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
- Vapor pressure

Materials
- Acetone solution, 60% in water, 10 mL
- Boiling stones, 2
- Construction paper, black
- 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 Material 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.”
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.
Freezing by Boiling continued

**Disposal**

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Allow the acetone solution to evaporate overnight and dispose of the remaining water down the drain the following day.

**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 document camera (Flinn Catalog No. AP7641) 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**

*Vaporization* is the process by which a substance changes from a liquid to a gas or vapor. When vaporization occurs gradually from the surface of a liquid, it is called evaporation. The pressure of the vapor in equilibrium with a pure liquid at a specific temperature is called the vapor pressure. When the vapor pressure equals the external pressure, vaporization can occur throughout the liquid, not just at the surface. Bubbles of vapor 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 vapor pressure of a liquid is equal to the external (atmospheric) pressure. Thus, the boiling point of a liquid depends on the external pressure. The vapor pressure of a liquid always increases as the temperature increases. Heating a liquid until its vapor 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 vaporization of a liquid is by heating it. When the heat energy for vaporization 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 vapor 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.

**NGSS Alignment**

This laboratory activity relates to the following Next Generation Science Standards (2013):

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<tr>
<td>MS-PS1 Matter and Its Interactions</td>
<td>HS-PS1 Matter and Its Interactions</td>
<td>Developing and using models</td>
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<tr>
<td>MS-PS3 Energy</td>
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<td>Constructing explanations and designing solutions</td>
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**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, Inc.

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<th>Catalog No.</th>
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<tr>
<td>A0009</td>
<td>Acetone, 500 mL</td>
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<tr>
<td>AP1597</td>
<td>Vacuum Pump, Two-Stage</td>
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<td>AP4506</td>
<td>Vacuum Chamber with Plate</td>
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<td>AP7641</td>
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