National Aeronautics and Space Administration

Discovery of Infrared Light

Sir Frederick William Herschel

A Classroom Activity

Herschel Discovers Infrared Light

Sir Frederick William Herschel (1738-1822) was born in Hanover, Germany, and became well known as both a musician and 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 had noted that filters of different colors seemed to pass different amounts of heat. Herschel thought that the colors themselves might be of varying temperatures and 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 the 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 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 apparently devoid of sunlight. 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 Sir William 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 Niño 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 to study 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.

New and fascinating discoveries are being made about our universe in the field of infrared astronomy. The niverse 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 short-wavelength 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.

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 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 from Herschel's original experiment, you should obtain similar results.

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, cardboard box (a photocopier paper box works fine), one blank sheet of white paper.

PREPARATION:

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.

You will need to blacken the thermometer bulbs to make the experiment work effectively. The best way is to paint the bulbs with black paint, covering each bulb with about the same amount of paint. Alternatively, you can blacken the bulbs using a permanent black marker. The bulbs of the thermometers are blackened in order to absorb heat better. After the paint or marker ink has completely dried on the thermometer bulbs, tape the thermometers together (on a 3 x 5 card, for example) such that the temperature scales will line up, as in Figure 2.

PROCEDURE:

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-facing) edge of the box.

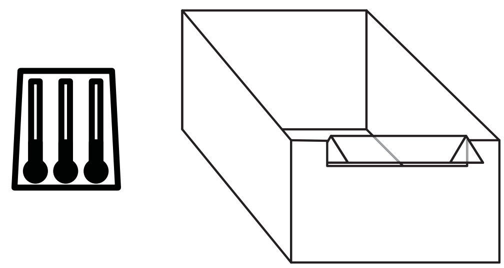

Figure 1. Thermometers taped to card and box with prism secured in notch cutout..

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.

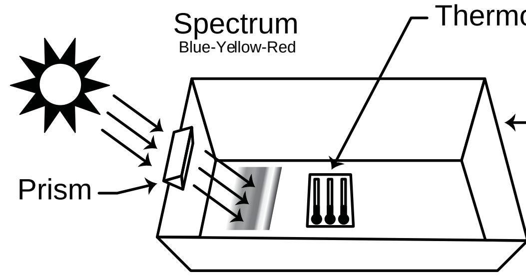

Figure 2. Box with white paper on bottom and prism creating widest possible spectrum.

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.

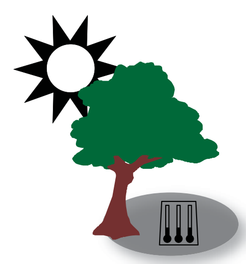

Figure 3. Record ambient temperature in the shade.

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 4).

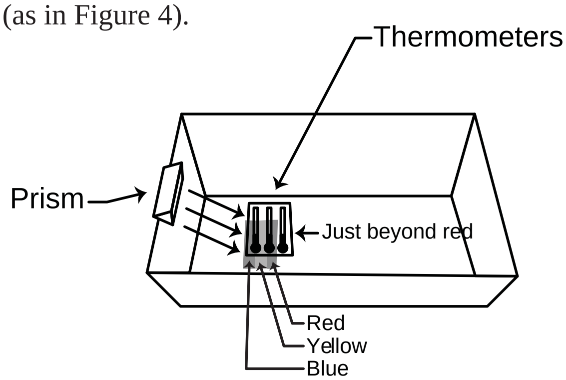

Figure 4. Herschel experiment.

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.

DATA / OBSERVATIONS:

Record your observations in a table like this:

Temperature in shade	Therm. #1	Therm. #2	Therm. #3
Temp. in spectrum after 5 minutes	Blue	Yellow	Just beyond red

NOTE: Depending on the orientation of your prism, red could be at either end of the spectrum. Adjust the positions of your thermometers accordingly.

QUESTIONS:

- 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:

Have the students answer the above questions. 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.

However, this result is actually counterintuitive. Herschel did not know that the peak energy output of the solar spectrum is at the wavelength of orange light, and certainly not infrared. However, the results he got were skewed because the different wavelengths of light are not refracted by the prism in a linear fashion. Thus, the colors (wavelengths) of light will not be evenly spaced along Herschel's table. If, for example, the light hits the prism at a 45° angle (passing from air into glass), the infrared part of the light will be refracted more sharply than would be expected, and thus be much more highly concentrated on the surface of the table than optical wavelengths. Thus, Herschel's temperature measurements of the parts of the spectrum peaked in the infrared.

Nonetheless, Herschel's experiment was important not only because it led to the discovery of infrared light, but also because it was the first time it was shown that there were forms of light 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.

For further information on the Herschel infrared experiment see:

coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/herschel_experiment.html

For further information on Infrared and Infrared Astronomy see:

www.ipac.caltech.edu

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