Lesson Plan: Measuring the solar constant

Students will measure the temperature change in a bottle of water as it is exposed to sunlight (see Figure S1 in Student Worksheet 1). Using this data and other parameters of the experiment, they calculate the solar constant, which is the amount of energy the Earth receives from the Sun per square meter per second.

Materials

Per group of 3:

- 1 small, flat-sided glass bottle with at least 150 ml capacity
- 1 cork stopper for the bottle
- 1 thermometer with a range up to at least 50ºC
- Books or rocks (to prop up the bottle)

Per class:

- Stopwatch
- Black, water-soluble ink
- Metric measuring cup
- Drill
- Optional: Caulk
- Optional: Masking tape

Preparation

- Prepare the cork stoppers by drilling a hole in them large enough to accept the thermometer. You can use the regular cap of the bottle and seal it with silicon or caulk. You can also use masking tape to fasten the thermometer to the side of the bottle (make sure you can read the thermometer scale without moving the bottle), and then seal the top of the bottle. You can also have the students prepare the cork stoppers.

- Try to collect the data as close to noon as possible on a clear, cloudless day.

- If there is not enough time in one class session to complete this lesson, the calculations may be done on a separate day. The collectors may also be prepared and/or water placed in the shade to regulate temperature prior to the class. (These are steps 1 and 2 in the Student Procedures in Student Worksheet 1.)

- Make enough copies of the Student Worksheets and MESSENGER information sheet for each student.

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

- It is best to have a flat-sided bottle with at least 150 ml capacity (a book-shaped glass bottle would be ideal). You can also use larger bottles, but to minimize the amount of measurement errors and sources of "noise" in the experiment, it is good to fill the bottle as full as possible. A noticeable rise in the water temperature in a large, full bottle will take longer to achieve than described here. Since 150 ml of water is ideal for making the calculation, the bottle size should be just a little over that. Important: Each group of students should use the same kind of bottle.

▼ Make sure the thermometer fits inside the jar and that the jar can still be properly corked. If possible, do not use a thermometer encased in heavy plastic. The plastic may absorb some of the heat and take away from the accuracy of the experiment.

▼ If you do not have access to a cork or a metal lid, you can also use masking tape to fasten the thermometer to the side of the bottle (just make sure you can read the thermometer scale without moving the bottle), and then use masking tape to close the top of the jar.

Warm-up & Pre-assessment

1. Discuss with the students the concepts of temperature and heat.

2. Ask the students to come up with sources of heat and explain how the heat travels from the source. What about sunlight?

3. Talk to the students about sunlight and its role in our life here on Earth. Where do they think the Sun gets its power? How do they think Earth is affected by the amount of power (energy per second) that reaches us? How would other planets be affected?

4. Ask the students how they could calculate the amount of sunlight falling on Earth. Use the concept that light coming from the Sun will end up on the surface of a sphere with a radius equal to the Earth's distance from the Sun.

5. Ask the students how they would go about measuring the power of sunlight. Remind them that we cannot go and take a direct measurement from the Sun, and, therefore, have to design an experiment on Earth to measure indirectly.

6. If it has not already been mentioned, introduce the idea of the solar constant (see Science Overview). Tell the students that they are going to build a device to measure the solar constant, and, therefore, the power of sunlight.

Procedures

1. Put students into groups of three. Give each group the materials necessary to make the experiment, including Student Worksheet 1.

2. If you have not already done so, have the students prepare the collector bottles (see Figure S1 on Student Worksheet 1). A hole should be drilled into the cork or metal top of the jar for the thermometer to fit through.

3. Make sure that the students keep the unit shaded while moving it. Have the students set the collector down so that the flat surface is as perpendicular to the incoming sunlight as possible.

> **Teaching Tip**
>
> The time it takes for the water to heat up a couple of degrees depends on the time of day (the intensity of sunlight), the amount of water in the bottle, and the surface area of the bottle. Some of the heat will leak away to the environment, so you do not want to have the bottle sit on the ground any longer than necessary.

4. When you return to the classroom, collect data from everyone, and have the students calculate class averages. Create the following chart on the board using the data from each group:

Group #	Initial Temp (˚C)	Final Temp (˚C)	ΔT (˚C)	Elapsed Time (s)	Surface Area (m^2)
1					
2					
3					
…					
Average					

5. Have the students use this information to complete the calculations on Student Worksheet 1.

6. Discuss deviations from the average and why these deviations may occur.
[A: Some possibilities include: errors in reading the temperature accurately, differences in calculating the exposed surface area of the bottle, different responses of the thermometers, and different amounts of ink put in the water.]

Teaching Tip

Have the students read the worksheet while they are waiting for the water to warm up. This will prepare them for what they will be calculating and give them something to occupy their time in-between temperature readings. You may want to discuss what they think will happen, how many degrees they think the thermometers may have changed, etc. Answer any questions that they may have during this time.

Discussion & Reflection

1. It is likely that the values of the solar constant derived by the students differ between groups. Reasons for this may include the amount of ink in the water (since this determines how much sunlight is absorbed by the water instead of reflected or let through), different amounts of heat leaking into the environment from the bottle, and differences in reading the thermometers or recording the time. The values may also differ from the real solar constant, and that may be due to the atmospheric conditions being different from what the correction factor used by the students assumes, the correction factor for the glass bottle being a little different, etc. The correction factors are determined for the specific conditions described, and differences in those (such as the thickness of the glass, or slight coloration in it) may affect the derived values.

Take this opportunity to discuss with the class the value of the scientific process. Remind them that scientists have to work very hard to be able to calculate the correct values, and that there are many parameters that must be controlled in order for this to be true. Usually scientists want to do the same experiment many times and use averages to calculate what is desired. The repetitions reduce the amount of error from measurements, environment changes, etc. In this case we use the group averages instead of every group repeating their experiment, but the principle is the same—many measurements of the same quantity reduce the effect of errors.

2. Remind students what it is that they have measured and how it relates to the power of sunlight.

3. Ask the class how they think things would change if Earth were closer to the Sun (or more distant).

4. Discuss the Sun as a star (some of its properties). Describe the Sun as one star among billions in our Galaxy. Describe how the Sun receives its power from nuclear fusion processes taking place at its center, and how the power is transmitted to Earth (via electromagnetic radiation). Discuss the importance of solar radiation on Earth.

5. Return to the essential question: what is the Sun's role on Earth? Remind them of the Sun's central role in the Solar System (it provides most of the energy available in the Solar System and guides the movements of the objects in the Solar System via gravity) and without it, none of us would be here. Remind them that it is the source of almost all energy on Earth. Remind them also that too much sunlight can be harmful to people and machines. (Use the example of UV damage to skin in the form of suntan, premature aging, and skin cancer.)

6. Hand out the MESSENGER information sheet and discuss the mission. Tell the students about the important role that the Sun and sunlight have on the mission. Remind them that sunlight is used in all planetary explorations. Most pictures the students have seen of other planets and moons were taken by cameras that capture sunlight reflected by the planets or moons. The engineers working on the MESSENGER mission to Mercury had to work hard to come up with solutions to the problem of protecting the spacecraft against the intense solar radiation at Mercury's close distance to the Sun.

7. Hand out additional worksheets that calculate planetary temperatures (Student Worksheet 2) and the potential of solar power use (Student Challenge Worksheet). You can have the worksheets filled out in class or as homework.

LESSON ADAPTATIONS

- For a mathematical challenge, have students complete the Student Challenge Worksheet.
- The Student Worksheets are mathematic in orientation. If you do not think your students can handle the math required, or that they will get discouraged, modify the worksheets for your students. Adapt this lesson to meet the needs of your students as you see fit.

EXTENSIONS

You can adapt the experiment described above by making a more accurate, sophisticated measuring device. Use the same ingredients as in the basic activity, but modified:

- Substitute temperature probes from a DMM (Digital Multimeter) or a computer to collect the data; the computer could also provide a more accurate time base.
- Design and build a more sophisticated, insulated collector bottle that minimizes heat loss to the environment.

You can also:

- Have students do the experiment with substances other than water. The only difference in calculating the solar constant is the number used for specific heat. If there is a discrepancy in the value of the solar constant, discuss why this might be the case.
- Have the students use different colored ink and test their results. Check if the solar constant is the same for various colors, discuss why or why not.
- Have the students repeat the activity without tilting the bottles toward the Sun. Calculate the difference between the solar constants and research why this is the case.
- The Sun is powered by nuclear fusion taking place in its core. On Earth, fission is used as an energy source in nuclear power plants. Have students research both of these processes and their efficiency. Have students discuss what is necessary for each, and why fusion is not used for energy generation on Earth.
- Have students research ways in which the Sun's energy is helpful to human activities, and describe how we use sunlight in our everyday lives. Have students discuss ways in which the Sun's energy is harmful to humans. What are some of the things that we can do to protect ourselves and our planet from harmful rays?
- Have students examine the properties of sunlight further with the help of the Wien displacement law, which states:

  $$\lambda_{max} = 2897 / T\,[K] \quad [\mu m]$$

  where λ_{max} is the wavelength of peak emission in micrometers (in μm, or 10^{-6} m), and T is the temperature of the radiating body in K. What does this mean? When is it effective? Describe what scientists mean by a "black body." Finally, calculate the wavelength of peak emission is for sunlight.

Curriculum Connections

- *History of Science:* Have the students examine the history of the study of the Sun. Have them write a timeline or essay about which scientists made important discoveries about the Sun and when.
- *Social science:* Have the students observe the importance of solar radiation at home and in industry. They can examine how it has affected daily life in modern society.
- *Technology:* Have the students research ways that solar radiation can be captured and applied to advance technology and cut back on the use of fossil fuels. Discuss the practicality, as well as advantages and disadvantages of this technology.
- *Geography/Agricultural Studies:* Have the students consider what effect sunlight has on the farming communities in various parts of the world. Consider locations that receive a lot of sunlight (toward the equator) and compare them to locations that receive varying amounts of sunlight during the year (toward the poles). Discuss how this affects the people of these locations and their contributions to the world. Research SAD (Seasonal Affective Disorder).
- *Environmental Studies:* Solar energy is a growing alternative to other natural resources. Discuss the advantages solar power has with regards to the environment, as well as any disadvantages.

Closing Discussion

Remind the students that they have discovered the central role sunlight plays in our lives here on Earth by calculating the amount of energy the Sun provides to Earth. Discuss other ways that the class could calculate the solar constant. Remind the class of ways they utilize solar radiation every day. Remind them that the solar constant is different for each planet, and ask them what they have learned about how the amount of radiation from the Sun affects conditions on each planet. Discuss the importance of sunlight for planetary exploration, including the MESSENGER mission to Mercury.

Assessment

4 points

- Student accurately calculated the group's solar constant and error, as well as the class average solar constant and error, on page 4 of Student Worksheet 1.
- Student justified the group's error for the solar constant in question 1 of Student Worksheet 1.
- Student set up and calculated questions 2 and 3 correctly in Student Worksheet 1.
- Student accurately filled in the table on Student Worksheet 2.
- Student accurately answered all questions on Student Worksheet 2.

3 points

- Student accurately calculated three of the following: the group's solar constant and error, as well as the class average solar constant and error.
- Student justified the group's error for the solar constant in question 1 of Student Worksheet 1.
- Student set up questions 2 and 3 correctly in Student Worksheet 1, but made errors in one of the calculations.
- Student accurately filled in six of the eight entries in the table on Student Worksheet 2.
- Student accurately answered four of the five questions on Student Worksheet 2.

2 points

- Student accurately calculated two of the following: the group's solar constant and error, as well as the class average solar constant and error.
- Student attempted to justify the group's error for the solar constant in question 1 of Student Worksheet 1.
- Student set up questions 2 and 3 correctly in Student Worksheet 1, but made errors in both of the calculations.
- Student accurately filled in four of the eight entries in the table on Student Worksheet 2.
- Student accurately answered three of the five questions on Student Worksheet 2.

1 point

- Student accurately calculated one of the following: the group's solar constant and error, as well as the class average solar constant and error.
- Student attempted to justify the group's error for the solar constant in question 1 of Student Worksheet 1.
- Student set up either questions 2 or 3 correctly in Student Worksheet 1, and made errors in both of the calculations.
- Student accurately filled in two of the eight entries in the table on Student Worksheet 2.
- Student accurately answered two of the five questions on Student Worksheet 2.

0 points

- No work completed.

Internet Resources & References

MESSENGER website

http://messenger.jhuapl.edu

NASA Goddard Space Flight Center's "Living with a Star" Website

http://lws.gsfc.nasa.gov/

NASA Goddard Space Flight Center's "Sun-Earth Connection" Website

http://sec.gsfc.nasa.gov/

NASA National Space Science Data Center's Planetary System Fact Sheets

http://nssdc.gsfc.nasa.gov/planetary/planetfact.html

NOAA Space Environment Center, U.S. Dept. of Commerce

http://www.sec.noaa.gov/

SpaceWeather.com

http://www.spaceweather.com/

The Solar and Heliospheric Observatory (SOHO)

http://sohowww.nascom.nasa.gov/

U.S. Department of Energy

http://www.energy.gov/

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

This activity has been adapted from the National Oceanic and Atmospheric Administration's "Space Physics and Terrestrial effects" curriculum (http://www.sec.noaa.gov/Curric_7-12/).