10 Comparing Colors

LABORATORY

*D*URING 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 distracted because my favorite great-aunt, Tía Ana, is having eye surgery."

"Surgery!" replied Jenna. "What happened?"

José explained, "Everything began to look a bit blurry and she became sensitive to the glare of lights, especially at night. When she went to her doctor, she learned that the lens in one of her eyes had developed a cataract. Today the eye surgeon is going to take out the cloudy lens in her right eye and put in an artificial one. I know it is a common procedure, but I am worried anyway."

Sighted people use their eyes for almost everything they 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 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.

GUIDING QUESTION

How are the colors of the visible light spectrum similar to and different from each other?

MATERIALS

For each pair of students

1 Phospho-box
1 card with a star-shaped cutout
1 colored-film card
1 timer

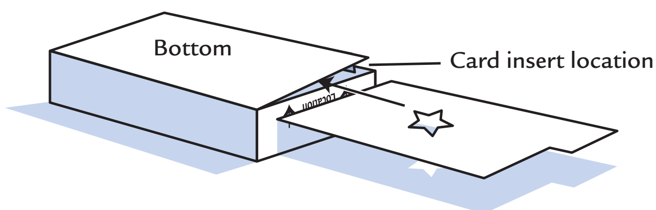
PROCEDURE

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 lid of the Phospho-box and examine the bottom of the box. The strip on the bottom of the Phospho-box is sensitive to a particular short-wavelength wave. Sketch and describe what you observe.
6. Close the Phospho-box and turn it over so that the top with the viewing slit is on the table. Slip the card with the star-shaped cutout into the card-insert location at the bottom of the box, as shown below. Leave the box in this position for 30 s.
7. Turn the Phospho-box right side up, open the top, and let light hit the entire bottom of the box for 20 s.



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.

A rainbow shows the colors of the visible light spectrum.

13. Rank each color of 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 s.
15. Repeat Steps 6–8 with the colored-film card, but this time let the light hit the bottom of the Phospho-box for 40 s. Record your results in your science notebook.

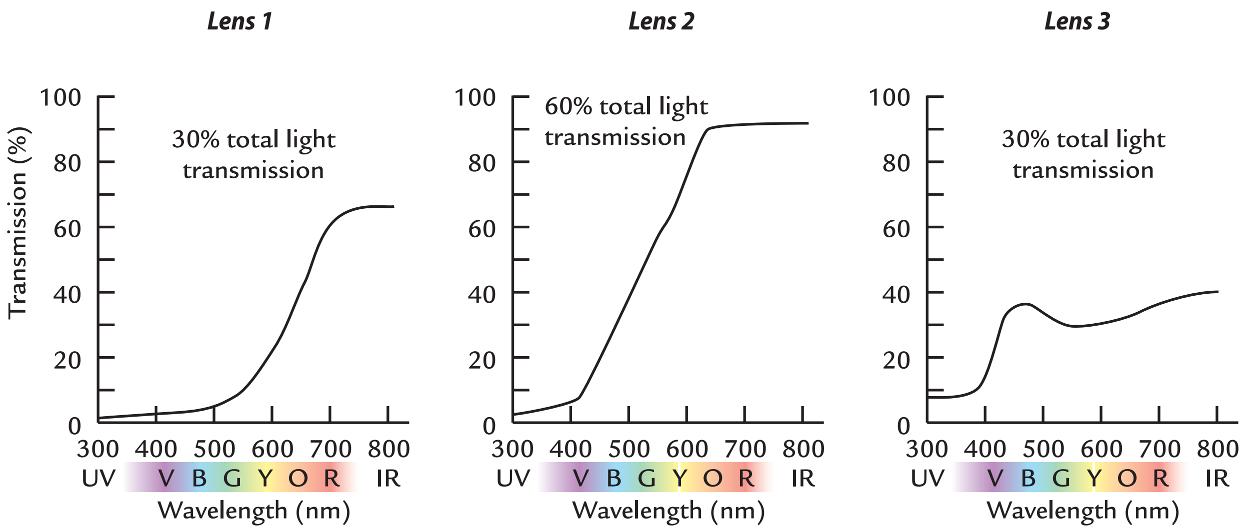
ANALYSIS

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? Describe how you might test your ideas to see if they are correct.
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—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? Explain your answer.

5. Which characteristic of a light wave explored in this activity affects the amount of energy that it carries?

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



   a. Which lens has the best protection for the eyes against high-energy waves? 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. A trade-off is an outcome given up to gain another outcome.

   Lens 1: $80

   Lens 2: $10

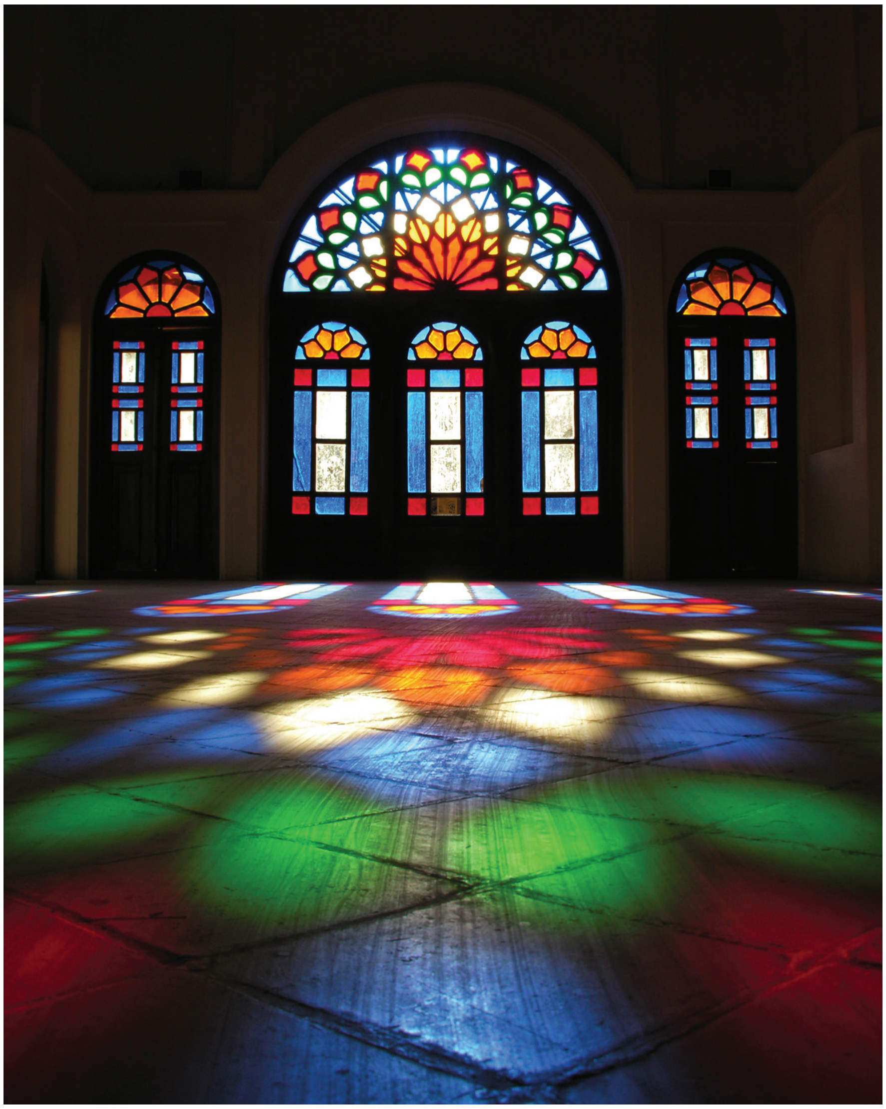
   Lens 3: $20

11 Selective Transmission

LABORATORY

IN PREVIOUS ACTIVITIES, you saw how waves, such as sound and light, transmit energy from one place to another. Light can be transmitted through one material into another. Any light that is not transmitted through a boundary between two materials is either reflected or absorbed by the object it hits. Like sound waves, light waves are reflected when light bounces off an object, either sent in one direction or scattered in many directions. When we see an object, we are seeing the light it reflects. Light waves are **absorbed** when light enters an object and does not exit the object again as light. The energy is not gone but is now in the object. This absorbed light is usually converted into heat that warms up the object. In this activity, you will investigate the transmission, reflection, and absorption of waves from the sun that are not visible to the human eye.

Sunlight is selectively transmitted through the stained glass window.



GUIDING QUESTION

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
1 timer
masking tape

SAFETY NOTE

Do not look directly into the sun as it can permanently damage your eyes.

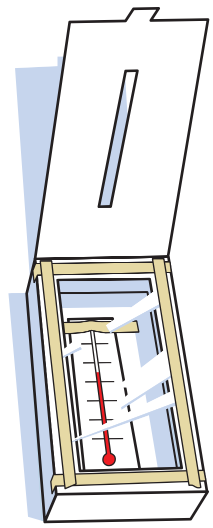
PROCEDURE

Part A: Comparing Temperatures

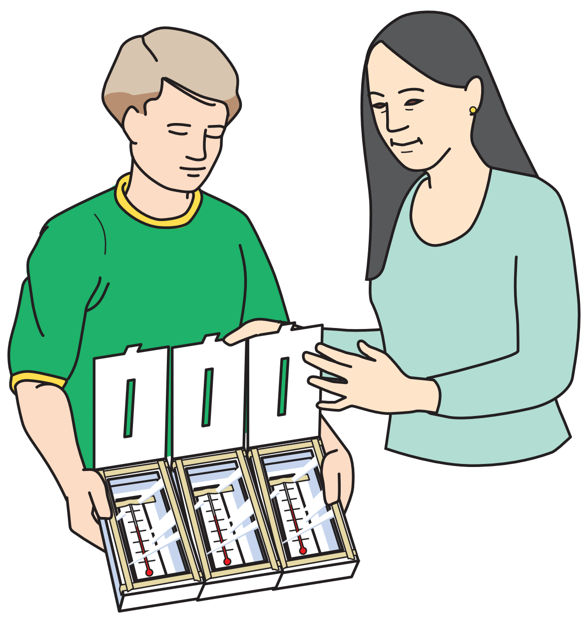
1. In your science notebook, create a data table similar to the one below.

Temperature Data			
Film	*Initial temperature (°C)*	*Final temperature (°C)*	*Change in temperature (°C)*
A			
B			
C			

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 entering 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 min.
8. Record in the data table the final temperature inside each box.
9. Calculate the change in temperature for each thermometer. Record these data in your data table.
10. Rank each film from 1 (smallest change) to 3 (highest change). Record your results in your science notebook.



Part B: Comparing Ultraviolet

11. Gently remove the films and replace the thermometers with the UV detector cards. Replace the films as instructed in Step 2.
12. Make a new data table with titles changed accordingly.
13. Repeat Steps 3–10. In Step 7, expose the UV cards for 20 seconds.
14. With your group, discuss if the results from 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 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 the structure and function of the films. Explain any trade-offs you made.

   Film A: $20/m^2

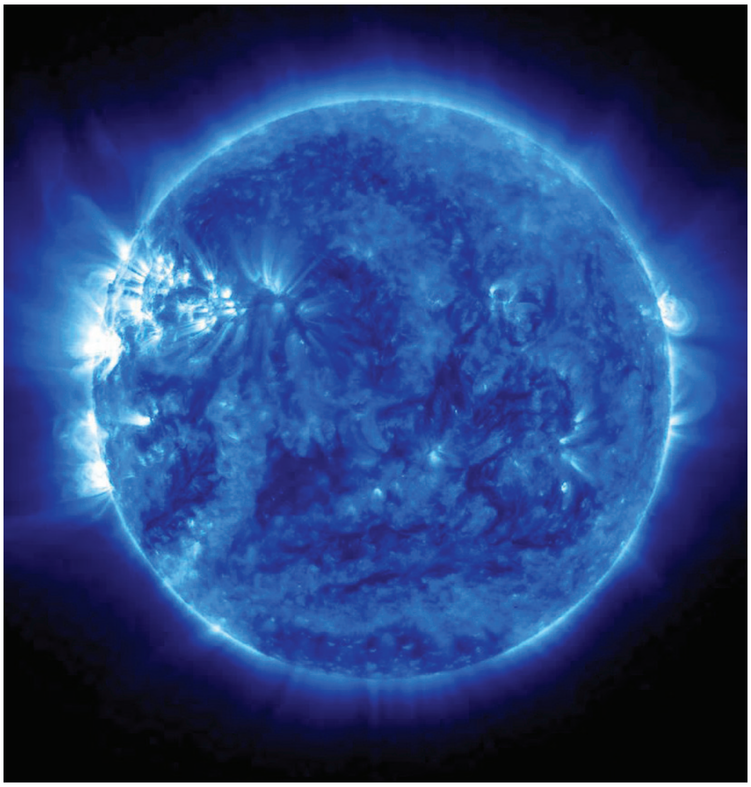
   Film B: $100/m^2

   Film C: $50/m^2

12 *The Electromagnetic Spectrum*

READING

SUNLIGHT IS A combination of light of various wavelengths. Some of the wavelengths 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 across distance as changing electrical and magnetic fields.



This image shows one wavelength of ultraviolet given off by the sun. This wavelength is not visible to the human eye but is typically colorized in blue.

GUIDING QUESTION

What are the characteristics of electromagnetic waves?

MATERIALS

For each student

1 Student Sheet 12.1, "Anticipation Guide: The Electromagnetic Spectrum"

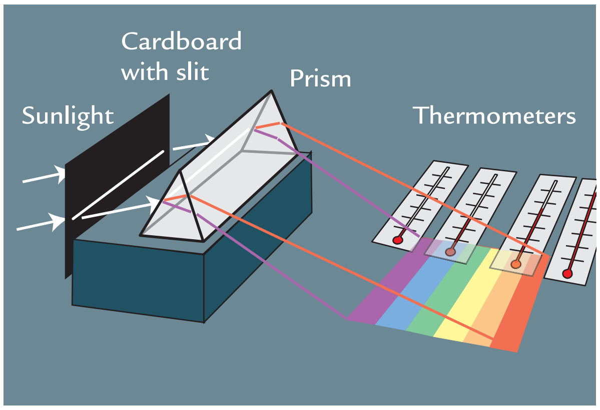
PROCEDURE

1. Fill in the Before column of Student Sheet 12.1, "Anticipation Guide: The Electromagnetic Spectrum."
2. Complete the Reading.
3. Fill in the After column of Student Sheet 12.1.

READING

Herschel's Famous Experiment

In 1800, German-born British musician and astronomer Sir Frederick William Herschel made a big discovery. While looking at the sun through colored lenses, he noted that some colors of light felt warmer than others. He wanted to learn more. He designed an experiment to try to measure the temperatures of the different colors of light.



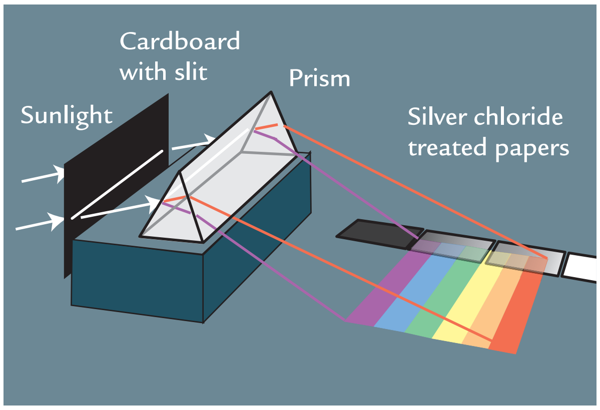
Herschel's experiment

In his experiment, Herschel used a prism, a triangular piece of glass to refract sunlight into the colors of the rainbow. When white light travels through a prism, each wavelength refracts a slightly different amount, creating a rainbow. Herschel first separated the light. Then he placed thermometers such that they were only struck by one color at a time. He noticed that red light caused a greater temperature rise than green or violet light, as shown in the diagram on the right. To his surprise, he also noticed that the temperature rose even more when the thermometer was in the unlit area just below the red end of the spectrum.

Based on his results, Herschel reasoned that sunlight must contain invisible energy that can heat up objects. He called the energy "calorific rays" since calorific refers to heat. When he carried out other tests, Herschel found that calorific rays behaved just like visible light. They could be reflected, absorbed, or transmitted like waves. Scientists named this kind of light **infrared,** where the prefix *infra-* means below. This discovery made Herschel the first person to detect a type of electromagnetic wave not visible to humans.

Infrared heats up objects more than visible light because of its wavelength. When infrared hits an object, the molecules in the object often absorb infrared. The result is an increase in the molecules' energy, which makes the molecules move faster. Faster molecules lead to a warmer object. Not only do most objects readily absorb infrared, but warm objects also give it off.

Ultraviolet Energy



Ritter's experiment

A year after the discovery of infrared, Johann Wilhelm Ritter in Germany decided to find out if there is energy beyond the violet end of the visible spectrum. He carried out an experiment like Herschel's. Instead of a thermometer, he aimed the light onto a special paper that turned black when exposed to light. The chemical on the paper, silver chloride, darkens more when hit by light from the violet end of the spectrum. When Ritter separated the light, the paper turned darkest just beyond the visible violet end of the spectrum. He first called his discovery "chemical rays" after the chemical reaction in the paper. Later this type of light just beyond the visible light spectrum became known as **ultraviolet** because the prefix *ultra-* means beyond.

Ritter's results stayed the same when he changed the amount of light shined on the paper. Reducing the brightness of the light is similar to reducing the intensity of a sound wave. Yet no matter how much Ritter dimmed the light, the paper turned black. This is because the reaction in the paper was due to the wavelength of the ultraviolet and not its brightness. Longer wavelength light of any brightness, such as visible light or infrared, does not turn the paper black. The paper only turns black when exposed to ultraviolet.

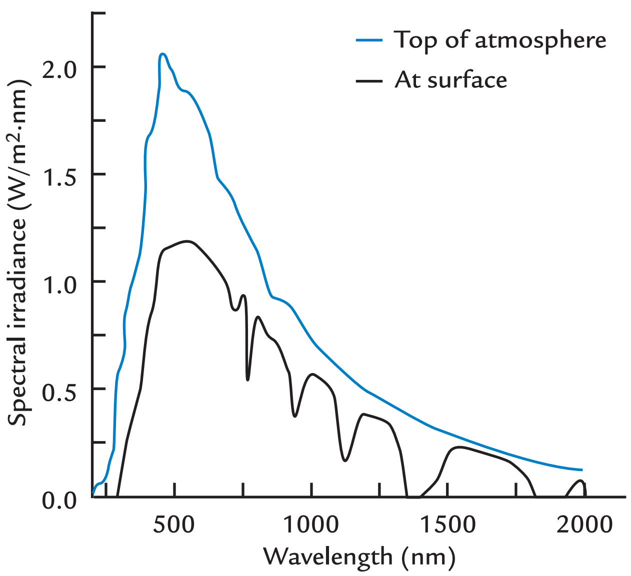
Despite its relatively high energy, ultraviolet can be helpful to humans. When human skin is exposed to ultraviolet energy, the body converts a chemical in the skin into vitamin D. Vitamin D is necessary for bone growth. Those people who lack sun exposure and whose diets lack vitamin D may develop a deficiency. This results in bone-growth problems in children or soft bones in adults. Low levels of vitamin D have been associated with cardiovascular disease, cognitive impairment, and cancer. One more benefit of ultraviolet is that it can be used to disinfect medical devices. The wavelength range of ultraviolet has enough energy to destroy bacteria, viruses, and molds.

At the same time, ultraviolet energy poses a danger to people and other living things. Its wavelength causes damage to living cells. Over time it can result in skin cancer and cataracts, like those in Tía Ana's eyes. Ultraviolet also causes some fabrics and materials such as those used in clothes, furniture, and car interiors to fade and become brittle.

Light From the Sun

Herschel's and Ritter's experiments showed that sunlight contains more energy 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. 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 short-wavelength, high-energy ultraviolet, X-rays, and gamma rays. Although ultraviolet has less energy than other short-wavelength waves (like gamma rays and X-rays), they pose more of a hazard to living things because more ultraviolet reaches Earth's surface. If Earth did not have a thick atmosphere, much more electromagnetic energy would reach Earth's surface, causing more harm to living things.

Amount of energy from the sun reaching earth



The Electromagnetic Spectrum

In addition to infrared, visible, and ultraviolet, the sun emits other kinds of invisible electromagnetic energies. They include radio waves, microwaves, X-rays, and gamma rays. Together, the continuous range of all possible electromagnetic wavelengths makes up the **electromagnetic spectrum** shown to the right.

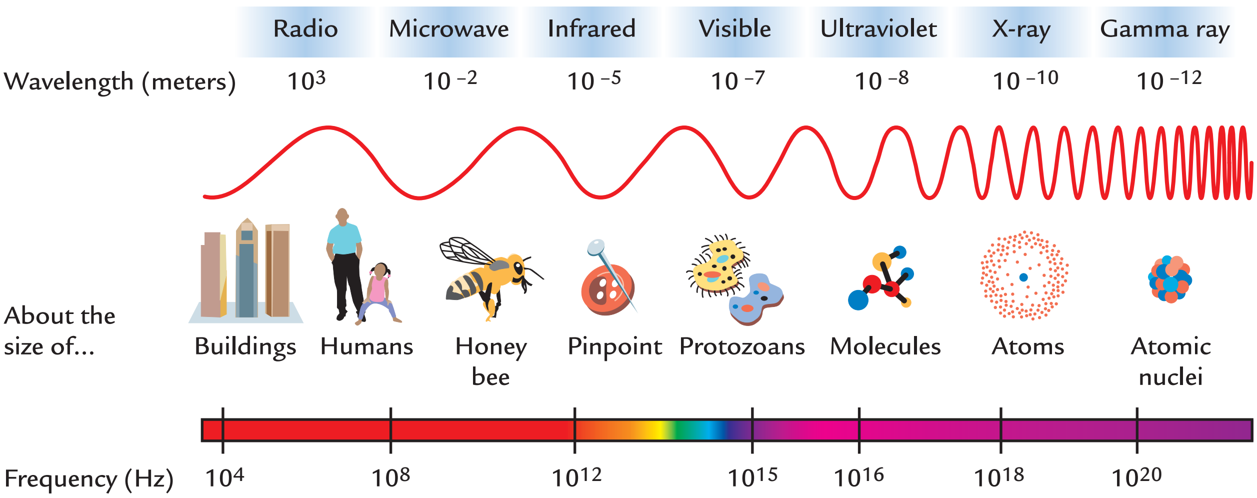
Although ranges of wavelengths in the electromagnetic spectrum are given specific names, such as radio, visible, and X-rays, the categories overlap. This is because it is often hard to define where one group of wavelengths ends and the next one begins. In fact, all electromagnetic energy has certain common traits. 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 or material it hits. For example, electromagnetic energy with the wavelength of microwaves is readily absorbed by water but not by other common materials. This is why water (and foods containing water) heat up more quickly in a microwave than in a conventional oven.

Although electromagnetic waves have many things in common, there is a huge difference in wavelength from one end of the spectrum to the other. Wavelengths range from less than one trillionth of a meter for gamma rays to 100 km and more for radio waves. Each range has some unique characteristics. For the same intensity, electromagnetic waves with shorter wavelengths (higher frequencies) carry more energy than those with longer wavelengths (lower frequencies). This is why waves from ultraviolet to gamma rays can penetrate living cells and damage them. Longer wavelengths of energy, like those in the radio range, can be generated or received by antennae. Human eyes can only detect a very small range of wavelengths from 380–750 nanometers (nm). One nanometer is equal to one billionth of a meter.

Electromagnetic Energy and Sound Energy

In many ways, visible light waves, and all the other types of electromagnetic waves, behave much like sound waves. However, there are some very significant differences. Sound requires a medium through which it is transmitted, but electromagnetic energy does

The electromagnetic spectrum



not and can, therefore, be transmitted through a vacuum. This is why sunlight is able to travel from the sun to Earth and through the void of space. Because light waves do not require the presence of atoms or molecules to be transmitted, they are not considered to be mechanical waves. Light is a transverse wave that carries electromagnetic energy. Electromagnetic waves also travel much faster than sound waves, as shown in the tables below.

Speed of Light

MEDIUM	SPEED (m/s)
Diamond	124,000,000
Glass	197,200,000
Plexiglass	198,500,000
Water	224,900,000
Ice	228,800,000
Air	299,700,000
Vacuum	299,800,000

Speed of Sound

MEDIUM	SPEED (m/s)
Vacuum	0
Carbon dioxide (0˚C)	258
Air (20˚C)	344
Helium (20˚C)	927
Water, fresh (20˚C)	1,481
Wood	3,500
Aluminum	6,400

Extending Our Senses with Electromagnetic Energy

We use electromagnetic waves in many ways in our daily lives. For example, we use X-rays to scan bones and teeth. Some remote controls send infrared signals to devices, such as TVs. Wireless Internet connections rely on radio or microwaves to send and receive data.

Microwave ovens transmit microwave energy to the water in food, thereby heating it.

Electromagnetic waves allow us to extend our senses. One way is through infrared imaging in night-vision goggles. Night-vision technology lets us see objects by changing the infrared rays given off by objects into an image we can see. 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 tools that can sense various ranges of electromagnetic energy. For example, astronomers use radio telescopes that detect radio waves. Astronomers use these telescopes to "see" distant objects in the universe.

An astronomer inspects a radio telescope in Germany.

ANALYSIS

1. With what evidence did Herschel support his discovery of infrared energy?
2. With what evidence did Ritter support his discovery of ultra-violet energy?
3. Compare infrared and ultraviolet. In what ways are these two energies similar? In what ways are they different?
4. From the following list, choose the option that describes the fraction of the electromagnetic spectrum that is visible.

   a. more than 1/2

   b. about 1/2

   c. 1/4–1/2

   d. 1/10–1/4

   e. much less than 1/10

   Explain your reasoning, citing evidence from this activity.

5. Is it likely that light with frequencies higher than ultraviolet was the main cause of Tía Ana's cataracts? Explain why or why not.
6. Provide an example, not found in the Reading, of a tool that uses electromagnetic waves to help scientists more accurately measure, explore, model, and compute during scientific investigation. Explain how the tool works.