Classifying Chemical Reactions

Analyzing and Predicting Products

Introduction

The power of chemical reactions to transform our lives is visible all around us—in our homes, in our cars, even in our bodies. Chemists try to make sense of the great variety of chemical reactions the same way that biologists organize their knowledge of life, by sorting reactions into groups and classifying them. Classifying chemical reactions allows us to predict what chemical reactions will occur when different substances are mixed.

Concepts

- Chemical reactions
- Combination vs. decomposition
- Single vs. double replacement
- Combustion reactions

Background

A chemical reaction is defined as any process in which one or more substances are converted into new substances with different properties. Chemical reactions change the identity of the reacting substance(s) and produce new substances. Observing the properties of the reactants and products is therefore a key step in identifying chemical reactions. Some of the observations that may be associated with a chemical reaction include: (1) release of a gas; (2) formation of a precipitate; (3) color changes; (4) temperature changes; (5) emission or absorption of light. As these observations suggest, chemical reactions can be dynamic and exciting events. The essence of any chemical reaction—reactants being transformed into products—is summarized in the form of a chemical equation. Consider the reaction represented by Equation 1, the burning of natural gas (methane, CH_4) in a laboratory burner.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g) \qquad \textit{Equation 1}$$

The reactants—or, more specifically, their formulas—are written on the left side of the equation, the products on the right side of the equation. An arrow represents the direction of the reaction and is read as "yields" or "produces." Other symbols are used to describe the physical state of the reactants and products and to describe the reaction conditions (see Table 1).

Chemical reactions may be classified by considering the number of reactants and products in the reaction, the physical or chemical nature of the reactants and products, and the rearrangement of atoms in the conversion of the reactants into products (see Table 2).

Table 1. Symbols in Chemical Equations

Symbol	Translation
→	Yields or produces (separates reactants from products)
+	Reacts with or forms alongside (separates two or more reactants or products)
Δ	Reaction mixture is heated (written over the arrow)
NR	No reaction takes place when reactants are mixed
(s)	Pure substance (reactant or product) is a solid
(l)	Pure substance (reactant or product) is a liquid
(g)	Pure substance (reactant or product) is a gas
(aq)	Aqueous solution (reactant or product is dissolved in water)
$\xrightarrow{Cat}$	Catalyst—a substance needed to initiate a reaction (formula is written over the arrow)

Table 2. Classification of Chemical Reactions

Type of Reaction	General Description and Example(s)
Combination	Two reactants combine to form a single product. The reactants may be elements or compounds. Also called a synthesis reaction. $Zn(s) + I_2(s) \rightarrow ZnI_2(s)$ $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$
Decomposition	One reactant, a compound, breaks down to give two or more products. $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
Single Replacement	An element reacts with a compound and replaces one of the elements in the compound. Metals replace hydrogen or other metals; nonmetals replace nonmetals. $Zn(s) + 2HCl(aq) \rightarrow H_2(g) + ZnCl_2(aq)$ $Cu(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Cu(NO_3)_2(aq)$ $Cl_2(aq) + 2NaI(aq) \rightarrow I_2(aq) + 2NaCl(aq)$
Double Replacement	Two ionic compounds (or compounds that break apart to form ions in solution) exchange ions to form new compounds. Examples include precipitation reactions (driving force is formation of a precipitate), acid–base reactions (driving force is formation of water), and gas-forming reactions (driving force is evolution of a gas). $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$ $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$ $Na_2SO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g)$
Combustion	A compound burns in the presence of oxygen, producing energy in the form of heat and light. The combustion of organic compounds produces carbon dioxide and water. $C_4H_8(l) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)$

Experiment Overview

The purpose of this experiment is to observe a variety of chemical reactions and to identify patterns in the conversion of reactants into products. The properties of the reactions will be analyzed to classify the chemical reactions into different groups.

Pre-Lab Questions

1. Which reactants used in this experiment are flammable? Discuss the safety precautions that are necessary when working with flammable materials in the lab.
2. Summarize the following description of a chemical reaction in the form of a balanced chemical equation.

   "When solid sodium bicarbonate is heated in a test tube, an invisible gas, carbon dioxide, is released into the surrounding air. Water condenses at the mouth of the test tube and a white solid residue, sodium carbonate, remains behind in the bottom of the test tube."
3. Common observations of a chemical reaction are described in the *Introduction* section. For each observation, name a common or everyday occurrence that must involve a chemical reaction. *Example:* When a candle burns, it gives off light and heat. The production of light and heat is evidence for a chemical reaction.

Materials

Ammonium carbonate, $(NH_4)_2CO_3$, 0.5 g
Calcium carbonate, $CaCO_3$, 0.5 g
Copper(II) chloride solution, $CuCl_2$, 0.5 M, 4 mL
Ethyl alcohol, C_2H_5OH, 1 mL
Hydrochloric acid, HCl, 1 M, 4 mL
Magnesium ribbon, Mg, 2–4 cm strips, 2
Phenolphthalein indicator, 1 drop
Sodium hydroxide solution, NaOH, 1 M, 1 mL
Sodium phosphate solution, Na_3PO_4, 0.5 M, 1 mL
Water, distilled
Zinc, mossy, or zinc shot, Zn, 1–2 pieces
Bunsen or laboratory burner
Butane safety lighter
Evaporating dish, porcelain
Forceps or crucible tongs
Heat-resistant pad
Litmus paper
Pipets, Beral-type, 6
Spatula
Test tubes, small, 6
Test tube clamp
Test tube rack
Wash bottle
Wood splints, 3

Safety Precautions

Ethyl alcohol is a flammable solvent and a dangerous fire risk. Keep away from flames and other sources of ignition. Solvent bottles should be kept capped at all times and must be removed from the work area when using the laboratory burner. Addition of denaturant makes ethyl alcohol poisonous. Hydrochloric acid and sodium hydroxide solutions are corrosive liquids. Notify the teacher and clean up all spills immediately. Phenolphthalein is an alcohol-based solution and is flammable; it is moderately toxic by ingestion. Magnesium metal is a flammable solid and zinc metal may contain flammable dust. Copper(II) chloride solution is toxic by ingestion. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles and chemical-resistant gloves and apron. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

For each reaction, record the color and appearance of the reactant(s), the evidence for a chemical reaction, and the properties of the product(s) in the data table.

Reaction #1

1. Obtain a 3–4 cm strip of magnesium metal ribbon. Hold the piece of magnesium with forceps or crucible tongs and heat the metal in a laboratory burner flame. *Caution:* Do not look directly at the burning magnesium—ultraviolet light that is produced may damage your eyes.
2. When the magnesium ignites, remove it from the flame and hold it over an evaporating dish or a Pyrex® watch glass until the metal has burned completely. Let the product fall into the evaporating dish.
3. Turn off the laboratory burner and observe the properties of the product in the evaporating dish.
4. Record observations in the data table.

Reaction #2

5. Using a Beral-type pipet, add about 2 mL (40 drops) of 1 M hydrochloric acid solution to a small test tube.
6. Obtain a 2–3 cm strip of magnesium metal ribbon and coil it loosely into a small ball. Add the magnesium metal to the acid in the test tube.
7. Carefully feel the sides of the test tube and observe the resulting chemical reaction for about 30 seconds.
8. While the reaction is still occuring, light a wood splint and quickly place the burning splint in the mouth of the test tube. Do not put the burning splint into the acid solution.
9. Record observations in the data table.

Reaction #3

10. Obtain a clean and dry test tube and place a small amount (about the size of a jelly bean) of ammonium carbonate into the test tube.
11. Use a test tube clamp to hold the test tube and gently heat the tube in a laboratory burner flame for about 30 seconds.
12. Remove the test tube from the flame and place a piece of moistened litmus paper in the mouth of the test tube. Identify any odor that is readily apparent by wafting the fumes toward your nose. *Caution:* Do NOT sniff the test tube!
13. Test for the formation of a gas: Light a wood splint and insert the burning splint halfway down into the test tube.
14. Record observations in the data table.

Reaction #4

15. Place a small amount (about the size of a jelly bean) of calcium carbonate in a clean and dry test tube.

16. Using a Beral-type pipet, add about 1 mL (20 drops) of 1 M hydrochloric acid to the test tube. Feel the sides of the test tube and observe the reaction for 30 seconds.

17. Quickly light a wood splint and insert the burning splint about halfway down into the test tube. Do not allow the burning splint to contact the reaction mixture.

18. Record observations in the data table.

Reactions #5

19. Using a Beral-type pipet, add about 2 mL (40 drops) of 0.5 M copper(II) chloride solution into a small test tube.

20. Add 1–2 pieces of mossy zinc or one piece of zinc shot to the test tube and observe the resulting chemical reaction.

21. Record observations in the data table.

Reaction #6

22. Using a Beral-type pipet, add about 2 mL (40 drops) of 0.5 M copper(II) chloride solution into a small test tube.

23. Using a fresh pipet, add about 25 drops of 0.5 M sodium phosphate solution to the test tube.

24. Record observations in the data table.

Reaction #7

25. Using a Beral-type pipet, add 20 drops of 1 M sodium hydroxide solution into a small test tube.

26. Add one drop of phenolphthalein indicator to the test tube and mix the solution by gently swirling the tube. *Hint:* Phenolphthalein is called an "acid–base" indicator.

27. Using a clean Beral-type pipet, add 1 M hydrochloric acid solution one drop at a time to the test tube. Count the number of drops of acid required for a permanent color change to be observed.

28. Record observations in the data table.

Reaction #8

29. Working in the hood or a designated work area, add about 1 mL (20 drops) of ethyl alcohol to a clean evaporating dish. Place the evaporating dish on a heat-resistant pad.

30. Cap the alcohol bottle and remove it from the work area.

31. Fill a test tube about one-third full with cold tap water for use in step 34.

32. Light a butane safety lighter and bring the flame close to the alcohol in the evaporating dish.

33. Turn off the safety lighter as soon as the alcohol ignites.

34. Place the test tube containing cold water in a test tube clamp and hold the test tube above the burning alcohol. Observe the outside of the test tube for evidence of product formation.

35. Allow the alcohol to burn until it is completely consumed. *Caution:* Do not touch the hot evaporating dish.

36. Record observations in the data table.

Name: ______________________________

Class/Lab Period: ______________________

Classifying Chemical Reactions

Data Table

Reaction	Appearance of Reactant(s), Evidence of Chemical Reaction, and Properties of Product(s)
1	
2	
3	
4	
5	
6	
7	
8	

Post-Lab Questions

1. Write a balanced chemical equation for each reaction #1–8. Classify each reaction using the information provided in the *Background* section (see Table 2).

   Reaction #1:

   Reaction #2:

   Reaction #3:

   Reaction #4:

   Reaction #5:

   Reaction #6:

   Reaction #7:

   Reaction #8:

2. Classifying chemical reactions helps chemists to predict the possible products that will form when two or more substances are mixed. Complete and balance the following equations by predicting the products of each chemical reaction.

   (a) Double replacement: $NaOH(aq) + CuSO_4(aq) \rightarrow$

   (b) Combination: $Al(s) + O_2(g) \rightarrow$

   (c) Combustion: $C_6H_{12}O_6(s) + O_2(g) \rightarrow$

   (d) Decomposition: $CaCO_3(s) \xrightarrow{\Delta}$

   (e) Single replacement: $Fe(s) + Pb(NO_3)_2(aq) \rightarrow$

3. *(Optional)* Complete the "Classifying Chemical Reactions Worksheet."

Name: ______________________________

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Classifying Chemical Reactions Worksheet

Write a balanced chemical equation for each reaction and classify the reaction.

1. Copper metal heated with oxygen gives solid copper(II) oxide.

2. Mixing ammonium nitrate and sodium hydroxide solutions gives aqueous sodium nitrate, ammonia gas, and water.

3. Mercury(II) nitrate solution reacts with potassium iodide solution to give a mercury(II) iodide precipitate and potassium nitrate solution.

4. Aluminum metal and sulfuric acid yield aqueous aluminum sulfate and hydrogen gas.

5. Acetic acid and lithium hydroxide solution produce water and aqueous lithium acetate.

6. Sulfur dioxide gas reacts with oxygen on a platinum catalyst surface to produce sulfur trioxide gas.

7. Sodium metal reacts with water to give sodium hydroxide solution and hydrogen gas.

8. Heating solid nickel chloride dihydrate yields solid nickel chloride and water vapor.

9. Heating solid potassium chlorate in the presence of manganese dioxide catalyst produces potassium chloride and oxygen gas.