Chapter 6.5 - 6.12

Combustion

What chemical reactions are involved when you strike a match? What further reactions happen when the match is brought close to a candle and the wax burns? Chemists use their knowledge of types of reactions to decide on the chemical composition of matches and to explain how these chemicals react (**Figure 1**).

There are different categories of chemical reactions. One possible category is combustion. **Combustion** is the very rapid reaction of a substance with oxygen to produce compounds called oxides. We often call this process burning. One way to represent combustion is using the following word equation:

fuel + oxygen → oxides + energy

Figure 1

A match provides the heat to start the combustion of the wax in the candle.

The energy produced is mainly in the form of heat and light. The fuel can be a variety of elements and compounds.

The most important fuels that we burn are hydrocarbons. Gasoline in our automobiles, natural gas in our home furnaces, kerosene in jet airplanes, and even the candles on a birthday cake are all made of hydrocarbons (**Figure 2**). When these fuels burn, the products are carbon dioxide and water. The word equation for the combustion of a hydrocarbon can be represented as

hydrocarbon + oxygen → carbon dioxide + water vapour + energy

The complete combustion of hydrocarbon fuels results in the production of millions of tonnes of water and carbon dioxide, which are released into the atmosphere. The carbon dioxide that we produce as a society is a significant contributor to the greenhouse effect discussed in Chapter 16. An example of the combustion of hydrocarbons is the burning of butane in a lighter. Butane (C_4H_{10}) is a gas at room temperature, but it is a liquid under pressure.

Figure 2

Jet aircraft engines burn hydrocarbons to produce energy.

When butane is allowed to escape the lighter through a valve and a spark ignites it, the following reaction occurs:

butane + oxygen → carbon dioxide + water + energy

$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$

Did You Know?

Inefficient furnaces, blocked chimneys, and space heaters may produce poisonous carbon monoxide, which does not affect smoke detectors. As a result, many communities now require carbon monoxide detectors in homes.

Incomplete Combustion

Hydrocarbons can also undergo a chemical reaction called **incomplete combustion.** Incomplete combustion occurs when there is not enough oxygen available. Instead of two products, four products are produced: carbon monoxide (CO), carbon (C), carbon dioxide, and water. Carbon monoxide is an odourless, colourless gas that is extremely poisonous. It combines with hemoglobin in the blood to starve the body of oxygen and cause death. The carbon sometimes produced in incomplete combustion is responsible for the black coating (soot) you observe in fireplaces.

Matches and Their Reactions

What reactions occur when a match ignites? The wood of the matchstick itself undergoes combustion to produce carbon dioxide and water vapour. But what reactions happen in the head of the match?

Matches are a complex mixture of chemicals (**Figure 3**). The head of a wooden match is dipped first in paraffin wax (a hydrocarbon) and then into a mixture of glue, colouring, a fuel, and a compound that is a source of oxygen. The fuel is sulfur (S), and the source of oxygen is potassium chlorate ($KClO_3$). Finally, the tip or striking surface is made by dipping the head into another mixture, which consists of more glue, another fuel — called tetraphosphorus trisulfide (P_4S_3) — and powdered glass. The match is ready to strike!

The process that makes matches burn is actually a series of connected reactions that start at the outside of the match and work their way in. Some matches are called "strike-anywhere" matches because that is exactly what you do to light them. When the tip of such a match is rubbed on any rough surface, the frictional heat produced by the powdered glass and glue is enough to ignite the tetraphosphorus trisulfide fuel as it reacts with oxygen from the air in the following reaction:

(1) $P_4S_3 + 6O_2 \rightarrow P_4O_6 + 3SO_2$ + heat

The heat that is produced causes the potassium chlorate in the next layer to break apart to form smaller molecules:

(2) $2KClO_3 \rightarrow 2KCl + 3O_2$

This oxygen gas, in combination with the heat from the first reaction, causes the sulfur to catch fire:

(3) $S + O_2 \rightarrow SO_2$ + heat

The heat from this reaction ignites the paraffin wax, which is a mixture of hydrocarbons:

(4) hydrocarbons + $O_2 \rightarrow CO_2 + H_2O$ + heat

The burning paraffin sets the wood of the match on fire in a remarkable series of reactions. No wonder the match lights!

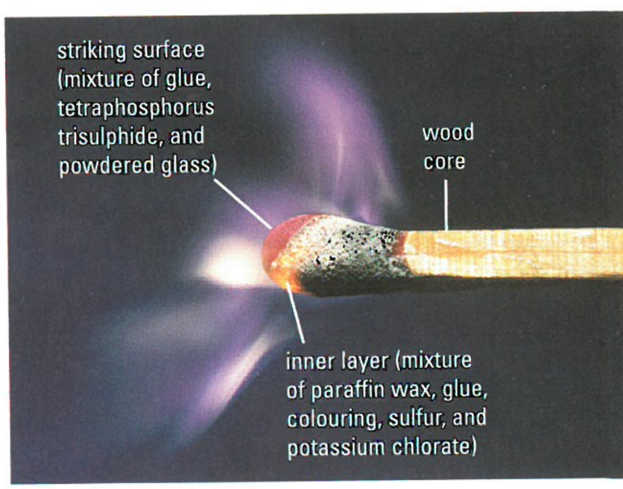

Figure 3

Matches are made in a series of layers of chemical mixtures

Safety matches are similar to "strike-anywhere" matches, except that the match must be struck on the matchbook cover (**Figure 4**). The inner layers of the safety match are similar to those of the "strike-anywhere" match, except that cardboard is used instead of wood for the core of the match. The striking surface is a layer of red phosphorus, powdered glass, and glue. The frictional heat produced by rubbing the match on the matchbook surface changes the red phosphorus to a different form of phosphorus, called white phosphorus, which then ignites spontaneously in air:

(5) P_4 (red) $\rightarrow$ P_4 (white)

(6) P_4 (white) + $5O_2 \rightarrow P_4O_{10}$ + heat

This heat is sufficient to set the rest of the match on fire.

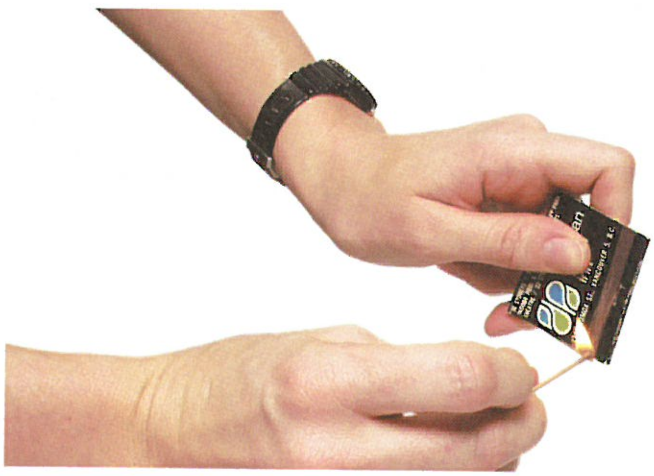

Figure 4

Safety matches can be struck only on the matchbook surface.

Challenge

2,3 How are complete and incomplete combustion involved in your Challenge?

Understanding Concepts

1. What is the meaning of the term "combustion"?
2. Describe the series of steps that result in the ignition of a match in a flow chart. Make sure you include heat and all the various materials in the appropriate steps.
3. Write word equations to represent the complete and incomplete combustion of propane, a fuel used in stoves and home heating.
4. Write balanced chemical equations for the reactions in question 3, given that the chemical formula of propane is C_3H_8.
5. **(a)** How are complete and incomplete combustion different?

   (b) Explain how both complete and incomplete combustion can pose environmental hazards.
6. Why should automobiles and gas barbecues never be operated in enclosed spaces like garages?
7. Canoeists going on long trips in the wilderness depend on matches for campfires. Some of them specially treat their matches by dipping the whole match in liquid paraffin, which hardens to a solid waxy coating. Why do they do this? Do you think it is an effective method? Explain.
8. One of the ways to understand chemical reactions is to categorize reactions that have similarities.

   (a) Why might you group reactions (3) and (6) together?

   (b) In what way is reaction (2) the opposite of reactions (3) and (6)?

Making Connections

9. Draw a labelled diagram showing how burning fossil fuels might lead to global warming.

Work the Web

Where do the chemicals used in matches come from? Are there any significant environmental concerns around match production? Research and report on match production by visiting www.science.nelson.com and following the Science 10, 6.6 links.

Types of Chemical Reactions: Synthesis and Decomposition

Imagine that you are baking some cookies at home and have decided to modify a recipe for oatmeal raisin cookies. You know that there are patterns in the ways that certain ingredients go together so you make a new recipe by substituting dried cranberries for raisins and cornmeal for oatmeal (**Figure 1**).

Just as a cook knows how ingredients will work together in a recipe, so a chemist knows that elements and compounds undergo particular types of chemical reactions. You know that elements can be classified into different chemical families. All members of a chemical family react in a similar way. For example, alkali metals behave in similar ways in chemical reactions. Compounds can also be classified as ionic or molecular, and have definite patterns of chemical properties.

Chemists use these patterns to classify groups of chemical changes. Most chemical reactions can be grouped into four categories:

- synthesis
- decomposition
- single displacement
- double displacement

Knowledge of these types of reactions is useful for two reasons. Firstly, we can better understand experimental observations of the behaviour of substances in chemical changes. Secondly, we can predict the products of unknown reactions.

Look at the reactants represented in **Figure 2**. Which reaction involves elements as reactants? Which reaction involves compounds as reactants? Recognizing the types of reactants is the key to identifying the reaction type. First we will look at two of the reaction types: synthesis and decomposition.

Figure 1

Baking cookies involves mixing a number of ingredients.

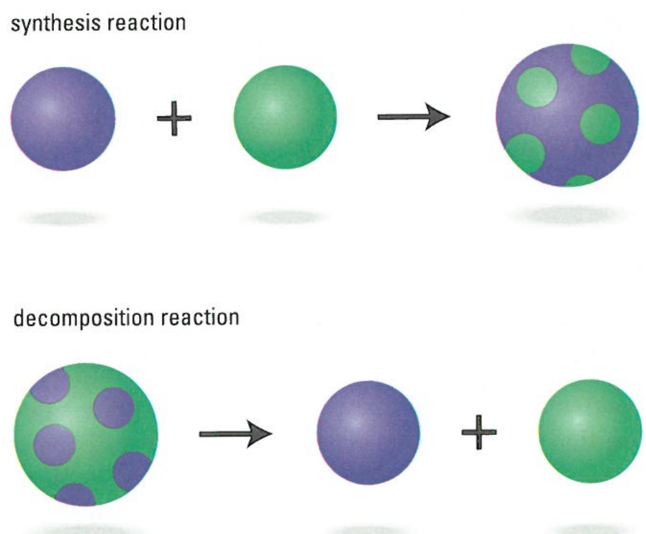

Figure 2

A synthesis reaction involves the combination of smaller molecules. A decomposition reaction involves the breaking apart of larger molecules.

Synthesis Reactions

Synthesis reactions involve the combination of smaller atoms and/or molecules into larger molecules. These reactions are also called **combination reactions**. Often the reactants are elements that combine chemically to form compounds. Synthesis reactions have the following general formula:

$$A + B \rightarrow AB$$

If you see two elements as reactants, you know the reaction has to be a synthesis reaction. Most of these elements are represented as single atoms, but some elements occur naturally as diatomic molecules (**Table 1**). For example, when hydrogen and oxygen gases react, the product is the compound water. This reaction can be represented as word, skeleton, and chemical equations:

hydrogen + oxygen → water

$$H_2 + O_2 \rightarrow H_2O$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

Table 1 Elements That Occur as Diatomic Molecules

Element	Diatomic molecule
hydrogen	H_2
oxygen	O_2
nitrogen	N_2
fluorine	F_2
chlorine	Cl_2
bromine	Br_2
iodine	I_2

Synthesis reactions can also involve combinations of small molecules. For example, when ammonia and hydrogen chloride vapours combine, they form a white smoke as solid particles of ammonium chloride are formed (**Figure 3**):

hydrogen chloride + ammonia → ammonium chloride

$$HCl + NH_3 \rightarrow NH_4Cl$$

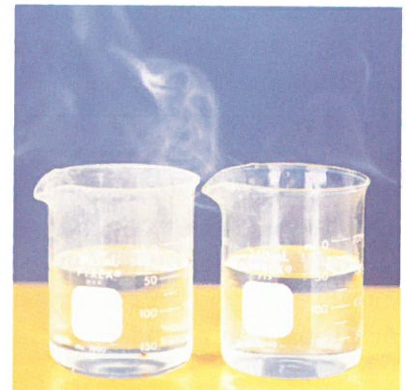

Figure 3

Ammonia and hydrogen chloride vapours combine in a synthesis reaction.

Similarly, the combination of water and carbon dioxide molecules to form carbonic acid is a synthesis reaction. The chemical equation for this reaction is

$$CO_2 + H_2O \rightarrow H_2CO_{3(aq)}$$

Normal rainwater is acidic because of this reaction (**Figure 4**). Acids will be discussed in more detail in Chapter 8.

Figure 4

Normal rainwater contains carbonic acid because of the synthesis reaction between carbon dioxide and water.

Decomposition Reactions

Decomposition reactions involve the splitting of a large molecule into elements or smaller molecules. Decomposition reactions have the following general formula:

$$AB \rightarrow A + B$$

If you see a binary compound (one made up of only two elements) as the only reactant, you know that the reaction has to be a decomposition reaction that produces two elements as products. For example, the electrolysis of water uses electricity to split water molecules into their elements. This reaction can be represented as word, skeleton, and chemical equations:

water → hydrogen + oxygen

$$H_2O \rightarrow H_2 + O_2$$

$$2H_2O \rightarrow 2H_2 + O_2$$

Sometimes decomposition reactions can involve large amounts of energy (**Figure 5**). Nitrogen triiodide decomposes rapidly to form the elements nitrogen and iodine. This decomposition reaction can be represented by the following word, skeleton, and chemical equations:

nitrogen triiodide → nitrogen + iodine

$$NI_3 \rightarrow N_2 + I_2$$
$$2NI_3 \rightarrow N_2 + 3I_2$$

Decomposition reactions can also involve the production of two small molecules from a large molecule. For example, when ammonium nitrate is heated to above 250°C, it decomposes explosively to form nitrous oxide and water molecules. This reaction can be written as the following word, skeleton, and chemical equations:

ammonium nitrate → nitrous oxide + water

$$NH_4NO_3 \rightarrow N_2O + H_2O$$
$$NH_4NO_3 \rightarrow N_2O + 2H_2O$$

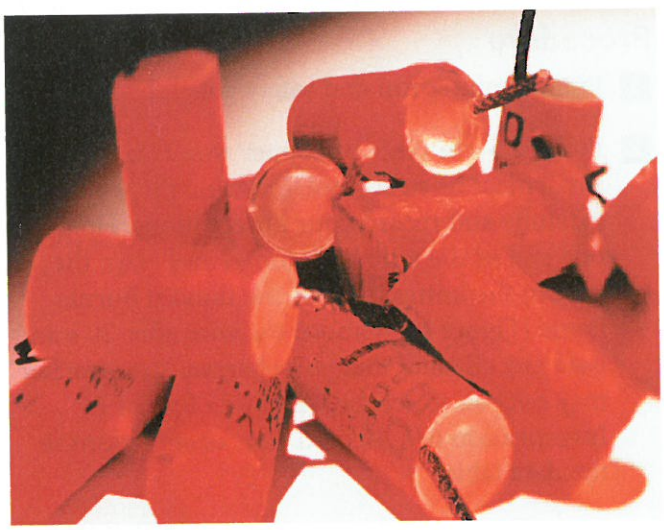

Figure 5

Nitroglycerine, the active chemical in dynamite, is an unstable compound. Its decomposition reaction is violent and results in the formation of carbon dioxide, water vapour, and molecular nitrogen and oxygen.

Work the Web

Visit the Nelson web site at www.science.nelson.com. Follow the Science 10, 6.7 links to web sites that show examples of synthesis and decomposition reactions. Report on three reactions, including balanced chemical equations.

Challenge

1 What synthesis or decomposition reactions are involved in the production of your consumer product?

Understanding Concepts

1. Why are synthesis and decomposition reactions sometimes described as opposite reactions? Explain with an example.
2. Classify each of the following reactions as either a synthesis reaction or a decomposition reaction:
   (a) iron + oxygen → iron(III) oxide
   (b) sodium iodide → sodium + iodine
   (c) hydrogen + oxygen → water vapour
   (d) zinc carbonate → zinc oxide + carbon dioxide
3. Write skeleton equations for each of the equations in question 2.
4. Balance each of the skeleton equations in question 3.
5. When water is electrolyzed, two gases are produced. As indicated in the chemical equation, twice the volume of one gas is produced compared to the other.
   (a) Which gas is produced in larger quantities? Explain.
   (b) How would you test the gases to confirm your choice?
6. Polymers are long-chain molecules that are made up of many smaller repeating units called monomers. For example, polyethylene is made up of hundreds of ethylene molecules linked together. What kind of reaction is polymerization? Explain, and write a word equation to illustrate.

6.8 Investigation

INQUIRY SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ○ Evaluating
- ● Communicating

Putting Things Together

A synthesis reaction involves the direct combination of two substances to produce one new substance. In this investigation, you will have the opportunity to observe synthesis (combination) reactions. Some synthesis reactions will involve elements, while others will involve small molecules combining to make a larger molecule. For example, one of the compounds that you will produce is a hydrate. A **hydrate** is a solid compound in which water molecules are part of the solid crystalline structure. For example, the formula of cobalt chloride dihydrate is $CoCl_2{\cdot}2H_2O$. The crystalline form of cobalt chloride that does not contain these water molecules is called anhydrous cobalt chloride and has the formula $CoCl_2$. Another example of a hydrate is copper(II) sulfate pentahydrate, or $CuSO_4{\cdot}5H_2O$.

Question

What are some examples of synthesis reactions?

Prediction

(a) Write word equations for the expected reactions in air of magnesium and copper.
(b) What would you expect to happen when water combines with anhydrous copper(II) sulfate?

Design

You will react various elements and compounds in air to form new compounds.

(c) Make a table to record all your observations. There should be four columns: *Starting material, Appearance of starting material, Observations during change*, and *Appearance of products*.

Materials

- apron
- safety goggles
- steel wool
- tongs
- magnesium ribbon (approximately 5 cm)
- large beaker
- anhydrous copper(II) sulfate
- eyedropper
- copper wire (approximately 5 cm, 1 mm in diameter)
- Bunsen burner
- watch glass
- water
- copper(II) sulfate pentahydrate (bluestone)

Procedure

1 Put on your apron and safety goggles.

2 Polish a 5-cm piece of copper wire (Cu) with a small piece of steel wool. Examine the wire carefully and record your observations. Hold one end of the wire with tongs, and place the wire in the hottest part of the Bunsen burner flame (**Figure 1**). Remove the wire after 20 s and note any changes that you observe. Your teacher may ask you to set the wire aside for use in Investigation 6.9. Record your observations in the data table.

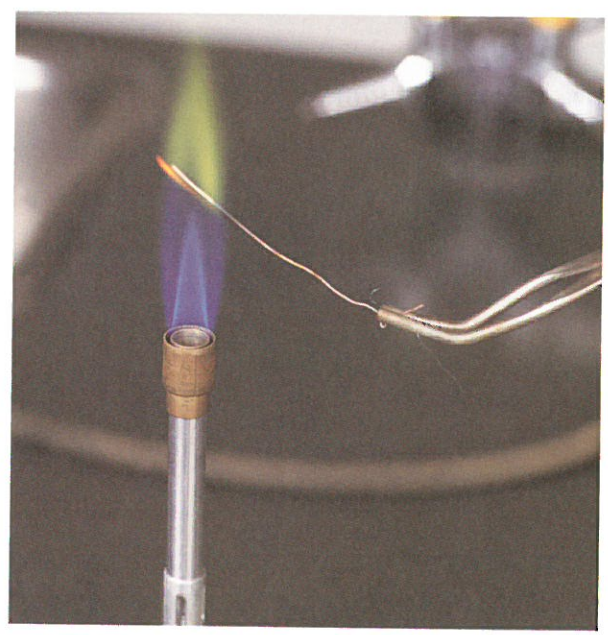

Figure 1

3 Repeat step 2 using a piece of magnesium ribbon (Mg), but remove the ribbon from the flame as soon as the reaction starts (**Figure 2**) and move the magnesium to a large empty beaker. Record your observations.

This demonstration should take place under a fume hood. Long hair should be tied back and loose clothing should be avoided when burning metals. Do not look directly at the piece of magnesium when it reacts.

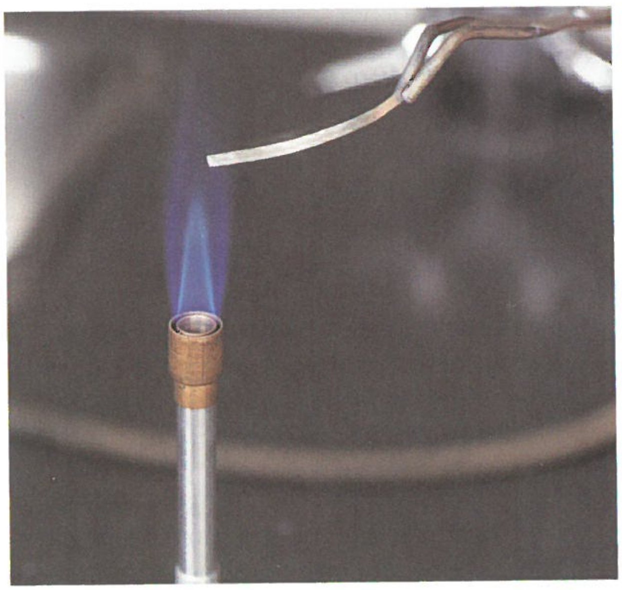

Figure 2

4 Place about 1 g of anhydrous copper(II) sulfate ($CuSO_4$) on a watch glass. Using an eyedropper, add a single drop of water to the powder. Compare the product to a small sample of copper(II) sulfate pentahydrate (bluestone) that your teacher may make available. Record your observations.

Copper(II) sulfate is poisonous and is an irritant. Report any spills to your teacher.

Analysis

(d) For each reaction, what evidence is there that a chemical change occurred?

(e) For each reaction, what evidence did you have that a synthesis reaction occurred?

(f) When the copper was heated, what gas did it combine with? Suggest a name for the product.

(g) When the magnesium burned, what gas did it combine with? Suggest a name for the product.

(h) What evidence was there that a synthesis reaction occurred when water was added to the anhydrous copper(II) sulfate?

(i) Summarize the three reactions as sentences, as word equations, and as balanced chemical equations.

Understanding Concepts

1. In your own words, explain what is meant by synthesis.
2. **(a)** What is another name for synthesis reactions that involve oxygen?
   (b) What are the names of the kinds of compounds that are produced in these reactions?
3. Was it appropriate to label your table's first two columns *Starting material* and *Appearance of starting material?* Suggest better headings for these columns.
4. Examine the reactions described in section 6.6. Which of these reactions could clearly be described as synthesis reactions? Explain.

Reflecting

5. Write a few sentences to complete the following phrase: "A question that this activity raised in my mind was...."

Work the Web

Visit www.science.nelson.com and follow the Science 10, 6.8 links to web sites that deal with fuel cells. Classify the reactions that occur in fuel cells by their type.

6.9 Investigation

INQUIRY SKILLS MENU

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ○ Communicating

Taking Things Apart

A decomposition reaction involves the breaking up of a compound into simpler substances. It is exactly the reverse of a synthesis reaction. In this investigation, you will observe the decomposition of compounds to form smaller molecules, including some common gases. For example, when cobalt chloride dihydrate ($CoCl_2 \cdot 2H_2O$) is heated, the water molecules are lost and the product is anhydrous cobalt chloride ($CoCl_2$).

Question

What are the products of the decomposition of some compounds?

Prediction

(a) What gases would you expect to be produced when hydrogen peroxide (H_2O_2), copper(II) carbonate ($CuCO_3$), and copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) decompose.

(b) What tests would you perform to test for these gases?

Design

You will decompose some compounds using heat, electricity, or another chemical substance.

(c) Make a table to record all your observations. For each reaction, there should be four columns.

Materials

- apron
- safety goggles
- scoopula
- copper(II) carbonate
- 4 test tubes (25 × 200 mm)
- test-tube holder
- test-tube rack
- Bunsen burner
- retort stand
- limewater (calcium hydroxide) solution
- anhydrous copper(II) sulfate
- wooden splint
- rubber stopper to fit test tube
- previously heated piece of copper wire from Investigation 6.8
- copper(II) sulfate pentahydrate (bluestone)
- cobalt chloride test paper
- 3% hydrogen peroxide solution
- manganese dioxide

Procedure

Part 1: Decomposition of a Carbonate

1. Put on your apron and safety goggles.
2. Using a scoopula, add one or two scoops of copper(II) carbonate to a test tube. Make certain that the copper(II) carbonate lies along the side of the large-angled test tube and does not remain at the bottom. Assemble the equipment as shown in **Figure 1**. The test tube should be mounted about 20° above horizontal.

Figure 1

3. Gently heat the test tube, making sure to distribute the heat evenly along the side of the tube underneath the copper(II) carbonate. Record your observations.
4. Obtain a second test tube roughly half-full of limewater solution. As you start to see changes in the copper(II) carbonate, position the second test tube so that any gas produced in the reaction can "flow" into the second tube. After about 60 s, stopper the test tube and shake its contents. Record your observations.
5. Continue heating for several minutes, and observe the contents of the test tube. Compare the appearance of the product in the test tube with a previously heated piece of copper wire. Record your observations.

Part 2: Decomposition of a Hydrate

6 Repeat step 2 using copper(II) sulfate pentahydrate (bluestone).

> Copper(II) sulfate pentahydrate (bluestone) is toxic if ingested and is an irritant.
> Copper(II) carbonate, anhydrous copper(II) sulfate, and manganese dioxide are toxic. Report any spills to your teacher.

7 Gently heat the test tube, making sure to distribute the heat evenly along the side of the test tube underneath the bluestone until a change occurs. Compare the product to a small sample of anhydrous copper(II) sulfate. If you see droplets of liquid near the top of the test tube, test them with cobalt chloride test paper. Record your observations.

Part 3: Decomposition of Hydrogen Peroxide

8 Place a test tube in a test-tube rack. Pour 3% hydrogen peroxide solution into the test tube to a depth of about 3 cm.

> Hydrogen peroxide is poisonous and a strong irritant. Report any spills to your teacher.

9 Add a small amount of manganese dioxide (enough to cover the tip of a wooden splint) to the test tube. Note any changes that occur. Put a glowing (not flaming) splint into the mouth of the test tube to test the gas produced. Record your observations.

10 Dispose of the mixtures in the test tubes and put away your materials as instructed by your teacher. Clean up your work station. Wash your hands.

Analysis and Evaluation

(d) For each reaction, what evidence is there that a chemical change occurred?

(e) For each reaction, what evidence did you have that a decomposition reaction occurred?

(f) What solid ionic compound was formed when copper(II) carbonate was heated? What gaseous molecular compound was formed at the same time?

(g) What ionic compound was formed when bluestone was heated? What molecular compound was produced at the same time?

(h) What gas was produced when manganese dioxide was added to hydrogen peroxide solution?

(i) What gases did you test for in this investigation? How successful were the tests?

(j) Suggest ways to improve the design of this investigation.

(k) Summarize the three reactions as sentences, as word equations, and as balanced chemical equations.

Understanding Concepts

1. Some chemical reactions can be reversed. Give an example of a reversible chemical reaction that you encountered in the past two investigations.
2. Sometimes a substance can be used to speed up a reaction without itself being consumed. Name the substance that performed this function in this investigation.
3. When hydrogen peroxide antiseptic is tightly capped and left on the shelf for a long period of time, the bottle is observed to swell. When opened, it "hisses" noticeably. Explain these observations. Is the antiseptic likely to be as effective?
4. Suggest a reason why hydrogen peroxide is not sold in clear bottles, and why it should be stored in a cool place.

Reflecting

5. Write a few sentences to complete the following phrase: "Something that captured my attention in this investigation was...."

6.10

Types of Chemical Reactions: Single and Double Displacement

You have investigated synthesis reactions, in which elements were "put together." You have also looked at some decomposition reactions where a compound was "taken apart." What happens when an element and a compound combine in a chemical reaction? What happens when two ionic compounds react with each other? In this lesson, you will learn to recognize displacement reactions and to predict the products that they form in chemical changes. The general pattern of displacement reactions is shown in **Figure 1**. In each type of displacement reaction, atoms are recombined to form new compounds.

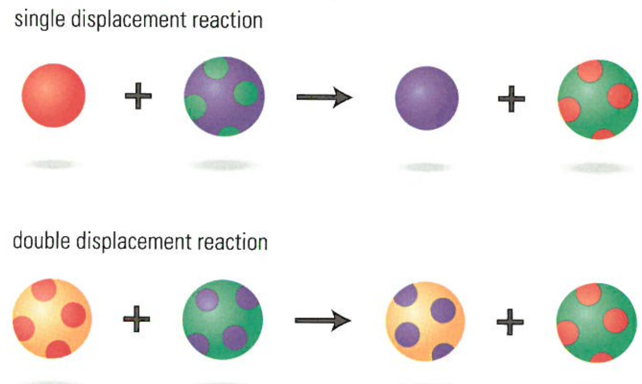

Figure 1

In single displacement reactions, an element takes the place of another element in a compound. In double displacement reactions, elements in two compounds "change partners."

Single Displacement Reactions

Single displacement reactions are chemical changes that involve an element and a compound as reactants. One element displaces or replaces another element from a compound. For example, consider the reaction that occurs when a coil of magnesium ribbon is placed in a solution of silver nitrate (**Figure 2**). This reaction can be represented as the following word, skeleton, and chemical equations:

magnesium + silver nitrate → silver + magnesium nitrate

$$Mg + AgNO_3 \rightarrow Ag + Mg(NO_3)_2$$

$$Mg + 2AgNO_3 \rightarrow 2Ag + Mg(NO_3)_2$$

Figure 2

Magnesium ribbon placed in a solution of silver nitrate rapidly displaces the silver because it combines with the nitrate group to form magnesium nitrate. The deposit formed is metallic silver.

Consider another reaction — one that occurs when the element bromine is added to a solution of calcium iodide. We say that bromine displaces (or takes the place of) the iodide ion. Remember that elements such as bromine and iodine exist as diatomic molecules (refer to section 6.7, **Table 1**). The word and chemical equations for this reaction are

bromine + calcium iodide → iodine + calcium bromide

$$Br_2 + CaI_2 \rightarrow I_2 + CaBr_2$$

Single displacement reactions have the following general formula:

$$Z + AB \rightarrow ZB + A$$

However, this general formula can also be written as follows:

$$Y + AB \rightarrow AY + B$$

In the first case, the metal Z has taken the place of element A. In the second case, the nonmetal Y has taken the place of element B.

Work the Web

One way that displacement reactions may be applied is in the process of refining metals such as aluminum and copper from their minerals. Visit the Nelson web site at www.science.nelson.com. Follow the Science 10, 6.10 links to find out more about this process.

How do we decide which element is displaced? Our knowledge of the periodic properties and naming of compounds can help. Metals are found on the left and centre of the periodic table. Nonmetals are found on the right side of the periodic table. In deciding which element is replaced, we use the general rule of metal replacing metal and nonmetal replacing nonmetal.

In the first example reaction, silver and magnesium are both metals and have positive ionic charges, or valences. The magnesium displaces the silver and forms a compound of magnesium nitrate, which remains dissolved in solution as the solid silver appears. In the second example reaction, bromine and iodine are both nonmetals in the same chemical family. They also have negative ionic charges, or valences, when they form compounds. Thus, bromine displaces iodine rather than the metal calcium.

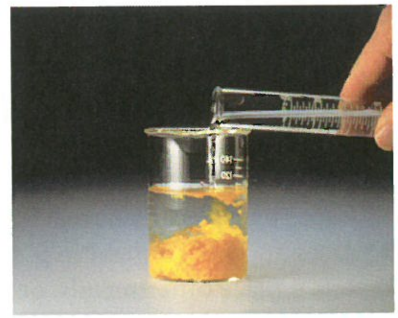

Figure 3

When lead(II) nitrate and potassium iodide solutions are mixed, a yellow precipitate of lead(II) iodide forms.

Double Displacement Reactions

Double displacement reactions occur when elements in different compounds displace each other or exchange places. For example, the reaction of solutions of lead(II) nitrate and potassium iodide is shown in **Figure 3**. This reaction can be represented in the following word, skeleton, and chemical equations:

lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

$$Pb(NO_3)_2 + KI \rightarrow PbI_2 + KNO_3$$

$$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$$

Both lead(II) nitrate and potassium iodide are ionic solids, and both are very soluble in water. When lead(II) nitrate is dissolved, it forms lead and nitrate ions. When potassium iodide is dissolved in water, it separates into potassium and iodide ions. When the two solutions are combined, lead ions from the lead(II) nitrate solution and iodide ions from the potassium iodide solution form the solid lead(II) iodide precipitate. Lead(II) iodide remains a solid because it will not dissolve in water. The potassium and nitrate ions will remain in solution as long as water is present because the compound potassium nitrate is highly soluble in water. As a result, this double displacement reaction is sometimes written as

$$Pb(NO_3)_{2(aq)} + 2KI_{(aq)} \rightarrow PbI_{2(s)} + 2KNO_{3(aq)}$$

where (aq) represents an aqueous (or water) solution, and (s) represents a solid.

Double displacement reactions have the following general formula:

$$AB + XY \rightarrow AY + XB$$

where A and X are metallic elements and B and Y are nonmetallic elements. During the reaction, B and Y (or A and X) exchange places.

Challenge

1 What displacement reactions are involved in the production of your product?

Understanding Concepts

1. Consider the four types of reactions you have learned about so far. They all involve elements and compounds as reactants. Which type of reaction has as reactant(s)
   (a) two compounds?
   (b) one element and one compound?
   (c) two elements?
   (d) one compound?
2. Classify each of the following reactions:
   (a) copper + silver nitrate → silver + copper(II) nitrate
   (b) zinc + hydrochloric acid → hydrogen + zinc chloride
   (c) calcium carbonate + hydrochloric acid → carbonic acid + calcium chloride
   (d) aluminum + copper(II) chloride → copper + aluminum chloride
3. Write a skeleton equation and a balanced equation for each reaction in question 2.

Making Connections

4. You work for a company with a large quantity of silver nitrate solution. It wants to recover and sell the silver metal. Design a process to recover the silver metal from solution.

6.11 Investigation

INQUIRY SKILLS MENU

○ Questioning	○ Planning	● Analyzing
○ Hypothesizing	● Conducting	● Evaluating
● Predicting	● Recording	○ Communicating

Single Displacement Reactions

In a single displacement reaction, one element replaces another element in a compound. Generally, metals replace other metals, or nonmetals replace other nonmetals. For example, the metal zinc replaces the metal silver from silver nitrate, and fluorine replaces bromine from sodium bromide. A single displacement reaction is also referred to as a substitution reaction. In this investigation, you will observe reactions in which one element takes the place of another element in a compound. The compounds, which may also be referred to as salts, will generally be dissolved in water.

Question

What are the products when an element reacts with a compound that has been dissolved in a solvent?

Prediction

Write word equations predicting the products of the following reactions:

(a) magnesium reacts with sulfuric acid,
(b) magnesium reacts with zinc chloride,
(c) magnesium reacts with copper(II) chloride,
(d) chlorine reacts with potassium bromide, and
(e) chlorine reacts with potassium iodide.

(*Hint*: Think of sulfuric acid as hydrogen sulfate when trying to predict the name of one of the products.)

Design

You will react a metal with an acid and a metal with two solutions of salts.

(f) Make a table to record all your observations. For each reaction, there should be three columns: *Appearance of starting materials*, *Observations during change*, and *Appearance of products*.

Materials

- apron
- safety goggles
- 3 test tubes
- test-tube rack
- sulfuric acid solution (5% or 1.0 mol/L)
- magnesium pieces (turnings)
- wooden splint
- magnesium ribbon
- steel wool or sandpaper
- microtray
- zinc chloride solution (2% or 0.2 mol/L)
- copper(II) chloride solution (2% or 0.2 mol/L)

The chemicals in this investigation are toxic. Some are also irritants.
Sulfuric acid is corrosive. There is risk of eye and skin damage.
Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water. Report any spills to your teacher.

Procedure

Part 1: Metals and Acid

1. Put on your apron and safety goggles.
2. Add sulfuric acid to a test tube to a depth of about 2 cm.

Add a 2- to 3-cm piece of magnesium to the test tube. Observe the reaction and test the gas produced with a burning splint (**Figure 1**). Record your observations in the data table.

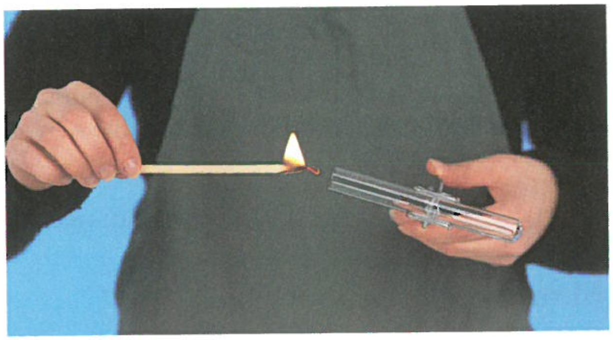

Figure 1

When testing for gases, point the mouth of the test tube away from yourself and other people.

Part 2: Metals and Salt Solutions

4 Clean two strips of magnesium ribbon, approximately 2 cm in length, with steel wool (or sandpaper) until shiny. Half-fill a microtray well with zinc chloride solution. Place one strip of magnesium in the well, as shown in **Figure 2**. Observe the reaction for several minutes then record your observations.

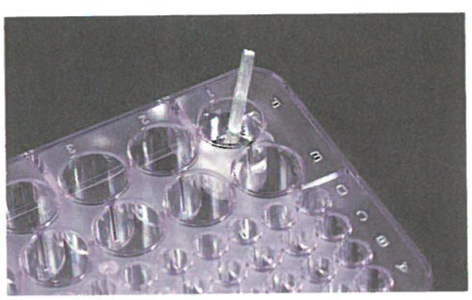

Figure 2

5 Repeat step 4, adding the second piece of magnesium to a well containing copper(II) chloride solution. Observe for several minutes and record your observations in the data table.

6 Dispose of the mixtures and put away your materials as instructed by your teacher. Clean up your work station. Wash your hands.

Analysis and Evaluation

(g) For each reaction, what evidence is there that a chemical change occurred?

(h) What gas was produced when magnesium and sulfuric acid reacted?

(i) What metals were produced when magnesium was added to the salt solutions?

(j) Look back at your predictions. Do you think they were correct? Make any necessary corrections.

(k) What are some sources of error in this investigation?

Understanding Concepts

1. What are single displacement reactions?
2. What happens when a metal is added to the solution of an ionic compound? Explain with an example.
3. Write word equations for all the reactions that occurred.
4. Write balanced chemical equations for all the reactions that occurred.
5. Predict the products of the single displacement reactions that occur when
   (a) magnesium is added to hydrochloric acid (HCl);
   (b) zinc is added to copper(II) sulfate solution; and
   (c) bromine is added to sodium iodide solution.
6. Write word equations to represent the reactions in question 5.
7. Write balanced chemical equations for the reactions in question 5.

Reflecting

8. Write a short paragraph to complete the following phrase: "What I learned from doing this lab was...."

6.12 Investigation

INQUIRY SKILLS MENU

- ○ Questioning
- ● Hypothesizing
- ● Predicting
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ○ Communicating

Double Displacement Reactions

A double displacement reaction, sometimes called a double decomposition reaction, involves the reaction of two compounds to form two new compounds. In effect, the compounds change partners with each other. Sometimes, if the reactions occur in solution, an insoluble product called a precipitate may form (**Figure 1**).

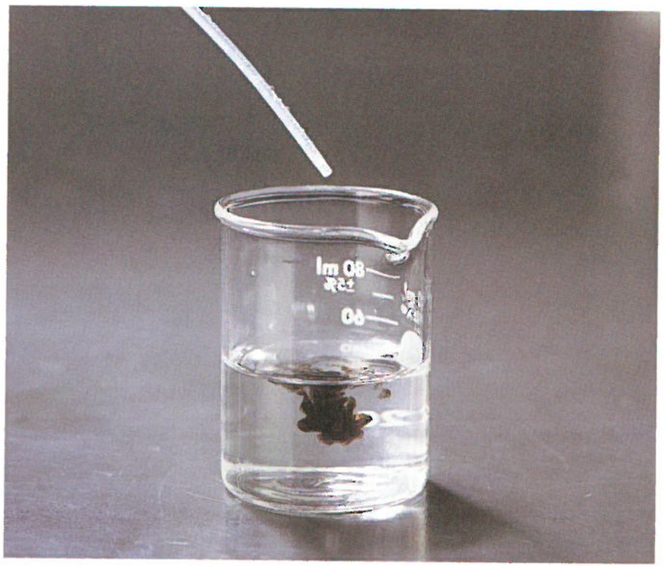

Figure 1

When lead(II) nitrate and sodium sulfide solutions are mixed, a precipitate of lead(II) sulfide is formed. Sodium nitrate remains dissolved in the water.

Question

What are the products when pairs of compounds react in double displacement reactions?

Prediction

Write word equations for the predicted products of the following reactions:

(a) sodium chloride and silver nitrate,
(b) silver nitrate and potassium iodide,
(c) iron(III) chloride and sodium hydroxide,
(d) sodium chloride and potassium nitrate, and
(e) sodium carbonate and calcium chloride.

Design

You will use microdroppers and a microtray to combine clear solutions of various compounds. If a precipitate forms in a solution, you will have evidence that a double replacement reaction has occurred.

(f) Make a table to record your observations.

Materials

- apron
- safety goggles
- microtray
- 8 labelled microdroppers
- sodium chloride solution (1% or 0.1 mol/L)
- silver nitrate solution (1% or 0.1 mol/L)
- potassium iodide solution (1% or 0.1 mol/L)
- iron(III) chloride solution (1% or 0.1 mol/L)
- sodium hydroxide solution (1% or 0.1 mol/L)
- potassium nitrate solution (1% or 0.1 mol/L)
- sodium carbonate solution (1% or 0.1 mol/L)
- calcium chloride solution (1% or 0.1 mol/L)

Silver nitrate solution is toxic and can stain skin and clothing. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water.

Iron(III) chloride is a strong irritant, corrosive, and toxic. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water. Report any spills to your teacher.

Sodium hydroxide is corrosive. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water. Report any spills to your teacher.

Procedure

1 Put on your apron and safety goggles.

2 Add two or three drops of sodium chloride to one of the wells on the microtray using the labelled microdropper. Add two or three drops of silver nitrate solution to the same well, using a second labelled microdropper (**Figure 2**). Record your observations, noting the appearance and colour of any product.

Figure 2

Avoid cross-contamination of microdroppers and solutions; let solutions "free-fall" into the microtray wells rather than touching the dropper to the microtray.

3 Repeat step 2 using the other labelled microdroppers and solutions as follows: silver nitrate and potassium iodide; iron(III) chloride and sodium hydroxide; sodium chloride and potassium nitrate; and sodium carbonate and calcium chloride.

4 Dispose of the mixtures in the microtrays, and clean and put away your materials as instructed by your teacher. Clean up your work station. Wash your hands.

Analysis and Evaluation

(g) What evidence was there that a chemical reaction occurred? Did a reaction occur in every combination of solutions? Explain.

(h) What were some sources of error in this experiment?

(i) One of the combinations of solutions did not produce any visible change. Can we conclude that no reaction occurred? Explain.

(j) Look back at your predictions and make any necessary changes.

Understanding Concepts

1. **(a)** What is a double displacement reaction?
   (b) How is it different from a single displacement reaction?
2. Write word equations for all the reactions that occurred in this investigation.
3. Use your knowledge of ionic charges to write a skeleton equation for each of the reactions in question 2.
4. Write balanced chemical equations for each of the skeleton equations in question 3.

Exploring

5. Hard water contains calcium, magnesium, and iron ions that can be removed by precipitation. Find out how water can be softened and write a report to explain the process. Include any significant health concerns regarding chemically softened water.
6. Many of the reactions that you observed in this investigation formed precipitates in solution. How could you decide which of the two possible products was the precipitate? Design an experimental procedure to answer this question. Most chemistry textbooks have "solubility tables" that may help you with this process.

6.13 Activity

Putting It All Together

You have learned that chemical reactions can be grouped into various categories. The system we have used looks at the reactants. Are they elements or compounds? Are they metals or nonmetals? In this activity, you will make a graphic organizer to summarize your knowledge of the types of chemical reactions.

Materials

- scissors
- paper
- coloured markers
- glue stick

Procedure

1 (X) Your teacher will put you into cooperative groups. Your teacher may also decide to assign you specific roles, such as Writer, Textbook Resource, or Materials Manager.

2 Cut out 30 small pieces of paper, each roughly a 2-cm × 4-cm rectangle. Write the following words on the rectangles, using your choice of appropriate coloured markers:

- "element" on 6 rectangles
- "compound" on 12 rectangles
- "smaller compound" on 4 rectangles
- "larger compound" on 2 rectangles
- "metal" on 2 rectangles
- "nonmetal" on 4 rectangles

(a) What are the meanings of the terms "element" and "compound"?
(b) What are several examples of elements and compounds?
(c) What are the meanings of the terms "metal" and "nonmetal"?
(d) What are several examples of metals and nonmetals?

3 Cut out 8 smaller rectangles, and draw an arrow on each rectangle. This arrow links reactants and products in chemical equations. Cut out 12 to 15 very small squares on which you can write a plus (+) sign to use in building some equations.

4 Review the four types of chemical reactions that you have encountered in this chapter. Cut out 4 large rectangles; on each of these rectangles, write in block capitals the name of one type of reaction (Synthesis, Decomposition, Single Displacement, or Double Displacement).

5 Write the heading "Types of Chemical Reactions" on a piece of paper. Place the labels for the types of reactions in different areas of the sheet. For example, below the "Synthesis" label, place words in different combinations that summarize the information you have learned about synthesis reactions (**Figure 1**). Make sure you leave some space underneath each of the labels.

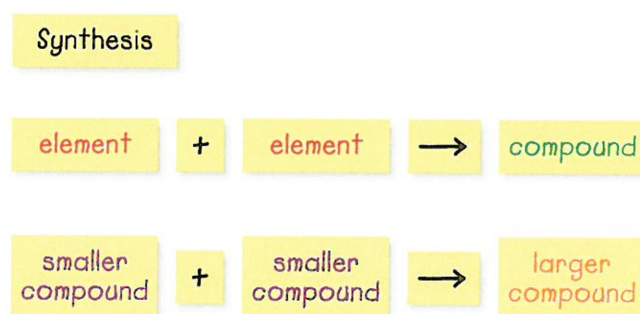

Figure 1

SKILLS HANDBOOK: (X) Working Together