8. Investigating Solar Energy

Black Coffee

Objectives

Students analyze the heat that reaches them in the form of light from the sun and identify the sun as the major source of energy for supporting life on the earth.

Procedural Overview

Students gain experience conducting the following procedures:

- Calculating the solar energy that reaches them by using a temperature sensor to measure the change in temperature of coffee as it is warmed by sunlight
- Constructing an insulated cup system to hold a coffee sample for testing
- Using math skills to compute differences in temperatures, times, and rates of warming
- Organizing and comparing their data in simple tables or graphs, and identifying relationships the temperature patterns reveal

Time Requirement

☐ Introductory discussion and lab activity, Part 1 – Making predictions	20 minutes
☐ Lab activity, Part 2 – Setting up	15 minutes
☐ Lab activity, Part 3 – Determining the temperature change	50 minutes
☐ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- ☐ Mobile data collection system
- ☐ Stainless steel temperature sensor
- ☐ Polystyrene coffee cups (2), small, that nest within each other
- ☐ Graduated cylinder, 25- or 50-mL
- ☐ Black coffee, cold, 20 mL
- ☐ Rubber bands (2)
- ☐ Clear plastic wrap (2 pieces) ~6 in. × 6 in.

For each student or group:

- ☐ Data collection system
- ☐ Stainless steel temperature sensor
- ☐ Graduated cylinder, 25- or 50-mL
- ☐ Polystyrene coffee cups (2), small, that nest within each other
- ☐ Black coffee, cold, 15 mL
- ☐ Rubber bands (2)
- ☐ Large insulated container or Thermos™ bottle (optional)
- ☐ Clear plastic wrap (2 pieces) ~6 in. × 6 in.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Energy can be measured in joules.
- Temperature is a measure of heat energy, while heat itself is the transfer of thermal energy from a warmer object to a cooler object.

Related Labs in This Guide

Labs conceptually related to this one include:

- Energy Transfer
- Exploring Environmental Temperatures

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system ◆(1.2)
- Connecting a sensor to the data collection system ◆(2.1)
- Changing the sampling rate ◆(5.1)
- Monitoring live data without recording ◆(6.1)
- Displaying data in a graph ◆(7.1.1)
- Adjusting the scale of a graph ◆(7.1.2)
- Displaying data in a digits display ◆(7.3.1)

Background

The sun is responsible for almost all forms of energy on Earth. Sunlight enters our atmosphere as electromagnetic radiation. By the time sunlight gets to you, this energy is reduced; only about 70% of the sun's radiation reaches the surface. Clouds reflect about 30% of this energy back into space.

Earth's atmosphere protects us from some of the sun's harmful ultraviolet radiation. We are able to see some of the sun's energy—the visible wavelengths of the electromagnetic spectrum. We are able to feel some of the sun's energy also—the infrared wavelengths of the electromagnetic spectrum.

As a source of energy, the sun is essentially limitless and clean. Scientists and engineers are developing ways this unlimited, clean energy can be harnessed to provide the power we need to run our modern world.

Pre-Lab Discussion and Activity

Engage students in the following discussion or activity:

Encourage students to determine if electricity, heat, light, and motion have anything in common. Students may know that they are all forms of energy. Ask them to list types of energy that are due to the sun. Have them discuss within their groups and share their answers with the class after a few minutes.

> Energy directly from the sun includes heat (infrared radiation), light (visible radiation), and ultraviolet radiation (powerful enough to damage skin cells, but isn't seen or felt). Energy on earth produced indirectly from the sun includes food that originates from plants that use sunlight; plants that provide energy for animals, which provide energy for other animals; oil, coal, and natural gas; wind power; and electricity generated using solar panels.

Ask students to discuss what color of clothing would be more suitable during different times of the year. Tell them to justify their color selections. Ask them to discuss this within their groups and share their answers with the class after a few minutes. You may feel it is necessary to hint that black appears black because it absorbs all light.

Display a black-coffee-nested-cup arrangement to the students prior to the investigation.

If the students have not used a temperature sensor before, briefly demonstrate how it works in the cold coffee. Demonstrate that the sensor can display small temperature variations (up to 0.10 °C).

Explain that the second plastic cup insulates the coffee so that the room temperature has little effect on it and the main way it can be warmed is from light. Remind students that the cold solution should be quickly moved to its outside location or the cup can be filled at its location from a Thermos® bottle or other insulated container.

Direct the students to “Thinking about the Question.” Then have students discuss within their groups where they would like to locate their data collection system and sensor and share these locations with the class. Encourage the students to select different locations with varying amounts of light (for example, shade versus sun).

Have student groups partner with another group that has chosen a location with a different amount of sunlight than they've chosen. Let them know they will share each other's collected data.

Direct the students to "Investigating the Question." Plan to allow them to share their results with the class after "Part III" to compare the rate of heating at different locations.

Preparation and Tips

These are the materials and equipment to set up prior to the lab:

Prepare the black-coffee-nested-cup apparatus as follows:

a. Nest one polystyrene cup inside another.

b. Pour 15 to 20 mL of cold coffee into the top cup.

c. Cover the top cup with clear plastic wrap and secure the wrap in place with a rubber band.

d. Now cover both cups with another layer of plastic wrap and secure this layer in place with the second rubber band.

e. Poke a small hole in the plastic wrap to insert the temperature sensor.

- Students should partner with another group that has chosen a location with a different amount of sunlight to obtain a second set of data.
- The temperature change is best observed if the cups with the coffee are placed outside at noon, when the sun is directly overhead.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Never look directly at the sun—severe eye damage can result.
- Consider the coffee as chemicals; it is not for drinking.

Driving Question

How much heat is in sunlight?

Thinking about the Question

Almost all the energy on earth arrives as light from the sun. Sunlight striking an object is partly reflected and partly absorbed. The absorbed light hits molecules, making them vibrate faster. We sense this as a rise in temperature.

Discuss with the members of your group how a black liquid is affected by the light that falls on it. Record your thoughts below. Be prepared to share your thoughts with the class.

The more light an object absorbs, the faster its temperature will rise. Therefore, measuring the rate of the temperature increase of an object is a way of finding out how much energy it is absorbing. A black liquid absorbs almost all the light that falls on it. By measuring how fast the temperature of a black liquid rises, we can determine the rate at which sunlight energy is absorbed.

Sequencing Challenge

Note: This is an optional ancillary activity.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

1	2	3	5	4
Make sure each lab group member is aware of safety rules and procedures for this lab.	Pour 15 mL of cold black coffee into an insulated polystyrene cup, cover it with clear plastic wrap and nest it inside another cup.	Cover the nested cups with a second layer of clear plastic wrap. Place them in your chosen location.	Determine the temperature change and compare it to the temperature change of coffee placed in another location.	Insert the temperature sensor and record the temperature of the coffee in the chosen location for 10 minutes.

Investigating the Question

Part 1 – Making predictions

1. ☐ Predict how fast the temperature of the cold coffee will change when placed outside.

   Student answers will vary based on the location they select for their cups.

2. ☐ Describe and explain your prediction.

   Depending on the location in the sun or shade, students should relate that energy from the sun will be transferred to the cup. The more direct the sunlight, the faster the contents of the cup will heat up.

Part 2 – Setting up

3. ☐ Using the graduated cylinder, measure 15 mL of cold coffee and transfer it into an insulated polystyrene cup. Record the volume V of the coffee in milliliters. The coffee should be colder than the air.

   V_{coffee} = 15 ml

4. ☐ Cover the top of the cup with clear plastic wrap, and secure the plastic with a rubber band.

5. ☐ Place the covered cup inside the second cup so they are nested together.

6. ☐ Cover both cups with another layer of plastic wrap, and secure this in place with the second rubber band.

7. ☐ Poke a small hole in the plastic wrap to insert the temperature sensor (don not insert the temperature sensor yet).

8. ☐ Quickly take the cup with the coffee, the temperature sensor, the instructions for using the data collection system if you need them, and the data collection system to your selected location.

9. ☐ Start a new experiment on the data collection system. ◆(1.2)

10. ☐ Connect the temperature sensor to the data collection system. ◆(2.1)

11. ☐ Display temperature in a digits display. ◆(7.3.1)

Part 3 – Determining the temperature change

12. ☐ Monitor the temperature without recording. ◆(6.1)

13. ☐ Set the sampling rate to 1 sample per second. ◆(5.1)

14. ☐ Push the temperature sensor through the clear plastic wrap covering the cups and down into the coffee, making as small a hole as possible.

15. ☐ Gently swirl the cups so the coffee mixes as you record the initial temperature. Be sure the sensor tip is always covered with coffee.

16. ☐ Display Temperature on the y-axis of a graph with Time on the x-axis. ◆(7.1.1)

18. ☐ Start data recording. ◆(6.2)

19. ☐ Record the initial temperature ($T_{initial}$) of the coffee at your chosen location in Table 1.

20. ☐ After 10 minutes, stop data recording and record the final temperature (T_{final}) in Table 1.

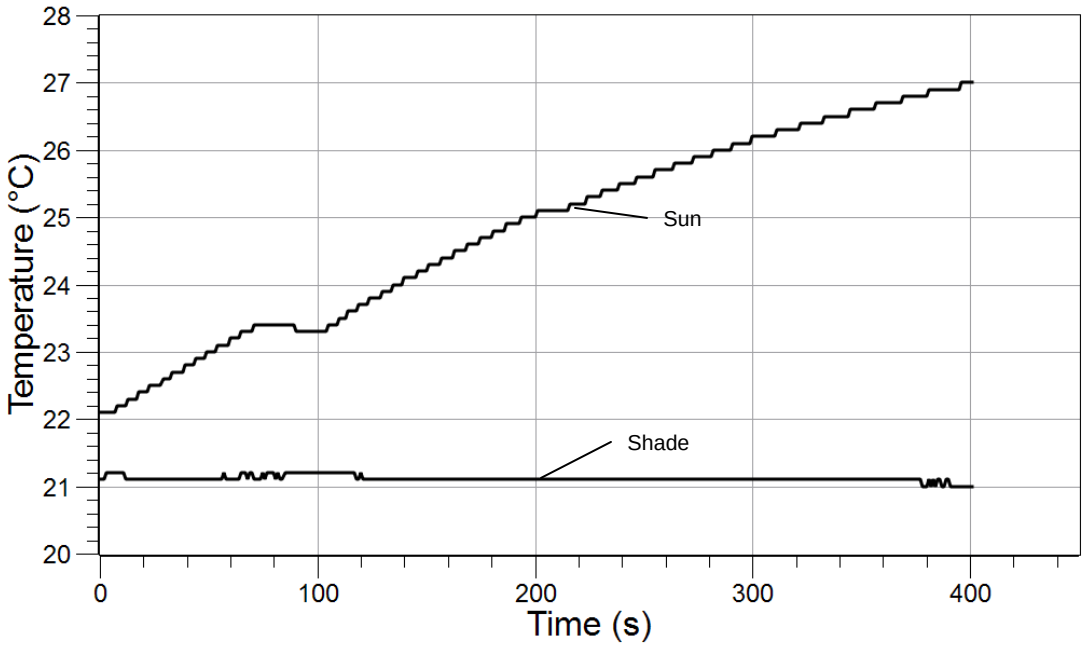
21. ☐ Record the type of sunlight in your selected location and the length of time you recorded data in both Table 1 and Table 2.

22. ☐ Obtain the amount of sunlight, air temperature, time interval, and the initial and final temperatures of the coffee from your partner group and record them as required in Table 1 and Table 2.

Table 1: Temperature change of coffee in varying levels of sunlight (raw data)

Sunlight Condition	Time Interval (s)	Coffee Temperature (°C)	
		Initial	Final
Full sun (our group)	400	22.10	27.00
Shade (partner group)	400	21.12	21.00

Sample Data



Answering the Question

Analysis

1. Determine the rise in temperature. You may need to adjust the scale of the graph ◆(7.1.2) Show your calculations below and record the answer in Table 2.

For the sample data for full sun:

$T_{final} - T_{initial} = T_{change}$

27.00 °C – 22.10 °C = 4.90 °C

2. Find the rate of temperature increase by calculating the increase per time. Show your calculations.

For the sample data for full sun:

$T_{increase}$/Time = Rate of temperature increase

4.90 °C/400 s = 0.0122 °C/s

3. Calculate the amount of sunlight energy (J) absorbed by the coffee. The equation for this is:

mass × energy needed to change 1 g of water 1 °C × temperature change = amount of heat transferred

The energy needed to change 1 g of water 1 °C is 4.19 J/(g °C), so the equation to use to calculate the amount of sunlight energy absorbed by the coffee is:

$m \times 4.19 \text{ J/(g °C)} \times \Delta T = Q$

where m is the mass, ΔT is the change in temperature, and Q is the symbol for the amount of heat transferred.

Note: 1 milliliter of water has a mass of 1 gram. For this calculation, assume that this is the same for the coffee.

For the sample data for full sun:

15 g x 4.19 J/(g °C) x 4.90 °C = 308 J

4. Obtain the data from your partner group and enter it in Table 2.

Table 2: Determination of energy from sunlight

Sunlight Condition	Time Interval (s)	Temperature Change (°C)	Amount of Energy Absorbed (J)
Full sun	400	4.90	308
Shade	400	–0.12	–7.5

5. Compare the amount of sunlight energy (J) absorbed by the coffee at your location with the results of your partner group and other students that had different amounts of sunlight heating their coffee. How does the amount of sunlight affect the amount of energy transferred to the coffee?

The more the coffee is exposed to sunlight, the more energy is transferred.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. A change in the amount of heat energy present in an object can be measured by the change in

A. Time
B. Mass
C. Temperature

2. An insulated cup of cold coffee is taken outdoors on a sunny day. It first spends 15 minutes in the shade, then 15 minutes in full sun, followed by 15 minutes in a partially sunny area. Which temperatures might have been measured at 15 minutes, 30 minutes, and 45 minutes?

A. 22 °C, 35 °C, 37 °C
B. 37 °C, 50 °C, 22 °C
C. 22 °C, 37 °C, 35 °C

3. Which aspect of a temperature versus time graph indicates the rate of change in heat energy?

A. The label on the y-axis
B. The slope of the curve
C. The final temperature recorded

4. Which statement below about the sun's energy is not correct?

A. Visible light is the only type of energy from the sun that we can use.
B. The sun's energy is essentially unlimited.
C. Thermal and light energy from the sun reach the earth's surface.

Key Term Challenge

Fill in the blanks from the randomly ordered words below:

temperature	heat	warm	cold
sunlight	time	Joules	degrees Celsius
increase	energy		

1. Almost all of the energy available on Earth comes from the sun.

2. A measure of the average kinetic energy of the particles of a substance is temperature.

3. Heat energy always flows from a warm object to a cold object.

4. We see some of the sun's energy as visible light, and we feel part of the sun's energy as heat.

5. Scientists and engineers look for ways to use sunlight as a renewable and clean source of energy.

6. In the SI system of measurement, energy is measured in units called Joules.

Further Investigations

Predict how the temperature of the coffee changes during different times of the day or under different weather conditions and test your prediction.

How does varying the area of the surface exposed to the sun affect the amount of energy absorbed by a black liquid such as coffee?

Design and perform an investigation that will use clear water or other liquids instead of coffee. How do the results compare?

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.