Acid-Base Theory

Strand Molar Relationships

Topic Investigating acids, bases, and electrolytes

Primary SOL CH.4 The student will investigate and understand that chemical quantities are based on molar relationships. Key concepts include

d) acid/base theory; strong electrolytes, weak electrolytes, and nonelectrolytes; dissociation and ionization; pH and pOH; and the titration process.

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;
d) manipulation of multiple variables, using repeated trials;
e) accurate recording, organization, and analysis of data through repeated trials;
f) mathematical and procedural error analysis;
g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis;
h) use of appropriate technology including computers, graphing calculators, and probeware for gathering data, communicating results, and using simulations to model concepts;
i) construction and defense of a scientific viewpoint;
j) the use of current applications to reinforce chemistry concepts.

Background Information

An acid is a substance that reacts with a base. Commonly, acids can be identified as tasting sour, reacting with metals such as calcium and bases like sodium carbonate (students should never taste acids or any unknown liquid.) Aqueous acids have a pH of less than 7, where an acid of lower pH is typically stronger. Chemicals or substances having the property of an acid are said to be acidic.

A base is a substance that can accept hydrogen ions (protons) or more generally, donate a pair of valence electrons. A soluble base is referred to as an alkali if it contains and releases hydroxide ions (OH^-) quantitatively.

Students will distinguish between acids and bases by means of physical and chemical properties. This lesson may require more than one class period or block.

Before beginning this lab, prepare a 0.1 molar solution of HCl from bottled hydrochloric acid. (If you purchase bottles of 1 molar HCl, dilute the solution with water 10:1.) Also, prepare a 0.1 molar solution of the base NaOH. (The atomic masses of Na, O, and H are 23, 16, and 1, respectively. One mole of NaOH is therefore 40 grams of NaOH. 0.05 of 40 g is 2 g. Mixing 2 g of NaOH in 500 mL of water yields a 0.1 molar solution of NaOH.)

Phenolphthalein, used as a base indicator in this lab, is available in solution through any laboratory supply house. Phenolphthalein is colorless below pH 7 and purple above pH 7. When titrating a base with an acid, it is convenient to stain the base with phenolphthalein so that the neutralization of the base is evident when the color disappears.

Materials

- 1 lemon
- Bottle of household cleaner containing ammonium hydroxide
- Bottle of vinegar
- Bar of soap
- Roll of antacid tablets
- Litmus paper
- 6 acid or base solutions
- Tape
- Sodium hydroxide (NaOH) pellets
- Water
- Balances
- Glass stirring rods
- Corks or stoppers (wax paper and rubber bands) for flasks
- Phenolphthalein indicator
- 500-mL beakers or Erlenmeyer flasks
- *M* HCl solution
- *M* NaOH solution (2 g of NaOH dissolved in 500 mL of water)
- Medicine droppers
- 10-mL graduated cylinders (or test tubes)
- Stoppers for graduated cylinders (or test tubes)
- Test tube rack (or cardboard)
- Ruler

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

Introduction

1. Display a lemon, a bottle of household cleaner containing ammonium hydroxide, a bottle of vinegar, a bar of soap, and a roll of antacid tablets. Point out that the lemon contains an acid called citric acid. The presence of citric acid gives the family of citrus fruits their name. Another acid found in citrus fruits is ascorbic acid, commonly called "vitamin C."
2. Emphasize that acids are common in our everyday lives. We even have acid in our stomachs to help us digest foods—a powerful solution of hydrochloric acid. Point out that the cleaner, the soap, and the antacid tablets contain substances called bases. Bases have a variety of uses but are mostly used to neutralize the acids employed in many different industrial and chemical procedures.
3. Display the following chart, and ask students to compare the chemical formulas of the acids and bases listed.

Acid	Base
HCl – hydrochloric acid H_2SO_4 – sulfuric acid H_2CO_3 – carbonic acid HNO_3 – nitric acid	NaOH – sodium hydroxide $Mg(OH)_2$ – magnesium hydroxide NH_4OH – ammonium hydroxide KOH – potassium hydroxide

4. Ask, "How are the acid formulas the same?" *(Each formula has an "H" for hydrogen at the front of it.)* All acids contribute a hydrogen ion (H^+) to water when in solution. Ask, "How are the base formulas the same?" *(Each formula has an OH for hydroxide at the end of it.)* All bases contribute a hydroxide ion (OH^-) to water when in solution.
5. Draw a KWL chart on the board, and have the class fill in the first two columns ("Know," "Want to Know") while comparing and contrasting the physical properties of acids and bases. Have students copy the chart into their notebooks.
6. Ask a volunteer to bite into the lemon (or do it yourself) to demonstrate the meaning of the term *sour*. Something that tastes sour makes us pucker our lips. Ask students what they would do if they bit into a bar of soap. Soap has a bitter taste that makes us want to expectorate.

Procedure

Pre-Lab: Preparing a Basic Solution

1. Inform students that in this lab, they will test for the presence of acids and bases and use an acid to neutralize a base. In order to do this, they will first prepare for use a 0.1 molar solution of a common base, sodium hydroxide (NaOH).
2. Assist students in preparing their own flask of a 0.1 *M* NaOH solution according to the following steps:
   a. Use the periodic table to find the atomic mass of sodium, oxygen, and hydrogen, and enter each into a table like the one shown at right. The atomic mass in grams of each of these elements is equal to 1 mole of the element.
   b. Add these three masses to get the mass of 1 mole of sodium hydroxide (NaOH).
   c. Use a balance to measure out 1/20 (0.05) of a mole of NaOH.
   d. Fill a 500-mL beaker or Erlenmeyer flask with water.
   e. Add the 0.05 mole of NaOH to the 500 mL of water. Since a 1 molar solution of any substance is the molecular weight of that substance in 1,000 mL of water, this mixture will be a 0.1 molar solution of NaOH.
   f. Stir gently until the NaOH is completely dissolved in the solution. Use wax paper and a rubber band (or a cork or rubber stopper) to cover your sodium hydroxide solution.
   g. Store the sodium hydroxide solution at room temperature for use later. Remind students that because the solution will be used at a later time, the flask must be labeled before storing.

Chemical Symbol or Formula	Atomic Mass (1 Mole)
Na	
O	
H	
NaOH	
1 mole of NaOH × 0.05 = ____ grams of NaOH + 500 mL water = 0.1 *M* NaOH solution	

Exercise: Calculating the pH of Acidic and Basic Solutions

1. Review the physical and chemical properties of acids and bases.

2. Explain that litmus is a dye obtained from lichen—i.e., a symbiotic community of algae and fungi that grows on rocks. Chemically, it is a mixture of several organic compounds (mostly carbon, hydrogen, and oxygen) that changes color in the presence of an acid or a base. The color created by a drop of acidic or basic solution on litmus paper reflects the concentration of hydrogen or hydroxide ions present in the solution. Litmus paper turns red in the presence of an acid and blue in the presence of a base.
3. Draw the pH scale on the board, and compare it to the color legend on the litmus paper roll. Explain how pH is the negative logarithm of hydrogen ion concentration.
4. A short review of logarithms may be useful for students. Point out that the logarithm of a number is the power to which 10 must be raised in order to equal the number. Have students create a pH scale based on the logarithms.
5. After the review of logarithms, have students practice calculating pH for an acidic or basic solution and calculating the concentration of hydronium ions (H_3O^+) and hydroxide ions (OH^-) from pH.

Experiment 1: Measuring the pH of Acids and Bases

1. Distribute six litmus paper strips to each student, and have them label the six strips “Test A” through “Test F.” Have students attach each strip to a sheet of paper in their lab book and next to each strip, write: “Solution: ________________/pH___________.”
2. Have students test a single drop of six solution samples, using a medicine dropper.
3. Instruct students to compare the color created by the sample drop against the color legend on the litmus paper dispenser, and record the approximate pH of each solution. Have them use tape to secure the samples to the page, making sure to label each solution used.
4. Have students answer the following questions:
   - What ion is characteristic of aqueous solutions of all acids? (The hydronium ion (H_3O^+) is characteristic of all acids, while the hydroxide ion is characteristic of all bases.)
   - What is the difference between a strong acid and a weak acid? (A strong acid is completely ionized; a weak acid is only partially ionized.)
   - What are three characteristics of an acid solution? (It tastes sour, it conducts electricity, and it reacts with metals above hydrogen in the activity series.)
   - What is the equation for the reaction of a strong acid, HBr, with water? ($HBr + H_2O \rightarrow H_3O^+ + Br^-$)

Demonstration: Titration

1. Begin the discussion by asking students what they commonly do when they have an upset stomach. What do they take to help it feel better? Explain that antacids contain hydroxides that neutralize acid like the HCl in stomach acid. This can be explained by the following general chemical equation: HX + YOH → XY + HOH
   acid base salt water
2. Draw the following chart on the board, one row at a time, to show how a variety of common acids and bases are neutralized to form salt and water.

Acid +	Base →	Salt +	Water
HCl	NaOH	NaCl	HOH

Stomach acid	Lye for soap	Table salt	H_2O = water
H_2CO_3 Soda pop acid	NaOH Lye for soap	Na_2CO_3 Washing soda	HOH H_2O = water
H_2SO_4 Industrial acid	$Mg(OH)_2$ Milk of Magnesia	$MgSO_4$ Epsom salt	HOH H_2O = water
H_2CO_3 Soda pop acid	$Ca(OH)_2$ Antacid tablets	$CaCO_3$ Limestone chalk	HOH H_2O = water
HNO_3 Fertilizer	KOH Potash	KNO_3 Saltpeter	HOH H_2O = water

3. Have students carefully observe as you add 100 mL of 0.1 *M* NaOH solution to an "empty" beaker that actually contains a drop of phenolphthalein placed there without students' knowledge. Keep the identity of the clear liquid secret. Seeing the clear liquid turn purple as you pour it into the "empty" beaker will cause some surprise.
4. Then, display the purple fluid and pour a few drops of it into another clear, unidentified liquid—100 mL of 0.1 *M* HCl (or slightly more concentrated) solution. This will also raise eyebrows when the liquid remains clear.
5. Pour the HCl into the NaOH until the color disappears. Now, identify all of your solutions, and explain that the purple fluid, phenolphthalein, can indicate the presence of a base only when there is base present. When the acid neutralizes the base to form salt and water, the base is no longer present, and the phenolphthalein becomes colorless.

Experiment 2: Titration

1. Obtain a 10-mL graduated cylinder. (If one is not available, the alternative is to use a test tube rack or a piece of cardboard with a hole cut in it to hold a test tube upright in a beaker.)
2. Retrieve your flask of previously prepared 0.1 *M* NaOH solution, and pour 3 mL of it into the 10-mL graduated cylinder. (Alternatively, use a ruler to measure 3 cm of the solution as you pour it into the test tube.)
3. Add one drop of phenolphthalein indicator to your 3mL of 0.1 *M* NaOH solution. The solution will turn purple, indicating the presence of a base.
4. Obtain 20 mL of a 0.1 *M* HCl solution from your teacher, and add a dropper full of the HCl solution to the base.
5. Use a small dropper or cork stopper to cap the tube or cylinder and turn it upside down, then right side up. This simple action will mix the solution thoroughly.
6. Repeat steps 7 and 8 until the base solution clears completely.
7. Determine the amount of acid that was needed to neutralize the base by finding the final amount of solution in the graduated cylinder and subtracting from it the original amount. (Alternatively, use the ruler to measure the final amount of solution, and subtract the original amount from it.)
8. Graph the gathered data, and describe the composition of the titration mixture represented by the graph.

Assessment

- **Other**
  - Write a step-by-step description of the process of titration.

Extensions and Connections (for all students)

- Have students read the list of ingredients in five common acidic household substances. Then, have them create a table listing those five common substances and the acids they contain.
- Have students read the list of ingredients in five common basic household substances. Then, have them create a table listing those five common substances and the bases they contain.
- Have students explore how certain flowers and shrubs thrive (or change color) in acidic vs. basic soils.