Acids and Bases

Strand Nomenclature, Chemical Formulas, and Reactions

Topic Investigating acids, bases, and electrolytes

Primary SOL CH.3 The student will investigate and understand how conservation of energy and matter is expressed in chemical formulas and balanced equations. Key concepts include
e) reaction types.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include
a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations.

Background Information

Properties of Acids:

- Aqueous solutions of acids have a sour taste.
- Acids change the color of acid-base indicators.
- Acids react with active metals to release hydrogen: $Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$.
- Acids react with bases to produce salts and water (neutralization): $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$.
- Aqueous solutions of acids conduct electric current (they are electrolytes).

Properties of Bases:

- Aqueous solutions of bases have a bitter taste.
- Bases change the color of acid-base indicators.
- Dilute aqueous solutions of bases feel slippery.
- Bases react with acids to produce salts and water.
- Aqueous solutions of bases conduct electric current (they are electrolytes).

Arrhenius Acids and Bases:

- Svante Arrhenius, Swedish chemist (1859–1927)
- Arrhenius Acid—a chemical compound that increases the concentration of hydrogen ions, H^+, in aqueous solution
- Arrhenius Base—a substance that increases the concentration of hydroxide ions, OH^-, in aqueous solution

Aqueous Solutions of Acids:

- Acids are molecular compounds that ionize in solution
  - $HNO_3 \rightarrow H_+ + NO3_-$
  - $HCl \rightarrow H_+ + Cl-$
  - $H_2SO_4 \rightarrow H^+ + SO_4^{2-}$

Strength of Acids:

- Strong acids ionize completely (100%) in solution and are strong electrolytes. Examples of strong acids are sulfuric acid (H_2SO_4), hydrochloric acid (HCl), and nitric acid (HNO_3).
- Weak acids ionize only slightly (<1%) and are weak electrolytes. An example of a weak acid is acetic acid ($HC_2H_3O_2$).

Bronsted-Lowry Acids and Bases:

- Bronsted-Lowry Acid—a molecule or ion that is a proton (a hydrogen ion H^+) donor
- Bronsted-Lowry Base—a molecule or ion that is a proton acceptor
- Bronsted-Lowry Acid-Base Reaction—a reaction in which protons are transferred from the acid to the base

Amphoteric Compounds:

- Any species that can react as either an acid or a base
  - Water acts as both an acid and a base: $H_2O + H_2O \rightarrow H_3O^+ + OH^-$.
  - H_3O+ is called the "hydronium ion" and is what actually exists in an acidic solution. There are no free H^+ ions.

Strong Acid-Strong Base Neutralization:

- Neutralization—reaction of an acid with a base to produce water and a salt, such as the reaction of hydronium ions and hydroxide ions to form water molecules, or as $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(l)$.

Hydronium Ions and Hydroxide Ions:

- Self-ionization of water: $H_2O(l) + H_2O(l) \rightarrow H_3O^+(aq) + OH^-(aq)$
- Neutral, acidic, and basic solutions
  - Neutral [H3O+] = [OH−] (pH = 7)
  - Acidic [H3O+] > [OH−] (pH < 7)
  - Basic $[H_3O^+] < [OH^-]$ (pH > 7)

pH Calculations:

- $pH = -\log [H^+]$ and $[H^+] = 10^{-pH}$
- $pOH = -\log [OH^-]$ and $[OH^-] = 10^{-pOH}$
- $[H^+] = [OH^-] = 1 \times 10^{-7}$ (in a neutral solution)
- $K_W = [OH^-] [H^+] = 1 \times 10^{-14}$
- pH + pOH = 14

In this activity, students will be exposed to the fundamental reactions of acid and bases, as well as the calculations necessary to determine pH, pOH, $[H^+]$, and $[OH^-]$. The first part of the lab requires the use of 100-mL volumetric flasks and 10-mL glass transfer pipettes and pipette bulbs. If you do not have these in lab quantities, you can do this part as a teacher demonstration or omit this step and prepare the 0.1 *M* solutions for students.

Materials

- 10-mL glass transfer pipettes and pipette bulbs
- *M* solutions of HCl and of NaOH (or prepared 0.1 *M* solutions of each)
- Water
- 100-mL volumetric flasks
- 3-mL plastic syringes

- 50-mL beakers
- Phenolphthalein indicator
- Clean, dry evaporating dishes
- Heat source
- Scales
- Solution of HCl with an unknown molarity between 0.05 *M* and 0.1 *M*
- 4 acid and/or base solutions with a variety of pH values (For use of universal indicator, the pH values 4, 6, 7, 8, and 9 work best.)
- 24-well plates
- Universal indicator
- Indicator color chart
- Goggles
- Vinegar solution

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Explain that in this activity, they will study some of the properties and reactions of acids and bases by conducting the following four experiments:
   - Preparing a dilute solution from a more concentrated one
   - Performing a neutralization reaction
   - Analyzing a solution by the technique of titration
   - Determining the pH, pOH, $[H^+]$ and $[OH^-]$ of acid or base solutions

Procedure

Experiment 1: Preparing a Dilute Solution from a More Concentrated One

1. Prepare the acid and base solutions as follows:
   - Pipette 10 mL of 1.0 M HCl into a clean, dry 100-mL volumetric flask. Add water to the mark on the volumetric flask. Label the flask.
   - Repeat the process, using the 1.0 M NaOH.
2. Calculate the new molarity of the acid and base solutions.
3. Calculate the pH and pOH for each of the prepared solutions.

Experiment 2: Neutralization Reaction

1. Obtain 2 plastic 3-mL syringes, and label one “Acid” and the other “Base.”
2. Use the Acid syringe to pull up 3 mL of the prepared acid solution and place it in a clean, dry 50-mL beaker. Add 2 drops of phenolphthalein indicator.
3. Use the Base syringe to pull up 3 mL of the prepared base solution and slowly add it drop by drop to the beaker containing the acid solution. Swirl after each addition. Keep adding the base until the solution turns a very pale pink and the color remains for at least 30 seconds.
4. Transfer the solution to a preweighed, clean, dry evaporating dish, and heat gently to remove the liquid. Do not allow the solid to splatter.
5. When the solid is dry and the dish is cool, weigh the dish and product and record the mass of dish and solid. Subtract to find the mass of the solid.

6. Write a balanced equation for the reaction that took place between the HCl and the NaOH.
7. Calculate the theoretical amount of solid that could be produced from the 3 mL of acid used in the reaction.
8. Weigh and record the amount of NaCl that you produced in the lab. Calculate your percent yield in the experiment.

Experiment 3: Analysis of an Unknown Acid—Titration

1. Obtain 3 mL of the unknown acid solution, and place it in a clean, dry 50-mL beaker.
2. Add 2 drops of phenolphthalein indicator.
3. Fill a syringe with your prepared base solution, and record the initial volume of base solution in the syringe.
4. Slowly add the base solution in the syringe, drop by drop, to the acid solution in the beaker, swirling after each addition. Keep adding the base solution until the acid solution turns a very pale pink. Record the final volume of the base solution remaining in the syringe.
5. Calculate the ΔV for base solution in the syringe.
6. Using the volume and molarity of the known base solution, calculate the molarity of the unknown acid solution, using this formula $M_A V_A = M_B V_B$

Experiment 4: Determination of pH, pOH, $[H^+]$, and $[OH^-]$

1. Place several drops of each of the labeled, unknown acid and/or base solutions in a well plate. Add 1 drop of universal indicator to each well. From the color of the indicator and using the indicator color chart, determine the pH of each solution.
2. Calculate the pH, pOH, $[H^+]$, and the $[OH^-]$ for each unknown acid and/or base solution, and record.

Observations and Conclusions

1. Use the student answers to the calculations within each experiment to lead discussions that will prompt correct conclusions about the behavior of acids and bases.

Assessment

- **Other**
  - Analyze the molarity of a vinegar solution, using the technique of titration used in the lab.

Extensions and Connections (for all students)

- Have students research the following common industrial acids:
  - Sulfuric acid
  - Nitric acid
  - Phosphoric acid
  - Hydrochloric acid
  - Acetic acid