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Classifying Some Chemical Reactions

prepared by **M. L. Gillette**, Indiana University Kokomo, and
H. A. Neidig, Lebanon Valley College

Purpose of the Experiment

Perform a series of chemical reactions. Write chemical equations for the reactions, based on your observations. Classify each reaction as one of four general types.

Background Required

You should be familiar with basic laboratory techniques for volume measurement. You should be able to recognize when a substance is in its elemental form, and when it is a compound.

Background Information

Many chemical reactions can conveniently be classified as one of four general types. The classification is based on the nature of the chemical transformation involved.

Four Types of Chemical Reactions

Type I: Combination, Synthesis, or Formation Reactions

A **combination, synthesis,** or **formation reaction** occurs when two substances, usually in their elemental forms, combine to form a compound. Equation 1 shows a generalized combination reaction, while Equation 2 shows a specific example.

$$A + B \rightarrow AB \qquad \text{(Eq. 1)}$$

$$2\ Ca(s) + O_2(g) \rightarrow 2\ CaO(s) \qquad \text{(Eq. 2)}$$

Type II: Decomposition Reactions

A **decomposition reaction** occurs when a compound breaks apart into two or more products. Equation 3 shows a generalized example, while Equation 4 shows a specific example.

$$AB \rightarrow A + B \qquad \text{(Eq. 3)}$$

$$2\ HgO(s) \rightarrow 2\ Hg(\ell) + O_2(g) \qquad \text{(Eq. 4)}$$

02 01 00 — 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Type III: Single Displacement or Single Replacement Reactions

When the uncombined form of one element displaces (and replaces) another element in a compound, forming a new compound, we call the process a **single displacement** or **single replacement reaction**. Equation 5 shows a generalized example, and Equation 6 shows a specific example.

$$A + BC \rightarrow AC + B \qquad \text{(Eq. 5)}$$

$$2\ Al(s) + 6\ HNO_3(aq) \rightarrow 2\ Al(NO_3)_3(aq) + 3\ H_2(g) \qquad \text{(Eq. 6)}$$

Type IV: Double Displacement or Double Replacement Reactions

A **double displacement** or **double replacement reaction** occurs when ions from two different ionic compounds change places to form two new compounds. One of the compounds formed usually has one of the following forms: a solid, called a **precipitate;** a slightly dissociated compound, such as water; or a gas. Equation 7 shows a generalized example, and Equation 8 shows a specific example. In Equation 8, $PbCl_2(s)$ is the precipitate.

$$AB + CD \rightarrow AD + CB \qquad \text{(Eq. 7)}$$

$$Pb(NO_3)_2(aq) + 2\ NaCl(aq) \rightarrow PbCl_2(s) + 2\ NaNO_3(aq) \qquad \text{(Eq. 8)}$$

Many reactions are **exothermic,** meaning that they release heat to their surroundings. Other reactions are **endothermic,** meaning that these reactions absorb heat from their surroundings. Therefore, temperature changes in a chemical system can be evidence that a chemical reaction has occurred.

Example

Problem When shiny red–brown (elemental) copper mesh is heated in an open crucible, the mesh turns black. If prodded with a stirring rod, the black mesh crumbles. What general type of reaction has occurred?

Solution *(1) Analyze your observations.*

Because only one reaction product was observed, for the purposes of this experiment, we will conclude that there was probably no second reaction product. The only substance with which the copper came into contact was the air, a mixture of compounds the most reactive of which is oxygen (O_2). Thus, we can conclude that the reaction must have occurred because, on heating, the metallic copper (Cu) reacted with atmospheric O_2.

(2) Suggest a formula for the reaction product.

We can conclude that Cu combined with O_2 to form black CuO.

(3) Write the chemical equation for the reaction.

$$2\ Cu(s, brown) + O_2(g) \rightarrow 2\ CuO(s, black)$$

(4) Classify the reaction as one of the four general types.

This reaction is a combination reaction (Type I) because two reactants (Cu and O_2) combined to form one product (CuO).

In This Experiment

You will perform several chemical reactions. Based on your observations, you will write chemical equations for the reactions. You will also classify each reaction as one of the four general types. The chemical formulas for the elements and compounds you will be working with are listed in Table 1.

Table 1 *Chemical formulas for some of the elements and compounds encountered in this experiment*

chemical name	*chemical formula*
ammonia	NH_3
ammonium carbonate	$(NH_4)_2CO_3$
carbon(IV) oxide (carbon dioxide)	CO_2
copper	Cu
copper(II) sulfate (cupric sulfate)	$CuSO_4$
copper(II) sulfate pentahydrate	$CuSO_4 \cdot 5H_2O$
hydrochloric acid	HCl
iron	Fe
iron(II) sulfate (ferrous sulfate)	$FeSO_4$
magnesium	Mg
sodium hydroxide	NaOH

Procedure

Caution: *Wear departmentally approved safety goggles while doing this experiment. Always use caution in the laboratory. Many chemicals are potentially harmful. Prevent contact with your eyes, skin, and clothing. Avoid ingesting any of the reagents. Take care not to burn your skin when using the Bunsen burner.*

Note:
- *Perform all or some of the following experiments, as directed by your laboratory instructor.*
- *Follow your laboratory instructor's directions for: dispensing and transferring solutions to a test tube using a Pasteur or Beral pipet; estimating the volume of solution transferred; and stirring reaction mixtures in a test tube.*
- *Dispose of your reaction mixtures, rinses, and used litmus paper according to your laboratory instructor's directions.*
- *Record all of your data on your Data and Observations sheet.*

I. Reacting Mg with 0.1*M* HCl

Caution: *Magnesium ribbon is flammable and moisture-sensitive. 0.1M HCl is toxic and corrosive. The gas produced by the reaction of Mg and HCl solution also is flammable. Be sure that there are no Bunsen burner flames in the area where you are performing this reaction.*

1. Transfer a 0.5-cm piece of Mg ribbon to the bottom of a clean 15 × 100-mm test tube. Record your description of the Mg ribbon.

Record your description of 0.1*M* HCl.

2. Holding the bottom of the test tube containing the Mg ribbon, transfer 2 mL of 0.1*M* HCl into the test tube. Observe the reaction mixture for evidence of a chemical reaction. Note any temperature change in the outside wall of the test tube. Record all observations.

3. Transfer the contents of your test tube to a small beaker. Rinse the test tube with tap water, then with distilled or deionized water. Transfer all rinses into the

beaker. Transfer the beaker contents into the collection container specified by your laboratory instructor.

II. Reacting 0.1*M* $CuSO_4$ with 0.1*M* NaOH

> **Caution:** *$CuSO_4$ is toxic. NaOH is toxic and corrosive.*

4. Record your descriptions of 0.1*M* $CuSO_4$ and 0.1*M* NaOH.

5. Transfer 10 drops of 0.1*M* $CuSO_4$ into a clean, dry test tube. Add 2 drops of 0.1*M* NaOH to the test tube. Thoroughly mix the solutions. Record your description of the reaction mixture and any evidence of temperature change in the mixture.

6. Dispose of your reaction mixture as you did in Step 3. Rinse and dry the test tube.

III. Reacting $CuSO_4 \cdot 5H_2O$ with Heat and Water

A. Heating $CuSO_4 \cdot 5H_2O$

7. Transfer the amount of $CuSO_4 \cdot 5H_2O$ that fills the end of a clean, dry microspatula into a clean, dry test tube. Record your description of $CuSO_4 \cdot 5H_2O$.

8. Grasp the top of the test tube with a test tube holder. Holding the test tube as shown in Figure 1, strongly heat the bottom of the test tube in a Bunsen burner flame until you see a change in the appearance of the solid. Remove the test tube from the flame. Carefully observe both the solid and the inner test tube wall near the open end of the test tube. Allow the tube to cool. Record your descriptions of the test tube inner wall and of the solid remaining in the test tube.

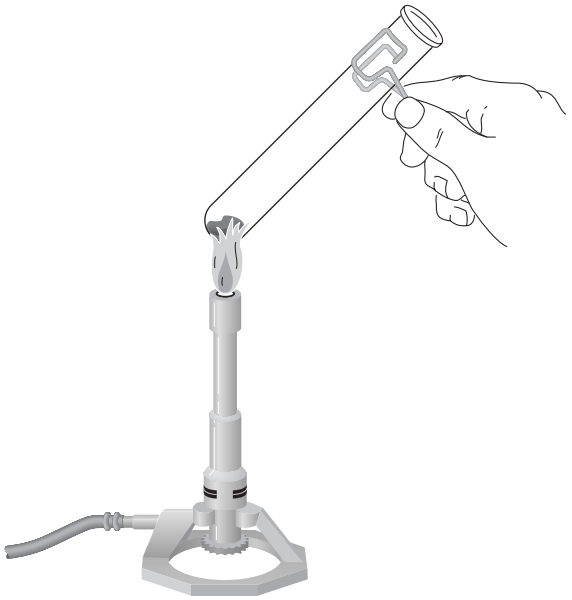

Figure 1 *Heating $CuSO_4 \cdot 5H_2O$ in a test tube*

B. Adding Water to Product of Heated $CuSO_4 \cdot 5H_2O$

9. Add 1 drop of distilled water to the solid remaining in the test tube. Record your description of the solid after the addition of water.

10. Dispose of your reaction mixture as you did in Step 3. Rinse and dry the test tube and microspatula.

IV. Reacting 0.1*M* $CuSO_4$ with Steel Wool (Fe)

11. Record your descriptions of steel wool (Fe) and 0.1*M* $CuSO_4$.

12. Obtain an amount of steel wool equivalent to the volume of a pencil eraser. Use a glass stirring rod to carefully slide the steel wool to the bottom of a clean, dry test tube. Add 2 mL of 0.1*M* $CuSO_4$ solution to the test tube. Stir the mixture for 2–3 min.

Observe the appearance of the steel wool and solution. Record your descriptions of the steel wool and reaction mixture after the reaction has occurred.

13. Dispose of the reaction mixture in the collection container specified by your laboratory instructor. Use your stirring rod to carefully transfer the steel wool from the test tube to the specified collection container. Rinse and dry the stirring rod and test tube.

V. Heating $(NH_4)_2CO_3$

14. Record your description of $(NH_4)_2CO_3$. Transfer the amount of $(NH_4)_2CO_3$ that fills the end of a clean microspatula to the bottom of a clean, dry test tube.

Note: *Red litmus paper turns blue in the presence of bases, such as NH_3.*

15. Place a piece of red litmus paper on a small watch glass. Moisten the litmus paper with 1–2 drops of distilled water. The moist paper will cling to the watch glass. Record your description of the moistened litmus paper.

Caution: *The vapors created by heating $(NH_4)_2CO_3$ are toxic and irritating.*

16. Working in a ***fume hood,*** strongly heat the bottom of the test tube containing the $(NH_4)_2CO_3$ in a Bunsen burner flame, holding it as shown in Figure 1. Carefully observe both the solid and the inner test tube wall near the open end of the test tube.

17. Holding the open end of the test tube about 6 in. from your face, ***carefully*** fan the fumes from the test tube toward your nose, as shown in Figure 2 on the next page. Note the odor of the vapors. Do ***not*** hold the test tube directly under your nose.

Then, invert the watch glass, and position it so that the moist litmus paper covers the open end of the test tube. Observe the color of the litmus paper. Record your descriptions of: what happened to the solid $(NH_4)_2CO_3$; the inner wall of the test tube; the odor of the vapors; and the color of the litmus paper after exposure to the vapors.

Figure 2 *Detecting odors*

18. Dispose of your reaction mixture as you did in Step 3. Discard the litmus paper in the specified container. Rinse and dry the watch glass, microspatula, test tube, and any other glassware you used in this experiment.

Caution: *Wash your hands thoroughly with soap or detergent before leaving the laboratory.*

name | partner | section | date

Post-Laboratory Questions

Use the spaces provided for the answers and additional paper if necessary.

1. (a) Write chemical equations for the decomposition reactions you observed.

(b) What evidence do you have indicating the presence of the reaction products you listed? Briefly explain.

(c) Write chemical equations for the single displacement reactions you observed.

(d) Besides being single displacement reactions, what, if anything, did the reactions you listed in (c) have in common?

2. First-generation automobile air bags contain a mixture of sodium azide (NaN_3), potassium nitrate (KNO_3), and silicon dioxide (SiO_2).

(a) The chemical reaction responsible for inflating this type of air bag is shown in Equation 9.

$$2\ NaN_3(s) \rightarrow 2\ Na(s) + 3\ N_2(g) \qquad \text{(Eq. 9)}$$

Classify this reaction as one of the four general types.

(b) The sodium (Na) formed when the air bag fills with nitrogen (N_2) reacts with KNO_3, as shown in Equation 10.

$$10\ Na(s) + 2\ KNO_3(s) \rightarrow K_2O(s) + 5\ Na_2O(s) + N_2(g) \qquad \text{(Eq. 10)}$$

Classify this reaction as one of the four general types. (Note: K_2O is a simple byproduct of the primary reaction, so you can ignore this product when you consider your answer.)

3. Iron is a relatively inexpensive and strong building material, but it tends to react with atmospheric O_2 to form iron(III) oxide, Fe_2O_3. In the presence of atmospheric moisture, Fe_2O_3 forms hydrated iron(III) oxide ($Fe_2O_3 \cdot nH_2O$), commonly called rust.

(a) Write the chemical equation for the oxidation of Fe to form Fe_2O_3.

(b) Classify the reaction you described in 3(a) as one of the four general types.

(c) Write the chemical equation for the hydration of Fe_2O_3 to form rust.

(d) Classify the reaction you described in 3(c) as one of the four general types.

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Data and Observations

I. Reacting Mg with 0.1*M* HCl

	appearance of reactants	*appearance of products*	*other observations (if any)*
Mg			
0.1*M* HCl			

II. Reacting 0.1*M* $CuSO_4$ with 0.1*M* NaOH

	appearance of reactants	*appearance of products*	*other observations (if any)*
0.1*M* $CuSO_4$			
0.1*M* NaOH			

III. Reacting $CuSO_4 \cdot 5H_2O$ with Heat and Water

A. Heating $CuSO_4 \cdot 5H_2O$

	appearance of reactant	*appearance of products*	*other observations (if any)*
$CuSO_4 \cdot 5H_2O$			

B. Adding Water to Product of Heated $CuSO_4 \cdot 5H_2O$

	appearance of reactants	*appearance of products*	*other observations (if any)*
product of heated $CuSO_4 \cdot 5H_2O$			
water			

name | partner | section | date

IV. Reacting 0.1*M* $CuSO_4$ with Steel Wool (Fe)

	appearance of reactants	*appearance of products*	*other observations (if any)*
0.1*M* $CuSO_4$			
Fe			

V. Heating $(NH_4)_2CO_3$

	appearance of reactants	*appearance of products*	*other observations (if any)*
$(NH_4)_2CO_3$			
moistened red litmus paper			

name | partner | section | date

Calculations and Conclusions

Write your conclusions in the spaces provided.

I. Reacting Mg with 0.1*M* HCl

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

II. Reacting 0.1*M* $CuSO_4$ with 0.1*M* NaOH

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

III. Reacting $CuSO_4 \cdot 5H_2O$ with Heat and Water

A. Heating $CuSO_4 \cdot 5H_2O$

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

B. Adding Water to Product of Heated $CuSO_4 \cdot 5H_2O$

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

IV. Reacting 0.1*M* $CuSO_4$ with Steel Wool (Fe)

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

V. Heating $(NH_4)_2CO_3$

evidence of a chemical reaction:

chemical equation for the reaction:

general reaction type:

name | partner | section | date

Pre-Laboratory Assignment

1. What hazards should you be aware of when working with:

(a) heated $(NH_4)_2CO_3$?

(b) 0.1*M* HCl?

(c) 0.1*M* NaOH?

2. Distinguish between:

(a) exothermic and endothermic reactions

(b) single and double displacement reactions

3. Identify the general reaction types illustrated by the following equations:

(a) $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$

(b) $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(\ell)$

(c) $Cu(s) + 2\ AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ Ag(s)$

4. What would you observe if you performed the reaction shown in:

(a) Equation 6?

(b) Equation 8?

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