For girls 11-15

Lighten Up!

Discovering the Science of Light

Girl Scouts.

OSA Foundation

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What's Inside

Introduction

Ever wonder why the sky is blue or how a telescope works or why you are able to read this page? The answers lie in optics. You rely on optics every day! Eyeglasses and contacts use simple lens configurations to improve your vision. Cameras, computers, TVs, CDs, and DVDs all rely on optics, too.

Optics is the science of light. More specifically, optics is a branch of physics describing how light behaves and interacts with matter. From exploring the universe to monitoring the environment to solving crimes, scientists who specialize in optics utilize their knowledge of how light behaves under different conditions to advance technologies that make the world around us better.

flash **FACT**

Optics "is." Optics sounds like a plural, but it isn't. Think of mathematics or physics. Would you say, "Physics are the study of matter and energy"?

CHAPTER 1

Light Is

To understand optics, first you need to understand light. Light is a form of energy made up of electric and magnetic fields, called **electromagnetic radiation.** Light comes from the sun, the stars, camp fires, lightning, flashlights, and even some living creatures like lightning bugs and some deep sea fish. There is light you can see (**visible light**) and light you can't (**ultraviolet light** and **infrared light**).

COLOR MY WORLD

Visible light may look white, but is it? Check out the next activity to find out!

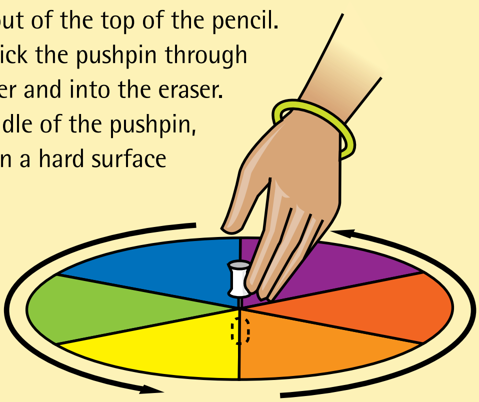
ACTIVITY spinning your (COLOR) wheels

What You NEED

- Pushpin
- Pencil eraser
- Ruler
- Scissors
- Markers or crayons in red, orange, yellow, green, blue, and violet
- Uncoated white paper plate (dessert or lunch size)

What You DO

- Trim the edge off the plate to create a flat white circle.
- Divide the circle into 6 equal sections, using the ruler and a pencil.
- Color each section a different color.
- Pull the eraser out of the top of the pencil.
- Color side up, stick the pushpin through the circle's center and into the eraser.
- Holding the handle of the pushpin, spin the circle on a hard surface like a top.



Continued...

What You SEE

What color(s) do you see? Does it matter which direction, or how fast, you spin the wheel? Does it matter what colors are next to each other?

HOW and WHY

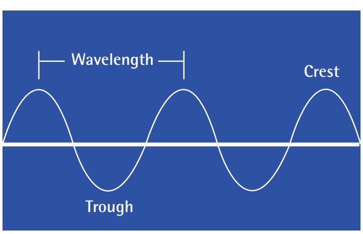
Have you ever held a prism or crystal up to the light to create a rainbow? In this activity, you instead combined all the colors, to create white, or a yellowish-white (like many lightbulbs).

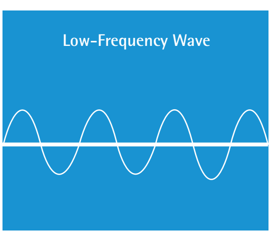
flash FACT

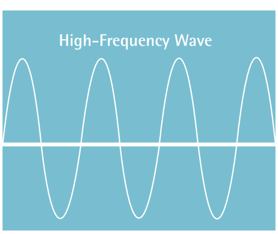
You will be exploring the science behind the order of colors in a rainbow. For now just remember ROY G BIV—Red, Orange, Yellow, Green, Blue, Indigo, Violet. You'll never be at a loss for the order of colors again!

CATCH A WAVE

Light energy travels in waves that vary in size (amplitude) and distance (wavelength) from each other. Think about waves in the ocean. If you measure the distance from the crest (top) of one wave to the crest of the next, you're measuring one wavelength. If you then count how many waves you see in a given amount of time, say 1 minute, you will know the frequency of the waves. On a calm day with few waves, the wavelength is long, and you will only see a few waves each minute (low frequency). On a stormy day, the water is more turbulent, the wavelength is shorter, and there are more waves in 1 minute (high frequency).

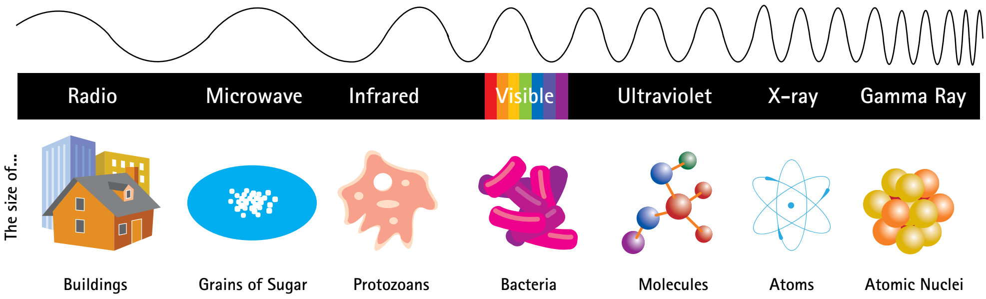






Still a little confused? Take a look at the electromagnetic spectrum chart below, which illustrates how different wavelengths relate to each other.

Electromagnetic Spectrum



This chart shows you the entire range for electromagnetic waves— from radio waves (long wavelength) to gamma waves (short wavelength). Here are key points to know:

- The shorter the wavelength, the higher the frequency.
- The higher the frequency, the greater the energy.
- The greater the energy, the shorter the distance it can travel.

Wait. The more energy a wave has, the shorter the distance it will travel? Yeah, that's right. When you have a short wavelength, it has more energy, and it reacts more "intensely" with the environment around it, depleting its energy more quickly.

Think of it this way. You decide to go out for a run. When you start, you have lots of energy, but if you sprint down the street, you will expend that energy very quickly. If you jog, however, your energy will last longer, and you can travel a greater distance before you need to take a break.

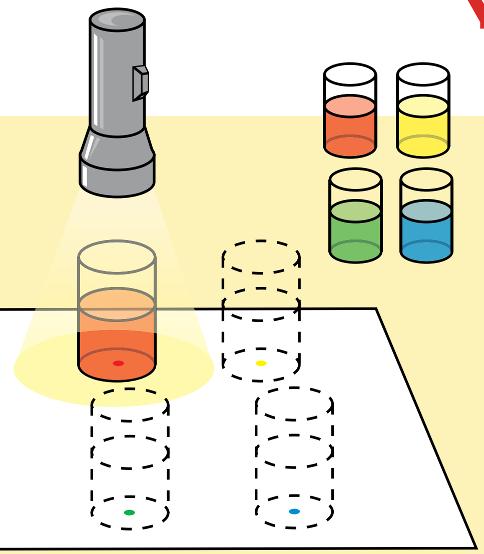
The three principles above explain why a microwave can cook your food and an X-ray can photograph your bones. The greater energy of the X-ray allows it to penetrate your skin, but it uses that energy quickly and so can't travel far enough to penetrate your bones.

flash **FACT**

Light from the sun takes about 8 minutes to reach Earth. If you traveled a highway from Earth to the sun, it would take 177 years at 60 mph to reach your destination. Nothing in the known universe can travel faster than light.

ACTIVITY

Mix and Match!



What You NEED

- 1 piece of white paper
- 4 clear plastic cups
- Water
- Ruler
- Pencil
- Flashlight
- 4 cotton swabs
- Newspaper
- Red, yellow, green, and blue food coloring

What You DO

- Cover your workspace with newspaper.
- Place a few drops of red food coloring on one end of a cotton swab.
- Using the swab, make a dark red dot about 2 cm in diameter on the white paper. Repeat this process with each of the remaining 3 colors.
- Fill each cup halfway with water.
- Add 3–5 drops of food coloring to each cup, and mix with a matching swab.
- Turn on the flashlight and darken the room.
- Hold the cup of red water directly above the red dot.
- Shine the flashlight straight down into the cup of red water and look at the red dot. What color do you see? Record your results on the chart.
- Repeat the process until you have tried all the water colors with all the colored dots. The data chart will help you keep track of the combinations to test.

Water Color	Dot Color	Color You See
Red	Red	
Red	Blue	
Red	Yellow	
Red	Green	
Blue	Red	
Blue	Blue	
Blue	Yellow	
Blue	Green	
Yellow	Red	
Yellow	Blue	
Yellow	Yellow	
Yellow	Green	
Green	Red	
Green	Blue	
Green	Yellow	
Green	Green	

What You SEE

What did you discover about mixing color and light? Does it make a difference if you set the cup down or hold it above the dot? Do you get the same results for blue if you make really dark blue water?

HOW and WHY

You've just mixed different wavelengths together. When you are looking into the red water as it is held above a yellow dot, you see two wavelengths at the same time. The wavelengths for red and yellow combine and you see orange.

Link it!

Visible light contains ROY G BIV, with three of the seven colors considered primary: red, yellow, and blue. Primary colors can be combined to make the other colors of the rainbow. Red + yellow = orange. Look at where orange is in ROY. Now what colors make green? Is the order of colors in a rainbow a coincidence?

flash FACT

By combining just three colors—yellow, cyan (a shade of blue), and magenta (a shade of red)—in varying amounts, color printers are able to generate all the colors you wish to print. Since black is the most used color, most printers come with an ink cartridge dedicated to it—though some create it through mixing.

LIVE IT!

Ripped from the Headlines

Optical Scientist Creates Process for Self-Illuminating Photos

Scientists at the University of Arizona are developing methods for using the inkjet printing process to produce self-illuminating photos. The process prints a special ink blend onto an electrically conductive medium. The resulting chemistry produces images that react strongly to light, giving them a special "lighted" appearance.

CAREER PROFILE

Optical Educator

Courtesy of Rensselaer Polytechnic Institute

Shirley Ann Jackson, Ph.D.
Rensselaer Polytechnic Institute

Currently the president of Rensselaer Polytechnic Institute in Troy, N.Y., Dr. Jackson is a theoretical physicist who has held leadership positions in academe, industry, and government. She was the first African-American woman to receive a Ph.D. from the Massachusetts Institute of Technology (MIT) in any subject, and one of the first two African-American women to receive a Ph.D. in physics in the United States.

In 1995, Dr. Jackson became the first African-American woman appointed to serve as chair of the U.S. Nuclear Regulatory Commission, and, in 1999, with her appointment to the presidency of Rensselaer, became the first African-American woman to lead a national research university. Dr. Jackson's research specialty is in the physics of optic-electronic materials, which convert electricity to light and visa versa. Her knowledge of physics and passion for discovery have led her to encouraging young people—particularly girls and young women—to prepare for careers in science and engineering.

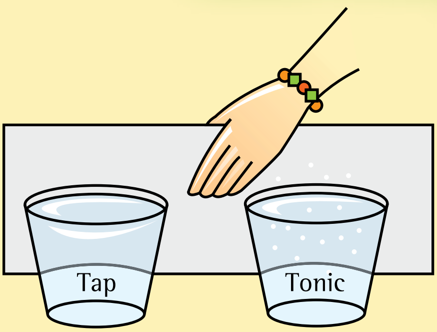
Light Moves

Now you are familiar with visible light and wavelengths. Next, you will investigate invisible light and how light moves. Ready to start?

ULTRAVIOLET LIGHT

Ultraviolet (UV) light has a shorter wavelength than the human eye can detect. Although you cannot see UV light, you can feel it coming from the sun.

ACTIVITY Glowing Tonic



What You NEED

- 2 clear plastic cups
- 1 liter of tonic water
- Tap water (enough to fill 1 cup)
- Permanent marker
- Black paper or felt
- Sunny day

What You DO

- Mark the plastic cups “tap water” and “tonic water.”
- Fill the cups almost to the top with either tonic or tap water.
- Set the cups outside in direct sunlight. Midday works best.
- Hold the black paper or felt behind the cups, and look across the top.

What You SEE

Do both cups of water appear the same? Do you see a blue glow on top of the tonic water?

HOW and WHY

Tonic water contains quinine, which transforms UV light into visible light. This process is called *fluorescence*. The brightness of the “glow” is determined by the amount of UV the tonic water is receiving.

Step it up!

Try blocking the UV light that reaches the tonic water with various household items such as sunglasses, cloth, glass, or plastic. Find clear plastic that allows UV light through, and then apply sunscreen to the plastic and see if you can decrease the blue glow.

Using the same items, see if you can block the IR beam between your remote control and the TV. Do the same materials block both?

Link it!

Ultra- means *beyond*, so *ultraviolet* means beyond violet. The prefix *infra-* means *below*. How does this increase your understanding of the color spectrum? (IR) ROY G BIV (UV)

flash FACT

SPF stands for Sun Protection Factor. If you apply SPF 15 sunscreen, then your skin is protected from the sun's UV rays 15 times more than without it.

HOW ANIMALS AND INSECTS SEE LIGHT

You can't see UV light, but some animals and insects can. Photo A shows what a flower looks like to you, while Photo B shows what the same flower looks like to a bee. In this image, the darker the color, the more UV light the flower is reflecting. Humans can't see it, but bees can.

Photo A

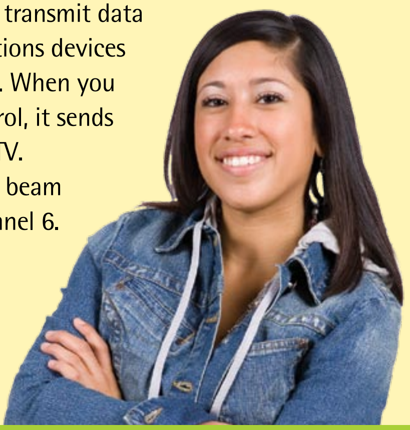
Photo B

INFRARED LIGHT

Infrared (IR) light has a longer wavelength than you can see, but you can feel it. Have you ever felt heat from a burner on the stove? Your hand is absorbing IR energy from the burner. IR light is used in night vision goggles, digital cameras, weather satellites, and more.

Night vision goggles are optical instruments that enable you to see in the dark, and use either passive or active technology. Passive goggles use available light (stars and moon) to amplify an image and produce that familiar green tinted night image you often see on television. Active goggles send out IR light and generate a very bright image from what is reflected back.

IR light can also be used to transmit data in short-range communications devices like your TV remote control. When you press 6 on the remote control, it sends an IR "data beam" to your TV. The TV receiver decodes the beam and the TV changes to Channel 6.



WHEN WAVES COLLIDE

Light travels in straight lines called light rays. Every time light interacts with something—such as air, water, or glass—the light rays slow down and change direction. These changes cause the light to be reflected, scattered, refracted, and/or absorbed.

When an object **reflects** light, it bounces the light back in a straight line with little change in speed (velocity). The angle at which light bounces off the object is determined by the angle at which light initially hits it. Think of a pool table. If you hit the ball against the side of the table at a 45° angle, it will reflect back onto the table in a straight line at a 45° angle from the table's edge. **Scattering** is a form of reflection that occurs when light encounters a rough surface, causing the light to be sent off in many different directions. Reflection and scattering allow you to see yourself in a mirror, cause a reflector to shine, and a diamond to sparkle.

Refraction of light occurs when a light ray slows down and changes direction as a result of passing through different mediums—such as water or air. The wavelength (energy) determines how quickly and how much each color in the visible light spectrum bends as it passes through a medium such as a glass prism or raindrop. Refraction helps explain why a rainbow always appears with its colors in the same order.

Absorption occurs when light energy is "taken in"—just like a paper towel absorbs water. When light hits a colored object, such as a red book, most of the colors are absorbed. The red wavelengths, however, are scattered off the book's rough surface, resulting in your seeing red. When only certain colors (wavelengths) are absorbed, you see the colors that are not.

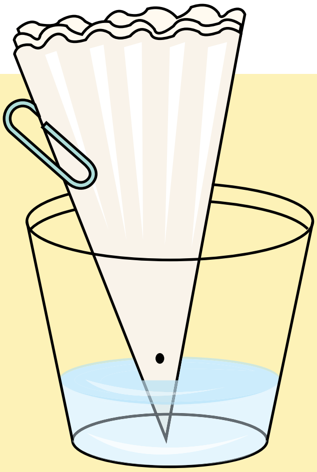
Wow, that is a lot of information.
Try the next two activities to help make sense of it all!

flash **FACT**

The statesman, philosopher, and dramatist Seneca is said to have read all the books in ancient Rome by peering at them through a glass globe of water to produce magnification.

ACTIVITY

Black Is Black OR IS IT?



What You NEED

- 1 white basket-style coffee filter
- Paper clip
- Water
- Clear plastic cup
- Ruler
- Black felt-tip pen or marker (nonpermanent)

What You DO

- Fold the coffee filter in half three times to form a triangle. Use a paper clip to hold it together, if necessary.
- Make a 1/4 inch dot with the black marker about a 1/2 inch above the point of the triangle. Allow the black dot to dry.
- Put a 1/2 inch of water in the bottom of the cup.
- Place the tip of the coffee filter in the cup, making sure the dot does not enter the water.
- Watch what happens as the filter absorbs the water.

What You SEE

What did you discover about the color black?

HOW and WHY

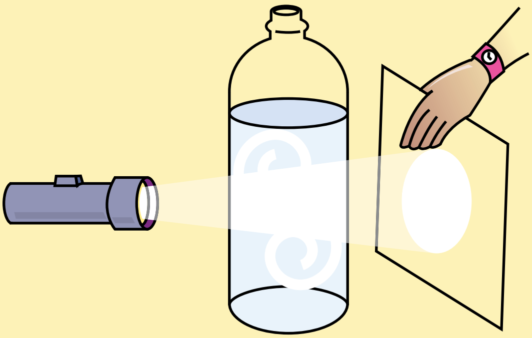
Your eyes determine color based on reflection, scattering, and absorption. When a color is absorbed, you do not "see" that color. Because black absorbs all colors, it reflects nothing and you see only black. When a color is reflected off an object, you see the reflected color.

Step it up!

Experiment with other marker colors. Do your results match those from the MIX AND MATCH! activity? Check out the primary colors. Are they "true" primary colors, or did another color get added to make the color more vibrant? How about different brands of markers? Do they use the same combinations of colors?

ACTIVITY

BLUE SKY RED SUNSET



What You NEED

- Flashlight
- Sheet of white paper
- Clear glass or plastic bottle
- Water (enough to fill 3/4 of a bottle)
- Milk or cream (1–3 tablespoons)

What You DO

- Fill the bottle 3/4 full with water.
- Turn on the flashlight and shine the flashlight through the side of the bottle.
- Look through the bottle from all sides. What do you see?
- Hold the paper opposite the light. What color is on the paper?
- Add 1 tablespoon of milk to the water.
- As the milk mixes with the water, continue shining the light through the bottle and observe what happens.

What You SEE

Do you see a light blue hue through the side of the bottle? Does the light move through the entire bottle the same way? Does the reflection on the paper change colors? As the milk sinks, is the light going through the top and bottom of the bottle differently? What happens if you add more milk?

HOW and WHY

The light from the flashlight represents the sun. The milk represents dust in Earth's atmosphere, scattering the light in many different directions. At midday, when the sun is closest to Earth, longer wavelengths, like red and orange, move through the atmosphere without enough time to scatter, so your eye does not detect their colors. The shorter, higher energy wavelengths—like blue—don't travel as far, and begin to bounce off atmospheric particles, causing the sky to appear blue. When the sun is farthest from Earth (sunrise and sunset), the longer wavelengths travel farther before reaching your eye, giving them time to interact with particles in the atmosphere, and for your eye to detect their color(s). The shorter wavelengths are scattered farther away from Earth and do not reach your eye to be seen.

Link it!

The electromagnetic spectrum categorizes light by wavelength. Based on an object's composition, it will absorb, reflect, scatter, and refract various wavelengths. The wavelengths reflected create a unique **spectral signature**. These interactions between light and objects allow you to see the world the way you do.

COMPLEX SPACE

Remember infrared (IR) light? Since the 1980s, scientists have placed IR telescopes into orbit around Earth, so they can see newly forming stars and the center of the galaxy. These telescopes generat much clearer images by capturing the IR waves before they are distorted by Earth's atmosphere. In just 25 years, astronomers have increased the number of known astronomical objects by about 35,000, or 70 percent.

Why do stars "twinkle"? When the starlight enters Earth's atmosphere, it encounters pockets of hot and cold air, each refracting light differently. As the light rays are bounced back and forth, the stars appear to twinkle.

LIVE IT!

Ripped from the Headlines

Jason Cammisa / *Automobile* Magazine

Night Vision Technology Makes Driving Safer

German automakers Mercedes-Benz and BMW know that driving at night can be tricky—especially when it is foggy or rainy. By installing night systems with in-dash displays, however, manufacturers are helping drivers see more clearly at night.

CAREER PROFILE

Optical Scientist

Courtesy of NASA

Dr. Ellen Ochoa, Ph.D.
National Aeronautics and Space Administration (NASA)

Dr. Ochoa received her bachelor of science (B.S.) in physics from San Diego State University, and then went on to earn her master of science (M.S.) and doctorate in electrical engineering from Stanford University in Palo Alto, California.

Dr. Ochoa is the co-inventor of three patented optical processes: an optical inspection system used for the quality control of manufactured parts, an optical object recognition method to aid in the robotic manufacturing of goods, and a method for minimizing distortion in photographic images. In 1991, she was chosen as NASA's first Hispanic female astronaut and has completed four flights, logging over 900 hours in space.

Bend It! Shape It!

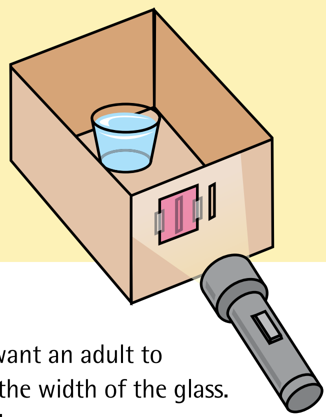
LENSES

By using lenses to change the path of light rays, scientists can direct light to create a clearer image and achieve other goals. The lens in a projector, for example, lets you watch a movie in focus. The lenses in binoculars allow you to see far away. The lenses in a microscope help you to see up close. You were born with lenses inside your eyes. So how does a lens work?

ACTIVITY BENDING LIGHT The Eyes Have It!

What You NEED

- Utility or Exacto knife
- Clear glass
- Water
- Scotch tape
- A piece of colored plastic
- Flashlight
- Shoebox or similar box, no top needed.



What You DO

- Carefully cut 2 vertical slits in one end of the box—you may want an adult to help you. The space between the slits should be smaller than the width of the glass.
- Place the colored plastic over one of the slits, and tape it in place.
- Darken the room and shine the flashlight into the box through the slits. What do you observe?
- Fill the glass with water, place it in the center of the box, and again shine the light through the slits.

What You SEE

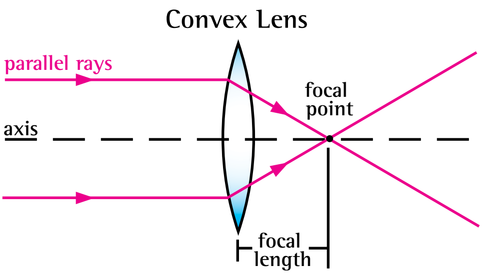
What happens to the light with and without the glass on water? Where does the light appear on the sides of the box?

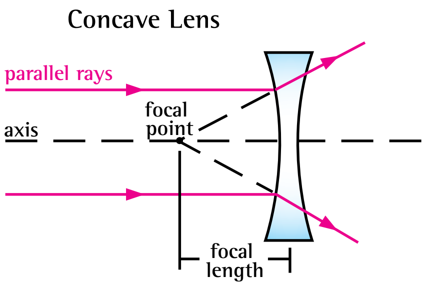
HOW and WHY

The box is a model of your eye. Light enters through the opening in the front of your eye, the iris, and passes through the lens, which focuses the light into an image that falls on your retina, the inside of the back of your eye. When an image falls on the retina, nerve cells send signals to your brain, which interprets them to create an image.

VEXING CAVES – Objects May Be Closer Than They Appear

You have just demonstrated how the lens in your eye focuses light to form an image. Scientists utilize two types of lenses to manipulate light—convex and concave. When light enters a **convex** lens, it converges or focuses into one point and will make an image seem smaller—like objects you see in the mirror on the passenger side of the car. Have you ever noticed what is written on that mirror? When light enters a **concave** lens, it will diverge, or spread out, and make the image appear larger, as with a magnifying glass.



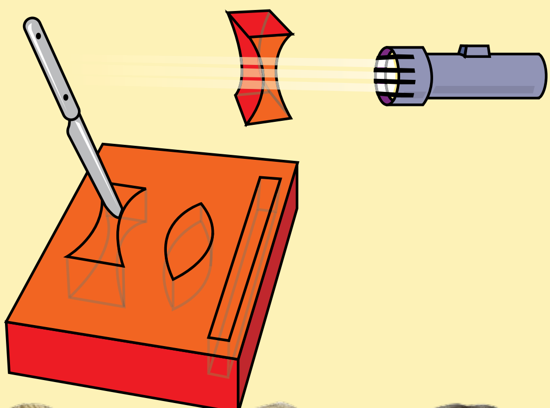


ACTIVITY Shimmering LENSES

Note: This activity requires advance preparation of Jell-O.

What You NEED

- 3 packets of Jell-O (lighter colors and sugar-free varieties work best)
- Hot water (read package for amount)
- Bowl
- Spoon or whisk
- Baking pan (8" x 8")
- Refrigerator (clear a space for the pan)
- Table knife
- Cutting board
- Flashlight
- Black electrical tape



What You DO

- Mix 3 packets of Jell-O with the directed portion of hot water. Do not add cold water; you want stiff Jell-O. Stir until the powder is dissolved.
- Pour the Jell-O into a baking pan, and refrigerate overnight.
- Loosen the Jell-O by soaking the bottom of the pan in warm water for 15 seconds and running a knife along the edge of the pan. Transfer the Jell-O to a cutting board.
- Use the knife to cut the Jell-O into convex and concave lens shapes from the Jell-O. Also, cut a long thin rectangle.
- Place strips of black electrical tape across the lens of the flashlight to create a few narrow beams of light.
- Turn on your flashlight and darken the room.
- Shine the light through the lenses and look at how light exits each lens.
- Shine the light in either of the two shorter sides of the rectangle. Gently bend the rectangle. What happens to the light inside?
- Try shining the flashlight with and without tape.

What You SEE

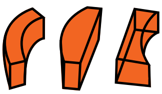
What happens as the light passes through each lens? What happens with the rectangle? What happens if you bend the rectangle to the point that it begins to come apart?

HOW and WHY

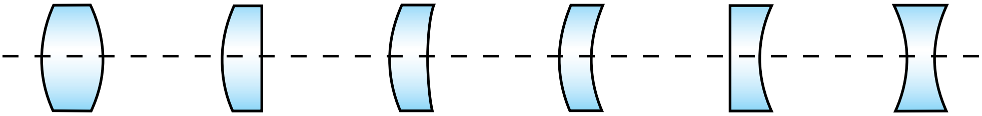
In a convex lens, the light rays converge (bend) together until they meet at a single point. They then crisscross and spread out again. In a concave lens, the light rays spread out, never converging to a single spot. The strength of the lens depends on its shape and the material it is made of. If you have more Jell-O, try different curvatures and see how the light behaves with each shape.

In the Jell-O rectangle, as you bend it, the light bends inside. This is called *total reflection*. You'll learn more about that in Chapter 4!

Step it up!



The neat thing about these simple lenses is that you can layer them to manipulate light in many ways. Optical engineers do this every day to advance the technology of devices such as binoculars, microscopes, and cameras. Try cutting some of the more complex lens shapes below, and see what happens when you shine the light through them.

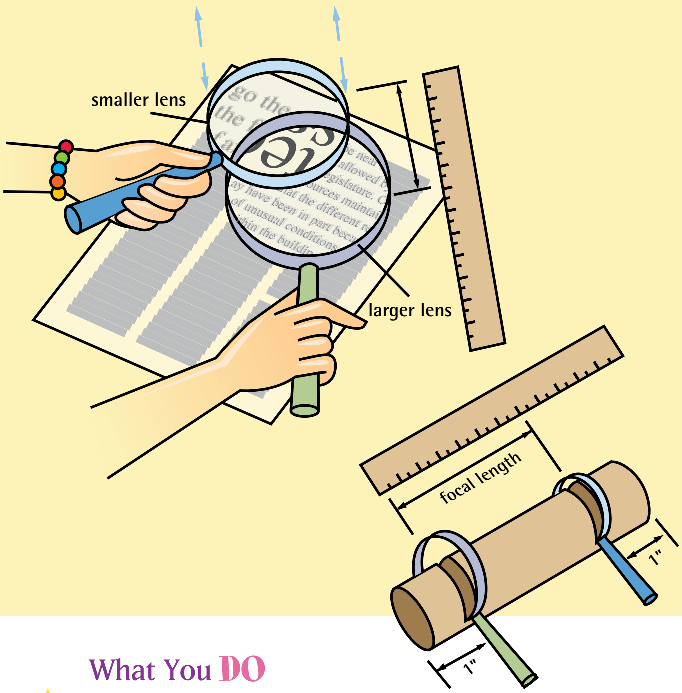


Biconvex | Plano-convex | Convex-concave | Meniscus | Plano-concave | Biconcave

FAR-OUT COMBINATIONS

Telescopes focus visible light from far away into a viewable image. They work by using a combination of lenses and mirrors to gather the light and focus the image where it can be viewed or recorded.

ACTIVITY Make a TELESCOPE



What You NEED

- 1 magnifying glass 1 inch to 1.5 inches in diameter
- 1 larger or smaller magnifying glass
- A sturdy cardboard tube (like a wrapping paper or mailing tube)
- Duct tape
- Hacksaw
- Utility knife
- Ruler
- Newspaper or magazine

What You DO

Use extreme care when making your cuts and ask an adult to help you. Hacksaws and utility knives are sharp, and the tube is difficult to hold stable.

- Use the large lens to look at the paper; the print should be blurry.
- Place the second lens between your eye and the first lens, and move it back and forth until the print comes into focus. The print should appear larger and upside down.
- Have a friend measure the distance between the two lenses, and write it down. This is your *focal length*.
- Cut a slot in the cardboard tube about an inch away from one end. Do not cut all the way through; the slot should hold the large lens.
- From the back of the first slot, measure and mark the focal length.
- Cut a second slot in the tube, to hold the smaller lens.
- Measure 1 inch behind the second slot and cut the tube.
- Place the lenses into the slots, and look through the telescope at the printed page. Adjust the lenses until the text is clear.
- Have a friend help you to tape the lenses in place once they are adjusted.
- Go exploring and see how different things look though your telescope. DO NOT look directly at the sun. Its rays can harm your eyes!

What You SEE

Compare your telescope to your eyes by looking at an object with one eye through the telescope while the other eye is looking directly at the object. Are the images you see different? In what way?

flash FACT

The Hubble Space Telescope can spot an object the size of a firefly from a distance roughly equal to halfway around Earth.

HOW and WHY

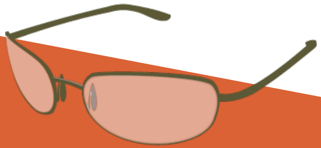
Telescopes use lenses to bend incoming light so the image appears larger. The magnification of a telescope depends on the arrangement and the focal length of the lenses in it. The quality of the picture depends upon the size (diameter) of the lenses. It is difficult to make a good quality lens greater than a foot wide; instead scientists often use curved mirrors to achieve a higher magnification and a clearer image. Some of the largest telescopes have mirrors over 26 feet wide! Binoculars, camera lenses, and portable telescopes (known as spotting scopes) utilize these same principles.

OPTICS ON MARS

In 2004, scientists at the National Aeronautics and Space Administration (NASA) landed two high-tech remote control vehicles on Mars to explore the planet. Originally intended to operate for only 90 days, the rovers—named *Opportunity* and *Spirit*—just celebrated their third anniversary on the red planet!

Each rover is heavily equipped with scientific instruments to help scientists unlock the planet's mysteries. To navigate and avoid hazards, the rovers depend on optical instruments, including six visible light 3-D cameras. To record the view, two panoramic cameras give scientists a view similar to that of the human eye. These panoramic cameras also contain special filters to generate multispectral (IR, UV, and visual light) images, which help scientists identify the surface features they are seeing. The rovers are also equipped with a microscopic imager to take close-up pictures of the surface soil and rocks.

Ripped from the Headlines



Optical Scientists to Develop Eyeglasses with Autofocus

Optical scientists at the University of Arizona are working to develop new technology for the next generation of eyeglasses. The new lenses will enable people to clearly see objects close up and far away without having to tilt their heads up or down, as wearers of bifocals now have to do.

CAREER PROFILE

Applications Engineer

Gloria Putnam
Eastman Kodak Company

Ms. Putnam has B.S. degrees in both physics and mathematics from California State University at Pomona. She uses her knowledge of the imaging process, along with her understanding of how Kodak imaging sensors are made and operate, to help engineers all over the world design digital cameras for a variety of applications. For example, she has helped design cameras that inspect computer chips, monitor traffic, and take detailed photographs in space.

CHAPTER 4

Light in Action

LASERS

A laser is a light source. The word itself is an acronym (a word formed from the first letters of the main words in a name or phrase) — **L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation. The first laser was demonstrated in 1960 to prove a theory that light could be transmitted as an intense beam.

Unlike a lightbulb, which scatters white light, a laser is a single wavelength focused into a narrow beam with a lot of energy. This ability to focus allows the light to travel great distances without scattering. Think of it this way. If you throw a baseball as hard as you can, it will only go a certain distance before it falls to the ground. If you use a pitching machine, however, the ball will go much farther before falling because it has a lot more energy. By focusing a particular wavelength, scientists can control the power of the laser so it can read your CD, complete a delicate surgery, or cut a gemstone.

Wonder how a laser interacts with a CD to play music?

A CD is made of plastic, and when you record music, images, or other data to it, a laser encodes the information to the surface in a collection of data "bumps." Each bump of data has a unique reflection signature. When you read the data from the CD, a laser lights up the bumps, and an opto-electronic sensor detects the differences in the bump's reflection. It then transmits this data to a processor inside the computer or CD player, which decodes the data reflection back into a message you can understand—music, photographs, or your school report.

⚠ **Lasers**—including laser pointers—are not toys and should be handled with care! Never look into a laser, or aim it at people or animals. To see if a laser pointer beam is on, point the laser at a wall or at the floor.

flash **FACT**

Scientists use lasers to monitor the distance between Earth and the moon. They shine the laser into 100 "corner-cube prisms" on the moon's surface (placed there during the *Apollo 11* mission in 1969) and measure the amount of time it takes the beam to return. They use a corner-cube prism because it always reflects the light beam back to its source.

flash FACT

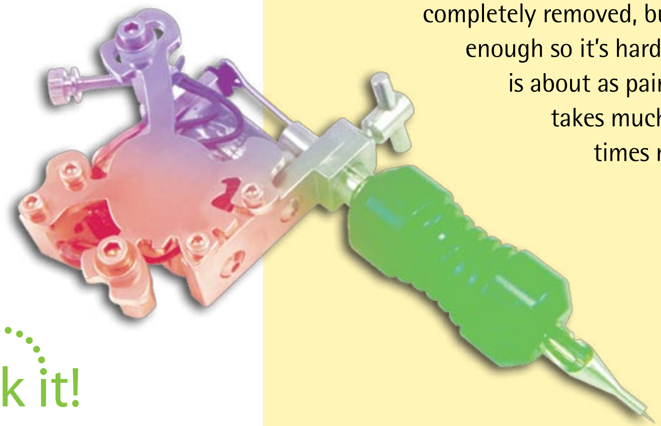
The microchips that make your computer work may soon get a turbo-boost from optical connections. Podcasts and videos take time to download on the Internet, even with a high-speed connection. Optical engineers are working on lasers that will increase speed and end downloading delays!

RETHINKING A TATTOO

Know people who wish they didn't get that tattoo?

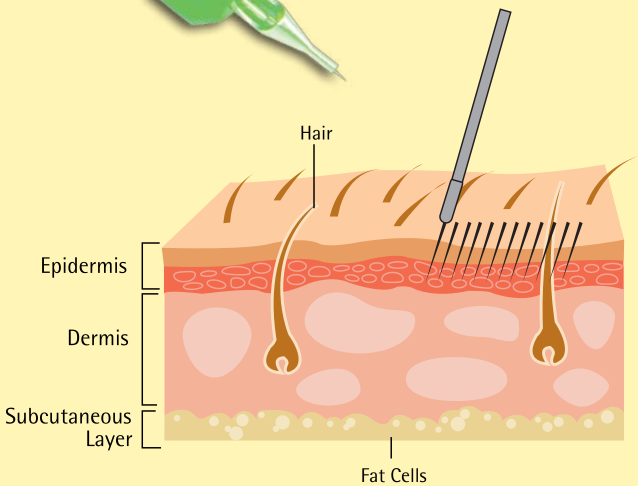
Tattoos are permanent because large blobs of ink are imprinted on the dermis (the lower layer of skin) and not the epidermis (the upper layer of skin that is constantly shedding). The blobs of ink are too large for your immune system to consume as it does with toxins or viruses that might enter your body.

Removing a tattoo used to involve scraping or cutting away the skin in a painful procedure. Today, a dermatologist shoots a laser through the epidermis and into the dermis, causing the ink blobs to break into smaller particles. The smaller particles are then consumed by the body's immune system. The more colors in the tattoo, the longer the process takes, as the laser must be tuned to a specific wavelength for each color. A tattoo is almost never completely removed, but it can be made faint enough so it's hard to see. Removing a tattoo is about as painful as getting one, but it takes much longer and can cost ten times more!



Link it!

The color of the tattoo impacts how easily it can be removed. Remember that primary colors are mixed together to make other colors (Mix and Match!, page 6). The proportion of each color present impacts how many wavelengths the laser needs to be adjusted to. Black is the easiest color to remove because it absorbs all wavelengths. Remember Black Is Black OR IS IT? (page 12)?



LIGHTS, CAMERA . . . SURGERY

Thanks to optics, surgeons can perform surgery through incisions less than half-an-inch long in almost every part of the human body. They use optical devices for laparoscopic surgery by placing a plastic tube in a small incision and inserting a light-and-camera device through the tube. Images are displayed on a video monitor, and high magnification allows easy viewing of details inside the body. Relying on these images as a guide, the surgeon is able to use specially designed tools that fit through the same tubes to then perform the surgery.

OPTICAL FIBER

Optical fiber transmits light waves the way copper wire transmits electricity. In fact, many underground telephone cables are made up of optical fibers, since a single strand can carry 10,000 phone calls! Thinner than human hair, optical fiber is a transparent tube (like fishing line) made of glass or plastic. Try your hand at replicating how light travels inside an optical fiber by exploring this simple model.

ACTIVITY Make a LIGHT FOUNTAIN

What You NEED

- Clear plastic bottle with label removed
- Duct tape
- Blue painter's tape
- Dark room
- Sink or bucket
- Thumbtack
- Corkscrew
- Flashlight

What You DO

- Place a 2 inch piece of duct tape on the side of the bottle to create a "patch."
- Use the thumbtack to punch a hole in the center of the tape patch.
- Stick a piece of painter's tape over the hole in the bottle. (Later, you will be able to pull off the blue tape without pulling off the duct tape.)
- Fill the bottle with water.
- Turn on the flashlight and turn out the lights.
- Place the bottle over the bucket or at the edge of the sink.
- Shine the flashlight through the side of the bottle.
- Remove the blue tape.

Continued...

What You SEE

How does the light enter the bottle and what does it do as it comes out of the hole in the side? Now place the tip of the corkscrew into the hole you already have made and turn it to make the hole a little larger. What do you see now? How about if you catch the water in another container—like a bowl—as it drains?

HOW and WHY

The light ray inside the stream of water behaves as it would inside an optical fiber. Optical fiber works like this: you send a light beam into one end of the fiber and it comes out the other end, just as light travels through the stream of water in your experiment. It doesn't matter if the fiber is straight, curved, or bent into loops; the light beam travels all the way through and comes out the other end. This is called *total internal reflection*. The light beam bounces around inside the fiber, reflecting back and forth off the walls. It doesn't pass through the walls and out of the fiber, and it doesn't stop until it comes out the far end.

Courtesy LUMINEX S.p.A

Link it!

You learned that reflection enables you to see colors as well as yourself in a mirror. In Shimmering LENSES (page 16), you bent a rectangle and illustrated total reflection inside the Jell-O.

flash FACT

A Swiss textile manufacturer has teamed with an Italian electronics company to produce fabric that lights up. The fabric is similar to optical fiber, and each garment has a tiny battery in a pocket. In daylight the fabric looks normal, but in dimmer light, it glows.

LIVE IT!

Ripped from the Headlines

Optics Track the Health of Ocean Reefs

All objects have a unique **spectral signature** (page 14). Using a special optical device known as a spectroscope, scientists are able to record the object's spectral signature (known as a spectrograph). Marine biologists use this technology to measure the health of the ocean's coral reefs. By comparing the spectrographs over time, the health of the reef can be tracked.

CAREER PROFILE

Biomedical Engineering

Nirmala Ramanujam, Ph.D.
Duke University

An associate professor in the Department of Biomedical Engineering, Dr. Ramanujam is working on optical technology that will aid in the early detection of breast and cervical cancers. By studying the way light moves through human tissue, Dr. Ramanujam and her team are developing noninvasive optical-based tools to image and characterize human tissue as either "normal" or "cancerous." Dr. Ramanujam completed her educational studies at the University of Texas, Austin, earning a B.S. and M.S. in mechanical engineering and a Ph.D. in biomedical engineering.

CHAPTER 5

Illuminating Illusions

THE MAGIC OF ILLUSIONS

The most spectacular visual illusions are those created not by a Hollywood film studio but by the brain. Your eyes help interpret what is being seen, but simple optical tricks can send mixed messages to your brain, making things appear different than they actually are! Ready for an eye-popping, brain-teasing adventure? All you need is a little direction and a few images.

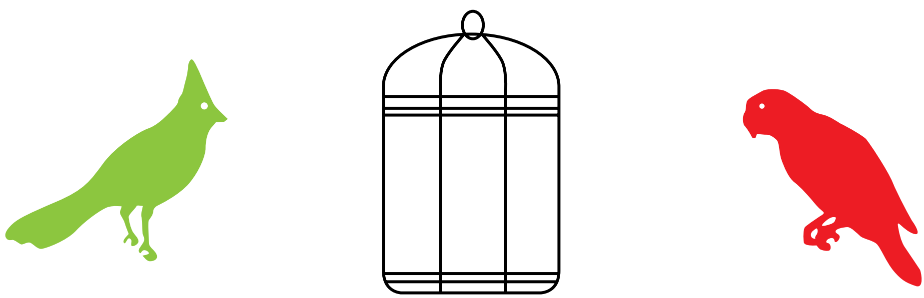
ACTIVITY AFTER-IMAGES

What You DO

- Stare at the eye of the red parrot and slowly count to 20.
- Look quickly at one spot in the empty birdcage.
- Try the same thing with the green cardinal.

What You SEE

Do you see magically appearing ghostly birds?



HOW and WHY

The faint birds you see are called after-images. The after-image stays with you a few minutes after you have stopped looking at an object. The back of your eye is lined with "cones," sensitive to specific colors (red, blue, and green) of light. When you stare at the green bird, your green sensitive cones adapt to the light and become desensitized to green. When you look at the white background, you see white - green = magenta.

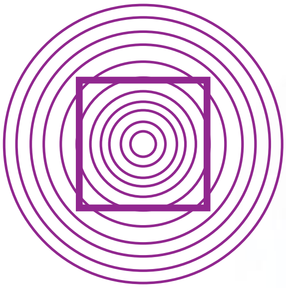
ACTIVITY PORTION DISTORTION

What You DO

- Stare at the pattern behind the rectangle.
- Now focus on the rectangle.

What You SEE

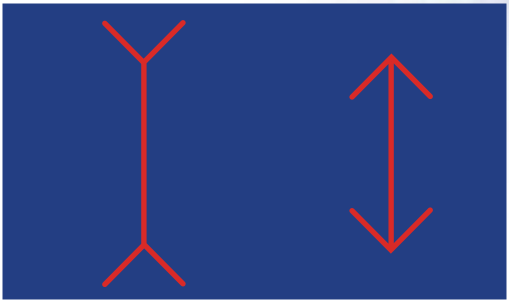
Is the rectangle made of straight lines? Does it appear to wobble?



HOW and WHY

The pattern behind the rectangle gives the illusion that the lines of the rectangle are bent. The pattern causes the brain to create an illusion of depth, making this 2-D image appear to be 3-D.

Which of these two lines is longer?



The arrowhead facing away from the line gives the illusion that the line is closer to you while the arrowhead facing the line gives the illusion of the line being farther away. The arrowheads create depth, and our brains assume that the closer line is smaller.

flash FACT

Perspective is the "point of view" from which you observe an object. Artists have been using perspective for centuries. M. C. Escher (1898–1972) was a famous illusionary artist. He mastered the art of perspective to make an image on a flat surface appear to be 3-D.

ACTIVITY

PHANTOMS

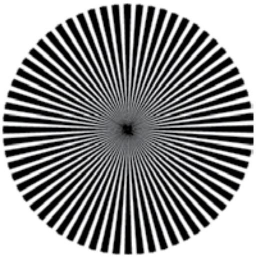
What You DO

- Look at each of the images quickly.
- Go back and really look at each image.

What You SEE

Do you see the same thing?

HOW and WHY



In the first image, did you see spots where the white lines intersect? What happened when you tried to look right at a spot? The spots are an illusion, generated by the way your eye responds to light and dark areas. When an object is bright or surrounded by white, your eye applies a natural dimmer switch to tone it down, making you see darkened spots. Think about playing outside on a bright, sunny day. When you go inside, it takes a few seconds for your eyes to adjust (turn up the brightness). And the opposite is true as well. If you've been inside a movie theater and go outside into bright sunlight, your eyes need to dim the brightness.

Is the circle image spinning? If you stare at the circle and move your head slightly, you'll see it spin more! The motion is not in the image but inside your eye! Your eye is constantly making tiny movements that act like "refresh" buttons inside your eye. These movements, which cause you to see more than one image at the same time, result in a shimmering circle.

LIVE IT!

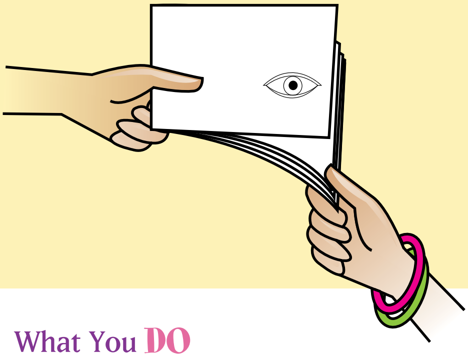
Ripped from the Headlines

U.S. Treasury Tricks Your Eye to Add Security to New Paper Bills

In 2003, the U.S. government released redesigned paper currency with increased security features to stay a step ahead of would-be counterfeiters. Take a close look at a new $20 bill. You will notice the "20" in the lower right corner is printed in ink that appears to be different colors, depending on the angle at which you view it. Hold the front of the bill, with the portrait of President Andrew Jackson, to the light, and see an invisible portrait—known as a watermark—of President Jackson appear on the lower right side. The coolest part, however, is that many of the lines that make up the image aren't what they seem. Break out your magnifying glass and discover their secret! (Try the black border below the treasurer's signature.)

ACTIVITY

Moving PICTURES



What You NEED

- 2 pieces of white paper
- Pencil
- Scissors
- Ruler

What You DO

- Cut the paper into 2-inch x 3-inch pieces, giving you 24 small pages.
- Draw on the right half of each page. Make each image slightly different from the one before it. Try this example with 3 repeating images.

Page 1 2 3 4 5 and so on

- Place your pages in order.
- Hold the stack tightly in your left hand and flip the pages with your right hand. Enjoy your illusion and try it with different repeating images!

What You SEE

Does the speed at which you flip the pages impact what you see?

HOW and WHY

You have just duplicated one of the earliest forms of animation. By quickly flipping the pages, the new image is superimposed on the old image and you "see" a single moving image.

Link it!

Why does the image appear to be moving? Your moving picture combines AFTER-IMAGES and the rate at which the eye refreshes the image it sends to the brain to create an optical illusion of movement. M. C. Escher would be proud!

CAREER PROFILE

Assistant Research Scientist

Elaine Lalanne, Ph.D.
University of Maryland, Baltimore County

Dr. Elaine Lalanne first became interested in optics during college. "Optics was very hands on," explained Dr. Lalanne, "a great way to visualize theory." Dr. Lalanne graduated from Wellesley College with a B.A. in physics and later earned a Ph.D. in applied physics from the New Jersey Institute of Technology/Rutgers University in Newark. Currently, Dr. Lalanne is a research assistant at the Center for Advanced Studies in Photonics Research (CASPR) at the University of Maryland, Baltimore County. She studies the optical properties of very small structures known as "nanostructures." One of her projects is creating material that could be used to protect soldiers' eyes from laser blasts on the battlefield.

CHAPTER 6

LIVE IT! Careers in Optics

As you've seen from the topics covered in this book, optics is a science with many applications in today's world. From simple household appliances to highly complex medical instruments, optics applications have created many products and play a key role in a range of industries.

ACTIVITY Career MATCH

Thinking about a career in optics? Circle the activities below that you think would be fun to do. Then move on to the quiz key.

1 Study the health of coral reefs.

2 Design ways to decrease noise vibration near major highways.

3 Develop an inspection system for herring eggs.

4 Develop new high-intensity headlights for cars and trucks.

5 Digitally restore ancient documents.

6 Use lasers to engrave trophies and plaques.

7 Calibrate flight-critical hardware supplied to the space program.

8 Research new methods for detecting breast cancer.

9 Improve the quality of barcode scanners' windows.

10 Improve the efficiency of car and truck engines.

11 Improve the clarity of document and photo scanners.

12 Monitor volcanic activity and lava flow.

13 Use optical instruments to research what colors animals see.

14 Preserve historic sites by locating moisture problems in their walls.

15 Study air pollution with laser-based systems.

16 Study the atmosphere and the distribution of ozone.

17 Research and monitor asteroids that could collide with Earth.

18 Map wildfires and aid forest firefighters.

QUIZ KEY

In the grid below, put a check under each number you have circled in the list on page 31. As you can see, there are three groupings: E, S, and T. These groupings are a way of gauging your particular area of interest.

E						S						T					
2	3	4	9	10	11	1	8	13	15	16	17	5	6	7	12	14	18

If most of the numbers you checked are under:

E you might explore a career as an optical **engineer** devoted to advancing technologies that will benefit society.

S check into being an optical **scientist**. Optical scientists advance our knowledge and understanding of light by studying why and how it affects the world around us.

T consider becoming an optical **technician** and have the opportunity to work in the different fields of optics. These technicians often assist scientists and engineers and maintain specialized equipment.

TAKE ACTION!

Has something in this book inspired you? Do you have a great idea for sharing what you've learned? Have you discovered a career in optics that interests you? Use this page to record your thoughts, ideas, notes, and doodles, and then brainstorm ideas for follow-up with your advisor or leader.

Girl Scouts®

How does music play from my CD? What makes the sunset so beautiful? Do stars really twinkle?

Lighten Up! Discovering the Science of Light will help you discover the answer to all of these questions and more. You'll learn about the exciting world of optics—a branch of physics—and why it's so important in everyday life. So come along and *Lighten Up!* You'll be glad you did!

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