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.

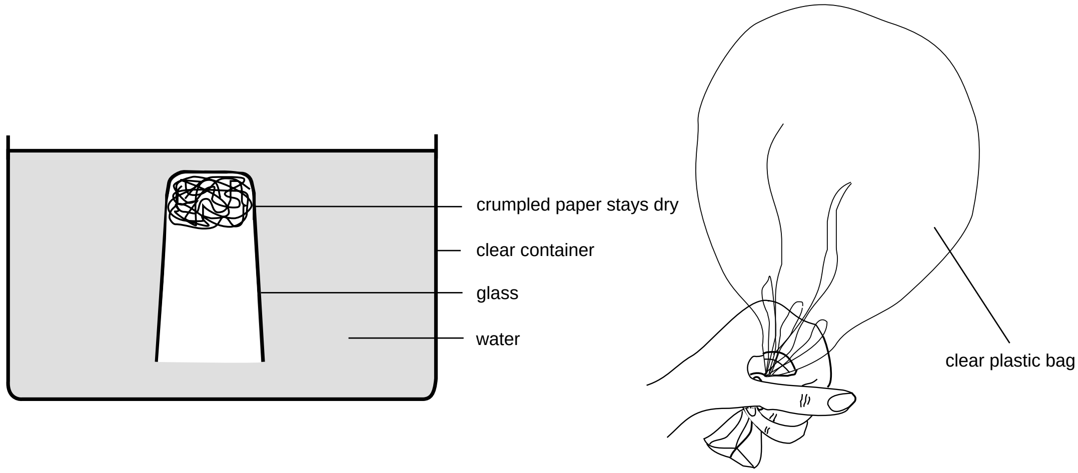

Figure 4.2. Two ways to demonstrate that air has volume and occupies space.

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.

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?

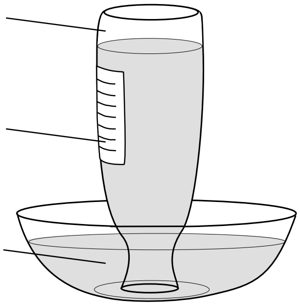

Figure 4.4. The water level in this barometer changes in response to changes in atmospheric pressure.

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.

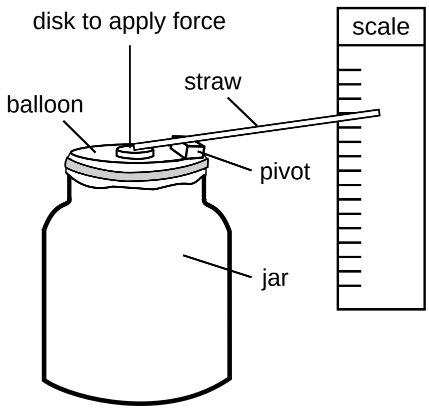

Figure 4.3. The elastic material in this barometer moves in response to changes in atmospheric pressure.

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).

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?

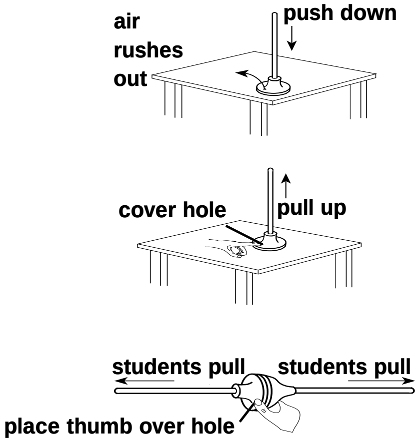

Figure 4.5. The rubber cup expands, increasing the volume and lowering the pressure of the trapped air.

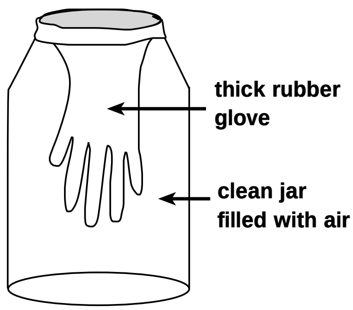

Figure 4.6. When the glove is removed, the volume of the trapped air increases, and its pressure decreases.

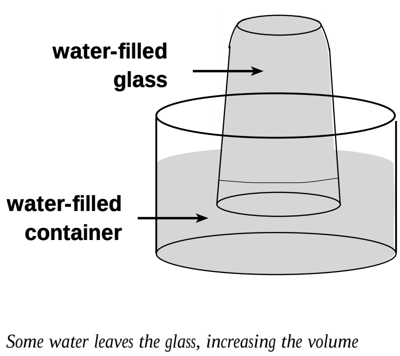

Figure 4.7. Some water leaves the glass, increasing the volume and decreasing the pressure of the trapped air.

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).

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.

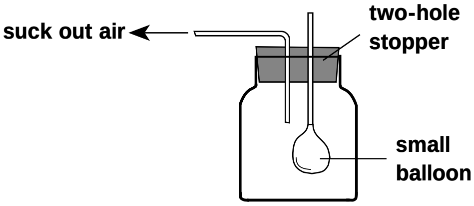

Figure 4.8. When air is removed from the jar, the pressure inside the jar decreases.

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).

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.

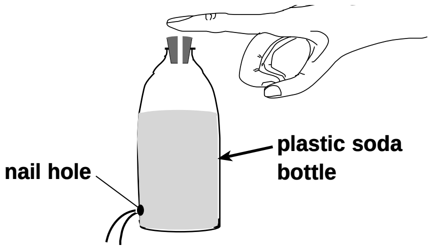

Figure 4.9. When some water flows out, the volume of the trapped air increases and its pressure decreases.

How Strong Is a Suction Cup?

Preparation and Pointers

1. Find suction cups with hooks *securely attached* with a loop of metal around the top of the suction cup rather than with a hook screwed into the rubber.
2. If a hook comes off, wrap wire around the bulb on top of the suction cup and form a loop. Alternatively, you can pierce the bulb and thread a wire through it.
3. Buy many backup suction cups if the hooks tend to come off easily. If keeping hooks attached is difficult, students can still get the point by just tugging at the suction cup. This gives them a good qualitative rather than quantitative experience.
4. *Stress caution.* Students will be pulling hard, and a sudden release will cause the puller's arm to swing back quickly.
5. Buy suction cups in a variety of sizes.
6. Use heavier duty scales, such as ones that measure up to 25 or 50 kilograms.
7. Make sure the surface is smooth enough for the suction cups to make a good seal.
8. Putting stiff suction cups in boiling water for a few minutes can revitalize them (Figure 4.10).

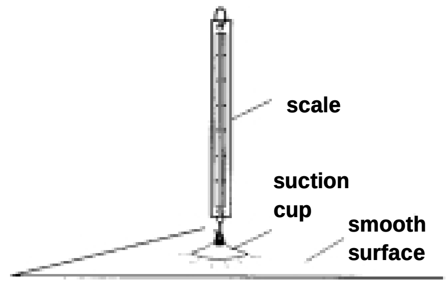

Figure 4.10. The rubber cup expands, increasing the volume and lowering the pressure of the trapped air.

Can You Trap Water Inside a Straw?

Preparation and Pointers

1. Make sure the straw is transparent. A glass tube can be substituted.
2. Adding color to the water can make it easier to see.
3. Provide towels at the station (Figure 4.11).

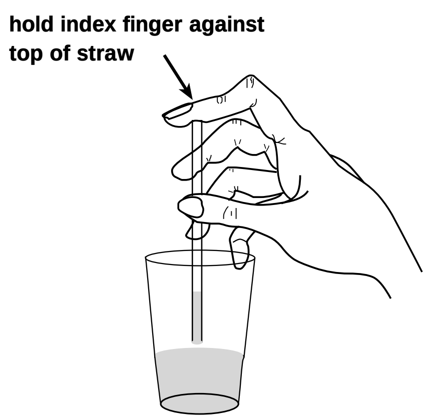

Figure 4.11. Gravity pulls the water down, increasing the volume and lowering the pressure of the trapped air.

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

Preparation and Pointers

1. Make sure the container is transparent and that its opening is smaller than a playing card. It must be made of a rigid material, such as glass. Otherwise, the card will be forced off when the container is squeezed.
2. Plastic-coated playing cards work well because they do not soak through. In addition, a deck of 52 cards assures that a dry card can be used each time.
3. Provide a marking pen, dishpan, and towels at the station (Figure 4.12).

Alternatives or Extensions

1. Other noncarbonated liquids will work equally well.
2. A container filled to the brim will also work. With no air pocket, there is no air pressure in the container. Therefore, the only pressure on the container side of the card is the weight of the water. If this weight is less than atmospheric pressure, the card will remain on the rim. You can determine the pressure gradient by comparing the pressure on the card with the weight of the water.

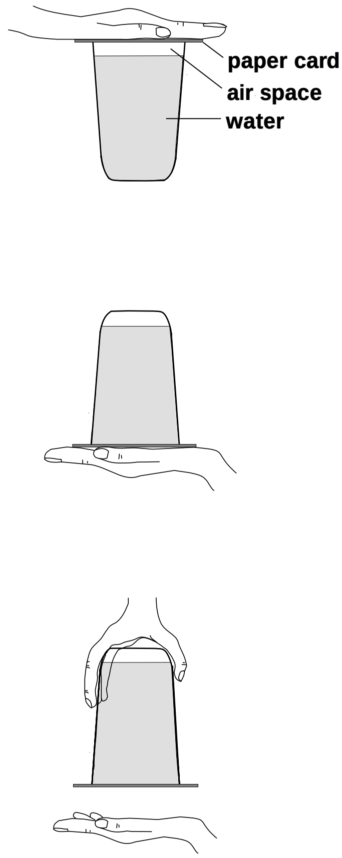

Figure 4.12. The card bows slightly, increasing the volume and lowering the pressure of the trapped air.

Teacher Demonstrations

These activities are better conducted as demonstrations because they either use materials that are in limited supply, involve fire or boiling water, take longer to complete than the activities recommended for the stations, or are best understood when you are able to use questions to guide students' thinking. Practice these demonstrations before trying them.

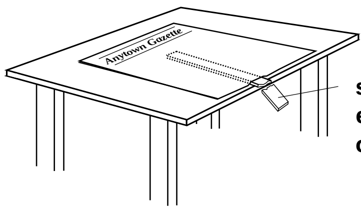

Figure 4.13. The pressure under the paper is far less than the pressure above the paper.

The Heavy Newspaper

Lay a long, thin, flat, breakable board (for example, paneling or a yardstick) on a table so that about 8 centimeters protrude. Ask students what will happen if you hit the end of the board. They will probably say that it will fly up. Hit the board so that it flies up. Next, spread one or two sheets of newspaper over the board. Position the newspaper flush with the edge of the table and remove all air pockets by smoothing it from the center outwards. Ask again what will happen if you hit the board. The students will probably think that the stick will fly up and tear the paper. Push down on the end of the board *slowly* and lift up the paper. Reset the paper and, this time, strike the end of the board sharply. The rising board will increase the volume of the small air pocket under the paper. However, there is too little time for air to get under the paper (Figure 4.13). The resulting pressure gradient temporarily turns the newspaper into an unyielding barrier, and the stick breaks. You can calculate the force on the paper by multiplying its area by atmospheric pressure. Pull another 8 centimeters of the board over the edge. Smooth the newspaper, and break the board as before. This can be repeated, but at some point the board will be able to rip the paper because of its mechanical advantage as a lever. Stop while you are ahead!

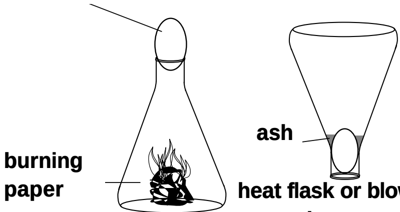

Figure 4.14. Fire drives out air and reduces the interior pressure, and atmospheric pressure pushes in the egg.

Egg in a Bottle

Lubricate a peeled, hard-boiled egg with vegetable oil or glycerin. Place it on the rim of a container whose opening is slightly smaller than the diameter of the egg. Ask: "What will happen if I light a fire under the egg?" Expect a wide variety of predictions. Light a piece of paper, lift up the egg, insert the burning paper, and set the egg quickly back onto the container's mouth. The egg will vibrate as the air warms, expands, and exits the container by slipping past the egg. When the fire goes out, the air cools and contracts. This lowers the pressure in the container, and atmospheric pressure *pushes* the egg into the container (Figure 4.14). To get the egg out, invert the container so that the egg blocks the passage, blow some air past the egg into the container, and let the increased pressure push out the egg. Alternatively, invert the container so that the egg blocks the passage, and heat the container. The air will expand when it warms and will push out the egg. This activity is also a good way to review the effect of heat on matter.

Drinking Through a Straw

Fill a flask with water, and seal it with a one-hole stopper fitted with a straw or glass tube. Challenge a student to drink water through the straw. When the student removes some water, the pressure in the flask drops (Figure 4.15). Because the pressure in the straw at that point is greater than the pressure in the flask, it quickly becomes impossible to extract any water. You can also use a two-hole stopper. By covering and uncovering the second hole, students can examine the effect of letting air move freely into the flask and contrast it with the situation when the hole is covered.

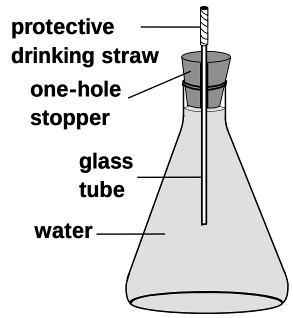

Figure 4.15. After a little water is removed, the interior pressure drops too low for students to overcome.

The Can Crush

Cover the bottom of a soda can with water. Using tongs, hold the can over a heat source until the water boils vigorously for around 30 seconds. Quickly, invert the can and dip 2 centimeters or so of the end with the opening into a container of cold water. With a dramatic crunching of aluminum, it will collapse instantly (Figures 4.16 a–c). The boiling water drove out the air and replaced it with water vapor. When the cold water cooled this vapor, it condensed. At 100 degrees Celsius and 1 atmosphere, liquid water is 1,600 times as dense as water vapor, so the volume of the vapor in the can drops significantly. The reduction in volume creates a partial vacuum in the can, and the atmospheric pressure outside the can crushes in to equalize the pressure differential. Although water is being sucked into the can through the opening, it cannot enter quickly enough to equalize the pressure. Plus, it further cools the vapor, further reducing the pressure. This activity is also a good way to review changes of state and the properties of liquids and gasses. This demonstration can also be done in "slow motion" by using a large metal can, such as a duplicator fluid gallon can (Figure 4.16 d–e). Instead of dipping it into cold water, screw on the lid, and let it cool slowly on a table top.

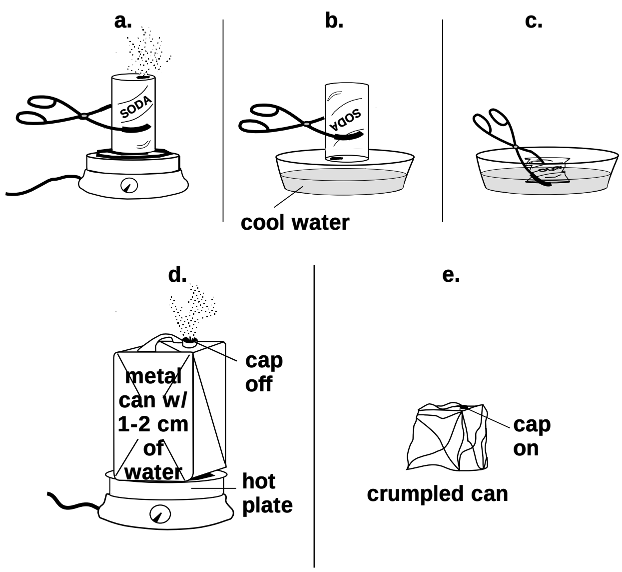

Figure 4.16. Condensing steam reduces the interior pressure, and atmospheric pressure crushes the can.