

ACTIVITY 4

Bring it into Focus

(Lenses and optics)

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Safety

Safety: Please note that while following the precautions in this guide can help teachers foster inquiry in a safe way, no guide could ever predict all of the problems that might occur. Good supervision and common sense are always needed.

FOR THE TEACHER

Disappearing Act *(demonstration)*

(Level 1)

This demonstration shows how you can make an object disappear based on its index of refraction. It is simple to complete, but the results can be difficult to understand without prior knowledge of how materials bend light. Two ways to carry out the demonstration are explained – as a magic trick or as a “show and discuss” demonstration.

Safety

If vegetable oil spills on the floor the floor will be very slippery. Be sure to clean up any spills immediately. Also, if you perform the magic trick be careful not to cut yourself when breaking the test tube and cleaning up the pieces.

Materials

■ Magic Trick

- Large beaker (*Must be big enough that you can completely submerge the Pyrex object in it*)
- 2 test tubes, or other small Pyrex objects (*stirring rods, small beakers, etc.*)
- Wessen brand vegetable oil (*enough to fill the beaker*)
- Rubber gloves (*optional*)
- Tongs
- Paper towels

■ Show and Discuss

- 2 large beakers (*Must be big enough that you can completely submerge the Pyrex objects in them*)
- 2 Test tubes, or other small Pyrex objects (*stirring rods, small beakers, etc.*)
- Wessen brand vegetable oil (*enough to fill one beaker*)
- Water (*enough to fill one beaker*)
- Rubber gloves (*optional*)
- Tongs (*optional*)
- Paper towels

Notes

- The small Pyrex objects should be cleaned before performing this demonstration.
- You may wish to wear rubber gloves to keep the oil off of your hands.

Magic Trick instructions

1. Before class begins submerge one test tube in a beaker filled with oil. The tube should be barely visible, if at all.
2. For the demonstration, take another test tube, break it carefully and then place the pieces in the “magic liquid.”
3. After some fancy magic words, pull out the unbroken test tube

Discussion questions

- There is science behind this magic trick, of course. How do you think the broken test tube was able to come out whole?
- Do you think this trick would work in a beaker full of water? Why or why not?
- How could you measure an object's index of refraction?
- Brainstorm other clear materials. Do you think they have higher or lower indices of refraction than oil? How could you test this?

Show and Discuss instructions

1. Fill one beaker with water and another with oil.
2. Place the test tube in the water-filled beaker and note its appearance.
3. Now submerge the beaker partway in the oil, but don't let the oil fill the test tube. The outside edges should be nearly invisible, but the inside edges should be easy to see.
4. Fully submerge the test tube, allowing oil to fill it completely. Now its edges should be very difficult to see.

Discussion questions

- What are some of the differences between oil and water?
- Why do you think you can see the test tube in the water but not in the oil?
- How could you measure an object's index of refraction?
- Brainstorm other clear materials. Do you think they have higher or lower indices of refraction than oil? How would you test this?

Discussion

We see the edges of objects because light is either reflected or refracted at their boundaries. In the case of clear objects, such as glass and some plastics, refraction allows us to discern their edges from the surroundings. For instance, water and glass have different indices of refraction, which makes the light bend at the boundary between the two materials. This makes the sides of a submerged test tube clearly visible when held underwater.

When a test tube is submerged in vegetable oil, however, the boundaries are invisible because the oil and Pyrex glass have the same index of refraction. This means that the light is not at all refracted when it crosses the boundary between the oil and glass.

This activity can also be performed as a laboratory session in small groups, though it can get very messy! Students may wish to test other liquids such as glycerin or other oils to see how the appearance of the test tube changes. You might also consider having students look up the index of refraction of the fluids they test on the Internet.

Another idea that can be introduced with this demonstration is that index of refraction changes with temperature. After students have observed the disappearing test tube, place the beaker containing the oil and the test tube on a hot plate. The edges of the test tube should gradually get easier to see as the temperature of the oil increases.

Suggested resources

“Index of Refraction.” HyperPhysics.

<http://hyperphysics.phy-astr.gsu.edu/hbase/tables/indrf.html>

Lists the indices of refraction table for common materials.

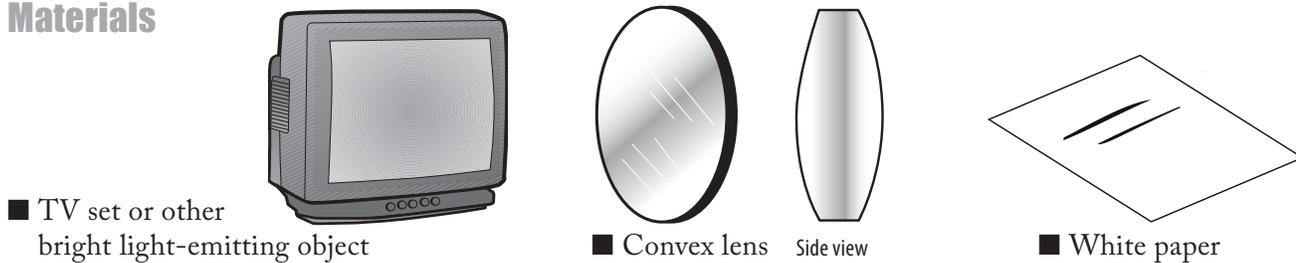
Television Projectors

Project an image of a television screen onto a piece of paper using a converging (convex) lens – and investigate how the distance between the TV and the lens affects the focal length of the lens.

Safety

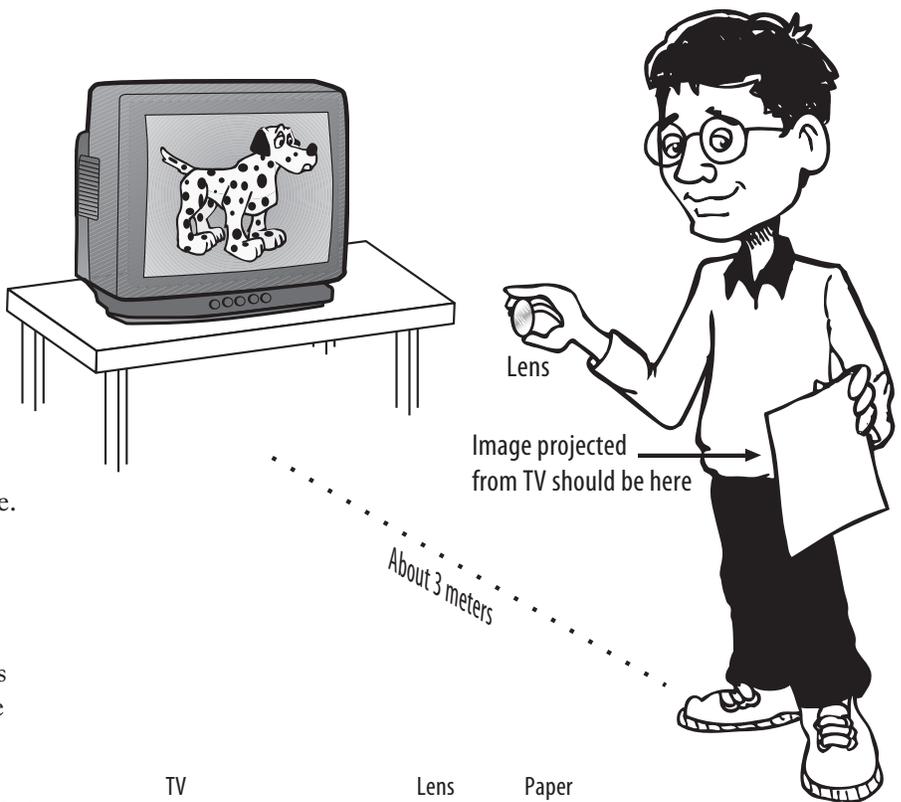
Never look directly at the sun or other bright light sources.

Materials



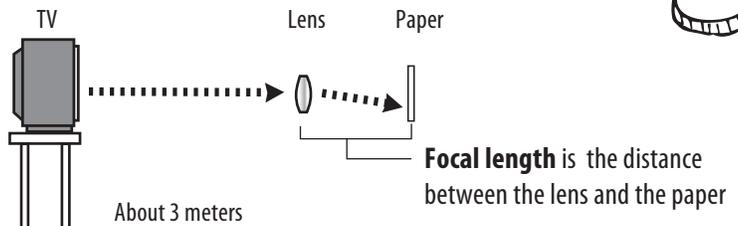
Instructions

1. Turn off the room lights.
2. Turn on the television and stand about 3-m from screen.
3. Face the screen and hold your lens parallel to the screen. Have a partner hold a sheet of white paper at the focal point of the lens.
4. Adjust the distance between the lens and paper until a clear image is visible.



Discussion questions

- Describe the image you see. How do its size and orientation compare to the image you see when you look at the TV screen?
- Is the distance between the paper and lens different from the focal length you measured earlier? If so, why do you think this is?
- When you bring the lens closer to the TV, do you need to change the distance between the lens and paper to get a clear image? If so, do you need to increase or decrease the distance?



NOTE: Diagram not to scale

FOR THE TEACHER

(Level 1, Level 2)

Television Projectors

Materials

- TV set or other bright light-emitting object

A television works well, but you can also use a computer monitor, bright window, or candle flame.

- Convex lens*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224520. \$3.95 each. Many places also offer classroom set specials.

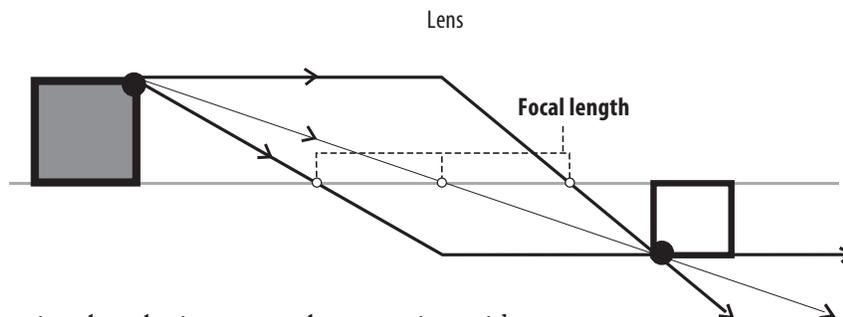
- White paper

- Dark room

Notes on the activity

If your class has geometry experience, you might have them use ray diagrams to explain the orientation of the image. They should use the following rules to draw the diagrams:

- Rays approaching a lens perpendicular to it pass through the focal point on the other side
- Rays passing through the center of the lens continue in a straight line
- Rays passing through the near focal point emerge perpendicular to the lens
- The image appears where all of the rays intersect



Discussion

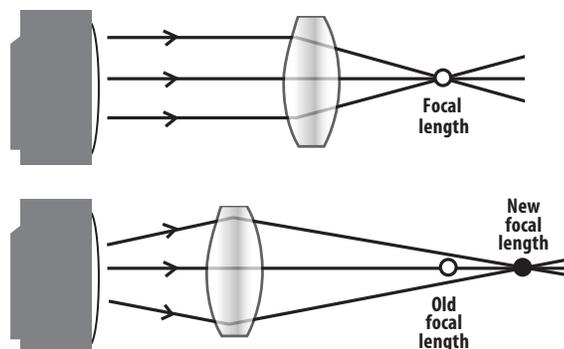
Students should notice that the image on the paper is upside down and backwards, as shown in the diagram. Students should also note that as they get closer to the TV the distance between the lens and the paper needs to increase to get a clear image. The technical focal length of a lens refers to the distance at which the lens focuses incoming parallel light rays (from far away objects). When the lens is close to the TV, the rays are no longer coming in parallel and so the focal length of the lens increases.

Suggested resources

Henderson, Tom. "Image Formation by Lenses." The Physics Classroom, 2004 <http://www.glenbrook.k12.il.us/GBSSCI/PHYS/CLASS/refrn/u14l5a.html>.
Information about how lenses bend light, ray diagrams, and links to more optics information.

Bibliography

Cobb, Vicki, Josh, and Theo. *Light Action: Amazing Experiments with Optics*. New York: Harper Collins Publishers, 1993. Pages 51-54.



- The focal length of a lens.
- If the same lens is moved closer to the TV, its focal length will increase.

FOR THE TEACHER

Total Internal Reflection

Several different ways to explore total internal reflection are explained here. Be sure to try these experiments before having your students try them in class.

Safety

Students should never look directly at bright light sources, even a flashlight. Warn students strongly about the dangers of looking directly into the laser beam. Shining the beam into their eyes or the eyes of their classmates may cause serious injury.

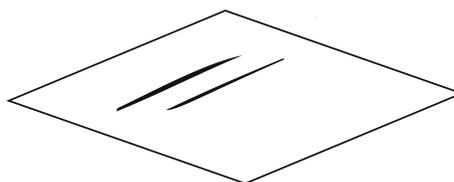
Trapped Underwater (*demonstration*)

Materials

■ Small fish bowl (or other clear container, such as a beaker or large drinking glass)



■ Water (enough to fill your container)



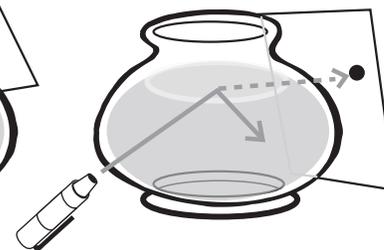
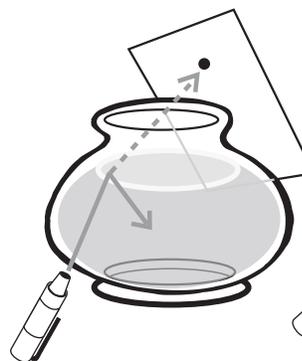
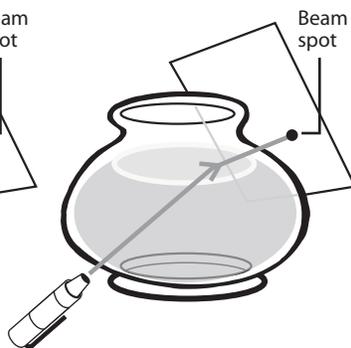
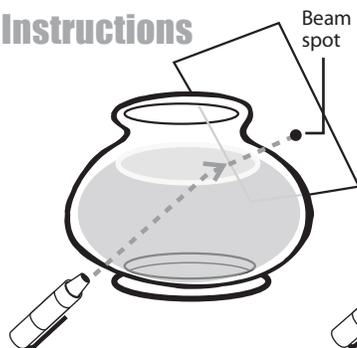
■ White paper



■ Milk

■ Laser pointer

Instructions



1. Fill the fish bowl with water and shine the laser through it. Find where the beam exits the bowl by moving a white piece of paper around the outside of the bowl until you see the spot from the laser.

2. Add a few drops of milk to the water and shine the laser through the bowl again. Continue adding milk until the beam is clearly visible inside the bowl.

3. Point the laser up through the water toward the liquid's surface, at a steep angle. Place a piece of paper on top of the container at an angle so you can see the exiting beam.

4. Slowly decrease the angle at which the beam hits the surface – you should see the exiting beam get closer and closer to the water's surface. Eventually, you will pass a critical angle beyond which all of the laser light is reflected by the water / air boundary.

Discussion questions

- Why do you have to add milk to the water for this demonstration?
- Why does the laser reflect off of the water?
- Does the laser reflect off the water at all angles?
- What would happen if you did this experiment in another clear liquid – like oil?

FOR THE TEACHER

Trapped Underwater *(continued)*

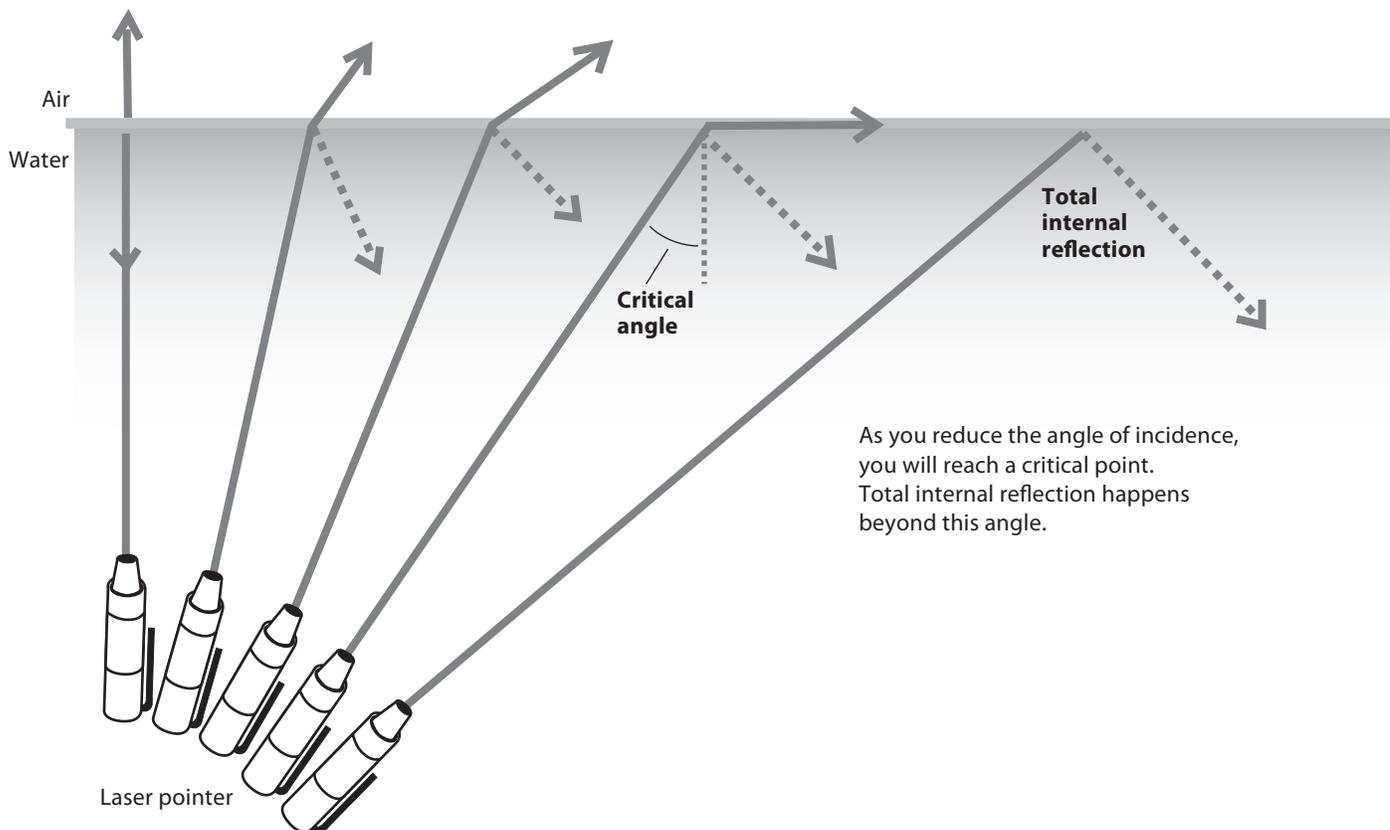
Discussion

The beam is visible when you add milk because of scattering – light bouncing in irregular directions off of impurities (our impurities are milk particles in the water). The laser light bounces off of the milk particles in random directions, so some light is reflected into your eyes. This reflected light allows you to see the beam.

When you point the light up at the water / air boundary, some of it is reflected by the boundary and some passes through into the air. The reflected light is reflected just as it would if the boundary was a mirror – the angle of reflection is the same as the angle of incidence. The light that passes through into the air is refracted, or bent, because water and air have different indices of refraction.

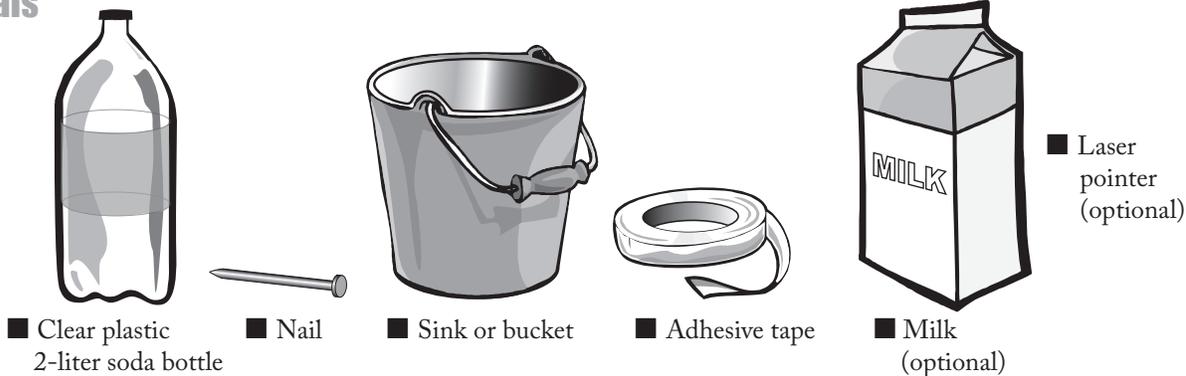
The percentage of light that is reflected and the percentage that is transmitted depends on the angle at which the light hits the boundary (see picture). If you keep increasing the angle, as in the demonstration, you eventually reach a critical angle where the light that passes through the boundary skims along the surface. This angle is determined by the indices of refraction of the two materials (at a water / air boundary, this angle is 48.6 degrees).

When the angle that the light hits the surface at is greater than the critical angle, all of the light is reflected within the water – this is total internal reflection.



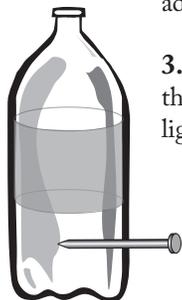
There's a hole in the bucket (*demonstration*)

Materials



Instructions

1. Use the nail to carefully punch a small hole in the side of the plastic bottle, about 8-cm from the bottom. Smooth out the plastic edge around the hole as much as possible.



2. Cover the hole with adhesive tape.

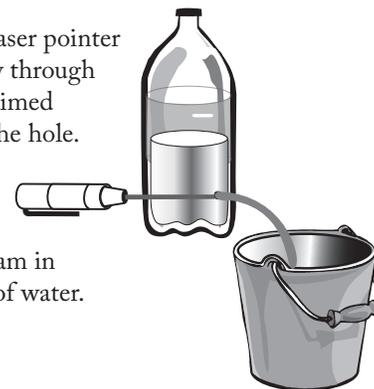
3. Turn off the room lights.



4. Fill the bottle 2/3 full of water, and add a small amount of milk.

5. Hold the bottle over a sink or an empty bucket and remove the tape.

6. Shine a laser pointer horizontally through the bottle, aimed directly at the hole. Add more milk if you cannot see the laser beam in the stream of water.



Discussion questions

- Are you surprised by what you see? Why or why not?
- Why does the light stay in the stream?
- Do you think the same thing would happen if you used another liquid instead of water?
- What was the purpose of adding the milk?
- Why did you need to point the laser beam directly at the hole?

Discussion

You should see light from the laser pointer travel with the stream of water as it flows out of the bucket. This is because the light is totally internally reflected within the water.

The laser beam has to be pointed directly at the hole because it does not spread out like a flashlight – if you pointed the laser down through the top of the bottle, not much of the light would make it out of the hole.

See discussion for Trapped Underwater for an explanation of total internal reflection and an explanation of how the milk makes laser light visible.

Fiber Optics

(Level 1)

Hand out sections (about 0.75-m) of fiber optic cable to small groups. Turn off the lights. Have students hold one end of their cable to the flashlight and observe what happens.

Materials

- Fiber optic cable
 - Flashlight
- Available at Arbor Scientific for \$0.75/m*
<http://www.arborsci.com/detail.aspx?ID=317>

Discussion questions

- When you shine a light in one end of the cable, where does the light come out? Is this what you expected? Why or why not?
- Why doesn't the light leak out of the side of the cable?
- Why would something like this be useful?
- What happens if you crack (or scratch) the cable? (If your teacher gives you permission)

Discussion

Students should see that although the cable is clear, no light escapes the sides and all is transmitted to the other end of the cable. This is because the light is totally internally reflected within the cable.

See discussion for *Trapped Underwater* for an explanation of total internal reflection

If you are not concerned with preserving the cable, you may wish to have some or all groups scratch their cables with scissors and report what happens. Light escapes from the cables when they have been scratched because the reflective coating is disrupted.

Fiber optic cables are used to send signals over long distances because all of the light stays in the cable. This means that the strength of the signal stays nearly the same even when transported over long distances. Fiber optic cables are also used in micro-surgeries so that doctors can see into patients' bodies without using large incisions.

Suggested resources

Goff, David. "A Brief History of Fiber Optic Technology." 2002.

<http://www.fiber-optics.info/fiber-history.htm>

History and applications of fiber optics and total internal reflection.

"Refraction, Snell's law, and total internal reflection." Boston University Physics Department, 1998.

<http://buphy.bu.edu/py106/notes/Refraction.html>

Total internal reflection explained using Snell's Law.

Bibliography

Gardner, Robert. Experiments with Light and Mirrors. Springfield, NJ: Enslow Publishers, Inc: 1995. Pages 72-73.

Homemade Telescope

(Level 2)

Use two lenses to make a simple refracting telescope. This telescope can be used to read a message posted across the room.

Safety

Never look directly at the sun or other bright light sources, especially through a telescope.

Materials

- Convex lens, focal length = 20-cm
- Concave lens, focal length = 5-cm
- Convex lens, focal length = 10-cm (optional)
- Ruler
- Modeling clay
- Cardboard (about 3-cm x 5-cm if using a standard-sized ruler)

Instructions

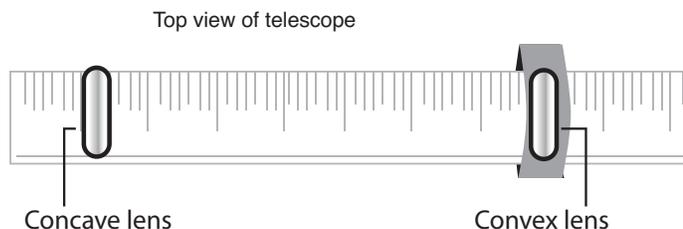
Cut two pieces of cardboard slightly wider than the ruler and tape them together with the ruler in the middle, as shown in the picture. You should be able to slide the cardboard sleeve up and down the ruler.

1. Stick the convex lens with the 20-cm focal length to this sleeve using a small blob of clay.

2. Attach the concave lens to the end of the ruler using another blob of clay.

3. Hold the end of the ruler with the concave lens up to your eye and look at a distant object out the window.

4. Move the convex lens toward or away from the concave lens until the image is in focus.



Discussion questions

- What are telescopes used for? What other instruments use lenses?
- What is the distance between the two lenses when you focus the telescope on a far away object? How does this relate to the focal lengths of the lenses?
- When you look at a nearby object with the telescope, do you need to change the distance between the two lenses? If so, do you need to increase or decrease the distance?
- How does the magnification of your telescope change if you replace the convex lens with one that has a shorter focal length? Can you explain why?

FOR THE TEACHER

Homemade Telescope

(Level 2)

Use two lenses to make a simple refracting telescope. This telescope can be used to read a message posted across the room.

Materials

- Convex lens with a focal length of 20-cm*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224520. \$3.95 each. Many places also offer classroom set specials.

- Concave lens with a focal length of 5-cm*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6224510. \$3.95 each. Many places also offer classroom set specials.

- Convex lens with a focal length of 10-cm (optional)*

These are available at science supply stores such as Science Kit & Boreal Labs, <http://sciencekit.com>, part number WW6223505. \$3.75 each. Many places also offer classroom set specials.

- Ruler

- Modeling clay (small amount)

- Cardboard (about 3-cm x 5-cm if using a standard-sized ruler)

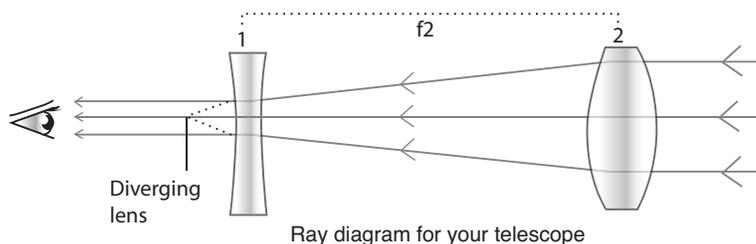
- A message to post across the room that is not easily readable without the telescope

Discussion

Students should notice that the telescope makes distant objects appear larger and that the distance between the lenses when the telescope is focused is about the difference between the focal lengths of the lenses. Note that this distance also depends on how far away the object is that the students are looking at.

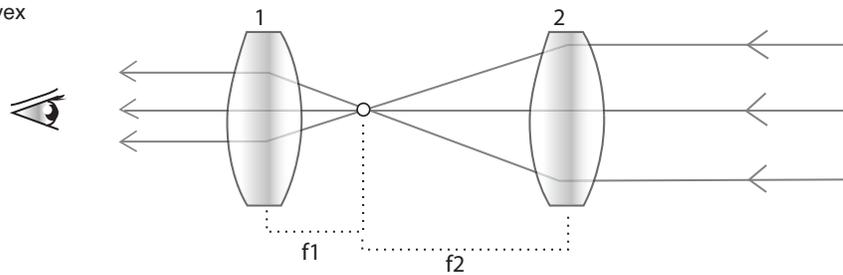
Below is a diagram of what happens to light rays in a refracting telescope like this one (some telescopes use mirrors instead of lenses, these are called reflecting telescopes). The parallel rays come in from distant objects and are bent by the two lenses. The rays then emerge from the second lens parallel again and the objects look bigger and clearer.

You may wish to have students replace the convex lens with another convex lens that has a different focal length and see how this affects the telescope. Since the distance between the lenses when the telescope is focused is about the difference in focal lengths, if students replace the convex lens with one that has a shorter focal length, they will have to move the lenses closer together to focus on an object. This will also change the magnification of the telescope, since the magnification power is equal to the focal length of the convex lens divided by the focal length of the concave lens.



The following diagram shows another type of refracting telescope. This one uses two converging lenses and the distance between the lenses is the sum of the two focal lengths. For an added challenge, have students make this kind of telescope as well. Note that the lens with the shorter focal length should be closer to the eye and that the image they see will be inverted. Keep in mind that it is much more difficult to read messages or locate small objects using this type of telescope because the inverted image can make adjusting the direction of the telescope confusing.

Ray diagram for a 2-convex lens telescope.



For more information

“Refracting and Reflecting Telescopes.” ThinkQuest, 2001.

http://library.thinkquest.org/J0112188/refracting_and_reflecting_telescopes.htm

Background on how telescopes work and information on the history of telescopes.

Bibliography

Pope, Tom and Jim Mosher. “Building a Galilean Telescope.” 2006.

http://www.pacifier.com/~tpope/Building_A_Galilean_Telescope.htm. 2006.

Trist, Bobbi. “Bouchet Outreach and Achievement in Science and Technology (BOAST): Building a Telescope.”

<http://www.life.uiuc.edu/boast1/sciencelessons/telescopes.htm>.