The Effect of Temperature on Gas Solubility

Introduction

Most solids are *more* soluble in hot water than in cold water so it comes as something of a surprise to learn that all gases become *less* soluble as water temperature rises. For an activity to graphically demonstrate this principle, and a few others, read on.

Materials (per lab team)

- Alka-Seltzer® tablet
- Bromthymol blue indicator solution, 0.04% aqueous, 10 mL
- Sodium hydroxide solution, NaOH, 1 M, 5 mL
- Balance with 0.1-g resolution
- Beakers, 250-mL, 3
- Dropping bottles
- Graduated cylinders, 10-mL and 25-mL
- Hot plate
- Ice
- Test tube rack
- Test tubes, 18 × 150 mm, 3
- Thermometer

Safety Precautions

Sodium hydroxide and its solutions are corrosive to skin and eyes. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Tongs are recommended whenever handling beakers of hot liquids. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

Prepare bromthymol blue indicator solution: Dissolve 0.04 g of bromthymol blue indicator powder in approximately 80 mL of distilled or deionized water. Stir to dissolve indicator and dilute up to 100 mL with additional water.

Prepare 1 M sodium hydroxide solution: Dissolve 4 g of sodium hydroxide (NaOH) in approximately 80 mL of water in a container held in an ice bath. Stir to dissolve and dilute up to 100 mL with additional water. Dispense the NaOH solution into individual dropping bottles.

Procedure

1. Add 200 mL of water to each of three 250-mL beakers. Place one beaker in an ice bath, heat the second on a hot plate, and leave the third at room temperature (the experimental control).
2. Weigh out two 1.0-g samples of Alka-Seltzer by snapping pieces off the tablet.
3. When the water on the hot plate has reached a temperature of 70 to 80 °C (160 to 176 °F) remove it from the heat. Remove the cold water beaker from the ice bath. Add 3 mL of bromthymol blue solution to each of the three beakers.
4. Simultaneously drop the two 1.0-g samples of Alka-Seltzer into the hot and cold beakers. Carefully observe and record the reactions and whatever changes occur. When the Alka-Seltzer has fully dissolved, note the color and appearance of the solutions in each beaker.
5. Place the three test tubes in the test tube rack. Label one test tube cold, one hot, and the last test tube room temperature.
6. Remove 25-mL samples from each of the three beakers and place them in the corresponding test tubes.
7. Using the samples in the tubes, titrate the hot and cold samples by the dropwise addition of NaOH solution, swirling to mix between drops. The endpoint is reached when the solution color matches that of the room temperature "control" tube. Wait a minute or two before recording the final drop counts as the colors may revert slightly.

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Tip

- Either phenol red or neutral red may, if necessary, be substituted for the bromthymol blue. The strength of the NaOH solution is not critical, although it should be in the range of 0.5 *M* to 2.0 *M* for good results. After the indicator has been added to the three beakers, check the color. The solutions should be bright blue. A drop of NaOH solution may be added to adjust the color, if needed.

Discussion

The dissolution of the Alka-Seltzer generates carbon dioxide (CO_2) gas which dissolves in, and reacts with, the water by the equation:

$$CO_2(g) + H_2O(l) \rightleftarrows H_2CO_3(aq) \rightleftarrows H^+(aq) + HCO_3^-(aq)$$

The free hydrogen ions (H^+) on the right side drive the pH of the solution down, making it more acidic. The degree to which the pH changes is directly proportional to the amount of CO_2 that dissolves in the water. When the pieces of Alka-Seltzer are dropped into the hot and cold water, a marked difference in reaction rate is observed—fast reaction in hot water, slow reaction in cold water. The relative color changes are also visibly different. Since the CO_2 gas is more soluble in the cold water, the decrease in pH is greater, making the solution yellow. In the hot water, the pH change is significantly less, resulting in the intermediate green color.

The number of drops of NaOH required to return each sample to the starting color will also be directly proportional to the degree of change in pH and, in turn, to the amount of CO_2 dissolved. The NaOH, a base, neutralizes the acidic solution. The NaOH dissociates into Na^+ and OH^- ions and the OH^- ions combine with the H^+ ions to produce H_2O by the following equation:

$$OH^-(aq) + H^+(aq) \rightarrow H_2O(l)$$

The implications of this experiment in chemistry include gas solubility, reaction rate, acid–base indicators, and acid–base neutralization reactions. In biology, the discussion might focus on oxygen solubility in water and what will inevitably result when natural waters are warmed either naturally or artificially (thermal pollution). What will happen as less oxygen becomes available to aquatic organisms? The increase in atmospheric CO_2 from burning fossil fuels and rain forests has been proposed as a potential cause of global warming (the greenhouse effect). The oceans are a major sink (storehouse) for CO_2. As global temperatures rise, ocean temperature will rise and some of the stored CO_2 will be driven out of solution.

For an optional activity, begin with 400 mL of well-chilled water and 6 mL of indicator solution in a 500-mL beaker. Dissolve 2 g of Alka-Seltzer in the cold water. Remove a 25 mL sample and titrate as described above against a room temperature control. Begin slowly heating the solution in the beaker on a hot plate. With each 10 °C rise in temperature remove another 25 mL sample and titrate. Stop when the temperature has reached 75 to 80 °C. The number of drops of NaOH required for each successive sample should decrease as CO_2 is driven out of solution. Plot a graph of drops required versus temperature.

Disposal

The resulting solutions can be rinsed down the drain with an excess of water according to Flinn Suggested Disposal Method #26b. Consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standard F: Science in Personal and Social Perspectives; natural hazards

Content Standards: Grades 9–12

Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions
Content Standard F: Science in Personal and Social Perspectives; natural and human-induced hazards

Acknowledgment

This activity was presented by Adele Gomez, St. John's School, Santurce, Puerto Rico during the 1995 Woodrow Wilson National Fellowship Foundation Chemistry Team 11 workshop at Northern Kentucky University.

Materials for *The Effect of Temperature on Gas Solubility* are available from Flinn Scientific Inc.

Catalog No.	Description
A0111	Alka-Seltzer®, Tablets, pkg/24
B0173	Bromthymol Blue Indicator Solution, 0.04% aqueous, 100 mL
S0148	Sodium Hydroxide Solution,1 M, 500 mL

Consult the Flinn Scientific website for current prices.