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 three:

- 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

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 three—one placed in blue, one in the infrared, and one control. It gives you the same basic observation, though with four 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 of the spectrum. 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 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 cannot detect infrared radiation, although some animals' can. 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? Sunlight and infrared radiation come from the Sun, but Mercury's surface is also hot. Does Mercury radiate infrared radiation?

7. Ask students what ways they can think of to protect the spacecraft from these sources of heat. 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 does not work since there is no light source) and detecting objects of differing temperatures (animals in a room, for example).

Lesson Adaptations

- If time permits, instead of showing students the experiment setup, 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. Some of the students may discover something similar to Herschel's experiment, 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.

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.

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, Spitzer Space Telescope. 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

4 points

- Student created a spectrum.
- Student completed tables in Student Worksheet.
- Student's experiment yielded correct results—that the highest temperature was recorded "just beyond red."
- Student concluded that there must be invisible light beyond the red.

3 points

- Student met three of the four criteria from above.

2 points

- Student met two of the four criteria from above.

1 point

- Student met one of the four criteria from above.

0 points

- No work completed.

Internet Resources & References

MESSENGER website

http://messenger.jhuapl.edu

American Association for the Advancement of Science, Project 2061 Benchmarks for Science Literacy

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

Cool Cosmos: Infrared Astronomy

http://coolcosmos.ipac.caltech.edu

Cool Cosmos: The Herschel Experiment

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

(Includes a Spanish-language description of the experiment)

NASA's Earth Observatory

http://earthobservatory.nasa.gov/

National Science Education Standards

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

Spitzer Space Telescope

http://spitzer.caltech.edu/

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