnifying power of the telescope.

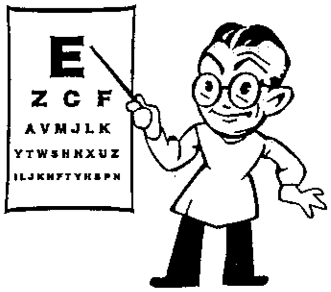
A Measure of Resolution

Overview

The resolution of a telescope is, in effect, a measure of how tiny a distant object can be and still be focused (or "resolved") by the telescope. Students will use the telescope and an eye chart to determine the resolution of their telescope and of their eye.

Students Will Learn...

- Resolution is a measure of how much detail can be observed.
- How to determine the resolution of objects.



What You Need:

For the class:

☐ 1-3 copies of the resolution chart or the eye chart

For each group of 2-3 students:

☐ a refracting telescope built from the kit
☐ ruler or tape measure

For each student:

☐ Copy of "STUDENT HANDOUT: A Measure of Resolution"

Getting Ready

You may need to do this activity in a long hallway. Post the resolution chart at the end of the hallway so many groups can see it. If you have a large class, you might need to post multiple resolution charts in different hallways or areas of the classroom.

GO: A Measure of Resolution

1. Make sure that each group has a refracting telescope and can see a resolution chart.

2. Have students complete the worksheet, "A Measure of Resolution."

What's Really Happening Here...

Students are exploring the resolution of a telescope. Resolution refers to a telescope's ability to see fine detail in an image. Resolution is usually measured by the smallest angular size you can resolve. Resolution can be measured in radians or degrees; in telescopes, it is most often given in arcminutes (1/60th of a degree) or arcseconds (1/3600th of a degree or 1/60th of an arcminute).

Resolution is determined by the diameter of the telescope's objective lens. You can change the magnification of a telescope by changing the eyepiece. However, you can not increase the resolution of a telescope no matter what eyepiece you use. Resolution is an optical property that cannot be changed, except by building a telescope with a larger objective!

The calculations of resolution should show that the telescope's resolution is on the order of .002 radians while that of a "normal" eye (this could be with corrective lenses) is approximately .02 radians.

Going Further

1. The graph that students have created can be used to find a numerical value for the resolution of a telescope. The slope of their graph will tell them the resolution of the telescope in radians. Have the students calculate the resolution of their telescopes. Do all telescopes in the class have the same resolution?
2. The theoretical resolution of a telescope can be approximated by $R = \frac{\lambda}{D}$, where λ is the wavelength of light used and D is the diameter of the objective lens (λ and D should be measured in the same units). Have students calculate the theoretical resolution of their telescopes and compare the theoretical value to what they found. The wavelength of the light is tricky. White light consists of light froom 400nm (violet) to 700nm (red). Using a value near the middle of this range will serve as a good approximation.

STUDENT HANDOUT: A Measure of Resolution

What You Need

- ☐ a refracting telescope
- ☐ ruler

What To Do

1. First, you will measure the resolution of your eye.

TO USE THE RESOLUTION CHART : Stand about six meters away from one of the resolution charts that your teacher has hung on the wall. Your partner should hold a sheet of paper across the top of the chart. Your partner will then slowly move the paper down the chart, keeping the paper horizontal. When you start to see the chart lines blur together, tell your partner to hold the paper in place and read the line spacing printed on the chart nearest to the top of the paper. Record the values of the line spacing and your distance in the table below.

TO USE THE EYE CHART : Stand about six meters away from the eye chart. Find the smallest line you can read. Have your partner measure the height of the letters in that line. Record your distance from the eye chart and the height of the smallest line you can read in the table below

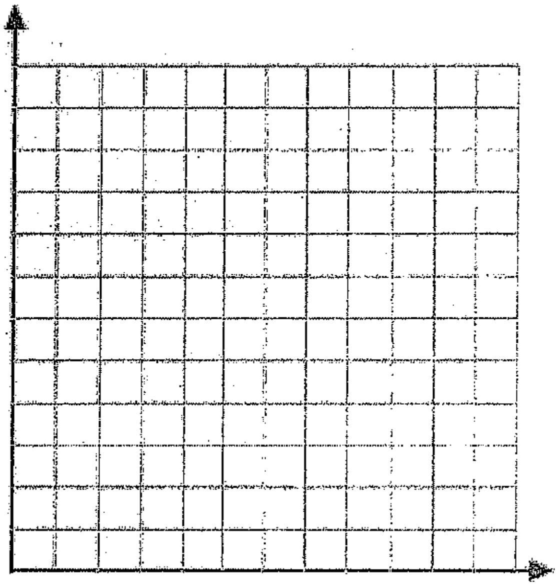
2. Move a few meters farther from the chart and repeat the measurement. Keep making new measurements until you have determined the smallest line spacing you can see from six different distances (or the smallest letter you can read from six different distances).

Resolution of the Eye		
Distance from chart (in meters)	Distance from chart (in millimeters)	Line spacing (or letter height) (in millimeters)

3. Make a graph of the height of the smallest line spacing you can see (y-axis) versus the distance from the chart in millimeters (x-axis).

4. Draw a best-fit line through the points. Remember that a best-fit line does not *connect* the points, but is a *straight* line that goes through the middle of the points as close as possible to each of them.

5. Choose two points that are ON the best-fit line – these may not be actual data points. Using these points, find the slope of the best-fit line. Recall that slope is "rise over run," or $m = \frac{y_2 - y_1}{x_2 - x_1}$.

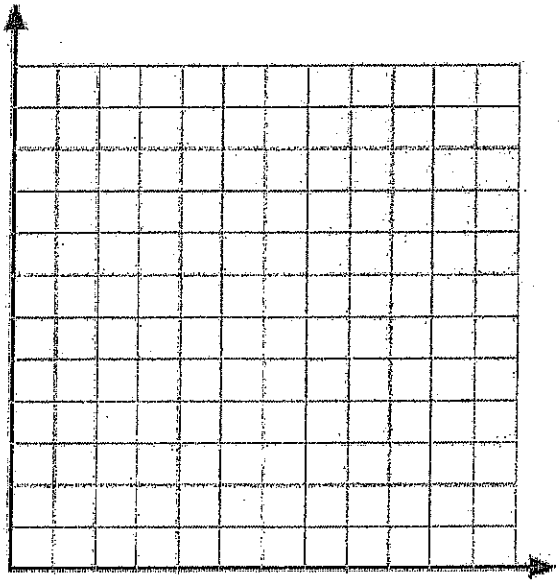


6. Now we are going to measure the resolution of a telescope. Stand about six meters away from one of the resolution charts (or eye chart) that your teacher has hung on the wall. Your partner should hold a sheet of paper across the top of the chart. Your partner will then slowly move the paper down the chart, keeping the paper horizontal. When you start to see the chart lines blur together, tell your partner to hold the paper in place and read the line spacing printed on the chart nearest to the top of the paper. Record the values of the line spacing and your distance in the table below.

7. Move a few meters farther from the chart and repeat the measurement. Keep making new measurements until you have determined the smallest line spacing (or letters) you can see from six different distances.

Resolution of the Telescope		
Distance from chart (in meters)	Distance from chart (in millimeters)	Line spacing (or letter height) (in millimeters)

8. Make a graph of the smallest line spacing you can see (y-axis) versus the distance from the chart in millimeters (x-axis).



9. Draw a best-fit line through the points. Remember that a best-fit line does not *connect* the points, but is a *straight* line that goes through the middle of the points as close as possible to each of them.

10. Choose two points that are ON the best-fit line – these may not be actual data points. Using these points, find the slope of the best-fit line. Recall that slope is "rise over run," or $m = \frac{y_2 - y_1}{x_2 - x_1}$.

11. The slope is the *resolution* of the instrument. The resolution tells you the size of the smallest object you can see. Compare the resolution of your eye to that of the telescope.

Build a Three-Lens Refracting Telescope: An Activity for Student Assessment

The large group size in this activity is a result of the limited number of lenses in the kit. Consider making smaller groups by having only half the class doing this while the other half does the Resolution activity, then have the groups switch.

Overview

Astronomical telescopes usually produce inverted images. This is not a big deal in astronomy as there is no true "up" in space. If you are a bird watcher, however, you might find it disorienting to see all your images upside down! Students will learn that they can use an extra lens to turn the image right side up. The drawback is that you have an extra lens in your system.

Students Will Learn...

- How to create a real, upright image.
- How to assemble more complicated optical systems.

What You Need:

For the class:

☐ Colored lamp

For each group of 4-5 students:

☐ 4 Styrofoam cups
☐ 2 7.5-cm focal length lenses
☐ 2 20-cm focal length lenses
☐ velum screen
☐ tape
☐ ruler
☐ drawing paper

Getting Ready

Set up the colored lamp at the end of the room where all the groups can see it easily. Be sure the lamp is several meters away from the nearest group. Dim the lights and draw the shades if possible. Be sure there is still enough light for students to safely move around the room.

GO: Build a Three-Lens Refracting Telescope

1. Have students mount the lenses and velum screen in the Styrofoam cups as in the previous activities. *HINT*: Although four lenses are provided, students will need to choose which three they want to use. They will not need all four.

2. Have the students create an upright image of the object placed in the far corner of the room. It is critical to the have the room as dark as possible without compromising safety.

3. Have the groups draw the optical layout of their telescope. They should be sure to indicate which lens is located where, with labels, and the necessary distances between them.

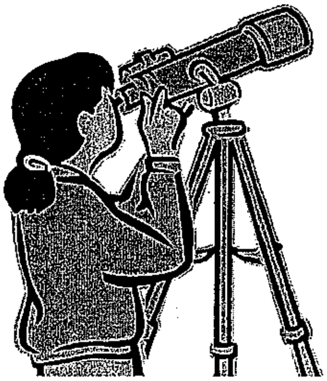
What's Really Happening Here…

A normal refracting telescope produces an inverted image. The first lens will invert the image and the second lens will magnify the image. By moving the second lens farther away, you can pass the "flip point" and turn the image right side up again! The third lens is used to magnify the image.

Going Further

Hold a contest can be made to see which group can make the largest image of the object.

STUDENT HANDOUT: Build a Three-Lens Refracting Telescope



What You Need

- ☐ 4 Styrofoam cups
- ☐ 2 7.5-cm focal length lenses
- ☐ 2 20-cm focal length lenses
- ☐ velum screen
- ☐ tape
- ☐ ruler
- ☐ drawing paper

What To Do

1. Make holders for the lenses and the velum screen as you have done previously by cutting slits in the bottom of the Styrofoam cups.

2. Using the three lenses, move them until you create a magnified, right side up image on the velum screen.

3. Draw and label the optical layout of your telescope in the space below. Identify the focal length of each lens and label all dimensions (the distances between the lenses and the screen).

4. What are the advantages of the telescope you designed?

5. What are this telescope's disadvantages?

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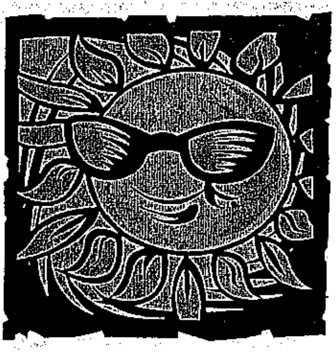
Introduction to Ultraviolet Light



Overview

Ultraviolet light cannot be seen with our eyes. It can be detected with a variety of substances including ultraviolet sensitive beads. This section gives you some ideas on how you can introduce ultraviolet light to your students.

Students Will Learn...

- UV sensitive beads change color in the presence of ultraviolet light.
- Earth's atmosphere scatters ultraviolet light.
- You can get a sunburn on a cloudy day.
- Certain substances block UV light while allowing visible light to pass.

What You Need

For the class:

☐ Bag of UV sensitive beads
☐ 1 Avon DermaSpec Skin Imager (black light)

Optional Items (To be provided by the instructor)

☐ Sunblock
☐ Prescription pill bottle (empty)
☐ Small plastic baggie
☐ Invisible Ink pen
☐ Fluorescent minerals
☐ Driver's license or credit card

Getting Ready

You do not want your students to look into the UV light. Think about your classroom setup and how you can have the students make observations without looking into the light. Putting the items into and empty aquarium and shining the light from above works well.

CAUTION

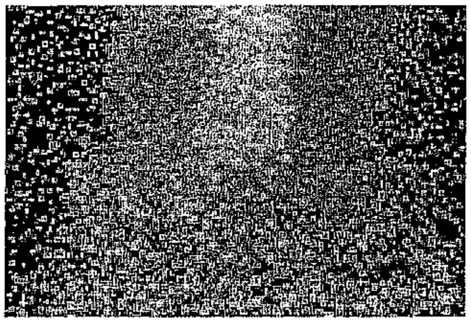
The lights included in the module are fluorescent ultraviolet lights. These lights are readily available at party stores and are generally considered safe. The ultraviolet lights give off UVA light. UVA is the lowest energy of UV light. However, it is still a good idea not to stare at them for long periods of time or from close range. Viewing the reflected light, as students are instructed to do, is safe.

Go: Introduction to Ultraviolet Light

1. Hand out some of the UV beads to a couple of students and ask them to examine the beads. Ask if they have any observations about the beads.

2. Shine an ordinary flashlight (or the room lights) on the beads. Ask the students if ordinary light effects the beads.

3. Place a small handful of beads on the table and turn on the UV light. Hold the UV light over the beads for a few seconds. Ask the students what changed about the beads. Ask the students what they think caused this change.



4. Have the students take the beads outside in the Sun, if possible. Ask the students why they think the beads change color in the Sun.

5. Tell the students that the black light and the sunlight both contain ultraviolet light. Our eyes cannot see ultraviolet light, but the beads will change color in the presence of ultraviolet light.
6. Give each pair of students a few beads. Have the students put the beads in a pocket or other dark place and take the beads outside. Have the students face away from the Sun and take out the beads. Make sure they keep the beads in their shadow. Ask the students why the beads changed colors even though they were in the shadows.

7. Tell the students that ultraviolet light is scattered by Earth's atmosphere. UV light from the Sun bounces off molecules in our atmosphere. Some of this UV light ends up bouncing into areas that are in shadow. Therefore, the beads will change colors even if they are in shadow!

What's Really Happening Here...

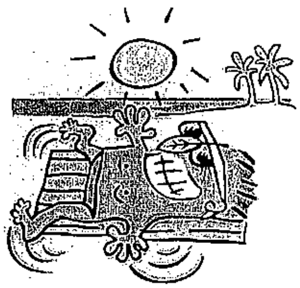
UV sensitive beads contain pigments that change color when exposed to ultraviolet light. When the light is removed, the beads will slowly return to their original white color. Any UV light source will cause the beads to change color. The two most common sources are the Sun and black lights.

When you hold the beads in your shadow, they still change color even though they are not in direct sunlight. Our atmosphere scatters light. Short wavelength light is scattered more than long wavelength light. Scattering of short wavelength blue light is why our sky is blue (see Module 4, "Excuse Me, While I Kiss the Sky," for more information). UV light has an even shorter wavelength so it is scattered even more than blue light. If your eyes could detect UV light, you would see UV light coming from every direction in the sky!

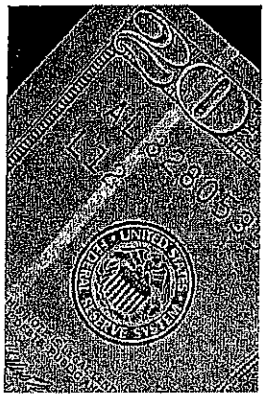
Going Further

1. Some substances block UV light while allowing visible light to pass through. Put some beads in an old pill bottle and shine the UV light on the beads. See if they change color.

2. You can test sunblock. Put the beads in a small plastic bag. Get some spray on sunblock. Spray the sunblock on the bag. Expose the bag to UV light and see if the beads change color.



3. Security features frequently show up under UV light. The new $5, $10, and $20 bills all have a strip that glows under UV light you can show students. Many credit cards and ATM cards have security features that glow under UV light. For example, Mastercards have a glowing "MC" that shows up under UV light.



4. Many minerals will fluoresce under UV light. You can buy minerals online or at many local mineral shops. You want to focus on long wavelength UV minerals. The Derma Spec light will not cause mid or short wave minerals to fluoresce.
5. Many household laundry detergents (both liquid and powder) contain whiteners that will fluoresce under UV light. Examine different detergents under UV light. You can also try whitening toothpaste.

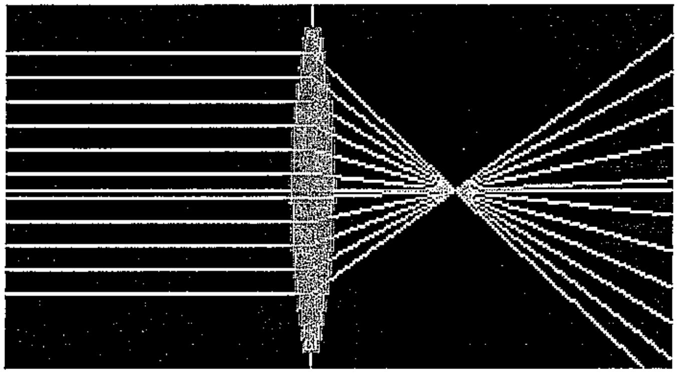
More Background for the Interested Educator

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.

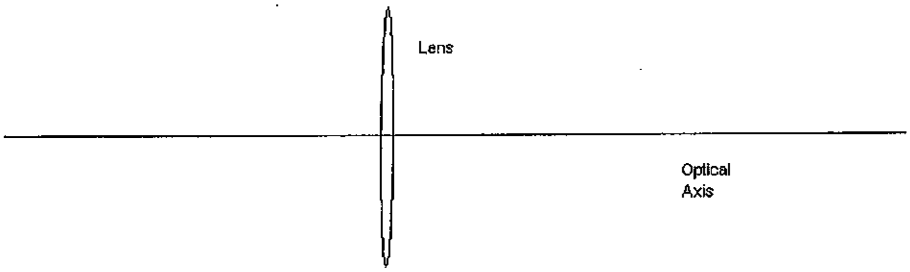


Recall the activity, "Finding the Focal Length Using a Distant Object," where we used a very distant object to create an image. When an object is very far away from the lens (much farther than the focal length), we consider the object to be infinitely far away. When you are very far away from the object, 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.

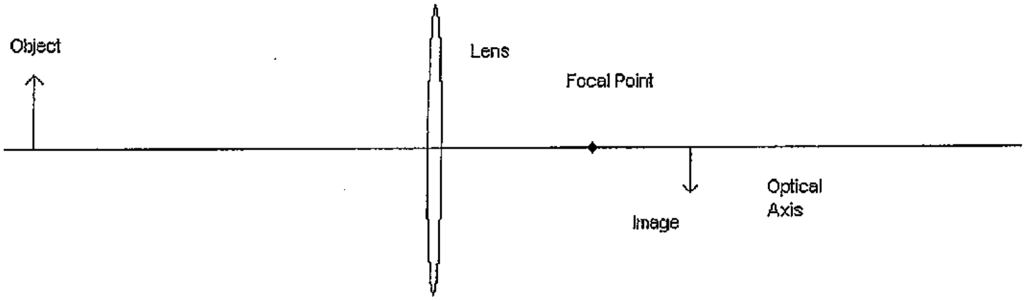
Ray Diagrams

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

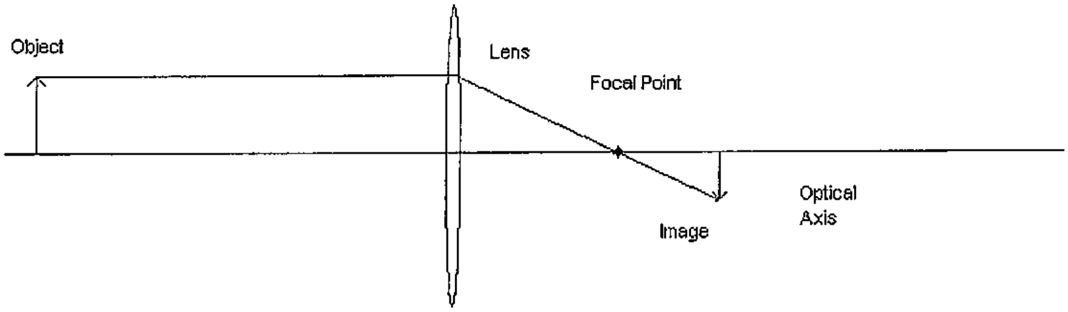
Step One: First draw the lens. Next draw a line through the center of the lens. This line is called the *optical axis.*



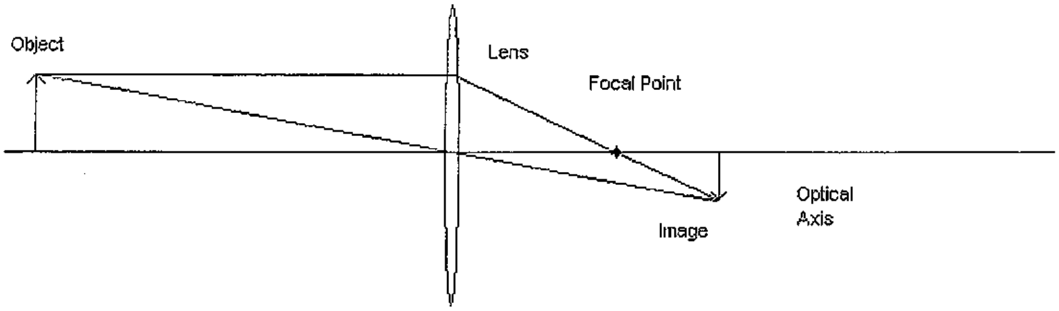
Step Two: Draw in the object and image locations and the location of the focal point. Make sure that you draw everything to scale.



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:

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

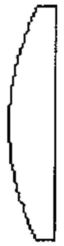
The letter c is the speed of light in vacuum ($3*10^8$ m/s) and the letter v is the speed of light in the medium. Common values for n are:

$n = 1$ 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.

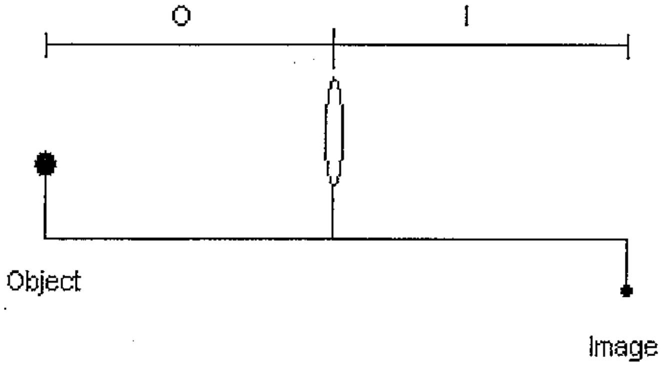
Positive lenses are used to create images. Light comes from an object and passes through the lens to form an image (see "Going Further: Ray Tracing and Diagrams"). There are two types of images that can be formed with positive lenses. A real image is one that can be projected onto a surface. A real image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

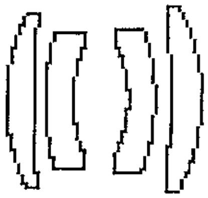


There are two common methods to measure the focal length of a positive lens. The simplest method is the "object at infinity" method. If you use an object that is very far away (many times longer than the focal length such as a distant building, light bulb, etc.), O becomes very large, so 1/O becomes 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. Dipsersion 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.

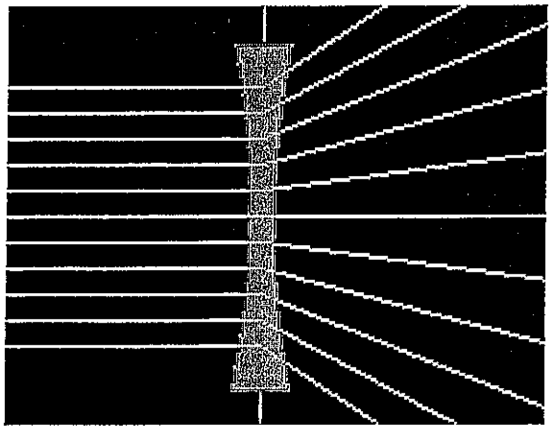
The problem can be further reduced by using special low dispersion glass. Modern glass containing fluorite is frequently used in high quality refractor telescopes due to its low dispersion.

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.

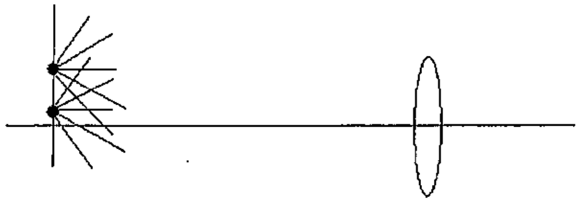
Partial Lenses

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:

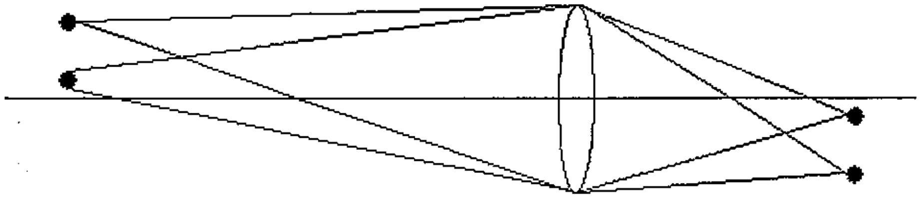
1. that light rays are emitted uniformly in all directions from a point source,
2. only the rays that enter the lens are focused at the image, and
3. points on the object map to points on the image.

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.

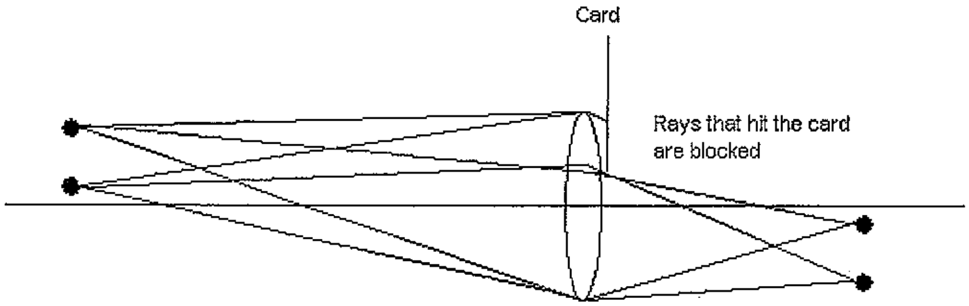
Once the light rays enter the lens they get bent and travel to where they cross each other and form images of each of the two point sources.



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 with easy activities to do on your own or in class.

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.

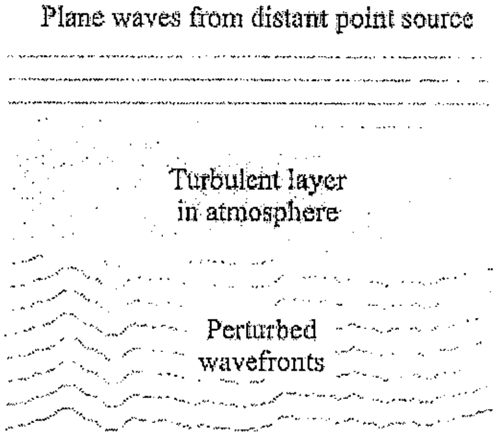
Many people believe you can always increase the magnification of a telescope. It is not uncommon to see advertisements for telescopes with diameters as small as 2 inches that will advertise magnifications of 575x!

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.

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).



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

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 time 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.

Vendor Information

If you wish to expand the supplies in your kit, many of the items are available at low cost. You can contact any of the vendors below to order more equipment.

Item	Catalog or Part #	Vendor Information
Laser Level	**3192-5VGA**	Harbor Freight Tools 5570 E. 22nd Street Tucson, AZ 85711 Phone 800-423-2567 http://www.harborfreight.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/
Telescope Kit	# PS-04B	Learning Technologies 40 Cameron Ave. Somerville, MA 02144 Phone 800-537-8703 http://www.starlab.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/

Reproducible Materials

For the remainder of this book, you will find repeats of the various handouts and other reproducible materials used throughout *Terrific Telescopes*. Although these materials are copyrighted by SPIE, OSA, and AURA, permission is granted for photocopying these sheets for classroom or workshop use. Any questions regarding these materials or the copyright should be directed to Stephen Pompea, National Optical Astronomy Observatory, by phone, 520.318.8285, or by email, spompea@noao.edu.

STUDENT HANDOUT: Finding the Focal Length Using a Distant Object

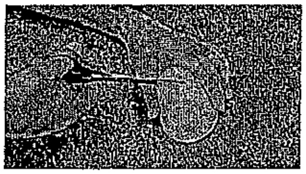
What You Need

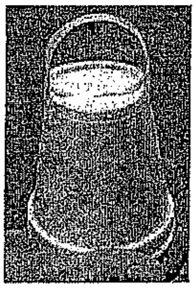
- ☐ 1 thick convex lens
- ☐ 1 thin convex lens
- ☐ 1 velum screen
- ☐ 3 Styrofoam cups
- ☐ ruler

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. 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 colored lamp 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.
    c. Is the image right side up or upside down? Is it bigger (magnified) or smaller than the original object?

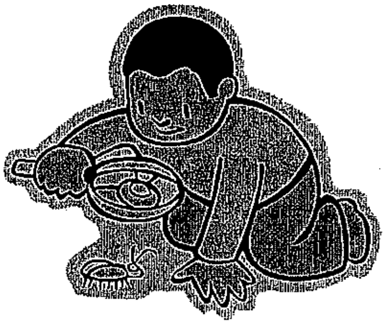
    d. Measure the distance from the thin lens to the velum screen. Record this distance.

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?

STUDENT HANDOUT: Simple Magnifiers



What You Need

- ☐ 1 20-cm focal length (thinner) lens
- ☐ 1 7.5-cm focal length (thicker) lens
- ☐ 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?

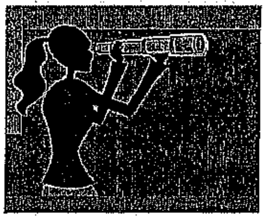
5. Move the 7.5-cm lens closer to and farther away from the objects. What is the relationship between the distance to the objects and the magnification?

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?

STUDENT HANDOUT: Build a Refracting Telescope I



What You Need

☐ 1 20-cm focal length lens
☐ 1 7.5-cm focal length lens
☐ 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. With your best arrangement, again look at the distant 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.

7. 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?

8. 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.

9. 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.

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

11. 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.

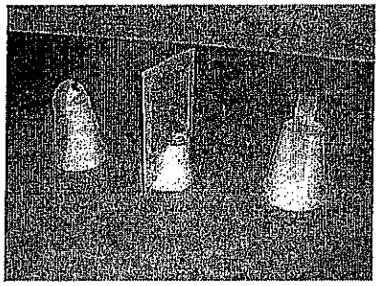
12. How does this distance change when you look at a nearby object?

STUDENT HANDOUT: Build a Refracting Telescope II

What You Need

- ☐ 1 20-cm focal length lens
- ☐ 1 7.5-cm focal length lens
- ☐ 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.

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STUDENT HANDOUT: Build a Refracting Telescope III

What You Need

- ☐ 1 telescope kit that includes:
  - ☐ a foam eyepiece holder
  - ☐ a lens (43 mm diameter)
  - ☐ a lens (17.5 mm diameter)
  - ☐ a pair of telescoping tubes
  - ☐ an eyepiece spacer
  - ☐ a cardboard washer
  - ☐ a plastic cap

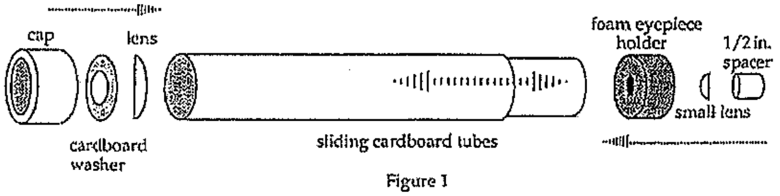


Figure 1

What To Do

1. Pick up the large lens, being careful not to smudge it with your fingers. Fit the curved side of the lens snuggly against the front of the outer tube, making sure it is positioned perpendicular to and centered in the tube. Slip the plastic cap over this end of the tube so that the lens is firmly held in place.

2. Using the small piece of cloth or tissue to prevent smudging, push the small lens into the foam lens holder, flat side in.

3. Slide the cardboard washer into the foam holder such that it pushes against the flat part of the lens. Push the washer into the holder just far enough so the end of the spacer is flat with the end of the foam holder.

4. With the curved side of the lens facing toward the large lens, slide the foam holder into the end of the smaller of the sliding tubes. The foam holder should be flat with the end of the tube.

5. You should now have a working telescope. You can focus the telescope by changing its length. Look at several objects and try to estimate the magnifying power of the telescope.

STUDENT HANDOUT: A Measure of Resolution

What You Need

- ☐ a refracting telescope
- ☐ ruler

What To Do

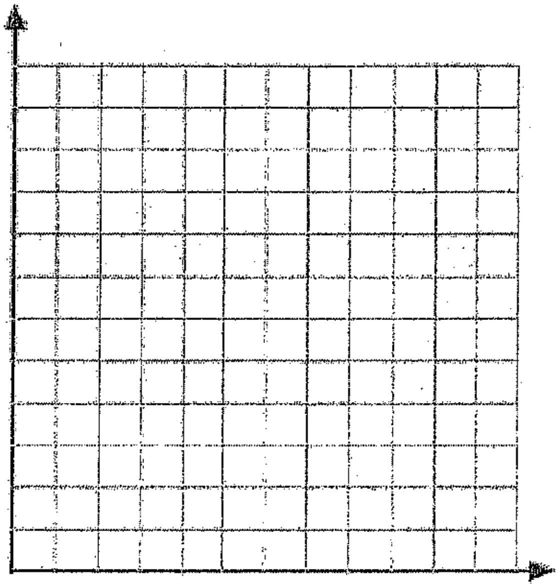
1. First, you will measure the resolution of your eye.

TO USE THE RESOLUTION CHART : Stand about six meters away from one of the resolution charts that your teacher has hung on the wall. Your partner should hold a sheet of paper across the top of the chart. Your partner will then slowly move the paper down the chart, keeping the paper horizontal. When you start to see the chart lines blur together, tell your partner to hold the paper in place and read the line spacing printed on the chart nearest to the top of the paper. Record the values of the line spacing and your distance in the table below.

TO USE THE EYE CHART : Stand about six meters away from the eye chart. Find the smallest line you can read. Have your partner measure the height of the letters in that line. Record your distance from the eye chart and the height of the smallest line you can read in the table below

2. Move a few meters farther from the chart and repeat the measurement. Keep making new measurements until you have determined the smallest line spacing you can see from six different distances (or the smallest letter you can read from six different distances).

Resolution of the Eye		
Distance from chart (in meters)	Distance from chart (in millimeters)	Line spacing (or letter height) (in millimeters)



3. Make a graph of the height of the smallest line spacing you can see (y-axis) versus the distance from the chart in millimeters (x-axis).

4. Draw a best-fit line through the points. Remember that a best-fit line does not *connect* the points, but is a *straight* line that goes through the middle of the points as close as possible to each of them.

5. Choose two points that are ON the best-fit line – these may not be actual data points. Using these points, find the slope of the best-fit line. Recall that slope is "rise over run," or $m = \frac{y_2 - y_1}{x_2 - x_1}$.

6. Now we are going to measure the resolution of a telescope. Stand about six meters away from one of the resolution charts (or eye chart) that your teacher has hung on the wall. Your partner should hold a sheet of paper across the top of the chart. Your partner will then slowly move the paper down the chart, keeping the paper horizontal. When you start to see the chart lines blur together, tell your partner to hold the paper in place and read the line spacing printed on the chart nearest to the top of the paper. Record the values of the line spacing and your distance in the table below.

7. Move a few meters farther from the chart and repeat the measurement. Keep making new measurements until you have determined the smallest line spacing (or letters) you can see from six different distances.

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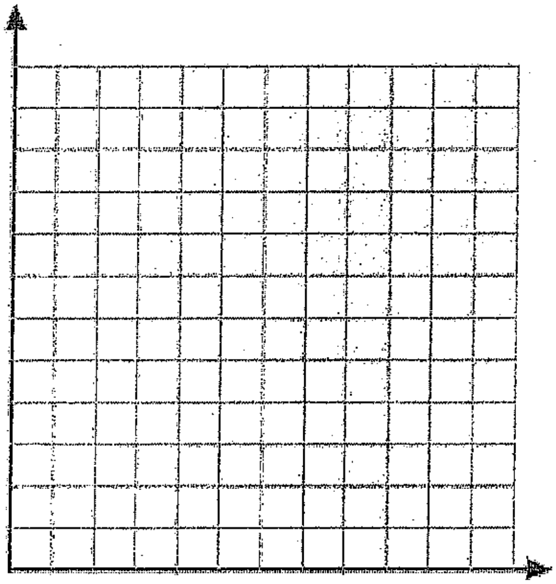
Resolution of the Telescope		
Distance from chart (in meters)	Distance from chart (in millimeters)	Line spacing (or letter height) (in millimeters)

8. Make a graph of the smallest line spacing you can see (y-axis) versus the distance from the chart in millimeters (x-axis).

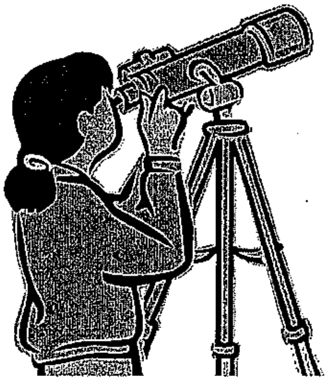
9. Draw a best-fit line through the points. Remember that a best-fit line does not *connect* the points, but is a *straight* line that goes through the middle of the points as close as possible to each of them.

10. Choose two points that are ON the best-fit line – these may not be actual data points. Using these points, find the slope of the best-fit line. Recall that slope is "rise over run," or $m = \frac{y_2 - y_1}{x_2 - x_1}$.



11. The slope is the *resolution* of the instrument. The resolution tells you the size of the smallest object you can see. Compare the resolution of your eye to that of the telescope.

STUDENT HANDOUT: Build a Three-Lens Refracting Telescope



What You Need

- ☐ 4 Styrofoam cups
- ☐ 2 7.5-cm focal length lenses
- ☐ 2 20-cm focal length lenses
- ☐ velum screen
- ☐ tape
- ☐ ruler
- ☐ drawing paper

What To Do

1. Make holders for the lenses and the velum screen as you have done previously by cutting slits in the bottom of the Styrofoam cups.

2. Using the three lenses, move them until you create a magnified, right side up image on the velum screen.

3. Draw and label the optical layout of your telescope in the space below. Identify the focal length of each lens and label all dimensions (the distances between the lenses and the screen).

4. What are the advantages of the telescope you designed?

5. What are this telescope's disadvantages?

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