SENSING THE INVISIBLE
THE HERSCHEL EXPERIMENT

GRADE LEVEL
5 - 8

DURATION
1-2 hours

ESSENTIAL QUESTION

Are there forms of light other than visible light emitted by the Sun?

LESSON OVERVIEW

LESSON SUMMARY

In this lesson, students find out that there is radiation other than visible light arriving from the Sun. The students reproduce a version of William Herschel's experiment of 1800 that discovered the existence of infrared radiation. The process of conducting the experiment and placing it in the historical context illustrates how scientific discoveries are often made via creative thinking, careful design of the experiment, and adaptation of the experiment to accommodate unexpected results. Students will discuss current uses of infrared radiation and learn that it is both very beneficial and a major concern for planetary explorations such as the MESSENGER mission to Mercury.

OBJECTIVES

Students will be able to:

- ▲ Construct a device to measure the presence of infrared radiation in sunlight.
- ▲ Explain that visible light is only part of the electromagnetic spectrum of radiation emitted by the Sun.
- ▲ Follow the path taken by Herschel through scientific discovery.
- ▲ Explain why we would want to use infrared radiation to study Mercury and other planets.
- ▲ Explain how excess infrared radiation is a concern for the MESSENGER mission.

Figure 1. Portrait of Sir William Herschel, who discovered the existence of infrared radiation in 1800. (Picture credit: NASA/IPAC; http://www.ipac.caltech.edu/Outreach/Edu/herschel.gif)

Concepts

- ▲ Visible light consists of different colors.
- ▲ Sunlight consists of invisible forms of light in addition to visible light, one of which is infrared light.
- ▲ Scientific discoveries are sometimes made by chance, as a by-product of another investigation.

MESSENGER Mission Connection

The MESSENGER mission to Mercury uses infrared light to study properties of the planet, and it is therefore beneficial to the mission. However, too much infrared radiation is detrimental to the spacecraft and its instruments, and engineers are faced with this problem when designing the MESSENGER spacecraft and mission.

WARNING

Do *not* look directly at the Sun!

This lesson is about the Sun and sunlight, but be sure to remind students frequently ***never* to look directly at the Sun!** Looking for even a few seconds can cause permanent damage to the eyes, and longer exposure can cause blindness. Note that sunglasses do *not* provide an adequate safeguard against looking directly at the Sun.

Standards & Benchmarks

National Science Education Standards

Standard B3 Transfer of energy

- ▲ The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Related Standards

Standard G1 Science as a human endeavor

- ▲ Science requires different abilities, depending on such factors as the field of study and type of inquiry. Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity—as well as on scientific habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas.

Standard G2 Nature of science

- ▲ Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation. Those ideas are not likely to change greatly in the future. Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.

Standard G3 History of science

- ▲ Many individuals have contributed to the traditions of science. Studying some of these individuals provides further understanding of scientific inquiry, science as a human endeavor, the nature of science, and the relationships between science and society.

American Association for the Advancement of Science, Project 2061

Benchmark 4 F/2: Light from the sun is made up of a mixture of many different colors of light, even though to the eye the light looks almost white. Other things that give off or reflect light have a different mix of colors.

Benchmark 4 F/5: Human eyes respond to only a narrow range of wavelengths of electromagnetic radiation—visible light. Differences of wavelength within that range are perceived as differences in color.

Benchmark 12 C/3: Read analog and digital meters on instruments used to make direct measurements of length, volume, weight, elapsed time, rates, and temperature, and choose appropriate units for reporting various magnitudes.

Related Benchmarks

Benchmark 1 B/1: Scientists differ greatly in what phenomena they study and how they go about their work. Although there is no fixed set of steps that all scientists follow, scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence.

Benchmark 1 B/4: New ideas in science sometimes spring from unexpected findings, and they usually lead to new investigations.

Science Overview

Sunlight is the source of life-sustaining energy on Earth. Its effects range from allowing temperatures on our planet to remain hospitable for life to providing energy for photosynthesis. In addition to light that can be seen with the human eye, visible light, there are other forms of energy emitted by the Sun. In this lesson, we discuss one of these other forms – infrared radiation.

The Electromagnetic Spectrum

Weather forecasters often show temperature maps of the United States based on the temperature measurements in different parts of the country that day. The maps are created by assigning each temperature a color, and then filling the map with colors corresponding to the temperatures measured at each location. A map created this way shows the temperature field of the United States on that particular day. The temperature field covering the United States, in this sense, is a description of the temperatures at every location across the country.

In a similar fashion, the universe can be thought of as being permeated by an electric field. All electrically charged particles (such as electrons) have a region of space around them where they influence the behavior of other charged particles wandering there. This region can be described as an electric field around the particle. Just as temperatures in different parts of the country create the temperature field of the United States, the electric charges in the universe can be thought of as creating an electric field permeating the whole universe. Magnetic objects behave in a similar fashion: every magnetic object creates a magnetic field around it, and their collective magnetic field permeates the universe.

Most things in the universe tend to move around, and electric charges are rarely an exception. If the velocity of an electric charge changes (that is, it accelerates or decelerates), it creates a disturbance in the electric and magnetic fields permeating the universe. These disturbances move across the universe as waves in the "fabric" of the electric and magnetic fields. The waves also carry energy from the disturbance with them, in a similar way that the energy of the wind striking a flag is carried across the fabric by the waving of the flag. The waves carrying the energy of the disturbance across the universe are characterized by their wavelength, which measures the distance between two consecutive wave crests.

A familiar example of this kind of wave is visible light. Different colors of visible light have slightly different wavelengths, and there are waves which have much higher and shorter wavelengths than the light that humans can see. Together, the waves of all different wavelengths are called electromagnetic radiation, and the whole array of different kinds of light, arranged according to their wavelength, is called the electromagnetic spectrum. Electromagnetic radiation travels at the speed of light (300,000 km/s or 186,000 miles/s in a vacuum such as space).
(See Figure 2.)

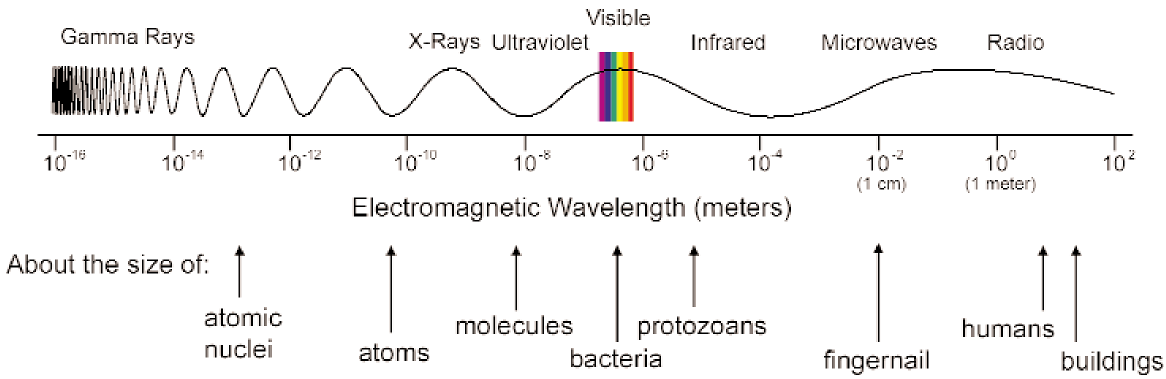


Figure 2. The electromagnetic spectrum. In the picture, different parts of the spectrum are shown as one continuous wave. In reality, a given electromagnetic wave has one particular wavelength. The continuous wave in picture above is used to better illustrate the difference between wavelengths from one part of the spectrum to another.

The complete electromagnetic spectrum includes:

- ▲ Radio waves (including microwaves): Used for transmitting radio and television.
- ▲ Infrared: Seen by many animals (not humans), also used in night vision goggles.
- ▲ Visible light: The portion of the spectrum that humans can see.
- ▲ Ultraviolet: Causes sunburns.
- ▲ X-rays: Used in hospitals to make internal images of the human body.
- ▲ Gamma rays: Used in radiation treatments of cancer.

Light travels at different speeds through different materials. When light moves from one substance to another (for example, when a beam of light passes through air and into water, or vice versa), it changes its speed, and therefore its direction if it enters the substance at an angle. This effect (called refraction) is noticeable if a stick is placed halfway under water; light from the submerged part of the stick changes direction as it reaches the surface, and our eyes perceive the refracted light as the illusion of a bent stick. The same effect happens when visible light passes through a prism. In this case the different colors of light are bent (refracted) onto different paths according to their wavelength. A beam of light can consist of just one color, so that only one color of light enters the prism and the same color exits, bent onto a new path; or, a beam of light can consist of a mixture of colors, so that the mixture of colors enters the prism and each color exits the prism bent onto a path of its own. Shorter wavelengths (blue and violet) are refracted, or bent, more than longer wavelengths (red), resulting in the familiar rainbow pattern of colors. Radiation that is not visible also is refracted according to wavelength. Beyond the red end of visible light is the infrared, and beyond the blue is the ultraviolet part of the electromagnetic spectrum.

Sunlight, as it emerges from the Sun, consists of all types of electromagnetic radiation. The Earth's atmosphere reflects away or absorbs much of the electromagnetic spectrum, so that only part of the radiation reaches the surface. Most radio waves come through the atmosphere unimpeded, visible light passes through without much difficulty, while only some infrared radiation, very little of the ultraviolet rays, and none of the X-rays and gamma rays reach the surface. This is very fortunate for life on Earth because some kinds of radiation (such as ultraviolet light, X-rays, and gamma rays) can break apart molecules in living things. Most forms of life could not survive unprotected on the Earth's surface if the atmosphere did not almost completely shield us from these harmful forms of radiation.

Infrared Radiation

Infrared radiation comes from warm objects – the warmer the object, the more infrared radiation it emits. If the temperature of the object becomes very high, it will emit visible light in addition to infrared radiation. For example, the filament in an ordinary light bulb glows with both kinds of radiation when its temperature rises to more than 2500º C (4500 °F). One way to think about this is to say that infrared radiation comes from warm objects while infrared as well as visible light comes from hot objects. Even hotter objects (for example, stars) will emit infrared, visible, as well as even more energetic forms of light such as ultraviolet or X-rays. Remember that most of the objects we see with our eyes are visible to us because they reflect the light from a hot source – the Sun during the day, a light bulb at night – and they are not hot enough to emit visible light themselves. Humans, with body temperatures around 37˚C (99˚F), emit infrared radiation but no visible light – we see each other because we reflect the light from a light source. If we could see infrared light, we would be able to see each other even in the middle of the night. Some animals, such as rattlesnakes, can detect infrared light. This allows the snake to find warm-blooded animals, such as small rodents, by detecting the infrared radiation that they emit.

Infrared radiation is used in many modern applications. The most familiar instance of everyday use of infrared radiation may be television remote controls. Other examples include security and surveillance cameras, and instruments used to observe the insides of a human body without having to do surgery. Firefighters use infrared cameras to locate people and animals hidden by smoke in burning buildings and to find hot spots in forest fires. Engineers use infrared-based scanners to find heat leaks in buildings and to test for problems in mechanical and electrical systems. Infrared satellites are used in investigating global climate properties, weather phenomena, and vegetation patterns, and even to discover ancient roads in archaeological studies. Astronomers use infrared imaging to study a variety of objects, such as newly formed stars and the most distant galaxies in the universe. Infrared radiation is very useful for studying planets in the solar system. Planets reflect much of the sunlight they receive away, but they absorb part of it. The light heats up the surface of the planets to warm (but not hot) temperatures, and the surfaces emit infrared light (as all warm objects do). Using this emitted infrared radiation to make observations of the planets provides invaluable clues to their properties which may be difficult to determine otherwise. Since much of the infrared radiation arriving from astronomical objects is blocked by Earth's atmosphere, infrared telescopes have been launched to make their observations from space.

Considering the many ways in which infrared radiation is important in our lives, it is remarkable to realize that its existence was not discovered until a little over two centuries ago by Sir William Herschel.

Sir Frederick William Herschel

Sir Frederick William Herschel (1738-1822) was born in Hanover, Germany, and became well known both as a musician and as an astronomer. He moved to England in 1757 and, with his sister Caroline, constructed telescopes to survey the night sky. Their work resulted in several catalogs of double stars and nebulae. Herschel is famous for his discovery of the planet Uranus in 1781, the first new planet found since ancient times.

The Herschel Experiment

Sir William Herschel made another important contribution to science in the year 1800. In his astronomical work, Herschel noticed that when he used filters of different colors to observe sunlight, the filters seemed to let through different amounts of heat. He thought that the colors themselves might be of varying temperatures and devised an experiment to investigate his hypothesis.

He directed sunlight through a glass prism to create a spectrum and then measured the temperature of a thermometer illuminated by each color in turn. He noticed that the temperature increased from the blue to the red end of the visible spectrum. After noticing this pattern, Herschel decided to measure the temperature just beyond the red portion of the spectrum in a region that did not appear to have any sunlight falling on it. To his surprise, he found that this region had the highest temperature of all. He realized that there must be another type of light beyond the red, light that we cannot see. He probably could not have been expected to discover ultraviolet light beyond the blue end of his spectrum, as most (but not all) materials that transmit visible light are very effective in absorbing ultraviolet light, and thus his prism would not have provided the ultraviolet portion of the Sun's spectrum.

Herschel performed additional experiments on the rays he had discovered beyond the red portion of the spectrum. He found that they were reflected, refracted, absorbed, and transmitted in a manner similar to visible light. He called this new kind of light "calorific rays," derived from the Latin word for "heat." Today, this form of light is known as infrared radiation. The word "infra" is derived from the Latin word for "below" - it describes where you find the infrared radiation on the electromagnetic spectrum when compared with visible light.

Herschel's experiment is important because it was the first time someone demonstrated that there are types of light we cannot see with our eyes. As we now know, there are many other types of radiation that we cannot see, and the visible colors are only a small part of the entire range of the electromagnetic spectrum.

The Herschel Experiment as an Example of Scientific Discovery

Herschel's experiment is a good demonstration of how scientific progress takes place. Herschel started out with a question based on his research and experience: he noticed that different color filters seemed to pass different amounts of heat and wanted to find out if this was really the case. He devised a hypothesis based on this observation – that the colors themselves could be of varying temperatures. He designed an experiment to test the hypothesis – measuring the temperatures of the different parts of the visible spectrum. After noticing that the temperatures of the different colors appeared to indeed be different, he was able to confirm his hypothesis. We now know that he was measuring the intensity of sunlight at different wavelengths rather than any inherent property of different colors of visible light, but when this distinction is made clear, the hypothesis still remains valid.

Herschel did not stop there, and this shows an important aspect of the scientific process. Sometimes experiments designed to investigate a specific question can produce unexpected results and lead to even more important discoveries. When Herschel noticed that the temperatures increased toward the red end of the visible spectrum, he continued the experiment to measure the temperatures beyond the visible part of the spectrum, and discovered the existence of infrared radiation. He had not originally designed the experiment to determine whether there was radiation beyond the visible part of the spectrum, but once the experiment hinted that this might be the case, he was able to come up with a new, modified question and augment his experiment to test the new hypothesis. This versatility and ability to modify one's perspective, questions, and experiment in the middle of the process, while still maintaining the integrity of the experiment, are important aspects of what makes a good scientist.

Infrared Radiation and the MESSENGER Mission

Infrared radiation is of great importance in the design of the MESSENGER spacecraft and in the operation of its scientific instruments. One of the instruments on MESSENGER, the Mercury Atmospheric and Surface Composition Spectrometer (MASCS), includes a visible-infrared spectrometer, which measures the amount of energy at different wavelengths in the visible and infrared parts of the electromagnetic spectrum. Just as rocks and minerals have specific colors in visible light (e.g. turquoise is blue), they have unique "colors" at infrared wavelengths, providing an enhanced opportunity for MESSENGER to learn what Mercury's surface is made of. This will help us understand the geologic history of Mercury, as well as provide clues to solving one of the biggest mysteries Mercury poses – why is the planet so dense?

Although it is useful to the scientific goals of the mission, infrared radiation also is a great concern for MESSENGER. The amount of infrared radiation (as well as visible light) that the spacecraft receives from the Sun during its orbit around Mercury will be up to 11 times higher than it would receive in Earth orbit. When we consider the fact that Earth's atmosphere typically passes through only about half of all solar radiation, the amount of sunlight MESSENGER will be exposed to can be 22 times as high as what objects experience on the surface of Earth. In addition, the surface of Mercury that faces the Sun heats up and emits infrared radiation.

This poses a great engineering challenge to the mission design team: How can the spacecraft and its sensitive instruments be protected against extremely high temperatures while remaining in Mercury orbit and exposed to Mercury itself, as required to complete its mission? To protect against direct sunlight, the spacecraft will have a sunshade that is at all times pointed toward the Sun so that the instruments are always shaded. The spacecraft's orbit around Mercury has been designed so that its closest approach to the planet is away from the most sun-baked region of the surface and so that it flies quickly over the sunlit areas. This is achieved by an orbit where the periapsis (the closest point to the surface of Mercury and also the part of the orbit where the spacecraft's speed is at its highest) is at a high latitude and the apoapsis (the farthest point of the orbit and also the part of the orbit where the spacecraft's speed is at its lowest) is far away from the surface of Mercury. In this manner, infrared radiation received by the spacecraft can be kept at safe levels.

With these safeguards, MESSENGER's instruments will be in a thermal environment that is roughly comparable to room temperature: During the orbital part of the mission, the temperature on the instrument deck of MESSENGER is expected to vary from a few degrees below 0˚C (32˚F) to 33˚C (91˚F).

Lesson Plan: Herschel's Infrared Experiment

The procedure described here is similar to Herschel's original experiment. The students will create a device in which sunlight will pass through a prism and produce a spectrum of light on the bottom of a cardboard box (see Figure S1 in Student Worksheet). Using a series of thermometers (see Figure S3) they will measure temperatures at various locations within, and outside of, the spectrum. By doing so, students should obtain similar results to Herschel and discover the existence of radiation beyond the spectrum of visible light.

Materials

Per group of 3:

▼ 1 glass prism (plastic prisms do not work well for this experiment, as they absorb infrared light); glass prisms costing around $6 are available at science teacher resources, such as Educational Innovations (http://www.teacher-source.com)

▼ 4 (alcohol) thermometers

▼ 1 pair of scissors or a prism stand

▼ 1 cardboard box (a photocopier paper box or another box with dimensions about 28 cm x 43 cm x 25 cm (11 in x 17 in x 10 in) works well)

▼ 1 blank sheet of white paper

▼ 1 stopwatch

▼ Optional: Prism stand

Per class:

▼ Picture or graph of visible light spectrum (or rainbow)

▼ Black paint or a permanent black marker

Preparation

▼ To make the experiment work effectively, you will need to blacken the thermometer bulbs, as they absorb light better than red bulbs. You can do this before the lesson or with the students. If you use paint, it must be done a day or more in advance. If you use spray paint, cover the tops of the thermometers with masking tape, leaving just the bulbs bare. After spray-painting the bulbs, remove the masking tape. Alternatively, you can use a permanent black marker to blacken the bulbs.

▼ Make copies of the student worksheets and the MESSENGER Information Sheet (one per student).

Points to consider in preparation of the experiment to ensure maximum results:

▼ The experiment works best if you have thin thermometers. If you have to use wide thermometers, you may need to use only two – one placed in blue, one in the infrared. It gives you the same basic observation, though with three thermometers it is more convincing. You may also need to have the wide thermometers point in opposite directions of the box – just make sure in every case that the thermometer bulbs are in the proper sections of the spectrum.

▼ Note that the Sun's position in the sky changes slightly during the experiment, and this may cause the size of the visible light spectrum projected to the bottom of the box to change. Make sure that the students do not remove thermometers from the spectrum or block the spectrum while reading the temperatures. If the colors move away from the bulbs or into the "beyond-red" bulb, you can note how much the Sun moved during the experiment, and repeat the experiment making sure the last bulb does not enter into light or move too far away from the red. The experiment is best done during the middle of the day in order to reduce this effect.

- If the box is placed so that the prism is far from the projected spectrum, the spectrum will spread out wider, and the different temperatures may be easier to measure. However, the thermometers will receive less solar energy and the temperature readings will be lower. The set-up described here is deemed to be the best way to negotiate the variables – but you and the students may want to experiment with different conditions.

- The differences between temperatures depend on the width of the spectrum, which in turn depends on several variables such as the time of the day and the size of the box. Regardless, the general trend of the temperatures going up from the blue end of the spectrum to the infrared should show up for all measurements.

- If you do not have access to the number of thermometers needed in this lesson, you can use thermal strips to illustrate the rise in temperature along the spectrum. However, by using this method, Benchmark 12C is no longer met, and the quantitative aspect of the lesson is lost.

Warm-up & Pre-assessment

1. Talk with students about sunlight. What is it? What do they know about it?

2. Discuss rainbows: What is a rainbow? How is it created?
Tell the students rainbows are created when sunlight passes through water droplets in the air and is broken into its constituent colors. Rainbows allow us to see all the colors of the sunlight, instead of just the combined light, which we see as white light.

3. Show a picture of a visible light spectrum – or a rainbow – with the constituent colors. Explain what a spectrum is – a display of the colors of which light is composed, arranged in order of wavelength. Explain how blue light has a shorter wavelength than red light. Ask if anyone knows why

the light breaks into separate colors when it passes through a water droplet or a glass prism. Explain that by passing through material light bends, and explain how colors of varying wavelengths bend different amounts.

4. Ask students if they think there are any other differences in the colors we see when sunlight passes through the prism. Write them down and discuss how they could test for any of the differences. (Make sure one of the ideas is the difference in intensity of the colors, or the resulting temperature of the colors.) Discuss the practicality of their experiments and whether they would detect the desired properties. Point out at some time that one way we feel sunlight is by the energy it carries – when we place our hand in sunlight it feels warmer than if our hand is in the shade.

5. Guide the students or introduce them to the idea of measuring temperatures in different parts of the spectrum to see if sunlight has an effect. Ask them where they should put two thermometers to compare different parts of the spectrum, and suggest that they have a third thermometer outside of the spectrum as a "control." The idea is to let the students discover for themselves that there is something going on outside of the visible spectrum. It is a good idea to also place a fourth thermometer completely away from the spectrum in a shaded area of the box as an additional control.

6. Have the students write down a hypothesis, or a prediction (based on the students' knowledge of the properties of light) about what will happen to each of the thermometers.

Teaching Tip

Use a KWL Chart to determine what students KNOW about light and rainbows; what they WANT to find out; and what they have LEARNED after conducting the experiment. This is a good way to connect new ideas with old ideas, and may increase students' retention and understanding of the new concepts.

Procedures

1. Show the students the setup for the experiment (see Figure S1 in Student Worksheet). Choose an experiment site with good lighting, preferably outside.

2. Form students into groups of three. Give each group the materials necessary to perform the experiment, including the Student Worksheet. The worksheet has the instructions how to set up and conduct the experiment, but you can guide them through it.

3. Have the students take the boxes to the experiment site. Do it outdoors, if possible, or in part of a classroom where sunlight comes clearly through the windows. The activity can be done in the classroom, because infrared radiation passes through a glass window, unlike, for example, ultraviolet radiation.

4. The students need to make sure the spectrum is wide enough for the thermometer array to sample different colors. They may have to tilt the box a little by placing rocks or books under one side to produce a sufficiently wide spectrum (about 5 cm wide).

5. Make sure that the students place the third thermometer just beyond the red end. The wavelengths of sunlight past red are condensed to a small region – if the thermometer bulb is too far out, it will not record any temperature change. Have students tape the thermometers in place so that they are easily read and will not move during the experiment.

6. Remind the students to record their results on their worksheets.

Teaching Tip

You can also try to see if the students can feel the infrared light. Have one student in the group close his or her eyes and have their finger outside the spectrum of light. Another student moves their hand toward the light. The one with closed eyes says when he/she feels warmth from the light.

Teaching Tip

If the students suggest that perhaps the differing rises in temperature are due to the thermometers being different, repeat the experiment but switch the thermometers around, for example so that the thermometer that was in the infrared range is now in the blue, etc.

Teaching Tip

As discussed in the Science Overview, the wavelength of radiation determines what kind of radiation it is; that is, the wavelength of "blue light" is shorter than that of "red light." The wavelength of light also determines the basic energy of that kind of radiation – shorter wavelength light has higher energy than longer wavelength light. The temperatures measured in the experiment do not measure the basic energy of individual types of light. Instead, they measure how strong sunlight is in the different colors. That is why the temperatures in the experiment are higher in the red region of the spectrum; more "red light" arrived during the experiment than "blue light," and so the temperature measured in red end of the spectrum was higher, even though the energy of an individual "blue light" wave is higher than that of "red."

Discussion & Reflection

1. After students have completed the worksheets, compile the results of the measurements from all groups on a chart like the one below. Have the students calculate the class averages.

Group	"Blue temperature"	"Yellow temperature"	"Beyond-red temperature"	"Shade temperature"
1				
2				
3				
4				
Average				

The results should indicate that the temperatures rise from the blue visible light to the "beyond-red." Discuss with students what this means. Confirm for them that this means that there is some "invisible light" arriving from the Sun that is just beyond the red part of the spectrum. Ask them if they know what this radiation might be called; if no one knows, tell them it is called infrared radiation. Tell them where the name comes from.

2. Tell the students that they performed a version of an experiment that a famous scientist named Sir Frederick William Herschel originally did in 1800. Tell them how he intended to measure the temperatures of the colors of sunlight and ended up discovering infrared radiation! Remind students that sometimes important scientific discoveries are made "by accident" – as a by-product of an investigation intended to answer another question. Both carefully designed investigations and discoveries by accident are important for scientific progress, as long as they can be verified and repeated. Have the students note that, in effect, they verified Herschel's results with their experiment. This ability to verify results is central to the scientific process.

3. Remind the students that the prism bends light according to its wavelength, which describes what kind of color of light it is. Blue light has a smaller wavelength than yellow light, so it bends more. Ask them how the wavelength of red light compares with blue? How does it compare with infrared?

4. Tell the students that there are even more forms of light besides infrared that we cannot see. Ask the students if they can name any of them. Write answers on the board according to the wavelength and fill in what students do not say.

Gamma rays
X-rays
Ultraviolet
Visible light
Infrared
Radio waves (including microwaves)

Discuss and brainstorm the many uses of these different forms of light with the students. Remind them that they all belong to the same family of so-called electromagnetic radiation. Visible light is just a small part of it. Show the students a chart or draw a picture of the electromagnetic spectrum. Discuss the differences and similarities between the various forms of electromagnetic radiation. Be sure to tell them that the only major difference between visible light and infrared radiation is the wavelength. Tell them that our eyes are not made to detect infrared radiation, although some animals' are. Remember that all forms of electromagnetic radiation travel at the same speed – the speed of light.

5. Discuss with students the relationship of heat and infrared radiation. They just detected the infrared radiation emitted from the Sun. Tell the students that all warm objects emit infrared radiation. Ask them if they know of any uses for this property. (For example: Infrared or night-vision goggles that allow us to see warm objects in the dark.) Discuss some of the uses of infrared radiation. (For example: Automatic door openers, automatic toilet flushers, burglar alarms, etc.)

6. Remind the students that infrared radiation is used for many different purposes. It is also important in space (as you may have discussed with the students in the previous step already with regards to infrared astronomy). Tell them about the MESSENGER mission to Mercury and hand out the MESSENGER information sheet. Ask the students what they know about Mercury – where it is in the solar system. Since it is so close to the Sun, how do the students think the amount of sunlight at Mercury compares with that on Earth? (Answer: It will be up to 11 times more.) Tell them that the temperatures on Mercury's surface can reach over 400°C (750°F). What do the students think this means for the MESSENGER mission? You get sunlight and infrared radiation from the Sun. But Mercury's surface is also hot. Does it radiate infrared radiation?

7. Ask students what ways they can think of to protect the spacecraft from these sources of heat. Write them down. Describe to the students how the MESSENGER spacecraft will deal with these problems. Remind them that infrared light is also beneficial, and the spacecraft will be making measurements of the infrared radiation from the surface of Mercury.

Teaching Tip

Most night vision devices do not use infrared radiation, but amplify the existing visible (and infrared) light many times over ("image enhancement"). If you want to show a video or picture of what night vision looks like, make sure that it is the right kind. Through night vision equipment that uses image enhancement, objects look the same as they do in visible light, only with a green or gray tint. Night vision equipment that uses infrared ("thermal imaging") may display bright colors (or shades of gray) representing different temperatures. Image enhancement devices are useful for detecting objects in low-light conditions, and they can distinguish between objects of the same temperature (furniture in a room, for example). Thermal imaging devices are useful in total darkness (where image enhancement doesn't work since there is no light source) and detecting objects of differing temperatures (animals in a room, for example).

Lesson Adaptations

- If time permits, before the students learn about Herschel, have them design their own experiment to test properties of different color light, using the prisms and the spectra they create. Ask what they want to know about light, and help create ways in which they can test their hypotheses. Perhaps one of the students will discover something similar to Herschel, and want to test for light beyond the visible. Then begin the lesson. This way, the students can experience the complete scientific process first-hand, including the cycles of trial, error and correction.

Extensions

- Students can measure temperature in other areas of the spectrum. Have them graph their data.
- The students may try the experiment at different times of the day. In this case, the exact temperature differences between the colors may change, but the relative comparisons will remain valid.

Curriculum Connections

- *History of science / Gender studies:* Have the students explore the role of women in astronomy. Sir William Herschel's sister, Caroline, was a great astronomer and made several important discoveries. Unfortunately, the general style of the times was that astronomical observations made by women were often credited to their fathers, brothers, and husbands. Have the students examine the role of women in astronomy throughout history, from the early period to modern times. Have the students profile a great female astronomer from the past or the present.
- *Technology:* Have the students choose an application where infrared radiation is used and write an essay about it.
- *Astronomy:* Have the students examine the importance of infrared astronomy, and especially the expectations laid on the final element of NASA's Great Observatories program, SIRTF (Space Infrared Telescope Facility). The other great observatories are The Hubble Space Telescope (visible light), Compton Gamma-Ray Observatory (gamma rays), and Chandra X-Ray Observatory (X-rays).
- *Art / Photography:* Purchase regular and infrared film to be used in a standard 35-mm camera. Infrared film can usually be purchased at a well-stocked photography supply store. Photograph test subjects in both infrared and visible film and see how the developed results compare.
- *Earth science:* Infrared satellites have provided a lot of information about environmental changes on Earth. Have the students explore the NASA Earth Observatory Web site (http://earthobservatory.nasa.gov/) and discover how various parts of the electromagnetic spectrum are used in Earth science observations.

Closing Discussion

Remind students how in this lesson they discovered that there is a lot of radiation coming from the Sun besides visible light, forms of "light" that we cannot see. Discuss how we use infrared light in many places today. Use the example of MESSENGER to review ways in which infrared radiation is useful, as well as harmful.

Assessment

You can use Page 4 of Student Worksheet 1 for assessment, or any graphs that the students may create as an Extension. You can have the students write an essay or do a report on one of the topics suggested above in the curriculum connections.

Students may also write an essay or design a poster or a brochure about one of the following topics:

- Visible light is only one of the kinds of radiation coming from the Sun. Explain the similarities and differences between different types of light, and how they are used.
- Research Sir William Herschel and explain how he came to discover infrared radiation.
- Explain why we would want to use infrared radiation to study Mercury and other planets.
- Explain how excess infrared radiation is a concern for the MESSENGER mission.

Internet Resources & References

MESSENGER website

http://messenger.jhuapl.edu

NASA's Earth Observatory

http://earthobservatory.nasa.gov/

NASA/IPAC/SIRTF: Infrared Astronomy

http://www.ipac.caltech.edu/Outreach/Edu/

NASA/IPAC/SIRTF: Discovering Infrared: The Herschel experiment

http://sirtf.caltech.edu/EPO/Herschel/index.html

(Includes a Spanish-language description of the experiment)

National Science Education Standards

http://www.nap.edu/html/nses/html/

American Association for the Advancement of Science, Project 2061

http://www.project2061.org/tools/benchol/bolframe.htm

Acknowledgments

The student activity in this lesson has been adapted from
NASA/IPAC Web site "Discovering Infrared: The Herschel experiment"
(http://sirtf.caltech.edu/EPO/Herschel/index.html)

THE HERSCHEL EXPERIMENT

Materials

Per group:

- A glass prism
- 4 thermometers with blackened bulbs
- Scissors
- A cardboard box
- A stopwatch
- A blank sheet of white paper
- Tape
- Optional: Prism stand

Your group will construct a device to measure temperatures in different parts (colors) of the spectrum of sunlight.

You will have three members in your group. When making the measurements, you will perform different functions:

- **Time Keeper** will operate the stopwatch
- **Temperature Monitor** will read temperatures in the thermometers
- **Recorder** will record the results

You will construct a device like the one shown in Figure S1.

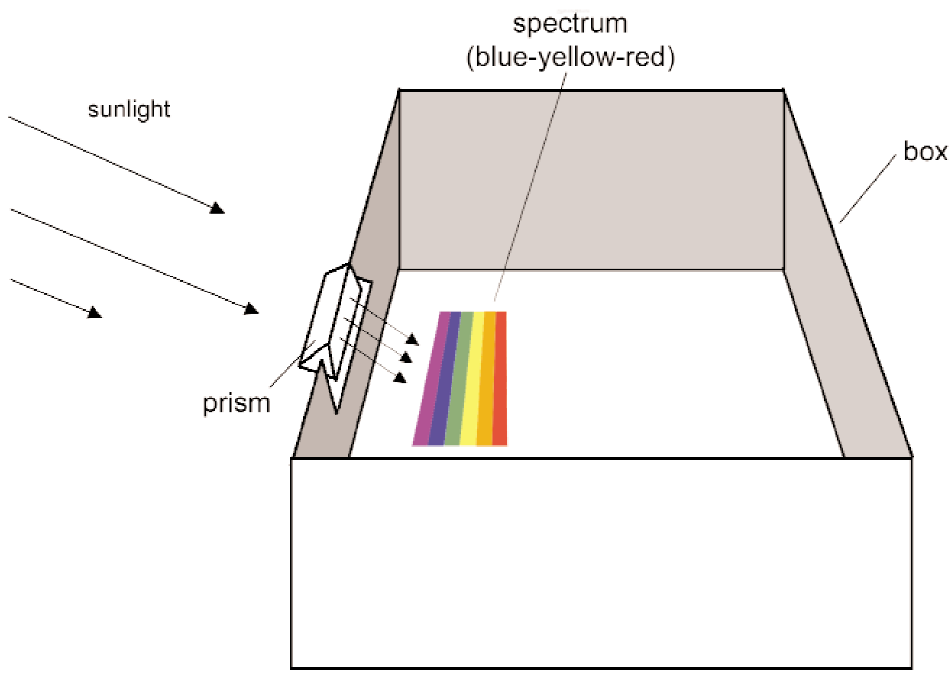


Figure S1.
The experiment device. Place a white sheet of paper in the bottom of a cardboard box. Fasten a glass prism to one side of the box. Place thermometers within the forming spectrum, with one thermometer bulb just beyond the red end of the spectrum and an extra thermometer in a shaded area of the box.

Procedures

Preparing the device

1) Tape the white sheet of paper to the bottom of the box.

2) Attach the glass prism near the top of one edge of the box. If you have a prism stand, you can use it. If not, you can cut out an area from the edge of the box. Make sure the cutout is just the right size for the prism to fit snugly while still allowing it to rotate about its long axis (see Figure S2). You can achieve this by making the side cuts so that the space is slightly less than the length of the prism, while the bottom cut is slightly deeper than the width of the prism. Now slide the prism into the notch.

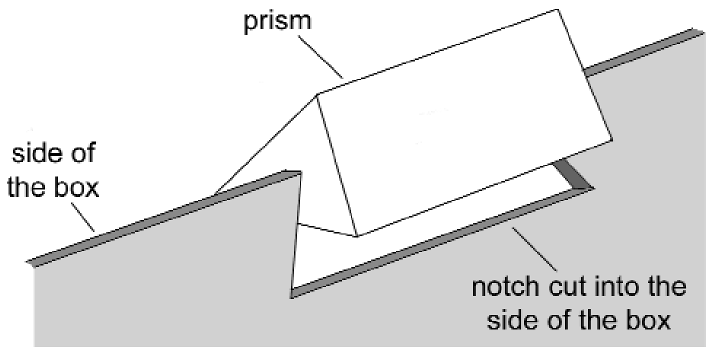


Figure S2.
A notch is cut in the side of the box so that the prism fits snugly and can rotate around its long axis.

3) Take the box to the experiment site.

WARNING

Do *not* look directly at the Sun!

Looking for even a few seconds can cause permanent damage to the eyes! Note that sunglasses do *not* provide an adequate safeguard against looking directly at the Sun.

So remember to ***never* look directly at the Sun!**

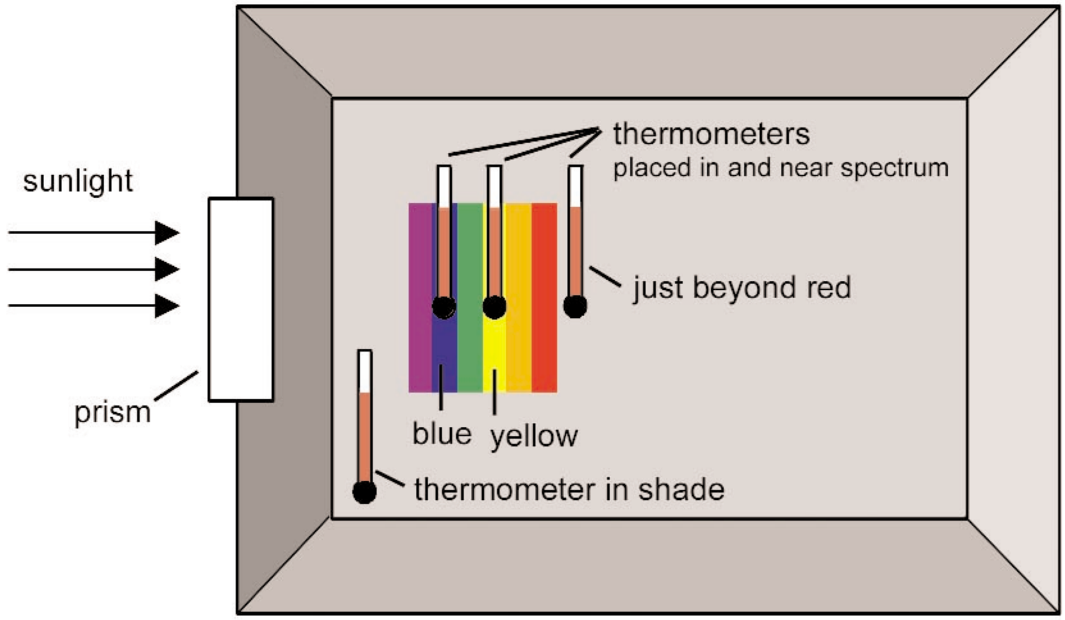


Figure S3.
Place the thermometers in the spectrum created by the prism, with two thermometer bulbs in different colors of the spectrum (such as blue, yellow), and one just beyond the red end of the spectrum. Place the fourth thermometer in a shaded area of the box.

4) Set down the box and place the thermometers so that they are in the shade inside the box. Let the box sit for five minutes. Check the temperature of the thermometers and record the result in the chart on Page 4.

5) Place the box so that the side with the prism faces the Sun (see Figure S1). Rotate the prism so that you get a nice, wide spectrum on the sheet of paper.

6) Place the thermometers on top of the spectrum so that one thermometer is on top of the blue band, one is on top of the yellow, and the third one is just beyond the red end of the spectrum where there is no visible light (see Figure S3). Place the fourth thermometer in a shaded area of the box. Tape the thermometers to the bottom of the box so that they do not move during the experiment, and they are easy to read. Be careful not to move the box while you tape down the thermometers!

7) When everyone in the group is ready, start the stopwatch. The Time Keeper will operate the stopwatch and tell the Temperature Monitor when to check the thermometers, and the Recorder will record the results in the chart on Page 4.

Observations in the Shade

Temperature in the Shade	Thermometer 1	Thermometer 2	Thermometer 3	Thermometer 4
After 5 minutes				

Observations with the Spectrum

Temperature in the Spectrum	Thermometer 1 (blue)	Thermometer 2 (yellow)	Thermometer 3 (beyond red)	Thermometer 4 (shade)
1 minute				
2 minutes				
3 minutes				
4 minutes				
5 minutes				

Answer the following questions individually.

1. What did you notice about your temperature readings?

2. Which thermometer recorded the highest temperature? The lowest?

3. What does this tell you about the Sun's light energy beyond the visible light spectrum?

4. List other observations.

5. List problems you had conducting the experiment.

Answer Key

Student Worksheet

1. What did you notice about your temperature readings?

The temperatures of the colors should increase from the blue to the red part of the spectrum.

2. Which thermometer recorded the highest temperature? The lowest?

The highest temperature should be just beyond the red portion of the visible light spectrum. The lowest of the three thermometers in the spectrum should be at the blue end of the spectrum. The lowest temperature of all four thermometers should be from the one in the shade.

3. What does this tell you about the Sun's light energy beyond the visible light spectrum?

There is some sort of invisible light there. Some students might know it is called infrared radiation.

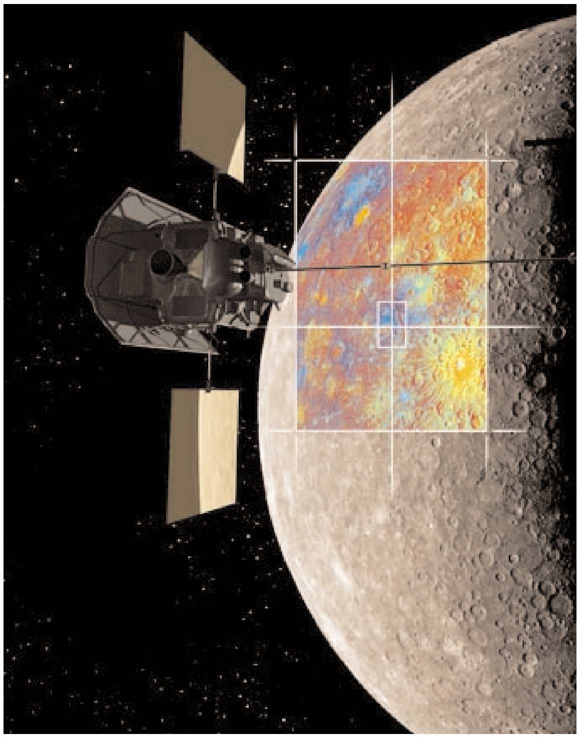
4. List other observations.

Answers will vary depending on how the experiment was done by different teams.

5. List problems you had conducting the experiment.

Answers will vary depending on how the experiment was done by different teams.

MESSENGER INFORMATION SHEET



The MESSENGER Mission to Mercury

MESSENGER is an unmanned U.S. spacecraft that will be launched in 2004 and will arrive at the planet Mercury in 2009, though it will not land. Instead, it will make its observations of the planet from orbit. MESSENGER will never return to Earth, but will stay in orbit around Mercury to gather data until sometime in 2010.

MESSENGER is an acronym that stands for "**ME**rcury **S**urface **S**pace **EN**vironment, **GE**ochemistry and **R**anging," but it is also a reference to the name of the ancient Roman messenger of the gods: Mercury, who, it was said, wore winged sandals and was somewhat of a trickster.

MESSENGER will be the second spacecraft ever to study Mercury: In 1974 and 1975 Mariner 10 flew by the planet three times and took pictures of about half the planet's surface. MESSENGER will stay in orbit around Mercury for one Earth-year, during which time it will make close-up and long-term observations, allowing us to see the whole planet for the first time.

One of the biggest problems MESSENGER will face is the intense heat it will encounter at Mercury. Visible and infrared radiation from the Sun can be as much as 22 times as high as on the surface of Earth. In addition, the temperatures on Mercury's surface can be more than 400ºC during the day. At this temperature, the surface will emit infrared radiation, becoming a second major source of heating for the spacecraft. MESSENGER engineers have had to figure out how to keep the spacecraft from heating up too much. They have designed a sunshade which will be pointed at all times toward the Sun, so that MESSENGER's instruments are always shaded from the Sun. To overcome the problem of infrared radiation from Mercury's surface, MESSENGER's orbit around the planet has been designed so that the temperatures in the spacecraft will remain at safe levels at all times.