Hold the Heat: Global Warming and Calorimetry

Joel D. Burley[1*] and Harold S. Johnston[2]
[1]Dept. of Chemistry, Saint Mary's College of California, Moraga, CA 94575; *jburley@stmarys-ca.edu
[2]Dept. of Chemistry, University of California; Chemical Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720; hsj@berkeley.edu

In this Activity, students perform quantitative calorimetric measurements on samples of ice/water heated by incandescent light bulbs and/or convection with room-temperature surroundings. They measure and graph temperature as a function of time. They observe that the temperature of the ice water samples remains constant for a time as the ice melts. This is linked with the topic of global warming.

Background

This Activity adapts an experiment previously published in *JCE (1)*. It highlights the distinction between global heat retention and global warming. Students observe that the addition of heat energy to a substance does not necessarily cause its temperature to increase. Sometimes, it does something other than increase the kinetic energy (i.e. the temperature) of the molecules present. For example, some of the heat energy retained by the Earth has melted polar ice rather than increased the Earth's temperature. Increased global heat retention contributes to two different observables—(i) temperature increases for the atmosphere, the oceans, and land masses, and (ii) long-term melting of surface ice with no change in temperature.

Integrating the Activity into Your Curriculum

We recommend presenting this Activity as part of a broader discussion of global warming. It can also be a stand-alone introduction to calorimetry. It utilizes very simple equipment and non-hazardous reagents (crushed ice and tap water). After completing this Activity students can attempt additional "word problem" calorimetric calculations *(1)* and read more detailed accounts that describe how global warming is affecting the Arctic *(2)*.

About the Activity

Each student group needs three identical 100 mL beakers, three glass stir rods, three thermometers (or temperature probes), and two small desk lamps (approx. 50-watt bulbs). Access to a balance with a capacity of 150–200 grams is also required. Students prepare three samples: 1) 80 g of room-temperature water heated by the 50-watt incandescent bulb of a desk lamp, 2) 80 g of an ice–water mixture heated by conduction from the room-temperature surroundings, 3) 80 g of an ice–water mixture heated by the 50-watt incandescent bulb of a desk lamp and by conduction from the room-temperature surroundings.

Completely shield sample 2 from the lamps used to heat samples 1 and 3. After the samples are ready, students stir and record the initial temperature of each sample (t = 0 min), turn on the lamps, and start timing. Temperatures are recorded every minute, in a staggered fashion (i.e. sample #1 is measured at t = 1 min, #2 at t = 2 min, #3 at t = 3 min, back to #1 at t = 4 min, and so on), with thorough stirring before each measurement. Data collection proceeds continuously until sample 2 melts and the temperature warms a few degrees above 0 °C. This took approximately 25–30 minutes during testing.

Answers to Questions

1. The beakers must be identical because their physical characteristics influence how quickly heat energy is transferred to the H_2O sample. If the masses of H_2O were not the same, it would not be possible to determine if differences in observed heating rates were caused by differences in sample mass (heavier samples require more heat input to attain the same ΔT, and therefore experience slower heating rates) or the different methods used to heat the three samples. We recommend testing the set-up to verify that sample 3 provides several 0 °C measurements. If the temperature rises too soon, pull the lamps farther away, or measure temperatures every 30 seconds.
2. Stirring is necessary to make sure that the samples are well-mixed and uniform in temperature.
3. Sample 1 started to change temperature as soon as the lamp was turned on.
4. Samples 2 and 3 displayed delayed warming, with a baseline temperature of 0 °C. The ice needed to melt.
5. Sample 1 is warmed by the lamp. Sample 2 is warmed from an initial temperature of 0 °C (after the ice melts) by conduction with the room-temperature surroundings. Sample 3 is warmed from an initial temperature of 0 °C (after the ice melts) by both the lamp and conduction. Sample 3 has the largest slope, approximately equal to slope 1 plus slope 2.
6. The ice-water samples used here differ from actual land based glaciers or sea ice because they are (i) thoroughly mixed, (ii) uniform in temperature, and (iii) free of impurities such as rocks or dirt.
7. No, the temperature does not increase if the sample is experiencing a phase transition (i.e. a solid melting to a liquid or a liquid vaporizing to a gas). In these cases the temperature remains constant—at either the melting point or the boiling point—until the phase transition is complete.
8. "Global heat retention" is a more accurate description than "global warming" because long-term melting of surface ice consumes heat with no increase in temperature.

References, Additional Related Activities, and Demonstrations

1. Burley, Joel D.; Johnston, Harold S. A Simple Calorimetric Experiment That Highlights Aspects of Global Heat Retention and Global Warming. *J. Chem. Educ.* **2007**, *84*, 1686–1688.
2. *Impacts of a Warming Arctic;* Hassol, S. J., Ed.; Arctic Climate Impact Assessment; Cambridge University Press: Cambridge, 2004.

***JCE Classroom Activities* are edited by Erica K. Jacobsen**

Hold the Heat: Global Warming and Calorimetry

Why are scientists who study global warming concerned about the melting of glaciers (land-based ice sheets) and Arctic sea ice? How does the melting of surface ice support the global warming hypothesis? Scientific concepts associated with global warming have received extensive media coverage in recent years and are now well-known to both expert researchers and the general public. Human activities such as the burning of fossil fuels are dramatically increasing atmospheric concentrations of carbon dioxide and other greenhouse gases. Rising concentrations of greenhouse gases have decreased the emission of infrared (heat) radiation from the Earth back into cold outer space. As a result, the Earth retains, or holds onto, more heat energy. However, this human-induced climate change consists of more than just "warming". Observed warming is not a complete measure of the increased energy retention the Earth experiences. How do you think additional heat energy affects both the temperature of the Earth and its glaciers and sea ice? Do the temperature increases observed to date actually under-represent the full extent of the problem of global warming? In this Activity, you will investigate these questions by simulating the melting of glaciers and Arctic sea ice. You will measure temperature changes over time as heat energy is added to samples containing either both solid ice and liquid water, or only liquid water.

Try This

You or your student group will need: water, crushed ice, three identical 100 mL beakers, three glass stir rods, three thermometers (or temperature probes), two small desk lamps (preferably similar or identical, each with a ~50-watt incandescent bulb), stopwatch, and access to a balance.

__1. Label three identical 100 mL beakers 1 through 3. Weigh each on a balance and record the resulting masses.

__2. Load beaker 1 with 80 g of room temperature water.

__3. Add 80 mL of crushed ice to beaker 2. Repeat for beaker 3.

__4. Add cold tap water to beaker 2 until the net ice-plus-water mass is 80.0 ± 0.2 g. Repeat for beaker 3.

photo by Joel D. Burley

Samples 1 and 3 are heated by the bulb of a 50-watt desk lamp placed 10 cm from the beaker.

__5. Place desk lamps behind samples 1 and 3. Position the head of the lamp so that it is directly facing the beaker from a distance of approximately 10 cm (the lamps should remain off for now). Shield sample 2 from the lamps that are used to heat samples 1 and 3.

__6. After the samples are ready, stir and record the initial temperature of each sample ($t = 0$ min). Then, turn on the lamps, and start the stopwatch

__7. Measure the temperature after thoroughly stirring each sample: sample #1 at $t = 1$ min, followed by #2 at $t = 2$ min, #3 at $t = 3$ min, back to #1 at $t = 4$ min, and so on.

__8. Continue to stir and measure the temperatures of all three samples until the ice in sample 2 completely melts and the temperature has warmed a few degrees above 0 °C.

__9. Plot your data (temperature as a function of time for all three samples) either by hand, or by using Microsoft Excel or a similar spreadsheet program.

Questions

1. Why was it necessary to use identical beakers, each containing the same total mass of H_2O (liquid water plus ice)?
2. Why was it necessary to stir each sample before each temperature measurement?
3. Which sample(s) started to warm right away (i.e. immediately after $t = 0$, when the lamps were turned on)?
4. Which sample(s) displayed delayed warming? What was the observed baseline temperature for these samples before the warming kicked in? What physical change had to occur before the samples warmed above the baseline temperature?
5. Estimate the slopes (for the initial warming, not the baseline regions) for each of the three samples. How do these slopes (which indicate the rate of warming) compare to one another?
6. In what ways do the ice–water samples used here differ from actual land-based glaciers or sea ice?
7. When a substance is heated, does the temperature of the substance always increase? Explain.
8. Based on your results, why is the phrase "global heat retention" a more accurate description of what is occurring on our planet than "global warming?"

Information from the World Wide Web *(accessed Nov 2007)*

U.S. Environmental Protection Agency: Climate Change. *http://www.epa.gov/climatechange/*

National Oceanic and Atmospheric Administration: Global Warming Frequently Asked Questions. *http://www.ncdc.noaa.gov/oa/climate/globalwarming.html*

Arctic Climate Impact Assessment. *http://www.ucsusa.org/global_warming/science/arctic-climate-impact-assessment.html*