Investigating Reusable Heat Packs

Overview

Can a small bag containing a solution act as a source of heat at a moment's notice? Students discover how a reusable heat pack provides heat and measure the amount of heat given off. In the culminating teacher demonstration, the class makes a heat pack.

Key Concepts

- calorimetry
- changes of state
- concentration
- conservation of energy
- crystallization
- energy changes
- exothermic processes
- experimental design
- heat
- heat energy
- insulators
- saturated solutions
- solutes
- solutions
- solvents
- specific heat
- supersaturated solutions
- temperature

National Science Education Standards

Science as Inquiry

Abilities Necessary to Do Scientific Inquiry

- *Students use a calorimeter to determine the amount of heat produced by the heat pack. (5–8, 9–12)*
- *Students use mathematical equations to determine the amount of heat produced in the crystallization process. (5–8, 9–12)*
- *Students see how mathematical tools and models guide and improve questioning, gathering data, constructing explanations, and communicating results. (5–8, 9–12)*
- *Students determine what data they will need to collect in order to calculate the amount of heat given off by a heat pack. (5–8, 9–12)*
- *Students design and conduct an experiment, using a control and testing one or more variables, to determine how to slow down the loss of heat from a heat pack. (5–8, 9–12)*
- *Students pose testable questions and design experiments to answer these questions. (5–8, 9–12)*

Physical Science

Structure and Properties of Matter

- *Students investigate the crystallization process and explore the use of seed crystals to initiate the process. (9–12)*

Conservation of Energy and the Increase in Disorder

- *The lesson illustrates a consequence of the second law of thermodynamics. Crystallization increases the order (reduces the entropy) of the contents of the heat pack, so to maintain an overall increase of entropy, energy is released to the surroundings as heat. (9–12)*
- *Students learn that heat is a form of energy produced by the motion of small particles of matter and that temperature is a measure of a system's ability to gain or lose heat. (9–12)*

Interactions of Energy and Matter

- *Students explore the effectiveness of various materials as insulators and discover that insulation slows the transfer of energy from the heat pack to the environment. (9–12)*

Transfer of Energy

- *Students learn that heat moves in predictable ways, in this case from the heat pack to its surroundings. (5–8)*

Part A: Teacher Demonstration

How does a heat pack work?

Materials

- reusable heat pack
- overhead projector

Procedure

➤ *Make sure the heat pack ingredients are in solution form, not crystalline form.*

1. Ask the students to name several different ways to generate heat. Then find out how many of these are "portable" sources. Show them the heat pack, asking if they know what it does.
2. Pass the heat pack around and ask students to make observations, cautioning them to handle the solution gently and not to touch the pack near the metal disk.
3. Place the bag on an overhead projector as you instruct the class to observe. Activate the heat pack by flexing the metal disk gently. After the students observe the crystallization process on the overhead, pass the bag from student to student so that all can observe.
4. Ask questions such as, "Where does the heat comes from? How can the bag be reused?" Demonstrate the redissolving process if time allows.

Part B: Student Exploration

How much heat does the heat pack give off? How can we keep the pack from losing its heat?

Materials

- reusable heat pack
- water
- thermometer
- graduated cylinder
- 480-mL (16-ounce) or larger Styrofoam® cup
- water
- other materials as needed for this student-designed experiment

Procedure

1. Decide what measurements you need to make in order to calculate the amount of heat (in Joules) given off by a heat pack.

➤ *Use the equation $q = m \times \Delta T \times C_p$ where q is the heat released in Joules, m is the mass of the water in grams, ΔT is the change in temperature in Kelvin, and C_p is the specific heat capacity. (For water, C_p is 4.18 J/g•K.) To convert °C to K, use the formula °C + 273 = K.*

2. Devise a plan to collect this data. Use a large Styrofoam cup as a calorimeter. Implement your plan, collect the necessary data, and calculate the heat released by the activated heat pack. *How much heat would be needed to return the contents of the heat pack back to a solution?*

3. *Make a list of the factors that affect the time required for the fully heated pack to cool to room temperature.* Design a method to delay this heat loss for as long as possible. Test your method and be sure your experiment includes a control.

Part C: Teacher Demonstration

Can we make it ourselves? Manufacture your own heat pack using a supersaturated solution of sodium acetate.

Materials

- sodium acetate trihydrate ($NaC_2H_3O_2 \cdot 3H_2O$)
- distilled water
- 1-L flask
- hot-water bath, made from the following:
  - large container or pot
  - hot plate or other heat source
- glass pie pan, crystallizing dish, or piece of clean hardboard measuring about 30 cm × 30 cm (about 12 inches × 12 inches)
- 2 clean 250-mL flasks or zipper-type plastic bags
- petri dishes
- watch glass or foil
- overhead projector
- table salt (NaCl) and other crystalline solids

Preparation

1. Combine 350 g (about 1½ cups) sodium acetate trihydrate ($NaC_2H_3O_2 \cdot 3H_2O$) and 100 mL distilled water in the flask.

2. Place the flask with its contents in the hot-water bath, cover with a watch glass or foil to minimize water loss, and heat the water to boiling. The flask can be swirled occasionally to speed the dissolution, but caution must be used, as the flask and the steam will be very hot. Once all of the solid has dissolved, turn off the heat source and allow the setup to cool to room temperature before removing the flask from the hot-water bath. Keep the mouth of the flask covered with a watch glass or foil until ready to use.

Procedure

1. Pour about ⅓ of the room-temperature supersaturated sodium acetate solution into either a clean flask or a zipper-type plastic bag container. Have volunteers feel the sides of the container and report what they feel to the class. Ask the students, "What is required to initiate crystallization?"

2. Add 1 or 2 small "seed" crystals of the sodium acetate trihydrate to the flask or bag and observe. Have the volunteers feel the container again and report their observations. Turn the container sideways to see if any liquid remains.

3. To show a dramatic example of crystallization, very slowly pour about half of the remaining supersaturated sodium acetate solution in the flask onto a few crystals of sodium acetate that are lying on a glass pie pan, crystallizing dish, or piece of clean hardboard or tabletop.

➤ *Crystallization of the supersaturated solution occurs as soon as the solution comes in contact with the seed crystal, forming a mound or column of white solid sodium acetate. The lip of the flask or container must not come into contact with the crystallizing sodium acetate, since this would cause the rest of the solution to crystallize while still in the flask or container. Uncontaminated solutions of sodium acetate can be reused many times. They should be stored covered, as the supersaturated solution, instead of in the crystalline form.*

Restore the crystals to a supersaturated solution by covering the mouth of the flask with a watch glass or foil and reheating the flask in a hot-water bath. (If the solid is in a plastic bag, transfer it to a flask first.) Be sure that no undissolved crystals remain. Turn off the heat source and allow the flask and its contents to cool to room temperature before removing from the hot water bath. Leave the flask covered until use. Small amounts of water may have to be added to compensate for loss of water due to evaporation when heating.

Instructor Notes

Tips and Instructional Strategies

- Discuss the terminology of solutions; for example, solute, solvent, unsaturated, saturated, and supersaturated.
- According to the manufacturer, the heat pack should always be stored in the solution form, not the crystalline form. Place the crystallized heat packs in boiling water for about 10 minutes to return to solution. Allow 45 minutes for the heat packs to cool to room temperature.
- For Part B, you may want to have students in lower grades calculate the heat released in calories, rather than Joules, according to the definition: 1 calorie equals the energy needed to raise the temperature of 1 gram of water by 1°C. (Specific heat for water in calories is 1.00 cal/g•°C.) Students in lower grades may also need hints on how to devise a plan to collect the necessary data.
- For Part B, step 2, students are likely to find that the maximum temperature is reached in 30–40 minutes when using 270 mL water. Note that stirring the water in the calorimeter will make a difference in the data collected. The maximum temperature will be reached sooner if the water is stirred.
- For Part B, step 3, discuss experimental design as a class. Emphasize the importance of controlling variables. Establish what the variables would be for each experiment proposed, and discuss how students would control these variables. You may want to develop a procedure as a class, assign different ways of insulating to different groups, and have one untreated heat pack serve as a control for the class. Alternatively, each group could develop and carry out their own experimental procedure.
- For Part C, prepare extra flasks of supersaturated sodium acetate solution, just in case. Flask contents may crystallize if jostled.
- In Part C, step 2, a small amount of solution may remain above the crystals. If observed, point out that a common misconception is that all of the solute crystallizes out of solution. Actually, only the "extra" solute crystallizes. The remaining solution is a saturated solution.
- You can also show the students that you can form intricate sculptures using a wash bottle of supersaturated sodium acetate to deliver the solution onto the seed crystals. (If the tip of the wash bottle comes into contact with the crystals, the entire contents of the bottle will crystallize.)
- Challenge students to pose testable questions based on what they've done and learned in the lesson. They can design experiments and collect evidence to answer these questions, formulate claims about their findings, and, if time allows, present and defend their claims with their group or class. While we strongly recommend that students develop their own testable questions, you may need to seed the discussion with possible questions such as these: Other than bending the metal disk as in Part A, can something be done to

the heat pack to cause the excess sodium acetate to precipitate from the supersaturated solution without cutting the bag open or otherwise destroying it? What effect does the starting temperature of the water have on the amount of heat released by the heat pack (as determined in Part B)? Can crystals of another solid be used to seed the crystallization process in Part C?

Explanation

The heat pack contains a supersaturated solution of the salt sodium acetate in water. A supersaturated solution is one in which there is more solute (sodium acetate) dissolved in the solvent (water) than would normally be possible at a given temperature. This is accomplished by heating the solution to a higher temperature and allowing it to slowly cool. With most salts, the extra solute that dissolved at the higher temperature crystallizes out of solution as it cools. However, with substances that form a supersaturated solution, this extra solute remains dissolved. Honey is an example of a supersaturated solution of sugar in water.

A supersaturated solution is inherently unstable but remains as a solution until something initiates crystallization. You may have seen jars of honey that became crystallized. In the heat pack, the flexing of the metal disk creates a shock wave that is sufficient to initiate crystallization. Once this occurs, the supersaturated solution immediately crystallizes to form the more stable solid. Heat is given off as the solution crystallizes. Supersaturated solutions can also be made to crystallize by adding a "seed" crystal, a crystal of the same solid that is dissolved in the supersaturated solution. Typically, crystals of different substances will not initiate crystallization.

Temperature is related to the average KE of the molecules and is measured in degrees C, K, F. Heat is a measure of total energy in a substance (PE and KE) measured in J or cal. Temperature is a measure of how hot or cold a substance is relative to another substance. Heat energy is transferred between two systems as a result of temperature difference, flowing in the direction of lower temperature.

The crystallization process is reversible. If the crystallized sample is heated, it goes back into solution. The heat absorbed by the crystallized heat pack to get the salt back into solution is released when the sodium acetate recrystallizes. (When sugar crystallizes in honey, it also can be made to go back into solution by heating.)

The amount of heat, q, transferred by the hot pack can be calculated from:

$$q = m \times \Delta T \times C_P$$

where m is the mass of the water used in grams, ΔT is the change in temperature in Celsius degrees or Kelvin*, and C_P is the specific heat capacity. (For water, C_P is 4.18 J/g•K or 1.00 cal/g•°C.) *Note: ΔT in °C is equal to the ΔT in K.

Answers to Student Questions

Part B

Step 2

a. *Calculate the ΔT using the starting and ending temperatures. Calculate the heat released in Joules (q) in the crystallization process using the equation below where m is the mass of the water used in grams and C_p is the specific heat capacity. (For water, C_p is 4.18 J/g•K.)*

$$q = m \times \Delta T \times C_p$$

b. *Since energy is conserved, the same amount of heat that was released when sodium acetate crystallized must be absorbed to return the solid to solution.*

Step 3

Factors include the size of the temperature change observed in the heat pack, the room temperature, and the type and amount of insulation.

Reference

Sarquis A.M., Sarquis, J.L., Eds. Crystallization of a Supersaturated Solution. *Fun with Chemistry: A Guidebook of K–12 Activities*, Vol. 2; Institute for Chemical Education: Madison, WI, 1993; pp 287–291.