10 Comparing Colors

LABORATORY

1 CLASS SESSION

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students first observe that visible light can be separated into different colors. Students then conduct an investigation to collect evidence that indicates that different colors of light carry different amounts of energy. In their final analysis, students analyze and interpret light transmission graphs for three different sunglass lenses. They determine which sunglass lens (structure) provides the best protection (function) for the eyes.

NGSS CORRELATION

Performance Expectation

Working towards MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

Disciplinary Core Ideas

MS-PS4.B.1 Electromagnetic Radiation: 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.

MS-PS4.B.3 Electromagnetic Radiation: A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media.

Science and Engineering Practices

Planning and Carrying Out Investigations: Conduct an investigation to produce data to serve as the basis for evidence that meets the goals of an investigation.

Crosscutting Concepts

Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Common Core State Standards—ELA/Literacy

RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

WHAT STUDENTS DO

Students explore light by investigating the colors of the visible spectrum. They first observe how a white light can be split into its component colors during a teacher demonstration. Then they investigate the energy levels of the different colors of white light through the use of a phosphorescent material.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  - 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T)
  - 1 diffraction grating
  - *1 flashlight
  - *1 white surface or wall

- *For each pair of students*
  - 1 Phospho-box
  - 1 card with star-shaped cutout
  - 1 colored-film card
  - 1 timer
  - *1 set of colored pencils (red, orange, yellow, green, blue, and purple) (optional)

- *For each student*
  - 1 Scoring Guide: EVIDENCE AND TRADE-OFFS (E&T) (optional)

**Not supplied in kit*

Practice using a diffraction grating to diffract white light into the visible spectrum for the demonstration described in Teaching Step 1.

For best results, conduct this activity inside.

TEACHING SUMMARY

GET STARTED

1. Introduce colors of the visible spectrum.
   a. Review how a rainbow is formed.
   b. Explain how a diffraction grating works.

DO THE ACTIVITY

2. Investigate the frequencies of visible light colors.
    a. Conduct a teacher demonstration.
    b. Suggest how the waves are separated by the grating.
    c. Review student responses to Procedure Part A.
3. Complete Part B of the Procedure where students carry out an investigation.
    a. Review the relationship between the amplitude and energy of a wave.
    b. Explain how the colored-film card works.
    c. Review student responses to Procedure Part B.
    d. Ask students, “Why don’t all of the colors make the strip glow?”
4. If you have not previously done so, introduce scientific evidence in science.
    a. Explain how scientists define and use evidence.
    b. Distinguish evidence from opinion.
    c. Consider the role of evidence in decision making.

BUILD UNDERSTANDING

5. Identify the relationship between color and frequency.
    a. Relate the results of the Phospho-box procedure to the story of Tía Ana.
    b. Review student responses to Analysis item 5.
6. Discuss the structure and function of selective transmission.
    a. Identify selective transmission in Analysis item 6a.
    b. Elicit more examples of structure and function.
7. If you have not previously done so, introduce the concept of trade-offs.
    a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.
    b. Provide an example of trade-offs.
    c. Develop some examples of trade-offs in students’ lives.
    d. (E&T ASSESSMENT) Introduce the E&T Scoring Guide.

TEACHING STEPS

GET STARTED

1. Introduce colors of the visible spectrum.

   a. Review how a rainbow is formed.

   Ask, "Who has ever seen a rainbow?" It is likely that all of your students have seen one. Next ask, "What causes the colors of a rainbow?" Record their responses on a white surface or wall (e.g., chart paper, a board, or projector). Make sure students are aware that for a rainbow to form, there must be water droplets in the air and sunlight to pass through the water droplets. This is another example of the phenomenon known as *refraction*.

   b. Explain how a diffraction grating works.

   Hold up the diffraction grating and explain that this film with grating on it can also make a rainbow by splitting up the white light that passes through it. Explain that the grating works by a different mechanism than a prism. While refraction, as explored in a previous activity, is a result of the different frequencies of light being redirected through the glass, *diffraction* is a result of white light being spread out when it is transmitted through very fine slits.

DO THE ACTIVITY

2. Investigate the frequencies of visible light colors.

   a. Conduct a teacher demonstration.

   In Part A of the Procedure, display the visible light spectrum to the class by holding the grating about 6 inches in front of a light source (e.g., a flashlight). Move the grating around a bit until the diffracted light is projected onto a white surface (e.g., a wall or paper). When introducing the term *visible light spectrum,* review that a *spectrum* does not include starts and stops but, in this case, implies a continuous band of light. *Visible light* refers to human vision, since some animals and insects can see some light that we cannot. For example, bees can see ultraviolet but not red.

   b. Suggest how the waves are separated by the grating.

   Observe that the rainbow is not formed directly in front of the grating but is, instead, angled upward or to the side of it. Ask students, "What does this tell you about the light that goes through the grating?" If necessary, explain that this is evidence that the grating splits up the white light. Then use the wave model of light to explain that the incoming white light is separated by the structure of the grating into the light's component colors due to its varying wavelengths.

c. Review student responses to Procedure Part A.

PROCEDURE STEP 2 SAMPLE STUDENT RESPONSE

In ascending order, the colors are red, orange, yellow, green, blue, violet.

Students might also mention the color indigo. Scientists no longer classify indigo as a color in the visible light spectrum because it is a relatively narrow band of color that is transitional between blue and violet.

In reviewing responses to Procedure Step 2, emphasize that the order of the visible light spectrum always shows in the same order of red, orange, yellow, green, blue, violet or vice versa, regardless of how it is diffracted or refracted. Review the terms *frequency* and *wavelength*. Explain that each color of light in the spectrum has a different frequency and wavelength.

PROCEDURE STEP 3 SAMPLE STUDENT RESPONSE

The colors blend from one to the next with a smooth transition between them.

Explain that the frequencies of the light waves continually increase from the red side of the spectrum to the violet side.

In reviewing responses to Procedure Step 3, reinforce the idea that the visible spectrum is continuous from red to violet. Although students are not familiar with the entire electromagnetic spectrum at this point, the evidence for answering this question foreshadows later activities where students learn about the continuous nature of the electromagnetic spectrum.

PROCEDURE STEP 4 SAMPLE STUDENT RESPONSE

Yellow appears the brightest, with the colors on the outside of it—orange and green—the next brightest. These are closely followed by red, with blue and violet the least bright.

Confirm with students that the yellow and green areas appear the brightest in the spectrum they observed. There could be several explanations for this observation. For example, it could be because the light arriving on Earth is strongest for those two colors or it could be that our eyes are more sensitive to those colors than to the other colors, or it could be both of these factors.

3. Complete Part B of the procedure where students carry out an investigation.

   a. Review the relationship between the amplitude and energy of a wave.

      From previous activities, students should know that as the amplitude of a wave increases, so does its energy. With light, the *intensity* or *brightness* of light is referred to more than amplitude. To informally assess whether students understand how the wave model of light describes the brightness and color (frequency) of light, ask students, "Are microwaves harmful to humans?" Accept all responses, but direct the discussion so that students understand that there is little evidence that long-wavelength microwaves in typical everyday use, such as those used by cell phones, are harmful to people. Ask the class a similar question about X-rays. Some students may suggest that all X-rays are harmful. Others might feel that their everyday experiences with X-rays at dentist and doctor offices show that some X-rays are safe or at least less harmful than others. Now ask students to speculate, from a safety perspective, why exposure to X-rays at the dentist or doctor is kept very short (less than a second) but cell phone conversations can last minutes (or hours!). Conclude the discussion by explaining that for some types of waves, the energy is not only associated with the amplitude or intensity but also the frequency. Students will learn more about this relationship in Part B of this activity and in subsequent activities.

   b. Explain how the colored-film card works.

      Each colored film on the card isolates a single color of light. Explain that colored film doesn't separate white light like a diffraction grating or a water droplet. Instead, it only allows one color to be transmitted through the film and come out the other side. A common student misconception is that color is transferred to the light from the colored film, much like paint is put onto an object. Make it clear to students that the films do not add any color to white light.

      In Part B, students engage in the science and engineering practice of carrying out an investigation using the Phospho-box and a card containing various colored films. They should observe that only blue and violet light cause the phosphorescent strip to glow, even when they double the exposure time. Since the phosphorescence in the strip is triggered by a threshold energy, this is evidence that the blue and violet lights have more energy than the other colors. For improved results, students should hold the boxes closer to the light source when exposing them.

c. Review student responses to Procedure Part B.

PROCEDURE STEP 10 SAMPLE STUDENT RESPONSE

Violet was the brightest, and then blue. The other colors did not trigger the phosphorescent strip. The violet seemed equally as bright as when the card was not used.

PROCEDURE STEP 15 SAMPLE STUDENT RESPONSE

When the time was doubled, the results were similar. This indicates that the phosphorous strip is sensitive to the frequency of the light and not the total exposure.

d. Ask students, "Why don't all of the colors make the strip glow?"

Some students may suggest that not all colors of light carry energy. Make it clear that all colors carry energy, but each color carries a different amount. Each color is due to a wave with a slightly different frequency. Only some frequencies carry enough energy to cause the phosphorescent material in the strip to glow. The colors that make the strip glow—blue and violet—are found right next to each other in the visible light spectrum. This gives some evidence that higher frequencies (and, therefore, energy) of a light wave are related to its position in the spectrum. For visible light, violet has the highest frequency and red has the lowest. The rest of the colors are in between, according to their position in the spectrum. The phosphorescent strip has threshold energy. Any energy equal to or greater than the threshold will make the strip glow. The threshold energy corresponds to the frequency delivered to the strip by blue light.

4. If you have not previously done so, introduce scientific evidence in science.

a. Explain how scientists define and use evidence.

Although the term *evidence* is used previously in the unit, Analysis item 4 provides an opportunity to review the definition of evidence provided in the Student Book. Explain that scientists collect information (data) with various tools and strategies, including observation and experimentation. Tell students that they will now use the data they collected from the film experiment to decide if it gives information about what is damaging Tea Ana's eyes. The consideration of evidence is a key step in scientific reasoning and decision making. Throughout this unit, and throughout all SEPUP courses, students will collect and analyze information, which may become evidence to support or refute claims.

b. Distinguish evidence from opinion.

Evidence is information that supports a claim. *Opinion* is the view someone takes about a certain issue based on their own judgment, often without the support of factual evidence. An informed opinion may be based on evidence; however, another person may have a different opinion based on the same evidence.

c. Consider the role of evidence in decision making.

One must be critical of the source, quality, and quantity of evidence available. Review with students that scientific conclusions are based on evidence, and biased or insufficient evidence compromises the validity of these conclusions. The criteria for quality evidence may vary among the scientific disciplines. However, evidence is generally considered of higher quality if it is obtained through systematic investigation and is reproducible, meaning another investigation under the same set of circumstances obtains similar data. Additionally, the greater the quantity of high-quality evidence that can be provided, the stronger the case is in support or against the claim. Criteria for quantity also vary but might include the sample size or number of trials in the experiment, the number of observations that support a conclusion, or the availability of multiple lines of evidence that lead to the same conclusion. Scientific conclusions should logically follow the evidence collected and should not be overly generalized beyond the context of the investigation.

BUILD UNDERSTANDING

5. Identify the relationship between color and frequency.

a. Relate the results of the Phospho-box procedure to the story of Tía Ana.

Ask students, “Which color light is more likely to damage eyes due to its higher energy?” Students should respond that the violet light is most likely to be damaging. In fact, it is not the violet light that is damaging but the ultraviolet that exists just beyond the violet frequencies. Students will be introduced to ultraviolet in subsequent activities, and so use this discussion of higher and lower energies to explore the frequencies of the various colors. It may be helpful to present a diagram that shows the relative frequencies through the visible spectrum. For the same intensity of light, those light waves with a higher frequency will also have higher energy than light waves of lower frequency. Students’ evidence from the activity supports this idea. For light, scientists use the term *intensity* to describe the brightness of a light wave in terms of the rate at which energy is delivered by the wave to a surface. Let students know that the energy level associated with light is dependent on both its brightness and its frequency. Tell them that in the next activity, they will consider waves that are of a frequency higher than violet light, such as those that could damage Tía Ana's eyes.

b. Review student response to Analysis item 5.

Students have seen in this activity that the frequency of light indicates its energy level. From previous investigations, students should know that its intensity is also related to its energy level. They also should know that *both* the frequency and intensity (or amplitude) are directly related to the amount of energy transmitted by a wave.

6. Discuss the structure and function of selective transmission.

a. Identify selective transmission in Analysis item 6a.

In this item, students are asked to identify the lenses that block out high-energy wavelengths. Model how to read one of the graphs, and describe how it shows transmission at different wavelengths and also provides an overall percentage of transmitted sunlight. This question is a good opportunity for assessing students' abilities to not only read the graphs, but to also apply the concept of selective transmission introduced by the colored films.

b. Elicit more examples of structure and function.

Ask the class to come up with other examples of the crosscutting concept of structure and function involving selective transmission (e.g., sunglasses, windshields, windows, and shades). Selective transmission is further investigated in the next activity. This prepares students for an assessment on Performance Expectation MS-PS4-2, "Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials," in Activity 13, "Where Does the Light Go?"

7. If you have not previously done so, introduce the concept of trade-offs.

a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

This unit includes issues that relate to science and/or engineering and that may lead to decisions about the best solutions or designs for solving problems. One goal of this curriculum is to teach students that

- decisions about possible solutions often involve trade-offs
- identifying trade-offs involves analyzing evidence.

Explain to students that in this unit they will make several decisions about health concerns related to ultraviolet. In this activity, students choose a sunglass lens. In a decision involving trade-offs, something is given up to gain something else. Since many decisions involve trade-offs, students should understand that a perfect choice is often not possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision.

b. Provide an example of trade-offs.

For example, when asked, “Paper or plastic?” at a store checkout counter, most shoppers make the choice quickly. But there are several trade-offs attached to choosing paper or plastic. A shopper who chooses paper over plastic may do so to avoid generating plastic waste. In requesting the paper bag, though, they are contributing to other environmental problems, such as increased water and energy use, and the higher amounts of solid waste and CO_2 emissions associated with making paper bags. Neither choice is ideal, and both choices have benefits and risks. Identifying the trade-offs helps clarify the reasoning being applied to make a decision.

c. Develop some examples of trade-offs in students’ lives.

To further explore trade-offs, brainstorm with the class a list of decisions they make every day that involve trade-offs. Choose one, and talk through the associated trade-offs of deciding one way or another. This practice will familiarize students with ways of identifying and considering trade-offs in this and subsequent activities.

d. (E&T ASSESSMENT) Introduce the E&T Scoring Guide.

Analysis item 6b introduces the concept of a *trade-off*. This concept is emphasized in the unit’s last activity, Activity 15, “Personal Protection Plan,” but is introduced here as part of the E&T assessment. Provide all students with an E&T Scoring Guide, and ask them to keep it with their science notebooks, as they will refer to it several times in this unit and throughout all SEPUP courses.

Analysis item 6b in this activity is the first use of the E&T Scoring Guide. Project or distribute the Scoring Guide, and point out how it has the same levels but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, “Assessment.”

Note that students could make their choices based on a balance of price and/or ultraviolet protection, but some may be more concerned with the style and appearance. Encourage students to be clear about what is influencing their choices. Look for responses that specifically identify the trade-offs being made (e.g., higher cost for effectiveness).

SAMPLE RESPONSES

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

   The star-shaped cutouts provide a control so that we can see what white light, which contains all of the colors, does to the strip in the Phospho-box. Then we can compare the effects of each color to the effect of white light.

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.

   Since the light goes through each film separately, each film is acting as a filter, letting only one color through and blocking the rest of the colors. One way to test my idea is to put one filter in front of another. If each filter only lets one color through, then using two different colored filters should allow little, or no, light through. Another idea is to use a diffraction grating on the light that has passed through a single filter to see if the light can be split into different colors or whether it is a single color.

   Teacher's note: Even though you discussed this earlier, some students will indicate that the color is transferred to the light from the colored film. Although it is hard to provide convincing evidence to the contrary, make clear that this is not what is happening.

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

   I think that the different colors of light carry different amounts of energy. When light is absorbed by a material, that energy is transferred to the material. In the case of the material on the strip on the box, the light has enough energy when it goes through certain films that it glows. The energy is absorbed by the strip and then reemitted as the glowing light. It is like those glow-in-the-dark toys that will glow after being exposed to light but won't glow unless exposed to light.

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.

   There is evidence that a range of energy is carried by white light, with some colors (blue, violet) having more energy than others (red, orange). However, there is no evidence that supports the idea that the relatively higher energy in some colors is enough to damage Tía Ana's eyes.

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

   In a previous activity, we learned that energy is related to the amplitude of a wave, and so a brighter light means more energy delivered to a surface. In this investigation, we have seen that the color (frequency) is also related to energy.

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.

      I think that Lens 1 provides the best protection. This is because the graph goes down close to zero for the ultraviolet wavelengths. Lens 3 is nearly as good because it lets only a little more of the ultraviolet through, and most of the light is transmitted more evenly (except it blocks more blue and violet). All three of the lenses provide a lot of blocking in the ultraviolet frequencies. In fact, both Lenses 1 and 3 transmit only 30% of the light.

   b. (E&T ASSESSMENT) 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

      SAMPLE LEVEL-4 RESPONSE

      Although Lens 1 is the best protection, I wouldn't buy it because it is the most expensive one. Lens 2 provides nearly as much ultraviolet protection and is only 1/8th the cost. I would choose this lens because it is cheaper than both of the other lenses and has similar protection to Lens 1. In fact, the cheaper Lens 2 has better protection than Lens 3. The trade-off is that it is a very light lens with 60% of the light going through it, and I prefer a dark lens. It is a better trade-off than selecting Lens 3, however, because I would not like to wear a red lens at all.

REVISIT THE GUIDING QUESTION

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

The colors of the visible light spectrum are similar in that they are all light waves. They are different in that each color is a different frequency of light. Some frequencies carry higher energy than others. Colors of the visible spectrum are selectively transmitted depending on the material and the light wave's frequency.

ACTIVITY RESOURCES

KEY VOCABULARY

evidence

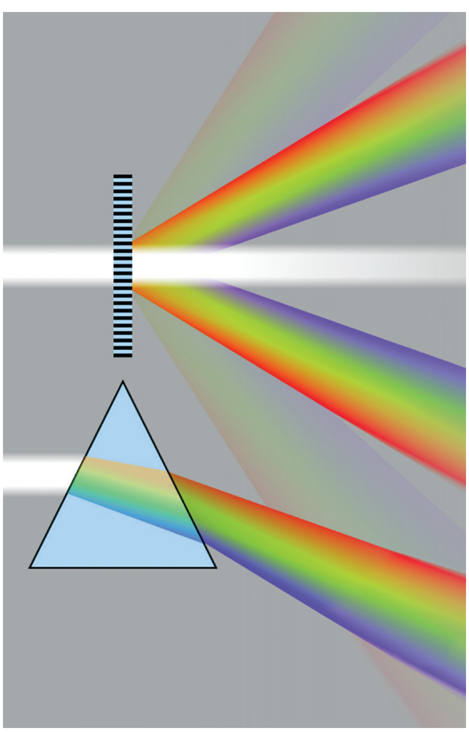
frequency

trade-off

visible light spectrum

wavelength

BACKGROUND INFORMATION



A diffraction grating (top) and a prism (bottom) will both separate white light into the visible spectrum.

REFRACTION

Refraction occurs when a wave propagating through one medium (or through a vacuum, in the case of light) encounters the interface of another medium at an angle. This results in a change in the direction of propagation of the wave as it travels across the interface. For example, the frequency of a wave is determined at the source and is fixed after the wave has left the source. However, the speed and the wavelength can change depending on the medium through which the wave travels. There is, as a result, a differential slowing of the wave front that causes the light to refract, or change direction. In the case of white light, different frequencies of the light are redirected at slightly different angles, producing the light spectrum that we observe as a rainbow.

DIFFRACTION GRATING

A diffraction grating is a tool that diffracts the light that passes through it. It has a similar effect on light as a prism that refracts white light into the visible spectrum, although the sequence of the spectrum is different, as shown at left.

The mechanism for the separation of light into a spectrum via diffraction is different from when light is refracted; in diffraction, the light bends around small obstacles that are roughly the same size as the wavelength of the light. A diffraction grating is a film with thin, parallel rulings on it, which cause this bending or dispersion of light. The change in direction of the light depends on the spacing of the grating and the wavelength of the light. Diffraction gratings are commonly found in spectrometers and monochromators. Likewise, the alternating pits and smooth reflecting surfaces that form closely spaced rows on a CD or DVD are separated by a similar distance to that on an ordinary lab diffraction grating and will produce a separation of white light.

VISIBLE LIGHT SPECTRUM

The visible light spectrum is that portion of the electromagnetic spectrum that is visible to the human eye and is perceived as color. It ranges in wavelength from about 400 nm (violet) to 700 nm (red). The boundaries are somewhat hard to distinguish as the colors blend and the outermost regions blend into ultraviolet and infrared. The table below shows the approximate range for each color. It also shows that the bandwidth for each color is not evenly distributed, with red having the widest wavelength range and yellow the narrowest.

Color	Wavelength (nm)	Wavelength range (nm)
Violet	380–450	70
Blue	450–495	45
Green	495–570	75
Yellow	570–590	20
Orange	590–620	30
Red	620–750	130

WAVE-PARTICLE DUALITY OF LIGHT

Electromagnetic radiation, such as light, exhibits wave properties including reflection, refraction, diffraction, and interference. However, the behavior of electromagnetic radiation cannot be explained entirely through an analysis of wave properties. In 1900, Max Planck suggested that electromagnetic radiation was not emitted continuously but, rather, intermittently in “packets” of energy. Such packets became known as quanta and photons. The energy of each quantum depends on the frequency of the electromagnetic radiation. Each quantum possesses a discrete amount of energy that is proportional to the frequency of the light. The energy of a quantum of violet light is higher than the energy of a quantum of red light, since violet light has a higher frequency than red light. Fractions of quanta cannot exist.

In 1905, Albert Einstein theorized that light and other forms of electromagnetic radiation were not only emitted in whole numbers of quanta; they were also absorbed as quanta. In the case of light falling on phosphorescent material, the energy of some of the incident photons is absorbed by the electrons of the atoms in the material. This occurs only if the energy of the photon matches the change in allowable energy states of the electrons in the material. If the energy matches, then the electron temporarily moves to a higher excited state. As the electron drops back to the ground state, it emits photons, causing the material to glow. The energy of the emitted photons will depend on the energy states through which the electron transitioned. Consequently, certain colors of light will make the phosphorescent material glow while others will not.

11 Selective Transmission

LABORATORY

1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students build on the concepts previously presented by investigating light beyond the visible spectrum. Students conduct an investigation to test how different films affect the transmission and absorption of light. As they analyze and interpret the data they have collected, they learn that there are invisible waves at both ends of the visible spectrum and that these waves, like visible light, transfer energy when absorbed. Students select and justify which structural films would be most functional to use on windows in three different situations.

NGSS CORRELATION

Performance Expectation

Working towards MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

Disciplinary Core Ideas

MS-PS4.B.1 Electromagnetic Radiation: 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.

Science and Engineering Practices

Planning and Carrying Out Investigations: Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation.

Analyzing and Interpreting Data: Analyze and interpret data to provide evidence for phenomena.

Crosscutting Concepts

Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Common Core State Standards—Mathematics

MP.2: Reason abstractly and quantitatively.

Common Core State Standards—ELA/Literacy

RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

WHAT STUDENTS DO

Students learn more about the properties of light by investigating transmission, absorption, and reflection of waves outside the visible spectrum. They investigate how three thin films, which all transmit visible light, selectively transmit waves that are not visible to the human eye, such as ultraviolet.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  - 1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID)

- *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, about 40 cm

- *For each student*
  - 1 Scoring Guide: ANALYZING AND INTERPRETING DATA (AID) (optional)

**Not supplied in kit*

This investigation works best if it is done outside during the middle of a clear, sunny day. It is the most sun-dependent activity in the unit. Make sure to check the weather and try out the Procedure first. If there is not enough sun to show a significant temperature difference, provide students with the sample data from the activity and have them complete the activity as it is written.

The Procedure instructs students to hold or prop up the three boxes for 5 minutes. If opting to allow them to prop up the boxes, prepare a way in which students can do this or provide time in class for them to come up with a design.

SAFETY NOTE

Do not allow students to look directly into the sun as it can result in permanent eye damage.

TEACHING SUMMARY

GET STARTED

1. Review the concept of selective transmission.
    a. Ask students, "What happens to the colors of light that do not pass through the colored films?"
    b. (LITERACY) Elicit student ideas with a word sort of relevant terms.

DO THE ACTIVITY

2. Students investigate the transmission properties of different films.
    a. Identify the transmission properties of each film.
    b. Review student responses to Procedure Part A.
3. Students collect more transmission data.
    a. Students detect ultraviolet that is selectively transmitted.
    b. Compare student results for Part A and Part B.

BUILD UNDERSTANDING

4. Students apply the data gathered in the activity.
    a. (AID ASSESSMENT) Assess student understanding of the evidence gathered.
    b. Discuss how the structure and function of the films contribute to the trade-offs of different window films.

TEACHING STEPS

GET STARTED

1. Review the concept of selective transmission.

   a. Ask students, "What happens to the colors of light that do not pass through the colored films?"

   In Activity 10, "Comparing Colors," the films of different colors transmitted some parts of white light but not others. Students often use such terms as *bounces back*, *goes into*, *goes through*, and *warms up*. Use the conversation to review the definitions of the terms *transmission*, *reflection*, and *absorption*. Review the concept of selective transmission by identifying that sunlight that does not transmit through an object is either reflected or absorbed. Let students know that for this activity, they will test materials for their abilities to transmit sunlight.

   b. (LITERACY) Elicit student ideas with a word sort of relevant terms.

   Finish introducing the activity by using a literacy strategy known as a categorization activity, or word sort. Word sorts help students build their use and understanding of new vocabulary as they identify relationships among the words. There is not always a single correct answer, and the purpose is not simply to cross out and circle words. Provide the following instructions:

   Copy the list of words shown below:

   transverse

   longitudinal

   reflect

   absorb

   transmit

   selective transmission

   light

   a. Look for a relationship among the words.

   b. Cross out the word or phrase that does not belong.

   c. Circle the word of phrase that includes the others.

   d. Explain how the word or phrase you circled is related to the other words on the list.

SAMPLE STUDENT RESPONSE

transverse

~~longitudinal~~

reflect

absorb

transmit

selective transmission

light

Selective transmission of light, which is a transverse wave, is when some light is simultaneously reflected, absorbed, and/or transmitted through a material.

The third step of the word sort, in which students explain the relationship among the words, is the most important. In some instances, students may identify and describe an accurate relationship that does not match the suggested answer in this Teacher's Edition. If a student's reasoning is clear and accurate, consider accepting the alternative answer. For more information on categorization activities, see the Literacy section of Teacher Resources II, "Diverse Learners."

DO THE ACTIVITY

2. Students investigate the transmission properties of different films.

   a. Identify the transmission properties of each film.

Teacher's note: Film A does not block out either ultraviolet or infrared; Film B blocks both ultraviolet and infrared; and Film C blocks ultraviolet but not infrared. These films are commonly placed on windows and used in other applications to block the wavelengths appropriate for the application.

   b. Review student responses to Procedure Part A.

After students finish conducting the investigation for Part A, have groups share the data they collected and come to consensus about the ranking of the films for blocking ability. A sample data set is provided below. Results may significantly differ depending on the light conditions, but the film rankings should be the same. Students should be able to see from the data that Film B is preventing full transmission of whatever in sunlight results in the heating of the air in the box.

PROCEDURE PART A SAMPLE STUDENT RESPONSE

Film	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)
A	*28.5*	*42*	*13.5*
B	*29*	*35*	*6*
C	*28*	*40*	*12*

3. Students collect more transmission data.

   a. Students detect ultraviolet that is selectively transmitted.

   At the conclusion of Part A, there is evidence of selective transmission although it is not obvious whether what is being transmitted is part of the visible spectrum or some invisible frequencies of sunlight. In Part B, students go a step further by conducting the investigation using a UV detector card, which detects only invisible ultraviolet. The results give evidence that the films selectively transmit ultraviolet frequencies of sunlight since the card behind Film A is much darker than the other two. This provides convincing evidence that some invisible light waves can be selectively transmitted.

   b. Compare student results for Part A and Part B.

   Since the Part B results do not correspond with the Part A results (i.e., Film B blocked out energy in Part A, and both Films B and C blocked energy in Part B), students can conclude that the films are selectively transmitting at least two different kinds of waves.

   When students have completed the Procedure, ask them to surmise whether the light that was not transmitted was reflected or absorbed. Students should be able to conjecture that the light not transmitted was likely absorbed, as the films do not have a shiny and mirror-like surface. It they looked like reflective lenses, it would be logical to assume the majority of light was reflected off the surface.

PROCEDURE PART B SAMPLE STUDENT RESPONSE

FILM DATA

Film	Initial color	Final color
A	*white*	*dark purple*
B	*white*	*light purple*
C	*white*	*light purple*

BUILD UNDERSTANDING

4. Students analyze the data gathered in the activity.

   a. (AID ASSESSMENT) Assess student understanding of the evidence gathered.

   Analysis item 2 in this activity can be assessed using the AID Scoring Guide. Project or distribute the Scoring Guide, and point out how it has the same levels but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment."

   Analysis item 2 provides an opportunity for students to demonstrate their skills in applying the science and engineering practice of analyzing and interpreting data.

   b. Discuss how the structure and function of the films contribute to the trade-offs of different window films.

   Analysis item 3 is similar to Analysis item 5 in Activity 10, "Comparing Colors," although it is not scored with a Scoring Guide. It relates to the crosscutting concept of structure and function. When reviewing students' responses, make sure they have identified the trade-offs they made in their choices. For example, for the snowy mountainous region, both Films B and C would be appropriate, but C would be the better choice based on cost.

SAMPLE RESPONSES

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

   Film A transmits the most energy. The evidence for this is that the temperature change behind the film was the highest, and the ultraviolet level was also the greatest. Film A was also the clearest film, which means the most visible light was transmitted through it. This combined evidence shows that Film A had the most transmission of sunlight.

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

   SAMPLE LEVEL-4 RESPONSE

   The data recorded from the investigation provide the evidence. The light waves that were transmitted through the films carried heat energy to the other side of the films, as indicated by the increased temperatures. This could be because some visible light in the sunlight heated up the box, but it could also be from light that we cannot see. However, the fact that the UV detector cards were darkened *behind the films in varying degrees showed that the invisible ultraviolet was present inside the box and was selectively transmitted through the films. There may have been bias in our results if the boxes did not all get the same amount of sun or if they were not fully sealed, but the trends would have been the same even if there was some error.*

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?

   Film B would be the best choice because it would keep the interior of the car from warming up but would also provide ultraviolet protection. Since the total area of the windows is small, the extra cost may be acceptable.

   b. windows in a home located in a desert?

   Film B would be a good choice in summer because it would keep the interior of the home cooler. But it would also prevent any benefits from the transmission of wavelengths that would warm the interior in the winter.

   c. windows in a home located in a snowy mountainous region?

   Film C would be the best choice because it would block out the ultraviolet but would allow transmission of wavelengths that would warm the interior of the house in cooler weather. It is less expensive than B and would provide adequate protection.

   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

REVISIT THE GUIDING QUESTION

What part of sunlight is transmitted through selected films?

The parts of sunlight that transmit through selected films depend on the structure of the films. Some colors (wavelengths) are transmitted and others are absorbed or reflected.

ACTIVITY RESOURCES

KEY VOCABULARY

absorbed, absorption

evidence

reflect, reflection

trade-off

transmit, transmission

BACKGROUND INFORMATION

SELECTIVE TRANSMISSION AND REFLECTION

When light hits an object, it is reflected, transmitted, or absorbed. When a light wave of a given frequency strikes a material that has electrons of the same natural frequency of vibration as the light, the electrons absorb the energy of the light wave and transform it into vibrational motion. The vibrating electrons interact with other atoms and convert their vibrational energy into thermal energy. The light wave has been absorbed by the object and is not released in the form of visible light, although some of the energy may be released as other frequencies of electromagnetic radiation. Because different atoms and molecules have different natural frequencies of vibration, they will selectively absorb different frequencies of visible light.

Reflection and transmission of light waves occur because the frequencies of the light waves do not match the natural frequencies of vibration of the objects. In this case, when the light waves of these frequencies strike an object, the electrons in the atoms of the object vibrate only briefly and at reduced amplitude. Then the energy is reemitted as a light wave. If the object is transparent, the vibrations of the electrons are passed on to neighboring atoms through the bulk of the material and reemitted on the opposite side of the object, which is called *transmission*. If the object is opaque, the electrons vibrate for short periods of time but are then reemitted on the side in which they were admitted, which is called *reflection*.

In many cases, the object causes the light to do more than one of these things if the light contains a variety of frequencies. For example, an everyday opaque object, such as a dark shirt, will absorb some energy, as indicated by its warming up in the sun, but it will simultaneously reflect the visible light frequencies into our eyes. Another example is a mirrored sunglass lens where some visible light is transmitted through and some is reflected by the mirror. A smaller portion of the light energy is absorbed by the lens itself.

12 The Electromagnetic Spectrum

READING

1 CLASS SESSION

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students complete a reading that integrates textual and visual information that extends their understanding of the electromagnetic spectrum. Through the examples of classic experiments, students see that scientific knowledge is based on logical and conceptual connections between evidence and explanations. Furthermore, these historical examples show how ideas are revised and/or reinterpreted based on new evidence. When reading about applications of electromagnetic energy and devices that extend human senses, students are simultaneously shown how technologies extend the capabilities of scientific investigation.

NGSS CORRELATION

Performance Expectation

Working towards MS-PS4-2: Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

Disciplinary Core Ideas

MS-PS4.A.2 Wave Properties: A sound wave needs a medium through which it is transmitted.

MS-PS4.B.1 Electromagnetic Radiation: 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.

MS-PS4.B.3 Electromagnetic Radiation: A wave model of light is useful for explaining brightness, color, and the frequency-depended bending of light at a surface between media.

MS-PS4.B.4 Electromagnetic Radiation: 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 the 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 the 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.

RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

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 the teacher*
  1 Scoring Guide: COMMUNICATING CONCEPTS AND IDEAS (COM)
  1 Visual Aid 12.1, "The Electromagnetic Spectrum."

- *For each student*
  1 Student Sheet 12.1, "Anticipation Guide: The Electromagnetic Spectrum"
  1 Scoring Guide: COMMUNICATING CONCEPTS AND IDEAS (COM) (optional)

TEACHING SUMMARY

GET STARTED

1. Explore students' ideas about light.
   a. Ask students to share any evidence that there are invisible forms of energy in sunlight.
   b. (LITERACY) Introduce the Anticipation Guide to support the Reading.

DO THE ACTIVITY

2. Identify Herschel's and Ritter's experiments as examples that show the nature of science.
   a. Discuss the procedure of Herschel's experiment.
   b. Discuss Herschel's and Ritter's scientific thinking.
3. Support students' investigation of electromagnetic energy.
   a. Introduce the term *electromagnetic spectrum*.
   b. Direct students to the diagram of the electromagnetic spectrum.
   c. Support students' efforts to integrate information.
   d. (COM ASSESSMENT) Use Analysis item 5 to assess students' understanding of ultraviolet energy.

BUILD UNDERSTANDING

4 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.
   b. Emphasize that all types of electromagnetic waves are fundamentally the same phenomenon.
   c. Ask students, "Where do we encounter electromagnetic waves in our daily lives?"
   d. (LITERACY) Review students' "After" responses to the Anticipation Guide.

TEACHING SUGGESTIONS

GET STARTED

1. Explore students' ideas about light.

   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. (LITERACY) Introduce the Anticipation Guide to support the Reading.

   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 more information, see the Literacy section of Teacher Resources II, "Diverse Learners."

DO THE ACTIVITY

2. Identify Herschel's and Ritter's experiments as examples that show the nature of science.

   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 *refraction*, 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. Herschel's experiment is a good example of how scientific knowledge is based on logical and conceptual connections between evidence and explanations.

b. Discuss Herschel's and Ritter's scientific thinking.

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. Science findings are frequently revised and/or reinterpreted based on new evidence. This shows the nature of science where scientific knowledge is open to revision in light of new evidence.

3. Support students' investigation of electromagnetic energy.

a. 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. Emphasize the continuous nature of the frequencies in the electromagnetic spectrum and the relationships between frequency, wavelength, and energy level.

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

Project Visual Aid 12.1 and discuss the information presented. 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. 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.

c. Support students' efforts to integrate information.

This Reading allows students to synthesize the previous hands-on activity with text. This is an opportunity in the unit to integrate qualitative scientific and technical information in written text that contains visual displays.

After discussing the diagram of the electromagnetic spectrum, review the other diagrams in the Reading to help clarify the claims in the text and the findings from the last activity.

d. (COM ASSESSMENT) Use Analysis item 5 to assess students' understanding of ultraviolet energy.

Analysis item 5 in this activity can be assessed using the COM Scoring Guide. Project or distribute the scoring guide, and point out the different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment."

BUILD UNDERSTANDING

4. Take a closer look at the electromagnetic spectrum.

a. After completing the reading and analysis questions, 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, identify how differences are considered in designing applications. For example, ultraviolet 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 use 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.

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 is detectable when it interacts with molecules in the skin.
- The electromagnetic spectrum is continuous, and there are no boundaries between the named portions. Scientists created the names 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 electromagnetic energy 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.

c. Ask students, "Where do we encounter electromagnetic waves in our daily lives?"

Students may reply with examples from the Reading such as X-rays, remote controls, and microwave ovens. Continue to brainstorm ideas where technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigation. Examples could be telescopes, wireless probes, and imaging devices used for scientific studies

d. (LITERACY) Review students' "After" responses to the Anticipation Guide.

Return to Student Sheet 12.1. Discuss whether any student ideas have changed.

STUDENT SHEET 12.1 SAMPLE STUDENT RESPONSE

— 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.

Ultraviolet has a frequency of 10^{16} Hz whereas visible has a frequency of 10^{15} Hz.

— 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.

Electromagnetic waves selectively transmit, reflect, and absorb.

— 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 these two energies similar? In what ways are they different?

Student responses may vary. The table below shows possible responses.

Infrared	Ultraviolet
Electromagnetic energy	*Electromagnetic energy*
Lower frequency, longer wavelength	*Higher frequency, shorter wavelength*
Less energy	*More energy*
Lots given off by the sun	*Lots given off by the sun*
Not visible to most species	*Not visible to most species*
Stimulates molecules in skin to produce heat	*Doesn't heat up skin*
Not generally damaging to skin or eyes	*Can damage skin and eyes*

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.

   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. (COM ASSESSMENT) Is it likely that light with frequencies higher than ultraviolet was the main cause of Tía Ana's cataracts? Explain why or why not.

SAMPLE LEVEL-4 RESPONSE

No, the frequencies higher than ultraviolet are not the main cause of Tía Ana's cataracts. Although electromagnetic waves with higher frequency energy than ultraviolet—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. The Reading had a graph that shows the low levels of X-rays and gamma rays that transmit through the atmosphere. The wave with the highest energy in sunlight is ultraviolet, and so it is more likely that the ultraviolet caused the cataracts.

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.

   Student responses may vary. One sample response is shown here:

   Electromagnetic waves, such as radio waves, are used to measure the distance to an object. They can easily be sent and reflected off an object far away so they are used to measure distances that would ordinarily be a challenge to measure. Examples are distances between cities or to astronomical objects.

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. All electromagnetic waves travel at the same speed through a vacuum, but the waves slow down when traveling through other media, and 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

BACKGROUND INFORMATION

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 Earth includes infrared (47%), visible (46%), and ultraviolet (7%) light. 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. 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* or *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

Name____ Date____________

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

Then, 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.

BEFORE	AFTER	
______	______	1. **All electromagnetic energy is visible.**
______	______	2. **Electromagnetic energy is the same thing as heat.**
______	______	3. **Ultraviolet has a frequency higher than visible light.**
______	______	4. **The electromagnetic spectrum includes only visible light and infrared.**
______	______	5. **Radio waves are not really electromagnetic.**
______	______	6. **Only visible light can transmit 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.**

VISUAL AID 12.1

THE ELECTROMAGNETIC SPECTRUM