

MEASURING THE SOLAR CONSTANT

Materials

Per group:

- ▼ 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 50°C
- ▼ Books or rocks (to prop up bottle)

Per class:

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

In this experiment, you will make a device to measure how much energy sunlight provides to Earth.

Procedures:

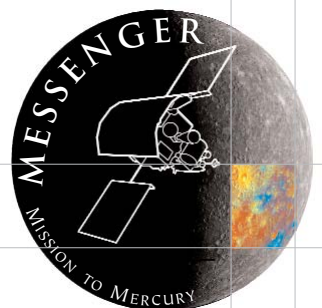
1. Prepare the collector bottle by pouring 150 ml of water into the bottle. Add a few drops of the ink to make it black, and place the thermometer through the hole in the cork or lid. Make sure the seal is as tight as possible by using caulk or masking tape, if necessary. You may need to drill a hole into the cork or metal top of the lid. Insert the cork/lid into the bottle with the thermometer in place and sealed (see Figure S1).
2. Place the collector in shade so that it stabilizes to the mean air temperature. This takes about 10 minutes or until the temperature does not change any more while checking every 2-3 minutes.
3. Move the collector to sunlight. Make sure the unit is shaded while moving. Set the collector down so that the flat surface is as perpendicular to the incoming sunlight as possible. You may need to prop up bottle with books or rocks (see Figure S1).

WARNING

Do *not* look directly at the Sun!

Looking for even a few seconds can cause permanent damage to the eyes!
Note that sunglasses do *not* provide an adequate safeguard against looking directly at the Sun.

So remember to *never* look directly at the Sun!



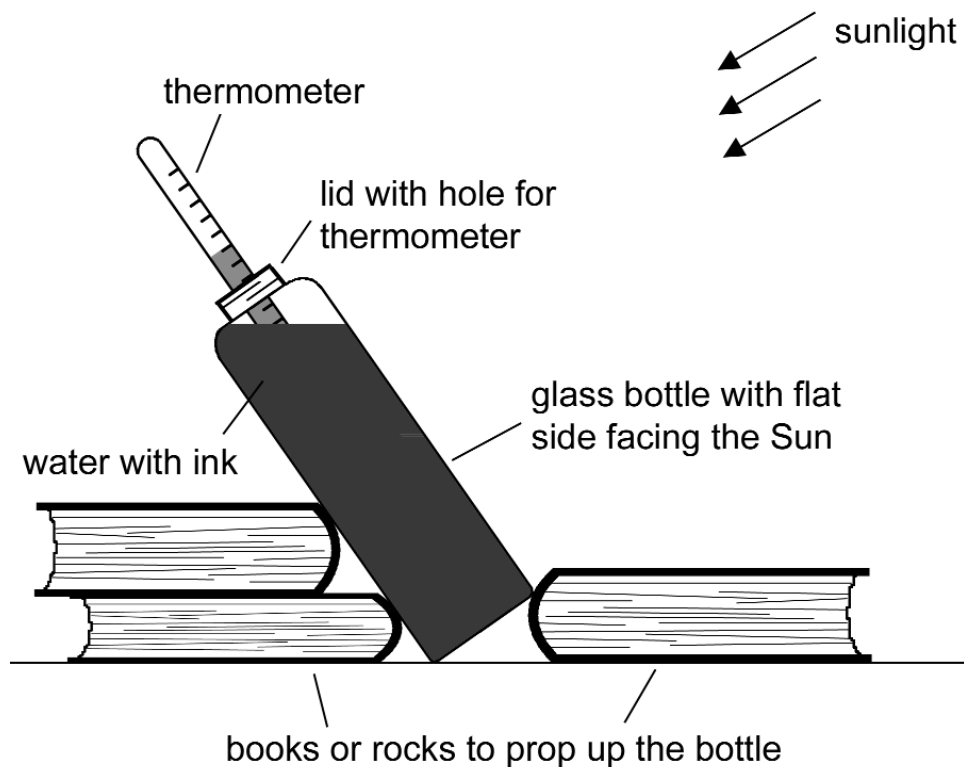


Figure S1. Side view of the experiment setup. Drill a hole to the cork or metal top of a bottle. Insert thermometer in the top and close the bottle. Make sure you can read the thermometer readings without moving the bottle. Place the device in the sunlight so that the flat side of the bottle is facing the Sun and the exposed surface is as perpendicular to the incoming sunlight as possible. You may need books or rocks to help tilt and balance the bottle properly.

4. Begin the experiment by unshading the collector. Start the stopwatch and record the temperature on the Data Table on the next page.
5. Allow the collector to absorb sunlight for 20 minutes or at least enough time to get at least a 3–4 °C temperature rise. Record the elapsed time and temperature rise.
6. Measure the amount of the bottle's surface that is exposed to the Sun and record the area in square meters on the Data Table.

Think: How can I use my data to find the solar constant (how much energy the Earth is receiving from the Sun per square meter per second)?

Making the measurements:

(Hint: To calculate the mass of the water, keep in mind that water has a density of 1.0 g/cm^3 , and that $1 \text{ ml} = 1 \text{ cm}^3$.)

Volume of water used: _____ liters

Mass of water used: _____ kilograms

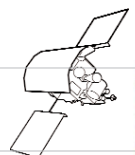
DATA TABLE

YOUR GROUP

Exposed Surface Area (m^2)	Initial Temp ($^{\circ}\text{C}$)	Final Temp ($^{\circ}\text{C}$)	ΔT ($^{\circ}\text{C}$)	Elapsed time (s)

AVERAGE OF ALL GROUPS

Exposed Surface Area (m^2)	Initial Temp ($^{\circ}\text{C}$)	Final Temp ($^{\circ}\text{C}$)	ΔT ($^{\circ}\text{C}$)	Elapsed time (s)



Calculate the solar constant for two cases: the values from your own group, and the class average.

Your group's $\Delta T/s =$ _____

Average $\Delta T/s =$ _____

The specific heat of a substance or object is defined as the amount of energy needed to raise the temperature of one kilogram of the substance one degree Celsius. The specific heat of water is $4186 \text{ J}/(\text{kg} \times ^\circ\text{C})$.

Therefore the energy absorbed by your water per second is:

$$\text{Energy/s} = 4186 \text{ J}/(\text{kg} \times ^\circ\text{C}) \times \text{water's mass}(\text{kg}) \times \Delta T (^\circ\text{C})/\text{sec}$$

$$\text{Energy/s} = \text{_____} \text{ J/s (your group)}$$

$$\text{Energy/s} = \text{_____} \text{ J/s (class average)}$$

Energy collected per unit of surface area is:

$$(\text{Energy/s}) / (\text{exposed surface area (m}^2)) = \text{_____} \text{ J/s/m}^2 \text{ (your group)}$$

$$(\text{Energy/s}) / (\text{exposed surface area (m}^2)) = \text{_____} \text{ J/s/m}^2 \text{ (class average)}$$

This is your uncorrected solar irradiation for Earth's surface, or how much energy your water is receiving from the Sun per second per square meter. Both Earth's atmosphere and the glass bottle have absorbed or reflected some of the incoming solar radiation, and this "lost" energy will not 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 you may need to find out a proper correction factor.

Multiply your uncorrected solar irradiation by 2 to correct for the glass (determined experimentally) and also by a factor (F_c) to correct for the atmosphere (to determine which factor you should use, look on the Condition Correction Table on Page 6):

$$\text{solar constant} = \text{irradiation} \times 2 \times F_c$$

$$= \text{_____} \text{ J/s/m}^2 \text{ (your group)}$$

$$= \text{_____} \text{ J/s/m}^2 \text{ (class average)}$$

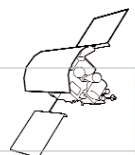
You have now calculated how much energy the Earth is receiving per second per square meter from the Sun. This value is called the solar constant. The accepted value of the solar constant is about 1370 J/s/m^2 .

Then your % error is:

$$(\text{your solar constant} - 1370) / 1370 \times 100$$

$$= \text{_____} \% \text{ (include the sign) (your group)}$$

$$= \text{_____} \% \text{ (include the sign) (class average)}$$

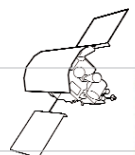


Questions and Interpretations:

1. Detail as many reasons as possible why your value of the solar constant differs from the accepted value (if it does).

2. The Sun radiates energy in all directions. After traveling a distance, r , the energy has spread over an area equal to the surface area of a sphere with radius r . Use the formula for surface areas of spheres and the values of the Earth—Sun distance as well as the solar constant to find how much energy is being released per second from the surface of the Sun.

3. Use the formula for the cross-sectional area of Earth (area of a circle with Earth's radius) and the solar constant to approximate how much solar energy is received by the Earth each day. (Note that the cross-sectional area of the Earth is smaller than half of a surface of a sphere exposed to sunlight at any given time. Since sunlight arrives from only one direction—from the Sun—the amount of solar radiation that the Earth intercepts is the cross-sectional area of the Earth, instead of half the surface area of a sphere.)



Condition Correction Table

Conditions	Correction factor (F_c)
Low humidity, completely clear sky	1.4
High humidity, clear sky	1.5
Some haze	1.6
Some clouds	1.8

Useful Formulae and Constants

Surface Area of Sphere = $4\pi r^2$ (where r is the radius of the sphere)

Cross-sectional Area of Sphere = πr^2 (where r is the radius of the sphere)

Astronomical Unit (1 AU = average Earth-Sun distance) = 1.50×10^{11} m

Solar Constant = 1370 W/m^2 (Remember: $1 \text{ W} = 1 \text{ J/s}$)

Radius of the Earth = 6.37×10^6 m

