Activity 3

Measuring the Solar Constant

Relevant Reading

Chapter 2, section 1

Purpose

With this activity, we will let solar radiation raise the temperature of a measured quantity of water. From the observation of how much time is required for the temperature change, we can calculate the amount of energy absorbed by the water and then relate this to the energy output of the Sun.

Materials

Simple Jar and Thermometer

small, flat sided glass bottle with 200 ml capacity—the more regular the shape the easier it will be to calculate the surface area later

cork stopper for the bottle with a hole drilled in it to accept a thermometer; the regular cap of the bottle can be used, but the hole for the thermometer may have to be sealed with silicon or caulking after the thermometer is placed in it.

thermometer with a range up to at least 50 °C

stopwatch

black, water soluble ink

metric measuring cup

Option: Insulated Collector Jar and Digital Multi-Meter (DMM) Temperature Probes

all of the above but substitute the temperature probes from a DMM or a computer to collect the data; the computer could also provide a more accurate time base

a more sophisticated, insulated collector bottle could be made—try to minimize heat loss to the environment with your design.

substitute different materials other than water as the solar collection material. Ethylene glycol (antifreeze) might be used, or even a photovoltaic cell could act as a collector. Remember, some of the parameters in your calculations will need to be changed if water is not used

different colors of water soluble ink

Procedures

1. Try to do the data collection as close to noon as possible on a clear, cloudless day.

2. Prepare the collector bottle with 150 ml of water with a few drops of the ink to make it fairly black.
3. Insert the cork/thermometer and let the temperature stabilize to a mean air temperature by placing the collector in the shade for 20–30 min or until a check every 2–3 min shows no temperature change.
4. Shade the collector as you move the unit into the sun and set it so that the flat surface is as perpendicular to the incoming solar radiation as possible.
5. As you unshade the collector, begin recording the time and the temperature. (See data sheet)
6. Allow the collector to absorb the sun's rays for about 20 min or at least enough time to get a 3–4 °C temperature rise. Record the elapsed time and temperature rise.
7. Cool the unit by placing it under running water and repeat the procedure two more times so that you have three total sets of data.
8. Measure the size of the bottle's surface that is exposed to the sun and express the area in square meters. This might be tough with odd shaped bottles.

Related Activities:

1. Students are always impressed with the heat that can be generated when the sun's energy is concentrated. Most have used simple hand lenses and magnifiers to do this but there are other interesting ways to accomplish the same thing.
2. Sheet magnifiers (a form of Fresnel lens) of various sizes can concentrate enough heat that small jewelry items can be enameled, soldered, or brazed.
3. With a class of students, have them each obtain a small plane mirror. Use one from a make-up compact, or, better yet, a 100 mm $\times$ 150 mm mirror that students put inside their lockers. Have the students gather outdoors on a sunny day and arrange themselves in a semi-circle facing the sun. Place a target such as a crumpled up sheet of paper out in front of the students and have them shine their reflection of the sun onto the paper. A thermocouple style temperature sensor could also be used to investigate the concentrated energy. The paper will ignite with the collective energy.
4. A great cold weather activity is to have students form lenses from ice. Lenses without air bubbles and other flaws are not easy to make but slightly flawed ice can still get the idea across. A 100-mm ice lens can set paper on fire. Some people have made ice lenses very carefully and then been able to use them in cameras and telescopes. (Handle the ice with gloves so melting is minimal.) This idea could be turned into many projects.

5. Redesign the experiment to use different sized collectors, or different lenses to concentrate the solar energy. How much energy is lost if lenses are used?
6. Try filtering the light before it reaches your collector. Sheets of colored cellophane could be used. What colors allow the greatest energy transmission? absorption? Does the filter material itself (i.e. cellophane, plastic, glass, etc.) make a difference?
7. Assuming that your collector design is a very accurate device, use the accepted value of the solar constant and the atmospheric absorption to calculate the energy absorbed by different transparent materials like plastic, Plexiglass, crystals, gelatin, etc. Note: even if your collector does not give the accepted solar constant value, as long as it is constant, this activity can still be done. Just use your “corrected” solar constant value instead of the accepted value.

Data Sheet and Calculations

Calculations: Follow the calculations on the data sheet. These will give you a step-by-step method for determining the solar constant from the data you've gathered from your simple collector.

Volume of water used:____________________liters

Mass of water used:______________________kilograms

Exposed surface area:_____________________m^2

Trial #	Initial Temp. °C	Final Temp.°C	ΔT°C	Elapsed Time (s)
1				
2				
3				

Average ΔT/sec   I.   Trial #1: $\frac{\Delta T_1}{elapsed\ time} =$

Trial #2: $\frac{\Delta T_2}{elapsed\ time} =$

Trial #3: $\frac{\Delta T_3}{elapsed\ time} =$

II.   Average of the 3 ΔT/time calculations=______°C/s

The specific heat of water is 4186 J/(kg°C). Therefore the energy absorbed by your water per second is:

$$4186 \times \frac{J}{kg \times {}^oC} \times your\ mass(kg) \times \frac{average\ \Delta\ T}{time}$$

$$\frac{Energy}{s} = \underline{\qquad\qquad\qquad} \frac{J}{s}$$

Average energy collected per unit of surface area is:

$$\frac{Energy}{s} \div your\ collection\ area\ (m) = \underline{\qquad\qquad\qquad} \frac{J}{\dot{s}\ m^2}$$

This is your uncorrected solar irradiation for the earth's surface. Both the earth's atmosphere and the glass bottle have absorbed some of the incoming solar radiation and therefore won't show up as energy absorbed by the water. If other materials are used for your collector, then these next calculations may not be valid and more research will probably be necessary.

Multiply your uncorrected solar irradiation by 2 to correct for the glass and also by 1.4 to correct for the atmosphere:

$$solar\ constant = irradiation \times 2 \times 1.4$$

$$\underline{\hspace{3cm}} = \frac{J}{s \cdot m^2}$$

The accepted value of the solar constant is about 1376 W/m^{2}.

Then your % difference is:

$$\frac{your\ solar\ constant - 1376}{1376} \times 100 = \underline{\hspace{3cm}}\%$$ *(include your sign)*

Questions and Interpretations:

1. Detail as many reasons as possible why your value of the solar constant differs from the accepted value.
2. Use the formulas for surface areas of spheres, earth-sun distance, geometry, etc. to find how much energy is being released per second from the surface of the sun.
3. Use the formula for the surface area of a sphere to approximate how much solar energy is received by the earth each day. (Remember that only a half of the earth is exposed to the sun at any given time.)