Outreach Magic - Easy Demonstrations from the PHOTON Projects

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Where the activities come from…

The PHOTON (ATE# 0053284) and PHOTON2 (ATE# 0302528) projects of the New England Board of Higher Education were funded by the National Science Foundation's Advanced Technology Education program to develop materials and provide professional development for secondary and post secondary instructors to enable them to teach optical science and photonics technology. The *PHOTON Explorations* were adapted from some of the favorite demonstrations of the projects' participants. We have used them with fifth graders who were part of EASTCONN's Expanding Horizons program, with high school students in Three Rivers Community College's Laser Camp, and as part of distance-learning courses for college students, working technicians and teacher professional development

In many of the following *Explorations*, there is an element of "optical magic" to be investigated. When doing these activities with students, we begin by posing one or more questions while demonstrating the "magic trick." Students are then challenged to explain what they have seen based on their knowledge of light and optics. Finally, we provide practical applications of the principles involved to show that optics is more than magic, it affects students' daily lives. Here, we present one application for each demonstration, you can no doubt think of many more.

Most of these demonstrations and activities use inexpensive and commonly found materials. They have all been student and teacher tested, but it's always a good idea to try them out first. Before doing any optics activities, be sure to find out in advance what the room lighting is like. Usually just turning room lights off is enough, but sometimes you might need to improvise if an activity works best in darkness. We once made a passable reflection hologram on a teacher's desk in a room with broken blinds, proving that excellent conditions are not always necessary.

All of the *Explorations* are available for download as a pdf document at www.photonprojects.org. On the same website you can find links to short video demonstrations of many of the *Explorations* by "real" teenagers. Suppliers for the materials are listed at the end of the instructions.

<u>A note on "how it works":</u> The explanations here are aimed at 10-12 year olds, that is, 4th-6th graders in the U.S. Of course you can adjust them to the sophistication of your audience, but if you can explain physics to a ten-year-old you can explain it to anyone.

#1 What Color is a Tomato?

Can your eyes be fooled by color and lighting? What determines the color you see when you look at an object?

This is an easy demo. It's amazing how many kids think that a tomato appears red because it absorbs red light. Perhaps this will convince them otherwise.

Materials:

- A small tomato, plum or tangerine work well. You can also use small colored candies and challenge students to correctly identify the color in order to "win" the candy.
- At least two different color LEDs. You could also use a flashlight, covering the end with blue, green or red plastic film.

Procedure:

In a very dark room, hold the tomato in your hand so that only a small portion of the surface is visible. If you are unable to darken the room, place the a few pieces of colorful candy in a small box so that it is well shaded from ambient light. It helps to paint the inside of the box flat black. Illuminate the tomato or candy with one of the LEDs and observe the color of the illuminated surface. For example, a red tomato illuminated by blue light looks like a purple plum.

What Color is a Tomato?: How it works

The color you see depends on the wavelengths reflected by the object, the wavelengths present in the illumination, and the color sensitivity of your eyes. A red tomato reflects a range of wavelengths, primarily red but also extending into the orange.[1] However, the skin is shiny so that when illuminated by a blue LED much of the blue light is reflected but no red light since the LED does not contain red light. Thus, the tomato looks like a blue plum.

What Color is a Tomato?: Application

Lighting plays an important role in marketing. Figure 1 shows the effect of illumination on a retail store display. Even though the items are identical on both left and right sides of the photo, the difference in lighting creates a large difference in perceived color. Check out the lighting in a local supermarket–are the same lights used for red meat and produce? In my hometown, there was a notorious warehouse store where you had to check every item near the windows to see the "real" color! On a recent trip to Home Depot, I noticed that the lighting department has a display of different bulbs illuminating the same colors, showing how lighting affects perceived color.

Figure 1. Photo taken at the Southern California Edison Lighting Center, 2004.

#2 Colors of Light

Is a red light bulb really red? How good a photography safelight is a red "party light" from the dollar store?

OK, so this isn't so much magical (although kids find it really interesting) but it's easy and very inexpensive to do with a big group. Don't forget to mention safety!

Materials:

- Cardboard tube. A paper towel or toilet tissue tube is fine!
- Diffraction grating. If you don't have one hand you can peel the label from a recordable CD with a piece of tape (scratch the label first) and cut the CD to fit the tube
- Aluminum foil or other opaque material for a slit.
- "CAUTION: DO NOT LOOK AT THE SUN OR INTO A LASER" sticker!

Procedure:

- Cover one end of a cardboard tube with aluminum foil. Hold the foil in place with a rubber band.
- Poke a small hole (about 2-3 mm) in the center of the foil with the point of a pencil or, if you can do it neatly, cut a small slit with a sharp knife.
- Place the diffraction grating or CD piece on the other end of the tube. Usually we don't glue the grating so it can be used without the tube for looking at small sources like a laser spot on a wall.
- Don't forget the safety sticker!
- To use, look through the grating at a light source. For large groups use incandescent and CFL bulbs, ceiling lights, EXIT signs, etc. If the group is small use sources they can get close to like an LED, gas tube or laser beam reflected from a piece of paper.

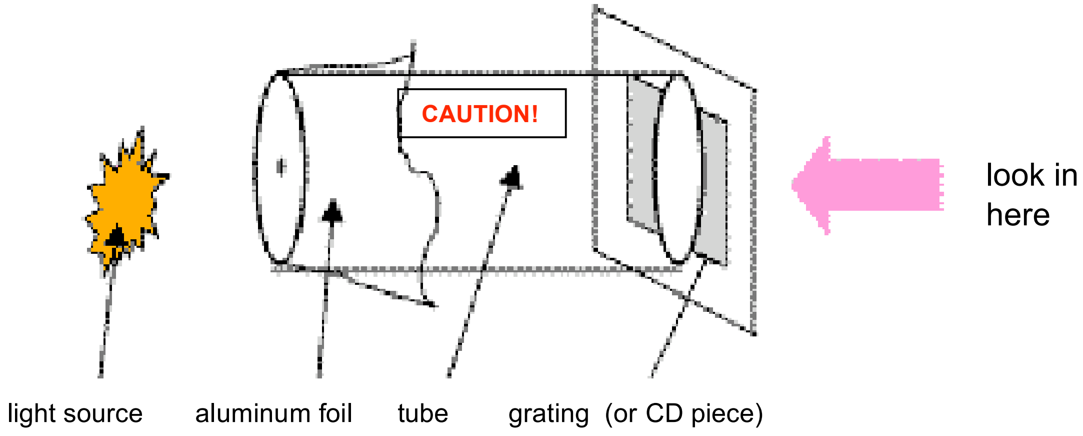


Figure 2. The cardboard tube spectroscope

Colors of Light: How it works

This activity is usually used to the observe spectra and how they are different rather than to explain how a grating works. Whether a continuous spectrum for an incandescent, line spectra for gas tubes or "patches of color" (to quote a fifth grader) for CFL, each source creates light in a different way. Students are encouraged to bring their "spectroscopes" home and look at light sources around the house- BUT DO NOT LOOK AT THE SUN. (We do explain how to view the solar spectrum by looking at the reflection of sunlight from a piece of white paper.) Neon lights, exit signs and LED indicator lights are also interesting to look at. You can provide crayons or colored pencils so the students can draw what they see, which may be easier than a written description.

Colors of Light: Application

There are lots of spectroscopy applications that appeal to young students. But we like to finish this activity by talking about how you can be fooled by something that seems "obvious." We needed a safelight for black and white photography and rather than spend the money at a photo shop, bought a red "party light" at a well known big-box store. We show students the red bulb and ask for a prediction of what the spectrum looks like. Nearly every fifth grader will say red, "maybe with a little orange." In fact, with this crude spectroscope, the spectrum is nearly the same as the white frosted incandescent they saw earlier, with plenty of green and some blue. So, that explains why our film was fogging!

#3 The Disappearing Beaker

Can a solid glass beaker disappear before your eyes?

This is a classic demonstration and you can find lots of video presentations on the web. Start by asking what "transparent" means. Students usually reply that it means you can see *through* something. So then how can you see something that's transparent?

Materials:

- Two Pyrex® beakers (preferably without printing), a small one that fits completely inside the larger one. Other types of glass may or may not work – experiment to find out! Also try stirring rods of different types of glass; some will disappear and some will not.
- Inexpensive vegetable oil

Procedure:

- Begin by placing the small beaker inside the larger one, and noting that the inner beaker is plainly visible. (Ask why!)
- Pour some oil into the smaller beaker; is it still visible?
- Continue to pour oil in the smaller beaker until it overflows into the larger beaker. As the space between the two beakers fills with oil, the inside beaker disappears!

There are a lot of variations on this demonstration. You can have the smaller beaker already submerged in the oil, inside the larger beaker. They then break another beaker and place pieces of broken glass into the submerged beaker. After some magic words, they pull out the inner beaker in one piece! The broken pieces can't be seen because they are submerged in the oil inside the smaller beaker.

We should mention that this may also be done with water, which is less messy. Clear water absorbing materials are available in a variety of shapes from science supply houses. When saturated, they are nearly all water so they can't be seen when submerged. It does take a while for this to happen, however.

The Disappearing Beaker: How it works

In order to see an object, some light must leave the object and enter your eye. In the case of a non-luminous object, light must be reflected from the object in order for you to see it. That is, a transparent beaker must reflect at least a small amount of light in order for you to see it. For young students, the explanation is that when light slows down or speeds up, some is always reflected. Light slows down when it goes from air into glass, then speeds up when it leaves. But light travels at about the same speed in glass and in vegetable oil, so there is no reflection.

Older students who know about index of refraction can calculate how much light is reflected. When light strikes glass head-on, the percent of the incident light reflected is given by

$$\%\text{Reflected} = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2} \times 100$$

For air (n = 1) and glass (n = 1.5), about 4% is reflected from each surface. If n_1 is the same as n_2 (glass and oil) then no light is reflected.

The Disappearing Beaker: Application

To minimize the amount of light reflected (and maximize the amount transmitted) the index of refraction (speed of light) in the incident and transmitting media should be as close as possible. Sometimes, "index matching fluids" are used, for example, when two optical fibers are joined in a temporary mechanical splice connection to minimize reflection back into the signal source.

A much more interesting application for many students is the gel applied before an ultrasound examination. Most students (and adults!) think the purpose is to make the transducer slide more easily over the skin. In fact, it is index- matching gel to maximize sound energy transmission from the transducer into the body.

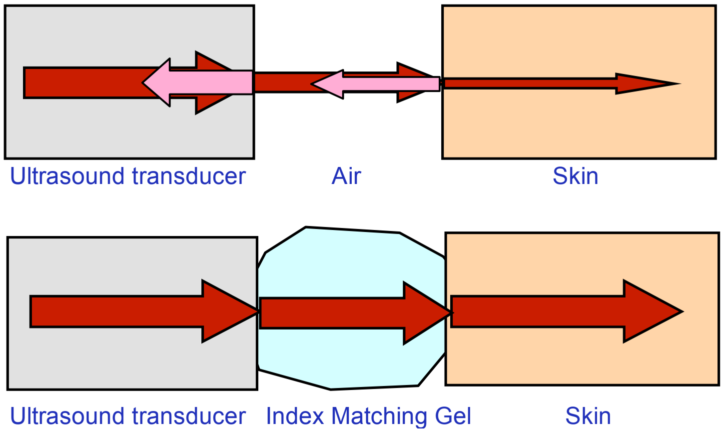


Figure 3. Top: Light traveling from left to right is partially reflected at each surface where the speed of light changes. Bottom: Index (of refraction) matching gel between the ultrasound transducer and skin minimizes back reflection and maximizes the amount of energy entering the body. Why isn't ultrasound used to image lung tissue?

#4 Amazing Jello®

Can you focus light with gelatin? Make a gelatin optical fiber? If you are really clever, can you make a graded index gelatin fiber?

This is another classic activity with a new twist. Younger kids can just observe the bending of light, older students can measure the index of refraction. Don't forget to talk about laser safety! And the rest of us can try to make GRIN gelatin. We won't be passing out gelatin during this workshop, but we'll demonstrate and provide you with the instructions so you can try it yourself. It's fun, but messy!

Materials

- Slabs (around 1.5 cm thick) of very stiff gelatin. You can use plain gelatin or flavored. Just don't use the kind with sugar- it makes a sticky mess. Spray the pan with oil to make it easier to remove the gelatin.
- Something to cut with–knives work, but 2 cm wide strips cut from a plastic folder can be bent to shape and are less dangerous
- Laser pointer use for a light source
- Ruler and protractor if you want to take measurements
- Sugar if you want to try GRIN gelatin (see below)

Procedure:

- Make the gelatin in a pan that will allow the gelatin block to be around 1.5 cm thick. If it's too thin it will be hard to handle. Use half the usual amount of water. On flavored gelatin packages, follow the recipe for "blocks" or Jigglers®- (on the Jello® package). You may want to experiment to find the right "mix".
- To make in quantity, try asking the local butcher for some small plastic meat trays. It's easier to handle in small trays rather than in a large pan. If the gelatin is stiff enough it will not need refrigeration.
- Remove the hardened gelatin carefully and cut into shapes for experimenting- rectangles, think strips or lens shapes as you prefer.
- To measure index of refraction, draw perpendicular lines on a piece of paper. Place the straight side of a gelatin block along one line. The other line is the normal to the surface (See Figure 4). Use a laser pointer to direct a beam into the block. Mark the end of the laser and the spot at the edge of the block where the beam exits. Remove the block to measure the angles of incidence and refraction and use Snell's law to calculate n_2 where $n_1 = 1$ and the angles are measured as shown in Figure 4. High school students should probably be able to handle Snell's law:

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

  Point out to younger students which way the beam bends (toward or away from the normal) as it goes from air to gelatin and back into air again.
- Make a gelatin optical fiber! Cut a long thin strip and shine the laser in from one end to illustrate total internal reflection (See Figure 5.) Try slicing the end of the fiber in two pieces along the length. Can you get light to travel down both branches of this "bifurcated fiber"?

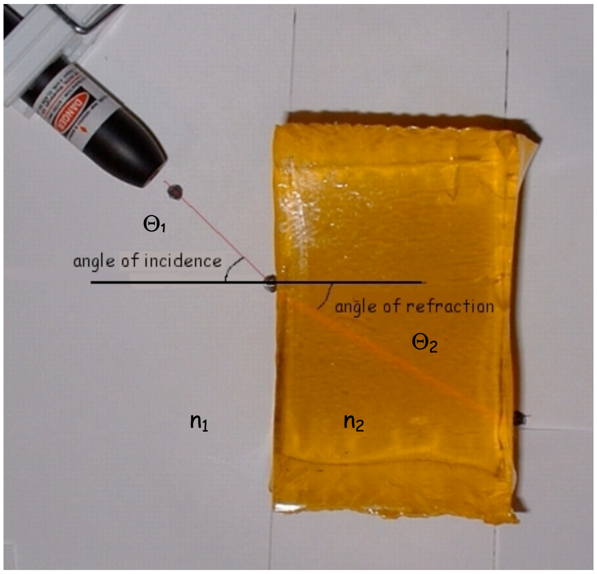


Figure 4. Measuring the index of refraction of gelatin . This photo shows lemon sugarless gelatin. Yellow looks cool with a red laser. (Yes, the beam is drawn on the air side.)

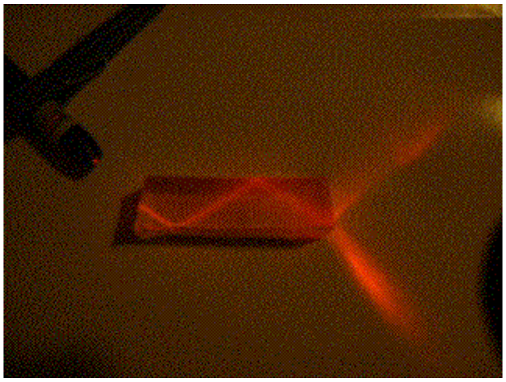


Figure 5. A gelatin "optical fiber" showing total internal reflection

<u>GRaded INdex gelatin</u>:

- The index of refraction of gelatin can be increased by adding sugar to the mix. To make GRIN gelatin, mix boiling water and gelatin powder as usual for gelatin optics. Then, add as much sugar as you can dissolve. You can make a slab or mold it in a cylinder, like a large plastic medicine container (Figure 6). Remember to coat the inside of the container with oil for easier removal.
- After the sugary gelatin has set, remove it from the container and place it in cold water for a few hours. Sugar will diffuse out from the surface in contact with the water, resulting a gradually changing sugar concentration and thus, a gradually changing index of refraction (See Figure 6).
- It may be possible to make a "step index" fiber by placing a higher gelatin content "core" into a lower gelatin content "cladding." I've had what can at best be called mixed success with this but I haven't given up.

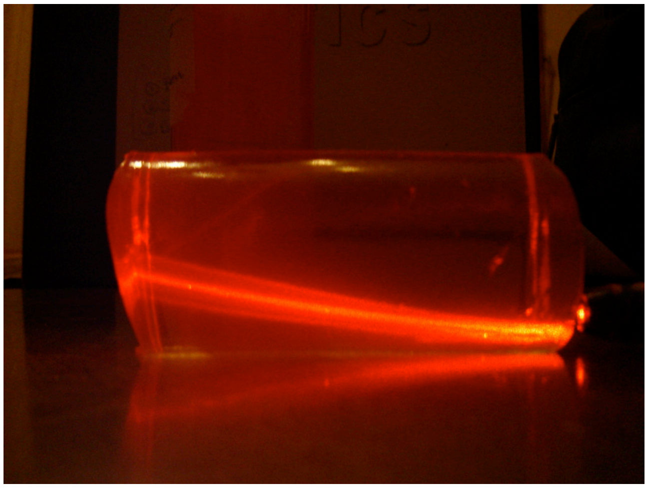


Figure 6. GRIN gelatin. This piece was made by in a large (4.5 cm diameter) plastic prescription medicine container. The laser beam enters horizontally from the lower right.

#5 The Misbehaving Lens

Can a double convex lens make light diverge?

Physics books have diagrams like Figure 7, leading students to believe that a lens needs only to be thicker in the middle to bring light to a focus. Is this always true?

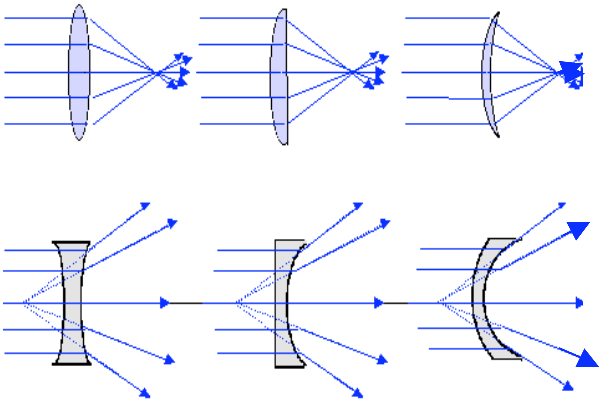


Figure 7. Converging and diverging lenses. From *LIGHT – Introduction to Optics and Photonics (Donnelly and Massa)*

<u>Materials:</u>

- Two watch glasses (from a chemistry lab)
- Silicone adhesive (such as sold for aquarium sealing)
- A transparent water tank large enough to completely submerge the "lens"
- A few drops of milk
- Laser pointer. If you have a laser ray box, it works even better.
- Optional: A glass lens of similar in shape to the “air lens”, such as a large magnifying glass.

Procedure:

- Coat the edge of one watch glass with a thick bead of silicone adhesive/sealant. Carefully place the second watch glass on top, creating an air bubble between. Allow to cure thoroughly.
- Fill the tank with water and add a few drops of milk so that the laser beam is visible. Lower the "air lens" into the tank so it is fully submerged. (You will need to hold it in place–an air lens floats!)
- Direct the laser beam through the top, middle and bottom of the lens and notice where the rays travel after being refracted by the lens. Do they converge or diverge?
- If you have a glass converging lens, repeat the demonstration. Explain the difference!

The Misbehaving Lens: How it works

Fifth graders can understand this explanation if they've done the gelatin activity first. We usually refer to the speed of light, not index of refraction, with fifth graders.

When light goes from a medium where it travels faster to where it travels slower, it bends toward the normal (perpendicular) line to the surface. If light goes from a medium where it travels slower to where it travels faster, it bends away from the normal line. Light travels faster through air than it does through water, and faster in water than it does in glass. (See Figure 8.)

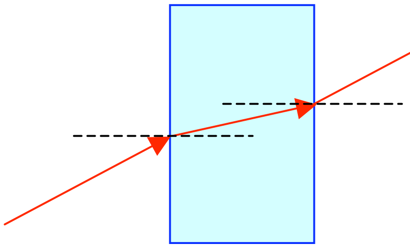


Figure 8. Refraction of a ray of light as it goes from air to glass (blue) and back into air.

So with a glass lens, light moves slower in the lens than in the surrounding air (or water). Light travels *faster* in an air lens than in the surrounding water so light rays behave exactly the opposite from a glass lens.

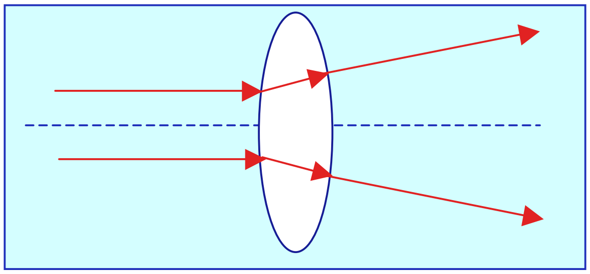


Figure 9. The "air" lens in a tank of water makes light coming from the left bend *away from* the axis.

The Misbehaving Lens: Application

How do swim goggles improve your vision? Your eyes focus light onto your retina, where sensors (rods and cones) detect the image and send the information on to your brain. But most of the focusing is actually done by the cornea, rather than the lens, because lens power depends in large part on the difference in index of refraction of the lens and surrounding media. Normally, the cornea is surrounded by air. (The lens is surrounded by fluids whose index of refraction is not that much different from the lens.) However, when you open your eyes underwater, your vision is blurry because the difference in index of refraction between water and your eye is not enough to focus light on the retina- you become severely hyperopic (farsighted). Swim goggles restore the air film in front of your eye and allow the cornea to do its job (Figure 10).

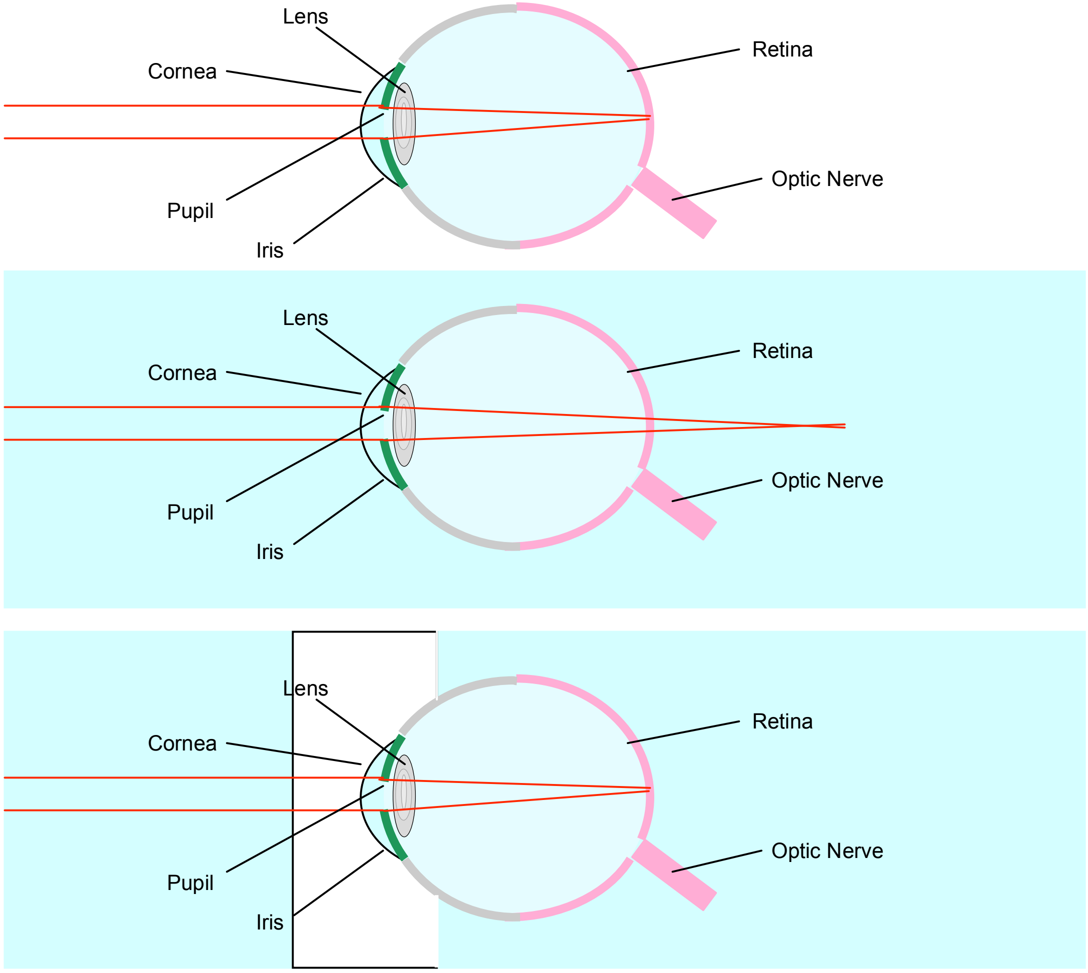


Figure 10. (Top) Normal eye in air. Most of the focusing power is due to the cornea. (Middle) Underwater, the index of refraction change between the medium (water) and the cornea is reduced. (Bottom) Swim goggles restore the air film, allowing the eye to focus.

#6 How Thick is Your Hair

Can you measure the diameter of your hair using just a laser pointer?

This Exploration is probably beyond the ability of most fifth graders, although they might be challenged to predict what they'll see when a hair blocks the laser aperture. This is a staple in hands-on high school and even college courses.

Materials:

- Laser Pointer
- Tape measure or ruler
- Calculator
- Two clothespins, if you're doing this by yourself

Procedure:

- Carefully tape a hair across the center of the laser pointer output aperture. Be sure the laser is off! Note the wavelength of the laser (from the caution label).
- Aim the laser at a wall across the room. (The pattern spreads more as distance increases, so measurements are easier if the wall is far away.) If you are working by yourself, you can mount the laser with two spring-type clothespins, as shown in Figure 11.
- Measure the distance from the laser output (the hair) to the wall.
- Tape a paper to the wall and mark the center of the pattern and the center of the first few dark spots on either side of the paper.
- Take the paper down and measure the distance from the center of the pattern to the centers of a few of the dark spots. Be sure to note the "order" of the spots you measure (See Figure 11).
- Use the equation below to determine the diameter of the hair. Does your measurement make sense?

$$d = \frac{m\lambda x}{y}$$

  In this equation,

  - x is the distance from the laser aperture to the wall
  - y is the distance from the center of the pattern to the dark spot you measured
  - m is the "order" of the dark spot you measured. For example, if you measured the distance from the center of the pattern to the second spot, m = 2.
  - λ is the wavelength of the laser light, marked on the laser caution label

- Something to think about: If the distance to the moon represents the diameter of your hair, how large would a nanometer be?

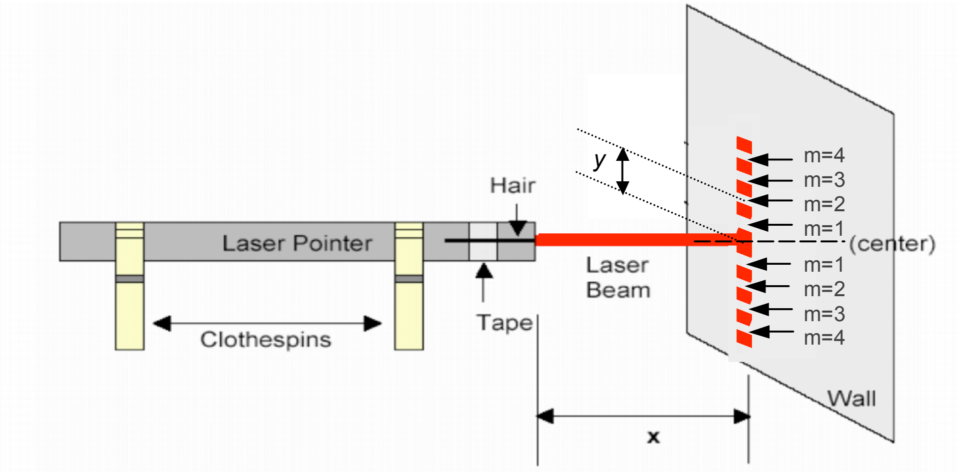


Figure 11. Using a laser pointer to measure the width of a hair. In the drawing, the laser is shown very close to the wall. You should be *at least* one meter from the wall. The drawing shows the measurement of *y* for *m* = 2, from the center of the pattern to the second dark spot (between the bright spots). You will see many more dark and bright spots than shown here, and they will probably be blurrier.

How thick is your hair?: How it works

When light passes through a small opening or around a small object, the light appears to "bend" around the edges. Parts of the light wave then interfere with each other, creating patterns of dark and light. This is called diffraction. You can see diffraction by holding two pencils close together side-by-side and looking at a light bulb through the tiny crack between them. You need to put your eye very close to the pencils. You will see dark and light bands between the pencils - you may even see faint colors. The bands are caused by light waves diffracting around the edges of the pencils. Note that the bands disappear if you spread the pencils apart. Diffraction is one of the most fascinating aspects of light!

When you shine laser light around the hair, the light diffracts and forms a pattern of bright and dark spots on a distant wall. The spacing of the spots depends on how wide the hair is as well as how far from the wall and the wavelength of the laser light. Most people's hair is around 60-90 microns in diameter, although yours may be thinner or thicker.

This experiment does not work with gray hair. Can you guess why?

How thick is your hair?: Application

Optical fiber is made by holding a special glass rod in a vertical position and heating one end until the glass is soft. (See Figure 12.) The softened end drips down, trailing a thin "thread" behind- the optical fiber. The fiber is wound onto a take-up spool that turns, drawing more fiber behind it. It is very important that the fiber diameter not change as the fiber is being drawn, and sensors are placed along the fiber path to constantly monitor the diameter. If the fiber starts to get thinner, the take-up spool spins more slowly, if it starts to get thicker, the spool spins faster. Diffraction can be used to make sure the fiber stays within specifications.

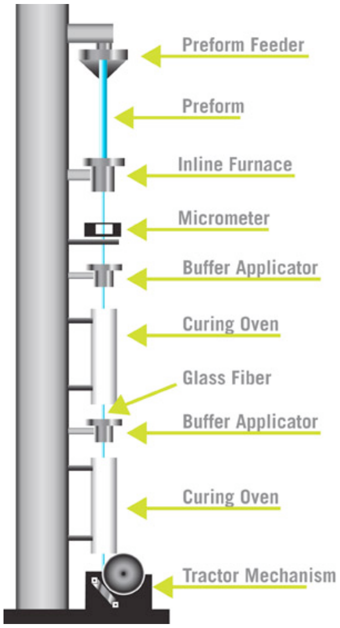


Figure 12. Diagram of optical fiber draw tower. (from Fiber Instrument Sales)

#7 The Magic Box

Can you build a "wall" that solid objects can pass through? Where does the "wall" come from? How do objects pass through it?

This is a very cool illusion. Even people who know how it's done find it fascinating.

<u>Materials:</u>

- A cardboard box about the size of a tissue box. Paint it black for best effect.
- Four 2"-3" squares of polarizing film
- Tape
- For dramatic effect- a knife or chopstick

<u>Procedure:</u> (See Figure 12.)

- Remove rectangles approximately 2" by 4" from both the front and the back of the box. Be sure that each opening can be completely covered by two polarizer squares when they are placed side by side. Carefully align these openings so you can look right through the box.
- Tape two of the polarizing filter squares to the front opening. One filter should have its transmission axis in the vertical direction and the other in the horizontal direction. Tape the other two the polarizing filter squares over the back opening. The orientation of the transmission axes is correct if, when viewed from the front, the vertical polarizers (front and back) are both on the same side.
- Look through the front of the box. Where did the black wall come from in the center of the box? Optional: carefully stick a knife or choptick into the box from the end- piercing the "wall" with no resistance! Others have suggested rolling a ball through the wall or even having a tiny action figure swing through the wall on a string.

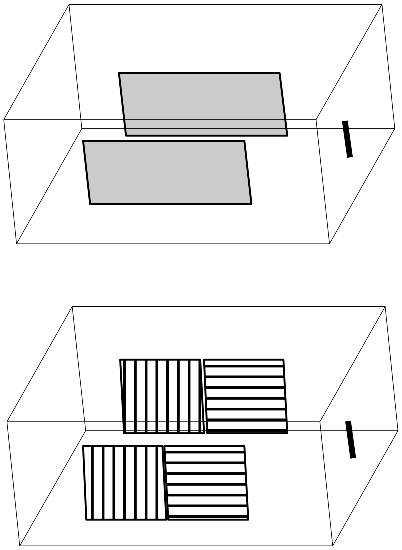


Figure 12. Construction of the Magic Box. Top: Cardboard box with rectangles cut out in the front and, directly opposite, in the back. Bottom: Polarizers mounted over holes, with transmission axes indicated. The slit on the end is optional, for piercing the “wall”’ with a knife, chopstick, or other long thin item.

The Magic Box: How it works

This is easier to explain to fifth graders if they previously worked with some polarization activities. (See the complete list of Explorations in the resources section.) They then should understand that

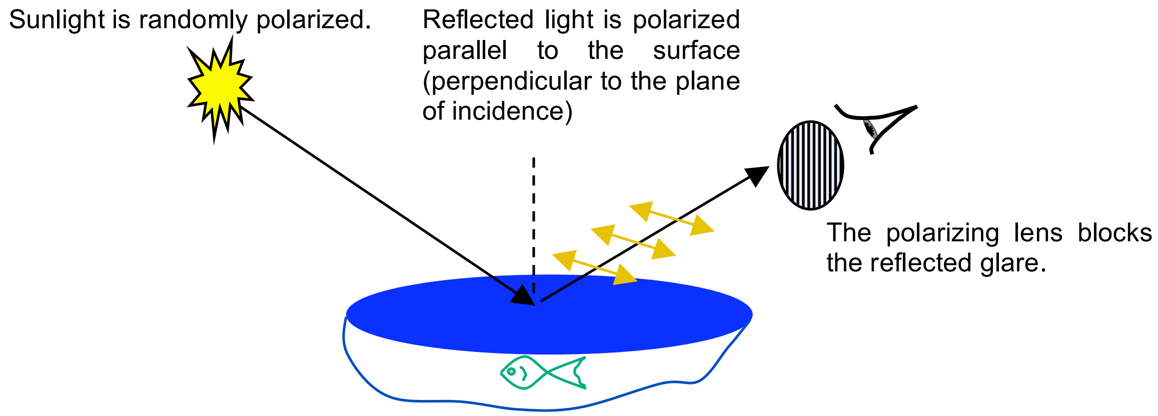
- Light is a wave that vibrates back and forth at right angles to the direction of motion.
- "Natural" or "randomly polarized" light can vibrate in any direction.
- Polarizing light restricts the vibration direction, for example, a horizontally polarized light wave vibrates only horizontally.
- A polarizing filter acts somewhat like a picket fence, only allowing one direction of wave vibration to pass.

Now suppose that natural light passes through a vertically oriented polarizer. Only vibrations in the vertical direction pass through. What happens if this vertically polarized light strikes a polarizer oriented in the horizontal direction? This second polarizer cannot pass vertical vibration so no light gets through.

Look again at the "wall" in the magic box. Where the horizontal polarizers in the front of the box overlap vertical polarizers in the back of the box no light passes. This is what gives the appearance of a wall in the center of the box.

The Magic Box: Application

Sunlight is randomly polarized; the light waves vibrate in all directions. However, when sunlight is reflected from a surface such as water or snow, it is polarized so that the vibrations are back and forth parallel to the surface. (We prefer to say perpendicular to the plane of incidence but that might be too much for a ten-year-old.) These vibrations can be blocked by a polarizing filter oriented perpendicular to this vibration direction. Polarized sunglasses block glare by preventing the polarized light from passing though.


Sunlight is randomly polarized.

Reflected light is polarized parallel to the surface (perpendicular to the plane of incidence)

The polarizing lens blocks the reflected glare.

Figure 12. Polarizing sunglasses work because the reflected glare of the sun from water or snow is polarized.

#8 Polarized Light Art

Can you make colorful art from plain old cellophane tape?

Clear cellophane tape is colorless. However, if it is placed between two polarizing filters, the tape can show brilliant colors. Where do the colors come from? Why do the colors change when the polarizer is rotated?

Materials:

- Two squares of polarizing film
- Cellophane tape or other pieces of cellophane, for example, from vegetable or flower packaging
- A piece of clear plastic, such as transparency film, the same size as the polarizers. This is not necessary, but gluing directly onto the polarizers means they can't be used for other purposes.
- Glue sticks or rubber cement if cellophane is used

Procedure:

- Place small pieces of tape or cellophane on the plastic film. You can attach them directly to the polarizer, but then the polarizer can't really be used for anything else. Attach the tape of cellophane in different directions, and try varying the thickness.
- Make a "sandwich" of the two polarizers with the tape-decorated film in between. Be sure to show students exactly what this looks like; they often put the cellophane pieces on top of the two polarizers by mistake.
- Rotate the top polarizer, while you look through the entire stack. In order to see the colors effectively, the stack should be back lit, for example, hold it up to a window and look through the layers. A photographer's light box works well too.

Polarized Light Art: how it works

Cellophane and other so-called *birefringent* materials can affect polarized light by changing the direction of vibration of the light wave. For example, if vertically polarized light passes through a piece of cellophane, the direction of polarization will be different on the other side. The exact amount the direction changes depends on the thickness of the cellophane and on the color of the light. The top polarizer passes light of a specific orientation. Since different colors are rotated to different directions, the top polarizer "chooses" which color you see.

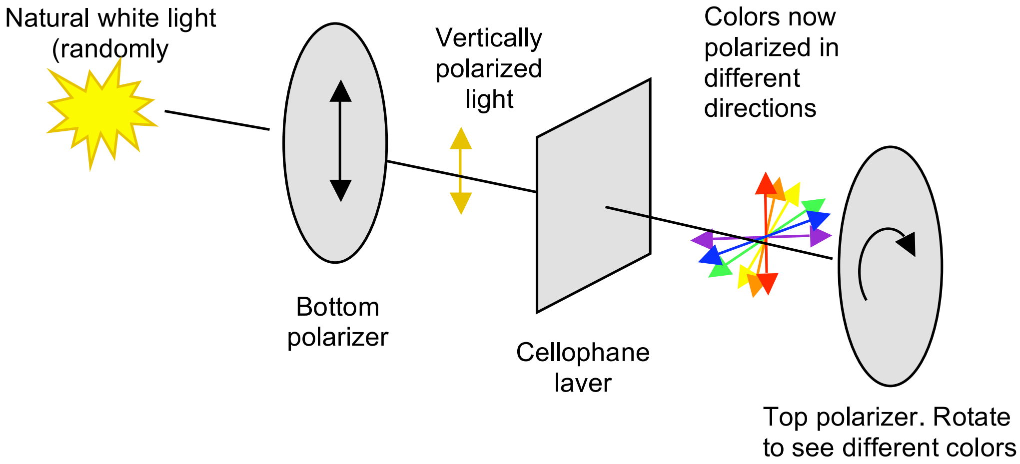


Figure 13. The cellophane rotates the direction of polarization. The amount of rotation depends on the thickness of the cellophane and the wavelength of light.

Polarized Light Art: Application

This technique can be used to create beautiful works of art that change from one image to another as the top polarizer is moved. Austine Wood Comorow, who coined the term Polage®, creates wall-sized art for museums and other public spaces using polarized light. In technology, the effect is used to detect stresses in transparent materials. Plastic and glass behave similarly to the cellophane in this experiment when placed under stress. This principle can be used to detect stress in materials such as glass (See Figure 14).

Figure 14. These eyeglasses are resting on a light box covered with a sheet of polarizing film. A second piece of film oriented at right angles to the first is covering the eyeglasses on the right. Stress in the glass lenses is apparent under the top polarizer.

#9 Light You Can't See

How does ultraviolet light work? How do we know it's there if we can't see it?

This is a potpourri of fun activities to do with UV flashlights, glow-in-the-dark materials and UV reactive beads.

Materials:

- UV flashlight (you can use sunlight for some activities as noted below)
- Small flashlight
- Red and blue LEDs
- square of phosphorescent vinyl or other "glow in the dark" material
- whitening detergent
- cotton swabs
- UV beads

Procedure:

- *Phosphorescence*: This works best with the room lights off, but it does not need to be really dark. Shine the flashlight onto the square of vinyl and observe the glow after the light is removed. Predict what will happen if you shine the red and blue LEDs on the material, then test your predictions. Why doesn't the red light have any effect?
- *Fluorescence:* This works best in a dark room. Use a cotton swab to write a "secret message" with the detergent on a piece of paper. Illuminate with the UV light. Does it continue to glow when the UV light is removed? Why not? How is this different from the glow-in-the dark material, which continues to glow when the light is turned off?
- *UV beads*: These can be illuminated with the UV light or just expose them to sunlight. Use the beads to test sunscreens! Choose a single color bead and dip some in sunscreen. Use different SPF factors if you can. You might also just cover some of the beads with different types of fabric to see which ones are better at blocking ultraviolet light. Put the beads on a plate and leave some uncovered and some completely covered. Take all the beads out in the sunlight (or use a UV flashlight) and after a few minutes compare the color of the covered, uncovered and sunscreen or fabric protected beads.

  Note: If the beads are hard to handle, they can be glued to popsicle sticks for ease of handling. Cover a pan with aluminum foil and place the beads flat on the foil. Put in a 300^{o}F oven for about 15 minutes until the beads are flattened. (They will look clear at this stage.) After the flattened beads are cooled they turn white again. At this point, glue them onto the sticks and proceed as above.

Things that Glow in the Dark: How it Works

Visible light is produced when atoms in a high-energy ("excited") level return to a lower energy level. Atoms and molecules can be excited in a number of ways, for example, when an atom absorbs light or is subjected to a high voltage. The excited atoms in a material may all give off light energy quickly in which case it is called fluorescence. Or, the atoms may release light energy over a longer period of time, which is called phosphorescence.

The ultraviolet light waves used in this exploration have high energy. By comparison, blue light has lower energy and red light has lower energy still. Red light does not have enough energy to energize the phosphorescent material. The more energetic blue light can provide enough energy to excite the material, and then it continues to glow for a while. Why does the white light of the flashlight work?

UV beads don't really fit in the "glow in the dark" category because they are neither fluorescent nor phosphorescent. Instead, they contain a polychromic dye molecule that changes shape when illuminated by UV light. The new shape absorbs visible light and so appears colored. We should note that the SPF factor on sunscreen bottles is a measure of UVB protection, but the UV flashlights are usually around 395 nm (UVA). UV beads respond to the relatively narrow range 300 nm-360 nm, which includes the high energy part of UVA (320-400 nm) and low energy part of UVB (280-320 nm). With older students this might lead to a discussion of the validity of using the beads and/or flashlights to test SPF of sunscreens.

Things that Glow in the Dark: Application

The detergent contains "whitener" that fluoresces (glows) when activated by UV light. This makes your white clothes look clean and bright in the sun! Certain toothpastes and eye drops are also fluorescent. Among other common fluorescent items are petroleum jelly and urine; in fact, some UV flashlights are advertised as "urine detectors."

Sources for Materials

The supplies for these experiments can be purchased from many sources; we list only one or two that we have purchased from recently.

- *What color is a Tomato?* Very bright (and expensive) PHOTON® LEDs are available from a number of sources, such as www.photonlight.com. They can sometimes be found at lower prices at sports and novelty shops
- *Colors of Light.* Diffraction gratings of all kinds are inexpensive in large quantities from Rainbow Symphony Store (www.rainbowsymphonystore.com.) If you'd prefer to buy cardboard tubes (rather than have your friends and family collect them) 1.5" x 9" mailing tubes are sold in boxes of 50 by a number of vendors. Check around for best price.
- *The Disappearing Beaker.* A pair of standard laboratory beakers works well but they usually have markings. If this is a problem, beakers with no markings can be purchased from Educational Innovations (www.teachersource.com).
- *The Misbehaving Lens*. Watch glasses are available from standard physical science suppliers. Most chemistry departments have plenty to share. Silicone adhesive can be found locally at stores that sell aquarium supplies or in home/hardware stores. For a water tank, we use a small pet carrier tank from a pet shop when a large aquarium is too large to work with. Large lenses can often be found at American Science and Surplus American Science and Surplus (www.sciplus.com). Another source of cheap lenses (and other optics) is Surplus shed (www.surplusshed.com)
- *How Thick is Your Hair*? Laser pointers can be found for a few dollars at surplus stores and some online vendors. One teacher we know purchased a number of inexpensive (under $10) from a closeout bin at a local hardware store.
- *The Magic Box* and *Polarized Light Art*. For inexpensive polarizing film (especially in quantity) try www.polarization.com. Polarization.com is also a great source of information on polarized light applications.
- *Light you Can't See*. Phosphorescent vinyl is available in small pieces from a number of suppliers such as Educational Innovations (www.teachersource.com) or Anchor Optics (www.anchoroptics.com). It's much less expensive to buy by the foot and if you give it away in small pieces it can last for years. Hanovia UV is one supplier (www.hanovia-uv.com). UV beads are pretty easy to find, but our usual source is Educational Innovations, which sells bags of 3000 beads (and includes information on how they work). They also carry UV flashlights. There are less expensive UV flashlights around, but some seem to be poor quality. One source of cheap UV flashlights (as well as LEDs, laser pointers and cheap batteries) is Jack's Tool Shed (http://jackstoolshed.net/).

Other Resources (Free Stuff)

- These are all available at http://www.photonprojects.org
    - The PHOTON Explorations (pdf file)
    - Links to videos of students performing the PHOTON Explorations
    - Links to PHOTON Lab Kit experiment videos ("Laser Geeks Present")
    - Papers and publications by teachers on their classroom and outreach projects
    - Link to the PHOTON PBL problem based learning Challenges
- Photos and videos of polarized light art and information on how it is created. Watch Austine at work! http://www.austine.com
- Experiments in Nanotechnology, including more on sunscreen testing at www.nanosense.org
- Links to optics applets and tutorials, assorted photos of "home lab" experiments and other neat optical effects http://www.lasertechonline.org.
- Great solar-related activities and links http://solar-center.stanford.edu/
- Arbor Scientific's *CoolStuff Newsletter* has great ideas for demonstrations and activities. The archives are at www.arborsci.com/CoolStuff/Archives3.aspx. Many of the activities here are also in the *CoolStuff* archives.
- SPIE has free posters and videos at http://spie.org/x30114.xml
- OSA's free posters at http://www.osa.org/educationresources/youtheducation/
- The *CRISP Website for Educators* has great ideas for demonstrations and activities. Access materials at https://www.southernct.edu/crisp/index.php. CRISP is a National Science Foundation Materials Research Science and Engineering Center (MRSEC) at Yale with components at Southern Connecticut State University (SCSU).

References

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[3] Clear Sunscreen: How Light Interacts with Matter, The NanoSense Project,
Center for Technology in Learning. SRI International, http://nanosense.org