DOCUMENT RESUME

ED 481 371 SE 068 361

TITLE	Mars Exploration: Is There Water on Mars? An Educator's Guide with Activities for Physical and Earth and Space Science.
INSTITUTION	TERC, Cambridge, MA.
SPONS AGENCY	National Aeronautics and Space Administration, Washington, DC.
REPORT NO	EG-2000-03-121-HQ
PUB DATE	2000-00-00
NOTE	41p.
PUB TYPE	Guides - Classroom - Teacher (052)
EDRS PRICE	EDRS Price MF01/PC02 Plus Postage.
DESCRIPTORS	Aerospace Education; Hands on Science; Science Activities; Science Instruction; Science Interests; Secondary Education; *Solar System; *Space Sciences; *Water

ABSTRACT

This educator's guide discusses whether there is water on the planet Mars. The activities, written for grades 9-12, concern physical, earth, and space sciences. By experimenting with water as it changes state and investigating some effects of air pressure, students not only learn core ideas in physical science but can also deduce the water situation on Mars by applying those concepts. Evidence is used from their work as well as data and images from NASA missions to Mars to take a position on whether there was ever water on Mars. (MVL)

National Aeronautics and
Space Administration

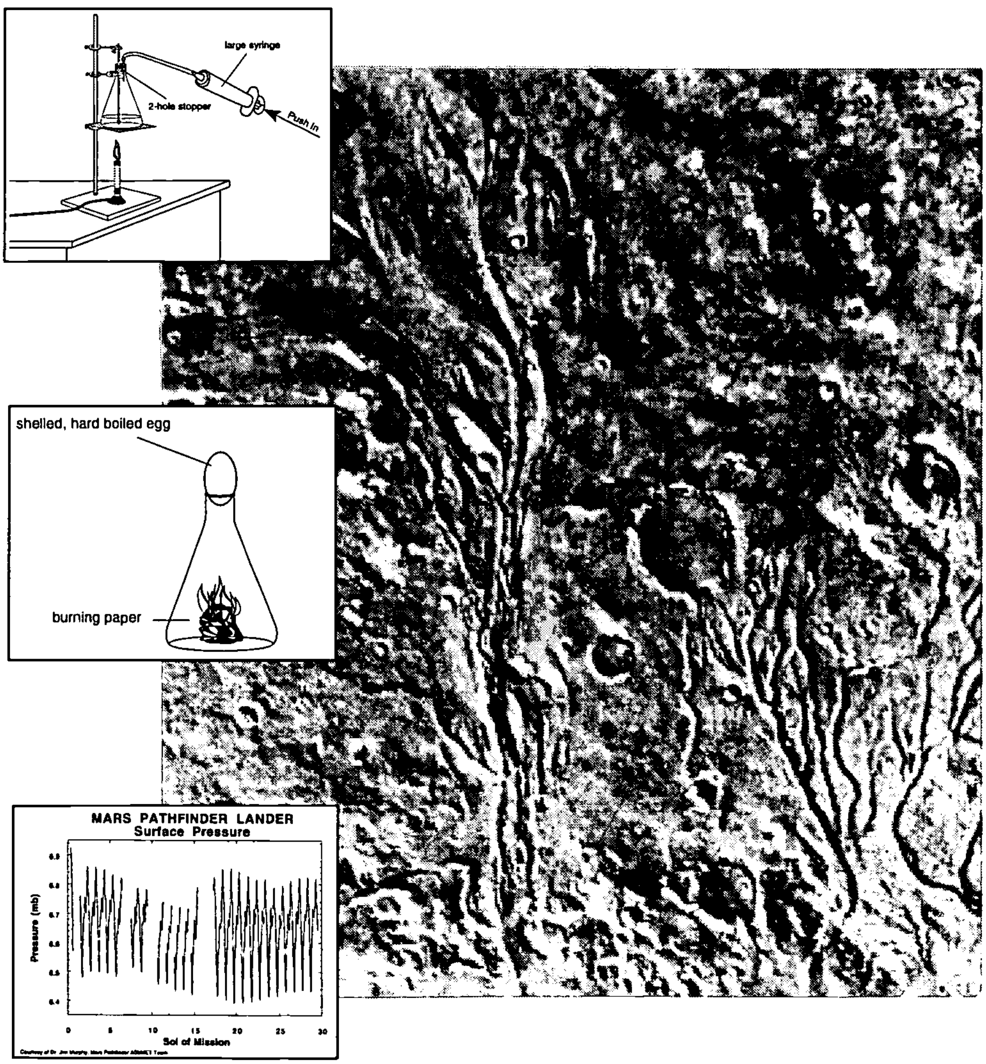
Educational Product	
Educators	Grades 9–12

EG-2000-03-121-HQ

Mars Exploration

Is There Water on Mars?

An Educator's Guide With Activities for Physical and Earth and Space Science



Is There Water on Mars?—An Educator's Guide With Activities for Physical and Earth and Space Science is available in electronic format through NASA Spacelink—one of the Agency's electronic resources specifically developed for use by the educational community.

This guide and other NASA educational products may be accessed at the following address: *http://spacelink.nasa.gov/products*

Is There Water on Mars?

An Educator's Guide With Activities for Physical and Earth and Space Science

NASA Aeronautics and Space Administration
Office of Human Resources and Education
Education
Washington, DC

Prepared by TERC, Inc.
2067 Massachusetts Avenue
Cambridge, Massachusetts 02140

EG-2000-03-121-HQ

Mars Exploration Education and Public Outreach Program

These modules were prepared by the TERC Center for Earth and Space Science Education with assistance from personnel of NASA's Mars Exploration Education and Public Outreach Program. This Program is managed for NASA by the Jet Propulsion Laboratory, a division of the California Institute of Technology.

These materials were developed for JPL's Mars Exploration Education and Public Outreach Program, which is part of NASA's Mars Exploration Program. The work is funded by NASA's Jet Propulsion Laboratory (JPL), which has overall responsibility for the Mars Exploration Program.

The curriculum materials were developed through a subcontract to the Center for Earth and Space Science Education (CESSE) at TERC, Inc., a nonprofit educational research and development company. The materials have been reviewed by NASA scientists and field-tested by scores of teachers.

Government Sponsorship is acknowledged under contract NASA7-1260.

Welcome to the Mars Education Program

Between 1997 and 2007, NASA plans to send 10 spacecraft to investigate Mars. To take advantage of this historic set of explorations, NASA's Mars Exploration Program has created a series of curriculum modules to connect students to the excitement and learning potential of these missions. The Mars Exploration Program will help you:

- Engage your students in hands-on, inquiry-based learning
- Involve students in questions central to current Mars exploration
- Teach engineering concepts and physical, life, and Earth and space science in a relevant way
- Provide a context for learning about both Mars and Earth
- Address student misconceptions
- Prepare students for using live data and images from Mars

The module series was developed and field tested by a team of educators and scientists to make sure that it is both scientifically accurate and educationally powerful. Each module contains a set of activities that relate to an over-arching theme. The activities are sequenced so students can progress from introductory experiences to more advanced investigations and deeper understandings. The educator handbook and correlated student materials enable you and your students to do the activities regardless of your previous knowledge about Mars and planetary exploration.

Modules Available in the Mars Exploration Series

Getting Started in Mars Exploration

Grades 4–10, 2 Weeks

How can students study Mars and Mars exploration in the classroom?

This comprehensive introduction to studying Mars in the classroom develops students' understanding of Mars, the solar system, and planetary exploration. The module introduces many of the intriguing riddles posed by Mars and provides teachers a variety of ways to integrate the study of Mars into their classrooms.

Is There Water on Mars?

Grades 9–12, 3 Weeks

Can water exist on Mars today?

By experimenting with water as it changes state and investigating some effects of air pressure, students not only learn core ideas in physical science but can deduce the water situation on Mars by applying those concepts. They use evidence from their work as well as data and images from NASA's missions to Mars to take a position on whether there was ever water on Mars.

The Grand Canyon of Mars and How It Formed

Grades 6–12, 3 Weeks

What can a colossal fracture tell us about Mars?

Students investigate the formation of Mars' 3,000-mile-long rift valley. After investigating how a planet's surface can be altered and analyzing data and images from NASA's missions to Mars, students develop hypotheses to explain the rift valley's formation and amass evidence to support their ideas.

The Great Martian Floods and Pathfinder Landing Site

Grades 6–12, 3 Weeks

Is the landing site in a floodplain, and why would that be good news?

Students learn how sediment, landforms, and drainage patterns provide clues about a planet's geologic history. They use evidence from their work and data and images from NASA's missions to Mars to understand the advantages of landing at the end of a flood channel.

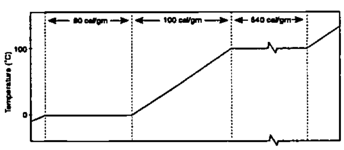
An Overview of What the Modules Provide

- Hands-on, inquiry-based activities written by educators, reviewed by NASA scientists, and field-tested by students
- Engaging physical and Earth science activities that use experiments, models, analogs, and image and data interpretation to investigate questions central to Mars research
- Practical applications of the National Science Standards
- Educator's guides with background information, procedures, teaching strategies, student sheets, assessment recommendations, and a resource list

Table of Contents

Module Overview

Is there liquid water on Mars? By experimenting with water as it changes state and investigating some effects of air pressure, students not only learn core ideas in physical science but can deduce the water situation on Mars by applying those concepts.

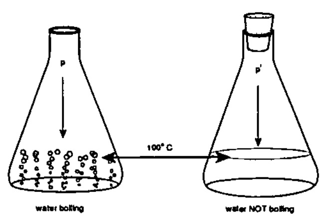


Calories added to 1 gram of water

In Activities 1 and 2, students discover the existence of two temperature plateaus as water changes state. Students have to make sense of these plateaus and come to grips with what changes of state mean at the molecular level. Once students understand the process of boiling and melting, they are ready to examine another factor that significantly impacts the existence of liquid water and atmospheric pressure.

Key Concepts in Activities 1 and 2

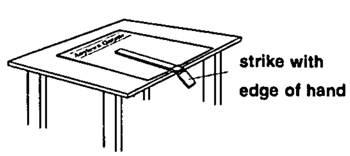
- Water can only be heated to its boiling temperature.
- The temperature of ice water can rise only after all the ice has melted.
- Temperature measures the average vibrational energy of a particle or group of particles.
- As the water in Activity 1 boiled and the ice in Activity 2 melted, the particles used the energy from the heat source to gain the extra kinetic energy required to change state. As a result, the temperature during these transitions never changed.



In Activity 3, students increase the boiling temperature of water by increasing the pressure in the container. In this activity, students not only develop an understanding of pressure's role in water's boiling temperature but also of its role in maintaining liquid water.

Key Concept in Activity 3

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

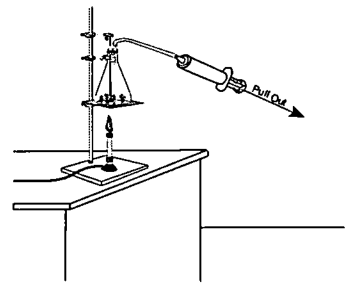


In Activity 4, students perform several activities showing that Earth's atmosphere exerts considerable force at the surface. Many students are unaware that they are subject to considerable atmospheric pressure and have little appreciation for how important this pressure is in their world. By acknowledging air pressure and understanding its role in maintaining water, students can consider questions such as: Why doesn't water on Earth boil away? Could water exist on planets such as Mars?

Key Concepts in Activity 4

- Air has mass and volume.
- Air pressure is a function of the height and density of the atmosphere in conjunction with a planet's gravitational pull.
- The particles in high-pressure air are packed more densely than those in low-pressure air.

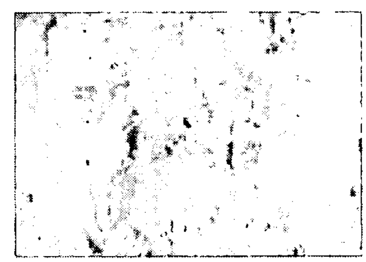
- Air flows from areas of high pressure to areas of low pressure to equalize the pressures.
- When the volume of a given mass of gas increases, its pressure decreases, provided that the temperature remains constant (Boyle's Law).



In Activity 5, students build on ideas introduced earlier and discuss ways to reduce the boiling temperature of water. Students find that water can boil well below its typical boiling temperature by reducing the pressure above the surface of the liquid. They learn about phase change diagrams and use one to better understand their previous work with pressure and changes of state.

Key Concepts in Activity 5

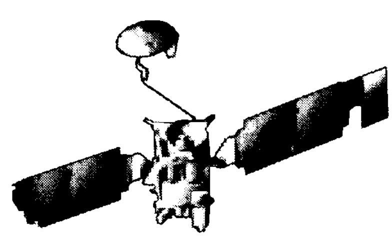
- Water boils when its vapor pressure equals atmospheric pressure. As a result, water's boiling temperature is pressure, rather than temperature, dependent.



In Activity 6, students analyze temperature and pressure graphs from the first 30 days of the Pathfinder mission and realize that liquid water could not have existed under these conditions. Next, students look at a number of images of Mars. By interpreting the landforms and comparing a river-cut valley on Mars with Earth's Grand Canyon, they identify water as the agent that shaped the surface. They hypothesize about how water could have flowed across the Martian surface, even though current conditions make it virtually impossible for liquid water to exist.

Key Concepts in Activity 6

- Current climatic conditions make the existence of liquid water virtually impossible.
- Features on the Martian surface provide strong evidence for past flows of large amounts of water.



In Activity 7, students generate questions based on their module experiences, and they pinpoint specific information they would like to obtain. They then read about the objectives and instrument payloads of the upcoming missions and see how these missions may provide data that can help them answer their questions. Finally, students create a calendar for the missions and consider how they will access the information returned by the missions.

Key Concepts in Activity 7

- Each Mars mission has specific objectives and the instruments it needs to achieve them.
- Space missions arise out of questions people have about Mars, and students can generate questions worthy of future study.
- Every mission has a specific timetable, and students can follow the progress of each mission in a number of ways.

An Overview of the Pedagogical Approach Used in This Module

Mathematics and science distinguish themselves from other disciplines in that they have certain absolutes and fixed principles. Science further distinguishes itself in that most students arrive at school with their own ideas and explanations of many of these absolutes. Unfortunately, many of their ideas are at odds with current scientific understanding. The discrepancy between naive and expert understandings gives science teachers an unusual and exciting opportunity—to help students move from incomplete or incorrect explanations to ideas consistent with current understanding.

A considerable and growing body of research shows that one of the best ways to change students' thinking is to first make them aware of their preconceptions and then provide experiences that probe or challenge those preconceptions. Say that students conduct an experiment that produces an unexpected result. If their preconceived ideas cannot explain the observations, the students should be encouraged to construct new explanations. If these explanations are superior to the ones they previously held, the students are likely to change their ideas. If a student's new explanation is better than his or her old one but is still incomplete or incorrect, the educator can provide another experience and repeat the cycle until the student's understanding is consistent with current scientific understanding.

> *The well established methods of inquiry are not only desirable but also are absolutely necessary for students to construct ideas, test them, and, if necessary, reject them and begin again in their search for ideas that more accurately reflect the real world.*
>
> "Pathways to the Science Standards—High School Edition," National Science Teachers Association, 1997, p. 3

To help educators identify students' preconceptions, each activity begins with a preassessment question. These questions help students become aware of their own ideas, take a position on a particular question, and have a personal stake in the activity. To avoid any embarrassment associated with feeling ignorant or uninformed, the students hand their answers in to the educator rather than state their ideas in a group or class discussion. At the end of each activity, the students are asked to respond to the preassessment question again and compare how they answered it before and after the activity. As the educator, you can use this comparison as:

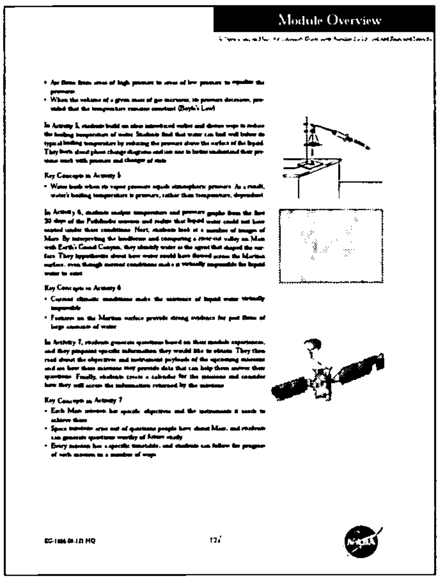
- An assessment of student understanding
- An assessment of the effectiveness of the learning experience
- An indication of whether additional experiences are necessary to develop concept mastery
- A way to structure your class discussion of the experimental observations
- A way to document how students develop an understanding of a concept

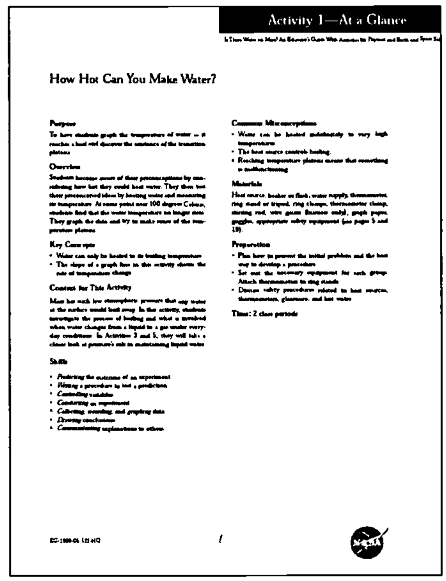
The activities early in the module are more proscribed than those later in the module. Progressing from structured to more open-ended investigations lays an indispensable foundation for the inquiry-based learning later in the module. This "guided" approach helps students become increasingly independent investigators by:

- Assuring the mastery of a core set of concepts
- Developing skills required in scientific inquiry
- Providing students a common set of experiences to refer to as they investigate their own questions

Furthermore, the module promotes inquiry-based learning by providing students opportunities to design experiments, develop procedures, or pursue their own ideas. By the end of the module, the students will have developed the skills and understanding they need to investigate their own questions.

How Do I Get Started?


Module Overview


Activity 1—At a Glance

How Hot Can You Make Water?

Finding Out What Is In a Module

To understand how the activities in the module examine a question or topic, read the overview of the science concepts starting on page vi. Each activity and its key concepts are succinctly described.

Finding Out What Is In an Activity

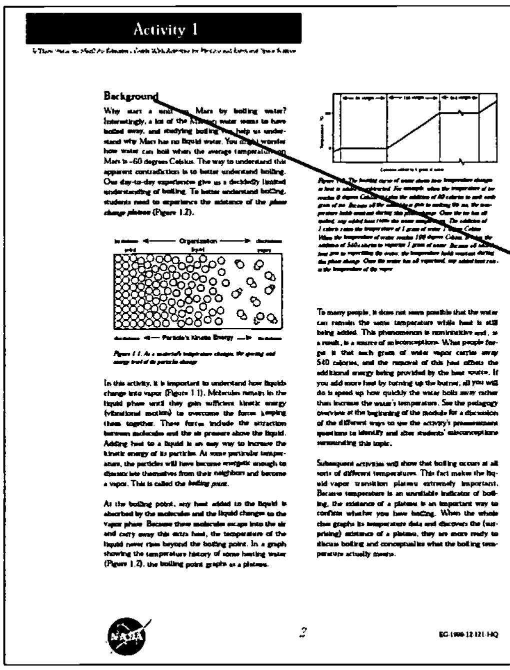
To understand each activity in greater detail (including material and time requirements), read the shaded "At a Glance" page at the beginning of each activity.

Materials

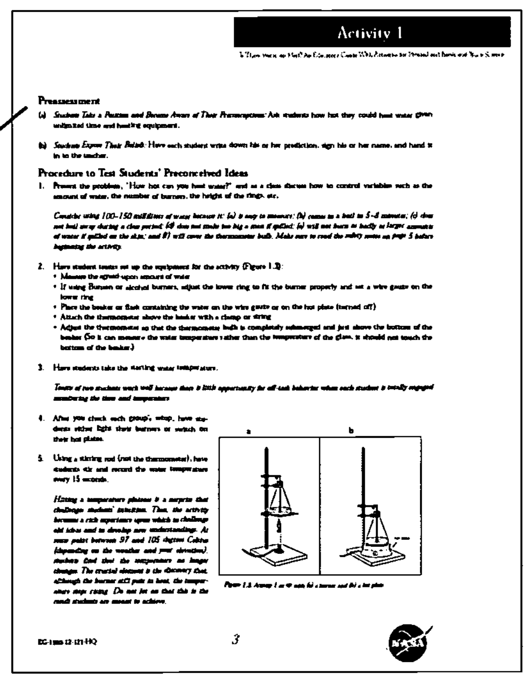
The "At a Glance" pages list the materials used in an activity. The activities use readily available materials.

How Is This Module Organized?

This module is written as an educator guide. This approach makes it possible to give it a conceptual and pedagogical structure while still providing educators the flexibility to tailor the activities to the needs of their classes. The educator guide prepares educators to conduct classes around core questions, and it outlines investigations that explore those questions.

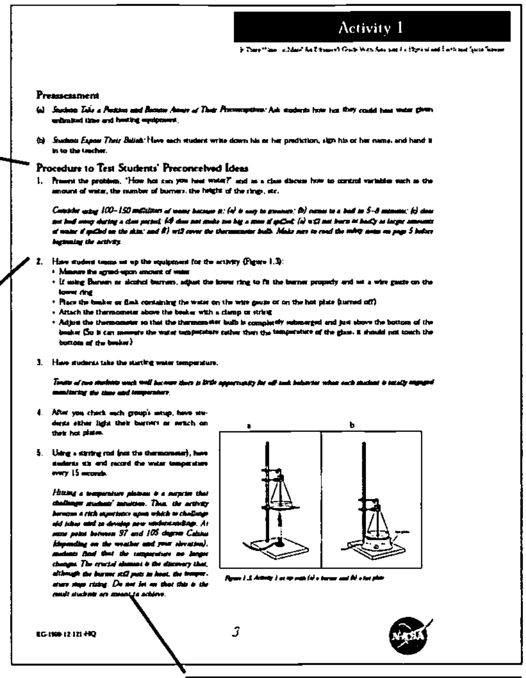


Background
Thorough, easy-to-understand background information enables you to understand the key concepts in an activity.



Learning Activities
Clear, detailed activity procedures (with reproducible student sheets, when required) facilitate planning and classroom implementation.

How Is This Module Organized?



Teaching Pointers

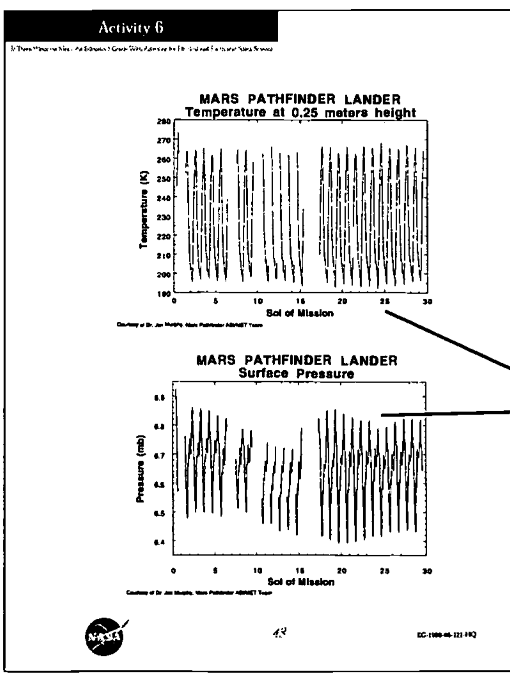
To assist you in conducting hands-on, inquiry-based activities, you will find pointers, classroom management strategies, discussion suggestions, extensions, and answers to the questions presented throughout the module.

Assessment Suggestions

This module outlines several options for assessing students, including preassessment questions, question sets, case studies, and suggestions for alternate ways of exhibiting student understanding.

Technology and Internet Recommendations

Computers and the Web can give students access to a rich set of support materials. The module lists pertinent Web sites, CD-ROM's, and videos and how to get actual Martian data and images. However, this module does not require the use of any classroom technology.



Case Study

Each activity in this module provides some of the information needed to answer the question: Is there water on Mars? In Activity 6, students take a position on this question and apply and integrate the module's concepts. This synthesis can be used as an assessment.

Which Science Standards Are Supported in This Module?

	Activity 1: How Hot Can You Make Water?	Activity 2: How Fast Does Water Warm as Ice Melts?	Activity 3: How Can We Increase the Height of the Transition Plateau?	Activity 4: Do Fish Believe in Water? Do Students Believe in Air?	Activity 5: Testing Your Hypothesis by Boiling Water Below Its Temperature	Activity 6: Is There Water on Mars?	Activity 7: Where Would You Search for Water on Mars?
Unifying Concepts and Processes							
• Systems, Order, and Organization				●		●	●
• Evidence, Models, and Explanation	●	●	●	●	●	●	●
• Constancy, Change, and Measurement	●	●	●	●	●	●	●
• Evolution and Equilibrium	●	●	●		●	●	
Science as Inquiry							
• Abilities Necessary to Do Scientific Inquiry	●	●	●	●	●	●	
• Understandings About Scientific Inquiry	●	●	●	●	●	●	●
Physical Science							
• Structure and Properties of Matter	●	●	●	●	●	●	
• Motions and Forces	●	●	●	●	●	●	
• Conservation of Energy and Increase in Disorder	●	●	●		●		
• Interactions of Energy and Matter	●	●	●		●		
Earth and Space Science							
• Energy in the Earth System	●	●	●		●		
• Origin and Evolution of Planets						●	●
• Origin and Evolution of Planetary Systems						●	●
Science and Technology							
• Abilities of Technological Design							●
• Understandings About Science and Technology						●	●
History and Nature of Science							
• Science as a Human Endeavor						●	●
• Nature of Scientific Knowledge	●	●	●	●	●	●	●

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).

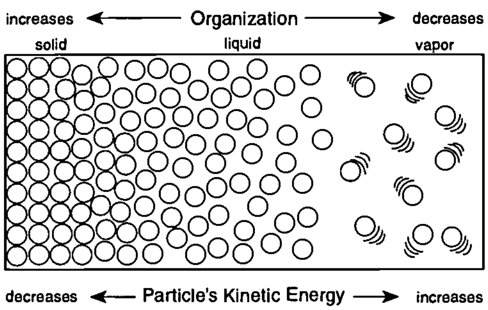


Figure 1.1. As a material's temperature changes, the spacing and energy level of its particles change.

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.

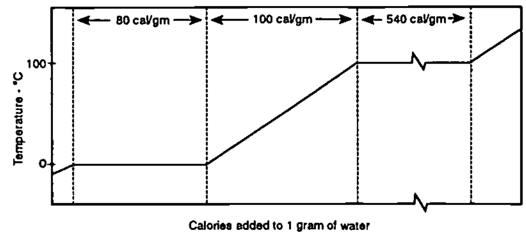


Figure 1.2. The heating curve of water shows how temperature changes as heat is added or subtracted. For example, when the temperature of ice reaches 0 degrees Celsius, it takes the addition of 80 calories to melt each gram of ice. Because all the added heat goes to melting the ice, the temperature holds 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.

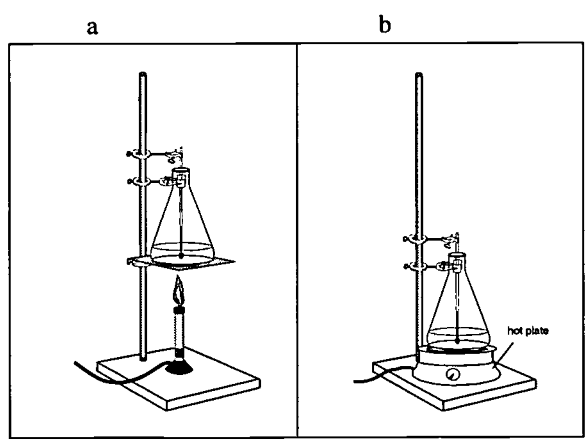


Figure 1.3. Activity 1 set up with (a) a burner and (b) a hot plate.

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.

How Fast Does Water Warm as Ice Melts?

Purpose

To have students graph the temperature of an ice-water slurry as it is heated and discover the existence of another transition plateau

Overview

Students become aware of their preconceptions by considering how hot they could heat ice water. They then test their preconceived ideas by heating an ice-water slurry and measuring its temperature. Until all the ice melts, students find that the temperature remains constant, nearly 0 degrees Celsius. They graph the data and try to make sense of the temperature plateau. Finally, the students explain what changes of state mean at the molecular level.

Key Concepts

- The temperature of ice water can rise only after all the ice has melted.
- The slope of a graph line in this activity shows the rate of temperature change.
- Temperature measures the average vibrational energy of a particle or group of particles.
- As the water in Activity 1 boiled and the ice in Activity 2 melted, the particles used the energy from the heat source to gain the extra kinetic energy required to change state. As a result, the temperature during these transitions never changed.

Context for This Activity

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

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 and *communicating* them to others

Common Misconceptions

- The temperature of ice-water will rise as soon as heat is applied.
- Ice melts as a result of high water temperatures.
- A temperature plateau means that something is malfunctioning.

Materials

Heat source, beaker or flask, ice-water slurry, thermometer, ring stand or tripod, ring clamps, thermometer clamp, stirring rod, wire gauze (burners only), dishpan, 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. Clamp thermometers to ring stands.
- Discuss safety procedures related to heat sources, thermometers, glassware, and hot water.

Time: 2 class periods

Background

Activity 2 exposes students to yet another transition plateau—the one in which ice melts and becomes liquid water (Figure 2.1). The explanation of the ice-liquid transition plateau is much the same as the explanation of the liquid-vapor transition plateau in Activity 1. As heat is added to an ice-water slurry, the ice consumes 80 calories per gram. The ice will absorb all the heat available in order to melt. When the ice melts, it becomes water at 0 degrees Celsius, so the water remains at 0 degrees Celsius until all the ice has melted.

What is amazing is that on Mars, the ice-liquid transition plateau occurs at virtually the same temperature as the liquid-vapor transition plateau! How do the two plateaus, which are separated by about 100 degrees Celsius at sea level on Earth, end up being the same line on Mars? By the end of the module, you and your students will not only have an answer to this question, but you will understand enough about the intriguing story of water on Mars to be able to ask the same kinds of questions being asked by planetary scientists. You and your students will also learn how to use the data and images returned by NASA's missions to Mars to answer those questions (Figure 2.2).

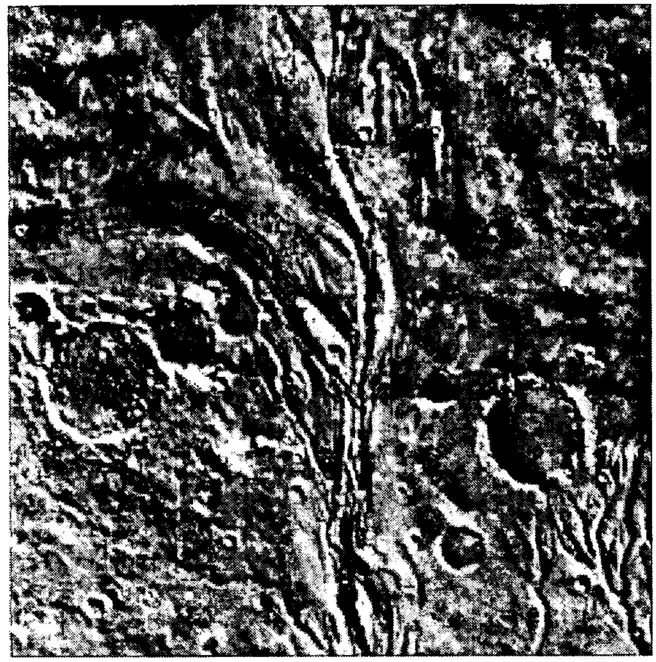


Figure 2.2. A Viking image of the channels between the Lunae Planum and the Chryse Planitia.

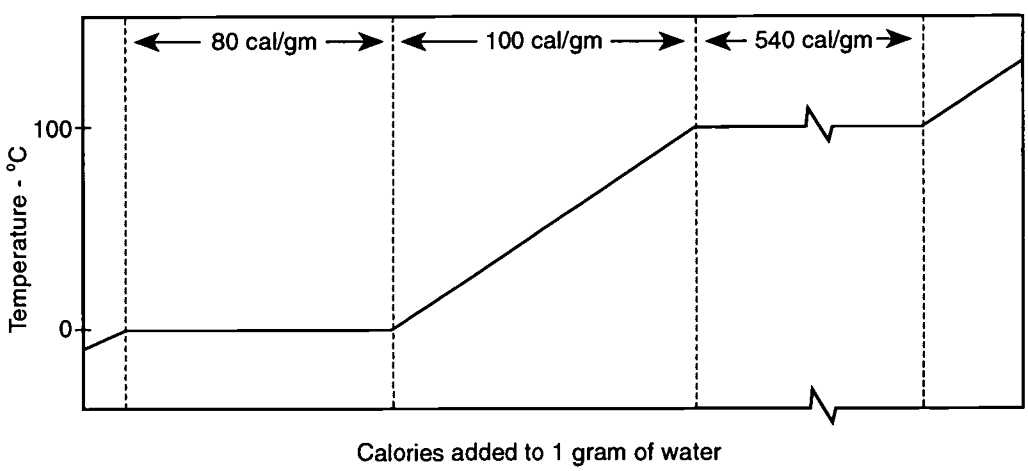


Figure 2.1. The heating curve of water shows how temperature changes as heat is added or subtracted.

Preassessment

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

- What will happen when you heat ice water?
- How hot can ice water get if 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.

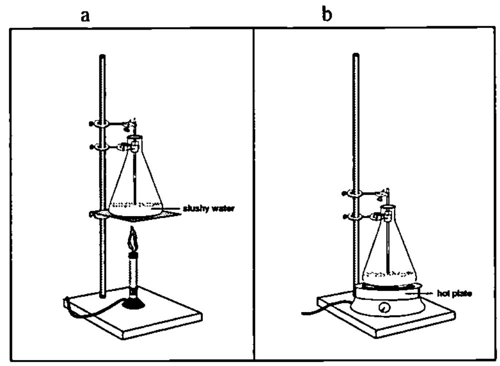


Figure 2.3. The activity set up with (a) a hot plate and (b) a burner.

Procedure to Test Students' Preconceived Ideas

1. Present the problem, "How hot can you heat ice 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.

2. Have students set up the equipment for the activity (see Figure 2.3):

   - Place crushed ice in a beaker up to the 150-milliliter line
   - Make an ice-water slurry by adding enough water to the beaker or flask to bring the ice-water mixture to the 150-milliliter line
   - Alternatively, prepare a large dishpan with the ice-water slurry and have students obtain 150 milliliters of it
   - If using a Bunsen or alcohol burner, adjust the lower ring to fit the burner properly and set a wire gauze on the lower ring
   - Place the beaker containing the slurry on the wire gauze or on the hot plate (turned off)
   - Attach the thermometer above the beaker with a clamp, string, or pipe cleaner
   - Adjust the thermometer so that the thermometer bulb is completely submerged and just above the bottom of the beaker (It should *not* touch the bottom of the beaker.)

3. Have students record the beginning temperature of the ice-water mixture.

   The temperature should be close to 0 degrees Celsius.

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 temperature of the ice-water mixture every 15 seconds until the water temperature reaches 25 degrees Celsius.

   Stirring is important because pockets of warm water can collect before all the ice has melted. This procedural mistake can give misleading results that take time to explain and might cause already disbelieving students to discount their observations.

   Their Activity 1 graph started at about 20 degrees Celsius. If this graph ends at 25 degrees Celsius, the graphs from the two activities can be joined to show the relationship between the two plateaus. If time permits, have students gather a continuous set of ice-to-water-to-vapor data by continuing to heat their water to boiling.

6. Have students graph their data.

   Have students use the same intervals they used for their Activity 1 graph. The graphs may be two or three papers long. If students use several sheets of paper to make their graphs, have them trim the edges and make one continuous graph.

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.

9. Conduct a discussion centered on having students explain changes of state in molecular terms based on the graphs generated in Activities 1 and 2.

   Some possible ways to discuss change of state include (a) reviewing the kinetic theory and having students act out what is happening at the molecular level; (b) using flow diagrams to show how energy enters and leaves the system; (c) inventing analogies related to changes that occur after overcoming a resistance; (d) challenging students' understanding with questions similar to Analysis Questions 10–15 below.

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 ice in your beaker melt? How does it compare to the melting temperature of the ice in your neighbor's beaker?

3. What did you notice happening during the time the temperature plateaued?

4. How can the temperature remain steady while the hot plate/burner is still providing heat to the ice? Where is all that energy going?

Analysis Questions

These questions pertain to both Activities 1 and 2 and probe students' assumptions and understanding of boiling and melting. They are listed after Activity 2 because students will get more out of them after having direct experience with both boiling and melting. Use these questions as the basis of a discussion, for group work, or for homework.

1. How might the temperature plateau be related to the process of water boiling?

2. How might the temperature plateau be related to the process of ice melting?

3. What does the heat from the hot plate/burner do to the water molecules?

4. What does the heat from the hot plate/burner do to the ice molecules?

5. When a molecule goes from the liquid to the vapor state, how does its energy level change? What happens to its vibrational speed?

6. When a molecule goes from the solid to the liquid state, how does its energy level change? What happens to its vibrational speed?

7. Name the states of matter involved in the boiling of water.

8. Name the states of matter involved in the melting of ice.

9. Draw a cartoon panel or sequence of pictures that shows what is happening when:
   (a) The hot plate/burner is heating the water but the water has not reached the boiling point and is not boiling
   (b) The hot plate/burner is heating the water and the water has reached the boiling point and is boiling
   (c) The hot plate/burner is heating the ice, but the ice has not fully melted
   (d) The hot plate/burner has melted the ice and is now heating liquid water

10. What would you have to do to make the boiling plateau last exactly 10 minutes? An hour?

11. What would you have to do to make the melting plateau last exactly 10 minutes? An hour?

12. How is the melting of ice similar to the boiling of water? How is it different?

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

14. What shape do you get when you attach the solid-to-liquid and the liquid-to-vapor graphs together? What do these shapes tell you about when water changes state?

15. Is water the only substance whose solid-to-liquid and liquid-to-vapor graphs have this shape? How could you test this idea? What differences would you predict between the change of state graphs of water and other substances?

16. Write a paragraph comparing how you answered the preassessment questions to Activities 1 and 2 with how you would answer them now.

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.

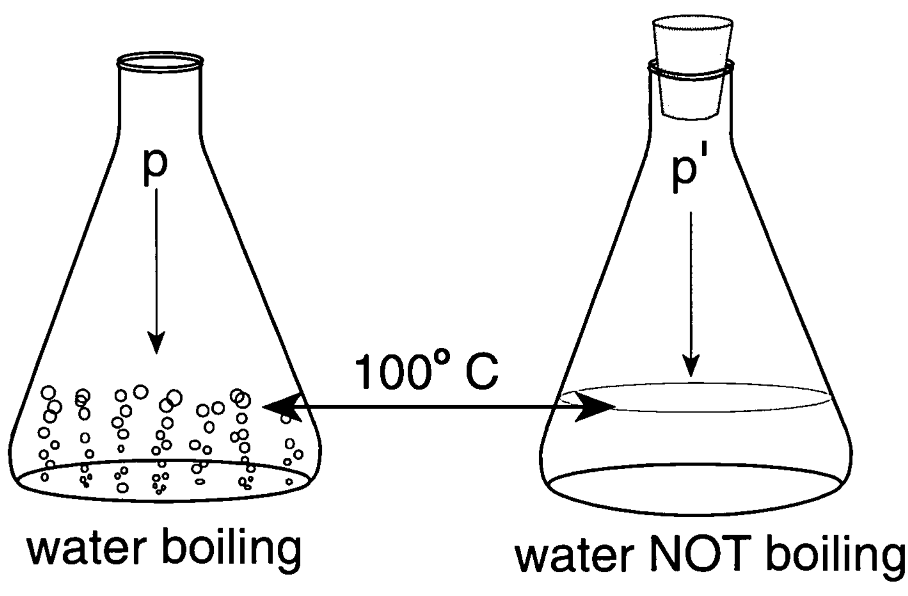


Figure 3.1. The water in both flasks is at 100 degrees Celsius, but it is only boiling in Flask A, which is open and at atmospheric pressure (p). Flask B is stoppered, and the pressure is above atmospheric pressure (p'), preventing the water from boiling.

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.

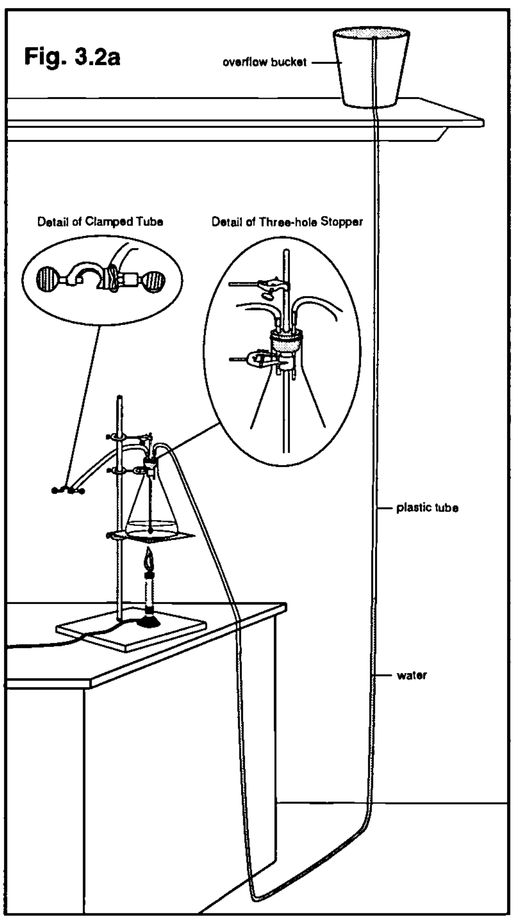
Procedure to Test Students' Preconceived Ideas

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.

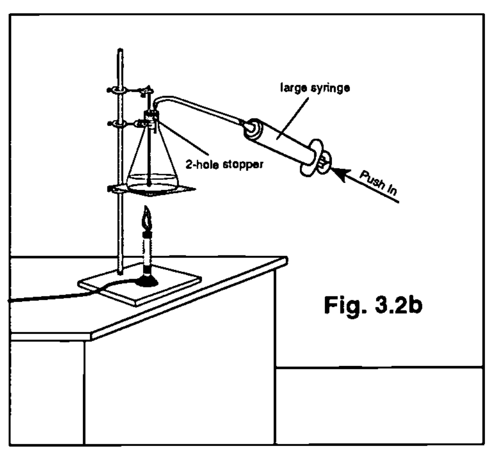
2. Ask groups to develop hypotheses based on the ideas listed in Step 1. List the hypotheses on the board.

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.



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.



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.

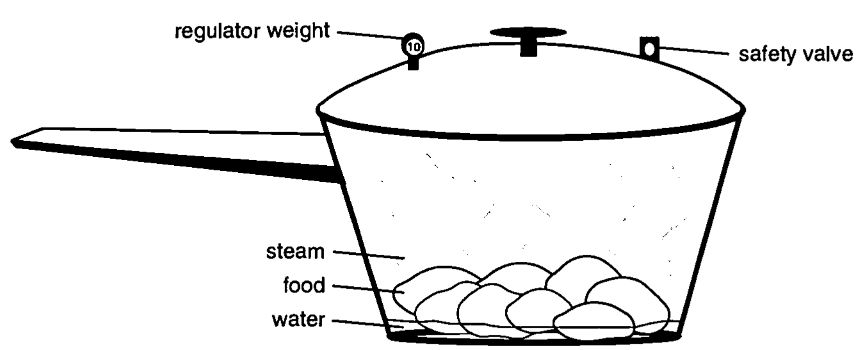


Figure 3.3. Cross section of a pressure cooker.

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.

Do Fish Believe in Water? Do Students Believe in Air?

Purpose

To have students perform several activities showing that Earth's atmosphere exerts considerable force at the surface

Overview

Students rotate through a number of stations, each of which has an activity that uses atmospheric pressure to produce an unexpected outcome. They then distill the activity's common elements into a set of core principles. Finally, they apply their understanding of atmospheric pressure by designing devices that make use of pressure differences.

Key Concepts

- Air has mass and volume.
- Air pressure is a function of the mass and temperature of the atmosphere in conjunction with Earth's gravitational pull.
- The particles in high-pressure air are packed more densely than those in low-pressure air.
- Air flows from areas of high pressure to areas of low pressure to equalize the pressures.
- When the volume of a given mass of gas increases, its pressure decreases, provided that the temperature remains constant (Boyle's Law).

Context for This Activity

Many students are unaware that they are subject to atmospheric pressure, or even that they live within an atmosphere. In this activity, students make the often-unnoticed effects of the atmosphere noticeable. Activity 4 sets the stage for Activities 5 and 6, when students consider the consequences of little or no atmospheric pressure.

Skills

- *Observing* a situation
- *Developing* a hypothesis
- *Drawing* conclusions and *communicating* them to others
- *Applying* their understanding
- *Designing* devices

Common Misconceptions

- Air has no mass or volume.
- Atmospheric pressure is negligible.
- Day-to-day air pressure changes have no rational explanation.

Materials

See notes pertaining to each station.

Preparation

- Determine how well the class understands that air has mass and volume, and consider ways to review or develop these ideas if they are new or if students need a refresher.
- Set up the stations you have selected for your class.
- Select one or two demonstrations to test the class's core principles.
- Decide which devices you want to have students design/build in Step 8.

Time: 2–3 class periods

Background

Because air is invisible and generally imperceptible, it is hard for people to identify it and its effects. In addition, many book presentations use abstract concepts and technical terminology to discuss air and air pressure. As a result, many students find these topics confusing and are discouraged from altering their prior views and ideas.

Students may not understand that air has mass and that our atmosphere, which is more than 100 kilometers thick, has considerable weight. Just as fish may be oblivious to the water that supports and sustains them, most people are oblivious to the fact that they live at the bottom of a great sea of air.

While we have little trouble understanding why we feel significant water pressure at the bottom of a swimming pool, we often find it hard to accept that we are subject to air pressure. Because our arms and bodies move so effortlessly, we find it hard to believe that the atmosphere presses down on us as hard as it does. In the case of a moving arm, what we forget is that the atmosphere presses equally hard on the top, sides, and bottom of our arms, so the force is equalized in all directions, effectively eliminating any sensation of pressure. It is, perhaps, testimony to the ways our bodies have adapted to air pressure that we can live quite happily without ever acknowledging air or air pressure.

Earth's atmosphere is estimated to weigh 5.8 million billion tons, and the atmosphere pushes with a force of 1,013 millibars at sea level (see Figure 4.1)—a function of the mass and temperature of the atmosphere in conjunction with Earth's gravitational pull. Higher pressures result when there is more atmosphere overhead. Conversely, lower pressures result when there is less atmosphere overhead (Figure 4.1). Under high pressure, particles are packed together more tightly than under low pressure. The scientific maxim, "Nature abhors a vacuum," also applies to partial vacuums and pressure

Altitude (Meters)	Pressure (Millibars)	Percent of Atmosphere Above This Altitude	Boiling Point (Celsius)
0	1,013	100	100.0
500	955	94	98.5
1,000	899	89	96.9
1,500	846	83	95.0
2,000	795	78	93.5
2,500	747	74	91.9
3,000	701	69	90.0
3,500	658	65	88.5
4,000	617	61	86.8
4,500	578	57	85.0
5,000	541	53	83.5
5,500	505	50	81.5
6,000	472	47	80.0
6,500	441	43	78.5
7,000	411	41	76.5
7,500	383	38	74.9
8,000	357	35	73.1
8,500	332	33	71.5
9,000	308	30	69.7
9,500	286	28	68.0
10,000	265	26	66.4

Figure 4.1. This vertical profile of air pressure is based on the Standard Atmosphere, a model averaged for all seasons and latitudes. It uses a fixed sea-level air temperature of 15 degrees Celsius and a pressure of 1,013 millibars. For comparison, Denver is at 1,500 meters, and Mount Everest is 8,848 meters tall. Ninety-nine percent of the atmosphere is below 32 kilometers.

differentials. As a result, high-pressure air moves to areas of low-pressure air to equalize the pressure and to achieve a consistent spacing between all the particles.

This module is about water. Because water could not exist in the liquid form without a certain amount of air pressure, it is crucial to understand that Earth's atmosphere exerts a significant force at the surface. Because of their kinetic energy, molecules in the liquid state can become vapor if the atmospheric pressure is low enough. To remain a liquid, molecules must be pressed together enough so that they cohere rather than separate and become vapor.

To get the most out of this activity, students will have to understand that air has mass and volume and that it can exert pressure. If these concepts are unclear to your students, there are a number of hands-on ways to develop them. For example, to show that air has volume, inflate a bag or invert a cup in a pan of water and discuss why the bag cannot collapse or why water cannot enter the cup (Figure 4.2). To show that air has mass, weigh a minimally inflated volleyball (something whose volume will remain constant, unlike a balloon), add some air with a pump, and weigh it again. It will weigh more.

There are two concepts that help explain the situations at each station in Activity 4:

- When the volume of a given mass of gas increases, its pressure decreases, provided that the temperature remains constant (Boyle's Law).
- Air flows from areas of high pressure to areas of low pressure to equalize the pressures.

In the situations at the stations, students increase the volume of a contained amount of gas. According to Boyle's law, when the volume of a given mass of gas increases, its pressure decreases. Because nature abhors a vacuum (or even a partial vacuum), whenever there is a decrease in pressure, higher pressure air moves in to equalize the pressure. At each station, there is a barrier between the areas of high and low pressure, so the higher pressure air is blocked from reaching the lower pressure air. This creates a pressure gradient. The atmosphere will push on the barrier in its attempt to overcome the gradient and equalize the pressures.

In each of the setups, students can calculate the force exerted by the atmosphere by multiplying atmospheric pressure (about 1 kilogram per centimeter^2) by the surface area of the barrier between the high and low pressures.

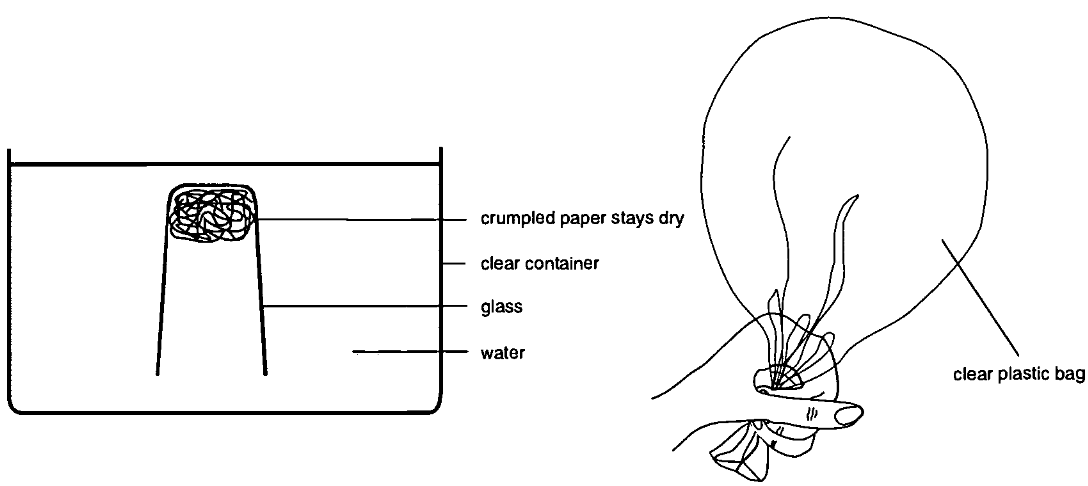


Figure 4.2. Two ways to demonstrate that air has volume and occupies space.

Preassessment

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

- Describe a time when the atmosphere was pushing on you.
- How hard was it pushing on you at that time?
- Why can you drink a milkshake through a straw?
- If the lid is on tightly, why is it sometimes hard to drink the milkshake through the straw?

(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. Set up a number of stations (see preparation notes on page 28) and have groups spend a few minutes at each one. Have each student record his or her observations and answers to the questions.

2. Have each student make sense of the observations in his or her own way by explaining how the situation at each station works.

   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.

3. Have students share their explanations in their groups. Have groups summarize the explanations and develop a set of operating principles that can explain the situations at the different stations.

4. Challenge the groups to eliminate duplication and redundancy and reduce their lists of explanations to a core set of operating principles.

5. Have each group share the operating principle with the greatest explanatory power. Record the principles on the board.

6. Examine the list for duplication. Ask whether there are other principles to add to the list.

7. Test the principles against the situations at each station. If the class is struggling to understand a particular situation, have them repeat Steps 2–6.

   Probe students' thinking by pointing out apparent contradictions and flaws. Consider using a demonstration not used in a station either as a way to open up students' thinking or as a test of the class's principles.

8. Test students' grasp of atmospheric pressure by giving them challenges, such as:

   - Devise a way to measure elevation using air pressure (for example, a barometer).
   - Build a device that measures differences in daily air pressure (for example, a barometer).
   - Without blocking the tube, modify a straw so it is impossible to use (for example, poke holes in the straw).
   - Design an exercise system based on differences in air pressure (for example, a resistance device employing pistons or suction cups).
   - Design three systems that let astronauts drink from a straw in the vacuum of space (for example, a squeeze bag, a pressurized cup, a pump, etc.).

Analysis Questions

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

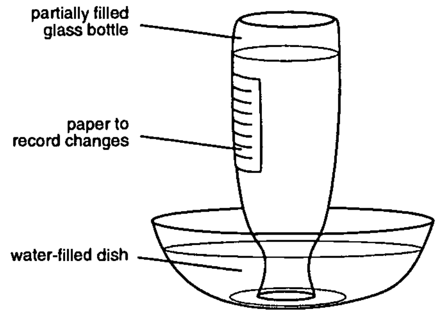


Figure 4.4. The water level in this barometer changes in response to changes in atmospheric pressure.

1. What causes air pressure?
2. What might cause air pressure to change?
3. On a molecular level, describe the differences between high- and low-pressure air.
4. Why does high-pressure air try to flow to areas of low pressure?
5. Name three ways to change high-pressure air into low-pressure air and three ways to change low-pressure air into high-pressure air.
6. Why is air pressure typically lower at the top of a mountain than at sea level?
7. If the atmosphere really presses down on your arm with great force, why is it so easy to move it?
8. What is the typical atmospheric pressure on Earth? What was it at your school today?
9. Write a paragraph comparing your how you answered the preassessment question with how you would answer it now.

Extension

Barometers measure changes in air pressure. You can easily make the aneroid barometers illustrated below from readily available materials. In each case, as the air pressure changes, the volume of the enclosed air will either increase or decrease, depending on the pressure gradient between the room air and the trapped air.

Stretch a piece of balloon over the mouth of a jar, and secure it with tape to trap some air. With rubber cement or petroleum jelly, attach two small pieces of wood or plastic to the balloon, one over the center of the opening and the other over the rim of the jar. Position a straw, as shown in Figure 4.3, and secure the end over the middle to the wood with some rubber cement or petroleum jelly. The straw functions as a lever, and its movement indicates the increase or decrease in the volume of the trapped air. *Caution:* If students handle the jar while they are taking measurements, the heat from their hands will warm the enclosed air and cause it to expand, increase the interior pressure, and alter the measurement.

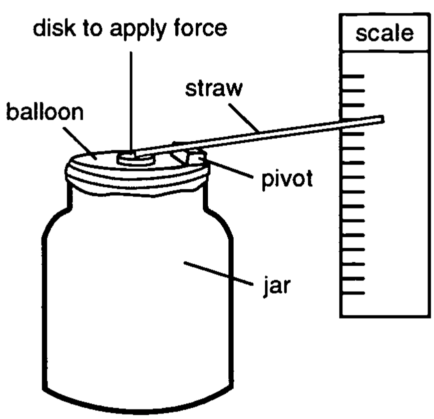


Figure 4.3. The elastic material in this barometer moves in response to changes in atmospheric pressure.

Partially fill a rigid bottle (for example, glass) with water. Invert it so its mouth is under the surface of a water-filled saucer. To prevent evaporation, cover the water exposed to air with a thin film of vegetable oil. You can record variations in air pressure by attaching a strip of paper to the outside of the bottle (Figure 4.4).

The Station Cards for the Eight Stations in Activity 4

Can You Unstick the Plunger?

Procedure

1. Press the plunger onto a smooth, hard surface. Note any air flowing in or out of the small hole.
2. Pull straight up and pull the plunger off the surface. Note any air flowing in or out of the hole.
3. Press the plunger onto a smooth, hard surface. Cover the small hole with a wetted finger.
4. Pull straight up and pull the plunger off the surface.

Questions

1. Why does air come out the small hole in Step 1?
2. Why does air enter the small hole in Step 2?

Can You Get the Glove Out of the Jar?

Procedure

1. Put your hand in the glove.
2. Keeping the jar on the table, pull the glove out of the jar without disturbing the jar's seal.
3. Keep the jar on the table at all times, and please do not rip anything.

Questions

1. When did you first feel resistance?
2. Can you curl your fingers without feeling any resistance?
3. What is keeping the glove in the jar?
4. How could you alter the setup so the glove could come out easily? Why would your change make a difference?

How High Can You Lift Water?

Procedure

1. Submerge the glass and tip it so it fills with water but still has a small air pocket above the liquid.
2. Lift the glass straight up. How high can you lift the water inside the glass before it spills out?
3. Try setups with bigger, smaller, and no air pockets. How high can you lift the water inside these situations before it spills out?

Questions

1. Does the size of the air pocket change as you lift the glass? Mark the water level, if necessary.
2. How did the size of the air pocket affect the outcome?
3. What changes occur to enable the water to flow out?
4. Why does the water stay in the glass instead of flowing back into the pool of water?

Can You Inflate the Balloon?

Procedure

1. Slip a section of drinking straw onto the open tube (for example, the tube without the balloon attached).
2. Inflate the balloon as much as possible by sucking on the straw.

Questions

1. How was air moving into the balloon?
2. What were you doing to help air move into the balloon? What important system of the body works this way?
3. What do you have to do to keep the balloon inflated? Why?
4. How else could you inflate the balloon? Describe the way the air would flow if you tried your method.
5. What would happen if you blew through the open tube?

Can You Fix a Leaky Bottle?

Procedure

1. Fill the bottle with water.
2. How can you stop the water from flowing out the small hole at the bottom of the bottle without turning it over?

Questions

1. Do any of your ideas involve air pressure? How?
2. Does the water stop flowing immediately after you cover the top?
3. When the top is covered, why does air not enter the bottle through the small hole?
4. Why did the water stop flowing out of the bottle?

How Strong Is a Suction Cup?

Procedure

1. Press one of the suction cups onto a smooth surface.
2. Attach the scale's hook to the suction cup.
3. Have people stand back so a flying elbow does not hurt someone. Pull straight up until the suction cup pops off, noting the amount of force required to remove it.
4. If available, try some of the other suction cups.

Questions

1. How much force did it take to remove a suction cup?
2. Did each suction cup require the same amount of force? If not, why are there differences?
3. What keeps the suction cup sticking to the surface?
4. Why is it so easy to remove a suction cup if you lift an edge?

Can You Trap Water Inside a Straw?

Procedure

1. Hold a finger over the end of a straw, and lower it into the water.
2. Remove the finger, and observe what happens.
3. Replace the finger on top of the straw, and lift it out of the water.

Questions

1. Why did the water not enter the straw in Step 1?
2. Why did the water rush in once you removed your finger?
3. How did you get the water out of the straw? What changed once the finger was removed that enabled the water to flow out of the straw?

Can You Use a Card to Keep Water Inside an Inverted Glass?

Procedure

1. Fill the container three-quarters full of water.
2. Place the card over the mouth of the container.
3. Holding the card to the rim with a dry hand, invert the container over the dishpan.
4. Mark the position of the top surface of the liquid.
5. Slowly, remove the hand holding the card.
6. Again, mark the position of the top surface of the liquid.

Questions

1. Did the position of the top surface of the liquid change?
2. Describe the shape of the card.
3. What is keeping the water in the container?
4. How far can you slant the container before the water pours out?

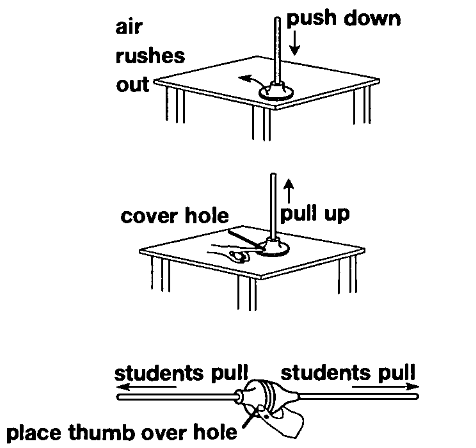


Figure 4.5. The rubber cup expands, increasing the volume and lowering the pressure of the trapped air.

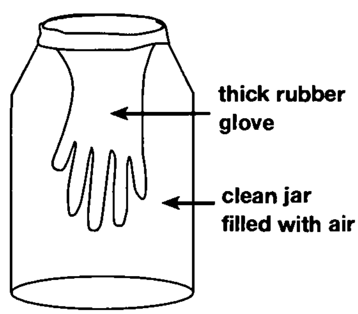


Figure 4.6. When the glove is removed, the volume of the trapped air increases, and its pressure decreases.

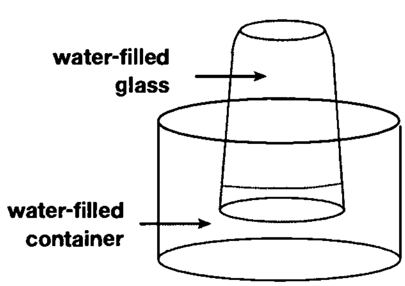


Figure 4.7. Some water leaves the glass, increasing the volume and decreasing the pressure of the trapped air.

Notes for Preparing Each Station

Can You Unstick the Plunger?

Preparation and Pointers

1. Make a small hole in the plunger cup with some scissors or an awl.
2. You can improve the seal by moistening the edge of the plunger or one's finger (Figure 4.5).

Alternatives or Extensions

Instead of using one plunger on a hard surface, stick two plungers together. Poke a small hole in one of them. In the year 1650, a similar experiment with two hollow iron hemispheres was performed in Magdeburg, Germany. The hemispheres were placed together, and some air was removed. The vacuum was so strong that it required 16 horses to separate them.

Can You Get the Glove Out of the Jar?

Preparation and Pointers

1. Use a clear, 1-gallon, wide-mouthed jar, such as a pickle jar. If you are worried that students might break a glass jar, consider using a clear plastic jug.
2. Use good quality, heavy-duty rubber gloves (Figure 4.6).

Alternatives or Extensions

1. A plastic bag, such as a bread bag, also works, although it is prone to tearing.
2. To show that air occupies space with this setup, invert a plastic bag over the mouth of the jar, blow a little air into the bag so that it stays inflated over the jar, and seal the bag air-tight against the jar. Ask students to push the bag into the jar. Because the jar is already full of air, the bag cannot go in.

How High Can You Lift Water?

Preparation and Pointers

At the station, provide a dishpan of water, a clear glass, a marker or tape for marking the water level, and towels (Figure 4.7).

Alternatives or Extensions

Ask students: "What is the least amount of water needed to support a glass full of water?" Fill the glass, place a petri dish over it, hold it over the dishpan, invert the glass and petri, and let a little water into the petri. The shallow pool of water will support an entire glass of water because atmospheric pressure acts on the surface area rather than the volume of the liquid.

Can You Inflate the Balloon?

Preparation and Pointers

1. Use a flask or a tall jar whose opening can accommodate a two-hole stopper.
2. Insert two glass tubes through the holes in the stopper. To keep the tubes away from the students' eyes during inflation, either make the balloon's tube stick only a short way above the stopper or use a glass tube with a 90-degree bend as the mouthpiece tube.
3. Use a rubber band or tape to attach a small balloon to one of the glass tubes.
4. For sanitary reasons, cut drinking straws into sections, and have students slip them over the glass tube and use them as mouthpieces.
5. Choose glass tubes and drinking straws that fit snugly together (Figure 4.8).

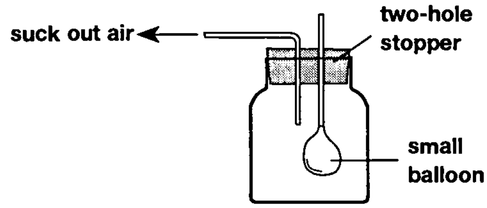


Figure 4.8. When air is removed from the jar, the pressure inside the jar decreases.

Alternatives or Extensions

1. Students will have to seal the open tube to maintain the lower pressure in the jar and keep the balloon inflated.
2. Students can also inflate the balloon by blowing into the tube attached to the balloon, provided the other tube remains unblocked.
3. Have students consider how their lungs are similar to and different from this model.

Can You Fix a Leaky Bottle?

Preparation and Pointers

1. A 12-, 16-, or 32-ounce plastic soda bottle with a small mouth works well.
2. Use a nail to make a small hole, and test the setup to make sure it works properly.
3. Provide a water supply, a cup for filling the bottle, a dishpan, and towels at the station (Figure 4.9).

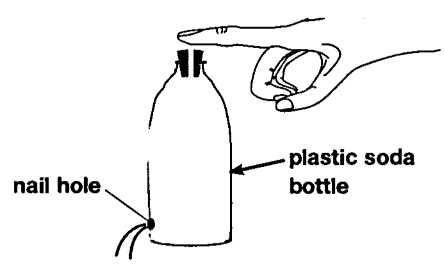


Figure 4.9. When some water flows out, the volume of the trapped air increases and its pressure decreases.

Alternatives or Extensions

1. If students turn the bottle upside down, can they prevent water from flowing out the unsealed stopper hole? Out of an unstoppered bottle? Why or why not?
2. Ask why it is a good idea to poke two holes in the top of a can, such as an evaporated milk or frying oil can.

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