How Big Is the Balloon?

Stoichiometry Using Baking Soda and Vinegar

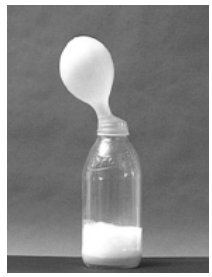
by the *Journal*'s Editorial Staff

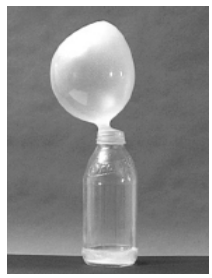
Background

This activity focuses on a familiar reaction, that of sodium bicarbonate (baking soda) with aqueous acetic acid (vinegar).

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$$

Students discover the concept of stoichiometry and limiting reactants in two ways: first by adding vinegar to a small quantity of baking soda until bubbles stop, and second by mixing a constant quantity of baking soda with increasing volumes of vinegar and collecting the carbon dioxide produced in balloons.





About the Activity

Students will discover in the first step that the bubbles stop appearing as soon as all of the baking soda has reacted. Addition of more vinegar does not produce more bubbles. (Sodium bicarbonate is soluble in water and so the solid may "disappear" before the reaction is complete. The reaction may be more vigorous once the base is in solution.)

In the main activity, students will discover that there is some maximum volume of carbon dioxide that can be produced by a given quantity of baking soda. Using larger quantities of vinegar causes evolution of a larger volume of gas until all the baking soda is consumed. After that, no more gas can be produced.

Discussion questions are included to lead students to the definition of a limiting reactant. In each case the student is asked which reactant limited the volume of gas formed. If they are not sure, they can test each container to see which reactant is left over after the reaction is complete.

In addition, you can ask students to consider why it might be important to know how much product is produced in a chemical reaction before doing the reaction. The importance of knowing how much product will be produced can be demonstrated by doing the baking soda plus vinegar reaction in a clear, shatterproof, plastic bottle, loosely corked (*not* rubber-stoppered). Point the opening away from all observers, and be sure all are wearing eye protection. The cork will shoot out of the bottle, perhaps followed by some of the reaction mixture. Knowing the quantity of product formed can prevent accidents and explosions.

Once students have established a need to know how much product can be produced from a given quantity of reactant, you can return to the chemical equation and talk about the relationship of atoms, moles, and grams of reactant and product represented by a balanced equation. Students should be able to recognize that all they need to predict the quantity of product is the balanced chemical reaction, the masses of reactants available, and the atomic and/or molecular mass of each reactant and product.

Integrating the Activity into Your Curriculum

The activity is written so that it can be performed by students in the laboratory, or at home as an outside assignment. This activity is most useful when introducing stoichiometry to beginning students. In addition it is a simple example of an acid–base reaction, and you may wish to refer to it when that topic is introduced. That is it a vigorous reaction between a weak acid and weak base may be surprising to some students who have not interpreted the description "weak" correctly. Finally, the inflation of the balloon could be discussed in relation to the ideal gas law. The increased pressure inside the container due to the formation of carbon dioxide causes the balloon to inflate.

This activity can be easily extended into a quantitative experiment by titrating an accurately weighed sample of sodium bicarbonate with acid of known concentration, by measuring the mass of CO_2 lost (weigh the baking soda and vinegar separately before the reaction, and the mixture again after the reaction), or by measuring the volume of carbon dioxide generated from a weighed sample of baking soda (this is probably the most difficult, because carbon dioxide is soluble in water.)

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Compounds that contain carbonate or bicarbonate ion react with acid to produce carbon dioxide gas and water. Baking soda consists of sodium bicarbonate ($NaHCO_3$). Wear goggles to protect your eyes. Place a small pile of baking soda, about the size of a pea, on a watch glass or saucer. Add a drop or two of vinegar. What do you see?

Vinegar is an aqueous solution of acetic acid ($HC_2H_3O_2$). Write a chemical equation to represent the reaction you observe.

After a few minutes, add another drop or two of vinegar. Is there more reaction? Continue to slowly add drops of vinegar until you observe a change in behavior. What happens?

Is there a limit to the number of bubbles (the amount of carbon dioxide gas) that can be produced? How much gas can you get from a given amount of baking soda? To find out, try the following experiment.

perforated

Try This

You will need: eye protection, baking soda, vinegar, a measuring teaspoon, four medium balloons (all the same size), four small containers such as flasks or transparent bottles (all the same size, 125–500 mL or 4–16 oz.), a funnel or piece of waxed paper, a marking pen, water, and paper towels. The balloons must be able to fit tightly over the tops of the containers. Wetting the balloon and the container top with a little water may help to get the balloon on.

1. Wear goggles to protect your eyes. Place one level teaspoon of baking soda in each balloon. Use a funnel or a piece of waxed paper rolled into a funnel shape to help transfer the baking soda into the balloons.
2. Rinse your teaspoon with water and dry it.
3. Label the test tubes or bottles 1, 4, 7, and 10.
4. Put 1 teaspoon of vinegar into the container labeled 1; 4 teaspoons into the container labeled 4; 7 teaspoons into the container labeled 7; and 10 teaspoons into the container labeled 10.
5. Place one of the balloons over the top of the container labeled 1. Turn the balloon over so that all the baking soda drops into the container. Shake or swirl the mixture. What happens to the balloon?
6. Repeat step 5 with the other balloons and containers. Record the result for each.

Questions

Do any of the balloons inflate? How much? Is there a relationship between the volume of vinegar used and the volume of the balloon? Is there a point at which more vinegar does not increase the size of the balloon? Is there a limit to the quantity of gas that can be produced from one teaspoon of baking soda?

Using what you know about chemical reactions, can you explain why adding more of one reactant would not increase the quantity of product produced?

Which of the two reactants is left in each of the four bottles after the reaction stops? (Hint: if you are not sure, open the container. Add a drop of vinegar. Does a reaction occur? If not, add a pinch of baking soda. Now what happens?)

Which reactant in each bottle limited the volume of gas formed, i.e., which is the limiting reactant?

fold here and tear out

Related Experiments from the World Wide Web

Making CO_2 foam: *http://tqd.advanced.org/3542/experiments/bottle.html*

Making CO_2 foam: *http://www.raindrops.com/dhs/EarthDay96/cappi.htm*

Recipe for foamed candy: *http://www.visi.com/~damsel/Alpha.html*

Dancing popcorn: *http://lisa.liberty.pps.pgh.pa.us/~dubus/popcorn.html*

CO_2-powered boat: *http://www.sci-ctr.edu.sg/interexh/spproject/boat.html*

CO_2-foam volcano: *http://volcano.und.nodak.edu/vwdocs/volc_models/eruptions.html*