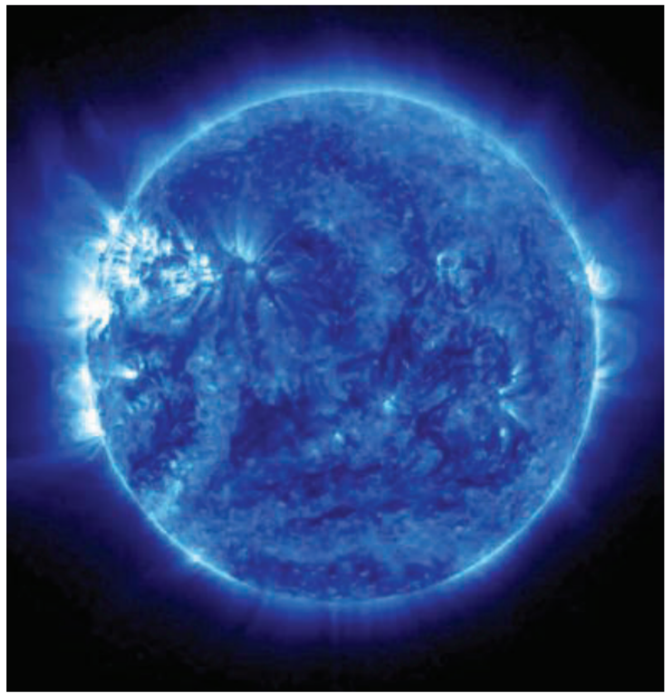
12 The Electromagnetic Spectrum

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

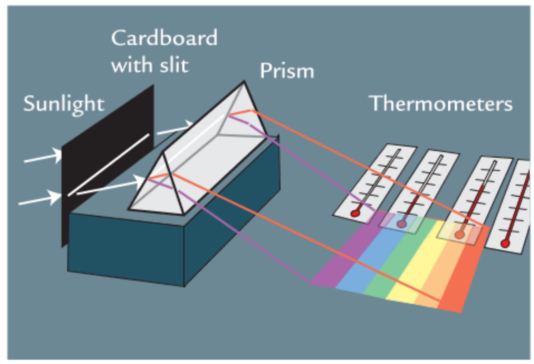
1. Fill in the Before column of Student Sheet 12.1, "Anticipation Guide: The Electromagnetic Spectrum."
2. Complete the Reading.
3. Fill in the After column of Student Sheet 12.1.

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.

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.

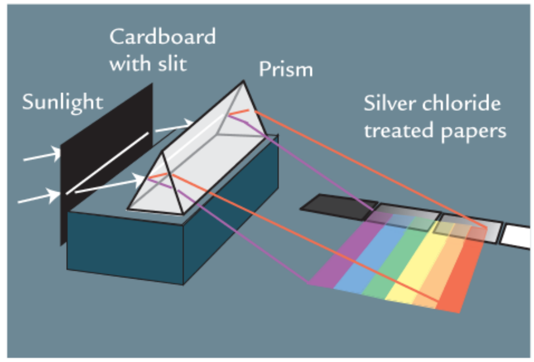


Herschel's experiment

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.

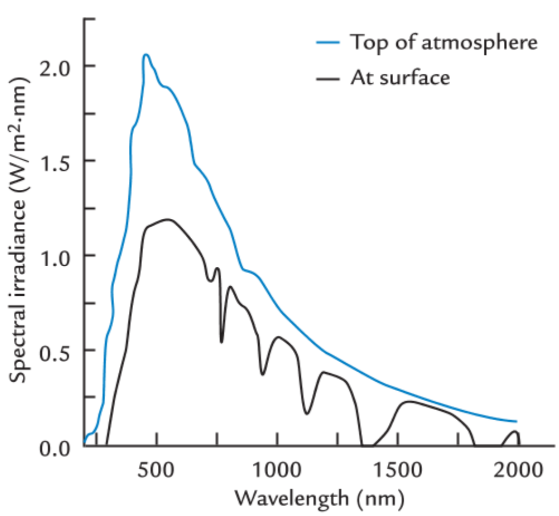
Despite its relatively high energy, ultraviolet can be helpful to humans. When human skin is exposed to ultraviolet energy, the body converts a chemical in the skin into vitamin D. Vitamin D is necessary for bone growth. Those people who lack sun exposure and whose diets lack vitamin D may develop a 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.

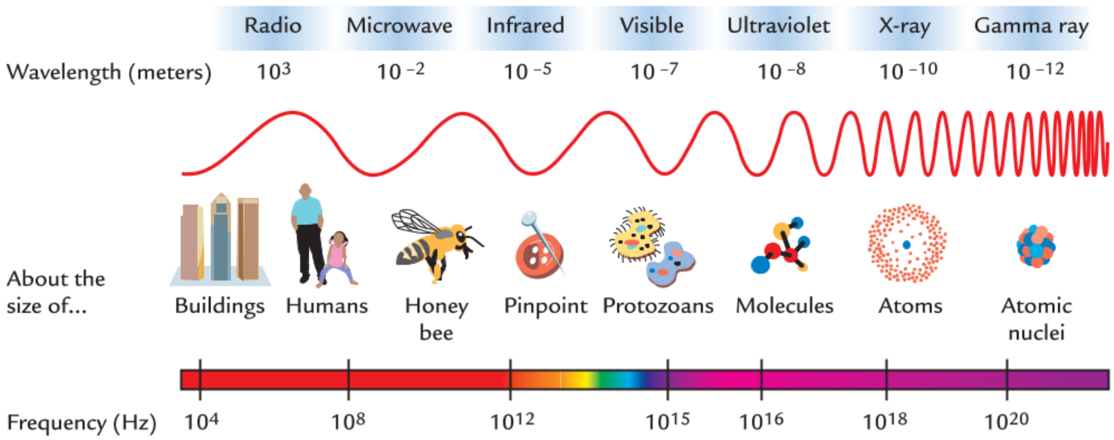
Although ranges of wavelengths in the electromagnetic spectrum are given specific names, such as radio, visible, and X-rays, the categories overlap. This is because it is often hard to define where one group of wavelengths ends and the next one begins. In fact, all electromagnetic energy has certain 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.