Activity 21– Proton Transfer: Acids and Bases Reacting with Water and One Another

Goals

- Understand what defines an acid and a base.
- Be able to distinguish the ionization of acids and bases from the neutralization of acids and bases.
- Characterize lab reagents and household products as acidic, basic or neutral using acid-base indicators.

Pre-Lab Lecture Questions. *Answer these questions on a separate sheet using complete sentences.*

1. Describe the bonds in a water molecule. Ionic or covalent? Nonpolar or polar?
2. What is an acid? What is a base?
3. What is a double displacement/replacement reaction?
4. What is an acid-base indicator? Give two examples.
5. What is the interpretation of an indicator color change?
6. Write the correct chemical equation describing the reaction between hydrogen chloride and water.
7. Write the correct chemical equation describing the reaction between ammonia and water.
8. Write the correct chemical equation describing the neutralization of ammonia by hydrogen chloride?
9. Understand the definitions of an Arrhenius acid and a Brønsted-Lowry acid.
10. Define monoprotic, diprotic and triprotic acids.

Concepts to Review

Nomenclature
Writing Chemical Equations
Small Scale Techniques
Arrhenius and Brønsted-Lowry definitions of acids and bases

Introduction

Early scientists characterized many substances by their taste. Substances that were sour were term **acids** (from the Latin word for sour, *acidus*). Bitterness was associated with alkaline or basic substances. Anything that was neither acidic nor basic was deemed **neutral**. These observations remain to this day but as information about acids and bases increased, the definitions changed. Svante Arrhenius discovered that acidic character was found in aqueous solutions that contained hydrogen ions attached to water molecules known as hydronium ions (H_3O^+). Acid concentration is still described in terms of hydronium ion concentration. Therefore, an **acid** can be defined as a substance that produces hydronium ions when dissolved in water.

All aqueous solutions contain hydroxide ions (OH^-). A **base** is defined as a substance that produces hydroxide ions when dissolved in water. Later, more general definitions of acids and bases were introduced because acids and bases can exist apart from aqueous media. These definitions are presented in the table below.

Definition	Alchemist	Arrhenius	Brønsted-Lowry	Lewis
Acid	Sour	A substance that produces hydronium ions when dissolved in water	Proton donor (H^+)	Electron pair acceptor
Base	Bitter Slippery	A substance that produces hydroxide ions when dissolved in water	Proton acceptor (H^+)	Electron pair donor

The inherent problem with using taste as a diagnostic tool in the lab has been recognized and is rarely used in analytical chemistry. One simple means to determine whether something is acidic or basic is to use a solution that has a different appearance in acid and base. The substances that exhibit different colors in the presence of acids on the one hand and bases on the other are called indicators. Naturally derived indicators like red cabbage juice abound in nature. Another example of a traditional natural indicator is found in litmus paper. Litmus is paper that is soaked in an extract of specific lichen. Red litmus turns blue in the presence of base and blue litmus turns red in the presence of acid. Chemists have developed synthetic indicators to suit a wide range of applications and conditions. Methyl red, a synthetic indicator, is red in acidic solutions and yellow in basic solutions.

In today's experiment you will test a variety of acids and bases using several indicators. After making observations of the colors associated with a variety of solutions in the presence of an indicator, you will represent the color changes using chemical equations. Chemical equations are symbolic representations of transformations of matter. These equations include the reactants (starting materials) written first, followed by an arrow, and finally the products (the outcome of combining the reactants):

$$\text{Reactants} \longrightarrow \text{Products}$$

To be valid, a chemical equation must have the correct formulas for all the reactants and products. In addition, the number and types of atoms on the reactant side of the equation must equal the number and types of atoms on the product side.

To help you in writing your equations, the Brønsted-Lowry definition of acids and bases may be the most useful. In this definition of acids and bases, only hydrogen ions (or protons (H^+)) are considered. An acid is defined as a proton donor; a base is a proton acceptor. The correct chemical equation describing the reaction between gaseous hydrogen chloride and water to produce hydrochloric acid is as follows:

$$HCl_{(g)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

(Note that not only do the number and type of atoms balance, but the sum of the charges on the reactant side equals the sum of charges on the product side as well.) The reaction between a molecular acid or base and water is known as an ionization reaction. In ionization reactions of acids, hydronium ion is always one of the products.

Ammonia (NH_3) is a common base that readily reacts with water to produce hydroxide ions along with another product. Can you write the equation for this reaction? Remember to write the correct formulas for the reactants first, insert an arrow and then write the correct formulas of the products. For a base reacting with water, one of the products must be hydroxide ion. Remembering that the base is a proton acceptor and the equation must be balanced, try to write the correct equation below:

ammonia + water $\longrightarrow$ hydroxide ion + ______________

Another important reaction occurs when acids and bases react with each other to form a salt and water. This is called a neutralization reaction and occurs when all of the protons on the acid are successfully neutralized by the hydroxide ions contributed by the base. An example of a neutralization reaction is the use of sodium hydroxide to neutralize battery acid (which contains sulfuric acid). Sulfuric acid is a diprotic acid (H_2SO_4) so it requires two moles of hydroxide ion to become neutralized:

$$H_2SO_{4(aq)} + 2\ NaOH_{(aq)} \longrightarrow Na_2SO_{4(aq)} + 2\ H_2O_{(l)}$$

Reaching the exact neutralization point using indicators is not possible. (Why not?) In this lab you will use indicators to determine the acid/base nature of a variety of substances. You will record your observations and then practice writing chemical equations describing ionization and neutralization. Make sure that you understand how to write these chemical equations before leaving lab today!

Safety

Act in accordance with the laboratory safety rules of Cabrillo College.
Wear safety glasses.
Avoid contact with all chemical reagents and dispose of reactions using appropriate waste container.

Materials:

Reagent Central solutions include:

Obvious Acids	Bases	Salt Solutions
Hydrochloric acid (HCl)	Sodium hydroxide (NaOH)	Sodium bicarbonate ($NaHCO_3$) Sodium carbonate (Na_2CO_3)
Nitric acid (HNO_3)	Potassium hydroxide (KOH)	Sodium acetate ($NaC_2H_3O_2$)
Sulfuric acid (H_2SO_4)		Sodium phosphate (Na_3PO_4)
Acetic acid ($HC_2H_3O_2$)	Ammonia (NH_3 also known as Ammonium hydroxide (NH_4OH)	Sodium hydrogen phosphate (Na_2HPO_4) Sodium dihydrogen phosphate (NaH_2PO_4)
Phosphoric acid (H_3PO_4)		Sodium hydrogen sulfate ($NaHSO_4$) Sodium hydrogen sulfite ($NaHSO_3$)

Indicators: Litmus paper, Bromthymol blue (BTB), cabbage extract (RCE), phenolphthalein (phen)

Equipment: Empty pipet for mixing Lab top reaction surface hot plates slides

Experimental Procedure

1. Insert your experimental page inside of your reaction surface. Place three drops of each solution on each box of your template. Use litmus to test the solution first. You will have both red and blue litmus available. The test requires a very small piece of paper touching the drop. If it does not change with the first piece, try the other color. Record any change as either "red to blue" or " blue to red". After testing using litmus, add the remaining three indicator solutions to your three drops (a unique indicator to each of the drops), making sure that the drops do not mix. Record any color changes using descriptive language.

2. Use BTB to characterize common household products as acids or bases. Make sure you describe the household product being tested.

3. Mix one drop of each solution on the glass slide, as depicted below. Carefully move the slide to a warm (**not hot**; setting should be on 1 or 2) hot plate. After the drops have evaporated, carefully remove the glass slide using a spatula or your forceps (tweezers). Record your observations.

NaOH	NaOH	KOH	NH_3
+	+	+	+
HCl	HNO_3	H_2SO_4	$HC_2H_3O_2$

4. Place one drop of ammonia on one end of a clean cotton swab. Waft the air above the swab towards your nose without placing the swab near your nose. Note any odor. Place two drops of HCl onto your reaction surface, and absorb this acid into the cotton swab containing the ammonia. Note and record its odor.

5. Answer all the questions on your worksheet.

Reaction Template: Insert this page into the labtop. Mix one drop of each, using a long stem pipet to blow air past the droplet to complete the mixing.

Indicator	Solution	Solution	Solution
Litmus BTB Phen RCE	a. $NaHCO_3$	f. $NaC_2H_3O_2$	k. H_3PO_4
Litmus BTB Phen RCE	b. $HC_2H_3O_2$	g. NaOH	l. NaH_2PO_4
Litmus BTB Phen RCE	c. HCl	h. HNO_3	m. Na_2HPO_4
Litmus BTB Phen RCE	d. Na_2CO_3	i. $NaHSO_4$	n. Na_3PO_4
Litmus BTB Phen RCE	e. H_2SO_4	j. NH_3	o. $NaHSO_3$

Activity 21– Proton Transfer Worksheet

Name_____________________________

Section_____________ **Date**_______

Experimental Data:

1. Complete the following table with your observations.

Indicator	Observations	Observations	Observations
Litmus BTB Phen RCE	a. $NaHCO_3$	f. $NaC_2H_3O_2$	k. H_3PO_4
Litmus BTB Phen RCE	b. $HC_2H_3O_2$	g. NaOH	l. NaH_2PO_4
Litmus BTB Phen RCE	c. HCl	h. HNO_3	m. Na_2HPO_4
Litmus BTB Phen RCE	d. Na_2CO_3	i. $NaHSO_4$	n. Na_3PO_4
Litmus BTB Phen RCE	e. H_2SO_4	j. NH_3	o. $NaHSO_3$

2. Complete the following table:

Household Product	Color of product after contact with Litmus	BTB	Acid or Base?

3. Record your observations in below:

Reactants				
Appearance before evaporation				
Appearance after evaporation				

   a. Write neutralization equations for each of the mixtures in Part 3:

4. Describe the odor of ammonia before the addition of HCl.

   a. What did you observe after the addition of HCl? Give an explanation for your observation.

5. Answer the following questions:
    a. Describe an acid and base in terms of the color changes they produce in the indicators litmus paper and BTB.

    b. Name each acid you identified in this experiment. (Include the letter designations; e.g. **hydrochloric acid, c**)

    c. Name each base you identified in this experiment. (Include the letter, designations; e.g. **ammonia, j**)

    d. What is the common feature in the chemical formula of each acid?

    e. Define an acid and a base in terms of the color changes produced for phenolphthalein.

    f. Predict the colors of the household products in the presence of phenolphthalein.

g. You saw the acidic solutions turn yellow with BTB. What was not directly visible is the reaction between water and the acid (the proton transfer to water). Such interactions can be described by chemical equations:

c. $HCl + H_2O \longrightarrow H_3O^+ + Cl^-$ i. $Na^+ + HSO_4^- + H_2O \longrightarrow H_3O^+ + Na^+ + SO_4^{2-}$

Note that acids ionizing in water always have hydronium ion as a product. Write the ionic equations describing the reaction of water with the remaining acids in the same format given in the example above.

h. You saw basic solutions turn blue in the presence of BTB. What was not visible is the reaction between water and the base (proton transfer to the base). Such interactions are described by chemical equations:

a. $Na^+ + HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + Na^+ + OH^-$ j. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

Note that bases ionizing in water always have hydroxide ion as a product. Write the ionic equations of water and the remaining bases in the same format given in the example above.

i. Can you predict whether something is an acid or base by looking at its formula? Explain your answer.