



ANSWER KEY

Student Worksheet 1

Materials, cost, and design will vary (but make sure that the students did not purchase materials the total cost of which is over the assigned limit).

Students Worksheet 2

Page 3

Answers will vary. You can check the students' calculations to make sure the "Weight of ice" is "Weight of empty coffee can" subtracted from "Weight of can with ice."

Page 4

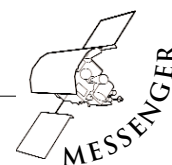
| | Shade can | Control can |
|--|--------------------------------|--------------------------------|
| Mass of ice melted (kg) | mass | mass |
| Amount of energy used (kJ) | mass x 334 | mass x 334 |
| Energy/time used (J/s) | energy / 1000 / time on page 3 | energy / 1000 / time on page 3 |
| Energy/s/unit area (J/s/m ²) | above line/surface area | above line/surface area |

What percent of the energy does your shade keep away from the ice-water mixture?

$(\text{Energy/time (Control)} - \text{Energy/time (Shaded)}) / (\text{Energy/time (Control)})$ Even a simple shade (such as the coffee can lid) reduces the energy used by at least 10%. Better designs should do a considerably better job.

What is your cost efficiency? (Your units should be %/\$)

Number in above line / cost on page 3. If the cost of the coffee can lid is estimated at 50 cents, the cost-efficiency using the 10% reduction would be 20%/\$. For a 90% reduction using a \$2 shade, the cost-efficiency would be 45%/\$. The answers will vary considerably based on the design.





Page 5-6

1. *How was your coffee can angled with respect to the arriving sunlight? How do you think it was beneficial or detrimental for your experiment?*

The best way to set up the coffee can with respect to the Sun is to point it so that its top is as perpendicular as possible to the arriving sunlight (or the can and the direction of the sunlight are as parallel as possible – i.e., the measured angles are the same). This ensures that the shade blocks the most sunlight from hitting the can. Otherwise sunlight coming at an angle could heat up the sides of the can and transfer heat to the water through conduction.

2. *Why did you have to weigh the can before the experiment as well as after? Were your results different? Why or why not?*

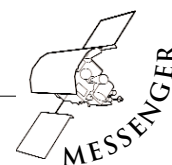
Weighing the cans with ice vs. cans without ice is also the best way to measure the mass of the ice quickly. After the experiment, the cans will have a few remaining water droplets on the insides. Though there would not be very much, it may mean the difference of one or two grams, which could affect the results of the experiment. Individual results may vary.

3. *Why do you think the control can is useful? (Name at least two reasons.)*

Examples of good answers: The control tells us when enough ice has melted without having to remove the shade, and provides an estimate of how much the experiment is affected by various error factors (e.g., heat conduction from the environment, variations of the amount of sunlight lost in the atmosphere due to local conditions such as clouds, humidity, weather, etc.). This makes the calculation of the efficiency of the shades more accurate.

4. *Why do we care how much the shade costs? Think of real-life examples where you might want to minimize your shade cost.*

Answers may vary. We care how much the shade costs because there are real-life applications, and we always want to minimize our costs in real life. Examples may include NASA missions (like MESSENGER), or every-day examples like hikers or farmers or people or things that may need to be out in the sunlight for long periods of time.





5. *What sources of error might you have?*

Answers will vary. Possible answers include heat conducted to the can from the environment, additional ice melting as a result of having time between measurements and start/stop of stopwatch, etc.

6. *The solar constant (the amount of solar energy received by Earth) on top of the atmosphere is about 1370 J/s/m². The atmosphere blocks 30-50% of the radiation (depending on the cloud cover), so that the typical amount of solar radiation arriving on the surface of Earth is 700-1000 J/s/m².*

a) How does the amount of energy used in melting the ice in the control (unshaded) can in your experiment compare with the solar radiation?

In the basic setup of the experiment done in roughly room temperature, the energy used is a lot more (even more than twice as much) as the real value of the solar constant. Under different conditions, the calculated value might be close to the actual value, but probably still somewhat higher.

b) How could you explain the similarities or differences in your value based on the experiment design?

There is additional heat coming into the can to melt the ice besides solar radiation. The most significant source is heat conduction from outside, either from warm air around the experiment device and/or sunlight striking the sides of the can. This question is used to prompt the students into thinking heat conduction as a significant source of errors and perhaps improving on their design of the experiment based on this realization if they were to perform the experiment again.

8. *Scientists often have to revise their experiments after an initial try when they discover possible sources of errors and must eliminate them. How would you conduct your experiment differently if you had to do it again? Why or why not?*

Answers will vary. For example, they could tilt the device more toward the Sun to eliminate sunlight striking the sides of the can, they could conduct the experiment more quickly, they could place the device in a cool, insulated container to reduce the level of heat conduction through the sides of the can, etc.

9. *Would you construct your shade differently if you had to do the experiment again? Why or why not?*

Answers will vary. The students may say they want it to cost less, use better materials, etc.



Page 7

Describe how you plan to modify the basic experiment setup described in Figure S1 in Student Worksheet

1. Explain why you think this experiment setup will work better.

Note that the idea behind asking the students to consider modifying the experiment setup is that the way the system is set up in Figure S1, heat conduction from the warm environment in which the coffee cans sit will be a source of errors in the experiment. The presence of the control can is needed to keep track of these errors. Possible modifications of the setup include performing the experiment as close to noon as possible so that the sunlight enters only through the shade and does not warm the sides, encasing the device in a cold environment (e.g., thermal lunch bag filled with ice), performing the experiment on as cold a day as possible with sufficient sunlight still present, etc. These answers have been considered in Question 8 on Page 6; here the ideas are put in the form of an actual improved design.

Student Challenge Sheet

Page 1

1. Think about the experiment you performed with ice melting in the coffee can.

a) Explain what happened to the motion of and the bonds between molecules of the ice.

The thermal energy received by the ice resulted in the breaking of the solid bonds between the ice molecules. As a result, their motion became more disorderly.

b) How can you express this in terms of entropy?

The entropy of the ice increased.

c) What about the water that was there at the beginning of the experiment? Did its entropy change? How did it change?

Since the thermal energy received by the contents of the coffee can went to the melting of the ice, and the temperature of the water did not increase, its entropy did not increase.

d) What happened to the total entropy in your classroom (or in the universe!) as a result of this experiment? Did it increase or decrease?

The total entropy increased. This is the result of all natural processes.





Pages 2-3

1. *What is the change in entropy for the amount of ice you melted in your shaded can?*

Answers will vary. A sample answer if mass of melted ice = 100 g

$$\Delta S = \Delta H / T$$

now $\Delta H = 334 \text{ kJ/kg} \times (\text{mass of melted ice})$

$$\begin{aligned}\Delta S &= \Delta H / T = 334 \text{ kJ/kg} \times 0.100 \text{ kg} / 273 \text{ K} \\ &= +0.122 \text{ kJ/K} = +122 \text{ J/K}\end{aligned}$$

The sign of the entropy change is positive: entropy increased in the ice.

2. *How much does entropy increase when transmitting 1370 J of energy from the Sun to the Earth?*

The temperatures of the Sun and Earth do not change appreciably during the process, so

$$\Delta S = q/T,$$

and therefore

$$\Delta S_{\text{Sun}} = -1370 \text{ J} / 5800 \text{ K} = -0.236 \text{ J/K} \text{ (minus sign because Sun emits energy)}$$

$$\Delta S_{\text{Earth}} = +1370 \text{ J} / 288 \text{ K} = +4.757 \text{ J/K} \text{ (plus sign because Earth gains energy)}$$

The total change of entropy for the Sun-Earth system is

$$\begin{aligned}\Delta S_{\text{Sun+Earth}} &= \Delta S_{\text{Sun}} + \Delta S_{\text{Earth}} \\ &= -0.236 \text{ J/K} + 4.757 \text{ J/K} \\ &= +4.521\end{aligned}$$

and the sign is positive – entropy increases in the process, as expected!

3. Potential energy $PE = mgh$

$$1 \text{ kg} \times 334 \text{ kJ/kg} = 1 \text{ kg} \times 9.8 \text{ m/s}^2 \times h$$

$$h = 34,000 \text{ meters} = 34 \text{ km}$$

