Priestly and Soda Pop
Teacher Activity

Procedure

Producing “Fixed Air” (Carbon Dioxide)

Carbon dioxide (CO_2) can be produced in multiple ways. It is a product of fermentation and combustion. It is also one product of the reaction between a carbonate (or hydrogen carbonate) and an acid. Priestley first noticed “fixed air” at the brewery near his house in England, where carbon dioxide was readily available as a result of the fermentation process. He used the carbonate-acid reaction, however, to create his carbonated water.

Demonstrate for the class the reaction between calcium carbonate and hydrochloric acid. As you produce carbon dioxide, bubble the gas through a limewater solution to demonstrate the presence of the gas. If students are not familiar with this test for CO_2, exhale through a straw into a limewater solution prior to the demonstration to show students the results.

For the demonstration you will need:

- 1MHCl
- Calcium carbonate (marble chips)
- Large test tube or Erlenmeyer flask
- 1-hole rubber stopper to fit test tube or flask Glass tubing, 10 cm
- Rubber tubing, 50 cm
- 1 00-mL beaker

Demonstration

Safety: Wear protective eyewear during the demonstration.

1. Insert glass tubing through the rubber stopper. Add rubber tubing to the end of the glass tubing that will extend outside the test tube or flask.
2. Carefully pour approximately 50 mL of limewater into a 1 00-mL beaker.
3. Add approximately 25 mL of HCl solution to the test tube or flask.
4. Add a pea-sized chunk of calcium carbonate to the acid.
5. Quickly insert the rubber-stopper assembly into the text tube or flask.
6. As CO2 bubbles form, insert the free end of rubber tubing into the limewater so that the gas bubbles through it.

Measuring the Volume of CO_2 in a Carbonated Beverage

This student lab activity is best done by students working in groups of two

Safety: Since students will be handling latex balloons, you should warn them about latex allergies and be on the alert for related problems.

In advance:

- Place 1 .0-L bottles of any clear carbonated beverage in a refrigerator overnight. You can assign students to bring the sodas from home in advance of this lab. You will need enough bottles of soda to supply groups of two students in your class.
- Purchase balloons. The 9-inch size works well.

For this lab you will need (per group of two students):

- 1 -L bottle of clear carbonated beverage
- One balloon
- Beaker, with diameter larger than the soda bottle (the beaker should also be able to hold the soda bottle so that the water reaches at least one-third of the way up the bottle)
- Plastic container to act as a water reservoir for measuring the volume of the CO_2 by water displacement

- Warm water supply
- Rubber tubing, 50 cm
- 2-L soda bottle, empty
- Graduated cylinder
- Felt-tip marker

Teacher Notes on Student Procedure

1. Obtain a 1 .0-L bottle of chilled soda from your teacher.

2. Carefully remove the cap and observe any changes that take place.
Students will immediately see bubbles rising in the soda. This is because the CO2 is dissolved under pressure and, as the pressure is decreased by removing the bottle cap, some CO2 comes out of solution.

3. Quickly place a rubber balloon over the opening of the bottle. Observe.
Students will see the balloon begin to fill with gas as the CO2 leaves the solution and enters the balloon.

4. After several minutes place the bottle and balloon assembly in a beaker, and add warm water to the beaker so that the water level is about one-third of the way up the soda bottle. Observe.
Bubbles will rise more quickly since the solubility of the CO2 decreases as the temperature of the solution increases.

5. GENTLY shake the soda bottle occasionally. You can remove it from the beaker of warm water as you shake it. Replace the soda bottle in the beaker. Observe.
Agitation will also cause more of the carbon dioxide to leave the solution.

6. When bubbles stop rising in the soda bottle, place about two inches of water in a plastic container. Fill the 2.0-L soda bottle completely with water. Place your hand over the opening and invert the 2.0-L bottle in the plastic container. When the mouth of the bottle is underwater, remove your hand.
The plastic container must be deep enough to accept the water displaced in this procedure. This method is the conventional one for measuring volume by water displacement. If you have pneumatic troughs, you may use them instead of the plastic container.

7. Carefully pinch the neck of the balloon to prevent any gas from escaping. Remove the balloon from the top of the soda bottle.

8. Insert the rubber tubing into the neck of the balloon, and use your fingers to seal the balloon around the tubing so no gas escapes. Thread the other end of the tubing into the mouth of the inverted 2.0-L bottle.
You may have to demonstrate to students how to do this step. By squeezing the balloon and tubing between thumb and forefinger, students can get a reasonable seal.

9. Be sure to keep the balloon sealed against the tubing, and SLOWLY allow gas to escape from the balloon by reducing the pinching pressure you exert on the balloon neck. Continue until all the gas has escaped into the larger bottle.
Most students will have experienced stretching out the neck of a balloon to allow air to leak out, causing the escaping air to make noise. Encourage them to use a similar procedure here.

10. Hold the inverted 2.0-L bottle so that the surface of the water inside is level, and mark the water level with a felt marker.

11. Empty all the water out of the bottle. Now refill the bottle to the mark you made.

12. Measure the volume of water by pouring it into a graduated cylinder. The measured volume will be at

least 1,200 mL.

13. Clean up. Be sure to recycle the plastic soda bottles according to your teacher's instructions.

Student Skills Required
In addition to basic knowledge of chemical reactions and solubility of gases, only general lab skills, such as measuring volumes, are required.to do this lab.

Student Misconceptions

1. **Gases do not dissolve in water.**
   Many students do not understand that gases dissolve in water. They do not see it happen, and since solutes are not visible in any solution, it is not often that students recognize a gas-water solution. They do learn that oxygen dissolves in water, which in turn leads to another misconception—that it is the oxygen that is part of the H_2O molecule that sustains aquatic life. Increasingly, students are becoming more aware of the general role of carbon dioxide in our environment, and that knowledge may in turn lead to more awareness of carbon dioxide's solubility in the oceans as one phase of the global-warming issue.

2. **The solubility of substances increases with increasing temperature.**
   Many chemistry texts provide emphasis to the point that gas solubility decreases with increases in temperature, but you should stress this point. Carbonated beverages going "flat" when they are taken from refrigeration and left at room temperature is a good example of decreasing solubility at increased temperature.

Answers to Pre-Lab Questions

1. Record your observations during the teacher demonstration.
   Answers will vary. Students should observe bubbles rising from the surface of the calcium carbonate when acid is added. They should note bubbles in the container holding the limewater, and they should note the cloudiness produced when the gas is bubbled into the limewater.

2. How do you know that a gas is produced in the demonstration?
   Bubbles are produced, indicating a gas.

3. How do you know that the gas is carbon dioxide?
   The test for carbon dioxide is the formation of a precipitate when the gas is bubbled through limewater.

4. Write the equation for the reaction you observed in the demonstration.
   $CaCO3 + 2\ HCl \rightarrow CaCl_2 + H_2CO_3$
   $H_2CO_3 \rightarrow CO_2 + H_2O$
   Students will likely write equation 1. You will have to point out to them that equation 2 also occurs. H_2CO_3 is a weak acid, which exists in equilibrium with CO_2 and H_2O. Since the CO_2 escapes from the system, the equilibrium shifts to the right and more CO_2 is produced.

5. Is it possible to determine from the demonstration whether CO_2 is soluble in water?
   No, it is not possible to determine the solubility of CO_2 directly from the demonstration. However, if some of the CO_2 generated in the demonstration is bubbled through water containing an acid-base indicator, the indicator will show the solution to be acidic. The acidity is due to the dissolved CO_2 interacting with water to form carbonic acid, H_2CO_3.

6. What factors affect the solubility of gases in water?
   Pressure affects the solubility of gases. As pressure increases, solubility increases. Temperature also affects solubility. For gases, as temperature increases, solubility

decreases. In addition, for carbon dioxide, as pH increases, its solubility also increases.

7. You already know that CO_2 is soluble in water. Predict the volume of CO_2 that is dissolved in 1 liter of a carbonated beverage. Record your prediction in writing.
Student answers will vary. The actual solubility of CO_2 in water (at room conditions) is 90 mL per 100 mL of water. You should note, however, that in carbonated beverages, CO_2 is dissolved under increased pressure, so the actual volume of the gas dissolved in a beverage is much greater than the solubility at ambient temperatures and pressures.

Answers to Post-Lab Questions

1. Compare your prediction of the volume of CO_2 gas that is dissolved in 1 liter of a carbonated beverage to the volume you measured in this activity. ***Student answers will vary. It is likely that most will have predicted a volume smaller than they actually measured.***

2. Look at your answer to pre-lab question 6, and show where each factor is used in this activity. ***Students should have identified temperature and pressure. When the cap is removed from the 1.0-L soda bottle, the pressure of the system is changed. This change will affect the solubility of the carbon dioxide, which is why students will see bubbles rising in the liquid as soon as the cap is removed. The temperature is changed as soon as the chilled soda is placed at room temperature. However, students will probably identify the point in the activity when the soda is placed in warm water as the point where temperature comes into play.***

3. Given what you have learned about the solubility of CO_2 in water, what are some possible sources of error in your measured volume of CO_2 in this activity?
First, given that CO_2 has a solubility in water at room temperature of about 900 mL per liter of water, some of the gas will remain dissolved at room temperature (and also at the somewhat higher "warm water" temperature). Further, if the gas is collected in the 2. 0-L bottle by water displacement, some of the CO_2 will dissolve in this water during the exchange. Both of these sources of error will lead to a lower-than-ideal volume of collected gas.

Assessment

1. As an authentic assessment you can ask students to design an experiment that shows directly the solubility of carbon dioxide in water. Depending on equipment available in your classroom, a suggested method might be to fill a container with CO_2 gas and expose the gas to a reservoir of water. Inverting a bottle of gas in a water reservoir and carefully shaking the bottle with the mouth underwater will cause the water level to rise in the bottle owing to CO_2 dissolving in the water. Priestley used this method. This experiment can be done on a microscale level with a piston assembly replacing the bottle. Fill the chamber with CO_2 and draw in a volume of water. As the CO_2 dissolves, the piston is drawn into the chamber.
2. You can use the post-lab questions as an assessment tool.
3. Assign students to research Priestley's contributions to the study of gases, including carbon dioxide.

Answers to Extension Questions

1. Why is carbon dioxide so important in our environment? Think about photosynthesis, the burning of fossil fuels, and global warming. What processes release CO2 into the atmosphere? What processes remove it?
This question could lead to a larger question about global warming and the role that carbon dioxide plays as a greenhouse gas. The concern about man-made global warming centers around the production of carbon dioxide from the combustion of fossil fuels. Green plants are important because of their ability to absorb CO2 and convert it during photosynthesis to oxygen. Priestley actually discovered that green plants could convert CO2 into oxygen.

2. Priestley lived at the time of both the French and American revolutions. How was the work of

Priestley (and Boyle and Lavoisier) part of a scientific revolution?
Students should be aware that Priestley, Boyle, and Lavoisier are considered "Forerunners" in chemistry because their work was characterized by laboratory experimentation and the use of resulting evidence from which to draw conclusions about matter. In this period, for example, the Aristotelian notion that matter was composed of one or more of the four elements—earth, air, fire, and water—was replaced by discovery and definition of chemical elements as single substances not subject to chemical decomposition. This overthrow of old ideas and practices is considered a scientific revolution.

Additional Teacher Resources

1. *American Heritage Magazine* (online) has a history of carbonated water from Priestley to modern times (http://www.americanheritage.com/articles/magazine/ah/1 962/5/1962 5 10 .shtml).
2. Microscale versions of several experiments related to Priestley's "soda water" can be found here (http://mattson.creighton.edu/SodaWater/SodaWater.html).
3. The chemistry of carbon dioxide is summarized here (http://scifun.chem.wisc.edu/chemweek/pdf/CarbonDio xide.pdf).
4. Another biography (http://pubs.acs.org/cen/acsnews/86/8614acsnews2. html) of Priestley by Mary Ellen Bowden of the Chemical Heritage Foundation appeared in *Chemical & Engineering News* in 2008.