How Hot Can You Make Water?

Purpose

To have students graph the temperature of water as it reaches a boil and discover the existence of the transition plateau

Overview

Students become aware of their preconceptions by considering how hot they could heat water. They then test their preconceived ideas by heating water and measuring its temperature. At some point near 100 degrees Celsius, students find that the water temperature no longer rises. They graph the data and try to make sense of the temperature plateau.

Key Concepts

- Water can only be heated to its boiling temperature.
- The slope of a graph line in this activity shows the rate of temperature change.

Context for This Activity

Mars has such low atmospheric pressure that any water at the surface would boil away. In this activity, students investigate the process of boiling and what is involved when water changes from a liquid to a gas under everyday conditions. In Activities 3 and 5, they will take a closer look at pressure's role in maintaining liquid water.

Skills

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

Common Misconceptions

- Water can be heated indefinitely to very high temperatures.
- The heat source controls boiling.
- Reaching temperature plateau means that something is malfunctioning

Materials

Heat source, beaker or flask, water supply, 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 out the necessary equipment for each group. Attach thermometers to ring stands.
- Discuss safety procedures related to heat sources, thermometers, glassware, and hot water.

Time: 2 class periods

Background

Why start a unit on Mars by boiling water? Interestingly, a lot of the Martian water seems to have boiled away, and studying boiling can help us understand why Mars has no liquid water. You might wonder how water can boil when the average temperature on Mars is –60 degrees Celsius. The way to understand this apparent contradiction is to better understand boiling. Our day-to-day experiences give us a decidedly limited understanding of boiling. To better understand boiling, students need to experience the existence of the *phase change plateau* (Figure 1.2).

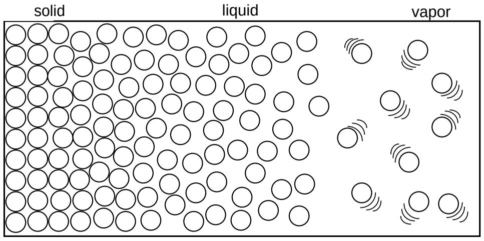

Figure 1.1. As a material's temperature changes, the spacing and energy level of its particles change.

In this activity, it is important to understand how liquids change into vapor (Figure 1.1). Molecules remain in the liquid phase until they gain sufficient kinetic energy (vibrational motion) to overcome the forces keeping them together. These forces include the attraction between molecules and the air pressure above the liquid. Adding heat to a liquid is an easy way to increase the kinetic energy of its particles. At some particular temperature, the particles will have become energetic enough to disassociate themselves from their neighbors and become a vapor. This is called the *boiling point.*

At the boiling point, any heat added to the liquid is absorbed by the molecules and the liquid changes to the vapor phase. Because these molecules escape into the air and carry away this extra heat, the temperature of the liquid never rises beyond the boiling point. In a graph showing the temperature history of some heating water (Figure 1.2), the boiling point graphs as a plateau.

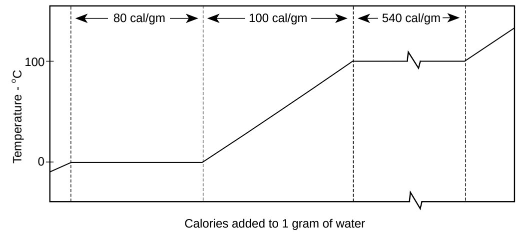

Figure 1.2. The heating curve of water shows how temperature changes as heat is added or subtracted. For example, when the temperature of ice reaches 0 degrees Celsius, it takes the addition of 80 calories to melt each gram of ice. Because all the added heat goes to melting the ice, the temperature holds constant during this phase change. Once the ice has all melted, any added heat raises the water temperature. The addition of 1 calorie raises the temperature of 1 gram of water 1 degree Celsius. When the temperature of water reaches 100 degrees Celsius, it takes the addition of 540 calories to vaporize 1 gram of water. Because all added heat goes to vaporizing the water, the temperature holds constant during this phase change. Once the water has all vaporized, any added heat raises the temperature of the vapor.

To many people, it does not seem possible that the water can remain the same temperature while heat is still being added. This phenomenon is nonintuitive and, as a result, is a source of misconceptions. What people forget is that each gram of water vapor carries away 540 calories, and the removal of this heat offsets the additional energy being provided by the heat source. If you add more heat by turning up the burner, all you will do is speed up how quickly the water boils away rather than increase the water's temperature. See the pedagogy overview at the beginning of the module for a discussion of the different ways to use the activity's preassessment questions to identify and alter students' misconceptions surrounding this topic.

Subsequent activities will show that boiling occurs at all sorts of different temperatures. This fact makes the liquid-vapor transition plateau extremely important. Because temperature is an unreliable indicator of boiling, the existence of a plateau is an important way to confirm whether you have boiling. When the whole class graphs its temperature data and discovers the (surprising) existence of a plateau, they are more ready to discuss boiling and conceptualize what the boiling temperature actually means.

Preassessment

(a) *Students Take a Position and Become Aware of Their Preconceptions:* Ask students how hot they could heat water given unlimited time and heating equipment.

(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. Present the problem, "How hot can you heat water?" and as a class discuss how to control variables such as the amount of water, the number of burners, the height of the rings, etc.

   Consider using 100–150 milliliters of water because it: (a) is easy to measure; (b) comes to a boil in 5–8 minutes; (c) does not boil away during a class period; (d) does not make too big a mess if spilled; (e) will not burn as badly as larger amounts of water if spilled on the skin; and (f) will cover the thermometer bulb. Make sure to read the safety notes on page 5 before beginning the activity.

2. Have student teams set up the equipment for the activity (Figure 1.3):
   - Measure the agreed-upon amount of water
   - If using Bunsen or alcohol burners, adjust the lower ring to fit the burner properly and set a wire gauze on the lower ring
   - Place the beaker or flask containing the water on the wire gauze or on the hot plate (turned off)
   - Attach the thermometer above the beaker with a clamp or string
   - Adjust the thermometer so that the thermometer bulb is completely submerged and just above the bottom of the beaker (So it can measure the water temperature rather than the temperature of the glass, it should not touch the bottom of the beaker.)

3. Have students take the starting water temperature.

   Teams of two students work well because there is little opportunity for off-task behavior when each student is totally engaged monitoring the time and temperature.

4. After you check each group's setup, have students either light their burners or switch on their hot plates.

5. Using a stirring rod (not the thermometer), have students stir and record the water temperature every 15 seconds.

   Hitting a temperature plateau is a surprise that challenges students' intuition. Thus, the activity becomes a rich experience upon which to challenge old ideas and to develop new understandings. At some point between 97 and 105 degrees Celsius (depending on the weather and your elevation), students find that the temperature no longer changes. The crucial element is the discovery that, although the burner still puts in heat, the temperature stops rising. Do not let on that this is the result students are meant to achieve.

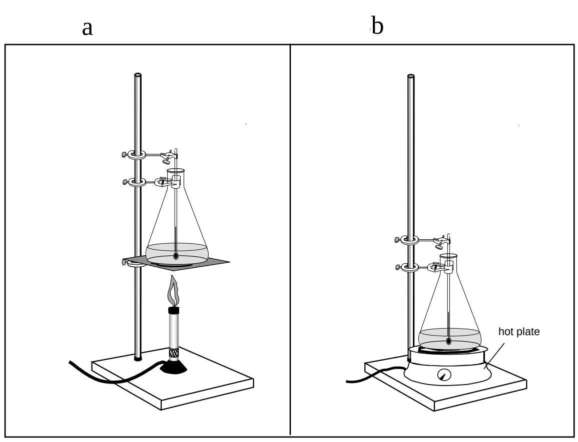

Figure 1.3. Activity 1 set up with (a) a burner and (b) a hot plate.

Have groups keep recording until most groups have several minutes' worth of temperatures at the water-to-vapor transition plateau. Obtaining a graph of the plateau is essential. Without it, students cannot fully understand boiling. Because the boiling temperature is pressure dependent, it is this plateau that indicates the boiling temperature—not the bubbling of water. When the whole class graphs the data and recognizes the (surprising) existence of a plateau, they are ready to discuss boiling and conceptualize the boiling temperature.

6. Have students graph their data.

   Use the horizontal axis for time and the vertical axis for temperature.

7. 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.

8. Have students share their conclusions in their groups.

Questions to Probe Students' Observations

1. What is the general shape of your graph? How does it compare to the shape of your neighbor's graph?

2. At what temperature did the water in your beaker boil? How does it compare to the boiling temperature of the water in your neighbor's beaker?

3. What did you notice happening around the time the water temperature stopped rising?

4. How can the temperature stop rising while the hot plate/burner is still providing heat to the water? Where is all that energy going?

Safety Notes

Time should be spent in establishing procedures for working safely with burners, hot plates, glassware, boiling water, and steam. Having students follow safe laboratory procedures is prudent both in terms of personal safety and in terms of avoiding giving hands-on science a bad name in your school. You can require students to pass a written quiz before being allowed to participate in the lab or have students write a sentence explaining the rationale behind each precaution.

For classrooms using alcohol or Bunsen burners:

- Use the small cylindrical-shaped alcohol burners. The ones with a large ballooned-shaped bases contain large amounts of fuel, which can pose a significant fire danger.
- Fill burners at a central supply table, and show students how full to fill them.
- Have matches carried only in *match petries*—petri dishes with half a strike plate from a box of standard kitchen matches taped on the lid. Only three or four matches are carried in the petri at one time, enough to light a burner.
- Make sure each group has a *fire extinguisher beaker*—a beaker of water into which burned matches are placed and that can be used to douse accidental fires. Classes using alcohol burners should have boxes of baking soda to smother fires. Water can spread an alcohol fire.
- Place burners on a ceramic tile (standard wall tile) or ring stand base. This marks where a flame may safely be located.
- Position a ring over the burner at the appropriate height. Place a wire gauze on the ring to support the beaker. Alternatively, tripods may be used with burners but tripods are less stable than ring stands, are more likely to result in spills, and provide no place to clamp a thermometer.
- Have groups call the teacher over each time a match is struck. Check to see that students have a fire extinguisher beaker (or baking soda) and a proper lab set up. Watch them strike the match. Consider establishing a rule that says that no one may strike a match in the lab without the teacher's supervision. Even with such a rule, it takes just 3 or 4 minutes to light the burners of a class with 10 to 12 groups.

For classrooms with either burners or hot plates:

- Make sure students wear goggles throughout the lab. Goggles remind students to behave in a safe manner. Most state and school policies require them.
- Make sure thermometers are *not* carried around the room. Prior to the lab, clamp or hang thermometers from the upper rings of the ring stands. Students may adjust their rings but not remove the thermometers. This preparation virtually eliminates breakage. Hanging thermometers with pipe cleaners allows students to move them in and out of beakers and flasks without untying them, thus minimizing breakage.
- Use clamps to secure the beakers, flasks, and thermometers to the ring stand.
- Equip any classroom using heating sources with fire extinguishers, fire blankets, and a first aid kit.