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Chemical Reactions

Student Laboratory Kit

Introduction

There are millions of chemical reactions occurring around us during every second of every day. Chemical reactions are involved in the making of food, paper, plastics, pharmaceuticals, fuel, soaps, and numerous other products that we enjoy using. They also enable us to breathe, grow, see, and digest and metabolize food for energy. In this laboratory activity, you will perform five reactions, look for evidence of a chemical reaction, write the chemical equations, and classify the reactions according to reaction types.

Concepts

- Writing chemical equations
- Evidence of a chemical reaction
- Types of chemical reactions

Background

Evidence of a Chemical Reaction

For many chemical reactions, clues to indicate that a reaction did indeed occur can be observed. Such clues include production or absorption of heat, absorption or emission of light, production of a sound, a change of color, formation of a precipitate or a new product, or release of a gas. Some chemical reactions may exhibit only one of these clues, while other chemical reactions may reveal several clues. By looking for these clues, you can determine whether a chemical reaction has occurred.

Writing Chemical Equations

Any chemical change involves the reorganization of the atoms in one or more substances. For example, when carbon (C) combines with oxygen gas (O_2) in the air and burns, carbon dioxide gas (CO_2) is formed. This process is represented by a *chemical equation,* a symbolic expression used in chemistry to represent a chemical reaction. The *reactants* (carbon and oxygen) are written on the left side of the equation and the *products* (carbon dioxide) are written on the right side of the equation. A plus sign is used between two substances to indicate reactants combined or products formed. An arrow represents the direction of the reaction and is read as "yields" or "produces"

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \textit{Equation 1}$$

Reactants *Products*

The chemical equation for a reaction provides two important types of information: the nature of the reactants and products (indicated by the correct chemical formula) and the relative numbers of each. The equation often gives the physical states of the reactants and the products using state symbols, which are written after the chemical formulas in parentheses. Solids are represented with (s), liquids with (l), gases with (g), and aqueous solutions with (aq) to indicate that the substance is dissolved in water.

Types of Chemical Reactions

Despite the fact that there are so many different chemical reactions that can occur, most can be classified into five basic types of chemical reactions—synthesis reactions, decomposition reactions, single replacement reactions, double replacement reactions, and combustion reactions.

Synthesis Reactions

In a *synthesis reaction,* two or more substances react to form one new substance. The general form for a synthesis reaction is shown in Equation 2.

$$A + B \rightarrow AB \qquad \textit{Equation 2}$$

The reactants A and B may be either elements or compounds, while the newly formed product AB is always a compound composed of the elements in A and B. The product AB has different chemical and physical properties than the reactants A and B. Synthesis reactions include such reactions as the corrosion of metals in air or water (Equation 3), the reaction of nonmetal oxides with water to produce an acid (Equation 4), or the reaction of a metallic oxide with water to produce a base (Equation 5).

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s) \qquad \textit{Equation 3}$$

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq) \qquad \textit{Equation 4}$$

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq) \qquad \textit{Equation 5}$$

Decomposition Reactions

A *decomposition reaction* is a reaction in which a single compound AB is broken down, or decomposed, into two or more products A and B. The products A and B may be either elements or smaller compounds. The general form for a decomposition reaction is shown in equation 6.

$$AB \rightarrow A + B \qquad \textit{Equation 6}$$

Frequently, decomposition reactions occur only when heat is added to the reactant compound AB. The requirement of heat in a reaction is often denoted with a Δ symbol above the arrow. Examples of decomposition reactions that require heat to proceed include the reactions shown in equations 7 and 8.

$$(NH_4)_2CO_3(s) \rightarrow 2NH_3(g) + CO_2(g) + H_2O(g) \qquad \textit{Equation 7}$$

$$CuCO_3(s) \rightarrow CuO(s) + CO_2(g) \qquad \textit{Equation 8}$$

Electrolysis is another common method for carrying out decomposition reactions. In this case, energy in the form of electricity must be added before the reaction will occur. Such reactions include the electrolysis of water to produce oxygen and hydrogen gases (equation 9), and the electrolysis of table salt, NaCl, to produce liquid sodium and chlorine gas (equation 10).

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) \qquad \textit{Equation 9}$$

$$2NaCl(s) \rightarrow 2Na(l) + Cl_2(g) \qquad \textit{Equation 10}$$

Single Replacement Reactions

Single replacement reactions involve the replacement of one element in a compound with another element. The general form for a single replacement reaction is shown in equation 11.

$$A + BC \rightarrow B + AC \qquad \textit{Equation 11}$$

In this type of reaction, a metal element always replaces another metal element, while a nonmetal element always replaces a nonmetal element. Some metals can replace other metals, while some metals cannot. The ability of one metal to replace another metal in a compound determines a metal's reactivity, or activity. The activity series of metals is a scheme that places the metals in order of reactivity. A metal can replace a second metal if it appears above the second metal in the activity series. Examples of single replacement reactions involving the replacement of metals include the reactions shown in equations 12 and 13.

$$2Al(s) + 3CuCl_2(aq) \rightarrow 3Cu(s) + 2AlCl_3(aq) \qquad \textit{Equation 12}$$

$$Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq) \qquad \textit{Equation 13}$$

Single replacement reactions will not occur in the reverse direction without a battery because, in the reverse reaction, a less active metal would have to replace a more active metal.

Double Replacement Reactions

Double replacement reactions involve the exchange of ions between two compounds. The general form for a double replacement reaction is shown in equation 14.

$$AB + CD \rightarrow AD + BC \qquad \textit{Equation 14}$$

The ionic compounds in a double replacement reaction can be thought of as a pair of partners. In equation 14, A and B are one set of reactant partners, while C and D are another set of reactant partners. When these two compounds react, they exchange partners so that A and D become a new set of partners, while B and C do the same.

A double replacement reaction generally occurs between two ionic compounds in aqueous solution and is driven by formation of a product that is released from solution, such as in the formation of a precipitate or a gas. Precipitation reactions occur when two soluble compounds react and exchange partners such that one of the resulting products is insoluble. Gas forming reactions occur when one of the products is a gas that bubbles out of solution. Examples of each of these types of reactions are shown in equations 15 and 16.

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$ *Equation 15*

$$Na_2CO_3(aq) + 2HCl(aq) \rightarrow CO_2(g) + H_2O(l) + 2NaCl(aq)$$ *Equation 16*

Combustion Reactions

A *combustion reaction* is a reaction in which a compound reacts with oxygen, often producing energy in the form of heat and light. Many combustion reactions involve the reaction of a hydrocarbon or a compound containing hydrogen, carbon, and oxygen atoms with oxygen gas. In the complete combustion of a hydrocarbon, the products are always carbon dioxide gas and water. The general form for complete combustion between a hydrocarbon and oxygen is shown in equation 17.

$$\text{hydrocarbon} + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$ *Equation 17*

Because energy is produced in sufficient quantities in combustion reactions, many hydrocarbons are burned as fuels. Common examples of fuels include methane, propane, butane, octane, and gasoline. The combustion of propane in a gas barbeque grill, for example, is shown in equation 18.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$ *Equation 18*

Elements can also be burned in oxygen to form oxides in a combustion reaction. If a piece of copper wire is burned in a flame, cupric oxide is formed on the surface of the wire (equation 19).

$$2Cu(s) + O_2(g) \rightarrow 2CuO(s)$$ *Equation 19*

Notice that equation 19 is not only a combustion reaction, but also a synthesis reaction. Some chemical reactions fit perfectly into a single category, while other reactions fit equally well into more than one category.

Materials (for each lab group)

Chemicals

- Calcium chloride solution, 0.5 M, $CaCl_2$, 3 mL
- Copper wire, Cu, 4 in
- Ethyl alcohol, CH_3CH_2OH, 1 mL
- Magnesium metal ribbon, Mg, 2 in
- Silver nitrate solution, 0.5 M, $AgNO_3$, 5 mL
- Sodium bicarbonate, $NaHCO_3$, 1 g
- Sodium carbonate solution, 0.5 M, Na_2CO_3, 3 mL

Equipment

- Balance
- Beral-type pipets, 3
- Bunsen burner
- Butane safety lighter
- Cobalt chloride test paper
- Graduated cylinder, 10-mL
- Scissors
- Scoop or spatula
- Test tube clamp
- Test tube rack
- Test tubes, borosilicate glass, 13 × 100 mm, 3
- Tongs or forceps
- Watch glass, Pyrex®
- Wooden splint

Safety Precautions

Avoid contact between silver nitrate and skin or clothing as it will readily stain skin and clothing brown. Ethyl alcohol is a flammable liquid and a dangerous fire risk. Addition of denaturant makes the alcohol poisonous—it cannot be made nonpoisonous. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure *(Record careful observations in the Data Table for each reaction as it is performed.)*

Reaction #1

Caution: Perform this reaction away from the ethyl alcohol solution—it is flammable.

1. Place about 1 g of sodium bicarbonate in a test tube. Record your observations of the solid before heating.
2. Light the laboratory burner.
3. Holding the test tube with a test tube clamp, heat the solid in the test tube gently in the burner flame for about one minute. Record your observations as the solid is heated.
4. While the solid is heating, light a wooden splint. While continuing to heat the solid, place the burning wooden splint in the mouth of the test tube. Record your observations.
5. While the solid is heating, place a piece of cobalt chloride test paper in the mouth of the test tube. Cobalt chloride test paper is blue when dry, but turns pink when in contact with water or water vapor. Turn off the burner. Record your observations.

Reaction #2

Caution: Perform this reaction away from the ethyl alcohol solution—it is flammable.

6. Obtain a strip of magnesium metal ribbon about two inches in length. Record your observations of the magnesium before burning it.
7. Light the laboratory burner.
8. Hold the piece of magnesium metal ribbon with a pair of tongs. Place the ribbon in the burner flame and allow it to burn. DO NOT LOOK DIRECTLY AT THE BURNING MAGNESIUM! The bright light emitted by the burning magnesium ribbon is UV light which can damage your eyes. Observe by looking slightly to one side and using peripheral vision.
9. When the magnesium metal ribbon is finished burning, place the remains in a watch glass. Turn off the burner.
10. Record your observations of the burned metal ribbon.

Reaction #3

Caution: Perform this reaction away from any open flame.

11. Using a pipet, place about 1 mL of ethyl alcohol in a Pyrex watch glass.
12. Light a butane safety lighter. Bring the flame close to the ethyl alcohol in the watch glass so that the alcohol begins to burn. Allow the ethyl alcohol to burn until it is completely consumed. Do not touch the hot watch glass. Record your observations.

Reaction #4

13. Place a test tube in a test tube rack. Add one pipet-full of a 0.5 M calcium chloride solution to the test tube.
14. Add one pipet-full of a 0.5 M sodium carbonate solution to the test tube. Record your observations.

Reaction #5

Caution: Silver nitrate can stain skin and clothing.

15. Place a test tube in a test tube rack. Fill the test tube about half-full with a 0.5 M silver nitrate solution.
16. Obtain a piece of copper wire about four inches in length. Wrap the wire around a pencil so that it forms a coil. Record your observations of the reactants before mixing.
17. Submerge the coiled copper wire into the silver nitrate solution. Observe for several minutes as the wire reacts with the solution. Record your observations during the reaction and once the reaction is complete.

Name: ________________________________

Chemical Reactions Worksheet

Data Tables

Reaction #1

Observations	
Evidence That a Chemical Reaction Occurred	
Balanced Chemical Equation	
Type of Reaction	

Reaction #2

Observations	
Evidence That a Chemical Reaction Occurred	
Balanced Chemical Equation	
Type of Reaction	

Name: ___________________________________

Data Tables *(continued)*

Reaction #3

Observations	
Evidence That a Chemical Reaction Occurred	
Balanced Chemical Equation	
Type of Reaction	

Reaction #4

Observations	
Evidence That a Chemical Reaction Occurred	
Balanced Chemical Equation	
Type of Reaction	

Name: ______________________________

Data Tables *(continued)*

Reaction #5

Observations	
Evidence That a Chemical Reaction Occurred	
Balanced Chemical Equation	
Type of Reaction	

Post-Lab Questions

1. Do any of the reactions performed in this laboratory activity fall into more than one category of reaction type? If so, which ones? What evidence supports your categorization?

2. For each of the following sets of reactants, (a) predict the products for each chemical reaction, (b) complete and balance each chemical equation using coefficients, and (c) list each reaction type.

Reaction Type

a. ____ $NaOH(aq)$ + ____ $CuSO_4(aq)$ →

b. ____ $CaO(s)$ + ____ $H_2O(l)$ →

c. ____ $Al(s)$ + ____ $O_2(g)$ →

d. ____ $BaCl_2(aq)$ + ____ $Na_2SO_4(aq)$ →

e. ____ $CH_4(g)$ + ____ $O_2(g)$ →

f. ____ $CaCO_3(s)$ →

g. ____ $HCl(aq)$ + ____ $Zn(s)$ →

h. ____ $Cl_2(g)$ + ____ $KBr(aq)$ →

Name: ______________________________

3. For each of the clues listed as evidence of chemical reaction, list a common occurrence that must involve a chemical reaction. For example, when a firefly glows it is giving off light. This emission of light is due to a chemical reaction.

   a. Production or absorption of heat.

   b. Absorption or emission of light.

   c. Production of sound.

   d. Change of color.

   e. Formation of a precipitate.

   f. Release of a gas.

Teacher's Notes
Chemical Reactions

Materials Included in Kit

Calcium chloride solution, 0.5 M, $CaCl_2$, 60 mL
Copper wire, 18 gauge, Cu, 6 ft
Ethyl alcohol, 95%, CH_3CH_2OH, 50 mL
Magnesium metal ribbon, Mg, 3 ft
Silver nitrate solution, 0.5 M, $AgNO_3$, 100 mL
Sodium bicarbonate, $NaHCO_3$, 20 g
Sodium carbonate solution, 0.5 M, Na_2CO_3, 60 mL
Cobalt chloride test paper, 100 strips
Pipets, Beral-type, 45
Test tubes, borosilicate glass, 13 × 100 mm, 45
Wooden splints, 100

Additional Materials Needed (for each lab group)

Balance
Bunsen burner
Butane safety lighter
Graduated cylinder, 10-mL
Scissors
Scoop or spatula
Test tube clamp
Test tube rack
Tongs or forceps
Watch glass, Pyrex®

Safety Precautions

Avoid contact between silver nitrate and skin or clothing as it will readily stain skin and clothing brown. Ethyl alcohol is a flammable liquid and a dangerous fire risk. Addition of denaturant makes the alcohol poisonous—it cannot be made nonpoisonous. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding.

Reactions #1 and #2: Dispose of the heated sodium bicarbonate and the burned magnesium metal ribbon in the trash according to Flinn Suggested Disposal Method #26a.

Reaction #3: Flush any excess ethyl alcohol down the drain according to Flinn Suggested Disposal Method #26b.

Reaction #4: Dispose of the calcium carbonate precipitate in the trash according to Flinn Suggested Disposal Method #26a. Flush the remaining sodium chloride solution down the drain according to Flinn Suggested Disposal Method #26b.

Reaction #5: Dispose of the silver precipitate according to Flinn Suggested Disposal Method #11. Flush the cupric nitrate solution down the drain according to Flinn Suggested Disposal Method #26b.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Tips

- In reaction #1, make sure students look carefully to see the moisture condensing on the inside of the test tube. Handle the test tube carefully—it will be very hot. The cobalt chloride test paper is used to detect water—it is blue when dry, but turns pink when moist.
- In reaction #2, warn students not to look at the bright light given off by the burning magnesium. It is UV light which can harm eyes. Have them observe it by looking slightly to one side and using peripheral vision.
- In reaction #3, use a safety lighter that has a handle and long tip so that students' hands don't get close to the burning alcohol. Let the alcohol burn until the flame goes out so that all the alcohol is consumed. Make sure that no open Bunsen burner flames are nearby when performing reaction #3. Be sure to use a borosilicate (Pyrex®) watch glass so that it does not crack. Warn students that the glass will be hot.
- In reaction #4, encourage students to let the test tube sit so that the white calcium carbonate precipitate has time to fall to the bottom of the test tube. If they check this test tube after performing reaction #5, they will see a little pile of white solid at the bottom of the test tube.
- In reaction #5, after observing the beautiful silver crystals, have students gently tap the test tube on the lab bench so that the newly formed silver falls from the wire to the bottom of the test tube. This will free the surface of the wire so that the reaction can continue. The reaction will proceed for several minutes before the appearance of the blue color in solution.

Sample Data Tables

Reaction #1

Observations	*The sodium bicarbonate is initially a white powder. As it is heated, it jumps around a bit in the test tube. Water vapor can be seen condensing near the mouth of the test tube. When cobalt chloride test paper is held at the mouth of the test tube, it turns from blue to pink, indicating the presence of water vapor. When a burning splint is placed in the mouth of the flask, it is extinguished, indicating the presence of carbon dioxide gas (it's not hydrogen gas since there is no "barking dog" sound).*
Evidence That a Chemical Reaction Occurred	*Heat is produced.*
Balanced Chemical Equation	$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$
Type of Reaction	*Decomposition*

Reaction #2

Observations	*The magnesium metal ribbon is initially silver in color and somewhat shiny. When it is placed in the flame, it burns slowly at first giving off a yellow flame, then bursts into an intensely bright white flame. The bright flame continues for a few seconds. After the bright flame disappears and the ribbon is removed from the flame, it appears dull, gray, and powdery.*
Evidence That a Chemical Reaction Occurred	*Heat is produced; light is given off.*
Balanced Chemical Equation	$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
Type of Reaction	*Synthesis and combustion*

Data Tables *(continued)*

Reaction #3

Observations	*The ethyl alcohol is clear. When a flame is brought near the liquid, it quickly catches on fire. The flame is blue near the surface of the alcohol and yellow-orange towards the tips of the flames. The flame continues to burn until all of the alcohol has been consumed. When the flame goes out, the watch glass is empty (but hot).*
Evidence That a Chemical Reaction Occurred	*Heat is produced; light is given off.*
Balanced Chemical Equation	$CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$
Type of Reaction	*Combustion*

Reaction #4

Observations	*Both solutions are clear initially. When mixed, they immediately form a white, cloudy solution. As the solution sits, white precipitate collects on the bottom of the test tube.*
Evidence That a Chemical Reaction Occurred	*Formation of a precipitate.*
Balanced Chemical Equation	$Na_2CO_3(aq) + CaCl_2(aq) \rightarrow CaCO_3(s) + 2NaCl(aq)$
Type of Reaction	*Double replacement*

Reaction #5

Observations	*The silver nitrate solution is clear initially. Once the copper wire is added to the solution, the reaction begins slowly (over several minutes). The wire begins to accumulate a silver coating. If the test tube is tapped on the lab bench, the silver coating drops to the bottom of the test tube. The solution slowly takes on a blue color as the copper from the wire becomes cupric nitrate.*
Evidence That a Chemical Reaction Occurred	*Color change.*
Balanced Chemical Equation	$Cu(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Cu(NO_3)_2(aq)$
Type of Reaction	*Single replacement*

Answers to Questions

1. Do any of the reactions performed in this laboratory activity fall into more than one category of reaction type? If so, which ones? What evidence supports your categorization?

   Answer: *Yes, reaction #2. The reaction between magnesium and oxygen forms a new product, magnesium oxide, so it is a synthesis reaction. But, magnesium is also being burned in oxygen gas, so it can be classified as a combustion reaction too.*

2. For each of the following sets of reactants, (a) predict the products for each chemical reaction, (b) complete and balance each chemical equation using coefficients, and (c) list each reaction type.

	Reaction Type
A. **2** $NaOH(aq)$ + ____ $CuSO_4(aq) \rightarrow$ *$Na_2SO_4(aq) + Cu(OH)_2(s)$*	*Double replacement*
b. ____ $CaO(s)$ + ____ $H_2O(l) \rightarrow$ *$Ca(OH)_2(s)$*	*Synthesis*
c. **4** $Al(s)$ + **3** $O_2(g) \rightarrow$ *$2\ Al_2O_3(s)$* *Combustion*	*Synthesis*
d. ____ $BaCl_2(aq)$ + ____ $Na_2SO_4(aq) \rightarrow$ *$BaSO_4(s) + 2NaCl(aq)$*	*Double replacement*
e. ____ $CH_4(g)$ + **2** $O_2(g) \rightarrow$ *$CO_2(g) + 2H_2O(g)$*	*Combustion*
f. ____ $CaCO_3(s) \rightarrow$ *$CaO(s) + CO_2(g)$*	*Decomposition*
g. **2** $HCl(aq)$ + ____ $Zn(s) \rightarrow$ *$ZnCl_2(aq) + H_2(g)$*	*Single replacement*
h. ____ $Cl_2(g)$ + **2** $KBr(aq) \rightarrow$ *$2\ KCl(aq) + Br_2(l)$*	*Single replacement*

3. For each of the clues listed as evidence of chemical reaction, list a common occurrence that must involve a chemical reaction. For example, when a firefly glows it is giving off light. This emission of light is due to a chemical reaction.

   Answer: *Student answers will vary. Examples are given below.*

   a. Production or absorption of heat. *A candle burning. Metabolism in our bodies.*

   b. Absorption or emission of light. *Plants must absorb light to carry out photosynthesis. A candle burning.*

   c. Production of sound. *A firecracker. Popcorn popping.*

   d. Change of color. *Corrosion of iron to form rust. Tarnishing of silver.*

   e. Formation of a precipitate. *Soap scum forming on the inside of a tea kettle or a bathtub.*

   f. Release of a gas. *Opening a can of soda releases carbon dixode gas. Intestinal gas after eating fibrous foods such as beans. The bacteria in the large intestine feed off of the undigested fiber and give off gases as by-products. Baking powder and baking soda produce bubbles of carbon dioxide which make a cake or dinner rolls rise in the oven.*

The *Chemical Reactions—Student Laboratory Kit* is available from Flinn Scientific, Inc.

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