The Hot and Cold of It

Endothermic and Exothermic Reactions

Introduction

Humans rely heavily on information from visual stimuli to draw inferences and make judgments about a situation. What happens if our senses deceive us? Sometimes the signals we receive (or perceive) in chemistry lab can cause us to draw the wrong conclusions about a chemical reaction. This demonstration pairs two different chemical reactions with opposite and unexpected temperature changes. The first mixture appears to bubble and "boil," but the temperature actually drops. In the second reaction, a solution appears to "freeze," and the temperature rises dramatically.

Concepts

- Endothermic vs. exothermic reactions
- Thermodynamics
- Supersaturated solutions
- Enthalpy

Materials

Baking soda (sodium bicarbonate), $NaHCO_3$, 7 g
Sodium acetate, trihydrate, $CH_3CO_2Na{\cdot}3H_2O$, 160 g
Vinegar (dilute acetic acid), CH_3CO_2H, 60 mL
Water, distilled or deionized
Balance
Erlenmeyer flasks, 500-mL, 2
Graduated cylinder, 50- or 100-mL
Digital thermometer
Temperature probe and computer or calculator interface system
Heat-resistant gloves or tongs
Hot plate or Bunsen burner
Parafilm M™ or small beaker
Stirring rod, glass
Wash bottle
Weighing dish

Safety Precautions

Sodium acetate is slightly toxic by ingestion, inhalation, and skin absorption and is a body-tissue irritant. The crystallization reaction is quite exothermic—wear heat-resistant gloves when handling the hot flask. Wear chemical splash goggles, chemical-resistant gloves, and chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Prepare a supersaturated solution of sodium acetate by dissolving 160 g of sodium acetate trihydrate in 30–40 mL of distilled or deionized water in a 500-mL Erlenmeyer flask. Heat the mixture on a hot plate, stirring occasionally, until all the solid has dissolved. (This may take about 15 minutes.) Wash down the sides of the flask with a small amount of distilled water from a wash bottle to dissolve any crystals. Make sure there is no solid remaining on the sides of the flask. Carefully remove the flask from the heat, cover it with a small beaker or Parafilm, and allow the solution to cool undisturbed until ready for use.

Procedure

Carry out two separate reactions: reaction of vinegar and baking soda (steps 1–3), and crystallization of sodium acetate (steps 4–6).

1. Pour about 60 mL of vinegar into a 500-mL Erlenmeyer flask and measure the initial temperature using a digital thermometer or temperature probe connected to a computer interface system such as Vernier LabQuest or CBL and graphing calculator. (See the *Tips* section.)
2. Weigh out approximately 7 g of baking soda into a weighing dish. Slowly add the baking soda to the vinegar.

3. Observe the signs of chemical reaction and measure and record the temperature of the mixture as the reaction proceeds. Stir the mixture using a stirring rod or the digital thermometer probe. *(Formation of gas bubbles provides evidence for a chemical reaction. The temperature decreases, falling about 10–15 °C.)*
4. Obtain the Erlenmeyer flask containing the supersaturated solution of sodium acetate. Move slowly to avoid crystallization.
5. Carefully place the digital thermometer into the sodium acetate solution and measure and record the initial temperature. The solution will probably begin to instantaneously crystallize. If it does not, add one small crystal of sodium acetate to the solution to initiate crystallization.
6. Observe the signs of physical or chemical change, and measure and record the temperature change as crystallization occurs. (There will be a very fast "chain reaction" as the solution solidifies in a beautiful crystalline pattern, from the top down. The temperature will rapidly increase to 45–55 °C.
7. Remove the thermometer or temperature probe from the flask and turn the flask upside down. There should be no leftover liquid remaining after recrystallization.
8. *Optional:* To reactivate the sodium acetate solution, reheat the mixture on a hot plate for 10–15 minutes. When all of the crystals have redissolved, remove the flask and allow to slowly cool to room temperature before using it again.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Save the sodium acetate solution for future use. Simply seal the Erlenmeyer flask with Parafilm and store in a a large plastic beaker to prevent breakage. To reuse the solution, simply heat the flask to re-dissolve the sodium acetate. Waste solutions from this experiment may be rinsed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- Record temperature versus time using a temperature probe or sensor and a computer or calculator interface system such as Vernier LabQuest or CBL-2 and a TI-83 graphing calculator.
- Use a borosilicate glass Erlenmeyer flask for the sodium acetate reaction. The temperature increase is very sudden.
- Sodium acetate solutions are used in commercial heat packs and instant hand warmers.
- A variation of the sodium acetate demonstration is to place a single crystal into a shallow container and slowly pour the supersaturated solution onto the crystal. A tall column of crystals should be produced.

Discussion

The bubbling action in the baking soda and vinegar mixture makes the solution appear to "boil" but the temperature goes down, indicating an endothermic reaction. When the sodium acetate solution appears to "freeze," the temperature actually increases. This is an exothermic process. Topics for discussion might include saturated and supersaturated solutions, crystallization, and heats of reactions or enthalpy changes.

The sodium acetate solution is actually supersaturated and supercooled, since it contains more dissolved sodium acetate than a saturated solution and has been cooled to below its freezing point without crystallization occurring. In a sealed container, the solution may be cooled to as low as –10 °C without freezing. Adding just a single "seed" crystal of sodium acetate trihydrate essentially starts a chain reaction that causes the entire solution to crystallize. In this case, crystallize means that the liquid becomes a solid—it freezes!

When crystallization is activated, the solution climbs to the freezing point of sodium acetate trihydrate, which is 54–58 °C. At this temperature, the sodium acetate solution changes from a liquid to a solid. The mixture will not exceed this temperature because as additional heat is released in the crystallization process, it is used to melt the crystals that have previously formed. The temperature of the system, therefore, will not rise above the freezing (melting) point until all the solid has melted again! Since the temperature of the system is above room temperature and heat is continuously lost to the surroundings, eventually all the sodium acetate trihydrate will solidify rather than melt.

The reversible crystallization–dissolving process for sodium acetate trihydrate may be represented by means of the following equation.

$$NaC_2H_3O_2{\cdot}3H_2O(l) \rightleftarrows NaC_2H_3O_2{\cdot}3H_2O(s) + \text{heat (19.7 kJ/mole)}$$

The forward reaction represents crystallization (freezing). Notice that heat is released in this reaction—the reaction is exothermic. The reverse reaction represents the melting process. Notice that heat must be added to the system in this reaction—the reaction is endothermic.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure of atoms, structure and properties of matter, chemical reactions, conservation of energy and increase in disorder, interactions of energy and matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of *The Hot and Cold of It* activity, presented by Michael Heinz, is available in *Endothermic and Exothermic Reactions*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *The Hot and Cold of It* are available from Flinn Scientific, Inc.

Materials to perform this activity may be purchased separately.

Catalog No.	Description
S0043	Sodium Bicarbonate (Baking Soda), Laboratory Grade, 25 g
S0036	Sodium Acetate, Trihydrate, 100 g
V0001	Vinegar, Cider, 1 L

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.