Creaking Plastic Soft Drink Bottles

Have you ever noticed the sounds of cracking and creaking when you throw an empty, capped plastic soft drink bottle in the recycle bin on a very cold day? What happens to a helium-filled balloon that sits in your car for several hours on a very cool day or on a very hot day? Try this activity to see how these occurrences are related. You may need to use your text for the mathematical expression of Charles' law.

Materials

- 2 plastic soft drink bottles with caps
- container large enough to completely submerge the soft drink bottles in
- hot tap water
- ice-cold water
- thermometer (if available)
- measuring cup (if using thermometer)
- balloon
- small-mouthed glass bottle
- (optional) funnel

Safety

Avoid water hotter than hot tap water because it can cause severe burns and will permanently deform the plastic bottle, interfering with the intended outcomes of the activity. Never use a closed glass container to conduct this or any other activity that might involve a change in volume or pressure: glass explosions or implosions are extremely dangerous!

Exploration

Step 1 Fill an empty soft drink bottle about 1/4 full with hot tap water. Cap the bottle and swirl the water around for about 30 seconds. Discard the hot water and immediately recap the bottle. Record any changes involving the bottle as it cools to room temperature. Place the bottle in ice-cold water. Are any further changes observed? What can be concluded about the changes that accompany this cooling process?

Step 2 (If a thermometer is available.) Repeat Step 1 and measure and record the room temperature, the temperature of the hot water (assume the temperature of the hot air in the bottle equals this), and the temperature of the ice water (assume the temperature of the cool air in the bottle equals this). Measure and record the original volume of the hot air in the container. Calculate the volume of the air at room temperature and at the cooler temperature. Devise a method of experimentally determining the volume of cooled air in the bottle. How does this value compare to the calculated value?

Step 3 Cool the air inside a partially collapsed, uncapped plastic soft drink bottle with ice-cold water. (One way of collapsing the bottle is to gently squeeze the sides of the uncapped bottle.) Pour out the cold water and cap the bottle. Warm the bottle by placing it in hot tap water and observe. What can be concluded about the relationship between the temperature and the volume of a gas?

Step 4 Stretch a balloon over the neck of an uncapped glass bottle. Set the bottle in hot tap water and observe the behavior of the balloon. Set the bottle in ice-cold water; what happens to the balloon? How does the behavior of the balloon reinforce or alter your previous conclusion about the effect of temperature on the volume of a gas? How do the occurrences mentioned in the introductory remarks relate to this activity?

Challenge

What factor(s) are responsible for the cracking and creaking sounds sometimes made by an empty, capped plastic soft drink bottle?

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You may need to provide each student with a balloon for Step 4. Other materials (except the optional thermometer) should be readily available even for a student living in a dormitory.

Concept

Charles' law

Expected Student Responses to Exploration

Step 1 (a) As the trapped air cools to room temperature, the sides of the plastic bottle cave in, typically accompanied with notable crunching, cracking, and creaking sounds.

(b) As the trapped air cools below room temperature, the amount of further collapsing depends upon the change in temperature.

(c) Cooling the trapped air causes its volume to decrease (Charles' law). Thus, the bottle collapses to that volume, accompanied by the indicated sounds. Alternatively, consider that cooling the trapped air causes its pressure to decrease (Gay-Lussac's law). The resulting relative increase in pressure on the outside of the bottle pushes in the sides.

Step 2 (a) The temperatures will vary.

(b) The volumes will vary.

(c) Calculated volumes (using Charles' law, $V_1T_1=V_2T_2$) will vary due to differences in temperatures and measures.

(d) To determine the volume of air in the collapsed bottle, students could either:
submerge the capped collapsed bottle and determine the volume of water displaced (which could be assumed to equal the volume of air)

or

measure the volume of water required to fill the collapsed bottle, taking care not to allow the sides of the plastic bottle to push back out during filling.

(e) Some variation between experimental and calculated volumes is expected.

Step 3 (a) The cooled bottle expands upon warming.

(b) The temperature and volume of a gas are directly proportional.

Step 4 (a) As the bottle is heated, the balloon expands.

(b) As the bottle is cooled, the balloon partially deflates and becomes limp.

(c) The behavior of the balloon reinforces the previous conclusion of a directly proportional relationship between temperature and volume of a gas: the balloon expands when the air is heated and deflates when the air is cooled.

(d) The capped soft drink bottle creaks on a cold day in the same way as it did with the ice-cold water in this activity. The helium-filled balloon expands and contracts with heat and cold, respectively, just as the balloon on the bottle did in this activity.

Expected Student Answer to Challenge

The contraction of air upon cooling is responsible for the cracking and creaking sounds sometimes made by an empty, capped soft drink bottle.

Acknowledgment

This activity was developed as a part of the NSF-funded “General Chemistry: Discovery-Based Advances for the Two-Year College Chemistry Curriculum” project, grant #DUE-9354378.