Battle of the Acids

Weak Acids and Bases

Introduction

Not all acids are created equal. This demonstration compares the “frothing and foaming” activity of different acids with calcium carbonate and examines their behavior in the presence of their conjugate bases to distinguish strong versus weak acids. The use of a “rainbow acid” universal indicator produces a rainbow spectrum of color changes as the mixtures react.

Concepts

- Strong acid
- Weak acid
- Conjugate base
- pH

Materials (for each demonstration)

Acetic acid, CH_3COOH, 1 M, 400 mL
Calcium carbonate, $CaCO_3$, 40 g
Hydrochloric acid, HCl, 1 M, 400 mL
“Rainbow acid” universal indicator, 5 mL (includes accompanying color chart)
Sodium acetate, $NaCH_3CO_2$, 16 g
Sodium chloride, NaCl, 12 g
Water, distilled or deionized
Demonstration tray, large
Graduated cylinder, 250-mL
Hydrometer cylinders, 600-mL, 4
Pipet, Beral-type
Weighing dishes or small beakers, 6

Safety Precautions

Hydrochloric acid and acetic acid solutions are toxic and corrosive. Avoid contact with skin and eyes. “Rainbow-acid” universal indicator solution is an alcohol-based solution and is flammable. Avoid contact with flames or other ignition sources. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

To save time in the presentation, pre-measure the amounts of solids needed for the demonstration. Weigh out 12 g of sodium chloride, 16 g of sodium acetate, and 4 × 10-g samples of calcium carbonate in separate, labeled weighing dishes or small beakers.

Procedure

1. Obtain 4 large hydrometer cylinders or tall-form beakers and place them on a large demonstration tray. Label the cylinders #1–4.
2. Using a graduated cylinder, add 200 mL of 1 M hydrochloric acid to cylinders #1 and 2.
3. Using a graduated cylinder, add 200 mL of 1 M acetic acid to cylinders #3 and 4.
4. Add about 20 drops (1 mL) of “rainbow acid” universal indicator to cylinders #1 and 3. Compare the color and pH of hydrochloric acid versus acetic acid.
5. Write equations for the ion-forming reactions of hydrochloric acid and acetic acid in water to give H_3O^+ ions. Identify the “common ion” or conjugate base of each acid (chloride ion and acetate ion, respectively).
6. Add 12 g of sodium chloride, followed by about 20 drops of “rainbow acid” universal indicator, to cylinder #2. Mix thoroughly to dissolve.
7. Compare the color and pH of cylinder #2 with that in cylinder #1. What effect does adding chloride ion (its “common ion” or conjugate base) have on the pH of hydrochloric acid?

8. Add 16 g of sodium acetate, followed by about 20 drops of "rainbow acid" universal indicator, to cylinder #4. Mix thoroughly to dissolve.
9. Compare the color and pH of cylinder #4 with that in cylinder #3. What effect does adding acetate ion (its "common ion" or conjugate base) have on the pH of acetic acid?
10. Add 10 g of calcium carbonate to each cylinder #1–4.
11. Compare the amount of frothing and foaming and observe the rainbow of indicator color changes in the four cylinders.
12. Relate the activity of the solutions to pH, the difference between strong and weak acids, and the "common ion" effect.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The waste solutions may be disposed down the drain with excess water according to Flinn Suggested Disposal Method #26b. Excess hydrochloric acid and acetic acid may be saved for future use or neutralized and disposed of according to Flinn Suggested Disposal Method #24b.

Tips

- Flinn Scientific offers a demonstration kit, Battle of the Acids—Strong versus Weak Acids Kit, (Catalog No. AP6287) that contains enough chemicals to perform the demonstration as written seven times: 1.5 L each of 2 *M* hydrochloric acid and acetic acid, 280 g of calcium carbonate, 120 g of sodium acetate, 100 g of sodium chloride, and 50 mL of "rain bow acid" universal indicator.
- The use of a demonstration tray to catch any spillover (particularly from reactions #1 and 2) is strongly recommended. The reaction mixtures bubble and froth and a solid wall of foam may erupt out of the hydrometer cylinders.
- "Rainbow acid" universal indicator is a new indicator solution that uses a combination of indicators to obtain a rainbow spectrum of colors for acid solutions having pH values between 1 and 7. Use the color chart that accompanies the indicator to estimate the pH of acidic solutions.

Discussion

The difference between strong and weak acids is confusing to many students. Some students assume that the difference arises solely due to pH. Others attribute the difference to concentration. This demonstration compares the pH, activity, and "common ion" effect in both hydrochloric and acetic acid solutions to illustrate the properties of strong versus weak acids.

Hydrochloric acid and acetic acid are Bronsted acids—they ionize in water to produce hydrogen ions (H_3O^+) and their conjugate bases, chloride ion and acetate ion, respectively (Equations 1 and 2).

$$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq) \qquad \textit{Equation 1}$$

$$CH_3COOH(aq) + H_2O(l) \rightarrow H_3O^+(aq) + CH_3COO^-(aq) \qquad \textit{Equation 2}$$

Comparing the pH of these two acids indicates that the amount of hydrogen ions produced in the two solutions is very different—there are more H_3O^+ ions present in the hydrochloric acid solution than in acetic acid. In the hydrochloric acid solution, all of the HCl molecules undergo ionization to form H_3O^+ ions. In acetic acid, however, only a few H_3O^+ ions are produced (most of the CH_3COOH molecules are not ionized). Note that this comparison—the relationship between pH and the degree of ionization of hydrochloric acid versus acetic acid—is only valid because their initial concentrations are the same (1 *M*).

The activity of the two acids with calcium carbonate, a strong base, reinforces the pH comparison. The rate of reaction of calcium carbonate with an acid (Equation 3) depends on the concentration of hydrogen ions in solution. The foam produced in this reaction is due to carbon dioxide gas mixing with water and calcium carbonate powder. The amount of foaming and the rate at which the foam rises are dramatically different for 1 *M* hydrochloric acid versus 1 *M* acetic acid. The reaction with hydrochloric acid is significantly faster, suggesting again that the concentration of H_3O^+ ions is greater than in acetic acid. A "rainbow spectrum" of indicator color changes is observed as the pH changes and the reaction proceeds.

$$2H_3O^+(aq) + CaCO_3(s) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O \qquad \textit{Equation 3}$$

The effect of chloride ion and acetate ion on the pH and reactivity of hydrochloric acid and acetic acid, respectively, further distinguishes the behavior of strong versus weak acids. Adding chloride ion to hydrochloric acid does not change either the pH or the activity of the acid solution. This suggests that the reaction shown in Equation 1 takes place in one direction only—ionization of hydrochloric acid is irreversible. Adding acetate ion to acetic acid, however, increases the pH of the solution from 2 to almost 5 and drastically slows down its reaction with calcium carbonate. Both of these observations suggest that the hydrogen ion concentration in the mixed acetic acid/sodium acetate solution is 100–1000× lower than in acetic acid itself. The reaction shown in Equation 2 is thus effectively reversed in the presence of acetate, the "common ion." Ionization of acetic acid is reversible (Equation 4) and the equilibrium constant for this reaction is very small (approx. 10^{-5}).

$$CH_3COOH(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + CH_3COO^-(aq) \qquad \textit{Equation 4}$$

The following table summarizes the observations and conclusions in this demonstration. The concentration of the acid and conjugate base components is 1 M in all cases.

	Strong Acid	**Weak Acid**
Example	Hydrochloric acid	Acetic acid
"Rainbow Acid" Color	Red	Yellow-Orange
pH	≤ 1	2–3
Rate of Reaction with $CaCO_3$	Extremely fast	Moderate
Ionization Reaction	Irreversible	Reversible
	Effect of Common Ion	
pH	≤ 1 (No change)	4–5
Rate of Reaction with $CaCO_3$	Extremely fast	Slow

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
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Answers to Worksheet Data and Questions

Results Table. Properties of a Strong Acid (Hydrochloric Acid) and a Weak Acid (Acetic Acid)

	Cylinder #1	**Cylinder #2**	**Cylinder #3**	**Cylinder #4**
Contents	1 M hydrochloric acid	1 M HCl + 2 g of sodium chloride	1 M acetic acid	1 M acetic acid + 16 g of sodium acetate
Color (pH)	Red (≤ 1)	Red (≤ 1)	Yellow-orange (2–3)	Light green (4–5)
Reaction Rate with $CaCO_3$	Fast	Fast	Moderate	Slow
Reversibility of Ionization Reaction	N/A	Irreversible	N/A	Reversible

Discussion Questions

1. Why was sodium chloride added to the hydrochloric acid in cylinders #1 and 2 and sodium acetate added to the acetic acid in cylinders #3 and 4?

   Sodium chloride and sodium acetate were added to hydrochloric acid and acetic acid, respectively, to show the effect on an acid when its common ion is added. Chloride is hydrochloric acid's common ion, and acetate is acetic acid's common ion. The addition of chloride ion to hydrochloric acid does not change the pH or reaction rate with calcium carbonate. The addition of acetate ion to acetic acid, on the other hand, raises the pH and slows the reaction with calcium carbonate. This shows that the ionization reaction of a weak acid such as acetic acid is reversible, while the ionization of a strong acid is not.

2. Write a balanced chemical equation for each of the following reactions:

   a. Ionization of hydrochloric acid in water

   $HCl(aq) + H_2O(l) \rightarrow H_3O^+ + Cl^-(aq)$

   b. Ionization of acetic acid in water

   $CH_3COOH(aq) + H_2O(l) \rightarrow H_3O^+ + CH_3COO^-(aq)$

   c. Calcium carbonate with H_3O^+

   $2H_3O^+(aq) + CaCO_3(s) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O$

3. Name two factors that distinguish a strong acid from a weak acid based on what you observed in this demonstration.

   The ionization reaction of a strong acid takes place in one direction only, and is therefore irreversible. The ionization reaction of a weak acid, however, is reversible. Thus, if the concentrations of a strong acid and a weak acid are equal, fewer H_3O^+ are produced when a weak acid is dissolved in water than when a strong acid is. This results in a higher pH for the weak acid.

4. Would this comparison between the strength of hydrochloric acid and acetic acid be valid if the hydrochloric acid was 2 *M* and the acetic acid was 1 *M*? Explain.

   No, because the initial concentration of the acid is a variable that affects the concentration of H^+ ions produced in water. Therefore, comparing the pH of the solutions would reflect the concentration of the acids, rather than the strength of the acids.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Battle of the Acids* activity, presented by Irene Cesa, is available in *Weak Acids and Bases*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Battle of the Acids* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Battle of the Acids—Strong versus Weak Acids Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6287	Battle of the Acids—Strong versus Weak Acids Kit
AP8599	Hydrometer Cylinder, 600-mL
AP5429	Demonstration Tray, Large
A0095	Acetic Acid Solution, 1 M, 1 L
C0347	Calcium Carbonate, Lab Grade, 100 g
H0057	Hydrochloric Acid Solution, 1 M, 1 L
U0012	Rainbow Acid Universal Indicator Solution, 100 mL
S0036	Sodium Acetate, Reagent, 100 g
S0061	Sodium Chloride, Reagent, 500 g

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Battle of the Acids Worksheet

Results Table

	Cylinder #1	Cylinder #2	Cylinder #3	Cylinder #4
Contents				
Color (pH)				
Reaction Rate with $CaCO_3$				
Reversibility of Ionization Reaction	N/A		N/A	

Discussion Questions

1. Why was sodium chloride added to the hydrochloric acid in cylinders #1 and 2 and sodium acetate added to the acetic acid in cylinders #3 and 4?

2. Write a balanced chemical equation for each of the following reactions:

   a. Ionization of hydrochloric acid in water

   b. Ionization of acetic acid in water

   c. Calcium carbonate with H_3O^+

3. Name two factors that distinguish a strong acid from a weak acid based on what you observed in this demonstration.

4. Would this comparison between the strength of hydrochloric acid and acetic acid be valid if the hydrochloric acid was 2 *M* and the acetic acid was 1 *M*? Explain.