Gemma looked outside. After days of rainy weather it was finally a bright and sunny day. “Ma, I am heading outside to meet Sam,” she called to her mother. She grabbed her headphones and headed for the door.

“Remember your sunglasses!” said her mother. Gemma swept them off the kitchen counter as she left and put them on. Listening to her music, she walked down the street and joined her friend Samantha at the corner.

“Hey,” said Sam, pointing at Gemma’s sunglasses. “My glasses are just like those. Only blue.”

Gemma took out her headphones to be able to hear to her friend. “Well, why aren’t you wearing them?”

“Oh, I don’t like wearing them. They make my nose itch,” Sam said.

“My mom says the sun can damage your eyes. Have you ever heard of that? We have a lot of bright days around here, so maybe you should wear them,” Gemma said with concern.

“Yeah, you’re probably right. But aren’t you worried about hurting your ears with those headphones turned up so loud?” said Sam with equal concern for her friend.

• • •

How is sound energy transmitted? Can light go through an object? What is ultraviolet?

How are sound and light waves similar?

In this unit, you will learn about several kinds of waves and investigate the transmission of sound and light. You will also investigate the situations in which some waves may be harmful to your health.
José and Jenna were talking at lunch. The cafeteria was noisy, though, and José was having a hard time understanding Jenna. Jenna thought it was weird that he wasn’t able to hear her very well. Later they talked in a quieter place.

“José, I’m a little worried about your hearing,” Jenna said.

“What do you mean?” José asked.

“Well, I noticed that sometimes you don’t hear me call to you. I have to repeat myself really loudly.”

“Well, actually, sometimes I don’t hear my teacher right. Like yesterday I wasn’t aware of what she said in class and I ended up doing the wrong thing.”

“You should get your hearing tested.”

“I’ve had it tested before, and it was fine. I don’t see why it would change.”

There are a number of causes of hearing loss. It can be present at birth or develop later in life. Some people are genetically more likely to lose their hearing, although it is not yet known which people are at higher risk. Occupational noises, recreational noises, some medications, and illnesses can all cause hearing loss.

When we hear something it is because sound waves have transferred energy to our ears. A wave is a disturbance that repeats regularly in space and time and that transmits energy from one place to another with no transfer of matter. Some sound waves are more intense than others. Sound intensity is a measurement of how much sound energy passes by a point in a certain amount of time as it spreads out from the source. Scientists measure sound intensity in watts per square meter (W/m²). A common way of describing sound is with the decibel scale. The decibel (dB) is a unit of measure that indicates the relative intensity of a sound. In this activity you will investigate the decibel scale and how the human ear responds to different levels of intensity.
What is the range of sound intensity that humans can hear?

**MATERIALS**

For each pair of students
1. set of 5 Sound Intensity cards

**PROCEDURE**

1. With your partner, examine the Sound Intensity cards. Each card represents a particular sound. The number of shaded squares in relation to the total squares on the card shows the relative intensity of the sound.

2. Make a data table similar to the one below.

```
<table>
<thead>
<tr>
<th>Card</th>
<th>Type of Sound</th>
<th>Number of Squares Shaded</th>
<th>Total Number of Squares on the Card</th>
<th>Proportion of Shaded Squares on the Card (relative intensity)</th>
<th>Decibel Level (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

3. Based on the data for each card, complete the table.
4. With your partner, examine the data in the table, and look for a relationship between the changes in relative intensity and the change in decibel level. Record your findings in your science notebook.

5. The table below shows the sound levels of some common sounds. In your science notebook, copy the first two columns of the table. Complete the second column of the table. Do this by using the relationship you determined in Step 4 to calculate how many times more intense each sound is compared to a whisper.

<table>
<thead>
<tr>
<th>Decibels</th>
<th>Relative Intensity</th>
<th>Noise Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Threshold of hearing</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Breathing</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Whisper; rustling leaves</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>Quiet bedroom; park</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>Quiet library</td>
</tr>
<tr>
<td>50</td>
<td></td>
<td>Average home or office</td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>Normal conversation, 1 m away; clothes dryer</td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>Vacuum cleaner, 1 m away; average road noise, 25 m away; inside car; headphone use in quiet environment</td>
</tr>
<tr>
<td>Risky range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td></td>
<td>Heavy city traffic, at curb; power lawn mower; hair dryer; freight train @ 40 km/h; noisy restaurant; headphone use most places outdoors</td>
</tr>
<tr>
<td>90</td>
<td></td>
<td>Diesel truck, 1 m away; average factory floor</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>Snowmobile, 15th row of rock concert, circular saw; typical musical instrument</td>
</tr>
<tr>
<td>110</td>
<td></td>
<td>Chain saw, 1 m away; leaf blower close by</td>
</tr>
<tr>
<td>Injury range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td></td>
<td>Ambulance siren; jackhammer; car horn; front row of rock concert or symphony; max headphone level</td>
</tr>
<tr>
<td>130</td>
<td></td>
<td>Threshold of pain</td>
</tr>
<tr>
<td>140</td>
<td></td>
<td>Jet engine, 50 m away; firecracker; gunshot</td>
</tr>
<tr>
<td>Instant perforation of eardrum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td></td>
<td>some explosions</td>
</tr>
</tbody>
</table>
6. Use the table and data from the Sound Intensity cards to calculate how many times more intense a noise at the threshold of pain is than a whisper. Discuss with your partner the range of intensities that the human ear can hear.

**ANALYSIS**

1. What is the range of sound intensities that the human ear can hear, from the quietest sound to one that causes pain?

2. What is the advantage of using the decibel scale to indicate intensity of sound?

3. If a sound increases by 10 dB, how many times more intense is the sound?

4. Most people perceive an increase of 10 dB as a doubling in volume of a sound. How many times louder would a 70 dB sound seem to be when compared to a 40 dB sound? Explain your answer.
José made an appointment with his doctor, who referred him to a hearing center. At the center José was seen by an audiologist, who conducted a hearing test. She asked José to wear headphones and then played different tones with varying loudness levels to one ear at a time. Each tone was a different frequency to allow the audiologist to measure at which decibel level José could hear a particular frequency. She repeated the tests several times for each ear.

Hearing loss does not necessarily mean a person hears all types of sound less clearly. The results of José’s hearing tests indicated that his hearing was fine for some frequencies, but not all. The frequency of the sound is the number of vibrations per second the ear receives, otherwise known as the sound’s pitch. High-frequency sounds have a high pitch, like a flute, while low-frequency sounds have a low pitch, like a bass drum.

An audiogram is a graph that shows the sensitivity of a person’s hearing for different frequencies. Frequencies are measured in hertz (Hz), or wave cycles per second. José’s audiogram showed that José’s hearing was most affected in the 3,000 Hz-and-higher range. This means he could have difficulty distinguishing female speech in a noisy environment.
How are frequency and wavelength related?

**MATERIALS**

For each group of four students
- 1 heavy metal washer
- 1 50 cm of thick string
- 1 1.5 m of yarn
- 1 timer
- 1 meter stick
- 1 calculator

**PROCEDURE**

1. Tie the thick string firmly to the washer, making sure that 50 cm of the string extends from the washer.

2. Tie the yarn firmly to the opposite side of the washer, making sure that 150 cm extends below the washer.

3. Assign one of the following roles to each member of your group.

<table>
<thead>
<tr>
<th>Role</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swinger</td>
<td>This person holds the thick string high enough that the last few centimeters at the bottom of the yarn lie on the ground. This person will keep the pendulum washer swinging at a steady rate.</td>
</tr>
<tr>
<td>Timer</td>
<td>This person times how long it takes for the washer to complete 10 swings.</td>
</tr>
<tr>
<td>Measurer</td>
<td>This person estimates the length of the wave produced in the yarn.</td>
</tr>
<tr>
<td>Recorder</td>
<td>This person creates the data table for Step 5. This person also records the data in the table.</td>
</tr>
</tbody>
</table>
4. Find a safe place for the swinger to stand so that the top of the thick string can be held in the air and the bottom few centimeters of the yarn lie on the ground, as shown in the picture at left.

5. **Recorder:** Create a data table like the one below.

<table>
<thead>
<tr>
<th>Thick String Length (cm)</th>
<th>Time for 10 Swings (s)</th>
<th>Time for One Swing (s)</th>
<th>Frequency (Hz)</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. **Swinger:** Hold the thick string at a point 5 cm above the washer, and move your wrist just enough to keep the washer swinging at a steady rate. Generate a steady **amplitude**, which is the wave's displacement from its state of rest. After a few seconds it should be possible to observe a wave in the yarn.

7. **Measurer:** Estimate the distance between any two successive places where the shape of the wave repeats itself. This is the **wavelength**, or the length of one wave cycle. The distances AB and CD in the figures below show examples of how wavelength can be measured.
8. **Timer:** When the wave is seen clearly, time 10 full swings of the washer. A full swing of the washer includes both its swing away and its return.

9. **Recorder:** Record your results for wavelength and time for 10 swings in the data table.

10. As a group, calculate the time for one swing. Use this value to calculate the wave’s frequency by taking the inverse of the time for one swing. Record the results in the data table.

11. Increase the length of the thick string to 25 cm, and repeat the experiment. Add those results to the data table.

12. Look for a relationship between the frequency of the washer and the wavelength of the wave produced in the yarn. Record your ideas in your science notebook.

13. Discuss your conclusions with the class.

**ANALYSIS**

1. Waves involve some type of disturbance that causes the transfer of energy from one point to another.
   a. What was the disturbance that caused the wave in the yarn?
   b. What evidence do you have that energy was transferred from one end of the yarn to the other?

2. The frequency of the swing of the washer can be calculated if the time for one swing is known. Suggest reasons why you were instructed to measure 10 swings instead of one swing.

3. Look at the diagram of a wave below.

   ![Wave Diagram](image)

   a. Describe the motion of the yarn at positions B and C.
   b. Between which two points is the energy transferred?
4. Looking at the diagram from the previous question above,
   a. draw what the wave would look like if the frequency were doubled.
   b. draw what the wave would look like if the wavelength were doubled.

5. Match the following descriptions of people to their audiogram:
   a: José has decreased hearing in the right ear at higher frequencies.
   b: Leon has noticed lately that he has trouble deciphering women’s speech.
   c: Shannon has moderate hearing loss involving sounds of 3,000–6,000 Hz.
   d: Sophia has less than 50% hearing in both ears.
The Frequency of Sound • Activity 90

**Figure:** Audiogram 3

- **Frequency (Hz):** 125, 250, 500, 1000, 2000, 4000, 8000
- **Hearing level (dB):** -10, 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110
- **Legend:**
  - Left ear
  - Right ear
  - MOD.
  - SEVERE
  - MODERATE
  - PROFOUND
  - MILD
  - NORMAL

**Figure:** Audiogram 4

- **Frequency (Hz):** 125, 250, 500, 1000, 2000, 4000, 8000
- **Hearing level (dB):** -10, 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110
- **Legend:**
  - Left ear
  - Right ear
  - MOD.
  - SEVERE
  - MODERATE
  - PROFOUND
  - MILD
  - NORMAL
Sound is one of many kinds of waves. Other common waves include those on the surface of water, light waves, radio waves, and seismic waves. All waves share some of the same characteristics, but they also differ in certain ways. For example, all waves (including sound waves and water waves) carry energy. However, one difference is that a sound wave is a longitudinal wave, while a water wave is a transverse wave. A longitudinal wave is one that transfers energy through compressions and rarefactions in the material through which the wave travels. A compression is the region of the wave in which the material through which the wave is transmitted is pressed together. A rarefaction is the region in which the material is spread apart. A transverse wave does not have compressions and rarefactions. For a transverse wave to be transmitted through a material, the motion of the material is perpendicular to the direction that the energy travels. In this activity you will investigate the similarities and differences between a transverse and a longitudinal wave.

How are sound waves similar to, and different from, other types of waves?

**MATERIALS**

- For each group of four students
  - 1 long metal spring

A longitudinal sound wave from a tuning fork is displayed as a transverse wave on the screen.
PROCEDURE

Part A: Longitudinal Waves

1. Assign each member of your group to one of the following roles:

<table>
<thead>
<tr>
<th>Role</th>
<th>Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holder 1</td>
<td>This person holds one end of the spring on the ground so that the circular end of the spring is flat against the floor.</td>
</tr>
<tr>
<td>Holder 2</td>
<td>This person holds the other end of the spring vertically above the bottom end.</td>
</tr>
<tr>
<td>Wave maker</td>
<td>This person creates wave pulses from the top of the spring.</td>
</tr>
<tr>
<td>Recorder</td>
<td>This person observes and records what happens to the spring.</td>
</tr>
</tbody>
</table>

2. Holders: Set the spring up so that one end is on the floor and it stretches vertically. The other end should be about 2 m above the ground.

3. Wave maker: Gather about one half of the coils of the spring and compress them into the top 10 cm of the spring. When everyone is ready, release a few of the compressed coils to make a wave pulse.

4. All group members should observe the pulse as it travels down the spring. Recorder: Record the group’s observations.

5. Wave maker: Create additional pulses by releasing more coils. Recorder: Observe and record what happens as the pulse travels down the spring each time.

6. Change roles, and repeat Steps 3–5, beginning with slightly more than half of the spring compressed.

Part B: Transverse Waves

7. Change roles again. Holders: Put the spring on the floor or a long table, holding the ends about 2 m apart.

8. Wave maker: Pull a handful of coils to one side at the end of the spring, close to one of the Holders. When everyone is ready, release the coils to make a wave pulse.

9. All group members should observe the pulse as it travels down the spring. Recorder: Record the group’s observations.

10. Wave maker: Create additional pulses by pulling and releasing more coils. Recorder: Each time observe and record what happens as the pulse travels down the spring.

11. Change roles, and repeat Steps 8–10 with the spring held to about a 4-m length.
Part C: Additional Investigations

12. Try experimenting with a series of transverse wave pulses, instead of a single pulse. To do this, continuously move one end of the spring to the left and right. Record your observations in your science notebook.

13. Try creating longitudinal wave pulses while the spring is laid along the floor or table. Record your observations in your science notebook.

ANALYSIS

1. Create a larger version of the Venn diagram shown below. Record the characteristics of longitudinal and transverse waves in the circle with that label. In the spaces that overlap, record common features.

2. Describe what happened when
   a. the longitudinal wave pulses hit the floor in Part A.
   b. the transverse wave pulses reached Holder 2 in Part B.

3. Describe what happened in Part B when the spring was stretched to double its length.

4. What happened to the amplitude of the wave pulse when it traveled along the spring in Part B? Suggest an explanation for your observations.

5. Make two tables like the ones on the next two pages, and fill in the missing diagrams to show changes in amplitude or frequency.
Wave Characteristic: AMPLITUDE

Longitudinal wave diagram

- a. diagram of amplitude decrease

- b. diagram of amplitude increase

Transverse wave diagram

- c. diagram of amplitude decrease

- d. diagram of amplitude increase
Wave Characteristic: FREQUENCY

Longitudinal wave diagram

a. diagram of frequency decrease

b. diagram of frequency increase

Transverse wave diagram

c. diagram of frequency decrease

d. diagram of frequency increase
Noise-induced hearing loss (NIHL) occurs when sounds damage hearing, either temporarily or permanently. Harmful noises are sounds that are too loud or loud sounds that last a long time. Long-term exposure to loud noises causes permanent hearing loss by damaging the inner ear. The small sensitive cells in the inner ear, called hair cells, ordinarily convert sound energy into electrical signals that travel to the brain. Once damaged, hair cells send an incomplete message to the brain, which results in sensorineural hearing loss, or “nerve deafness.”

Exposure to excessive noise is the most frequently avoidable cause of permanent hearing loss. This exposure puts people at risk, which is the chance that an action or event could result in something unfavorable happening, such as injury. People at risk for NIHL are those who are exposed to loud sounds regularly, such as firemen, musicians, truck drivers, and headphone users. People exposed to a sudden burst of noise may suffer hearing loss, but NIHL more commonly occurs gradually from long-term noise exposure. People at risk for damage can prevent permanent damage with a few simple strategies. Unfortunately, most people are not aware of the degree of risk.

What can be done to prevent noise-induced hearing loss?

Headphones are often turned up significantly when users are in noisy places.
PROCEDURE

Part A: How Much Is Too Much?


<table>
<thead>
<tr>
<th>Sound Level, Decibels</th>
<th>Typical Activities</th>
<th>Maximum Allowed Job-Noise Exposure, Daily Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>Typical factory work</td>
<td>8 hr</td>
</tr>
<tr>
<td>95</td>
<td>Driving a subway, tractor</td>
<td>4 hr</td>
</tr>
<tr>
<td>100</td>
<td>High-volume headphone use; playing musical instrument; power boating; riding snow mobile, motorcycle</td>
<td>2 hr</td>
</tr>
<tr>
<td>105</td>
<td>Sporting events, mowing the lawn</td>
<td>1 hr</td>
</tr>
<tr>
<td>110</td>
<td>Dancing at a club, playing drums; using power tools, chain saw</td>
<td>30 min</td>
</tr>
<tr>
<td>115</td>
<td>Front-row rock concert; cheering stadium crowd</td>
<td>15 min or less</td>
</tr>
</tbody>
</table>

2. Plot a line graph of daily duration (y-axis) vs. sound level (x-axis). Use the graph to determine the maximum allowed time for a sound level of 97 dB.
Part B: What Can Be Done?

3. With your partner, discuss ideas you have for reducing your chance of getting noise-induced hearing loss. Make a list of strategies in your science notebook.

4. With your group, compile a list of strategies that would help reduce the risk of hearing loss. Then go through the list, and identify types of activities that each strategy might succeed with.

5. For each person described in the profiles below use the table to decide
   a. if they have a high-, medium-, or low-level risk for noise-induced hearing loss.
   b. why you gave them the rank.
   c. what could be done to protect their hearing.

José
José is an active middle school student who recently has had trouble hearing. When he went to the doctor, she didn’t find any structural problems or inflammation in his ears. She sent him for a hearing test, which showed he has some difficulty being able to hear higher frequencies in one ear. It is not clear at this time whether his hearing will return, or what is the exact cause. José will continue to undergo tests to determine the cause. In his free time, José likes to read, plays the drums in a band, and often listens to music loudly on his MP3 player with the earpiece in his right ear only.

Leon
Leon is 68 years old and just retired from his work as a computer engineer. He has always loved anything electronic, including games and robots. As a child he was fascinated by robots, a passion that led him to study robotics in graduate school. Eventually he began programming them full-time. His other love is music, and he goes to concerts regularly. He loves rock concerts as much as symphony concerts. He has been a band technician for many years, and when he noticed ringing in his ears that wasn’t going away, he started getting concerned. Over the years, he has lost some hearing but has only recently noticed it. In particular, he has trouble understanding women when they are talking to him. His doctor has told him that he should buy hearing aids.
**Shannon**
Shannon is a middle-aged woman who has worked at a paper mill for many years. Lately her work has involved running the big trucks that pull the felled trees into the mill entrance. Her favorite part of the paper mill is watching the massive automated machines run paper rolls at high speed. She knows she should wear ear protection because she has some hearing loss at 3,000–6,000 Hz, but admits she occasionally forgets to bring them to work.

**Sophie**
Sophie is a high school student with congenital deafness in both ears, which means she was born with little hearing. The cause of her deafness is most likely genetic as her father is also deaf. She has some hearing in one ear, and she would like to protect it. She has studied lipreading and had speech training, which is helpful in her everyday life but not particularly natural for her. She is most comfortable communicating through American Sign Language (ASL), which she learned from her parents and at school. She wonders if she might be making her hearing worse when she hangs out with her brother, who loves to take her to college soccer games.

**ANALYSIS**

1. List the people in the profiles from highest to lowest risk of further hearing loss, and explain how you choose their rank.

2. What kinds of things should be done to make people aware of the common risks to their hearing?

3. How does your own risk compare to the case studies in this activity? Explain how you will or will not change your behavior based on what you learned here.

4. What would you recommend for the following people to help them protect their hearing?
   a. Snowmobile driver
   b. Concertgoer
   c. Hair stylist
   d. MP3 user
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
STOPPING TO THINK 2

How is a transverse wave different from a longitudinal wave?

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

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

   ![Venn Diagram](Figure: 3789Waves SB05_09)

   Sound  
   Light  
   WAVE COMPARISON

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?

![Graph of visible light spectrum]

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.

![Transmission graphs for three pairs of sunglasses]

   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.

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>Film</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/m^2
   Film B: $100/m^2
   Film C: $50/m^2
Sunlight is a combination of light-waves of various frequencies. Some of the frequencies can be seen and some cannot be seen by the human eye. The reading in this activity explores the nature of these waves, which are electromagnetic. An electromagnetic wave transmits energy that is emitted from vibrating electrical charges, such as electrons. The vibrations send energy across distance as moving electrical and magnetic fields, which act as waves.

What are the characteristics of electromagnetic waves?

**PROCEDURE**


2. Complete the Reading.


**READING**

**Herschel’s Famous Experiment**

In 1800, British astronomer Sir Frederick William Herschel made an important discovery. While observing the sun through colored lenses, he noticed that some colors of light felt warmer than others. This observation interested him so much that he designed an experiment to try to measure the temperatures of the different colors of light.

In his experiment, Herschel used a prism to separate sunlight into the colors of the rainbow. He then placed a thermometer so that it was only struck by one color of light at a time. He discovered that violet light had the lowest
temperature as shown in the diagram at left. Herschel was surprised at this, because he knew that violet light was a higher frequency than red light and carried more energy. He then decided to investigate of the unlit area just past the red end of the spectrum. He found the temperature on the thermometers rose even higher than it had in the red light.

The only explanation for this data that made sense to Herschel was that sunlight must contain invisible “calorific rays” of low frequency that heat the thermometer. Herschel performed other experiments and found that these waves behaved just like visible light. They were reflected, absorbed, or transmitted. Because these “calorific rays” have a frequency just below visible red light, later scientists, in 1881, established a name for them: infrared. This name was chosen because the prefix “infra-” means “below.” Herschel was the first to detect an electromagnetic wave that was not visible to humans.

The reason infrared heats things up more than visible light does is related to its frequency. When infrared hits the molecules that make up many substances, it is often just the right frequency to be absorbed by the molecules. This increases the molecules’ energy. The increase in energy makes the molecules move faster, which heats up the substance. In a separate process, warm objects also give off infrared radiation as well as other wavelengths of electromagnetic energy.

**Ultraviolet Energy**

A year after Herschel’s experiment, Johann Wilhelm Ritter in Germany decided to find out if there were waves beyond the violet end of the visible spectrum as well. He conducted an experiment similar to Herschel’s, but directed the light onto a chemically coated paper that turned black when exposed to light. He chose this chemical, silver chloride, because it darkened more at the violet end of the spectrum. When he separated the light, the silver chloride was darkest just beyond the visible violet end of the spectrum. He called them “chemical rays,” which later became known as ultraviolet because “ultra-” means “beyond.”

Ultraviolet waves transmit more energy than infrared and visible light. In fact, ultraviolet has the most energy of all of the waves that commonly reach Earth’s surface. The energy transmitted to us by ultraviolet waves can be helpful. For example, human bodies transform some of the sun’s ultraviolet energy into vitamin D, which is necessary for bone growth. Those people whose diets lack vitamin D and who do not have much sun exposure may develop a vitamin deficiency. This results in defective bone growth in children.
or soft bones in adults. Lack of sun exposure, including ultraviolet wavelengths, also results in seasonal affective disorder for some individuals who are prone to depression. Scientists have invented machines with which to use ultraviolet light to sterilize equipment because it destroys bacteria, viruses, and molds.

At the same time, the high energy of ultraviolet waves poses a danger to people and other living things. They cause damage to living cells, which can result in cancer and cataracts, like those in Tía Ana’s eyes. Ultraviolet waves also cause materials, such as those used in clothes, furniture, curtains, and car interiors, to fade and become brittle.

**Light From the Sun**

Herschel’s and Ritter’s experiments showed that there is more energy in sunlight than meets the eye. As shown in the diagram below, most of the energy that reaches Earth is in the form of infrared, visible, and ultraviolet light waves. The diagram also shows that much of the energy given off by the sun never reaches Earth’s surface. This happens because the gases of Earth’s atmosphere reflect and absorb some of the energy. The atmosphere acts as a shield that protects all living things from most of the very dangerous high-frequency, high-energy ultraviolet waves, x-rays, and gamma rays. Although ultraviolet light has less energy than other high-frequency waves (like gamma rays and x-rays), it poses more of a hazard to living things because of the large amount of it that the sun emits. If Earth’s atmosphere did not have a thick ozone layer, much more electromagnetic energy would reach Earth’s surface, causing more harm to living things.
The Electromagnetic Spectrum

In addition to infrared, visible, and ultraviolet waves, the sun emits a large amount of other kinds of invisible electromagnetic energies. They include radio waves, microwaves, x-rays, and gamma rays. Together, the continuous range of all possible electromagnetic frequencies makes up the electromagnetic spectrum shown below.

Although portions of the frequencies of electromagnetic spectrum are given specific names, such as radio, visible, and x-rays, the categories overlap. This is because the wavelength ranges with which scientists classify each type of energy are somewhat arbitrary. It is often hard to distinguish where one group of waves ends and the next one begins. Fundamentally, all electromagnetic energy is of the same nature. For example, all electromagnetic waves can travel through a medium or through a vacuum. They can all be reflected, absorbed, and transmitted through various materials. The degree to which each type will reflect, absorb, or transmit depends on the wavelength of the wave and the surface it hits.

Although electromagnetic waves have common properties, there is an astounding difference in wavelength from one end of the spectrum to the other. The range of wavelength from gamma rays to typical radio waves is over 1,000 meters. Each range has some unique characteristics. Shorter wavelengths—those from ultraviolet to gamma rays—have the ability to penetrate living cells and damage them. Longer wavelengths of energy, like those in the radio range, can be generated or received by antennae. Our eyes can only detect a very small range of wavelengths from 380–620 nanometers (1 nanometer is one billionth of a meter).
Extending Our Senses with Electromagnetic Energy

There are hundreds of applications of electromagnetic energy. For example, x-rays are used to scan bones and teeth. Remote controls send an infrared signal to a device. WiFi relies on radio or microwaves to send and receive data. Microwave ovens create microwaves to transmit energy to the water in food, thereby heating it up.

Some technologies allow us to extend our senses by using electromagnetic waves. One example is infrared imaging in night-vision goggles. Night-vision technology lets us see objects by changing the invisible infrared light given off by objects into an image we can see with visible light. Since warm bodies give off infrared energy, a person wearing night-vision goggles can scan an area to see people and other warm-blooded animals in the darkness. Additionally, there are detectors that can sense all kinds of electromagnetic energy. For example, astronomers use radio telescopes that detect radio waves by which astronomers “see” distant objects in the universe.

ANALYSIS

1. With what evidence did Herschel support his discovery of infrared waves?

2. With what evidence did Ritter support his discovery of ultraviolet waves?

3. Compare infrared and ultraviolet. In what ways are they similar? In what ways are they different?

4. From the following list, choose the one that describes the portion of the range of electromagnetic waves that is visible.
   a. More than ½
   b. about ½
   c. ¼–½
   d. 1/10–¼
   e. much less than 1/10

   Explain your reasoning, citing evidence from this activity.

5. Is it likely that light frequencies higher than ultraviolet were the main cause of Tía Ana’s cataracts? Explain why or why not.
In Activity 95, “Selective Transmission,” you learned that electromagnetic energy is selectively transmitted. This means that not all frequencies of light are transmitted through an object when light hits its surface. Energy transmission depends on the combination of the wave’s frequency the properties of the material it hits. In this activity, you will gather evidence on whether electromagnetic energy can be selectively absorbed and reflected.

**CHALLENGE**

How do different materials absorb or reflect light?

### MATERIALS

For each group of four students

- 1 UV card
- 1 card holder
- 3 thermometers
- 1 piece of wrinkled aluminum foil
- 1 black cloth
- 1 dark cloth or paper covering
- 1 timer

An Inupiaq guide protects his eyes, left, by wearing glasses that reflect light. The black asphalt, right, absorbs more sunlight than the surrounding land.
**PROCEDURE**

**Part A: Reflection**

1. Before going outside, assemble the ultraviolet (UV) card in the card holder with the card facing down. Cover the assembly with the cloth covering before going outside.

2. Go outside, and spread out the black cloth and the piece of wrinkled aluminum foil next to each other in the sunlight.

3. With the dark covering over the UV card assembly, place it on the wrinkled aluminum foil and the black cloth so that one side of the UV card is only exposed to the foil while the other side is only exposed to the black cloth as shown below. Be sure to direct the assembly toward the sun so the assembly does not cast any shadow on the cloth or foil.

4. Expose the setup to sunlight for exactly 20 sec. Remove the UV card from the sun, and look at the UV-sensitive strip. Compare both sides, and record your observations in your science notebook.

5. Place the UV card in a dark place, such as a pocket, where it will reset, or turn the sensitive strip face down.
Part B: Absorption

6. In your science notebooks make a table like the one below.

<table>
<thead>
<tr>
<th>Material</th>
<th>Initial Temperature (°C)</th>
<th>Final Temperature (°C)</th>
<th>Change in Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black cloth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum foil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Place the three thermometers next to each other in the shade outside. Wait 1 min, and record the initial temperatures of each thermometer in your data table.

8. Place one thermometer on top of the aluminum foil and the other on top of the black cloth. Fold over the bottom of each material so that it covers the bulb of the thermometer as shown below. Leave the third one uncovered to serve as a control.

9. Expose all three thermometers to sunlight for 5 minutes. After 5 minute record the final temperatures of each thermometer.

10. Calculate the change in temperature of each thermometer, and record it.
ANALYSIS

1. Which surface—the black cloth or the aluminum foil—reflected more ultraviolet on the UV card? Cite evidence from this activity to support your answer.

2. Copy the diagram below.

![Diagram of light path](Figure: 3789Waves SB09_04 2e)

Draw a line that traces the path of the light from the sky to the aluminum foil and then onto the UV card.

3. In this activity, the black cloth models the dark ground. What could the aluminum foil and the UV card model?

4. Use evidence from this activity to support one of the following two statements:
   a. There is a decreased risk for ultraviolet exposure when playing at the beach or in the snow compared to playing at the park.
   b. There is an increased risk for ultraviolet exposure when playing at the beach or in the snow compared to playing at the park.

5. Which surface—the black cloth or the aluminum foil—caused a greater temperature increase when covering the thermometer? Explain why you think this happened.

6. Explain why the temperature will increase more in a house with a black roof than in one with a reflective roof.

7. Provide an example of a material that transmits, reflects, and absorbs light simultaneously.
In this investigation, you will apply what you know about transmission, absorption, and reflection to the use of sunscreens. People often rub sunscreens on their skin to reduce the ultraviolet energy that reaches the skin. The evidence you gather will help you decide if sunscreen absorbs or reflects the electromagnetic energy that is not transmitted.

**Does sunscreen transmit, absorb, or reflect ultraviolet waves?**

**MATERIALS**

*For each pair of students*

- 1 UV card
- 1 UV card holder
- 1 piece of clear plastic
- 2 Phospho-boxes
- 1 30-mL bottle of moisturizing lotion
- 1 30-mL bottle of SPF 30 sunblock lotion
- 1 paper towel
- 1 timer
PROCEDURE

Part A: Ultraviolet Transmission

1. Position the clear plastic so that it covers one half of the UV-sensing strip on the UV card.

2. Expose the UV card to the sun for 20 sec. Observe the UV card level of the two sides of the sensing strip, and record your results.

3. Place the UV card in a dark place, such as a pocket, where it will reset, or turn the sensing strip face down.

4. Spread a thin layer of moisturizing lotion on one half of the clear film and a thin layer of sunblock lotion on the other half, as shown in the diagram below. Make both layers as close to the same thickness as possible.

   Note: Do not put the lotion directly on the UV card as it will damage the sensing strip.

5. Position the plastic over the UV card so that about half of the sensing strip is covered with each kind of lotion.

6. Expose the UV card to the sun for 20 sec. Observe the UV levels of the two sides of the sensing strip, and record your results.

7. When you are finished, clean the lotion off the plastic with the paper towel.
Part B: Ultraviolet Absorption

8. With the equipment assigned to you design an experiment that will determine whether the sunblock lotion absorbs or reflects UV light. When designing your experiment, think about the following questions:
   - What is the purpose of your experiment?
   - What variable are you testing?
   - What is your hypothesis?
   - What variables will you keep the same?
   - What is your control?
   - How many trials will you conduct?
   - What data will you record?

9. Record your hypothesis and your planned experimental procedure in your science notebook.

10. Make a data table that has space for all the data you need to record during the experiment.

11. Obtain your teacher’s approval of your experiment.

12. Conduct your experiment, and record your results.

ANALYSIS

1. What evidence from this activity indicates that moisturizing lotion has different ingredients than sunblock lotion?

2. What effect do you think the ingredients in sunblock lotion have on the ultraviolet waves? Be sure to state any evidence you observed from the activity.

3. Do the results of this experiment allow you to predict the actual results of using sunblock lotion on your skin? Why or why not?
When Tía Ana recovered from her surgery, her sight was much better. José told her about the increased risk of ultraviolet exposure from sunlight. She was impressed that he knew so much about light. José gave her a pair of sunglasses in her favorite color for her birthday. Then he got a pair himself. Although he still loved spending time outside, José was a little more thoughtful about when and where he was exposed to ultraviolet waves.

Although doctors agree that people need vitamin D, there is some controversy over whether it is best to obtain it through food, from natural sun exposure, or both. Some doctors support the ideas that people should get their vitamin D through eating vitamin-D rich foods such as seafood and eggs. Other experts recommend limited exposure to sunlight, around 10 minutes a day without sunscreen, as a way to produce enough vitamin D. While excessive exposure increases risk of health problems, there are trade-offs involved in trying to avoid ultraviolet altogether. A trade-off is an exchange of one outcome for another—giving up something that is a benefit or advantage in exchange for something that may be more desirable. In this activity, you will analyze risk factors associated with ultraviolet exposure. Then you will make trade-offs while deciding how to protect yourself from ultraviolet waves.

What personal ultraviolet protection plan fits your risk factors and lifestyle?
Procedure

Part A: Analyzing Other People’s UV Exposure

1. Read the UV exposure risk assessment table shown below.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Lower risk</th>
<th>Medium risk</th>
<th>Higher risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age at exposure</td>
<td>20 and over, equal risk</td>
<td>Under 20</td>
<td></td>
</tr>
<tr>
<td>Intensity due to location: latitude</td>
<td>Far from equator</td>
<td>Mid-distance to equator</td>
<td>Close to, or on, the equator</td>
</tr>
<tr>
<td>Intensity due to location: altitude</td>
<td>Sea level–6,000 ft</td>
<td>3,000–6,000 ft</td>
<td>Over 6,000 ft</td>
</tr>
<tr>
<td>Time of day exposure</td>
<td>Before sunup or after sundown</td>
<td>Morning or late afternoon</td>
<td>10 a.m.–2 p.m.</td>
</tr>
<tr>
<td>Duration of exposure</td>
<td>Less than 1 hr/week</td>
<td>1–10 hr/week</td>
<td>More than 10 hr/week</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>Dirt, grass</td>
<td>Water, sand</td>
<td>Snow</td>
</tr>
<tr>
<td>Family history</td>
<td>No relatives with history</td>
<td>Relatives have disease</td>
<td>Close relatives have disease</td>
</tr>
<tr>
<td>Skin type: skin cancer</td>
<td>Dark skin</td>
<td>Medium skin</td>
<td>Fair skin</td>
</tr>
<tr>
<td>Skin type: cataracts</td>
<td></td>
<td>Equal risk</td>
<td></td>
</tr>
<tr>
<td>Mitigating behavior: hats, sunglasses, sunscreen</td>
<td>Always wear</td>
<td>Sometimes wear</td>
<td>Never wear</td>
</tr>
</tbody>
</table>

2. Read the case studies starting on the next page carefully. For each risk factor, assign a value of low, medium, or high risk for each case. If the case study doesn’t give you enough information to assign a value, leave the space blank. Record these values on Student Sheet 99.1, “Assessing Ultraviolet Risk.”

3. When you finish all of the cases, go back and make sure you rated consistently.

4. Examine each row of factors, and approximate the cataract and skin cancer risk for each case.
Case Studies

José
José is a 14-year-old, dark-skinned 8th grader who lives near the coast of Southern California. Since he got his dog Freddie five years ago, he has spent most mornings and evenings with Freddie at the park. José is amazed that his dog never seems to get tired, even when they have been playing for hours. Every Saturday, José and his friend pack lunches and take them to the beach so that they can stay all day. José is concerned about getting too much sun because his great-aunt just had cataract surgery, but he only recently started wearing sunglasses.

Shannon
Shannon is 50 years old and has lived in the mountains of Maine all of her life. She has fair skin and freckles. Because of this, she is careful to wear long sleeves and a hat during the summer when she spends part of the day outside. She also wears sunglasses all summer. As a teenager, Shannon and her twin brother worked at their dad’s grocery store after school and spent all of their free time playing basketball or baseball, which she still does on weekends. Last year, her twin had a small, dark spot of skin cancer removed from his similarly fair skin.

Leon
Leon, age 65, is very proud of the garden in his backyard. Now that he’s retired, he spends several hours each morning tending it. While growing up on the Gulf Coast in Mississippi, he spent afternoons fishing on his dad’s small boat. Now on weekends, Leon enjoys taking his own boat to a peaceful cove in the evenings to relax and fish. A dark-skinned African American, he never thought about protecting himself from the sun. However, recently he has noticed that his vision is a little cloudy. His sister who lives nearby says she’s having difficulty seeing, too, and just made an appointment to see her doctor.
Part B: Your Own UV-Exposure Risk

5. Create a case study about yourself in your science notebook. Write a paragraph that describes where you live, your activities, and your personal risk factors for cataracts and skin cancer.

6. Add your name at the bottom of the first column on Student Sheet 99.1, “Assessing Ultraviolet Risk.”

7. Assign ratings to yourself, and approximate your cataract and skin cancer risk.

ANALYSIS

1. In the case studies that you analyzed, who has the greatest risk for
   a. cataracts?
   b. skin cancer?

2. What risk factors are common for both cataracts and skin cancer?

3. Why do you think childhood ultraviolet exposure is considered a bigger risk factor than ultraviolet exposure later in life?

4. In the activity you used a scale of low–medium–high to rate people’s risk. Do you believe there can be zero risk of a particular outcome? Why or why not?

5. Prepare a personal ultraviolet protection plan by making a list of all of the things you can do to reduce your ultraviolet exposure while still participating in the outdoor activities that you enjoy the most. Then identify any trade-offs that are part of your new strategy.

Sophie

Sophie and her family live in Colorado. She has blond hair, blue eyes, and very light skin. Although Sophie was born with very little hearing, she loves participating in sports, particularly those outdoors. She spends a lot of time swimming in the summer and skiing in the winter. She enjoys skiing the most, and she spends most winter weekends at her uncle’s ski area nearby. He has eye damage from years of skiing, and the weathered skin on his tanned face makes him look older than he is. Sophie always remembers to wear her UV-blocking goggles when she’s skiing or sunglasses when just outside in the snow. She also tries to remember sunscreen but tends to forget.