Sink or Swim: The Cartesian Diver

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photo by J. J. Jacobsen and E. K. Jacobsen

Background

Cartesian divers rise and sink in water that fills a capped bottle when there are changes in pressure, volume, temperature, and buoyancy. The dropper that functions as the diver is partially filled with water so its bulb just floats. When pressure is increased in the bottle while temperature remains constant, the volume of the air bubble in the dropper is reduced. Additional water enters the dropper, the dropper's buoyancy decreases, and it sinks. When the pressure decreases, the process is reversed, and the diver floats to the top of the bottle again. When temperature is decreased while pressure remains constant, the volume of the air bubble in the dropper is decreased. The dropper's buoyancy decreases, and it sinks. When the temperature increases, the process is reversed.

Integrating the Activity into Your Curriculum

Cartesian divers are a quick and simple way to illustrate relationships among pressure, volume, temperature, and buoyancy. The Activity could be used in connection with the concepts of gases and liquids and discussions of Boyle's, Charles's, and the ideal gas laws. A biological application is that some fish have a small sac containing an air bubble inside their bodies. They control the size of the sac to alter their buoyancy in the water. The optional extension could be a chemistry recruitment exercise or a year-end engineering project with considerable room for student inventiveness.

About the Activity

Students assemble a Cartesian diver and observe the effects of changing the pressure and temperature. This Activity can be done qualitatively or quantitatively. For quantitative study, students can calibrate the dropper by marking known volume positions on the glass tube. To increase the pressure proportionally, one can use C-clamps or a vise to exert pressure on the sides of the bottle, or press a bathroom scale against the 2-liter bottle. An optional extension challenges students to cause the diver to hit the bottom in one minute by connecting the diver bottle to a second bottle in which baking soda and vinegar are reacted. Other Cartesian diver activities are available (*1, 2*) and a video of a Cartesian diver is available on *JCE Online* at *http://jchemed.chem.wisc.edu/Journal/issues/2001/Feb/abs200A.html.* W Additional information on the optional extension is in this issue of *JCE* (*3*).

In the optional extension, one way to connect the reaction chamber to the diving chamber is with a flexible tube, 1-hole stoppers, and glass tubing. Students experiment with the amounts of vinegar and baking soda required. Key variables include production rate of CO_2, water temperature in the diving chamber, and room pressure. The most reliable results occur with solutions of baking soda rather than dry powder. Things to do include:

1. Determine the appropriate quantities of baking soda solution and vinegar using theory. Boyle's law, PV = a constant, and the ideal gas law, $PV = nRT$, can allow a reasonable estimate of the number of moles of CO_2 required to make the dropper dive. Students can then base their experimentation on what theory predicted.
2. Determine the appropriate quantities of baking soda solution and vinegar by experimentation. Place an excess of vinegar (~200 mL) in the reaction chamber. Prepare a series of baking soda solutions from 0.25 to 0.75 M. Mix 100 mL of each solution with a new portion of vinegar and record the dive time. A plot of concentration versus dive time allows students to predict the winning concentration.

Answers to Questions

1. See information in Background above.
2. As pressure increases on the gas in the dropper, volume decreases—an inverse relationship. Changing the temperature would introduce another variable that could affect the volume along with the pressure.
3. As temperature increases, so does the volume of gas in the dropper, a direct relationship. With the cap off, pressure is held reasonably constant. Changing the pressure would introduce another variable that could affect the volume along with temperature.

Optional Extension

1. Carbon dioxide gas is generated from the reaction between vinegar and baking soda in the reaction chamber. The increased pressure from the generated gas causes the diver to dive, in the same way as when the bottle is squeezed.
2. Answers will vary.

References and Additional Activities

1. Sarquis, M.; Sarquis, J. *Fun with Chemistry*, Vol. 2; Institute for Chemical Education: Madison, WI, 1993; pp 121–167.
2. Thompson, J. U. S.; Goldsby, K. A. *J. Chem. Educ.* **1994**, *71*, 801.
3. Pinkerton, K. D. J. Chem. Educ. 2001, 78, 198–200.

***JCE Classroom Activities* are edited by Nancy S. Gettys and Erica K. Jacobsen**

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Many conveniences in life depend on how gases behave. For example, in a car, a gaseous mixture of gasoline and air fills the cylinders. Then spark plugs set off a chemical explosion that causes gas pressure, temperature, and finally volume to change inside the cylinder. The resulting forces ultimately move the car forward. In this Activity, you will use simple materials to investigate how pressure, temperature, and chemical reactions affect the volume of gases.

Try This

You will need a clear, colorless 2-liter plastic soda bottle and cap, glass medicine dropper that fits inside the 2-liter bottle, water, glass container taller than the dropper, grease pencil or waterproof marker, paper towels, cooking pot, stove, spoon, and ice.

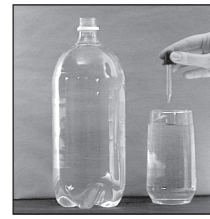

photo by J. J. Jacobsen and E. K. Jacobsen

__1. Completely fill a clear, colorless 2-liter plastic soda bottle with room-temperature water.

__2. Fill a glass container taller than the dropper with water at room temperature. Draw some of the water into a glass medicine dropper. Place the dropper in the glass container with the bulb side toward the surface of the water and see if it sinks or floats. You want it to float with a very small portion of the bulb above the surface. Adjust the volume of water in the dropper until it does this. Use a grease pencil or waterproof marker to mark the resulting water level in the medicine dropper. (You will need to dry off part of the dropper with paper towels to do this.)

__3. Remove the dropper from the glass container, leaving the water inside. Then place it into the filled 2-liter bottle from step 1 with the bulb end toward the mouth of the bottle. Screw the cap onto the bottle tightly.

__4. Watch the dropper as you squeeze the sides of the bottle slowly, then release the sides of the bottle. What happens to the dropper? What happens to the air and water levels *inside* the dropper?

__5. Remove the dropper from the bottle and place it back in the full glass container. Make sure it still floats.

__6. Place the glass container with the dropper inside into a cooking pot. Fill the rest of the pot with ice and cold water. The ice and water level should not be higher than the height of the glass container. Every few minutes, gently stir the water in the glass container to ensure that the water in the container all remains the same temperature. What happens to the dropper? What happens to the air and water levels in the dropper?

__7. Remove the glass container from the ice water. Empty the pot and refill it with room-temperature water. Heat the water on a stove until it boils. Remove the pot from the stove and place the glass container in the hot water. What happens to the dropper? What happens to the air and water levels in the dropper?

__8. Remove the glass container from the hot water. Empty the pot and refill it with ice water. Place the glass container in the ice water. What happens to the air and water levels in the dropper ?

Optional Extension: You will need a second plastic bottle to serve as a reaction chamber, material to make an airtight connection between the diver bottle and reaction chamber, baking soda, and vinegar.

You can use a chemical reaction instead of squeezing the bottle to increase pressure and make a diver sink. Design a procedure using the reaction of baking soda and vinegar to make the diver hit the bottom of the bottle in exactly one minute. Challenge your classmates to see who can achieve this using the smallest quantities of baking soda and vinegar.

__1. Invent a way to make an airtight connection between the diver bottle and the reaction chamber bottle.

__2. Experiment to find the most reproducible way to make the diver hit the bottom in one minute and to use the smallest amounts of vinegar and baking soda in the reaction chamber. Try dissolved and solid baking soda as well as full strength and dilute vinegar. Brainstorm with other students or your teacher to determine how to avoid trial and error methods when determining the winning combination of variables.

Questions

__1. Explain what causes the diver to rise and fall.

__2. What is the relationship between pressure and volume of gas in the dropper when the bottle is tightly capped? Why is it important to keep the temperature constant to be sure about your answer?

__3. What is the relationship between temperature and gas volume in the dropper when it is in an uncapped container? What quantity is held nearly constant by using an uncapped container? Why is this important?

Optional Extension Questions

__1. How is the pressure generated to make this version of the Cartesian diver?

__2. How did you determine the combination of variables that made your dropper dive in one minute?

Information from the World Wide Web *(accessed December 2000)*

1. Cartesian Diver. *http://littleshop.physics.colostate.edu/Cart.html*
2. General Chemistry Online. *http://antoine.fsu.umd.edu/chem/senese/101/gases/faq/everyday-gas-laws.shtml*
3. Applet: diver. *http://lectureonline.cl.msu.edu/~mmp/applist/f/f.htm*