Freezing by Boiling

A Discrepant Event Demonstration

Introduction

The boiling point of a liquid depends on the external air pressure. When water is placed under vacuum, the boiling point decreases and the water boils. Boiling, however, is an endothermic process—as the water boils, the temperature decreases, and the water soon freezes!

Concepts

- Boiling point
- Vapour pressure

Materials

Acetone solution, 60% in water, 10 mL
Boiling stones, 2
Construction paper, black
Ken-a-Vision Flex Cam 2 Document Camera (optional)
Graduated cylinder, 10-mL
Pipet, disposable
Plastic wrap, 8 × 8 in.
Scissors
Polystyrene foam cup, 8-oz
Vacuum pump with vacuum tubing and 3-way valve
Vacuum plate and bell jar (vacuum chamber)

Safety Precautions

Check the bell jar or vacuum chamber for cracks or chips before use—never place a chipped or cracked jar under vacuum. Placing all items under vacuum behind a safety shield is recommended. Acetone is a flammable liquid and slightly toxic by ingestion and inhalation. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please consult current Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Cut a piece of black construction paper large enough to line the inside walls of the foam cup. (Boiling and freezing will be more visible against a dark background.)
2. Place a piece of plastic wrap over the mouth of the cup and push the plastic wrap down into the cup to create a shallow "well" as shown in Figure 1. (The well will prevent the liquid from splattering and also make it easier to see the phase changes.)
3. Mix 6 mL of acetone with 4 mL of distilled or deionized water in a graduated cylinder to form an aqueous solution.
4. Carefully add about 4–5 mL of the acetone solution into the "well" formed by the plastic wrap and add two boiling stones to prevent "bumping."

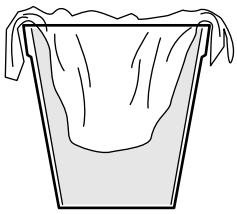

Figure 1.

5. Set the cup on the vacuum plate (don't cover the hole on the vacuum plate) and place the bell jar or vacuum chamber over the cup.
6. Start the vacuum pump and close the valve to evacuate the vacuum chamber.
7. Observe the phase changes for the aqueous solution. *Within seconds, the acetone solution will start to boil. After a few minutes, the solution will start to freeze, but there will be boiling bubbles visible under the ice. Boiling and freezing will occur simultaneously for at least five minutes! Some of the bubbles seem to "explode" into tiny pieces of ice.*
8. Slowly open the three-way valve to "release" the vacuum in the bell jar, and then turn off the vacuum pump.

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Disposal

It is recommended that you consult your local school board and/or municipal regulations for proper disposal methods that may apply before proceeding.

Tips

- Make the well in the plastic wrap as deep as possible so the solution does not escape. The more liquid in this well, the easier it is to see the boiling and freezing.
- Set up a Ken-a-Vision Flex Cam 2 Document Camera (Flinn Catalogue No. AP7668) to give students a close-up view of special effects!
- Acetone and water form a minimum boiling azeotrope containing 88% acetone and 12% water.

Discussion

Vapourization is the process by which a substance changes from a liquid to a gas or vapour. When vapourization occurs gradually from the surface of a liquid, it is called evaporation. The pressure of the vapour in equilibrium with a pure liquid at a specific temperature is called the vapour pressure. When the vapour pressure equals the external pressure, vapourization can occur throughout the liquid, not just at the surface. Bubbles of vapour then form in the liquid and rise to the surface—the liquid boils. The boiling point of a liquid is defined as the temperature at which the vapour pressure of a liquid is equal to the external (atmospheric) pressure. Thus, the boiling point of a liquid depends on the external pressure. The vapour pressure of a liquid always increases as the temperature increases. Heating a liquid until its vapour pressure equals the surrounding atmospheric pressure will cause the liquid to boil. A liquid will also boil, however, at a lower temperature when the external pressure is reduced.

Evaporation is an endothermic process—energy in the form of heat is required for molecules to leave the liquid phase and enter the gas phase. The most common way to provide energy for the vapourization of a liquid is by heating it. When the heat energy for vapourization comes from the surroundings rather than from continuous external heating, however, the temperature of the liquid will decrease as it evaporates. Thus, a liquid cools as it evaporates. (This fact explains why perspiration cools the body.)

In this demonstration, the acetone solution in the cup begins to boil at room temperature almost as soon as the external pressure is reduced (under vacuum). The temperature of the solution decreases, and when the liquid gets cold enough, it freezes—boiling and freezing occur simultaneously! The acetone–water solution has a higher vapour pressure than pure water and the acetone boils first. Water, however, freezes at a higher temperature than acetone, so the frozen solid is mostly water.

Reference

This activity was adapted from *Solids and Liquids*, Vol. 11 in the *Flinn ChemTopic™ Labs* series; Cesa, I., Editor; Flinn Scientific: Batavia IL (2005).

Materials for *Freezing by Boiling—Discrepant Event* are available from Flinn Scientific Canada Inc.

Catalogue No.	Description
AJ0009	Acetone, 500 mL
AP4506	Vacuum Chamber with Plate
AP7668	Ken-a-Vision Flex Cam 2 Document Camera

Consult your www.flinnsci.ca or *Flinn Scientific Canada Catalogue/Reference Manual* for current prices.