Boiling Water in a Bell Jar

Introduction

Demonstrate the conditions necessary for liquids to boil.

Concepts

- Vacuum properties
- Vapor pressure
- Boiling point

Materials (for each demonstration)

Bell jar, large, transparent
Boiling stone
Clear plastic cup
Three-way valve (optional, depends on operation of vacuum plate)
Thermometer, digital or spirit-filled (appropriate to fit inside the bell jar)
Vacuum plate
Vacuum pump, two-stage
Vacuum tubing
Water, 50–100 mL

Safety Precautions

Wear safety glasses when working with an evacuated bell jar or vacuum pump. All students and teachers near an evacuated bell jar must wear safety glasses. Do not use a mercury thermometer. Mercury vapors could be quickly released into the classroom if the thermometer breaks.

Preparation

1. Fill a clear plastic cup with approximately 50–100 mL of water (students should be able to see the water in the cup). Add a boiling stone to prevent "bumping."
2. Place the water-filled cup off-center on the vacuum plate so that the evacuation portal is not covered (see Figure 2).
3. Place a digital or spirit-filled thermometer in the water. ***Caution:*** Do NOT use a mercury thermometer for this demonstration.
4. Place the bell jar on the vacuum plate, and properly connect the vacuum plate to the vacuum pump (see Figure 1).

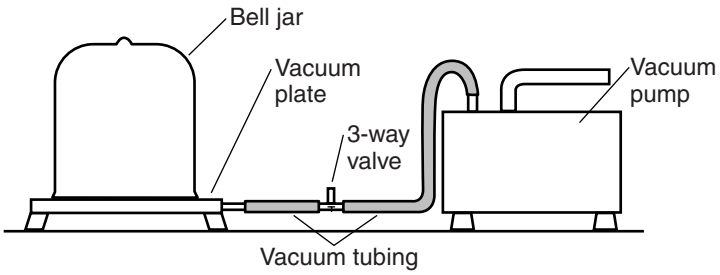

Figure 1.

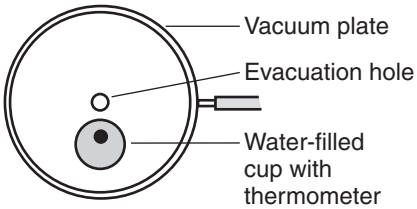

Figure 2.

Procedure

1. Show students the water in the cup inside the bell jar.
2. Use the thermometer to measure the temperature of the water in the cup. Report this temperature to the students to record in their worksheets.
3. Discuss the concepts of vapor pressure and boiling with students.
4. Ask students to predict what will happen when the air is removed from inside the bell jar, reducing the air pressure.
5. Once students have made their predictions, turn on the vacuum pump and evacuate the bell jar. *Note:* If using a digital thermometer, make sure that it is ON before evacuating the bell jar. Some digital thermometers have automatic shut-off features.
6. Students should observe the water in the cup as the air is pulled out of the bell jar. Have them record their observations on the worksheet.

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7. Once enough air has been removed from inside the bell jar (the water should be boiling), properly close the valve on the vacuum plate (or the three-way valve) and turn off the vacuum pump. The vacuum should be maintained inside the bell jar and the water should continue to boil.
8. Students should continue to observe the water as the temperature is measured and recorded.
9. Once observations are complete, carefully open the valve on the vacuum plate (or the three-way valve) just enough to allow the bell jar to slowly fill with air. Students should continue to observe the water in the cup. *Caution:* Do not open the valve too quickly, as this may cause a lot of turbulence inside the bell jar, which may knock over the cup of water and possibly break the thermometer.

Teaching Tips

- A two-stage vacuum pump is *required* for this demonstration. A single-stage vacuum pump will not reduce the pressure inside the bell jar enough to cause water to boil at room temperature.
- Use a 400-mL beaker if clear plastic cups are not available.
- Students may need to get close to the bell jar in order to see the water begin to boil at reduced pressure. Make sure all students who approach the evacuated bell jar wear safety glasses. Or, use a ChemCam™ camera to show the demonstration on a TV or monitor.
- Use water at different starting temperatures to show students that vapor pressure is related to temperature. Water at 10 °C will not boil under the reduced pressure of a two-stage vacuum pump.
- If the bell jar is not sealed after is has been evacuated, the water may begin to evaporate causing the water temperature to drop below 10 °C and the water will stop boiling.
- See the demonstration "Freezing by Boiling" in *Solids and Liquids*, Volume 11 in the *Flinn ChemTopic™ Labs* series (Flinn Catalog No. AP6660) for a related activity.

Discussion

Vapor pressure is a measure of the amount of vapor that is present above a liquid at a given temperature. The vapor pressure above a liquid is proportional to the temperature of the liquid, meaning the higher the temperature of the liquid, the higher its vapor pressure will be. A liquid begins to boil when the vapor pressure of the liquid is the same as the atmospheric pressure surrounding the liquid. The reason water boils at a lower temperature in Denver (approximately one mile above sea level) compared to Boston (approximately at sea level) is due to the lower atmospheric pressure at higher altitude. The lower atmospheric pressure in Denver means the vapor pressure of the water reaches local atmospheric pressure at a lower temperature, which causes water to boil at around 97 °C.

There are two ways to make a liquid boil. Either heat the liquid to a temperature in which the vapor pressure matches the atmospheric pressure, or reduce the pressure surrounding the liquid to match the vapor pressure of the liquid at the given temperature. In this demonstration, the pressure surrounding the water is reduced enough to cause the water to boil at room temperature. The vapor pressure of water at room temperature (20 °C) is approximately 18 mm Hg. At 10 °C, water vapor pressure is approximately 9 mm Hg. Therefore, in order for water to boil at room temperature, the atmospheric pressure surrounding the water must be lowered to at least 18 mm Hg.

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

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Answers to Worksheet *(Student answers will vary.)*

Initial Water Temperature: _____

Final Water Temperature: _____

Observations during evacuation process

Vacuum pump was loud and became quieter as the air was sucked out. The water began to bubble after about 30 seconds. The temperature dropped a few degrees, too. When the bell jar was sealed and the vacuum pump shut off, the water continued to boil in the cup. As the air was let into the bell jar, the boiling stopped.

Answers to Questions

1. Why does water boil at room temperature when the pressure is reduced?

   The vapor pressure of the water is greater than the atmospheric pressure surrounding the water, so the water begins to boil.

2. What would happen to the boiling point of water if the pressure were increased above normal atmospheric pressure? Explain.

   The vapor pressure would need to increase to the higher atmospheric pressure, so the temperature of the water would need to rise above 100 °C before it would begin to boil.

3. Why does the temperature of the water decrease as it boils?

   The temperature of the water decreases because the water evaporates and removes heat from the water, causing the temperature to drop.

Reference

http://www.s-ohe.com/Water_cal.html (accessed December 2005)

Materials for *Bell Jar Demonstrations* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1870	Bell Jar with Molded Glass Knob, Glass
AP6543	Cups, Clear Plastic, 16 oz
AP4560	Flinn ChemCam™ Camera
AP6049	Thermometer, Flinn Digital Pocket, Economy Choice
AP1452	Thermometer, Spirit-filled, Partial Immersion
AP1869	Vacuum Plate, Nalgene
AP1597	Vacuum Pump, Two-Stage
AP8789	Vacuum Tubing, 10 feet
AP5353	Valve, Three-Way

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

Student Worksheet

Boiling Water at Room Temperature

Initial Water Temperature: _____

Final Water Temperature: _____

Observations during evacuation process

Questions

1. Why does water boil at room temperature when the pressure is reduced?

2. What would happen to the boiling point of water if the pressure were increased above normal atmospheric pressure? Explain.

3. Why does the temperature of the water decrease as it boils?