How Can We Increase the Height of the Plateau?

Purpose

To have students increase the boiling temperature of water by increasing the pressure in the container

Overview

Students become aware of their preconceptions by considering what will happen to the boiling temperature of water if they increase the pressure in the container. They then test their preconceived ideas by heating water in an enclosed container and measuring its temperature. Students find that the boiling temperature is higher than when measured in an open container. They try to make sense of their observations and share their conclusions. Finally, students develop a hypothesis about the relationship between pressure and water's boiling temperature.

Key Concept

Water boils when its vapor pressure equals atmospheric pressure. As a result, water's boiling temperature is pressure, rather than temperature, dependent.

Context for This Activity

Most people think that a planet's temperature determines whether it can have liquid water. However, pressure plays a vital role, too. In this activity, students experiment with the relationship between pressure and temperature by increasing the pressure in a container and seeing that the boiling temperature of the water rises. This sets the stage for their work in Activity 5, when they reduce the pressure in a container.

Skills

- *Predicting* the outcome of an experiment
- *Developing* a hypothesis
- *Writing* a procedure to test a prediction
- *Controlling* variables
- *Conducting* an experiment
- *Collecting, recording,* and *graphing* data
- *Drawing* conclusions and *communicating* them to others

Common Misconceptions

- Boiling is a process that is controlled solely by the heat source.
- Atmospheric pressure is negligible.
- Pressure has no bearing on water's boiling temperature.

Materials

Heat source, 500 or 1,000-milliliter Erlenmeyer flask, three-hole stopper, plastic tubing, thermometer, ring stand or tripod, ring clamps, thermometer clamp, stirring rod, wire gauze (burners only), graph paper, goggles, appropriate safety equipment (see pages 5 and 19).

Preparation

- Plan how to present the initial problem and the best way to develop a procedure.
- Set up the apparatus for safely increasing the pressure in a container.
- Insert thermometers in the rubber stoppers.
- Set out the necessary equipment for each group.
- Discuss safety procedures related to heat sources, thermometers, glassware, and hot water.

Time: 2 class periods

Background

In Activity 3, the water story gets more involved and more interesting. For reasons such as the atmosphere's height, density, temperature, and humidity, atmospheric pressure can change. As a result, the force the atmosphere exerts on molecules, squeezing them together, can change. When a liquid tries to boil under high pressures, its molecules require more kinetic energy than usual to break free of their neighbors and become vapor (Figure 3.1). Higher kinetic energy translates into higher boiling temperatures. This is why a pressure cooker cooks food so fast. The high pressure inside the cooker requires that water reaches a higher temperature in order to boil. This higher temperature cooks the food faster. Conversely, under low pressures, molecules require little kinetic energy to break free of their neighbors and become vapor. Low levels of kinetic energy translate into low boiling temperatures. Consequently, under low pressures, water can boil at temperatures as low as 0.0098 degrees Celsius! And this is the reason there is no liquid water on Mars today. The pressure is so low that water boils away as soon as the temperature rises high enough to melt the ice. This concept is explored further in Activity 5.

It is important that students "play" with the relationship between pressure and boiling temperature. Activity 3 gives students an introductory experience with this relationship and sets them up for a more complete exploration of it in Activity 5.

Students' answers to Activity 1 and 2's preassessment questions will reveal many misconceptions about the temperature at which water changes state. Some will say that they can heat water to 500 degrees if given enough burners and time. Others will recite the memorized answer that water boils at 100 degrees Celsius. Because the boiling point of water—the temperature at which it changes from liquid to vapor—is pressure dependent, water can be made to boil at temperatures between 0.0098 and several hundred degrees C! Consequently, *both* answers reveal a lack of understanding.

Students almost always think of boiling as something that happens from underneath. Intuitively, focusing on the heat source makes sense—the bottom of a pot is where the heat is concentrated, where the molecules have the most kinetic energy, and where bubbles form. This module provides experiences that can help change this perception to the idea that boiling is controlled by what is *on top* of the liquid. That boiling is pressure dependent is a significant concept in physical and Earth science. Therefore, it is important to address and alter any misconceptions students may hold.

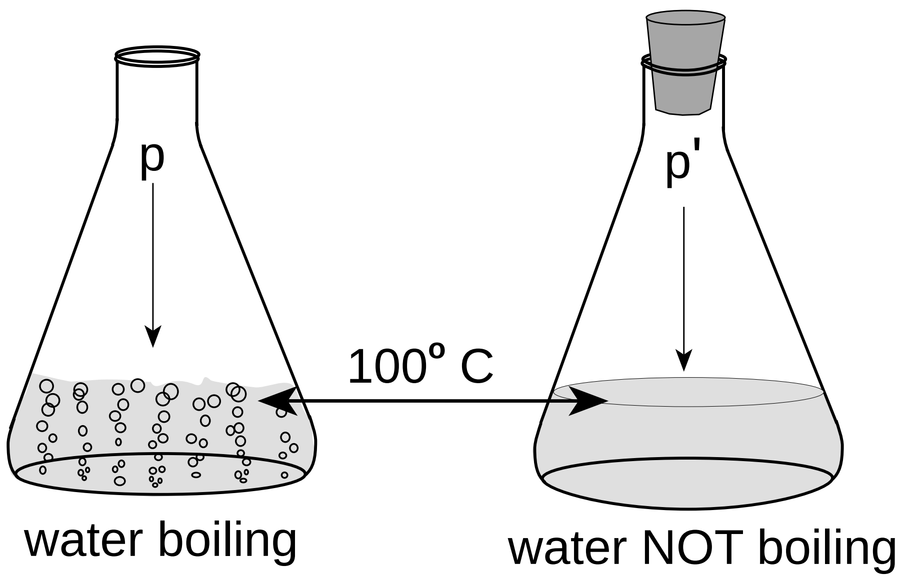


Figure 3.1. The water in both flasks is at 100 degrees Celsius, but it is only boiling in Flask A, which is open and at atmospheric pressure (p). Flask B is stoppered, and the pressure is above atmospheric pressure (p'), preventing the water from boiling.

Preassessment

(a) *Students Take a Position and Become Aware of Their Preconceptions:* Ask students:

- What would it take to change the boiling temperature of water?
- What will happen if one increases the air pressure in a container of boiling water?

(b) *Students Expose Their Beliefs:* Have each student write down his or her prediction, sign his or her name, and hand it in to the teacher.

Procedure to Test Students' Preconceived Ideas

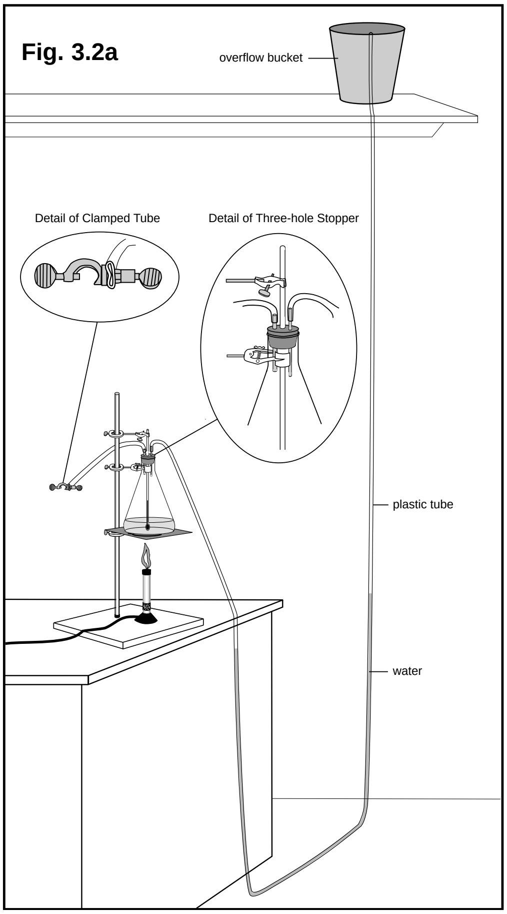
1. Have groups discuss the possible effects of increasing the pressure above the water's surface. How would increasing the pressure affect a water molecule's ability to go from the liquid to vapor state? Have each group present its best idea. List them on the board.

2. Ask groups to develop hypotheses based on the ideas listed in Step 1. List the hypotheses on the board.

3. Select a hypothesis for students to investigate related to increasing the boiling temperature by increasing the pressure.

   If you need to justify choosing a particular hypothesis, you can say that it lends itself best to the equipment you have available. Record any unused hypotheses for future projects.

Fig. 3.2a



In Figure 3.2a, students can adjust the clamp on the tube and regulate the pressure inside the flask. Changes in pressure cause changes in the boiling temperature. The long tube serves as a manometer that enables students to measure the pressure in the flask. It also acts as a pressure relief valve. To measure the pressure inside the flask, students must measure the difference in the water levels between the two vertical sections of the plastic tube. Each centimeter of difference equals about 1 millibar. The manometer is no longer accurate when the water reaches the horizontal section of the tubing. Figure 3.2b shows how a syringe can be used to increase the internal pressure and stop the boiling process.

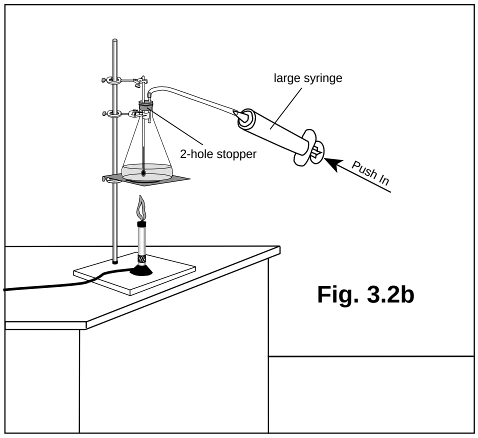


Fig. 3.2b

4. Ask students to describe any hazards associated with building up pressure inside a glass container.

   The container may be unable to withstand the internal pressures and explode. See safety notes.

5. Show students the apparatus for safely increasing the pressure in a container and explain to them how it works (Figure 3.2).

6. Have the class outline a procedure to test the hypothesis.

   The goal is for students to be able to measure a rise in the boiling temperature when there is an increase in pressure inside the container. Make sure that they record the boiling temperature before increasing the pressure so they have a baseline for comparison.

7. Have groups follow the procedure.

8. Have each group summarize its observations.

9. Have each student make sense of the observations in his or her own way.

   This step is vital in helping students resolve any conflicts between their preconceptions and observations. By making sense of the observations, students are forced to confront their earlier thinking and to accommodate a new concept.

10. Have students share their conclusions in their groups.

11. In a class discussion, have groups share their findings.

    The focus of this activity is the role pressure plays in determining water's boiling temperature. Press students to explain the relationship between boiling temperature and pressure. Consider having students make analogies or act out skits to explain what is happening on a molecular level.

12. At the conclusion of the discussion, ask each group to develop a hypothesis about the relationship between pressure and water's boiling temperature.

Questions to Probe Students' Observations

1. What was the boiling temperature of the water before you increased the pressure? How does that compare to your neighbor's initial boiling temperature?

2. How did the boiling temperature change when you increased the pressure? How did it change for other groups when they increased the pressure?

3. How might pressure influence the way molecules behave?

Analysis Questions

This series of questions probes students' assumptions and understanding of boiling. Use them as the basis of a discussion, for group work, or for homework.

1. Why did the boiling temperature increase in this activity?

2. How can you change the following analogies so they help explain why increasing the pressure raises the boiling temperature?

   (a) The load on a ski lift's motor as more and more skiers fill the chairs
   (b) The load on a bulldozer's engine as it scrapes the surface and builds a large dirt pile
   (c) The resistance on a pump's motor as it raises some water to a pond at the top of a hill

   In each of these cases, the motors (and, by extension, the amount of energy) have to work harder as the resistance increases. Likewise, pressure influences how easily a molecule in the liquid state can disassociate itself from its neighboring molecules and enter the vapor state. The greater the pressure, the greater the resistance to becoming vapor. When the pressure is increased, molecules in the liquid state need to vibrate faster than before to break away and enter the vapor state. Since temperature is a measure of a particle's vibrational speed, an increase in pressure raises the boiling (that is, the water-to-vapor) temperature of water.

3. Draw a cartoon panel or sequence of pictures to show what is happening when the pressure above a container of boiling water increases.

4. Why does water not boil at room temperature? What stops it from turning into a vapor?

5. How are boiling and melting like:

   (a) Jumping out of bed after throwing back a sheet versus a blanket versus three heavy blankets?
   (b) Lifting a car with a jack versus lifting a house with a jack?
   (c) Running while pushing a shopping cart versus running while not pushing anything?

6. Write a paragraph comparing your how you answered the preassessment question with how you would answer it now.

Extension—What Is This Mystery Object?

Procedure

1. By way of introduction, tell students that archaeologists found an interesting object at the site of an ancient yard sale. Their job is to help you figure out what it is and how it works.

2. Have the class gather around the pressure cooker and examine it (Figure 3.3).

   - Let them determine how all the parts fit together.
   - Have them feel the heft of the pressure regulator.
   - Ask them what the markings or gauge on the pressure regulator might mean.
   - Ask them to speculate about what goes in the pot.
   - Have them examine the thickness of the walls and the way the lid secures. Is this typical of kitchen pots? Why might this pot be made this way?

   Make sure students understand that pressure cookers are used to increase the pressure inside the pot. The pot has thick walls to withstand the pressure, and it seals tightly to keep in the pressure.

3. After students understand the principle behind pressure cookers, ask why anyone would want to increase the pressure when they cook.

4. Have student groups write a brief paragraph that could be used in an advertisement. The ad copy must explain what pressure cookers do, how they work, and why someone would want one.

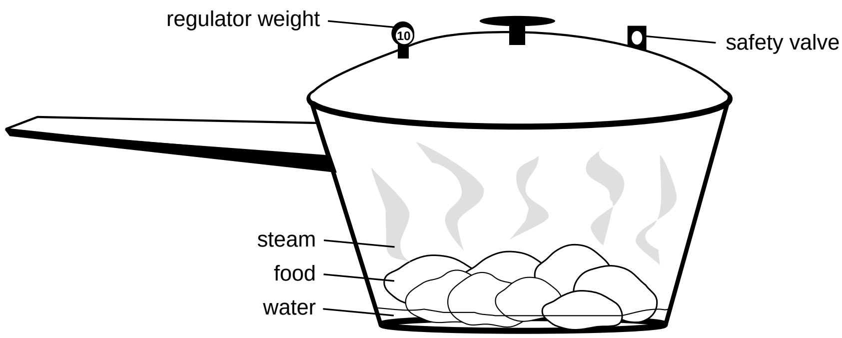


Figure 3.3. *Cross section of a pressure cooker.*

Safety Procedures: True Tales of a Teacher's Worst Nightmare

Steam and hot water burns are particularly dangerous. Not only are the temperatures high, but the specific heat of water is very high. This means that water contains more heat than the same amount of almost any other substance at the same temperature. When a spill concentrates all of this heat on someone's skin, serious second- and third-degree burns result. In addition to the safety procedures mentioned in Activity 1, additional safety procedures include:

- Use a safe setup. In the field test, some teachers asked students to increase the pressure inside a flask by having students use a pencil to apply pressure to a loosely set stopper. In several cases, the steam jetted around the stopper and burned students' hands. In addition, several students tipped over their unsecured flasks, sending glass and hot water across their table.

- Provide a pressure relief valve. Stoppers use friction to maintain a tight seal. Depending on the type of material used to make a stopper and on its age and condition, some stoppers can hold very tenaciously. Unfortunately, people often mistakenly believe that the stopper is the weak point of the system and that it will pop when pressures in a container build to unsafe levels. They trust that the stopper will act as a de facto pressure-relief valve. However, stoppers can hold unexpectedly firmly. In addition, classroom glassware is often scratched. Even minor, undetectable scratches weaken the glass. The combination of a tight stopper and scratched glassware is a recipe for serious harm.

- Avoid building up internal pressures. Some teachers attached a long plastic tube to one of the holes in a two-hole stopper (the thermometer occupied the other hole). They wanted students to open and close the end of the tube to control the pressure in the flask. In theory, this works well. Unfortunately, some overzealous students wanted to see how high the pressure (and, correspondingly, the temperature) would go. The pressure built to a point where the flask shattered. The stopper never popped.