The Electromagnetic Spectrum

ACTIVITY OVERVIEW

NGSS RATIONALE

In this activity, students integrate textual and visual information to extend their understanding of the electromagnetic spectrum. They see how scientific knowledge is based on logical and conceptual connections between evidence and explanations as they learn about the classic experiments that established the existence of infrared and ultraviolet radiation. Students also learn how technologies extend the capabilities of scientific investigation as they read about applications of electromagnetic energy and devices that extend human senses.

NGSS CORRELATION

Disciplinary Core Ideas

PS-4.B Wave Properties: When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object’s material and the frequency (color) of the light.

PS-4.B Wave Properties: A wave model of light is useful for explaining brightness, color, and the frequency-depended bending of light at a surface between media.

PS-4.B Wave Properties: Because light can travel through space, it cannot be a matter wave, like sound or water waves.

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings.

Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence
Scientific knowledge is based on logical and conceptual connections between evidence and explanations.
Connections to Nature of Science: Scientific Knowledge Open to Revision in Light of New Evidence
Science findings are frequently revised and/or reinterpreted based on new evidence.

Crosscutting Concepts

Connections to Engineering, Technology, and Applications of Science: Influence of Science, Engineering, and Technology on Society and the Natural World
Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigation.

Common Core State Standards—ELA/Literacy
RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

WHAT STUDENTS DO
Students read about the kinds of electromagnetic energies emitted from the sun that are not visible. They refer to their knowledge of frequency, wavelength, and energy levels to learn about the discovery and applications of infrared and ultraviolet energy. Finally, they read about ways that humans have used electromagnetic energy to extend their sensory capabilities.

MATERIALS AND ADVANCE PREPARATION

For each student

TEACHING SUMMARY

GET STARTED
1. (LITERACY) Explore the concept that there are light waves that we cannot see.

DO THE ACTIVITY
2. (LITERACY) Examine electromagnetic energy.

BUILD UNDERSTANDING
3. Take a closer look at the electromagnetic spectrum.

TEACHING SUGGESTIONS

GET STARTED

1. (LITERACY) Explore the concept that there are light waves that we cannot see.
   a. Ask students to share any evidence that there are invisible forms of energy in sunlight.
      Students should cite the results from the last two activities as evidence that there are energies from the sun that are not detectable by the eye.
   b. Introduce the Anticipation Guide.
      Student Sheet 12.1, “Anticipation Guide: The Electromagnetic Spectrum,” provides a preview of important concepts in the Reading. It is also an opportunity for students to explore misconceptions they have about the material, and correct them when they have finished the Reading. You might read the statements aloud and clarify any questions students have about their meaning. Instruct students to record whether they agree or disagree with each statement by placing a “+” or “−” in the “Before” column. You may also want to discuss with students their reasoning for their predictions. Explain that they will have a chance to revisit these statements after the activity to see whether their ideas have changed or remain the same. Instruct them to complete the Reading. Tell them to mark the “After” column for each statement on the Anticipation Guide after they finish the Reading. For a sample student response, see the sample Student Sheet at the end of this activity. For more information, see the Literacy section of Teacher Resources II: Diverse Learners.

DO THE ACTIVITY

2. (LITERACY) Examine electromagnetic energy.
   a. Discuss the procedure of Herschel’s experiment.
      Connect the prism used in Hershel’s experiment to the previous refraction activity. Use this opportunity to discuss how the wave model of light describes dispersion, or the frequency-dependent bending of light at a surface between media. Discuss with students the scientific process that Herschel followed in his experiments. Focus on the significance of Herschel’s use of controls in the experiment, namely the visible forms of light and his sharp observations. Ask students, “What would the result of the experiment have been if Herschel had not used a control?” It is likely that Herschel would not have seen the effects of infrared light at all if he had not used a control in his experiment.
b. Discuss the scientific thinking of Herschel and Ritter.

Point out that when Herschel did not get the results he expected, he did not dismiss his results as erroneous; instead, the results spurred him to further investigate. Discuss how Ritter built on Herschel’s ideas, which is an important part of the process of science. This is an example of how science findings are frequently revised and/or reinterpreted based on new evidence.

c. Introduce the term electromagnetic spectrum.

*Electromagnetic spectrum* is the scientific name for the range of all waves that are electromagnetic in nature. Explain that all of the frequencies of light in the electromagnetic spectrum are emitted by the sun and travel at the speed of light. Point out the continuous nature of the frequencies in the electromagnetic spectrum and the relationships among frequency, wavelength, and energy level.

d. Direct students to the diagram of the electromagnetic spectrum.

The left side of the diagram shows lower energy waves, and the right side shows higher energy waves. This is a good time to review the concepts of frequency and wavelength, with particular emphasis on the inverse relationship between the two, as introduced earlier in the unit.

*Teacher’s Note:* The diagram in the Student Book, “The Electromagnetic Spectrum,” shows the most familiar wavelengths and is not an exhaustive list of electromagnetic waves. For example, there are ultra-low frequency (ULF) waves with a wavelength up to 10 Hz. The emphasis in this unit is on infrared, visible, and ultraviolet light. The depth of your discussion of other waves in the electromagnetic spectrum is a matter for your discretion, depending on your time constraints, background, and interest.

### BUILD UNDERSTANDING

3. Take a closer look at the electromagnetic spectrum.

a. Compare the characteristics of different types of electromagnetic energy and how they can be used to extend human senses.

Use the final section of the reading to help students make connections with the ways in which science, engineering, and technology influence society and the natural world. Begin by identifying some different behaviors of the electromagnetic energies, such as those that are visible to humans and those that are not. Also, point out the differences considered
in designing applications. For example, ultraviolet light is used for sanitizing medical equipment because it carries enough energy to destroy germs. On the other hand, one reason that some handheld remote controls use infrared waves is because those waves generally do not carry enough energy to do any harm. Finally, discuss technologies that utilize various parts of the electromagnetic spectrum to extend human senses, and how scientists use them to learn more about the natural world and universe.

b. Emphasize that all types of electromagnetic waves are fundamentally the same phenomenon.

Point out that any of the electromagnetic waves can be either helpful or harmful, depending on the circumstances. They can be refracted, reflected, and absorbed in the same way as visible light. Here are some points that students may notice or that you might explain in your discussion of electromagnetic energy and the spectrum:

- Electromagnetic waves move energy away from a source, such as the sun. The technical term for this is radiation. (The term radiation is also used to identify certain kinds of energy, such as energy produced in a nuclear reaction.)

- Electromagnetic waves are detectable only when they interact with something and transfer energy. For example, visible light is detectable when it interacts with cells in the back of the eye, and ultraviolet light is detectable when it interacts with molecules in the skin.

- The electromagnetic spectrum is continuous, and there are no “boundaries” between the named portions. The names were created to more easily refer to those groupings of waves that share similar properties. It is interesting to note that the scientific community has not decisively defined the range of each portion.

- The range of wavelengths across the spectrum is tremendous. If students have trouble understanding the powers of 10 shown on the diagram, refer to the size-of-wavelength illustrations below the wavelength scale on the diagram.

- The frequency range of visible light is a relatively tiny part of the entire range of frequencies found in the electromagnetic spectrum.

- The sun emits much more light in the narrow band of frequencies that include infrared, visible light, and ultraviolet than it does for all the other frequencies combined.
• Any kind of electromagnetic energy, even low-energy waves like radio waves, can be harmful if the level of exposure is high enough. Waves carrying high energy, such as gamma rays, are dangerous with very minimal exposure.

• Electromagnetic energy does not need a medium for transmission, so it is not a matter wave like sound or water.


SAMPLE STUDENT RESPONSE: STUDENT SHEET 12.1; “ANTICIPATION GUIDE: THE ELECTROMAGNETIC SPECTRUM”

— 1. All electromagnetic energy is visible.
   Those wavelengths outside the visible light spectrum are not visible to humans.

— 2. Electromagnetic energy is the same thing as heat.
   Electromagnetic energy is a massless wave, whereas heat is energy given off as a result of molecular motion.

+ 3. Ultraviolet has a frequency higher than visible light.

— 4. The electromagnetic spectrum includes only visible light and infrared.
   The electromagnetic spectrum includes radio, microwaves, infrared, visible, ultraviolet, x-rays and gamma rays.

— 5. Radio waves are not really electromagnetic.
   Radio waves are a kind of electromagnetic energy found at the lowest end of the frequency range.

— 6. Only visible light can transmit through a vacuum.
   All electromagnetic waves can travel through a vacuum.

+ 7. All electromagnetic waves are transmitted, reflected, and absorbed depending on the material they hit.

— 8. All electromagnetic waves have the same frequency.
   Electromagnetic waves have a range of frequencies across the spectrum and within each type.
SAMPLE RESPONSES

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

   The temperature of the area just outside the red part of the spectrum was higher than that of the visible light spectrum, indicating an invisible source of energy.

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

   The paper coated with silver chloride turned darkest in the area just beyond the violet area. The paper turned dark as a result of its exposure to relatively high energy.

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

   The table shows possible answers to the comparison of infrared to ultraviolet:

<table>
<thead>
<tr>
<th>Infrared</th>
<th>Ultraviolet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electromagnetic energy</td>
<td>Electromagnetic energy</td>
</tr>
<tr>
<td>Lower frequency, longer wavelength</td>
<td>Higher frequency, shorter wavelength</td>
</tr>
<tr>
<td>Less energy</td>
<td>More energy</td>
</tr>
<tr>
<td>Lots given off by the sun</td>
<td>Lots given off by the sun</td>
</tr>
<tr>
<td>Not visible to most species</td>
<td>Not visible to most species</td>
</tr>
<tr>
<td>Stimulates molecules in skin to produce heat</td>
<td>Doesn’t heat up skin</td>
</tr>
<tr>
<td>Not generally damaging to skin or eyes</td>
<td>Can damage skin and eyes</td>
</tr>
</tbody>
</table>

4. From the following list, choose the option that describes the portion of the range of electromagnetic waves 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.

   e. Visible is much less than 1/10 of the whole spectrum. Its range is wavelength 400–700 nm, which is tiny in comparison to the range of less than 10 pm (gamma)–1,000 m (radio).
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.

Although electromagnetic waves with higher-frequency energy than ultraviolet light—such as X-rays and gamma rays—could have contributed to Tía Ana’s cataracts, the amount of these rays that reach Earth is very low. Therefore, because the highest notable energy in sunlight is ultraviolet, it is unlikely that waves with higher energy than ultraviolet could have caused the cataracts.

REVISIT THE GUIDING QUESTION

“What are the characteristics of electromagnetic waves?”

Review the characteristics of electromagnetic waves by discussing the similarities and differences between waves across the electromagnetic spectrum. Remind students that all waves can be transmitted, reflected, and absorbed. Point out that all electromagnetic waves travel at the same speed through a vacuum but that the waves slow down when traveling through other media, and that the amount of slowing varies with wavelength. This helps to explain phenomena such as refraction and dispersion. Check that students understand the relationship between frequency and energy when applied to the electromagnetic spectrum.

ACTIVITY RESOURCES

KEY VOCABULARY

absorption

electromagnetic spectrum

electromagnetic wave

infrared

reflection

transmission

ultraviolet
INFRARED

Infrared radiation has wavelengths in the range of 750 nm–1 mm, spanning three orders of magnitude and comprising 3–6 subcategories, ranging from near-infrared to far-infrared. Sunlight that reaches the Earth includes infrared (47%), visible (46%), and ultraviolet (7%) light. The Earth’s climate depends on the critical balance between absorbed and emitted infrared radiation.

Infrared radiation is popularly known as “heat,” since many people attribute all radiant heating to infrared light and all infrared radiation to being a result of heating. This is a widespread misconception. Actually, electromagnetic waves of any frequency will heat a surface that absorbs them. It is true that objects at room temperature will emit radiation mostly concentrated in the 8–12 µm band (i.e., infrared), but hotter objects also emit radiation, typically visible or ultraviolet. Likewise, two objects at the same temperature will not necessarily emit the same amount or wavelength of infrared. Heat transfer is the process of energy flow due to temperature difference. Unlike heat energy transmitted by thermal conduction or thermal convection, electromagnetic radiation can propagate through a vacuum.

ULTRAVIOLET

Electromagnetic waves with a wavelength range of 10 nm–400 nm are called ultraviolet (UV). The ultraviolet spectrum has been further broken into three subcategories—UVA, UVB, and UVC—from longest to shortest wavelength, respectively. Although present in the sunlight that reaches Earth, nearly 99% of ultraviolet radiation is blocked by the atmosphere. Some UVB and all UVA reach Earth. Although UVB is higher frequency and, therefore, more of a health concern, the levels of UVA radiation are more constant than for UVB. In addition, UVA radiation is not filtered by glass or plastic unless coated with an appropriate film.

THE NATURE OF ELECTROMAGNETIC ENERGY

Before the discovery of electromagnetic radiation, Michael Faraday had shown that varying electric currents induce a changing magnetic field and vice versa. James Maxwell furthered the study of electromagnetism when he postulated the existence of electromagnetic waves. He elegantly uncovered the wave behavior of electric and magnetic fields, concluding that light itself was an electromagnetic wave. An electromagnetic wave is the result of a varying electric field that causes an associated magnetic field to change. Likewise, a varying magnetic field causes changes in the associated electric field. In an electromagnetic wave, these fields form a propagating field moving periodically through space.
At the start of the 20th century, the recognition of the quantum nature of electromagnetic radiation began to emerge. Quantum mechanics showed that electromagnetic radiation neither completely fit Maxwell’s classic wave theory nor the Newtonian concept of particle motion. For example, electromagnetic radiation is created and destroyed at specific points in space, like a classic Newtonian particle. However, electromagnetic radiation does not move in the simple uniform motion of Newtonian mechanics. The motion of large numbers of light particles (or photons) is that of a wave that is affected by both diffraction and interference.
STUDENT SHEET 12.1
ANTICIPATION GUIDE: THE ELECTROMAGNETIC SPECTRUM

Before starting the activity, mark whether you agree (+) or disagree (–) with each statement below.

After completing the activity, mark whether you agree (+) or disagree (–) with each statement below. Under each statement, explain how the activity gave evidence to support or change your ideas.

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