Activity A10

Inquiry Lab

Student Reference 2

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Formation, Decomposition, and Single Replacement Reactions

The Question

What chemical changes happen during formation, decomposition, and single replacement reactions?

Materials and Equipment

anhydrous copper(II) sulfate

3% hydrogen peroxide solution

manganese(IV) oxide

15-cm length of copper wire

steel wool

water

balance

test tube

medicine dropper

tongs

Bunsen burner

Erlenmeyer flask

copper(II) sulfate pentahydrate

1-cm^2 pieces of copper, silver, and magnesium metal

copper(II) nitrate solution

silver nitrate solution

microscope slides

microscopes (preferred), hand lenses, or magnifying glasses

Procedure

Part 1: Formation Reaction: Anhydrous Copper(II) Sulfate + Water

1. Place about 2 g of anhydrous copper(II) sulfate in a test tube. Record the colour.
2. Hold the test tube by curling your fingers around it, so you can detect any temperature changes when you add water.
3. Using a dropper, add 5 drops of water to the anhydrous copper(II) sulfate in the test tube. Record any colour changes and temperature changes in your notebook.

Part 2: Formation Reaction: Iron + Oxygen

4. Light the Bunsen burner. Using the tongs, light one of the pieces of steel wool, and record the result.
5. Place about 1 g of manganese(IV) oxide in an Erlenmeyer flask. Add 5 mL of 3% hydrogen peroxide solution. Observe bubbles forming. This is pure oxygen gas.
6. Using the tongs and the Bunsen burner, light the second piece of steel wool and plunge it into the Erlenmeyer flask. Record the result.
7. Follow your teacher's instructions for disposing of all the chemicals you have used.

Part 3: Decomposition Reaction: Copper(II) Sulfate Pentahydrate

8. Place 5 g of copper(II) sulfate pentahydrate in a test tube.
9. Using tongs, heat the test tube over a Bunsen burner flame. Note particularly the formation of any product on the walls of the test tube at the top. Note any colour changes in the material at the bottom of the test tube. Record your observations.
10. Once the test tube is cool enough to touch, add a few drops of water to the product. Record any changes.

Part 4: Single Replacement Reaction: Metal Ion Solutions with Magnesium and Copper Metals

11. Use a microscope or magnifying glass for the following steps.
12. Put a piece of magnesium on a clean slide, and place the slide under the microscope lens. Focus on the edge of the magnesium.
13. Put a drop of silver nitrate solution on the magnesium. Record your observations. Note whether a reaction is occurring or not. If you are using a microscope, try to describe the growth of the metallic crystals.
14. Repeat steps 12 and 13 with the copper metal and the silver nitrate solution.
15. Repeat steps 12 and 13 using the silver metal with the copper(II) nitrate solution.
16. These solutions contain toxic metal ions. They require special disposal procedures. Follow your teacher's instructions for disposing of all the substances you have used.

Analyzing and Interpreting

Part 1: Formation Reaction: Anhydrous Copper(II) Sulfate + Water

1. What evidence is there that adding water to anhydrous copper(II) sulfate creates a chemical reaction and not just a mixture?
2. Is the reaction of anhydrous copper(II) sulfate with water exothermic or endothermic? Explain.

Part 2: Formation Reaction: Iron + Oxygen

3. Describe the differences between burning steel wool (a source of iron) in air and burning it in pure oxygen.
4. Rewrite the following sentence as a balanced formula equation. Include the state symbols.
   Solid iron reacts with oxygen gas to form solid iron(III) oxide.

Part 3: Decomposition Reaction: Copper(II) Sulfate Pentahydrate

5. What evidence is there that water is one of the products of the decomposition of copper(II) sulfate pentahydrate?
6. What is the other product of this decomposition reaction?

Part 4: Single Replacement Reaction: Metal Ion Solutions with Magnesium and Copper Metals

7. Do all the combinations of metals and solutions appear to react in the same way? Include the rate of the reaction and the shape of the crystals in your answer.
8. Translate the following sentences into balanced formula equations, showing state symbols:
   a) Magnesium metal reacts with silver nitrate solution to produce silver metal and magnesium nitrate solution.
   b) Copper(II) nitrate solution reacts with magnesium metal to give magnesium nitrate solution and copper metal.
   c) Silver nitrate solution reacts with copper metal to give silver metal and copper(II) nitrate solution.

Forming Conclusions

9. Write a summary describing the observations that you made that indicate a chemical reaction has occurred for each type of reaction.

Applying and Connecting

10. Drying agents are used to keep humidity low by absorbing moisture from the air. For example, hearing aids are often stored at night in an airtight container that has a drying agent inside it. The drying agent must be regenerated when it has reached its water absorption limit. Use the results of this investigation to suggest a means for producing a drying agent that indicates when it has reached its absorption limit.

Extending

11. Based on your results, which is a more reactive metal: copper or silver? Explain.

Double Replacement Reactions

Double replacement reactions commonly occur between two ionic compounds. Ionic compounds are always solids at room temperature, so these reactions happen in solution (that is, dissolved in a liquid), where the ions have the opportunity to mix. This type of reaction often results in the formation of at least one precipitate.

A general statement for a double replacement reaction is:

$$AB + CD \longrightarrow AD + CB$$

The ions in the first compound join with ions from the second compound. This is called a double replacement reaction because two new ionic compounds are formed.

There are several facts to keep in mind as this double replacement occurs:

- A and C are both positive ions. They will never pair up together because they repel each other.
- A and C will always appear first in formulas because positive ions are always written first.
- B and D are negative ions, so they will combine with any positive ions. They are always written second in formulas.

Practice Problem

9. Write the word, skeleton, and balanced equations for the following reactions.
   a) When aqueous copper(I) nitrate and aqueous potassium bromide are mixed, a precipitate of solid copper(I) bromide forms. Another product also forms.
   b) When aqueous aluminium chloride and aqueous sodium hydroxide are mixed, a precipitate of solid aluminium hydroxide forms. Another product also forms.

Example Problem A3.9

When aqueous lead(II) nitrate and aqueous sodium iodide are mixed, a bright yellow precipitate of solid lead(II) iodide forms (Figure A3.20). Another product also forms. It is aqueous. Write the balanced equation for this double replacement reaction.

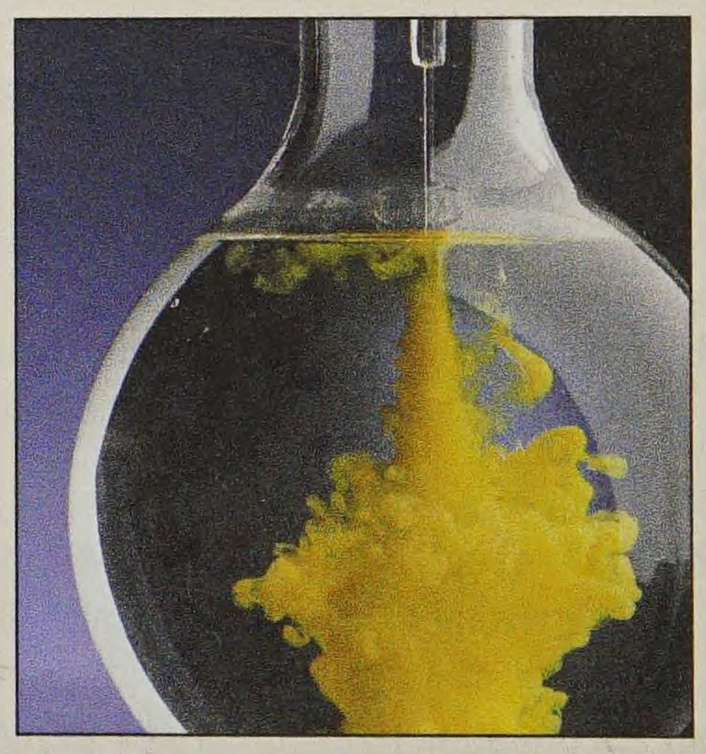


FIGURE A3.20 The yellow precipitate lead(II) iodide was widely used as a paint pigment in the past. Lead-based paints were popular, and today lead paint dust is a health hazard in very old homes.

1. Write the word equation: The question does not name the second product. However, every ionic compound has two parts to its name. Look at the reactants and switch the parts of their names around.

   Word equation:
   lead(II) nitrate + sodium iodide ⟶ lead(II) iodide + sodium nitrate

2. Write the skeleton equation: All these substances are ionic. Use the solubility table (Table C) in Student Reference 12 to determine that PbI_2 is only slightly soluble. It appears in the equation as a solid.

   Skeleton equation: $Pb(NO_3)_{2(aq)} + NaI_{(aq)} \longrightarrow PbI_{2(s)} + NaNO_{3(aq)}$

3. Write the balanced equation: Remember—do not change any subscripts. Simply add coefficients.

   Balanced equation: $Pb(NO_3)_{2(aq)} + 2\ NaI_{(aq)} \longrightarrow PbI_{2(s)} + 2\ NaNO_{3(aq)}$

In Example Problem A3.9, $PbI_{2(s)}$ was one of the products. It is only slightly soluble. Another way to describe its solubility is to say that its solubility is low. Such substances do not dissolve very well. In chemical equations, they are shown as a solid *(s)* even if they are formed in the presence of water. The other product in the last example is $NaNO_{3(aq)}$. It is very soluble, and remains completely in solution unless most of the water is removed. Its solubility is high. When formed in water, it is shown in the chemical equation as aqueous *(aq)*.

Recall that the solubility table lists the combinations of ions that are slightly soluble and very soluble (see Table A2.13 on page 57 or Table C in Student Reference 12). Consult this table to determine the states of the products of replacement reactions.

Activity A11

QuickLab

Double Replacement Reactions

Purpose

To observe the formation of precipitates, and write the chemical equations that represent the reactions

Materials and Equipment

dropper bottles containing the following solutions:

- sodium iodide solution
- silver nitrate solution
- iron(III) chloride solution
- sodium hydroxide solution
- sodium carbonate solution
- calcium chloride solution

5 test tubes

test tube rack

Procedure

1. Using a separate test tube for each reaction, combine 5 drops of each of the following solutions. Check for the formation of a precipitate. If there is a precipitate, note its colour. If there is no precipitate, write NR (no reaction).
   a) sodium iodide solution and silver nitrate solution
   b) iron(III) chloride solution and sodium hydroxide solution
   c) sodium carbonate solution and calcium chloride solution
   d) sodium iodide solution and calcium chloride solution
   e) silver nitrate solution and sodium carbonate solution
2. Follow your teacher's instructions for disposing of all the substances you have used.

Questions

1. Which combinations above produced a precipitate? For each reaction that produced a precipitate, write a word equation and a skeleton equation. Then balance the equation.
2. Use the solubility table (Table C) in Student Reference 12 to determine the solubility of the products in each reaction. Which are only slightly soluble? Which are very soluble?
3. Write the state symbol for each compound in each equation. All the reactants are very soluble, so they are all aqueous *(aq)*. One product in each reaction is soluble, and the other is only slightly soluble. The slightly soluble product should be shown in the equation as solid *(s)*.

Predicting the Products of Chemical Reactions

Now that you have become familiar with five simple types of chemical reactions, you have the foundation for predicting the outcome of thousands of chemical reactions. Each reaction type follows a pattern that is different from the others. An examination of the reactants usually makes it possible to predict the identity of the products.

The first step in predicting what will happen in any reaction is to classify the reaction. Then, the products can be determined by following the pattern for that type. Table A3.3 summarizes the types of reactions.

TABLE A3.3 Summary of Types of Reactions

Type of Reaction	Reactants		Products
formation (synthesis)	A + B	$\longrightarrow$	AB
decomposition	AB	$\longrightarrow$	A + B
hydrocarbon combustion	$C_xH_y + O_2$	$\longrightarrow$	$CO_2 + H_2O$
single replacement	(A is a metal) A + BC (D is a non-metal) D + BC	$\longrightarrow$ $\longrightarrow$	B + AC C + BD
double replacement	AB + CD	$\longrightarrow$	AD + CB

Note that there are many kinds of reactions that do not fit into the five categories that you have just learned. There are even variations of these five types for which the products are difficult to predict.

FIGURE A3.21 Hexane ($C_6H_{14(l)}$), in part (c) of Example Problem A3.10, is one of the components of gasoline.

Example Problem A3.10

Classify each of the following reaction types. Predict the names of the product(s), and write the skeleton equation.

a) $PbBr_{4(s)} \longrightarrow$

b) $Ni(NO_3)_{3(aq)} + Na_2SO_{3(aq)} \longrightarrow$

c) $C_6H_{14(l)} + O_{2(g)} \longrightarrow$ (assume plenty of oxygen is available during the reaction)

d) copper + gold(III) chlorate $\longrightarrow$

e) zinc + sulfur $\longrightarrow$

a) $PbBr_{4(s)} \longrightarrow$

- Classify the reaction: Since there is only one reactant, this must be a decomposition reaction.
- Predict the names of the products: This compound contains the lead(IV) ion, Pb^{4+}, and the bromide ion, Br^-. It can be decomposed into the elements lead and bromine.
- Write the skeleton equation: Lead metal is shown by its element symbol in the products because it is an atom and has no charge. Bromine is diatomic.

Skeleton equation: $PbBr_{4(s)} \longrightarrow Pb_{(s)} + Br_{2(l)}$

b) $Ni(NO_3)_{3(aq)} + Na_2SO_{3(aq)} \longrightarrow$

- Classify the reaction: Two ionic compounds mean this is a double replacement reaction.
- Predict the names of the products: The nickel(III) ion, Ni^{3+}, will combine with the sulfite ion, SO_3^{2-}, to make nickel(III) sulfite. Similarly, the sodium ion, Na^+, will combine with the nitrate ion, NO_3^-, to make sodium nitrate.
- Write the skeleton equation:

Skeleton equation: $Ni(NO_3)_{3(aq)} + Na_2SO_{3(aq)} \longrightarrow Ni_2(SO_3)_{3(s)} + NaNO_{3(aq)}$

c) $C_6H_{14(l)} + O_{2(g)} \longrightarrow$

- Classify the reaction: The presence of a hydrocarbon with oxygen indicates that this is a hydrocarbon combustion reaction.
- Predict the names of the products: Assuming that there is plenty of oxygen available during combustion, the products will be carbon dioxide and water vapour.
- Write the skeleton equation:

Skeleton equation: $C_6H_{14(l)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$

d) copper + gold(III) chlorate $\longrightarrow$

- Classify the reaction: An element reacting with a compound is characteristic of a single replacement reaction.
- Predict the names of the products: The element is a metal, so it will replace the gold(III) ion, Au^{3+}. The gold is an element in the products, and since it is in the form of an atom, it will have no charge. The copper forms the Cu^{2+} ion. This is the most common form of the ion (2+), so it appears first in the periodic table. The Cu^{2+} ion exists in combination with the chlorate ion, ClO_3^-, to give the ionic compound copper(II) chlorate.
- Write the skeleton equation:

Skeleton equation: $Cu_{(s)} + Au(ClO_3)_{3(aq)} \longrightarrow Cu(ClO_3)_{2(aq)} + Au_{(s)}$

e) zinc + sulfur $\longrightarrow$ (assume that there is enough heat to start the reaction)

- Classify the reaction: Both zinc and sulfur are elements. This must be a formation reaction, with only one product.
- Predict the names of the products: Zinc is a metallic element and is shown in the reactants simply by its symbol, Zn. It has no charge in this form because it is an atom. Sulfur exists at room temperature as the molecule S_8, which is how it appears in the reactants. The product is the compound formed from the zinc ion, Zn^{2+}, and the sulfide ion, S^{2-}, to give zinc sulfide.
- Write the skeleton equation:

Skeleton equation: $Zn_{(s)} + S_{8(s)} \longrightarrow ZnS_{(s)}$

Practice Problem

10. Classify each of the following reaction types. Predict the names of the product(s), and write the skeleton equation.

a) $C_4H_{10(g)} + O_{2(g)} \longrightarrow$ (assume plenty of oxygen is available during the reaction)

b) $Ca(NO_3)_{2(aq)} + Na_3PO_{4(aq)} \longrightarrow$

c) calcium + silver nitrate $\longrightarrow$

d) magnesium + oxygen $\longrightarrow$

e) $AlCl_{3(s)} \longrightarrow$

Activity A12

QuickLab

Classifying Chemical Reactions

Purpose

To classify a variety of chemical reactions and write the chemical equations that represent them

Materials and Equipment

- aluminium foil
- copper(II) chloride solution
- cobalt(II) chloride hexahydrate
- silver nitrate solution
- calcium chloride solution
- sodium carbonate solution
- 10-cm length of copper wire
- Bunsen burner or hot plate
- 4 test tubes
- test tube rack
- 10-mL graduated cylinder
- tongs
- balance

Procedure

1. Roll up a 5 × 5 cm square of aluminium foil. Place 5 mL of copper(II) chloride solution in a test tube, and drop the aluminium foil into it. Record your observations.
2. Place 1 g of cobalt(II) chloride hexahydrate in a test tube. Use tongs to heat the test tube over a Bunsen burner. If you do not have a Bunsen burner, place the cobalt(II) chloride hexahydrate on aluminium foil and heat on a hot plate. Record your observations.
3. Place 5 drops of silver nitrate solution in a test tube and add the copper metal. Record your observations.
4. Place 5 drops of calcium chloride solution in a test tube. Add 5 drops of sodium carbonate solution. Record your observations.
5. These solutions contain toxic metal ions. They require special disposal procedures. Follow your teacher's instructions for disposing of all the substances you have used.

Questions

1. Write a word equation and a balanced formula equation for the reaction of copper(II) chloride solution with aluminium metal. Include state symbols.
2. Classify the reaction involving cobalt(II) chloride hexahydrate. Name one of the products of the reaction. What evidence was there that it was produced?
3. Classify the reaction of silver nitrate and copper metal. Only one of the products was a solid. What was it?
4. Classify the reaction involving calcium chloride and sodium carbonate. Write a word equation and a balanced formula equation for this reaction. Include state symbols. One of the products of the reaction is white. Indicate on the formula equation which one is white.
5. Which two reaction types that you studied did not occur in this experiment?

Example Problem A3.11

A solution of copper(II) nitrate is placed in an aluminium pot for storage. Almost immediately this proves to be a mistake. A sudden colour change and an increase in temperature indicate that a chemical reaction is taking place. Explain what is happening by using a word equation, a skeleton equation, and a balanced equation. Include state symbols in the balanced equation.

1. Identify the reactants and classify the reaction: An element and a compound are reacting together so this is a single replacement reaction. The element is a metal, so it will replace copper in the compound. Copper metal will be produced. The aluminium metal will form the Al^{3+} ion. This means the aluminium pot should look corroded.

2. Write the word equation:

Word equation:
aluminium + copper(II) nitrate ⟶ copper + aluminium nitrate

3. Write the skeleton equation:

Skeleton equation: $Al_{(s)} + Cu(NO_3)_{2(aq)} \longrightarrow Cu_{(s)} + Al(NO_3)_{3(aq)}$

Both aluminium metal and copper metal are solids at or near room temperature. The copper(II) nitrate was in solution so it is aqueous. In the solubility table (Table C) in Student Reference 12, you can see that all nitrates are very soluble, so there will not be any precipitate from this new compound. It is aqueous.

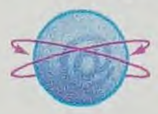
4. Write the balanced equation:

Balanced equation: $2\ Al_{(s)} + 3\ Cu(NO_3)_{2(aq)} \longrightarrow 3\ Cu_{(s)} + 2\ Al(NO_3)_{3(aq)}$

We can conclude that the aluminium pot is corroding from the inside because of its reaction with the copper(II) nitrate solution. A pile of metallic copper powder should be sitting in the bottom of the pot. There is no pile of aluminium nitrate powder, because it is very soluble and remains in solution. Try plastic or glass next time!

*re*SEARCH

Most fertilizers contain ammonium (NH_4^+) salts and nitrate (NO_3^-) salts. These are synthesized from ammonia ($NH_{3(g)}$). Research the formation of ammonia from hydrogen and nitrogen using the Haber process. Begin your search at



www.pearsoned.ca/school/science10

Practice Problems

11. A lead(IV) nitrate solution is placed in a zinc pot for storage. A sudden colour change and an increase in temperature indicate that a chemical reaction is taking place. Explain what is happening by using a word equation, a skeleton equation, and a balanced equation. Include state symbols in the balanced equation.

12. A reaction occurs when silver metal is placed in a solution of gold(III) nitrate. Write a balanced equation. Include the state symbols.

A3.3 Check and Reflect

Knowledge

1. Classify each of the following reactions, and balance the equations.
   a) $CaCl_{2(s)} \longrightarrow Ca_{(s)} + Cl_{2(g)}$
   b) $Mg(ClO_4)_{2(s)} + Na_{(s)} \longrightarrow NaClO_{4(s)} + Mg_{(s)}$
   c) $NaN_{3(s)} \longrightarrow Na_{(s)} + N_{2(g)}$
   d) $Ca(NO_3)_{2(aq)} + Cu_2SO_{4(s)} \longrightarrow CaSO_{4(aq)} + CuNO_{3(aq)}$
   e) $C_5H_{10(l)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$
   f) $Li_4C_{(s)} + Ca_{(s)} \longrightarrow Li_{(s)} + Ca_2C_{(s)}$
   g) $PbO_{2(s)} \longrightarrow Pb_{(s)} + O_{2(g)}$
   h) $CH_{4(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$
   i) $Li_{(s)} + Cl_{2(g)} \longrightarrow LiCl_{(s)}$
   j) $NaI_{(aq)} + AlCl_{3(aq)} \longrightarrow NaCl_{(aq)} + AlI_{3(s)}$

2. Classify each of the following reactions, and write balanced formula equations for them.
   a) sodium sulfate + calcium chloride ⟶ sodium chloride + calcium sulfate
   b) magnesium + nitrogen ⟶ magnesium nitride
   c) strontium hydroxide + lead(II) bromide → strontium bromide + lead(II) hydroxide
   d) nickel(III) nitrate + calcium ⟶ calcium nitrate + nickel
   e) methane + oxygen ⟶ carbon dioxide + water
   f) sodium + oxygen ⟶ sodium oxide
   g) nitrogen + hydrogen ⟶ ammonia
   h) hydrogen chloride ⟶ hydrogen + chlorine
   i) aluminium iodide + bromine ⟶ aluminium bromide + iodine
   j) water + sodium ⟶ sodium hydroxide + hydrogen

3. Classify each reaction, and write the formula of each product or products:
   a) $Li_{(s)} + O_{2(g)} \longrightarrow$
   b) $CuCl_{(s)} \longrightarrow$
   c) $CuSO_{4(aq)} + Al_{(s)} \longrightarrow$
   d) $CaBr_{2(aq)} + Pb(NO_3)_{2(aq)} \longrightarrow$
   e) $C_4H_{10(g)} + O_{2(g)} \longrightarrow$
   f) $AgNO_{3(aq)} + KCl_{(aq)} \longrightarrow$
   g) $NI_{3(s)} \longrightarrow$
   h) $Li_2S_{(aq)} + Cl_{2(g)} \longrightarrow$
   i) $Al_{(s)} + S_{8(s)} \longrightarrow$
   j) $C_{18}H_{38(s)} + O_{2(g)} \longrightarrow$

Applications

4. Write the balanced equation for the formation of solid zinc nitride from its elements.

5. Write the balanced formula equation for the decomposition of mercury(II) oxide into its elements.

6. Write the balanced formula equation for the combustion of benzene. Benzene is a liquid hydrocarbon with the formula $C_6H_{6(l)}$.

7. Liquid bromine is added to a solution of calcium iodide, and the mixture is stirred. A chemical reaction occurs that produces two products. Write the balanced equation.

8. When aqueous lead(II) nitrate is mixed with aqueous sodium iodide, a double replacement reaction occurs. Write the balanced formula equation for the reaction. Use the solubility table (Table C) in Student Reference 12 to determine the states of the products.

Extensions

9. An acid–base neutralization reaction is a specific example of one of the five reaction types that you have studied. Write the word and skeleton equations for the reaction of aqueous hydrochloric acid with sodium hydroxide. Then write the balanced formula equation. Decide which reaction type it resembles. Explain your reasoning.

10. Carbohydrates burn in oxygen to produce the same products as a hydrocarbon combustion reaction does. Write the formula equation for the combustion of table sugar, $C_{12}H_{22}O_{11(s)}$, and balance the equation.

A 3.4 The Mole

Chemists deal with atoms and molecules all the time, and they need to measure quantities of matter precisely. Balanced equations indicate the correct proportion of atoms and molecules to use in a reaction. Of course, chemists cannot measure materials by counting individual atoms or molecules. Instead, they place large numbers of them into groups of a convenient size and then count the number of groups.

We often group objects when counting them, both in chemistry and in everyday situations. The most common grouping quantity is the dozen. A dozen is a group of 12 objects. It makes no difference what the objects are. A dozen means 12 whether it is a dozen eggs, a dozen donuts, or a dozen pencils.

Since atoms and molecules are very small, the quantity used to measure them needs to be a very large number. Like the dozen, this quantity never changes, but unlike the dozen, its value is very, very large.

info **BIT**

Mole day is celebrated on October 23 each year. It begins at 6:02 A.M. and ends at 6:02 P.M. The numbers associated with these dates and times are derived from Avogadro's number, a constant known to all chemists in the world. Its value is approximately 6.02×10^{23}.

Avogadro's Number and the Mole

The quantity that chemists use to measure elements and compounds is called the **mole** (symbol: mol). Like the dozen, the mole represents a number. The number of particles in 1 mol is called **Avogadro's number** (symbol: N_A).

To define the mole, chemists chose to work with an isotope of the element carbon: carbon-12. Carbon is a stable solid, so it is easy to work with, and it can be obtained in very pure form.

Here's how a chemist defines a mole:

1. Get a 12 g sample of carbon-12. The number of atoms in the sample is, by definition, exactly one mole (1 mol). Why use a 12-g sample? This way, the mass of one mole of any element will be the same or nearly the same as the mass number.
2. Find a way to count how many carbon atoms are in the sample. The total number of carbon atoms in the sample gives Avogadro's number (N_A). Avogadro's number is the number of atoms in 1 mol of carbon atoms. This number is approximately 6.02×10^{23}.

The mole can be used to measure any kind of particle—atoms, ions, molecules, and formula units. It is possible to have a mole of iron atoms, a mole of water molecules, and a mole of sodium chloride. They each contain the number of particles that is equal to Avogadro's number: 6.02×10^{23}.

Avogadro's number is to the mole what 12 is to the dozen. Sometimes, Avogadro's number is referred to as the "chemist's dozen." It is a very convenient amount of atoms to use in the lab, because 1 mol of most substances would just fill a small beaker. Figure A3.22 shows 1-mol amounts of five different elements.

This is how Avogadro's number looks when written out in common notation:

602 000 000 000 000 000 000 000

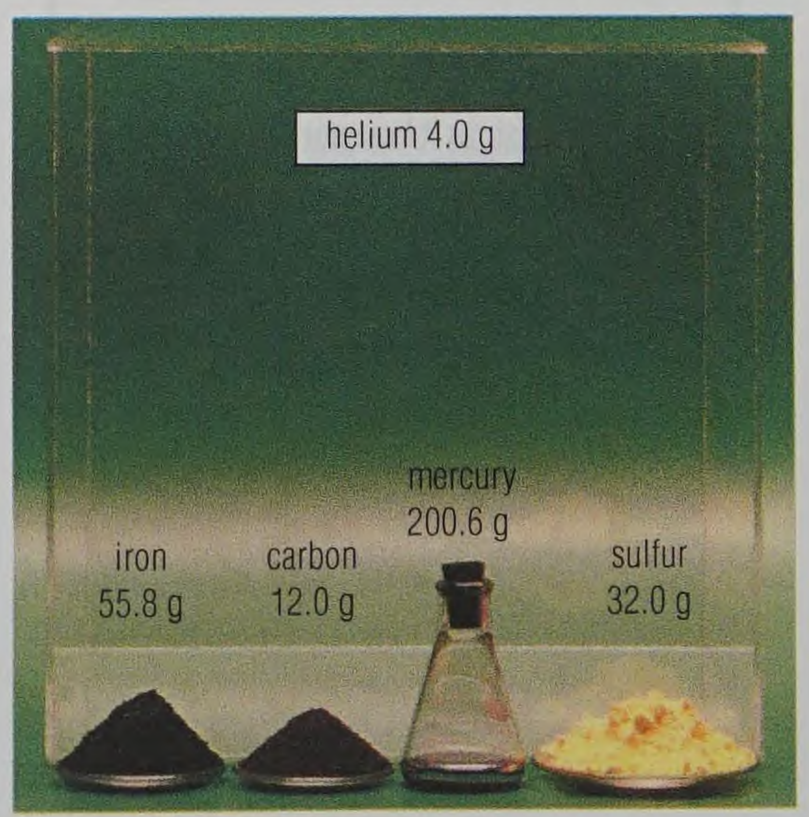


FIGURE A3.22 Each sample contains 1 mol: 6.02×10^{23} of atoms. Which element do you think has the heaviest atoms?

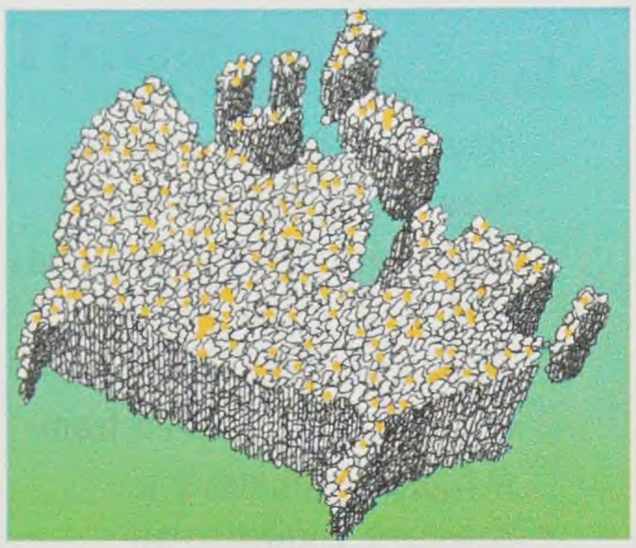


FIGURE A3.23 How large is Avogadro's number? One mole of popcorn kernels will cover all of Canada to a depth of 10 km.

Avogadro's number was named in honour of Amedeo Avogadro, an Italian scientist (1776–1856). Avogadro himself did not identify this number. It was named after him to honour his many contributions to chemistry. For example, he was the first to predict that oxygen was diatomic.

Molar Mass

The mass of one mole of a substance is called its **molar mass**. Experiments have been performed to find the mass of one mole of each of the elements. These have been recorded in the periodic table under the name **atomic molar mass**. The atomic molar mass of an element is the average mass in grams of one mole of atoms of that element. For example, in the periodic table in Figure A3.24, the molar mass of carbon is 12.01 g/mol.

You can use the atomic molar mass information from the periodic table to find the molar mass of any substance if you know its chemical formula. Recall that the molar mass of a substance is the mass of one mole of that substance. Example Problem A3.12 shows how to calculate molar mass of a compound.

info **BIT**

A sample of pure carbon contains a mixture of the isotopes carbon-12, carbon-13, and carbon-14. The atomic molar mass is an average of these masses. For carbon, the atomic molar mass is very close to 12.00 because 99% of carbon on Earth is composed of carbon-12.

Example Problem A3.12

What is the molar mass of methane?

The formula of methane is $CH_{4(g)}$, so one molecule contains one carbon atom and four hydrogen atoms.

atomic molar mass of H = 1.01 g/mol × 4 = 4.04 g/mol

+ atomic molar mass of C = 12.01 g/mol × 1 = 12.01 g/mol

= molar mass of $CH_{4(g)}$ M = 16.05 g/mol

The molar mass of methane is 16.05 g/mol.

Practice Problems

13. What is the molar mass of $CH_3OH_{(l)}$?
14. What is the molar mass of $Na_2SO_{4(s)}$?
15. What is the molar mass of $CO_{2(g)}$?
16. What is the molar mass of $(NH_4)_3PO_{4(s)}$?

The number of moles of a substance is related to its molar mass by the following equation:

$m = n \times M$

where

m is the quantity of matter (mass) in grams,

n is the quantity of matter in moles, and

M is the molar mass.

Although this formula can be manipulated to convert between mass and moles, it is very common to use another method called the factor-label method.

The Factor-Label Method of Converting between Quantities

The factor-label method is a simple technique for converting between the number of moles of a substance and its mass. This method is based on

the idea that different units can represent the same quantity of matter. For example, from the periodic table we know that 1 mol of carbon has a mass of 12.01 g. Both 1 mol of carbon and 12.01 g of carbon represent the same amount of carbon. From this equivalence we can write:

$$1 \text{ mol C} = 12.01 \text{ g C}$$

Because 1 mol C is equal to 12.01 g C, their ratio has a value of 1; that is,

$$\frac{1 \text{ mol C}}{12.01 \text{ g C}} = 1$$

This fraction is called a "factor" and the units are the "labels." It can also be written as:

$$\frac{12.01 \text{ g C}}{1 \text{ mol C}} = 1$$

Suppose we want to find the mass of 3.000 moles of carbon. This is a moles-to-mass conversion, so we choose the factor that has "mole" in the denominator so it will cancel out the "mol" in the 3.000 mol.

$$m_C = 3.000 \cancel{\text{mol}} \times \frac{12.01 \text{ g}}{1 \cancel{\text{mol}}}$$

$$= 36.03 \text{ g C}$$

Using the factor-label method, all the units will cancel except the one we want in the answer.

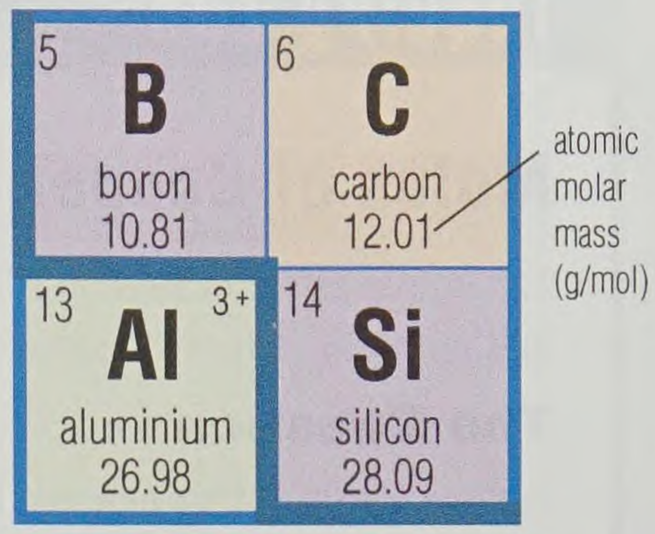


FIGURE A3.24 The periodic table shows the mass, in grams, of one mole of each of these elements.

Example Problem A3.13

How many moles of silicon are in a 56.18-g sample?

Using the atomic molar mass of Si 1 mol = 28.09 g

The factor is $\frac{1 \text{ mol}}{28.09 \text{ g}}$

Therefore $n_{Si} = 56.18 \cancel{\text{g}} \times \frac{1 \text{ mol}}{28.09 \cancel{\text{g}}}$

$= 2.000 \text{ mol}$

There are 2.000 mol of silicon in a 56.18-g sample.

Example Problem A3.14

What is the mass of 10.0 mol of water?

The molar mass of $H_2O_{(l)}$ is 18.02 g/mol

so 1 mol = 18.02 g

The factor is $\frac{18.02 \text{ g}}{1 \text{ mol}}$

Therefore $m_{H_2O} = 10.0 \cancel{\text{mol}} \times \frac{18.02 \text{ g}}{1 \cancel{\text{mol}}}$

$= 180 \text{ g}$

The mass of 10.0 mol of water is 180 g.

Practice Problems

17. What is the mass of 5.0 mol of $NaOH_{(s)}$?

18. How many moles are in 360 g of glucose, $C_6H_{12}O_{6(s)}$?

19. What is the mass of 5.00 mol of $NH_{3(g)}$?

20. How many moles are in a 20.0-g sample of magnesium nitrate?

Activity A13

Inquiry Lab

Student Reference 2, 5

Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Moles of Copper and Iron

The Question

Is there a relationship between the number of moles of iron that are consumed and the number of moles of copper that are produced when iron nails react with copper(II) chloride?

The Hypothesis

If copper(II) chloride and iron react, then they will do so according to a precise mole ratio.

Variables

Identify the manipulated, responding, and controlled variables in this inquiry.

Materials and Equipment

2 iron nails (not galvanized and not stainless)

copper(II) chloride

2 100-mL beakers

tongs

drying oven

paper towels

balance

Procedure

1. Measure and record the mass of a clean, dry 100-mL beaker. To get good results in this experiment, it is particularly important to measure all masses to as many decimal places as the balance will permit.
2. Add about 5 g of copper(II) chloride to the beaker. Record the mass of copper(II) chloride.
3. Add about 80 mL of water to the beaker. The actual amount added is not critical and need not be recorded.
4. Put both iron nails on the balance at the same time. Record their total mass.
5. Use one of the nails to stir the copper(II) chloride solution, then place both nails in the solution. The ends of the nails should stick out of the solution so you can pick the nails up again easily. After about 1 minute, lift one of the nails partly out of the solution and examine it. Record the colour. Place the nail back in the solution, and let it react for at least 30 minutes.
6. After waiting for at least 30 minutes, pick up the nails by the ends that are sticking out of solution. Clean them by scraping them together over the beaker. Make sure any copper falls into the beaker.
7. Dry the nails with paper towels. Measure and record their total mass.
8. Wait about 2 minutes. Then carefully decant (pour off) the liquid in the beaker. The purpose of this step is to leave the copper residue at the bottom of the first beaker.
9. Wash the copper by adding water to the beaker until the beaker is almost full. Then decant it, leaving the copper in the beaker. Repeat this several times.
10. Place the beaker containing the copper in a drying oven for at least 30 minutes or overnight.
11. Measure and record the mass of the copper and the beaker together.
12. Follow your teacher's instructions for disposing of all the substances you have used.

Analyzing and Interpreting

1. Subtract the mass of the nails after the reaction from the mass of the nails before the reaction. This gives the mass of the iron that reacted.
2. Subtract the mass of the beaker from the mass of the beaker and the dried copper. This gives the mass of the copper that was produced.
3. Calculate the number of moles of iron that reacted, based on the mass of iron that reacted.

4. Calculate the number of moles of copper that formed, based on the mass of copper that was produced.
5. Divide the number of moles of iron by the number of moles of copper, and round off to the nearest whole number. This number gives the ratio of moles of iron reacted to moles of copper produced.
6. Compare your result with the results of other students in the class.

Forming Conclusions

7. Using your result and the results of other students in the class, state your conclusion about whether there is a relationship between the number of moles of iron that are consumed and the number of moles of copper that are produced.

The Mole Concept and the Law of Conservation of Mass

Recall that the law of conservation of mass states that, in any reaction, the total mass of the reactants equals the total mass of the products. In balancing chemical equations, you applied this law. You made sure that the total number of atoms of each element in the reactants was equal to the total number of atoms of that same element in the products. You did this by placing coefficients in front of the element symbols and chemical formulas. When chemists read equations that have been balanced, they often read the coefficients as moles. One reason is that you can see a mole of something, while it is impossible to see an atom of something. Another reason is that chemists use the mole to measure out chemicals. For example, consider the reaction of sodium metal with oxygen gas in a formation reaction. The word equation for this reaction is:

sodium + oxygen $\longrightarrow$ sodium oxide

The balanced equation for this reaction is:

$$4\ Na_{(s)} + O_{2(g)} \longrightarrow 2\ Na_2O_{(s)}$$

You can read the balanced equation as:

4 atoms $Na_{(s)}$ + 1 molecule $O_{2(g)} \longrightarrow$ 2 molecules $Na_2O_{(s)}$

You can read this same equation as:

4 moles of $Na_{(s)}$ + 1 mole of $O_{2(g)} \longrightarrow$ 2 moles of $Na_2O_{(s)}$

A chemical equation is like a recipe where the quantities are measured in moles.

*re*SEARCH

Find out more about Amedeo Avogadro (1776–1856). What was his main contribution to chemistry? Find out how he came to distinguish between Dalton's idea of the atom and a new concept called a molecule. How did this lead Avogadro to predict that oxygen gas was diatomic? Begin your search at

www.pearsoned.ca/school/science10

A3.4 Check and Reflect

Knowledge

1. How many particles are in one mole?
2. Which element was chosen as the standard for defining the mole? How many grams of this element are equal to one mole?
3. What is meant by the term "molar mass"?
4. What is the name given to the number of particles in one mole of substance? What is the symbol for this number?

Applications

5. How many atoms or molecules are present in each of the following?
   a) 1.0 mol of $Au_{(s)}$ atoms
   b) 2.5 mol of $He_{(g)}$ atoms
   c) 10.0 mol of $H_{2(g)}$ molecules
   d) 0.628 mol of $CO_{2(g)}$ molecules
6. How many moles are present in each of the following?
   a) 28 g of sodium
   b) 28 g of iron
   c) 150 g of zinc
   d) 100.0 g of $NaCl_{(s)}$
   e) 26.0 g of $N_{2(g)}$
7. What is the mass of each sample?
   a) 1.0 mol of nickel atoms
   b) 1.0 mol of carbon dioxide molecules
   c) 5.0 mol of water
   d) 36.8 mol of $MgCl_{2(s)}$
   e) 0.00127 mol of $Al_2S_{3(s)}$
8. In your notebook, complete equations a), b), and c). They are all related to the following formula equation:

	$3\ H_{2(g)}$	+	$N_{2(g)}$	$\longrightarrow$	$2\ NH_{3(g)}$
a)	3 mol	+	_____	$\longrightarrow$	2 mol
b)	_____	+	28 g	$\longrightarrow$	34 g
c)	1.83×10^{24} molecules	+	6.02×10^{23} molecules	$\longrightarrow$	_____

Extensions

9. What is the mass of 3.01×10^{23} atoms of copper?
10. How many molecules of water are in 1000 g of water?
11. How many oxygen atoms are in 64 g of oxygen gas?
12. Which contains more atoms: a mole of iron or a mole of oxygen gas? Explain.
13. Write the balanced equation for the combustion reaction involving methane. Assume 15 mol of methane burned in the reaction. Predict how many moles of water would be produced.

Section Review

Knowledge

1. Explain what is meant by the term "chemical reaction." List three characteristics common to all reactions.
2. List five different indications that a chemical reaction is taking place.
3. Many chemical reactions produce one or more gases. Give one example of a gas-producing reaction used in each of the following applications:
   a) household
   b) commercial
4. Use the following balanced chemical equation to answer the questions below:

$$4\ Na_{(s)} + O_{2(g)} \longrightarrow 2\ Na_2O_{(s)}$$

   a) What state symbols are present and what are their meanings?
   b) What coefficients are present and what are their meanings?
   c) Name the reactant(s) and the product(s).
   d) How do you know that this equation was properly balanced?
5. List five classes of chemical reactions. Write a general equation for each.
6. What is the value of Avogadro's number?
7. What is a mole?
8. What is meant by the term "atomic molar mass"?
9. How many moles are present in each of the following?
   a) 36.03 g of carbon
   b) 1000 g of $H_2O_{(l)}$
   c) 50.0 g of $CaCO_{3(s)}$
   d) 22.61 g of $NH_4NO_{3(s)}$
   e) 0.795 g of aluminium hydroxide
10. What is the mass of each sample below?
   a) 1.00 mol of gold atoms
   b) 5.6 mol of $Cu_{(s)}$ atoms
   c) 100 mol of $H_{2(g)}$ molecules
   d) 0.918 mol of $NaOH_{(s)}$
   e) 3.00 mol of magnesium acetate

Applications

11. Some single and double replacement reactions produce a precipitate. Weather forecasters also speak of the chance of precipitation occurring. Explain how the term "precipitation" actually has similar meaning in both cases.
12. Write the following sentences as balanced formula equations.
   a) Liquid bromine plus solid aluminium produces solid aluminium bromide.
   b) Solid ammonium carbonate plus aqueous calcium nitrate produces aqueous ammonium nitrate and solid calcium carbonate.
   c) Solid sodium hydroxide plus aqueous hydrochloric acid produces aqueous sodium chloride and liquid water.
13. Classify each of the following reactions, and balance the equations.
   a) $KBrO_{3(s)} \longrightarrow KBr_{(s)} + O_{2(g)}$
   b) $C_2H_{2(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$
   c) $AuCl_{3(aq)} + Pb_{(s)} \longrightarrow PbCl_{4(aq)} + Au_{(s)}$
   d) $K_{(s)} + N_{2(g)} \longrightarrow K_3N_{(s)}$
   e) $Sn(NO_3)_{4(aq)} + Ca(OH)_{2(s)} \longrightarrow Ca(NO_3)_{2(aq)} + Sn(OH)_{4(s)}$
14. Classify the following reactions. Then complete the equations and balance them.
   a) $F_{2(g)} + Ca_{(s)} \longrightarrow$
   b) $Cl_{2(g)} + NiBr_{3(aq)} \longrightarrow$
   c) $C_5H_{10(l)} + O_{2(g)} \longrightarrow$
   d) $KBr_{(s)} \longrightarrow$
   e) $AlF_{3(aq)} + Na_3PO_{4(aq)} \longrightarrow$

Extensions

15. Suppose that it was proposed that the law of conservation of mass be renamed the law of conservation of atoms. Explain why this new name would or would not correctly describe the processes that happen in a chemical reaction.
16. What is the mass of 1.204×10^{23} atoms of sodium?
17. How many molecules of carbon dioxide are there in 66.0 g of $CO_{2(g)}$?

UNIT A

Case Study

Air Quality

The growth of industry and urbanization, combined with social and political events, has had many impacts on air quality. A number of pivotal events have resulted in legislation to prevent recurrences. Some of these events have happened over a long period. Others happened suddenly with dramatic and tragic consequences. Environmental legislation sometimes imposes standards that are technically impossible at the time that the legislation is introduced. To comply with the legislation, companies must develop new technologies. In this way, legislation can protect people's health and the environment and drive research and development.

Scenario

You are a member of a government committee responsible for advising on legislation for air quality. However, time is limited. Legislation can be written only in one area in the following year, so your committee can recommend only one area to focus on. To help decide on a priority area, your committee will examine events in transportation, industrial accidents, disaster response, and indoor air quality. Examples from each area are summarized below.

A) Transportation

Roughly one-half of the air pollution in Canada comes from transportation. Cars and other motor vehicles release the pollutants that include carbon monoxide, hydrocarbons, nitrogen oxides, lead, and particulate matter.

B) Industrial Accidents

Wherever chemicals are used or produced in large quantities, there is a potential for major industrial accidents. In Bhopal, India, a disaster occurred in December 1984 when a toxic chemical called methyl isocyanate gas was released from the Union Carbide plant located in the middle of the city. The massive leak resulted in the deaths of thousands of residents and in the permanent disability of tens of thousands of people.

C) Disaster Response

The twin towers of the World Trade Center in New York City were destroyed in a terrorist attack on September 11, 2001. Heroic efforts of emergency personnel were hampered by toxic fumes and dust from the burning and crumbling materials used to construct these buildings. Rescue workers were exposed to massive doses of particulates and chemicals, resulting in respiratory illness and exposure to cancer-causing chemicals. Existing protective devices either were not available or were ineffective.

D) Indoor Air Quality

Asthma rates and respiratory illness may have less to do with the air we breathe out of doors and more to do with indoor air quality. Secondhand smoke, poor ventilation, and materials used to build and furnish our living spaces affect indoor air quality. The poor quality of indoor air can affect our health because of the amount of time we spend inside buildings.

Research the Issue

Research the issue by referring to the following resources:

1. Look at the Web. Check the Internet for information on the occurrence you choose to investigate. Search for legislation that may have been written as a direct response to these occurrences.
2. Ask the experts. Contact community groups that have formed in response to any of these issues. Contact companies or agencies that have been directly involved with these events.
3. Look in magazines, newspapers, or books for information on the social impacts of, and responses to, these occurrences.

Analyze the Issue

4. Summarize the information you have found into a short report or electronic presentation. Include your recommendation to the committee on which area of air quality control requires new legislation. Briefly outline what the legislation should cover. Be sure to connect the need for the legislation to the importance of the issue in your particular community in the next several years. Also, consider whether the legislation should be enacted at the community, provincial, or federal level to have the greatest impact.

Address the Issue

5. Present your findings and conclusions to your classmates in a convincing presentation.

Classifying Chemical Reactions Involving Magnesium

In this activity, you will perform and observe tests to distinguish between several types of chemical reactions. By carefully noting the reactants and observing the chemical changes, you will be able to classify them. You will also write balanced equations for these reactions.

Criteria for Success

- You must be able to distinguish between the types of chemical reactions.
- You must provide written observations and balanced formula equations showing states for each reaction.

Materials and Equipment

2 2-cm magnesium strips

1 mol/L hydrochloric acid

magnesium sulfate

sodium carbonate

magnesium carbonate

aluminium foil

4 test tubes

10-mL graduated cylinder

water

2 test tube stoppers

hot plate

CAUTION: Hydrochloric acid is corrosive.

Procedure

1. Pour 5 mL of 1 mol/L hydrochloric acid into a test tube. Drop in a piece of magnesium ribbon. Add a second piece so you can see the reaction again. Record your observations.
2. Place about 1 g of magnesium sulfate in a test tube and add about 5 mL of water. Stopper the test tube and shake it to dissolve the magnesium sulfate.
3. Place about 1 g of sodium carbonate in a test tube and add about 5 mL of water. Stopper the test tube and shake it in order to dissolve the sodium carbonate.
4. Mix the magnesium sulfate solution and sodium carbonate solution together. Record your observations.
5. Place magnesium carbonate on a sheet of aluminium foil and heat it on a hot plate. Record any observed changes in the magnesium carbonate.

Analysis

1. When magnesium reacts with hydrochloric acid, the hydrogen in the hydrochloric acid behaves chemically like a metal. What type of reaction is this? Write word and formula equations for this reaction.
2. When magnesium sulfate and sodium carbonate solutions mix, a white precipitate is observed. What is the identity of this precipitate? What type of reaction is this? Write word and formula equations for this reaction.
3. When the magnesium carbonate is heated on aluminium foil, the only reactant is magnesium carbonate. One of the products is carbon dioxide gas. The other product is also an oxide. What type of reaction is this? Write word and formula equations for this reaction.

Reporting

4. Write a summary report that contains your observations and the word and balanced chemical equations for each reaction.

UNIT A

Unit Summary

A 1.0 The understanding that particles make up the underlying structure of matter has led to advancements in technology.

Key Concepts

- WHMIS and safe practices
- evidence of chemical change
- how chemical substances meet human needs

Learnings

- Knowing how to interpret WHMIS symbols, other hazard symbols, and Material Safety Data Sheets is essential for lab safety.
- Chemical change occurs when a substance or substances react to create a different substance or substances in a chemical reaction. These products have completely different properties from the reactants.
- Human understanding of matter developed gradually as people learned to manipulate matter.
- The Greek philosopher Aristotle stated that matter was made up of earth, air, fire, and water.
- Aristotle's ideas were used for 2000 years, until John Dalton and other early scientists inferred the existence of atoms from experiments.
- Further investigation by scientists such as J. J. Thomson, Ernest Rutherford, and Neils Bohr gradually brought us to our current understanding of the atom.

A 2.0 Elements combine to form many substances, each with its own set of properties.

Key Concepts

- how chemical substances meet human needs
- International Union of Pure and Applied Chemistry (IUPAC) nomenclature, ionic and molecular compounds, acids and bases

Learnings

- Elements are substances made up of only one type of atom. There are 90 naturally occurring elements, and approximately 25 synthetic ones.
- Most elements are metals. Only 17 elements are non-metals. The remaining elements are called metalloids.
- The periodic table is an organized display of information about the elements. Rows are called periods, and columns are called groups or families. Elements in families tend to have similar properties.
- An atom is made up of a nucleus containing protons and neutrons and surrounded by electrons. Protons are positively charged; electrons are negatively charged; and neutrons have no charge.
- Electrons in the atom occupy specific energy levels around the nucleus, which can be empty, partly full, or full.
- Atoms of the same element containing different numbers of neutrons are called isotopes. Each isotope is assigned a mass number that equals the total number of neutrons and protons in its nucleus.
- An atom that loses or gains electrons has either a positive or a negative charge. It is called an ion.
- The International Union of Pure and Applied Chemistry (IUPAC) is responsible for the rules governing how chemical compounds are named.
- Ionic compounds form when electrons transfer from one atom to another to form an ionic bond. An ionic compound always contains a positive metal ion called a cation and a negative non-metal ion called an anion.
- Molecular compounds form when non-metallic atoms combine by sharing electrons to form a covalent bond.
- An acid is a compound that dissolves in water to form a solution with a pH lower than 7. A base is one with a pH higher than 7. The pH is a measure of the number of hydrogen ions in solution.
- Our society uses many potentially harmful chemicals. Their manufacture, use, and disposal must be carefully controlled and monitored.

A 3.0 Chemical change is a process that involves recombining atoms and energy flows.

Key Concepts

- how chemical substances meet human needs
- evidence of chemical change
- role and need for classification of chemical change
- writing and balancing equations
- law of conservation of mass
- the mole concept

Learnings

- Chemical changes are always accompanied by energy flows.
- Exothermic reactions release energy. Endothermic reactions absorb energy.
- The law of conservation of mass states that in a chemical reaction, the total mass of all the products equals the total mass of all the reactants.
- Five common types of chemical reactions are: formation, decomposition, hydrocarbon combustion, single replacement, and double replacement.
- Chemists use a quantity called the mole (symbol: mol) to measure elements and compounds. A mole contains the number of particles equivalent to Avogadro's number: 6.02×10^{23}. A mole is just a measure of quantity: it can be used to measure the number of atoms, molecules, ions, or any other item. The mass of 1 mol of any substance is called its molar mass.

Unit Review

Vocabulary

1. Create a concept map with the word "matter" at the centre that links all the terms in the list below.

acid
atomic number
base
compound
electron
element
energy level
endothermic
exothermic
group
ion
isotope
law of conservation of mass
molecule
neutron
nucleus
period
pH scale
proton
valence electron

Knowledge

A 1.0

2. Where are the fire extinguishers, the fire alarms, and the fire exits in your science class?
3. How does heating or freezing food each help to preserve it?
4. What are some of the practical advantages of copper over gold?
5. How did the Inuit obtain copper, and what did they use it for?
6. What is the difference between copper and bronze?
7. J. J. Thomson discovered a subatomic particle. What was it and how did he include it in his model of the atom?
8. State the law of conservation of mass.
9. What part of the atom did Rutherford discover? How did he include it in his model of the atom?

A 2.0

10. Name five groups in the periodic table and indicate where they appear in it. Which groups contain metals, and which ones contain non-metals?
11. Distinguish between the terms "period" and "family" as they apply to the periodic table.
12. How are mass number and atomic number of an element related?
13. Distinguish between cations and anions.
14. Complete the following table in your notebook. Use the periodic table (Table A) in Student Reference 12, as needed, to fill in the number of protons or the name of the element.

Element	Mass Number	Protons	Neutrons
carbon	13		
bromine	79		
bromine			46
	36		19
	57	26	
sodium			22

15. Use the periodic table (Table A) in Student Reference 12 to complete the following table in your notebook.

Atom or Ion	Overall Charge	Protons	Electrons	Symbol
sulfur atom				S
sulfide ion			18	S^{2-}
lithium ion		3		
		8	10	
				Cl^-
	2+	26		
	3–		10	

Unit Review

16. Using the solubility table (Table C) in Student Reference 12, state whether the following are slightly soluble or very soluble:
    a) Na_2SO_4
    b) NH_4Cl
    c) PbI_2
    d) $SrSO_4$
    e) MgS
    f) K_3PO_4

17. A pH measurement indicates whether a solution at 25°C is acidic, basic, or neutral. What values on the pH scale correspond to these types of solutions?

18. List three chemical properties that are unique to acidic solutions, and three properties that are unique to basic solutions.

19. Why is the IUPAC system of naming chemical compounds important?

20. List three high-risk activities associated with the misuse of alcohol.

A 3.0

21. Distinguish between a chemical reaction and a chemical equation.

22. Balance each of the following equations:
    a) $Cl_{2(g)} + KBr_{(aq)} \longrightarrow KCl_{(aq)} + Br_{2(l)}$
    b) $Li_{(s)} + O_{2(g)} \longrightarrow Li_2O_{(s)}$
    c) $C_2H_{6(g)} + O_{2(g)} \longrightarrow H_2O_{(g)} + CO_{2(g)}$
    d) $Na_{(s)} + N_{2(g)} \longrightarrow Na_3N_{(s)}$
    e) $(NH_4)_3PO_{4(aq)} + Ca(NO_3)_{2(aq)} \longrightarrow NH_4NO_{3(aq)} + Ca_3(PO_4)_{2(s)}$
    f) $CaCO_{3(s)} \longrightarrow CaO_{(s)} + CO_{2(g)}$

23. For each of the following equations, identify which reaction type it represents: formation, decomposition, hydrocarbon combustion, single replacement, or double replacement.
    a) methane + oxygen ⟶ carbon dioxide + water
    b) strontium + nitrogen ⟶ strontium nitride
    c) aluminium bromide + fluorine ⟶ aluminium fluoride + bromine
    d) calcium chloride ⟶ calcium + chlorine
    e) magnesium iodide + sodium carbonate ⟶ magnesium carbonate + sodium iodide
    f) silver nitrate + aluminium chloride ⟶ aluminium nitrate + silver chloride

Applications

24. List five of the most important safety rules for your science class.

25. What safety hazard symbols would you expect to see on the following containers? What WHMIS symbols would you expect to see on each?
    a) a bottle of bleach
    b) a can of gasoline
    c) a can of spray paint
    d) a bottle of helium gas
    e) a bottle of hydrochloric acid

26. Improvements in technology sometimes increase our ability to both wage war and to prosper in peace. Explain this idea using metallurgy advancements as an example.

27. What is the octet rule? How is it related to the filling of energy levels?

28. Draw diagrams to show the electron arrangements in:
    a) a calcium atom
    b) a calcium ion

29. Choose the correct words to complete the following statements:
    a) When metals become ions, they (gain/lose) electrons in order to become (positively/negatively) charged.
    b) When non-metals become ions, they gain (protons/electrons) in order to become (anions/cations).

30. Explain the meaning of the term "ion charge," using the iron(II) and iron(III) ions as examples.

Unit Review

31. Explain the term "electrolyte." Why do ionic compounds dissolve to form electrolytes but most molecular compounds do not?

32. Many molecular compounds melt below 200°C, while almost all ionic compounds melt above 200°C. Why?

33. Write formulas for the following ionic compounds:
a) lithium chloride
b) barium nitride
c) zinc oxide
d) silver carbonate
e) calcium nitrite
f) rubidium hydrogensulfate
g) cadmium phosphate
h) cobalt(III) hydroxide
i) copper(II) permanganate
j) chromium(III) oxide
k) iron(III) chlorate

34. Write names for the following ionic compounds:
a) $Na_3P_{(s)}$
b) $MgS_{(s)}$
c) $BeCl_{2(s)}$
d) $(NH_4)_2S_{(s)}$
e) $Cs_3N_{(s)}$
f) $ZnI_{2(s)}$
g) $FeF_{2(s)}$
h) $Fe(HS)_{3(s)}$
i) $AuNO_{3(s)}$
j) $Pb(MnO_4)_{4(s)}$
k) $NaCH_3COO_{(s)}$

35. Write formulas for the following molecular compounds:
a) dinitrogen monosulfide
b) sulfur dibromide
c) chlorine monofluoride
d) hydrogen sulfide
e) methane
f) phosphorus pentachloride

36. Write names for the following molecular compounds:
a) $P_4O_{10(s)}$
b) $NO_{2(g)}$
c) $NCl_{3(g)}$
d) $XeF_{6(s)}$
e) $H_2O_{2(l)}$
f) $NH_{3(g)}$

37. Explain how the polarity of water results in cations and anions surrounding it in special ways.

38. Use the solubility table (Table C) in Student Reference 12 to help you answer these questions. For each of the following solutions, state whether adding OH^- to it would result in the formation of no precipitate, one precipitate, or two precipitates. Identify any precipitates.
a) a solution of $CsNO_{3(aq)}$ and $Fe(NO_3)_{2(aq)}$
b) a solution of $CuNO_{3(aq)}$ and $Sr(NO_3)_{2(aq)}$
c) a solution of $AgNO_{3(aq)}$ and $Cd(NO_3)_{2(aq)}$

39. A solution of hydrochloric acid has a pH of 1.0. It is mixed with a small amount of solid sodium hydroxide. After mixing, the pH of the solution is 3.0. Has the solution become more acidic or less acidic? Explain.

40. How can you recognize acids and bases by their formulas?

41. In what ways are alcohol and nicotine similar?

42. Give an example of a regulated substance used in industry. What kinds of regulations may be set in place governing its use?

43. Provide two examples where a chemical reaction and its reverse both occur: one in living systems and one in non-living systems.

44. A chemical reaction occurs inside a beaker. As the reaction progresses, the beaker becomes warmer. Is the reaction endothermic or exothermic? Explain your answer.

45. Explain the difference between a chemical change and a physical change.

Unit Review

46. Write balanced formula equations for the following reactions. Include state symbols:
    a) solid iodine reacts with liquid mercury to produce solid mercury(II) iodide
    b) aqueous potassium phosphate reacts with aqueous strontium hydroxide to produce aqueous potassium hydroxide and solid strontium phosphate
    c) solid magnesium reacts with aqueous hydrochloric acid to produce aqueous magnesium chloride and hydrogen gas

47. Classify each of the following reactions, and balance the equations:
    a) $CaI_{2(s)} + AgNO_{3(aq)} \longrightarrow Ca(NO_3)_{2(aq)} + AgI_{(s)}$
    b) $C_6H_{14(l)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$
    c) $MgCO_{3(s)} \longrightarrow MgO_{(s)} + CO_{2(g)}$
    d) $Li_2SO_{3(aq)} + Au(NO_3)_{3(aq)} \longrightarrow LiNO_{3(aq)} + Au_2(SO_3)_{3(s)}$
    e) $Cs_{(s)} + S_{8(s)} \longrightarrow Cs_2S_{(s)}$
    f) $Al_{(s)} + CuSO_{4(aq)} \longrightarrow Al_2(SO_4)_{3(aq)} + Cu_{(s)}$

48. Classify each of the following reactions. Write the skeleton equation and balance it.
    a) $CaF_{2(aq)} + I_{2(s)} \longrightarrow$
    b) $RbI_{(s)} \longrightarrow$
    c) $C_3H_{8(g)} + O_{2(g)} \longrightarrow$
    d) $Cu(ClO_4)_{2(aq)} + Li_3PO_{4(aq)} \longrightarrow$
    e) $Zn_{(s)} + FeBr_{3(aq)} \longrightarrow$

49. How many moles are present in each of the following?
    a) 8.00 g of $He_{(g)}$
    b) 11.50 g of $Na_{(s)}$
    c) 72.08 g of $H_2O_{(l)}$
    d) 0.251 g of $Na_2SO_{4(s)}$
    e) 6.2 kg of $KCl_{(s)}$

50. What is the mass of each of the following samples?
    a) 2.00 mol of silver atoms
    b) 0.50 mol of $Pb_{(s)}$ atoms
    c) 10 mol of $O_{2(g)}$ molecules
    d) 9.67 mol of carbon disulfide
    e) 0.832 mol of calcium carbonate

Extensions

51. Describe how Antoine Lavoisier's experiments were an improvement over experiments conducted by earlier researchers.

52. The number of protons and electrons in a neutral atom are equal. Why is the atomic number defined as the number of protons rather than the number of electrons?

53. Distinguish between the terms "mass number" and "atomic molar mass."

54. Write the name or the formula for each of the following:
    a) $Na_2O_{(s)}$
    b) $Al_2(OOCCOO)_{3(s)}$
    c) $CH_3OH_{(l)}$
    d) ammonium hydrogenoxalate
    e) propane
    f) ruthenium(IV) dihydrogenphosphate
    g) $N_2O_{4(g)}$
    h) $W(Cr_2O_7)_{3(s)}$
    i) $OsO_{4(s)}$
    j) glucose
    k) platinum(IV) cyanide
    l) sodium thiosulfate

55. Commercial aircraft are equipped with oxygen masks in case of depressurization at high altitudes. A chemical reaction produces the oxygen supplied to the masks. The equation is:

$$KClO_{3(s)} \longrightarrow KCl_{(s)} + O_{2(g)}$$

Suggest at least three reasons why this method of delivering oxygen is better than supplying it from pressurized oxygen tanks.

56. How many atoms or molecules are present in each of the following?
    a) 2.0 mol of $Al_{(s)}$ atoms
    b) 36.0 mol of $SO_{3(g)}$ molecules
    c) 0.023 mol of $He_{(g)}$ atoms

57. How many moles are present in each of the following?
    a) 9.31×10^{22} molecules of $NH_{3(g)}$
    b) 1.63×10^{24} atoms of $Cu_{(s)}$
    c) 3.91×10^{23} molecules of $H_{2(g)}$

Unit Review

Skills Practice

58. A student wanted to verify the law of conservation of mass, so she reacted aqueous calcium chloride with aqueous sodium carbonate in a beaker. Although a precipitate formed, no change in the total mass of the reactants and products was observed. In a second experiment, the student reacted magnesium metal with hydrochloric acid in a beaker. A vigorous reaction occurred, and the mass of the products was several grams less than the mass of the reactants. Why did the law of conservation of mass seem to be obeyed in the first reaction and not in the second reaction?

59. Explain to a friend in a letter or e-mail how to determine whether an unknown liquid is an acid, a base, or neither. Specify several tests to perform, and explain how to interpret the results of the tests chemically. Include some safety precautions.

Self Assessment

60. What is one thing you learned in this unit that you would like to find out more about?

61. Why is it important to consider a variety of alternative perspectives when attempting to regulate the use of a potentially toxic industrial chemical?

62. Describe one aspect of your lifestyle that you could modify to reduce your use of environmentally hazardous materials.