Sound is only one of several kinds of waves. Some waves carry small amounts of energy, such as the waves you observed in the long coil on the floor, a whisper, or gentle water waves. Other waves transfer tremendous amounts of energy, such as the energy transferred in earthquakes, tsunamis, or gamma waves. There are waves that humans cannot detect directly, even though some of them carry a lot of energy. In this activity you will learn more about the nature of various kinds of waves. You will also learn about how certain devices have extended humans’ sensory capabilities.

What are the properties of certain kinds of waves?

Some animals, such as the bat and dolphin shown here, navigate their environments with sonar.
READING

Wave Media

No matter what kind of wave or what amount of energy it transmits, it is important to note that when waves transmit energy, the individual molecules or particles in the medium are not transmitted. In other words, the medium does not move along with the wave. A medium (plural is media) is the material in which wave energy travels. Mechanical waves, such as sound or seismic waves, move through the ground, water, air, and other materials. For example, when making waves in the long metal spring in Activity 91, “Longitudinal and Transverse Waves,” the metal of the spring was the medium. The disturbance moved away from the source. The coils of the spring temporarily moved up and down or closer together and farther apart, but the spring did not undergo a permanent change of position relative to the source. In this case, the medium itself—the metal of the spring—was not transferred from the wave maker to the other end.

STOPPING TO THINK 1

What is the medium for an ocean wave? Provide evidence that the medium is not transferred when a water wave moves on a lake.

Two Major Kinds of Waves

In Activity 91, “Longitudinal and Transverse Waves,” you investigated two fundamentally different kinds of waves, longitudinal and transverse. A longitudinal wave is one that transfers energy through compressions and rarefactions in the medium through which the wave travels. Sound is an example of a longitudinal wave. When you hear a sound wave through the air, you are detecting a disturbance in the pressure of the air. When the pressure is increased the air molecules are pushed closer together, into a compression. When the pressure is reduced and the air molecules move farther apart, it is referred to as a rarefaction. A longitudinal wave is one that causes the medium to move parallel to the direction of transmission, or propagation of the wave.

A transverse wave that travels through a medium is a result of the medium moving perpendicular to the direction of propagation. The long coil used in a previous activity was an example of a transverse wave. Light is another example of a transverse wave.
LONGITUDINAL WAVE

Direction of particle motion  Direction of wave propagation

TRANSVERSE WAVE

Direction of particle motion  Direction of wave propagation
The Nature of Waves

Transmission of Waves Through Various Media

Mechanical waves, such as earthquakes, sound waves, or waves in a coil will travel differently depending on the medium. The same wave will travel at different speeds through two different substances. In general, waves travel faster through materials that have “springier” molecules. This means sound moves faster through solids than liquids and faster through liquids than gases. For example, sound travels about five times faster through metal than through air.

Because sound waves always involve the physical disturbance of atoms or molecules they are referred to as mechanical waves. A mechanical wave must have a medium in order to travel. Mechanical waves cannot travel through a vacuum because there are no atoms or molecules in a vacuum. Although outer space is not a perfect vacuum, the molecules are so far apart that they do not allow the production of compressions and rarefactions. Therefore, sound cannot travel in space.

Some waves, however, do not require a medium and can be transmitted through a vacuum. For example, light travels through the vacuum of outer space, whereas sound does not. Because light waves do not require the presence of atoms or molecules, they are not considered to be mechanical waves. Light is a transverse wave that carries electromagnetic energy. This energy in light waves travels about 900,000 times faster than the energy carried by sound waves.

Wave Speed

Every wave has four basic characteristics: frequency, wavelength, amplitude, and speed. Wave speed, measured in meters per second (m/s), is the distance traveled by a certain feature on the wave, such as a crest, in a given amount of time. The speed at which the wave travels depends on what type of material it travels through. Sound is transmitted through the air at about 340 m/s. The exact speed depends on such factors as the temperature and humidity of the air. The tables on the next page show the speeds of sound and light through various media. Although light slows down a little in air, it still travels about 900,000 times faster than sound. This is why you will see a lightning flash long before you hear the sound of thunder from a storm several miles away.
STOPPING TO THINK 3

What does it mean if you hear thunder and see lightening at almost the same time?

<table>
<thead>
<tr>
<th>Speed of Sound</th>
<th>Medium</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vacuum</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Carbon dioxide (0°C)</td>
<td>258</td>
</tr>
<tr>
<td></td>
<td>Air (20°C)</td>
<td>344</td>
</tr>
<tr>
<td></td>
<td>Helium (20°C)</td>
<td>927</td>
</tr>
<tr>
<td></td>
<td>Water, fresh (20°C)</td>
<td>1,481</td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td>3,500</td>
</tr>
<tr>
<td></td>
<td>Aluminum</td>
<td>6,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Speed of Light</th>
<th>Medium</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diamond</td>
<td>124,000,000</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>197,200,000</td>
</tr>
<tr>
<td></td>
<td>Plexiglass</td>
<td>198,500,000</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>224,900,000</td>
</tr>
<tr>
<td></td>
<td>Ice</td>
<td>228,800,000</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>299,700,000</td>
</tr>
<tr>
<td></td>
<td>Vacuum</td>
<td>299,800,000</td>
</tr>
</tbody>
</table>

Extending the Senses

Although our world is full of sights and sounds of waves, there are many waves our sensory organs cannot detect directly. However, people have invented devices to detect waves having frequencies that fall outside our range of hearing and vision. These devices include cell phones, radios, X-ray film, radar, and sonar. Each of these devices receives energy from a wave that we cannot detect and converts it into something that we can see or hear.
Radar works by sending radio waves from a radar source to the surface of a target, such as an airplane or a cloud. The waves are reflected back to the radar source, and the location or speed of the target is calculated from the measurements. Radar systems are based on radio waves or microwaves. Sonar works in a similar way but relies on sound waves at frequencies that are not detectable by human ears. Sonar allows personnel on ships and submarines to detect the depth of water and the presence of fish and other boats on or under the surface. Seismic waves are low-frequency mechanical waves that move through the Earth. They are caused by such events as explosions and earthquakes. By measuring seismic waves with a seismograph, even those waves that are not felt by humans on the surface of the Earth, scientists locate earthquake epicenters and create maps showing regions at risk of earthquakes. All of these examples illustrate ways in which people have invented devices to employ the energy of waves to hear things we wouldn’t normally hear and discover things we wouldn’t normally see.

**STOPPING TO THINK 4**

What is another example of a device that uses waves to extend our senses?
ANALYSIS

1. Create a larger version of the Venn diagram shown at right. Record the characteristics of sound and light waves in the circle with that label. In the spaces that overlap, record common features.

2. Explain why a satellite orbiting Earth could use radar to detect other objects but not sonar.

3. If you started the motor of a boat in the middle of a lake, who would detect the sound of the motor first: a friend sitting on the shore of the lake, or a friend snorkeling just below the surface of the water along the same shore? Explain your answer.

4. Dolphins and whales communicate with other dolphins and whales, respectively, by making low-frequency sounds. They navigate by making high-frequency sounds that echo back to them. Military sonar systems on ships produce sounds as loud as 200 dB, and these sounds travel great distances across oceans. Describe how such systems might affect whales and dolphins.
During first period, Jenna noticed that her friend José looked worried. After class she asked, “José, is everything okay with you?”

José replied, “Well, actually, I’m a little worried because my favorite great-aunt, Tía Ana, is having eye surgery.”


José explained, “Everything started to look blurry for her, and when she went to her doctor, she found out she had cataracts. Today the eye surgeon is going to take out the cloudy lens in her right eye and put in an artificial one.”

We use our eyes for almost everything we do, and so it is important to take care of them. One thing that hurts our eyes is too much exposure to the sun. Even people with limited vision may damage their eyes further by exposing them to too much sunlight.

In this activity, you will explore some of the characteristics of white light, or the light we can see, to investigate what might have damaged Tía Ana’s eyesight. White light can be separated into the visible light spectrum, which is the scientific name for the colors of the rainbow.

How are the colors of the visible light spectrum similar to and different from each other?
**Comparing Colors • Activity 94**

**PROCEDURE**

**Part A: The Visible Light Spectrum**

1. Observe how your teacher splits white light into the colors of the visible spectrum.

2. List the colors that you see in the order that they appear.

3. Describe whether the colors blend from one to the next or have distinct boundaries between them.

4. Which color of light seems to be
   a. the brightest?
   b. the least bright?

**Part B: Colored Light**

5. Open the top of the Phospho-box, and examine the bottom of it. The strip on the bottom of the Phospho-box is sensitive to a particular high frequency wave. Sketch and describe what you observe.

6. Turn the Phospho-box over so that the top with the viewing slit is on the table. Slip the card with the star-shape cutout into the card insert location at the bottom of the box, as shown above. Leave the box in this position for 30 seconds.

**MATERIALS**

*For each pair of students*

- 1 Phospho-box
- 1 card with a star-shaped cutout
- 1 colored-film card
- 1 timer
7. Turn the Phospho-box right side up, open the top, and let light hit the entire bottom of the box for 20 sec.

8. Close the top of the Phospho-box, and remove the card with the star-shaped cutout. Quickly look through the viewing slit, and record your observations.

9. Turn over the Phospho-box as you did in Step 6. Lay the colored-film card on top of the Phospho-box.

10. Describe or sketch what you see. Rank the colors from brightest to least bright.

11. Describe or sketch what you predict you will observe if you repeat Steps 6–8 using the colored-film card instead of the card with the star-shaped cutout.

12. Repeat Steps 6–8, but use the colored-film card instead of the card with the star-shaped cutout.

13. Rank each color and the cutout shape according to how brightly it caused the strip on the bottom of the Phospho-box to glow.

14. Describe or sketch what you predict you will observe if you repeat Steps 6–8 with the colored-film card, but this time let the sunlight hit the bottom of the box for 40 sec.

15. Repeat Steps 6–8 within the colored-film card, but this time let the light hit the bottom of the box for 40 sec.

16. Record your results in your science notebook.

ANALYSIS

1. What is the purpose of the card with the star-shaped cutout?

2. How do you think the colored-film card changes the white light into colored light?

3. Why do you think only some colors make the strip on the bottom of the Phospho-box glow? Explain.

4. Is there enough evidence, or information that supports or refutes a claim, that supports the idea that the higher-energy colors of white light are damaging Tía Ana’s eyes?
5. Look at the graph of the visible light at the surface of the earth, below. Why do you think sunlight is yellow instead of blue?

6. Sunglass lenses are an example of a material that blocks some white light and some other high-frequency light that is harmful to the eyes. Examine the transmission graphs about three pairs of sunglasses below.

a. Which lens has the best high-energy protection for the eyes? Explain how you decided.

b. The price for each pair of sunglasses is shown below. Which pair would you buy? Why? Describe any trade-offs you made in your choice.

Lens 1: $80
Lens 2: $10
Lens 3: $20
In the last activity, you saw colors of the visible light spectrum being transmitted, which is when light energy quickly enters the material and is reemitted on the other side. Any light that is not transmitted through an object is either reflected or absorbed by the object it hits. Light waves are reflected when light bounces off the object, either in one direction or scattered in many directions. Reflected light is what enters our eyes so that we can see an opaque object. Light waves are absorbed when light enters the object and it does not come out of the object again as light, thereby adding energy to the object. Often light that is absorbed by an object is converted into heat that warms up the object.

In the last activity, you learned that not all frequencies of sunlight are transmitted through a translucent object, such as a colored film. In this activity, you will investigate the transmission, reflection, and absorption of waves from the sun that are not visible to the human eye.

**CHALLENGE**

What part of sunlight is transmitted through selected films?

**MATERIALS**

For each group of four students

- 3 thermometers
- 3 UV detector cards
- 3 Phospho-boxes
- 1 film A
- 1 film B
- 1 film C
- masking tape
- 1 timer

Sunlight is selectively transmitted through the stained glass window.
PROCEDURE

Part A: Comparing Temperatures

1. In your science notebook create a data table similar to the one below.

<table>
<thead>
<tr>
<th></th>
<th>Initial Temperature (°C)</th>
<th>Final Temperature (°C)</th>
<th>Change in Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Place one thermometer face up in the bottom of each of the boxes, and tape it in place so that it will not move. Place a film on each open box, and secure it with tape, as shown in the diagram at right. Make sure to tape the film on all four sides to keep air from blowing into the box during testing.

3. Close the Phospho-box lids until you are ready to perform the experiment in the sun.

4. When in the sunlight have one member of your group hold the closed Phospho-boxes together so they are oriented toward the sun in the same way. Do this so no shadow falls on the thermometer.

5. Record in the data table the initial temperature inside each box.

6. Have another group member open each box and expose it to the sun.
7. Hold or prop the boxes in this position for 5 minutes. Then record in the data table the final temperature inside each box.

8. Calculate the change in temperature for each thermometer. Record these data in your data table.

9. Rank each film from 1 (smallest change) to 3 (highest change). Record your results in your science notebook.

**Part B: Comparing Ultraviolet**

10. Gently remove the films, and replace the thermometers with the UV detector cards. Replace the films as instructed in Step 2.

11. Make a new data table with titles changed accordingly.


13. With your group, discuss if the results from either Part A, Part B, or both give evidence for invisible waves transmitted into the Phospho-box.

**ANALYSIS**

1. Which film transmits the most energy? What is your evidence?

2. What evidence from this investigation supports the idea that sunlight contains invisible waves that behave similarly, but not identically, to visible light waves?

3. Films, like the ones used in this activity, are commonly put on glass windows as energy-saving devices and to prevent sun damage. If the costs of the films A, B, and C from this activity are those listed below, which material would you choose to put on
   a. your car windows?
   b. windows in a home located in a desert?
   c. windows in a home located in a snowy mountainous region?

   Explain your choices, citing evidence from this activity. Explain any trade-offs you made.

   Film A: $20/m²
   Film B: $100/m²
   Film C: $50/m²