Seeing the Invisible: Discovering Infrared and Ultraviolet

Activity J9

Grade Level: 7–12

Source: These activities are from the "Cool Cosmos" site of the Spitzer Science Center and the Infrared Processing and Analysis Center (Caltech and the Jet Propulsion Laboratory): http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/index.html As NASA documents, they are in the public domain.

What's This Activity About?

Most of the electromagnetic spectrum is invisible to our eyes, but these simple experiments elegantly show the existence of longer-wavelength *infrared* radiation, and shorter-wavelength *ultraviolet* light. Detecting the ultraviolet light requires ammonia and blueprint paper; some teachers may prefer to do this part of the activity as a demonstration.

What Will Students Do?

To study infrared light, students observe a thermometer placed at the edge of a band of light created by a prism (or diffraction grating) and notice a temperature increase even though no "visible" light falls on the thermometer. To study ultraviolet light, students observe as sunlight is passed through a prism, and its spectrum is spread onto blueprint paper. Students mark the paper where the visible spectrum appears. Both visible and (unseen) ultraviolet light cause a chemical reaction in the paper. Students hold the blueprint paper near ammonia fumes to "develop" the paper and reveal the reaction caused by the UV light.

Tips and Suggestions

- For the ultraviolet activity if pure ammonia and blueprint paper are not available, you can use an ammonia-rich cleaning solution and "sun paper" to make solar prints of leaves and flowers (available in nature stores).
- Once students understand more about the infrared, they might enjoy seeing what animals look like in the "Infrared Zoo": http://coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/index.html

What Will Students Learn?

Concepts

- The electromagnetic spectrum
- Light (visible and invisible)
- Temperature

Inquiry Skills

- Observing
- Experimenting
- Inferring
- Describing
- Using instruments
- Explaining
- Recording

Big Ideas

- Energy
- Interactions
- Diversity and unity

Seeing the Invisible: Discovering Infrared and Ultraviolet

1. Herschel Infrared Experiment

PURPOSE/OBJECTIVE

To perform a version of the experiment of 1800, in which a form of radiation other than visible light was discovered by the famous astronomer Sir Frederick William Herschel.

BACKGROUND

Herschel discovered the existence of infrared light by passing sunlight through a glass prism in an experiment similar to the one we describe here. As sunlight passed through the prism, it was dispersed into a rainbow of colors called a *spectrum*. A spectrum contains all of the visible colors that make up sunlight. Herschel was interested in measuring the amount of heat in each color and used thermometers with blackened bulbs to measure the various color temperatures. He noticed that the temperature increased from the blue to the red part of the visible spectrum. He then placed a thermometer just beyond the red part of the spectrum in a region where there was no visible light and found that the temperature was even higher! Herschel realized that there must be another type of light beyond the red, which we cannot see. This type of light became known as *infrared*. *Infra* is derived from the Latin word for "below." Although the procedure for this activity is slightly different than Herschel's original experiment, you should obtain similar results. See page 5 for more background information.

MATERIALS

One glass prism (plastic prisms do not work well for this experiment), three alcohol thermometers, black paint or a permanent black marker, scissors or a prism stand, shallow cardboard box, one blank sheet of white paper.

PREPARATION

You will need to blacken the thermometer bulbs to make the experiment work effectively. One way to do this is to paint the bulbs with black paint, covering each bulb with about the same amount of paint. Alternatively, you can also blacken the bulbs using a permanent black marker. (Note: the painted bulbs tend to produce better results.) The bulbs of the thermometers are blackened in order to better absorb heat. After the paint or marker ink has completely dried on the thermometer bulbs, tape the thermometers together such that the temperature scales line up as in Figure 1.

PROCEDURE

The experiment should be conducted outdoors on a sunny day. Variable cloud conditions, such as patchy cumulus clouds or heavy haze will diminish your results. The setup for the experiment is depicted in Figure 1. Begin by placing the white sheet of paper flat in the bottom of the cardboard box. The next step requires you to carefully attach the glass prism near the top (Sun-

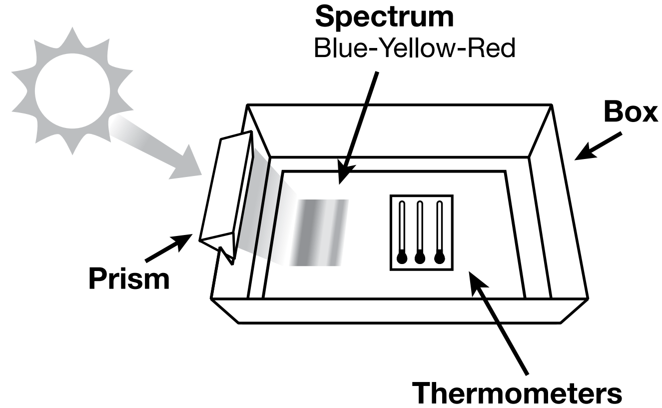

Figure 1

facing) edge of the box.

If you do not have a prism stand (available from science supply stores), the easiest way to mount the prism is to cut out an area from the top edge of the box. The cutout notch should hold the prism snugly, while permitting its rotation about the prism's long axis (as shown in Figure 2). That is, the vertical "side" cuts should be spaced slightly closer than the length of the prism, and the "bottom" cut should be located slightly deeper than the width of the prism. Next, slide the prism into the notch cut from the box, and rotate the prism until the widest possible spectrum appears on a shaded portion of the white sheet of paper at the bottom of the box. The Sun-facing side of the box may have to be elevated (tilted up) to produce a sufficiently wide spectrum. After the prism is secured in the notch, place the thermometers in the shade and record the ambient air temperature. Then place the thermometers in the spectrum such that one of the bulbs is in the blue region, another is in the yellow region, and the third is just beyond the (visible) red region (as in Figure 3).

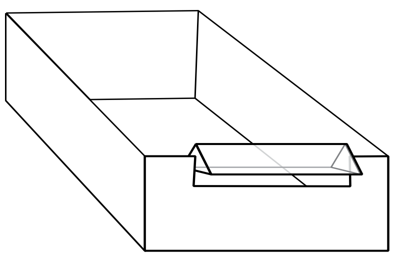

Figure 2

It will take about five minutes for the temperatures to reach their final values. Record the temperatures in each of the three regions of the spectrum: blue, yellow, and "just beyond" the red. Do not remove the thermometers from the spectrum or block the spectrum while reading the temperatures.

QUESTIONS TO ASK STUDENTS

What did you notice about your temperature readings? Did you see any trends? Where was the highest temperature? What do you think exists just beyond the red part of the spectrum? Discuss any other observations or problems.

REMARKS TO THE TEACHER

The temperatures of the colors should increase from the blue to red part of the spectrum. The highest temperature should be just beyond the red portion of the visible light spectrum. This is the infrared region of the spectrum. Herschel's experiment was important not only because it led to the discovery of infrared light, but also because it was the first time that it was shown that there were forms of light that we cannot see with our eyes. As we now know, there are many other types of electromagnetic radiation ("light") that the human eye cannot see (including x-rays, ultraviolet rays and radio waves). You can also have the students measure the temperature of other areas of the spectrum including the area just beyond the visible blue. Also, try the experiment during different times of the day; the temperature differences between the colors may change, but the *relative* comparisons will remain valid.

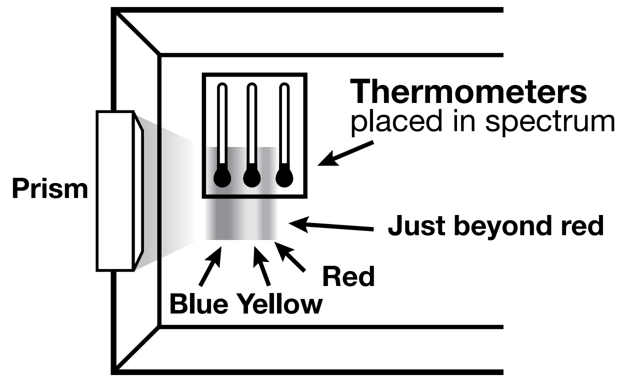

Figure 3

For further information on the Herschel infrared experiment see:
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html

For further information on infrared and infrared astronomy see:
http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/index.html

DATA/OBSERVATIONS

	Thermometer #1	Thermometer #2	Thermometer #3
Temperature in the shade			

Temperature in the spectrum	Thermometer #1 (blue)	Thermometer #2 (yellow)	Thermometer #3 (just beyond red)
After 1 minute			
After 2 minutes			
After 3 minutes			
After 4 minutes			
After 5 minutes			

Note: Depending on the position of the prism relative to the Sun, the colors of the spectrum may be reversed from what is show in the figures.

CALCULATIONS

Compute the differences between the **final** temperatures measured in the spectrum and the temperatures measured in the shade for the three thermometers.

TEMPERATURE DIFFERENCES

	Thermometer #1 (blue)	Thermometer #2 (yellow)	Thermometer #3 (just beyond red)
$T_{spectrum}$			
T_{shade}			
Difference ($T_{spectrum} - T_{shade}$)			

Calculate the differences between the **final** temperatures in each part of the spectrum.

$T_{yellow} - T_{blue}$	$T_{just\ beyond\ red} - T_{yellow}$	$T_{just\ beyond\ red} - T_{blue}$

CLASS AVERAGE TEMPERATURES

Compute the average **final** temperature measured by the class in each part of the spectrum.

	Sum of temperatures (T_{sum})	Total number of observations (N)	Class average (T_{sum}) / N
Yellow portion of the spectrum			
Blue portion of the spectrum			
Just beyond red			

Compute the average differences measured by the class between the **final** temperatures in the spectrum and the shade temperatures for the three thermometers.

	Sum of temperature differences (T_{sum})	Total number of observations (N)	Class average (T_{sum}) / N
$T_{yellow} - T_{blue}$			
$T_{just\ beyond\ red} - T_{yellow}$			
$T_{just\ beyond\ red} - T_{blue}$			

The Discovery and Uses of Infrared Light

Sir Frederick William Herschel (1738-1822) was born in Hanover, Germany and became well known as both 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 antiquity.

Herschel made another dramatic discovery in 1800. He wanted to know how much heat was passed through the different colored filters he used to observe sunlight. He noted that filters of different colors seemed to pass different amounts of heat. Herschel thought that the colors themselves might be of varying temperatures, so he devised a clever experiment to investigate his hypothesis.

He directed sunlight through a glass prism to create a spectrum (the rainbow created when light is divided into its colors) and then measured the temperature of each color. Herschel used three thermometers with blackened bulbs (to better absorb heat) and, for each color of the spectrum, placed one bulb in a visible color while the other two were placed beyond the spectrum as control samples. As he measured the individual temperatures of the violet, blue, green, yellow, orange, and red light, he noticed that all of the colors had temperatures higher than the controls. Moreover, he found that the temperatures of the colors increased from the violet to the red part of the spectrum. After noticing this pattern Herschel decided to measure the temperature just *beyond* the red portion of the spectrum in a region where no sunlight was visible. To his surprise, he found that this region had the highest temperature of all.

Herschel performed additional experiments on what he called "calorific rays" (derived from the Latin word for *heat*) beyond the red portion of the spectrum. He found that they were reflected, refracted, absorbed and transmitted in a manner similar to visible light. What Herschel had discovered was a form of light (or radiation) beyond red light, now known as infrared radiation. [The prefix *infra* means below.] Herschel's experiment was important because it marked the first time that someone demonstrated that there were types of light that we cannot see with our eyes.

Recent developments in detector technology have led to many useful applications using infrared radiation. Medical infrared technology is used for the non-invasive analysis of body tissues and fluids. Infrared cameras are used in police and security work, as well as in military surveillance. In fire fighting, infrared cameras are used to locate people and animals caught in heavy smoke and for detecting hot spots in forest fires. Infrared imaging is used to detect heat loss in buildings, to test for stress and faults in mechanical and electrical systems, and to monitor pollution. Infrared satellites are routinely used to measure ocean temperatures, providing an early warning for El Nino events that usually impact climates worldwide. These satellites also monitor convection within clouds, helping to identify potentially destructive storms. Airborne and space-based cameras also use infrared light to study vegetation patterns and the distribution of rocks, minerals and soil. In archaeology, thermal infrared imaging has been used to discover hundreds of miles of ancient roads and footpaths, providing valuable information about vanished civilizations.

Fascinating new discoveries are being made about our Universe in the field of infrared astronomy. The universe contains vast amounts of dust, and one way to peer into the obscured cocoons of star formation and into the hearts of dusty galaxies is with the penetrating eyes of infrared telescopes. Our universe is also expanding as a result of the Big Bang, and the visible light emitted by very distant objects has been red-shifted into the infrared portion of the electromagnetic spectrum.

2. Ritter Ultraviolet Experiment

PURPOSE/OBJECTIVE

To perform a version of the experiment of 1801, in which ultraviolet light was first discovered by Johann Wilhelm Ritter.

BACKGROUND

After learning about William Herschel's discovery of infrared light, which he found beyond the visible red portion of the spectrum in 1800, Johann Ritter began to conduct experiments to see if he could detect invisible light beyond the violet portion of the spectrum as well. In 1801, he was experimenting with silver chloride, which turned black when exposed to light. He had heard that blue light caused a greater reaction in silver chloride than red light did. Ritter decided to measure the rate at which silver chloride reacted to the different colors of light. He directed sunlight through a glass prism to create a spectrum (the rainbow created when light is divided into its colors). He then placed silver chloride in each color of the spectrum and found that it showed little change in the red part of the spectrum, but darkened toward the violet end of the spectrum. Johann Ritter then decided to place silver chloride in the area just beyond the violet end of the spectrum, in a region where no sunlight was visible. To his amazement, this region showed the most intense reaction of all. This showed for the first time that an invisible form of light existed beyond the violet end of the visible spectrum. This new type of light, which Ritter called Chemical Rays, later became known as ultraviolet light or ultraviolet radiation (the word ultra means beyond). Although the procedure for this activity is slightly different than Ritter's original experiment, you should obtain similar results.

MATERIALS

One glass prism, blueprint paper, household ammonia, warm water, one small and shallow square pan, a piece of cardboard slightly larger than the pan, water, a thin black marker, a prism stand or a cardboard box, scissors, a ruler, one blank sheet of white paper, and tape. NOTE: BLUEPRINT PAPER IS EXTREMELY SENSITIVE TO LIGHT — KEEP IT IN A DARK AREA UNTIL IT IS PLACED IN THE SPECTRUM PRODUCED BY THE PRISM IN THE EXPERIMENT!

NOTE: This experiment uses ammonia to develop blueprint paper. The ammonia should handled by an adult only. To reduce the ammonia vapors and increase safety, we conducted a test to determine the amount by which the ammonia could be diluted and still effectively develop the blueprint paper within a reasonably short time. Our results showed that a mixture of 90% very warm water and 10% ammonia works very well for blueprint paper exposed to its vapors for 90 seconds.

For the best results, read the preparation and procedure sections carefully before attempting this experiment. Teachers should try this experiment first before having their students perform it.

PREPARATION

This experiment should be conducted outdoors on a sunny day. Variable cloud conditions, such as patchy cumulus clouds or heavy haze will diminish your results. In a very dimly lit area cut out a piece of blueprint paper which is slightly larger than the small, shallow pan and at least 4x4 inches (or 10x10 cm) in area. Keep the piece of blueprint paper out of the light until needed. If you do not have a prism stand (available from science supply stores), the easiest way to mount the prism is to cut out an area from the top edge of the cardboard box. The cutout notch should be able to hold the prism snugly, while permitting its rotation about the prism's long axis (as shown in Figure 2 on the next page). That is, the vertical "side" cuts should be spaced slightly closer than the length of the prism, and the "bottom" cut should be located slightly deeper than the width of the prism. Next, cut out a piece of cardboard which is slightly larger than your piece of blueprint paper.

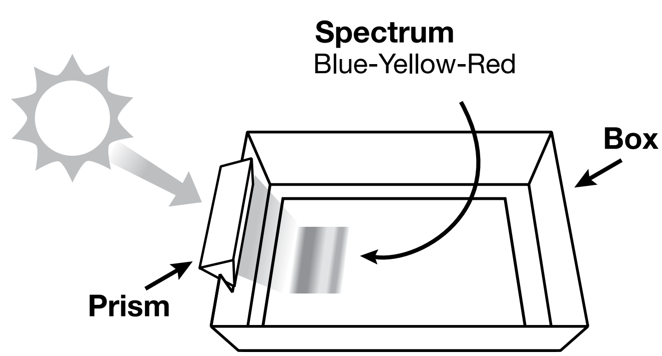

Figure 1

PROCEDURE

The setup for the experiment is depicted in Figure 1. Begin by placing the white sheet of paper flat in the bottom of the cardboard box. This will help you see the colors of the spectrum more clearly. The next step requires you to carefully attach the glass prism near the top (Sun-facing) edge of the box.

If you do not have a prism stand, slide the prism into the notch cut from the cardboard box, and rotate the prism until the widest possible spectrum appears on a shaded portion of the white sheet of paper at the bottom of the box. The Sun-facing side of the box may have to be elevated (tilted up) to produce a sufficiently wide spectrum.

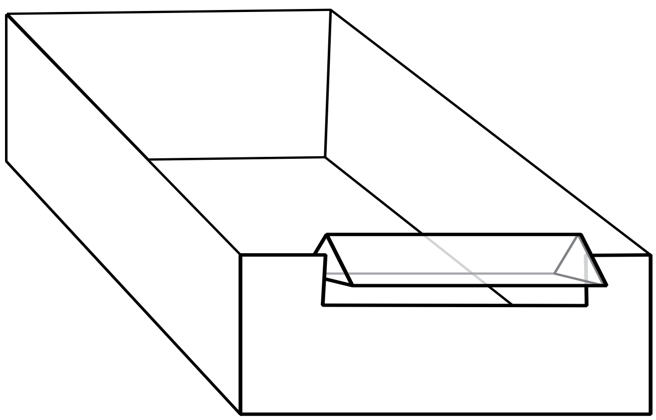

Figure 2

Without exposing the blueprint paper to direct sunlight, quickly place it in the bottom of box, where the spectrum is visible, with the colored side of blueprint paper facing up (exposed to the spectral colors). Be sure to have a large section of the blueprint paper in the area past the blue-violet portion of the spectrum. Tape the paper down at the corners to keep it from moving (this is easier if the tape is already in place on the blueprint paper before placing it in the spectrum). Immediately afterward, while being very careful not to move the box or the blueprint paper, use a thin marker to draw an outline on the blueprint paper around the visible part of the spectrum created by the prism. Label the violet end of the spectrum with a "V". Leave the paper in the box, exposed to the spectrum, for about 30 seconds. Then carefully remove the paper and try not to expose it to sunlight during the process.

Bring the piece of blueprint paper to a well ventilated area. Here pour a mixture of 90% very warm water and 10% ammonia into the pan to a depth of about 1 centimeter. NOTE: The mixing and pouring of the ammonia mixture should be done by a teacher, parent or other adult. Place the blueprint paper across the top of the pan with the colored side of the paper facing the pan and cover it and the entire pan with the piece of cardboard. Do not let any of the ammonia mixture come into contact with the blueprint paper. The cardboard will help contain the ammonia fumes and will decrease the development time. Keep the paper in place above the pan for about 90 seconds.

Once the blueprint paper is developed, move to a location away from the ammonia and study your results. There should be a white (or light-colored) rectangle around the area where the blueprint paper was exposed to the solar spectrum. The white area should be surrounded by a much darker region. You should notice that the area which was exposed to the red end of the spectrum is not as lightly colored as the area exposed to the violet region. Most importantly, you should notice that the light-colored area of the blueprint paper extends far beyond the line marking the violet end of the spectrum. This is the region that was exposed to invisible ultraviolet light.

Using a ruler, students should measure the marked width of the visible spectrum. Then measure how far the light-colored region of the blueprint paper extends beyond the line marking the violet end of the spectrum. Add these two numbers to compute the total width of the exposed region. Compare your results to those of your classmates and compute average values for the class.

QUESTIONS FOR STUDENTS

What happened to the blueprint paper after it was developed? Describe what happened to the area which was exposed to the visible part of the spectrum. Describe what happened to the blueprint paper in the region beyond the violet part of the spectrum — where no visible light could be seen. What do you think exists just beyond the blue part of the spectrum? Do you think that this proves the existence of an invisible form of light? Why or why not? Discuss any other observations or problems.

DATA/OBSERVATIONS

Width of the Visible Spectrum	Width of the Ultraviolet Region	Total Width

CALCULATIONS

Compute the average widths measured by the class.

	Sum of the Widths (W_{sum})	Total number of observations (N)	Class average (W_{sum}) / N
Width of Visible Spectrum			
Width of Ultraviolet Region			
Total Width			

Compute the percentage of the light-colored region on the blueprint paper that was exposed to visible light and to ultraviolet light.

Percentage of Region Exposed to Visible Light: (Width of Visible Spectrum / Total Width) x 100	Percentage of Region Exposed to Ultraviolet Light: (Width of Ultraviolet Region / Total Width) x 100

The Discovery and Uses of Ultraviolet Light

Johann Wilhelm Ritter was born in 1776 in Samitz, Silesia, which is now part of Poland. He worked as a pharmacist between 1791 and 1795 and then attended the University of Jena to study science and medicine. While at the University, Ritter performed numerous experiments.

Johann Ritter is best known for his discovery of ultraviolet light in 1801. A year earlier, in 1800, William Herschel discovered infrared light. This was the first time that a form of light beyond visible light had been detected. After hearing about Herschel's discovery of an invisible form of light beyond the red portion of the spectrum, Ritter decided to conduct experiments to determine if invisible light existed beyond the violet end of the spectrum as well.

In 1801, he was experimenting with silver chloride, a chemical which turned black when exposed to sunlight. He had heard that exposure to blue light caused a greater reaction in silver chloride than exposure to red light. Ritter decided to measure the rate at which silver chloride reacted when exposed to the different colors of light. To do this, he directed sunlight through a glass prism to create a spectrum. He then placed silver chloride in each color of the spectrum. Ritter noticed that the silver chloride showed little change in the red part of the spectrum, but increasingly darkened toward the violet end of the spectrum. This proved that exposure to blue light did cause silver chloride to turn black much more efficiently than exposure to red light.

Johann Ritter then decided to place silver chloride in the area just beyond the violet end of the spectrum, in a region where no sunlight was visible. To his amazement, he saw that the silver chloride displayed an intense reaction well beyond the violet end of the spectrum, where no visible light could be seen. This showed for the first time that an invisible form of light existed beyond the violet end of the spectrum. This new type of light, which Ritter called Chemical Rays, later became known as ultraviolet light or ultraviolet radiation (the word ultra means beyond). Ritter's experiment, along with Herschel's discovery, proved that invisible forms of light existed beyond both ends of the visible spectrum.

After his discovery of ultraviolet light, Ritter continued to do research and became increasingly interested in electrical experiments. He had discovered the process of electroplating earlier in 1800. In 1802, he invented the dry cell battery and later developed a storage battery in 1803. In 1804 he began work at the Bavarian Academy of Science in Munich where he remained until his death in 1810 at the age of 33.

We now use ultraviolet light in many ways. In medicine, ultraviolet light is used to help kill bacteria and viruses and to sterilize equipment. It is used to disinfect products and containers. In science, ultraviolet light is used to study atoms, and to learn about especially hot objects in space. Several animals, including birds, butterflies and other insects can see ultraviolet light.