Quick Freeze

Saturated, Unsaturated, and Supersaturated Solutions

Introduction

A bottle of liquid club soda is removed from an ice bath and opened. Moments later the club soda freezes inside the bottle.

Concepts

- Freezing point depression; the freezing point of a pure solvent will be lowered by the addition of a solute. As the concentration of solute in a solvent increases, the freezing point is lowered and the liquid phase exists over a greater temperature range.
- Dissolved gases; as the pressure decreases, the solubility of a gas in a liquid decreases.
- Gas bubbles coming out of solution act as nucleation sites in a solution supersaturated with gas. Physical changes occur around this "seed."

Materials

Beaker, 1-L
Club soda, 10 oz. in a clear glass bottle
Crushed ice
Rock salt
Thermometer, –20 to 110 °C

Safety Precautions

Do not shake the unopened bottle; this may cause the dissolved gas to come out of solution, causing the beverage to freeze and the bottle to explode. Cool the soda behind a safety shield or away from students. Avoid contact of all chemicals with eyes and skin. Follow all laboratory safety guidelines. All food-grade items that have been brought into the lab are considered laboratory chemicals and are for lab use only. Do not taste or ingest any food items in the chemical laboratory and do not remove any remaining food items after they have been used in the lab. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information. Remember to wash hands thoroughly with soap and water before leaving the laboratory.

Warning

The freezing point of club soda is about –10 °C. Be sure to keep the ice mixture above this temperature. If the sealed bottle freezes, the change in volume will cause the bottle to break, possibly even explode.

Preparation

1. Remove the labels from the club soda bottles so that the freezing action will be seen well.
2. Cool the club soda in a refrigerator or an ice chest for at least five hours before the demonstration.

Procedure

1. Place a thin layer of crushed ice at the bottom of a 1 liter beaker.
2. Sprinkle a thin layer of rock salt into the beaker, overlaying the ice.
3. Place the cooled bottle of club soda in the center of the beaker and continue alternating layers of ice and rock salt around the bottle. Be sure to completely cover the bottle.
4. Place a thermometer into the ice/salt mixture. The thermometer should be very close to or touching the bottle in order to obtain an accurate reading of the temperature of the mixture affecting the soda.
5. The club soda must reach a temperature of –8 °C (17.6 °F) and remain there for about 10 minutes. Do not allow the

soda to get too cold. The soda may freeze, ruining the demonstration. If the soda gets too cold (< –10 °C), there is a possibility of the bottle exploding.

6. After 10 minutes, remove the bottle from the ice and observe (but do not shake). The soda is still a liquid at this point. Remind the students that pure water would have frozen at this temperature.
7. Open the bottle and notice how the club soda quickly solidifies.

Tips

- Instructions for the preparation of cold temperature baths can be found in Gordon, A. J.; Ford, R. A. *The Chemist's Companion: A Handbook of Practical Data, Technique, and References:* Wiley New York, 1972 p. 452
- The colder the carbonated water, the more rapid and complete the subsequent ice formation will be. Excessively low temperatures are to be avoided, however, as the solution freezes at approximately –10 °C, often breaking the bottle and ruining the demonstration.

Discussion

Freezing point depression is a colligative property. When a solute is mixed with a solvent, the freezing point of the resulting solution decreases. The amount that the freezing point falls is dependent on the concentration of solute, not the identity of the solute. In this demonstration, water is the solvent. Sodium chloride is the solute in the ice–water mixture and carbon dioxide is the primary solute in the club soda.

Why does the solute lower the freezing point? The carbon dioxide molecules disrupt the capacity of the water molecules to organize into the solid state. As more solute is added, the colder the mixture has to be in order to organize the water into a solid. These properties are seen in the students' world with the spreading of salt on icy roads, ice cream makers, and auto antifreeze.

Pressure affects the solubility of a gas in a liquid. As the pressure increases, more gas is forced into the liquid where it can dissolve. A bottling company maintains a high concentration of carbon dioxide in the carbonated beverages by bottling them under about 15 pounds of pressure. When the cap is unscrewed, the excess pressure is released and some of the dissolved carbon dioxide leaves the solution, thus decreasing the concentration of CO_2 in the water.

Pure water has a freezing point of 0 °C. When carbon dioxide is dissolved in water a solution is formed and the freezing point is lowered. The greater the concentration of CO_2 the lower the freezing point of the solution. As a result, the soda in this demonstration will actually have two different freezing points, one before the cap is removed and the concentration of CO_2 is high and another freezing point after the cap is removed and the escaping CO_2 lowers the solution concentration. A soda that has been cooled to the proper temperature can remain fluid as long as the cap is not opened. When the cap is unscrewed, the escaping CO_2 lowers the solution concentration, the freezing point raises. Ice immediately forms near the mouth of the bottle and the soda freezes instantly. The rapidness of the ice formation causes the crystals to be very small and white in appearance so they are easily observed. A thermometer will show the ice/water mixture in the bottle has quickly risen from –8 °C to a new freezing point just below 0 °C.

Is there a sufficient amount of carbon dioxide in the soda water to lower the freezing point to –8 °C? The mole fraction solubility of carbon dioxide in water at 20 °C is 7.07×10^{-4}. When bottling the soda, pressure is used to increase the amount of dissolved CO_2, but could the increased amount of dissolved CO_2 be sufficient to lower the freezing point to –8 °C? Calculations show the mole fraction of dissolved carbon dioxide would have to be approximately 7.3×10^{-2} or a 100 fold increase.

Something besides a pressure change contributes to the freezing of the soda. Consider the smooth inside surface of the glass bottle. Picture the rapidness of the ice formation and the very small crystals that form. Nucleation sites in the container allow the bubbles to form and escape to the surface. Small initial bubbles of gas coming out of solution serve as nucleation sites for more gas to form around. The soda water is supersaturated with carbon dioxide when under pressure and the first bubbles of gas to come out of solution act as a "seed" for the solid to form around.

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
Form and function
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Acknowledgement

Special thanks to Roxanne Vought and Ken Lyle of St. John's School in Houston, Texas, and Penney Sconzo of Westminster Schools in Atlanta, GA for bringing this demo to our attention.

Reference

Bare, W. D. *J. Chem Ed.* 1991, *68*, 1038.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Quick Freeze* activity, presented by John Mauch, is available in *Saturated*, *Unsaturated*, *and Supersaturated Solutions*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Quick Freeze* are available from Flinn Scientific, Inc.

Catalog No.	Description
S0065	Sodium Chloride, Rock Salt, 1 kg
AP1452	Thermometer, Spirit-Filled, –20 ° to 110 °C

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