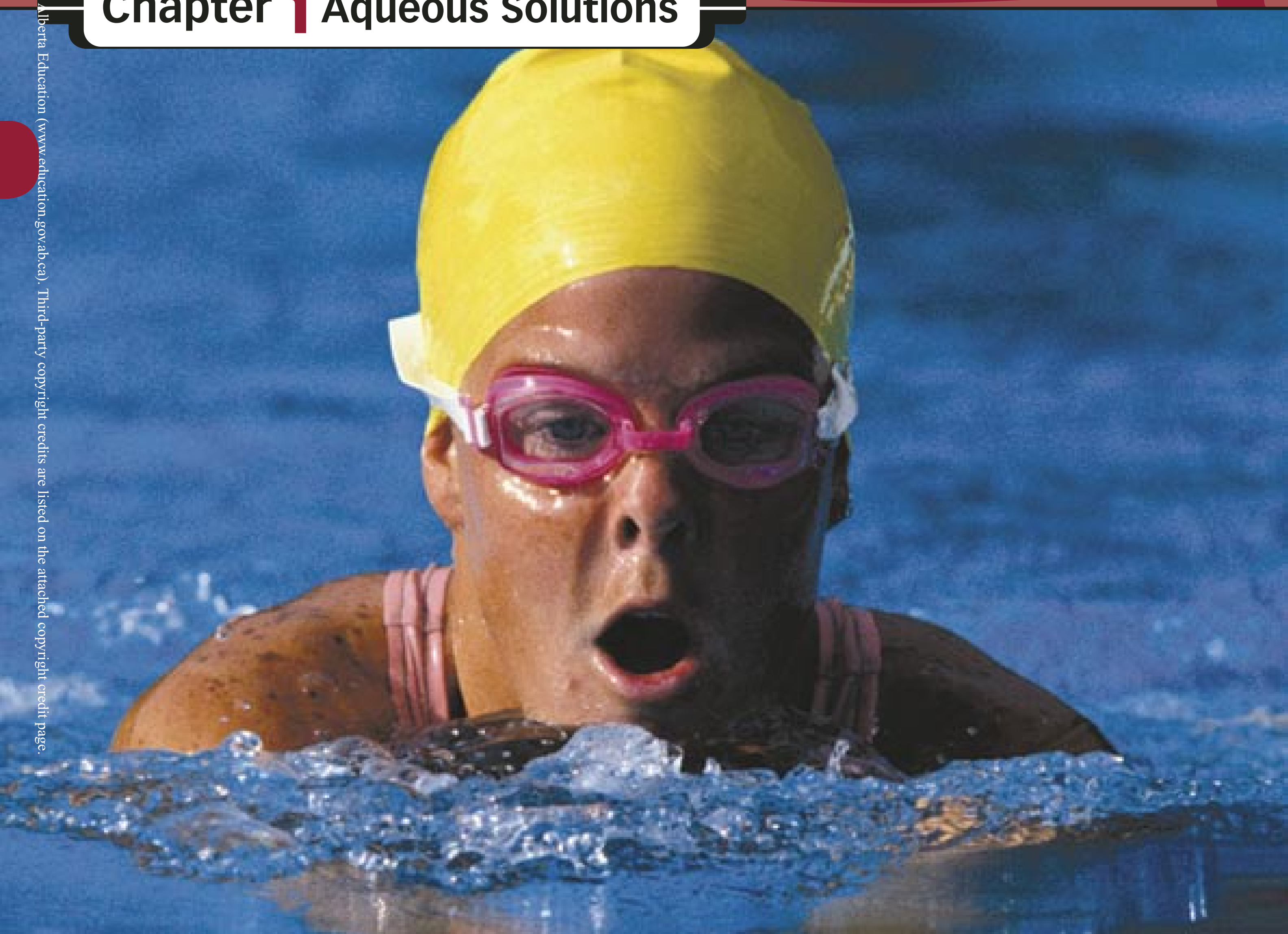
Chapter 1 Aqueous Solutions



Think back to the last time you were in a swimming pool. Was it for swimming lessons, swim-team practice, or having a fun time with your friends? If you have ever been in a pool for more than an hour, you know about the reactions that can occur because your body was exposed to the chemicals in the pool water: sore eyes, itchy skin, and hair that can feel like straw. For athletes playing water polo or training with swim teams, the effects of these chemical reactions may require taking preventative action.

Goggles prevent pool water from coming into contact with the sensitive tissues of the eye, since the plastic lens forms a water-tight boundary between the swimmer's eyes and the water. Similarly, a swim cap helps reduce the contact between a swimmer's hair and the water. This is particularly important for swimmers with blonde hair, as high concentrations of copper in the water have been known to leave a green film that can be noticeable on light-coloured hair.

Another way to reduce these problems is to go to a pool that uses salt water instead of a chlorination system. Many people find that saltwater pools have fewer of the unwanted side effects on eyes, hair, and skin.

A swimming pool is just one place where the properties of solutions are dependent upon the elements and compounds dissolved in them. In this chapter you will look at the building blocks of matter and explore how they connect with each other. You will study how many of the methods developed by scientists to disassemble and reassemble basic parts of matter involve solutions. These methods are used to produce many of the consumer goods you use today.

Try This Activity

Observing Properties

When a product is designed and manufactured, the raw materials are selected based upon their physical and chemical properties and other factors, such as availability and cost.

Science Skills

✓ Performing and Recording

Purpose

You will observe the properties of a number of different substances: aluminium foil, rock salt, and a strip of hard plastic.

Materials and Equipment

- large crystal of halite (or other rock salt)
- piece of vinyl (or other hard plastic)
- piece of aluminium foil
- conductivity meter
- Bunsen burner (or hot plate)
- tongs
- ice
- beaker

CAUTION!

Safety glasses are required for this activity.

Procedure

Read through this entire procedure. Set up a table to record your observations.

step 1: Describe each substance (rock salt, plastic, and aluminium foil). Include a description of the colour, texture, lustre, state, and hardness of each substance.

step 2: Bend each substance. How does each substance react to and recover from the stress of being bent?

step 3: Test the response of each substance to a change in temperature. Pick up a sample of each substance with tongs and carefully bring it near, but not touching, a source of heat (such as a Bunsen burner or a high-temperature hot plate). Take a cool sample of each substance and place it in your hand. Place an ice cube on the upper surface of the substance. Record the time it takes for you to feel the coldness from the ice on your hand.

step 4: Test the electrical conductivity of each substance. Connect a sample of each substance to a conductivity probe, and note if it conducts electricity.

step 5: Test how each substance reacts with water. Place a sample of each substance into a beaker with 50 mL of water for 3 min. Note any changes you observe.

Analysis

1. Looking at the properties you recorded, determine which substance (rock salt, plastic, or metal) would be best suited for each of the following products. Provide a reason for your choice.
   - **a.** lightweight sports gear
   - **b.** diving board
   - **c.** framing material of a building
   - **d.** a cable to conduct electricity
   - **e.** a protective covering for a cable that conducts electricity
   - **f.** heating tiles for a barbecue
   - **g.** the head of a hammer
2. Explain how a substance's properties can determine how you use that substance to make a tool.

1.1 The Structure of Matter

Figure A1.1: It is very important for competitors in any race to be properly hydrated.

The Sun seemed like a blast furnace, forcing all the competitors to contend with the oppressive heat. Despite the lightweight aluminium alloy frames of their bicycles and the ventilation holes in their plastic helmets, it was a challenge for the athletes to keep the pace when even the breeze felt hot. Knowing that harsh conditions would be facing the racers, the event's medical staff made sure that each competitor was properly hydrated before the race started. The fluids were carefully chosen to contain the salts and other substances racers would lose naturally during the race.

The "Observing Properties" activity on page 5 involved testing substances—aluminium, plastic, and rock salt—important to cyclists in a race. What gives these particular materials their unique properties? What is it about the **elements** making up these substances that make them desirable to cyclists?

To answer these questions, you first need to understand the structure of the basic unit of matter—the **atom**.

element: a pure substance that cannot be broken down into simpler substances by chemical means

atom: the smallest part of an element that has all the properties of that element

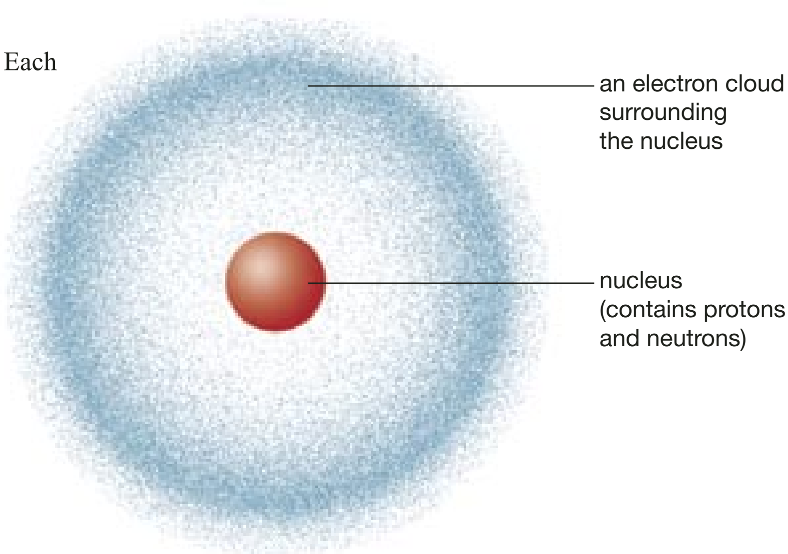
The Atom

Many different kinds of atoms exist in the universe. Each atom, however, is made up of the same three major particles: **protons**, **neutrons**, and **electrons**.

proton: a positively charged particle located in the nucleus of an atom

neutron: a neutral particle located in the nucleus of an atom

electron: a negatively charged particle located in the region surrounding the nucleus of an atom



The number of protons within the atom is so important it is given a special name—the **atomic number**. An atom with one proton, for example, is called a hydrogen atom. Hydrogen atoms have an atomic number of 1. An atom with six protons is called a carbon atom. Carbon atoms all have an atomic number of 6. It is the number of protons that makes the atom of one element differ from the atoms of all other elements.

Neutrons are also located in the nucleus of an atom. To determine the average number of neutrons in an atom, simply subtract the number of protons (the atomic number) from the atom's **atomic mass** and round to the nearest whole number. The sum of the number of neutrons and protons is called **mass number**. This value is always a whole number. For most elements, the difference between the atomic number and the mass number is the number of neutrons in the most common form of the atom.

atomic number: the number of protons in the nucleus of an atom

atomic mass: the average mass of the atoms of an element including all isotopes

mass number: the total number of protons and neutrons in an atom

Comparing Protons, Neutrons, and Electrons

Recall from previous science courses the modern model of the atom. This model has a number of features that are quite surprising. For example, the protons and neutrons make up most of the atom's mass, but these particles do not occupy much volume because they are located in a tiny space in the centre, called the nucleus. The electrons are particles with much less mass, but they move rapidly through the larger region surrounding the nucleus. This is why the space outside the nucleus is often described as "an electrons cloud."

Particle	Location	Mass (g/mol)	Charge
proton	nucleus	1.007 28	1+
neutron	nucleus	1.008 66	0
electron	surrounding nucleus	0.000 549	1–

The electrical characteristics of these particles explain why the fast-moving electrons are bound to the nucleus. Since oppositely charged objects are attracted to each other, the negatively charged electrons are attracted to the positively charged protons. In a neutral atom, the number of protons and electrons are equal, balancing the positive charges with the negative charges.

The electrical characteristics of protons and electrons can also explain why one atom will bond with another. When two atoms approach one another, the atoms may initially repel due to the interactions between the negatively charged outer electrons. However, it is the large concentration of positive charge in each nuclei that can exert greater attractive forces on all electrons in the vicinity.

DID YOU KNOW?

Protons and neutrons are made up of even smaller particles, called quarks.

All matter is made up of a large number of atoms associated with each other. The protons, neutrons, and electrons that make up each atom determine how that atom bonds with other atoms. These particles also determine the physical and chemical properties of each substance.

When you are wondering why a material shines, why it is soft or rigid, or why it has the ability to conduct electricity, you need to ask yourself these questions:

- How are the protons, neutrons, and electrons interacting within that substance?
- What is the structure of the atoms within that substance?

The answers to these questions will provide you with information about the properties of the atoms that make up a substance. They will also provide you with information about how the atoms within a substance interact with each other. You can use these two insights to explain the unique properties of a substance.

Practice

1. Outline the characteristics, location, and how each particle contributes to the properties of an atom.
   a. protons
   b. neutrons
   c. electrons
2. An atom has 6 protons, 6 neutrons, and 6 electrons.
   a. Determine the mass number of this atom. Support your answer.
   b. Determine the identity of this atom. Support your answer.
   c. Does this atom have a charge?
3. An atom has a mass number of 35. It has 18 neutrons and 18 electrons.
   a. Determine the number of protons in this atom. Support your answer.
   b. Determine the identity of this atom. Support your answer.
   c. Does the atom have a charge? Support your answer.
4. Explain why it is important to understand the structure of the atom in order to understand the behaviour of matter.

DID YOU KNOW?

Aluminium is a popular material for building high-quality bicycle frames. It is light and durable. Serious riders really appreciate an aluminium frame because it adds a stiffness that is very desirable when hill climbing.

Sketching Diagrams of Atoms

Once you have determined the number of protons, electrons, and neutrons that make up an atom, it is easy to put this information together to sketch a diagram of the atom of a particular element. The type of diagram often used in this course is called a Bohr diagram, named after the scientist Niels Bohr. Bohr developed the idea that only a certain number of electrons are able to occupy an **energy level**. Electrons in the energy levels closest to the nucleus have the lowest amount of energy.

energy level: a specific region surrounding the nucleus that is available for electrons

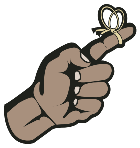
To sketch a Bohr diagram for an atom of a particular element, follow these steps:

step 1: Use the atomic number and atomic mass listed on the periodic table (on pages 554 and 555) to determine the number of protons, electrons, and neutrons (PEN) that make up the atom.

step 2: Draw the nucleus of the atom with the appropriate number of protons and neutrons within the nucleus.

step 3: Use dots to represent the electrons in each energy level that surrounds the nucleus. Each energy level holds a specific number of electrons. The number of electrons in a given energy level is shown by the number of elements in each period (row) on the periodic table. For example, the first energy level can hold two electrons. This is shown by the first period having only two elements: H and He. The second energy level of an atom can hold eight electrons. This is shown by the second period of the periodic table having eight elements: Li, Be, B, C, N, O, F, and Ne.

Remember: Energy levels closest to the nucleus (lower energy levels) are filled first, followed by energy levels farther from the nucleus (higher energy levels).

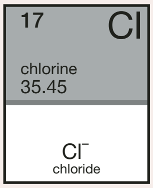


Example Problem 1.1

Sketch a Bohr diagram of the most common form of a chlorine atom.

Solution

step 1: Determine the number of protons, electrons, and neutrons.



P: number of protons = atomic number
= 17

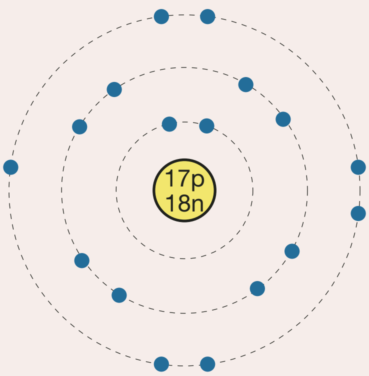
E: number of electrons = number of protons
= 17

N: number of neutrons = atomic mass − number of protons
= 35.45 − 17
= 18 ← rounded

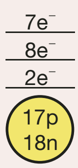
step 2: Draw the nucleus of the atom. The nucleus of the atom contains the protons and neutrons.

step 3: Draw the electrons in their appropriate energy levels. Chlorine has 17 electrons. The first energy level can hold 2 electrons, leaving 15 more to place. The second energy level can hold 8 electrons, leaving 7 more to place. The third energy level can hold 8 electrons, but there are only 7 remaining. The final 7 will fit on the third energy level.

Chlorine



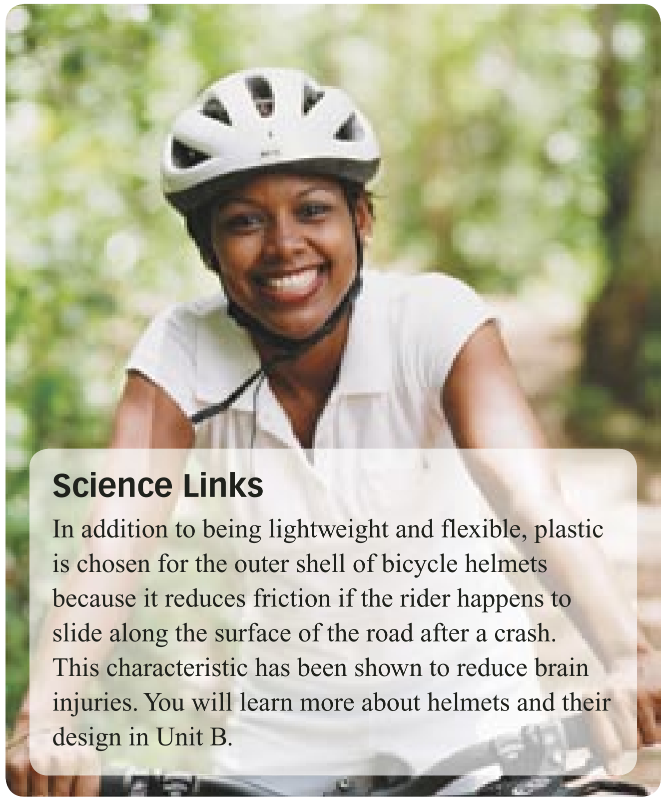
Here is a more concise way to represent the final Bohr diagram.



Practice

5. Draw Bohr diagrams to represent the atomic structure for the most common form of each element.

a. carbon **b.** hydrogen **c.** aluminium
d. lithium **e.** sodium **f.** fluorine
g. neon **h.** helium



Science Links

In addition to being lightweight and flexible, plastic is chosen for the outer shell of bicycle helmets because it reduces friction if the rider happens to slide along the surface of the road after a crash. This characteristic has been shown to reduce brain injuries. You will learn more about helmets and their design in Unit B.

Lewis Dot Diagrams

Lewis dot diagram: a representation of an atom that shows only the valence electrons

The electrons in the outermost energy level become involved in chemical interactions. Therefore, chemists are most interested in these electrons. So, rather than draw Bohr diagrams, a more efficient way to represent atoms is to use **Lewis dot diagrams**.

Drawing a Lewis Dot Diagram of an Atom

step 1: Write the chemical symbol. This symbol will represent the inner electrons and the nucleus.

step 2: Determine the number of electrons in the outermost energy level.

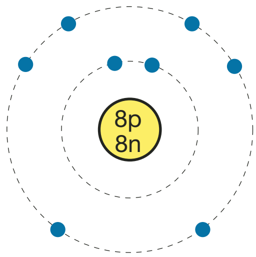
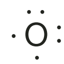
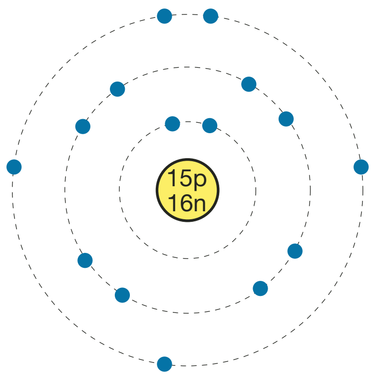
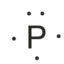
step 3: Use a dot to represent each electron in the outer energy level. The dots are placed on the north, east, south, or west sides of the symbol. Each position only has room for two electrons. Double up on electrons only after all the other positions contain at least one electron.

Example Problem 1.2

Draw the Bohr diagram and the Lewis dot diagram of the atoms for oxygen and phosphorus.

Solution

These diagrams are best organized in a table.

Atom	Bohr Diagram	Lewis Dot Diagram
oxygen		
phosphorus		

Practice

6. Draw the Lewis dot diagram of each of the following atoms.

   a. carbon **b.** hydrogen **c.** aluminium **d.** lithium
   e. sodium **f.** fluorine **g.** neon **h.** helium

Try This Activity

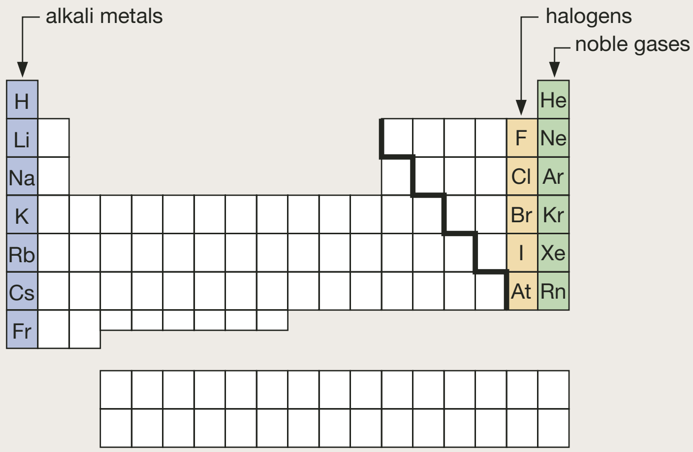
Diagrams of Atoms and the Periodic Table

Science Skills
✓ Analyzing and Interpreting

Background

In the opening to this chapter, you completed an activity in which you observed the properties of different substances. A more detailed version of this same process has occurred over many years as scientists studied the properties of the known elements. Once the results were organized by listing the elements from lowest atomic number to largest, it was noticed that many properties recurred periodically throughout the list. The periodic table is the result of these studies. The vertical columns (or groups) contain families of elements that have the same chemical properties.

The first vertical column (or group) of the periodic table contains a very reactive family of elements called alkali metals. Elements in this group have very similar properties. At the other end of the periodic table, the second-last group contains the halogens. This family of elements is also very reactive and has distinct properties compared to alkali metals. The last group on the right side of the periodic table contains the noble gases. These elements are not reactive and have other properties unique to that group.



Purpose

You will use diagrams of atoms to explore the connections between chemical properties, the periodic table, and the structure of atoms.

Procedure

1. Copy and complete the following table into your notebook. Be sure to leave enough room for your diagrams.

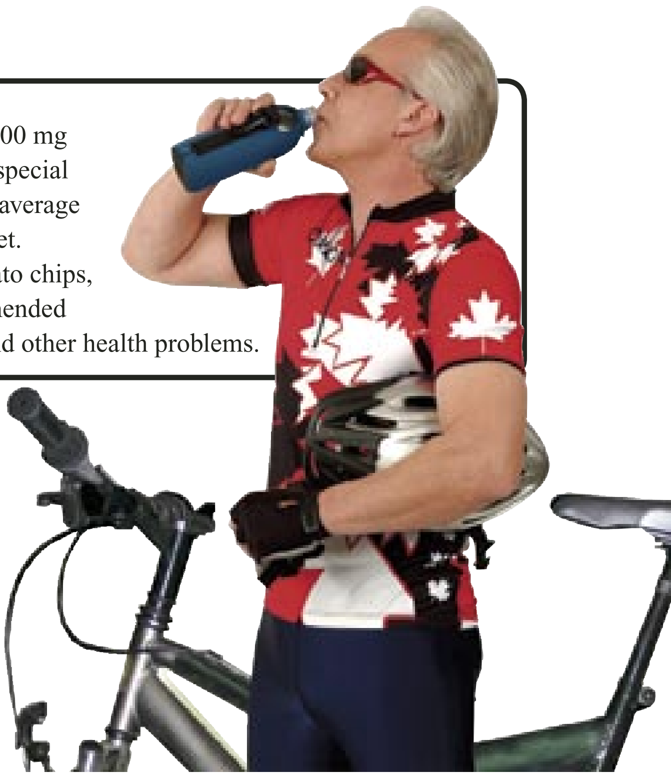
	Atom	Bohr Diagram	Lewis Dot Diagram
Alkali Metals	lithium		
	sodium		
Halogens	fluorine		
	chlorine		
Noble Gases	neon		
	argon		

Analysis

2. Sodium and lithium both come from the same family of elements—alkali metals. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.
3. Fluorine and chlorine are also from the same family of elements—halogens. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.
4. Neon and argon both come from the same family of elements—noble gases. By comparing the structures you drew for these elements, write a hypothesis that explains why these two elements have similar properties.
5. Alkali metals and halogens are very reactive elements. Write a hypothesis that explains why these elements are so reactive in comparison to noble gases.

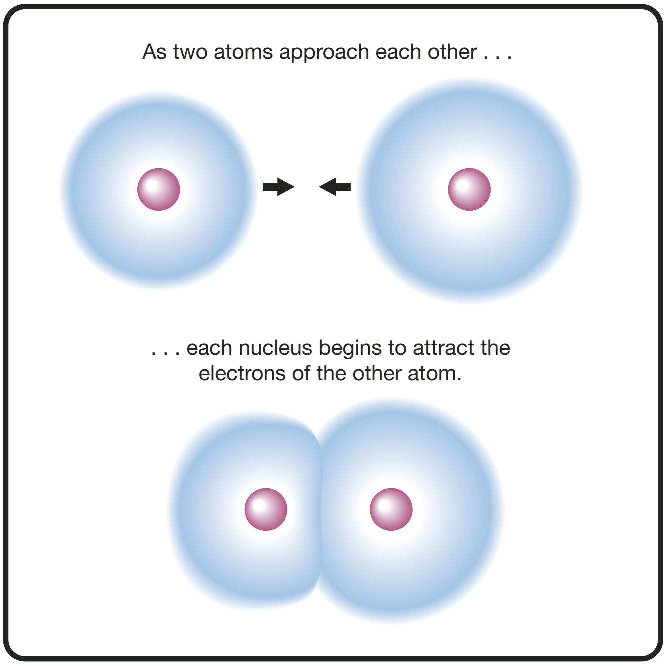
DID YOU KNOW?

World-class cyclists competing in hot weather can lose 400 mg to 800 mg of sodium through perspiration every hour. They plan for this by drinking special fluids during the race to replace the sodium they lose. By comparison, the average person only needs between 200 mg and 500 mg of sodium in their daily diet. Unfortunately, people who eat excessive amounts of salty foods—like potato chips, corn chips, and pretzels—end up consuming many times the daily recommended amounts of sodium. This has been known to lead to high blood pressure and other health problems.



Atomic Bonding

When two atoms come into close proximity to one another, their electrons are attracted to both nuclei.



The electrons in the outer energy level are the most significant electrons in this process. These electrons are called **valence electrons**. Valence electrons are those that indicate the bonding properties of an atom.

valence electron: an electron that occupies the outermost energy level in an atom

If you, for example, look at the Lewis dot diagrams of lithium and sodium, you will notice that their Lewis dot diagrams are very similar—each atom has one valence electron. As a result of their similarity, these two atoms also have similar bonding properties.

lithium	sodium
Li	Na

The same is true if you compare the Lewis dot diagrams of fluorine and chlorine. In this case, both atoms have seven valence electrons. As a result of their similar electron arrangement, these two elements have similar characteristics when they form bonds with other atoms.

fluorine	chlorine
F	Cl

Why are these outer electrons so significant? What characteristic determines the bonding ability of an atom and how it is related to valence electrons? To answer these questions, you need to look at the Lewis dot diagrams of the elements that generally do not react or bond—the noble gases.

Lewis Dot Diagrams of the Noble Gases

helium	neon	argon	krypton	xenon	radon
He	Ne	Ar	Kr	Xe	Rn

If you look at each Lewis dot diagram, you will notice that each atom—helium, neon, argon, krypton, xenon, and radon—has a full outer energy level. Stable atoms, such as these, rarely form bonds as a result of their filled outer energy levels. As you saw earlier, the arrangement of protons, neutrons, and electrons determines the properties of an atom. For noble gases, having their outer energy levels filled with the maximum number of electrons results in these atoms being unreactive.

Atoms can obtain a configuration to become more like a noble gas in one of three ways: by gaining electrons, by losing electrons, or by sharing electrons.

Gaining Electrons

An atom can gain electrons to fill empty spaces in its outermost energy level.

$$:\!\ddot{\underset{\cdot\cdot}{Cl}}\!: + 1e^- \longrightarrow [:\!\ddot{\underset{\cdot\cdot}{Cl}}\!:]^-$$

chlorine atom — chloride ion — P = 17, E = 18, N = 18

Chlorine has one empty spot on its outer energy level. It is easier for chlorine to gain 1 electron than lose 7; therefore, it will gain 1 electron.

By gaining an electron, the chloride ion now has 1 more electron than it has protons. It, therefore, has a charge of 1–.

This results in the atom having more electrons than protons. The net charge for the atom changes to a negative charge. A charged atom is called an **ion**. A negatively charged ion is called an **anion**. Non-metallic atoms have a tendency to become negatively charged ions, or anions.

ion: an electrically charged atom or group of atoms

anion: a negatively charged ion

Losing Electrons

An atom can lose electrons from its outermost energy level to produce a positively charged ion.

$$\dot{Na} \longrightarrow Na^+ + 1e^-$$

sodium atom — sodium ion — P = 11, E = 10, N = 12

The sodium atom has 1 electron in its outer energy level. It is easier for the sodium atom to lose 1 electron than gain 7; therefore, it will lose 1 electron.

By losing an electron, the sodium ion now has 1 more proton than it has electrons. It, therefore, has a charge of 1+.

The net charge for the atom changes to a positive charge. A positively charged ion is called a **cation**. Metallic atoms have a tendency to form cations.

cation: a positively charged ion

Sharing Electrons

An atom can share electrons with other atoms to produce a covalent bond.

$$:\!\ddot{\underset{\cdot\cdot}{Cl}}\cdot + \cdot\ddot{\underset{\cdot\cdot}{Cl}}\!: \longrightarrow :\!\ddot{\underset{\cdot\cdot}{Cl}}\!:\!\ddot{\underset{\cdot\cdot}{Cl}}\!:$$

covalent bond

Both chlorine atoms require 1 electron to fill their outer energy levels. They can share electrons to produce a covalent bond.

Two or more non-metallic atoms tend to share electrons to complete their outer energy levels. You'll learn more about covalent bonds in Lesson 1.2.

Practice

7. Use Lewis dot diagrams to explain how the following atoms obtain a full outer energy level.
   - **a.** oxygen
   - **b.** fluorine
   - **c.** phosphorus
   - **d.** potassium
   - **e.** calcium
   - **f.** lithium
   - **g.** carbon
   - **h.** hydrogen
   - **i.** neon
8. Compare your answers to question 7 with the ion charge for each of the atoms given on the periodic table. Describe any generalizations you can make from this comparison.

1.1 Summary

The variety of products that have become a part of everyday life are made from combinations of the elements listed in the periodic table. The smallest part of each element that still has the properties of that element is called an atom.

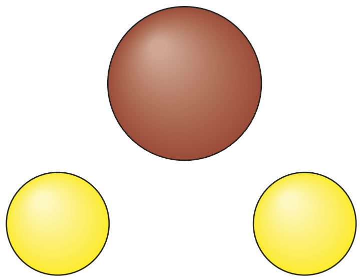


Figure A1.2: To build a model of a water molecule, you need two pieces to represent hydrogen atoms and one piece to represent an oxygen atom.

All the atoms of an element, like hydrogen, are identical and are distinct from the atoms of another element, like oxygen. Even though the atoms of different elements are distinct, they are made from the same basic parts: protons, neutrons, and electrons. You can use the information from the periodic table to sketch a diagram of an atom for a particular element to show how these parts are arranged.

The elements contained in the same vertical column on the periodic table, called groups or families, have the same number of valence electrons and similar properties. An atom is most stable when its outer energy level is filled with electrons. Atoms can gain, lose, or share electrons to obtain a full outer energy level.

1.1 Questions

Knowledge

1. Define the following terms.
   - **a.** atom
   - **b.** proton
   - **c.** neutron
   - **d.** electron
   - **e.** element
   - **f.** mass number
   - **g.** atomic number
   - **h.** energy level
   - **i.** Lewis dot diagram
   - **j.** valence electron
   - **k.** ion
   - **l.** anion
   - **m.** cation
2. Describe in terms of atomic structure how a chlorine atom differs from an oxygen atom.
3. Describe in terms of atomic structure how a sodium ion differs from a sodium atom.
4. Explain why an oxygen atom will tend to produce an ion with a charge of 2−.
5. Explain why a magnesium atom will tend to produce an ion with a charge of 2+.
6. Describe the similarities and differences between an anion and a cation.

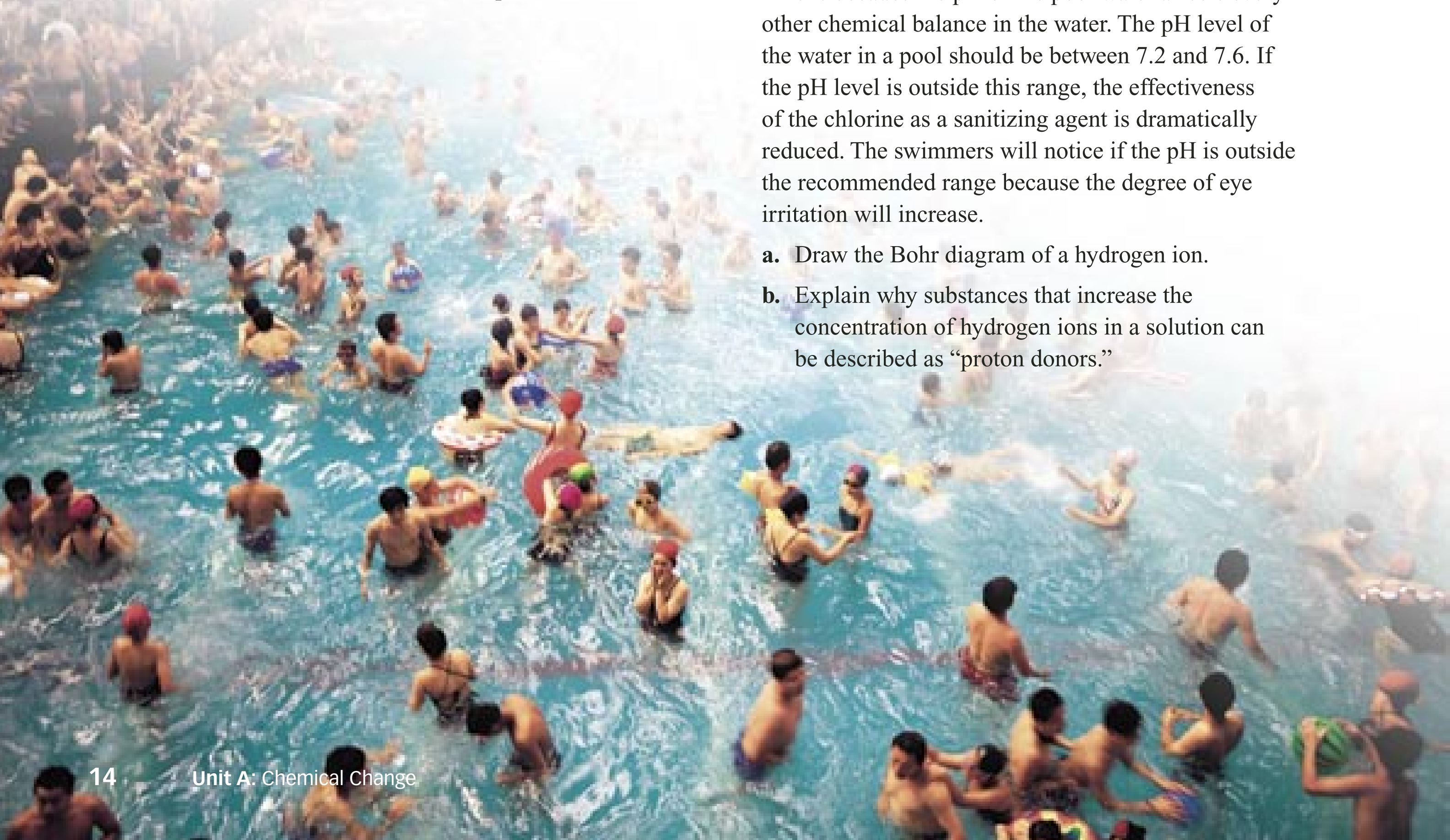
Applying Concepts

7. Create a cartoon that summarizes the characteristics of each particle that makes up an atom.
8. Use Lewis dot diagrams to explain why non-metallic atoms tend to gain electrons to form negative ions and metallic atoms tend to lose electrons to become positive ions.

Use the following information to answer questions 9 and 10.

> In the opening of this chapter, the need for wearing goggles and a bathing cap was linked to the chemistry of the pool water. One of the duties of lifeguards at local pools is to routinely test the water to ensure that key measures of the water's chemistry are within acceptable limits. Typical substances tested include the concentration of hydrogen ions—done as a pH test—and a test for the concentration of chlorine.

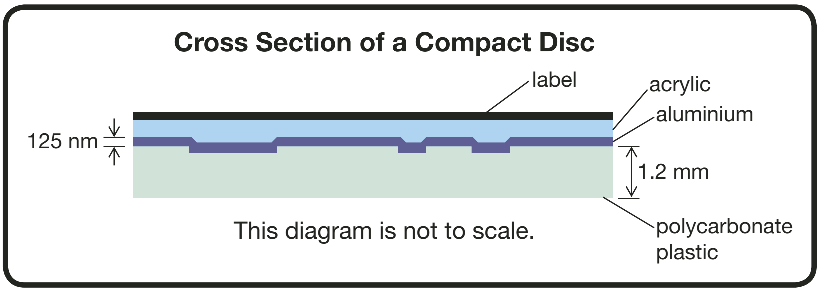
9. Chlorine is added to pool water to act as a disinfectant to kill harmful bacteria. The chlorine can be added as a gas or in combination with other substances in powdered form.
   - **a.** Draw the Lewis dot diagram of a chlorine atom.
   - **b.** Explain why chlorine is a very reactive element.
   - **c.** Chlorine's properties as a powerful disinfectant stem from its ability to react with molecules on the outer surfaces of bacteria and viruses. Provide a reason why chlorine is added to pool water from a special room through a pipe that re-circulates the pool water, and not at the side of the pool next to the swimmers.
10. The most important test in swimming-pool chemistry is the one that determines the pH of the pool water. This is because the pH of the pool water affects every other chemical balance in the water. The pH level of the water in a pool should be between 7.2 and 7.6. If the pH level is outside this range, the effectiveness of the chlorine as a sanitizing agent is dramatically reduced. The swimmers will notice if the pH is outside the recommended range because the degree of eye irritation will increase.
    - **a.** Draw the Bohr diagram of a hydrogen ion.
    - **b.** Explain why substances that increase the concentration of hydrogen ions in a solution can be described as "proton donors."



1.2 Atomic Bonding and Properties

Figure A1.3: Music CDs are made from a type of plastic called polycarbonate.

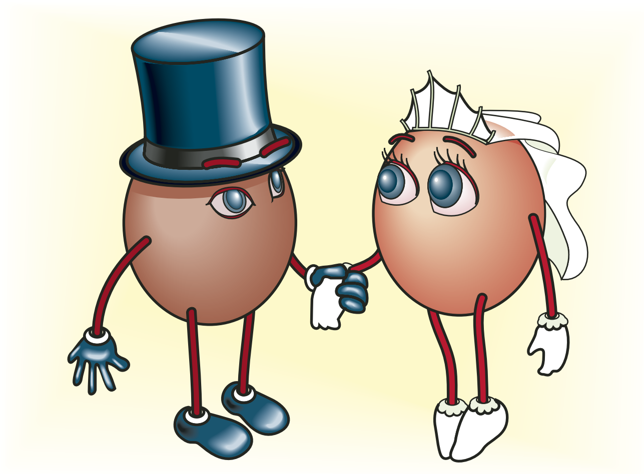
Are you the kind of a person who likes to take your music with you everywhere you go? If so, you probably own some sort of portable audio system. For some people, this involves a personal CD player with headphones. The heart of such a system is the music stored on the CD.



CDs themselves are made of a tough, transparent type of plastic called polycarbonate. A thin layer of aluminium under the label of the CD reflects the laser light from the CD player so it can read the musical information encoded in a microscopic series of pits and bumps. To protect the aluminium, a thin layer of acrylic is sprayed on top. The label for the CD is then printed onto the acrylic. It is amazing that commercially sold music CDs can be produced so inexpensively, given the intricate and incredibly small structure of the pits and bumps on the CDs. The costs are kept low by using a stamping process. The stampers themselves are produced by an electrochemical process that uses salt and other substances in a chemical bath to create the stampers from a glass master copy.

The same three substances you examined in the introduction to this chapter—aluminium, plastic, and salt—are all used in the process of manufacturing CDs. Clearly, the manufacturing process depends upon knowing the individual properties of each of these materials. In addition, it is critical to know how each of these bond with other materials.

Principles for Understanding Bonding



In Lesson 1.1 you were introduced to some important principles that play a key role in understanding the bonding behaviour of atoms. These principles are as follows:

- An atom is most stable when its outer energy level is full of electrons.
- Atoms can obtain full outer energy levels by gaining electrons, by losing electrons, or by sharing electrons with other atoms.
- If an atom gains electrons, it becomes negatively charged. If it loses electrons, it becomes positively charged.
- Negatively charged particles and positively charged particles attract each other, and similarly charged particles repel each other.

These principles will be used to sketch the atomic structure of a variety of substances. Once you have sketched diagrams of the atomic structures of rock salt, a piece of plastic, and a piece of metal, you will be better able to explain the properties of these different materials. Sketching the atomic structure of substances containing more than one atom has four basic steps.

Process for Sketching Atomic Structure

step 1: Draw the Lewis dot diagram of each atom that makes up the substance.

step 2: Determine which atom needs the most electrons to fill its outer energy level. Draw the Lewis dot diagram of this atom in the centre of your diagram.

step 3: Connect the atoms in a way so each atom's outer energy level is filled. Examine the finished diagram.

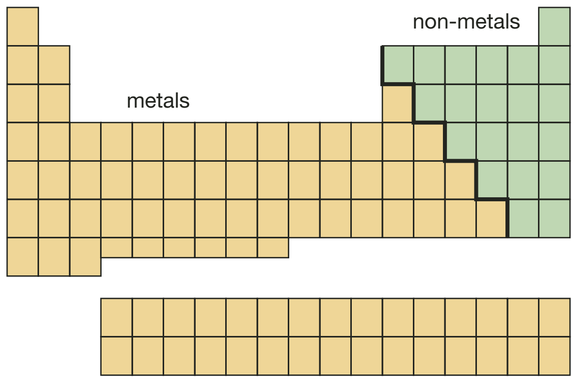
step 4: Make sure each atom has a completely filled outer energy level. If it doesn't, repeat step 3.

Aluminium

Aluminium is a **metal**. This means that aluminium has lustre and good heat and electrical conductivity. It also means that aluminium is malleable (can be hammered into different shapes without crumbling) and ductile (can be stretched to form long wires). Chemists classify all the elements that lie to the left of the staircase line on the periodic table as metals. The elements to the right of this line are classed as **non-metals**.

metal: a malleable and ductile element that has lustre, has good heat and electrical conductivity, and tends to form positive ions

non-metal: an element that is not flexible, does not conduct electricity, and tends to form negative ions



Metals tend to form positively charged ions or cations, whereas non-metals tend to form negatively charged ions or anions. So, if you are handling a piece of aluminium, you are holding a collection of positive ions. If the aluminium ions are all positively charged, why do these ions stay together? Shouldn't they repel one another? The answers to these questions are explained in Example Problem 1.3.

Example Problem 1.3

Following the process of sketching atomic structure, illustrate how atoms of aluminium bond together to form a solid piece of aluminium metal.

Solution

step 1: Draw the Lewis dot diagram of the atom.

aluminium

$\dot{\underset{\cdot}{\mathrm{Al}}}\cdot$

continued on next page

step 2: Determine how the atom can fill its outer energy level.

An aluminium atom can obtain a full outer energy level by

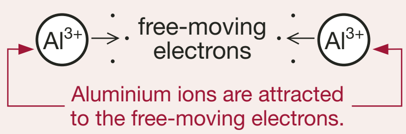
- gaining five electrons
- losing three electrons

It is much easier to lose three electrons than it is to gain five. So, an aluminium atom will tend to lose three electrons to become a stable aluminium ion.

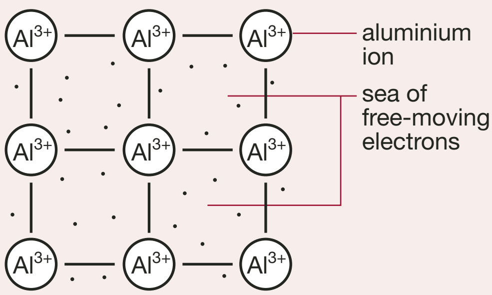
$$\dot{\underset{\cdot}{\mathrm{Al}}}\cdot \longrightarrow \mathrm{Al}^{3+} + 3e^{-}$$

step 3: Make a bond with aluminium ions.

Two aluminium ions are both positive ions. Why would they stick together if they naturally repel each other? The key to this answer is that both atoms lost electrons to become ions.



You can think of a strip of aluminium metal as aluminium ions remaining together because of their mutual attraction to free-moving electrons.



Note that there are an equal number of protons and electrons in this system. So, even though the electrons are free moving, overall, each atom is still neutral.

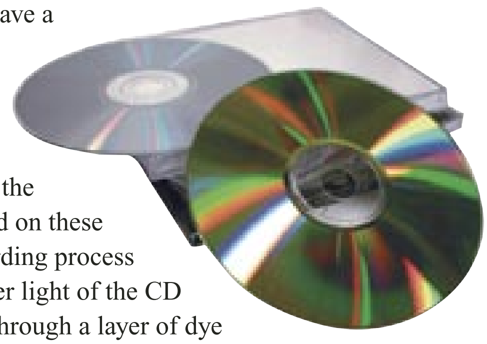
Practice

9. Sketch the atomic structure for each of the following. Follow the steps outlined in Example Problem 1.3.
   - **a.** beryllium
   - **b.** magnesium

Metal Coatings

It is the lustre of aluminium that makes it a good candidate for the prerecorded CDs you buy in a music store; it reflects the laser light very well. The other possible metals include gold, silver, and copper. Gold and silver are more reflective, but they are more expensive.

You may have noticed that many recordable compact discs, CD-Rs, have a different colour than the prerecorded CDs. That's because gold is the metal often used on these discs. The recording process requires the laser light of the CD burner to pass through a layer of dye in the recording process. So, the extra expense is warranted in this case because a more reflective metal is required.



Rock Salt

Rock salt is a **compound** called sodium chloride; it is made up of the elements sodium and chlorine. Since sodium is a metal and chlorine a non-metal, the resulting compound is called an **ionic compound**.

The ions in sodium chloride are held together by the force of attraction between the positive sodium ions and the negative chloride ions. This is called an **ionic bond**.

Example Problem 1.4 will show you how to apply the process to produce a sketch of the atomic structure of sodium chloride. This example will also shed light on why sodium chloride forms rectangular crystals.

compound: a pure substance formed from atoms of two or more elements with the different atoms joined in fixed ratios

ionic compound: a pure substance formed from a metal and a non-metal

ionic bond: a bond formed by the simultaneous attraction between positive and negative ions

Figure A1.4: The special lighting of this photograph reveals the rectangular crystals of sodium chloride (or salt).

Example Problem 1.4

Sketch a diagram illustrating how the atoms of sodium and chlorine form ions and bond together to make sodium chloride—a common crystalline compound.

Solution

step 1: Draw the Lewis dot diagram of each atom.

sodium	chlorine
Na	Cl

step 2: Determine how each atom can obtain a full outer electron energy level.

Na

A sodium atom can obtain a full outer energy level by

- gaining seven electrons
- losing one electron

Metals tend to have a weaker attraction for valence electrons; therefore, they tend to lose electrons. So, a sodium atom will tend to lose one electron to become a stable sodium ion.

$$Na \longrightarrow Na^{+} + 1e^{-}$$

Cl

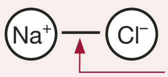
A chlorine atom can obtain a full outer energy level by

- gaining one electron
- losing seven electrons

Non-metals tend to have a greater attraction for valence electrons; therefore, they tend to gain electrons. So, a chlorine atom will tend to gain one electron to become a stable chloride ion.

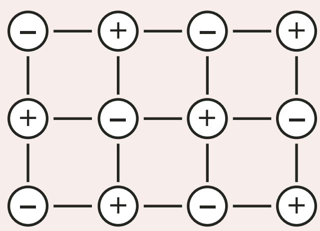
$$Cl + 1e^{-} \longrightarrow Cl^{-}$$

step 3: Make a bond with positive and negative ions.



The ionic bond is represented by a line segment between the ions.

Positively charged ions are attracted to negatively charged ions, and vice versa. This attraction holds the substance together to form a sodium chloride crystal.



Each ionic crystal results from the natural attraction of positive and negative ions.

Practice

10. Sketch the atomic structure for the following ionic crystals.

a. calcium oxide

b. potassium chloride

History and Salt

Throughout history, salt has been a highly prized commodity. Because of its ability to inhibit the growth of bacteria, it has been and still is used to preserve food.

DID YOU KNOW?

In ancient Rome, soldiers were paid in salt, called "salarium argentum." This is the origin of the modern word *salary*.

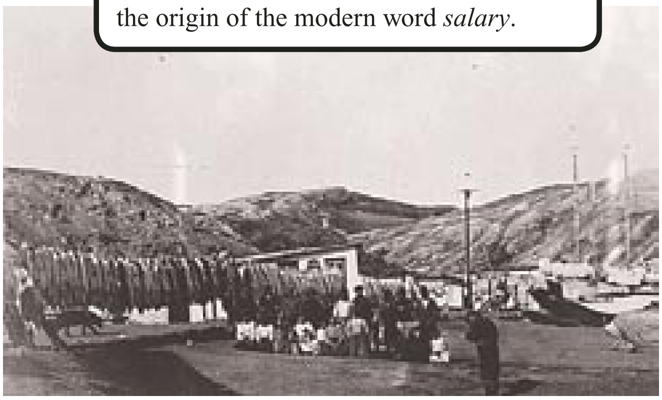


Figure A1.5: Fur is hung out by the building at the Hudson's Bay Company post at Lake Harbour, NWT.

Canada's First Nations peoples prized salt because it was used to cure meat and fish and to tan hides. Outcroppings of salt were often considered sacred places because of the deer, elk, bear, and bison that were attracted to these natural salt licks. The Dene Th'a people utilized the natural salt deposits found on the Salt Plains in Wood Buffalo National Park. These people used the salt at this site for their own needs and as a valuable commodity for trade.

Plastics

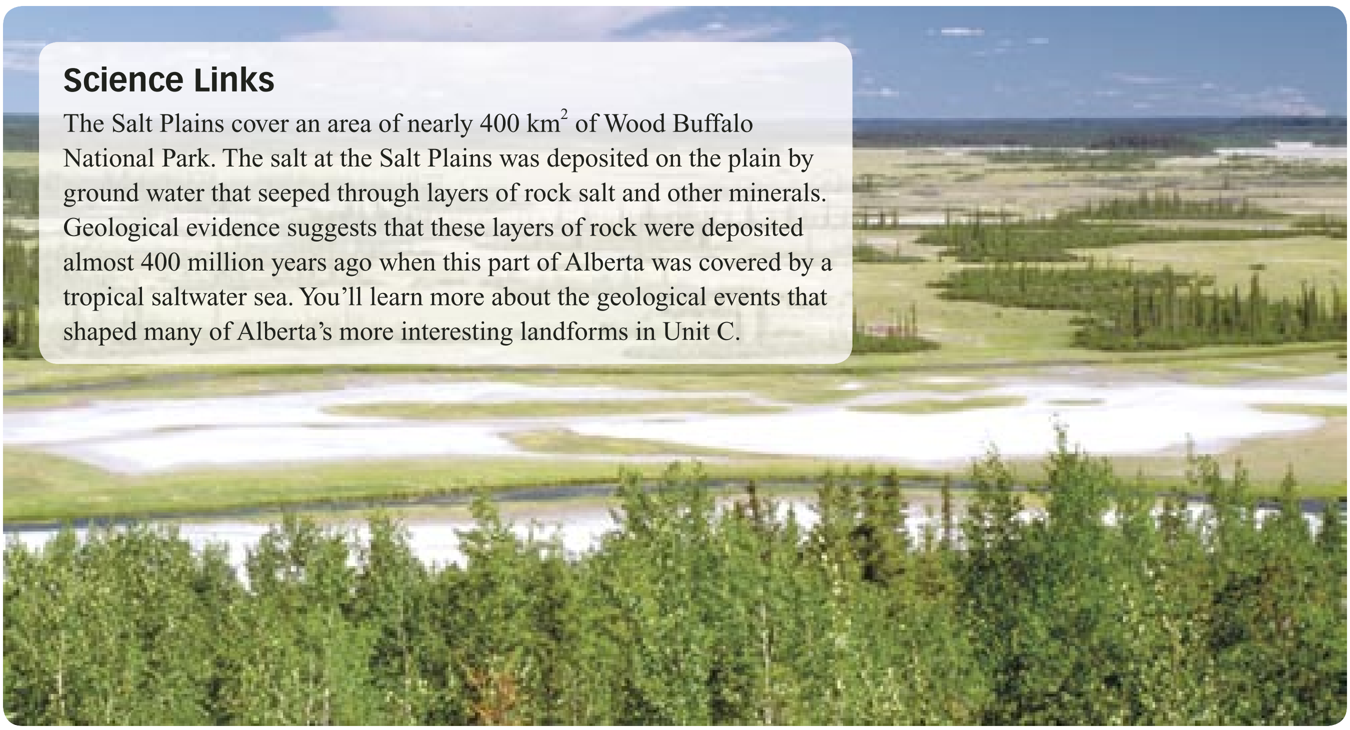
Although you will look at plastics in much greater detail in Chapter 3 of this unit, for now, the essential idea is that plastics are primarily made up of carbon and hydrogen atoms. Since both carbon and hydrogen are non-metals, the resulting combination is called a **molecular compound**.

Molecular compounds do not involve ions. So, the carbon and hydrogen atoms are held together because the nucleus of a carbon atom is simultaneously attracted to the same electrons as the nucleus of a hydrogen atom. This simultaneous attraction is called a **covalent bond**.

The resulting combination of carbon and hydrogen atoms is called a **molecule**.

- **molecular compound:** a pure substance formed from non-metals
- **covalent bond:** a bond formed by the simultaneous attraction of two nuclei for a shared pair of electrons
- **molecule:** a particle containing a fixed number of covalently bonded, non-metal atoms

The basics of sketching a diagram of a molecule consisting of carbon and hydrogen atoms is illustrated in Example Problem 1.5. You'll do this in more detail in Chapter 3.



Science Links

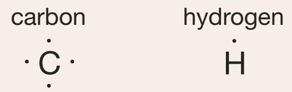
The Salt Plains cover an area of nearly 400 km^2 of Wood Buffalo National Park. The salt at the Salt Plains was deposited on the plain by ground water that seeped through layers of rock salt and other minerals. Geological evidence suggests that these layers of rock were deposited almost 400 million years ago when this part of Alberta was covered by a tropical saltwater sea. You'll learn more about the geological events that shaped many of Alberta's more interesting landforms in Unit C.

Example Problem 1.5

Sketch a diagram illustrating how atoms of carbon and hydrogen bond together to form a long, chain-like molecule.

Solution

step 1: Draw the Lewis dot diagram of each atom.



step 2: Determine how the atoms can obtain a full outer energy level.

A carbon atom can obtain a full outer energy level by

- gaining four electrons
- losing four electrons

In a case like this, an atom will often share electrons.

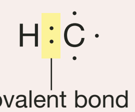
A hydrogen atom can obtain a full outer energy level by

- gaining one electron
- losing one electron

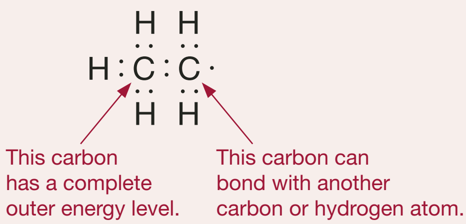
In a case like this, an atom will often share electrons.

step 3: Make bonds with two non-metal atoms.

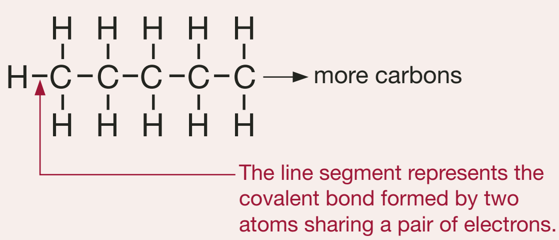
Non-metal atoms, like carbon and hydrogen, tend to require electrons to fill their outer energy levels. When this situation occurs, both atoms share electrons to form a covalent bond.



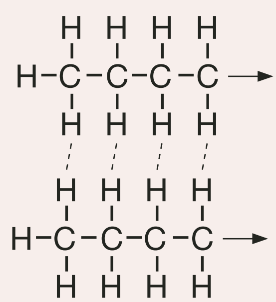
In this diagram, the carbon atom still does not have a full outer energy level. So, it will either bond with more hydrogen atoms or more carbon atoms.



A plastic strip is made up of long strands of carbon atoms sharing electrons with one another and with hydrogen atoms. Each long strand is a molecule.



Adjacent strands will have a slight attraction toward each other, forming the piece of plastic.



Plastics All Around You

Figure A3.6: Polycarbonates are used to make a variety of consumer goods.

Polycarbonate, a type of plastic used to make CDs, consists of long molecules—each molecule built around a backbone of over a thousand carbon atoms. The recipe can be varied to produce products that are incredibly resilient, like bulletproof window glazing. Future applications might include a plastic coating for automobiles that is scratchproof. This will eliminate the need to paint vehicles.

The same properties that make plastics like polycarbonates highly desirable become a significant liability when it comes to disposal. The fact that these materials are strong, durable, and resistant to the effects of heat, cold, water, weather, and even ultraviolet light means that recycling plastics has become very important, given the limited space available for landfills.

The thin metal coating on CDs makes it even more difficult to recycle the polycarbonate in these products. Given the widespread use and popularity of CDs, special recycling centres have been developed to reclaim the polycarbonate for the manufacture of automobile parts.

Categories of Matter

Earlier, you sketched diagrams of the atomic structure of commonly found categories of matter: an ionic compound, a molecular compound, and a metal.

Common Name	Atoms That Make Up This Substance	Category of Matter	Properties
rock salt	sodium and chlorine	ionic compound	• brittle • high melting point • soluble in water
hard plastic	carbon and hydrogen	molecular compound	• flexible • low melting point • insoluble in water • does not conduct electricity
aluminium foil	aluminium	metallic element	• malleable • high melting point • insoluble in water • a good conductor of heat and electricity

Everything you own, see, and interact with is comprised of substances that are made from atoms. If you want to understand the properties of a substance, a good place to begin is by identifying the category of matter. The next step is to link the diagrams of the atomic structures you sketched for that category of matter to the properties of these materials.

Practice

11. Draw a representation of the structure of the following substances. Identify the substance that contains ionic, covalent, or metallic bonds.

a. magnesium oxide, MgO
b. a sample of calcium
c. a water molecule, H_2O

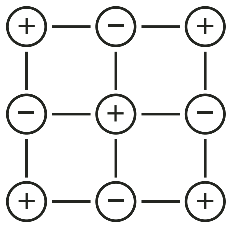
Explaining the Properties of Categories of Matter (Extension)

Thus far, you have looked at the structure and composition of three types of matter: an ionic compound, a molecular compound, and a metal. You can use these three models to explain the unique properties you noted in the "Observing Properties" activity in the chapter introduction on page 5.

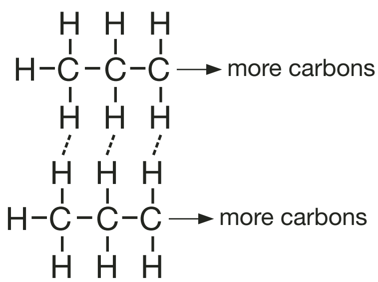
Why are molecular compounds more likely to melt if heated?

When subjected to high temperatures, the three tested substances responded differently. The rock salt (an ionic compound) and the aluminium foil (a metal) change little when heated compared to the plastic (a molecular compound). The attractive forces between particles in metals and in ionic compounds must be stronger, since these substances changed little when exposed to high temperatures.

Strong Ionic Bonds



The bonds within an ionic compound are very strong because you have full negative and positive charges attracting each other.



There is only a slight attraction between molecules within a molecular compound.

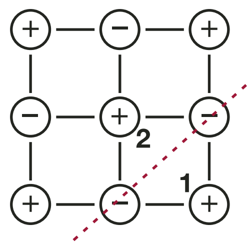
The plastic quickly melting next to a heat source suggests that the bonds between atoms in this molecular compound must be weaker in comparison to ionic bonds. Generally speaking, the compounds composed of atoms with covalent bonds will melt at lower temperatures than ionic compounds.

Figure A1.7: Plastic food containers will start to melt if they are left too close to a heat source.

Why do ionic crystals snap if you try bending them?

If you attempt to bend an ionic crystal, you may bring like charges next to each other. Like charges repel each other, and the crystal will break.

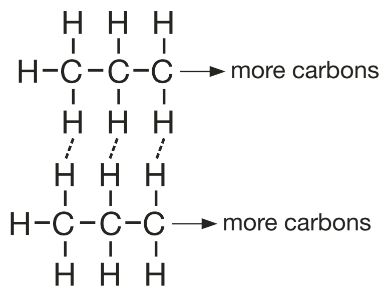
Bending an Ionic Compound



If you bend the crystal along the dotted line, positive ion **1** will come closer to positive ion **2**. They will repel each other, causing a break in the crystal structure.

The atoms of molecular compounds are not charged. Therefore, when bent, the atoms do not repel one another.

Bending a Molecular Compound

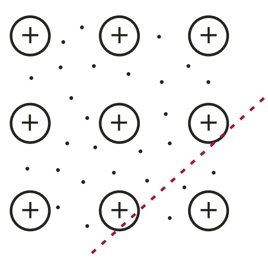


There are no positive or negative charges in molecular compounds. (If there are, they are very weak.) If you fold them, no like charges will come close to each other.

The electrons within a collection of metal atoms are held less tightly to any individual atom than the electrons involved in either an ionic or molecular compound. It is the free electrons that give a metal its ability to bend.

The nuclei of the metal atoms within the structure of a metal are all positively charged, so you would think the metal would snap if you bend it. However, the electrons of all the metal atoms act as a cushion between the repulsive force if two metal ions come too close to each other. Metals can be bent because of the movement of free electrons.

Bending a Metal

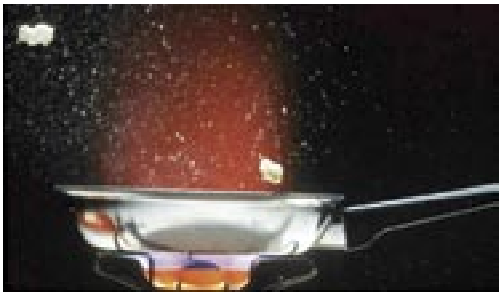


If you bend the metal along the dotted line, the positive ions do come closer to each other; however, the free electrons will move to cushion the repulsive force.

Why did metal effectively conduct heat and electricity?

In the "Observing Properties" activity on page 5, the aluminium (metal) foil was the only substance to conduct electricity. Since an electric current involves the movement of charges along a path or circuit, can you think of a reason why the metal was the best conductor of electricity?

Think back to your diagram of metallic bonding. In the metal, the valence electrons are held less tightly by the bonding between atoms. Since the electrons have the ability to move throughout the metal, some people describe the electrons as behaving like an "electron gas"—able to drift and flow among the positive metal ions. An external circuit takes advantage of this arrangement and introduces a stream of moving electrons—an electric current—that can move through the electron gas quite easily. In an ionic crystal or molecular compound, the electrons are held so tightly that there is no path for the external electric current to flow.



You might be surprised to know that the free electrons are also responsible for metals being good conductors of heat. If the end of a piece of metal is exposed to a source of heat, the positive ions within the metal closest to the heat source begin to vibrate more. Although some energy is transferred to the neighbouring metal ions, most of the energy is transferred to the nearby free electrons. These free electrons can then move to the cold end of the metal and transfer this energy to another positive metal ion, causing it to vibrate more. Again, in an ionic crystal or molecular compound, there are no free electrons available. In these materials the heat is passed from one vibrating ion or atom to its neighbour, which is a much slower process.

Why did the rock salt start dissolving in the water?

Only rock salt—the ionic compound—responded to the addition of water. Water is able to dissolve many ionic compounds; and, as you will see later in this chapter, diagrams that show the bonds in matter can help explain why this occurs.

Looking at matter in terms of atoms and atomic structure is a powerful tool. Understanding the atomic structure of a substance helps explain the observations you make about matter every day. You will be referring to these diagrams throughout this unit; so, make sure you have a good understanding of them.

Practice

12. a. Draw diagrams of the atomic structure of the ionic compound potassium chloride, KCl, the molecular compound methane, CH_4, and the metal magnesium, Mg. Use these models to explain the observations in 12.b. to 12.e.

b. Insulators prevent electrical conduction. Molecular compounds make excellent electrical insulators, whereas metals make excellent electrical conductors.

c. Many minerals in rocks are composed of ionic compounds. If you try bending a rock, it will snap.

d. Heat travels along a metal coat hanger as you use it to roast a marshmallow over an open fire.

e. The end of a coat hanger is black after you take it out of an open fire.

1.2 Summary

Atoms bond with each other to form a variety of substances. The properties of a particular substance can be explained by sketching diagrams of the atomic structure of the atoms, ions, and molecules it is composed of. Ionic, covalent, and metallic bonds result in matter having unique properties.

1.2 Questions

Knowledge

1. Define the following terms.
   - **a.** compound
   - **b.** metal
   - **c.** ionic compound
   - **d.** ionic bond
   - **e.** covalent bond
   - **f.** molecule
   - **g.** molecular compound
2. Identify the difference between each pair of terms.
   - **a.** a chlorine atom and a chloride ion
   - **b.** a sodium ion and a chloride ion
   - **c.** an ionic bond and a covalent bond
   - **d.** an ionic compound and a molecular compound

Applying Concepts

3. Explain why using sketches of the atomic structure of a substance improves the ability to explain the physical properties of a substance.
4. Refer to valence electrons. Explain why non-metal atoms tend to gain electrons to form negative ions and metal atoms tend to lose electrons to become positive ions.
5. Metallic substances have "free" electrons moving around positive ions. List three metallic properties that result from these "free" electrons.

1.3 Breaking Bonds

Figure A1.8: Alchemy dates back to the ancient Egyptians.

Humans have been attempting to manipulate matter since the time of the ancient Egyptians, when the pseudoscience called *alchemy* developed. The goal of alchemy was to find some way to change non-precious metals, like lead, into gold—turning a resource of lesser value into a product of greater value. Alchemists were unsuccessful in many of their goals, but they did learn much about matter and became the forerunners of chemistry.

The alchemist's mind-set—wanting to turn resources into products of greater value—is still very much alive in modern societies. Today, industries take resources from Earth and chemically change them into the products you buy as a consumer. Industries are able to carry out this transformation because of their knowledge of matter. They change matter from raw materials into finished products by applying chemical properties.

How are raw materials transformed into products? In Lesson 1.2 you explored the different ways in which atoms bond with each other to form matter. You also found that the different categories of matter are made up of different combinations of atoms. To make a specific material, you need to create a specific combination of atoms. To create a specific combination of atoms, you need to do the following:

1) Find a natural source of the atoms you want. These atoms most likely will be bonded in a way that is different from what you want.
2) Break the existing bonds between the atoms in the natural source to separate them.
3) Create new bonds between the atoms required to form your product.

Assuming you have a natural source of the atoms you require, how can the existing chemical bonds between atoms be broken? For many substances, it is just a matter of adding water.

Practice

13. Outline the similarities and differences between the goals and methods of alchemy and the goals and methods of modern industry.

14. List the steps that must occur for you to successfully change a resource into a desired product.

15. Explain why it is necessary to disassemble the bonds of a resource before you assemble the bonds required for a desired product.

Observing Chemical Change

You can tell a **chemical change** is occurring if a new substance is produced, accompanied by a change in colour, odour, state, or energy. Changes in state usually involve the formation of a gas or a solid. Changes in energy may be **exothermic**—energy is released—or **endothermic**—energy is absorbed. Chemical changes indicate that bonds between atoms in the original substances have been broken and that bonds have been formed to create new substances. In the next activity you will observe chemical change.

- **chemical change:** a change in which one or more new substances with different properties is formed
- **exothermic change:** a chemical change in which energy, usually in the form of heat, is released into the surroundings
- **endothermic change:** a chemical change in which energy is absorbed from the surroundings

Try This Activity

Water Helps Break Chemical Bonds

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will observe a chemical change.

Materials

- 4, 100-mL beakers
- 10 mL (2 teaspoons) of cobalt(II) nitrate, $Co(NO_3)_2(s)$ (powder)
- 10 mL (2 teaspoons) of sodium carbonate, $Na_2CO_3(s)$ (washing soda)
- 20 mL of distilled water

CAUTION!
Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Carefully add 5 mL of cobalt(II) nitrate, $Co(NO_3)_2(s)$, to a beaker.

step 2: Add 5 mL of sodium carbonate, $Na_2CO_3(s)$, to the beaker with the cobalt(II) nitrate. Stir the two solids together and note any signs of chemical change.

step 3: Add 5 mL of cobalt(II) nitrate, $Co(NO_3)_2(s)$, to another beaker.

step 4: Add 10 mL of water to the beaker with the cobalt(II) nitrate, and dissolve the crystals.

step 5: Repeat steps 3 and 4 with sodium carbonate, $Na_2CO_3(s)$.

step 6: Combine the two solutions, and note any evidence of chemical change.

Analysis

1. Compare your observations in step 2 with those in step 6.
2. Describe the effect water appears to have on solid cobalt(II) nitrate and solid sodium carbonate. Describe the effect water has on this chemical reaction between the two substances.
3. Write the chemical equations for step 2 and for step 6. Be sure to communicate the states of each substance.
4. Provide an explanation for both of your observations in this activity.

Solutions: An Excellent Medium for Chemical Changes

A **solution** is a mixture made up of more than one type of particle, where the particles intermingle with one another. Solutions appear as though they are composed of only one substance, even though they contain more than one species within them. Many of the reactions that occur in the world occur when matter is dissolved in water, forming an **aqueous solution**.

solution: a homogeneous mixture of dissolved substances that contains a solute and a solvent

aqueous solution: a solution in which water is the solvent

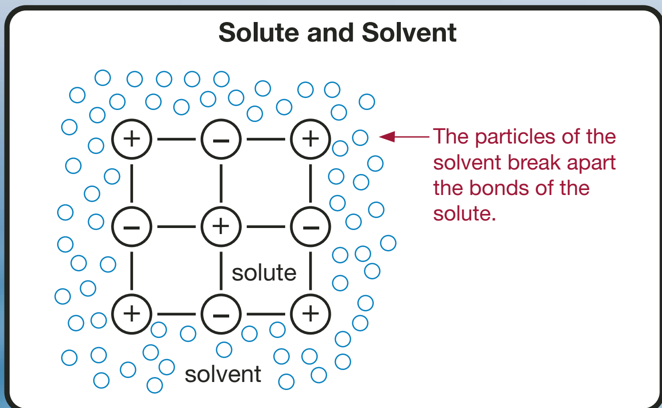
Figure A1.9: The salt crystals are no longer visible because the water broke the bonds of the ionic crystal.

Why does the salt solution shown in Figure A1.9 appear transparent? Where have the particles of the ionic crystal gone? In the "Water Helps Break Chemical Bonds" activity—where you added water to solid cobalt(II) nitrate—the ionic bonds between the positive cobalt(II) ions, Co^{2+}, and the negative nitrate ions, NO_3^-, were broken. The particles of the ionic crystal became dispersed throughout the water. The cobalt ions are responsible for the pink colour of the solution. The ionic compound has dissolved, but why does it appear to break apart?

When something becomes dissolved, its bonds have been broken down in some way. As the bonds break, the particles separate and are then free to move as individuals throughout the solution. These particles can be either molecules or ions. The substance that is broken down is called the **solute**, and the substance that breaks the bonds of the solute is called the **solvent**. Remember, a solute dissolves in a solvent.

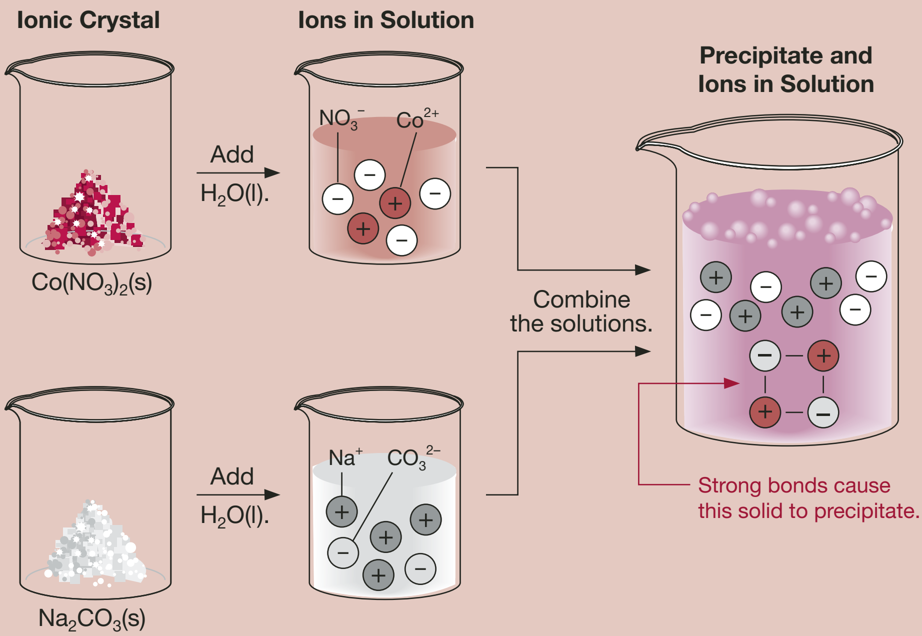
solute: a substance in a solution whose bonds are broken by a solvent; a substance that dissolves

solvent: a substance in a solution that breaks down the bonds of a solute; a substance that does the dissolving and is in greater proportion in the mixture



Using a solvent, like water, is an excellent way to break down certain types of bonds in a substance. For this reason, many reactions naturally occur in solution. When a solute has been broken down into its individual parts, these parts are no longer bonded to other ions. This allows each ion to collide with and form new bonds with substances introduced into the solution. In the "Water Helps Break Chemical Bonds" activity, you purposely broke the bonds between the cobalt(II) ions and the nitrate ions and the bonds between the sodium ions and the carbonate ions with the addition of water, which acted as a solvent. Once the old bonds were broken, the particles were free to collide and form new bonds, some of which resulted in the formation of the precipitate cobalt(II) carbonate, $CoCO_3(s)$.

Solutions: An Excellent Medium for Chemical Change



Practice

16. Define and provide an example for the following terms.
    a. solution
    b. solute
    c. solvent
17. Explain why solutions look as though they are only one substance.
18. Compare and contrast the concept of dissolving with the concept of melting.
19. Explain how water is an excellent medium for chemical change.
20. Refer to the "Water Helps Break Chemical Bonds" activity on page 25. Identify the solvents and solutes you encountered.

Why Is Water a Good Solvent?

Take an inflated balloon and rub it on your head to produce a static charge on the balloon. Turn on a faucet just enough to get a small stream of water. Now, slowly place the balloon close to the stream of water. What happens to the stream?

Figure A1.10: A balloon that is statically charged will bend a stream of water without touching it.

You will notice that the stream of water bends toward the balloon. In fact, it doesn't matter whether the charged object is negative—like the balloon—or positive. The stream of water will always bend toward the charged object. The bending of the stream of water, and its apparent attraction to positive or negative objects, means that water molecules contain both negative and positive charges. How does this property connect to water's ability to act as a solvent?

Lewis Dot Diagram of Water

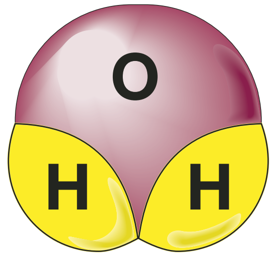
$$\mathrm{H:\underset{\cdot\cdot}{\overset{\cdot\cdot}{O}}:H}$$

To answer this question, it helps to look at the atomic structure of a water molecule. A water molecule is composed of two hydrogen atoms covalently bonded to an oxygen atom. The covalent bonds within a water molecule involve oxygen and hydrogen sharing electrons so each obtains a full outer energy level.

Although the Lewis dot diagram communicates that the oxygen atom and both hydrogen atoms have full outer energy levels, it has limitations. A Lewis dot diagram is a simplified two-dimensional representation of a three-dimensional object.

A three-dimensional diagram reveals that a water molecule has a bent shape.

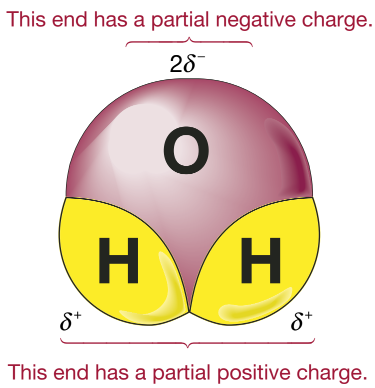
Water Molecule



This shape becomes significant because the sharing of electrons between a hydrogen atom and an oxygen atom is unequal. The oxygen atom tends to keep the shared pairs of electrons from its bonds to the two hydrogen atoms closer to itself. By keeping the electrons close to itself, the unequal sharing of electrons results in a partial negative charge on the oxygen atom and a partial positive charge on each of the hydrogen atoms. The bent shape, combined with the unequal sharing of electrons, results in a water molecule that has a partial positive charge on one end and a partial negative charge on the other end.

The symbol for a partial positive charge is δ^+ (read as "delta positive"), whereas the symbol for a partial negative charge is δ^- (read as "delta negative"). Note that the two single partial positive charges are balanced by the partial negative charge. This results in a neutral water molecule.

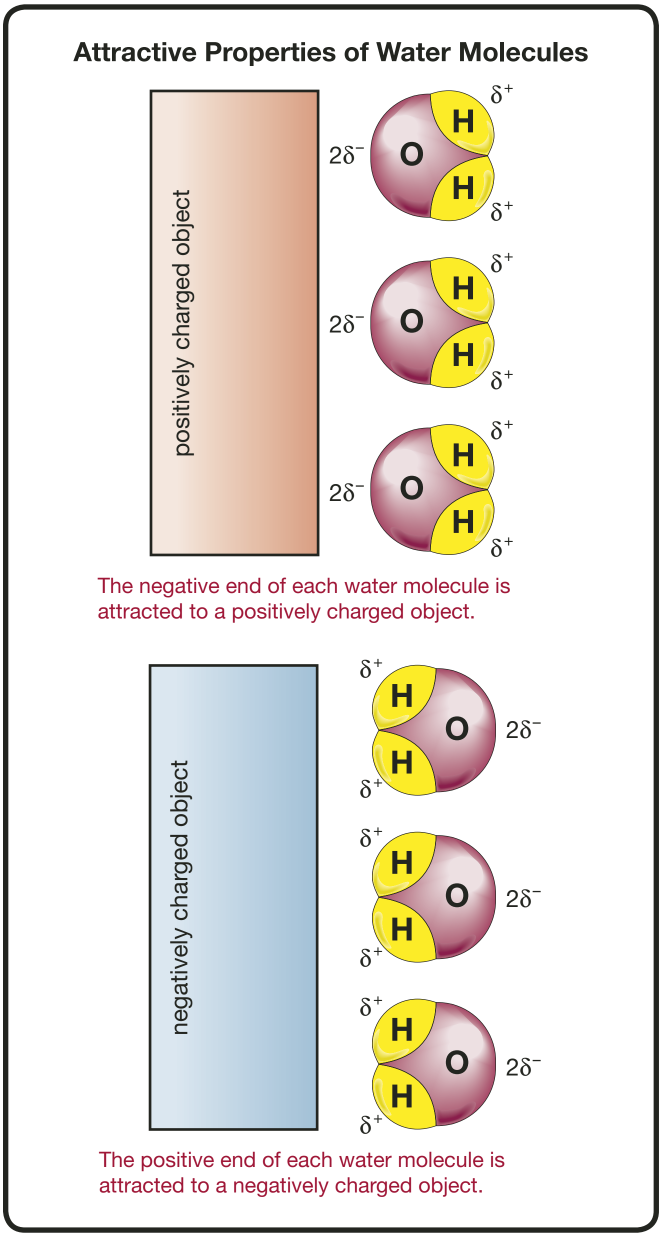
Charge Distribution Within a Water Molecule



The uneven charge distribution is why water is called a **polar molecule**. As you learned in previous courses, many of water's special properties are due to its polar nature.

> **polar molecule:** a molecule with a partial positive charge at one end and a partial negative charge at the other end

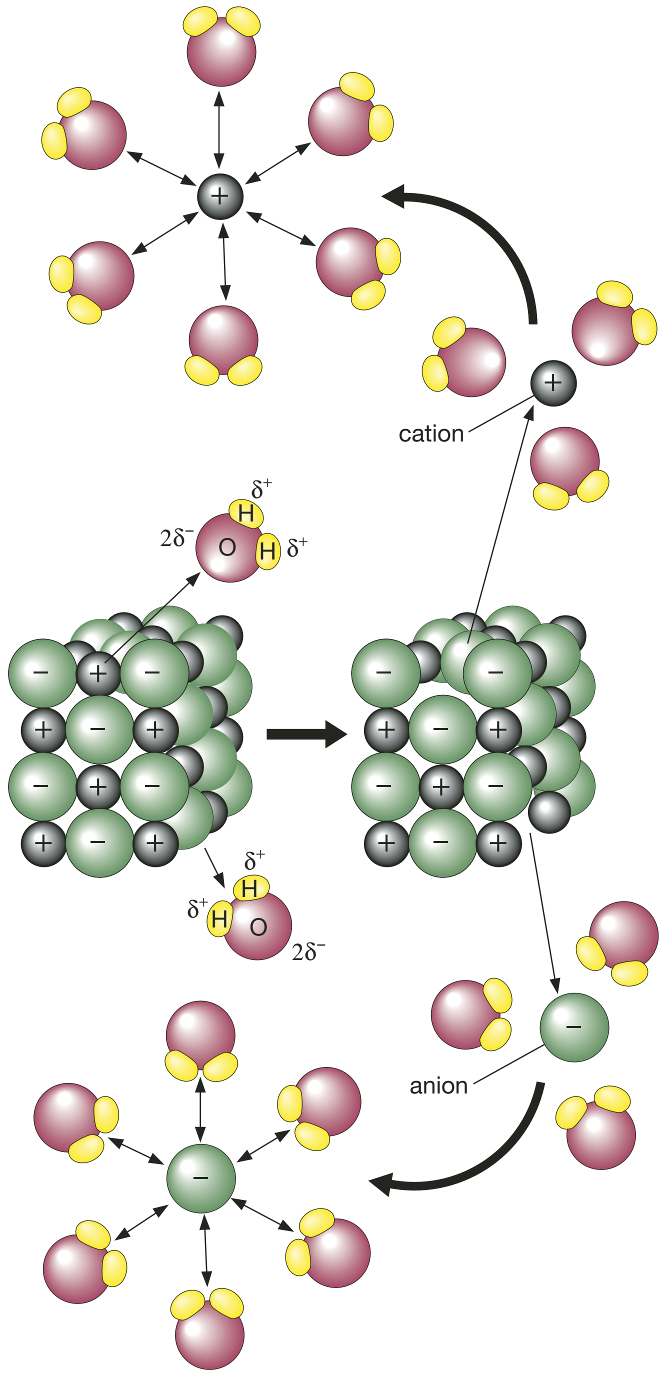
Because water molecules are polar, slightly positive on one side and slightly negative on the other side, they can be attracted to objects that are either positively or negatively charged. The following graphic shows this.



Understanding the partial charges on a water molecule helps explain why the water from the tap was attracted to the statically charged balloon. Static electrical charges are produced when electrons are transferred. The balloon becomes negatively charged because it picks up some electrons when it is rubbed against your hair. When the stream of water is exposed to the negatively charged balloon, the positive ends of the water molecules are attracted to the balloon and the stream of water is drawn toward the balloon.

Does the fact that water is a polar molecule help explain why water is a powerful solvent? To answer this question, you need to look at the process of dissolving on a microscale.

Water Molecules Dissolving an Ionic Crystal



Water is a very powerful solvent. It has the ability to dissolve most ionic crystals because they are all made up of positively and negatively charged ions. Some ionic compounds have lower solubility in water than others, but all ionic compounds dissolve in water to some extent.

Some substances held together by covalent bonds, like oil, do not dissolve in water; but others, like glucose, readily dissolve in water. Could dissolving a molecular compound in water be related to the compound's charge? As described earlier, in some covalent bonds, electrons are not shared equally and the molecule ends up with an uneven charge distribution (just like water). Water molecules are electrostatically attracted to these molecules. Water molecules will surround the slightly charged particle and cause it to dissolve. Some molecules, however, will not have areas with different charges. As a result, they will not attract water molecules and, therefore, will not dissolve in water.

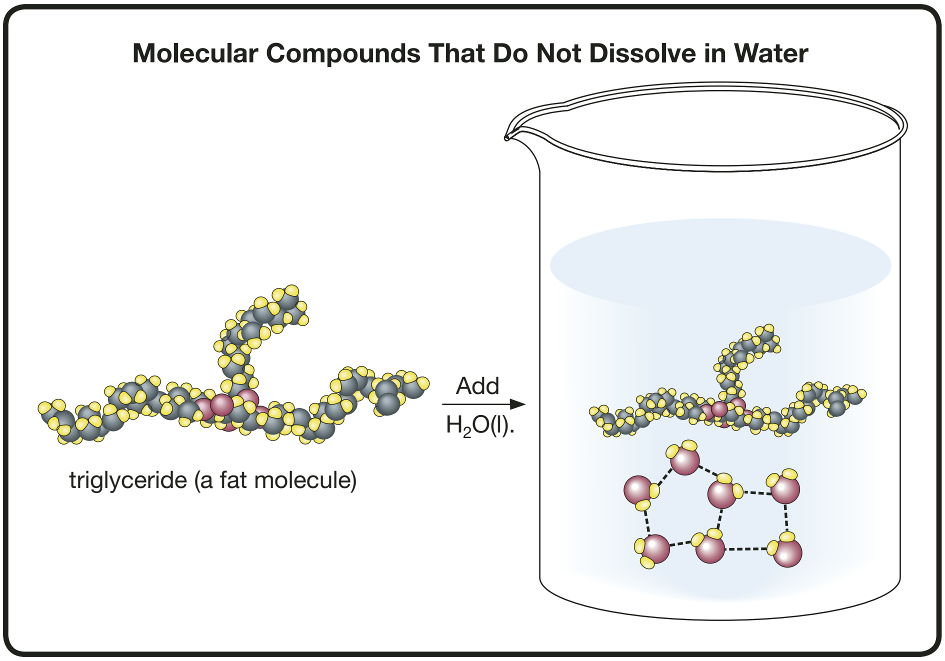


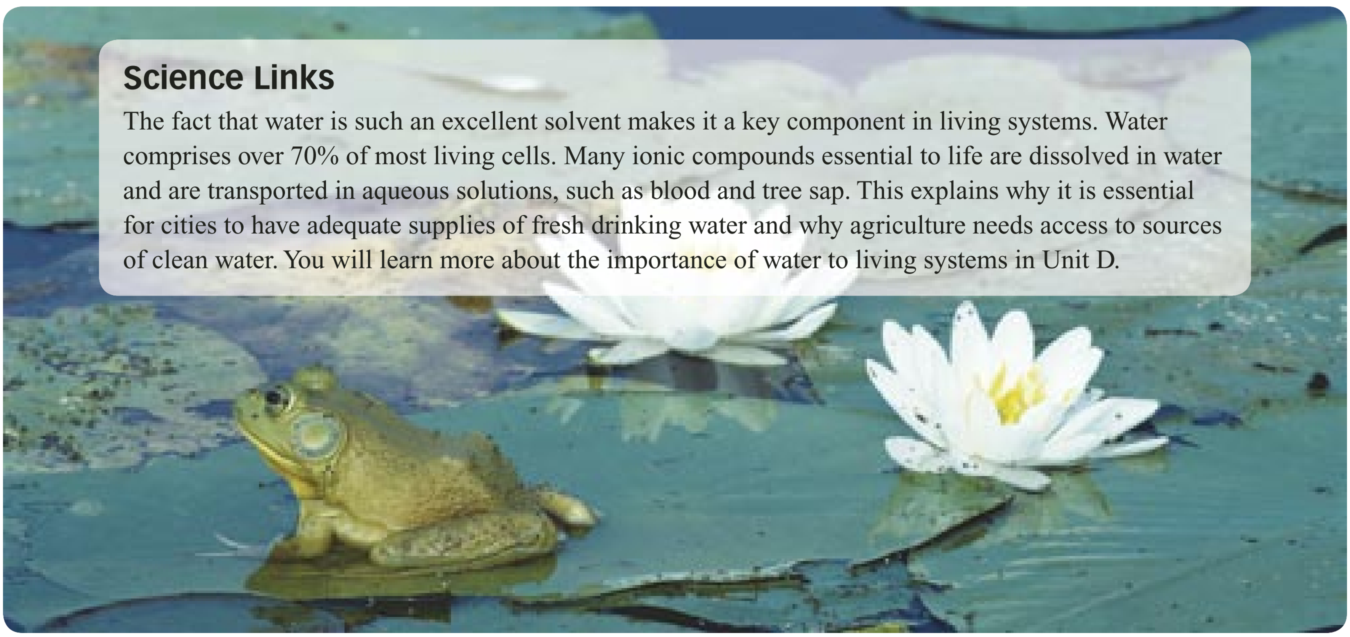
Figure A1.11: The positive and negative ends of the water molecules attract each other instead of being attracted to the triglyceride molecule.

Practice

21. Explain why water is an effective solvent for ionic compounds.

22. Draw a diagram outlining the process of water dissolving a solute.

23. Explain why it is difficult to wash oil-based paints off your hands using only water.



Science Links

The fact that water is such an excellent solvent makes it a key component in living systems. Water comprises over 70% of most living cells. Many ionic compounds essential to life are dissolved in water and are transported in aqueous solutions, such as blood and tree sap. This explains why it is essential for cities to have adequate supplies of fresh drinking water and why agriculture needs access to sources of clean water. You will learn more about the importance of water to living systems in Unit D.

The Dissociation of Ionic Compounds

Figure A1.12: Many factories are located near water because of water's dissolving capabilities.

Did you ever wonder why many industrial factories are located by a source of water? The simple answer is that plant processes often require large amounts of water for the chemical reactions that occur within the plant. Water is a major requirement for most chemical industries because it effectively breaks down bonds and allows chemical reactions to occur.

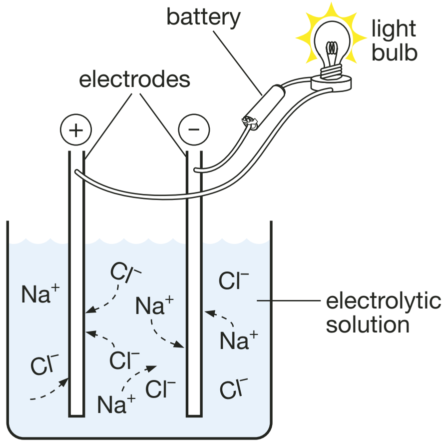
When an ionic compound dissolves in water, the bonds between ions within the ionic solid are broken by water molecules. As a result, free ions exist in the water. The breaking down of an ionic compound into its smaller parts is called **dissociation**.

Notice that when ionic compounds dissociate, they produce negatively charged and positively charged particles within the solution. If you have negatively charged and positively charged particles within a solution, the particles can move in response to other charged objects. A simple conductivity test involves placing two electrodes of a conductivity apparatus in a solution. The different charges of each electrode attract different ions. If the ions are dissociated and free to move, they can move toward one of the electrodes. The resulting movement of ions acts to move charged particles, completing the electrical circuit of the conductivity meter. Solutes that conduct an electrical current when in a solution are called **electrolytes**.

dissociation: the separation of an ionic compound into individual ions in a solution

electrolyte: a solute that forms a solution that conducts electricity

Conductivity Meter and an Electrolyte



Dissociated ions can move toward the oppositely charged electrodes of the conductivity meter. The movement of ions (charges) completes the circuit of the conductivity meter.

Non-electrolytes

Water cannot break the covalent bonds between atoms in molecular compounds, yet many dissolve in water. Molecular compounds do not dissociate like ionic compounds. Water simply separates the molecules of the solute if they have an uneven distribution of charge due to the unequal sharing of electrons in the covalent bonds.

A Dissolving Equation for a Molecular Compound

$$\underbrace{C_{12}H_{22}O_{11}(s)}_{\text{solid molecular compound}} \xrightarrow{H_2O(l)} \underbrace{C_{12}H_{22}O_{11}(aq)}_{\text{aqueous molecular compound}}$$

A solution of a molecular compound does not contain negative and positive ions. Because of the lack of oppositely charged particles in the solution, the electrical circuit of the conductivity apparatus will not be completed. A substance that forms a non-conducting solution is called a **non-electrolyte**.

non-electrolyte: a solute in a solution that does not conduct an electric current

Practice

24. Identify each compound as either an ionic compound or a molecular compound. List the ions that each ionic compound would dissociate into. State whether the compound would be classified as an electrolyte or a non-electrolyte if it was added to water.

 a. $KBr(s)$ b. $AgNO_3(s)$
 c. $Li_3PO_4(s)$ d. $CO_2(g)$
 e. $Al_2(SO_4)_3(s)$ f. $Na_2S(s)$

Investigation

Aqueous Solutions

Purpose

You will design and perform an experiment that will allow you to classify solutions as either electrolytes or non-electrolytes.

Science Skills
- ✓ Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Prediction

Make predictions for each solution using what you know about the different types of compounds.

Materials

- conductivity meter
- multi-well dish, watch glasses, or Petri dishes
- the following solutions in dropper bottles:
  - 0.100-mol/L aqueous sodium chloride, NaCl(aq)
  - 0.100-mol/L aqueous sucrose, $C_{12}H_{22}O_{11}(aq)$
  - 0.100-mol/L hydrochloric acid, HCl(aq)
  - 0.100-mol/L aqueous ethanol, $C_2H_5OH(aq)$
  - 0.100-mol/L aqueous sodium hydroxide, NaOH(aq)
  - 0.100-mol/L aqueous sodium sulfate, $Na_2SO_4(aq)$
  - 0.100-mol/L aqueous acetone, $CH_3OCH_3(aq)$
- **MSDS** information for each solution

MSDS: Material Safety Data Sheet

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation.

Procedure

step 1: Predict which solutions are electrolytes and which are non-electrolytes. Use the information that has been presented in this chapter to support your predictions.

step 2: Develop an experimental design that includes the following considerations:
- **Safety:** Identify solutions that contain compounds that are irritants or that may cause some other safety concern. Consult the MSDS information for each solution.
- **Manipulation of apparatus:** You have already used a conductivity meter in Lesson 1.1; but if necessary, seek further instruction from your teacher.
- **Clean-up:** Learn the proper procedure for the disposal of chemical wastes. Determine how the conductivity meter and the glassware should be cleaned and put away.

step 3: Have your teacher approve your procedure before you begin.

step 4: Follow your procedure, and record the results.

step 5: Compare your results with the findings of other groups. Identify which of your results are consistent with those collected by other groups. Identify the results that are inconsistent.

Analysis

1. Compare your predictions with your results. Did they match? Were there some solutions that surprised you?
2. Discuss any difficulties you came across as you carried out your investigations. Did these difficulties affect your ability to draw conclusions?
3. Suggest two ways to improve your investigation. How can you make your results more accurate?
4. Account for any inconsistencies between the results your group obtained and the findings of other groups.

1.3 Summary

People have been attempting to manipulate matter for a very long time. The first step in making a specific compound from a resource is to break the existing bonds and then produce the desired bonds.

Dissolving a substance in water can be an effective way of breaking bonds. Water is a strong solvent because it has a partial positive charge on one end and a partial negative charge on the other end.

All ionic compounds dissociate into separate ions in aqueous solutions, whereas only some molecular compounds dissolve into separate molecules in aqueous solutions. This is because in order for a substance to dissolve in water, it must be attracted to water molecules. Substances that are not attracted to water molecules do not dissolve in water.

Electrolytes are solutes that form solutions that conduct electricity. Non-electrolytes are solutes that form solutions that do not conduct electricity.

1.3 Questions

Knowledge

1. Define the following terms.
   - **a.** solubility
   - **b.** dissolving
   - **c.** aqueous solution
   - **d.** dissociation
   - **e.** electrolyte
   - **f.** non-electrolyte
2. Describe what occurs when something dissolves in water.
3. Compare and contrast how an ionic compound dissolves with how a molecular compound dissolves.

Applying Concepts

4. State at least three ways in which you use aqueous solutions.
5. Medication is often given to patients in the form of a solid pill that must be swallowed. An alternative method is to administer the medication in an intravenous solution. Concisely explain why medications administered in a solid pill acts much more slowly than those administered in an intravenous solution.
6. Pure water does not conduct electricity. Explain why you still need to be careful about electricity near water.

1.4 Solutions and Concentrations

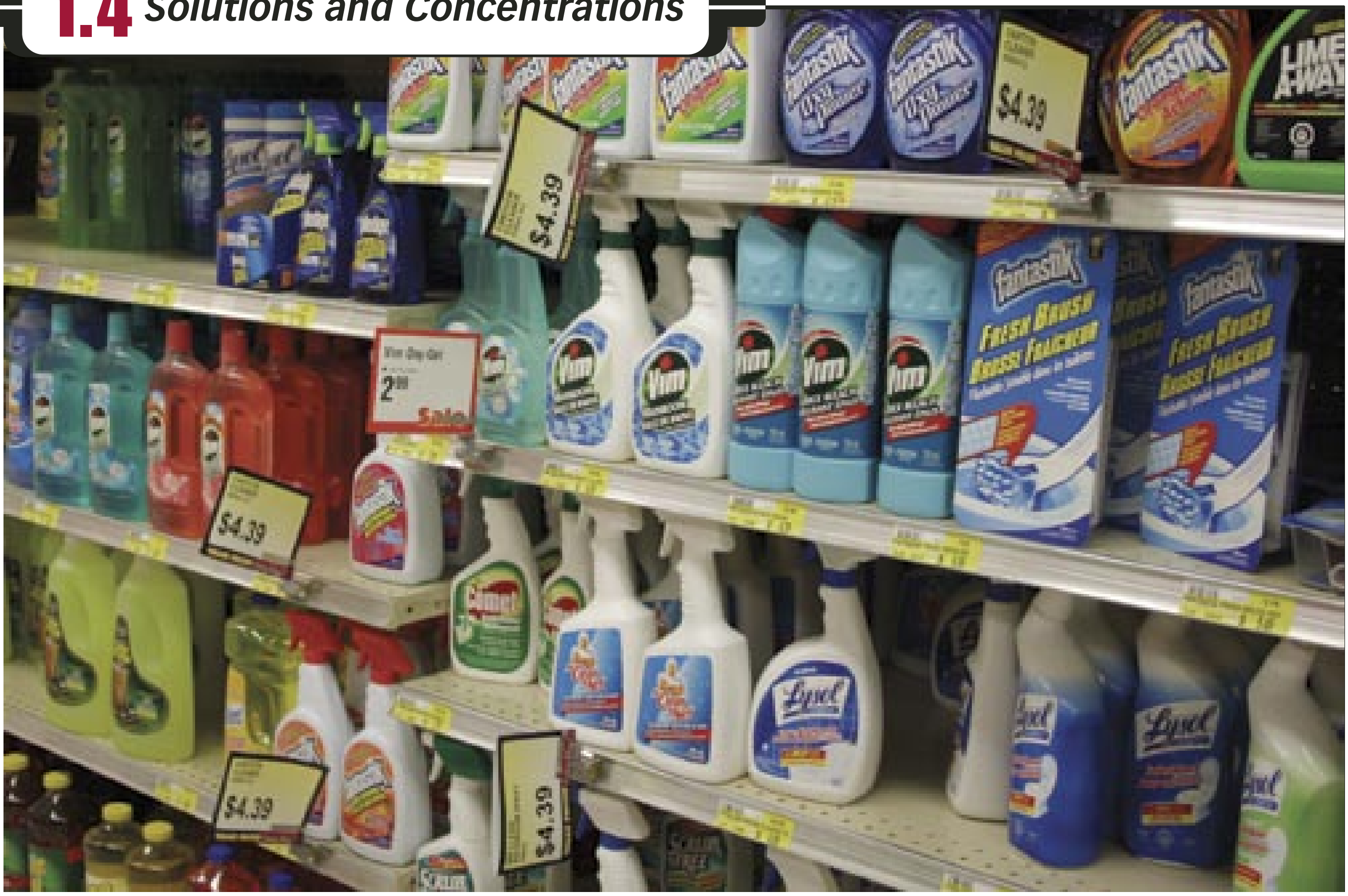


Figure A1.13: Most household cleaners are sold in solution form.

As a consumer, you use many products that are sold in the form of solute dissolved in a solvent—a solution. Beverages, medicines, household cleaners, and hair-care products are all examples of commercial solutions people use on a regular basis. In each case, manufacturers make sure that the ratio of solute to solvent is safe and appropriate for the application. Changing this ratio can dramatically change the properties of the solution.

DID YOU KNOW?

A concentrated solution of acetic acid would hurt you if you drank it. Yet, most people commonly use vinegar—a 5% solution of acetic acid—as an ingredient in their cooking. To keep consumers safe, there are regulations about the proper labelling of products. The ratio of solute to solvent is often noted on the product's label.

In some cases, the solute that may be part of the product is an unintended ingredient. Polychlorinated biphenyls (PCBs) are pollutants that can be present in water. They may also be found in fish living in water polluted with PCBs. The maximum concentration allowed by Canada's health guidelines regarding the level of PCBs in fish that are harvested to be eaten is 2 parts per million (ppm). This guideline is to ensure that the fish you eat will not harm you.


Figure A1.14: Canada has strict guidelines regarding the levels of PCBs present in fish sold for human consumption.

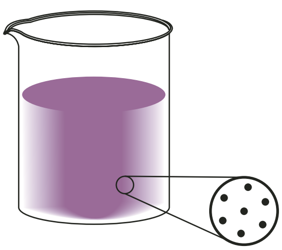
All of these examples relate to the amounts of a certain substance present in a solution. Whether it is the amount of PCB in fish or the amount of acetic acid in vinegar, the ratio of solute to solution is described as a solution's **concentration**. A solution with more solute in it than a solution of the same volume is said to be more concentrated. A solution containing a large amount of solute per given volume is called a **concentrated solution**. A solution containing a small amount of solute per given volume is called a **dilute solution**.

concentration: the ratio of the quantity of solute to the quantity of solution

concentrated solution: a solution containing a high ratio of solute to solution

dilute solution: a solution containing a low ratio of solute to solution

Concentrated Solutions and Dilute Solutions


A concentrated solution has a high ratio of solute to solution.

A dilute solution has a low ratio of solute to solution.

The concept of concentration is something you encounter every day. Whether you are buying juice or cleaning products or looking at government guidelines for water quality, you are dealing with concentrations. Understanding concentration will help you answer questions like the following:

- How much of the solute is in the product you are buying?
- What are the safe or acceptable limits for certain chemicals in food or drinking water?
- Are there safety concerns associated with products that have higher solute concentrations?
- Can you save money by buying concentrated solutions and diluting them yourself?

These are a few of the questions you will be exploring in this lesson and the next. Not only will you find that understanding concentration gives you a greater knowledge of the information listed on the products you buy, but it will also give you a better understanding of how to interpret and analyze this information.

Practice

One of the "hidden costs" included in the price of most consumer products is shipping—the cost of transporting the goods from the factory or warehouse to the store. If the consumer product is in the form of an aqueous solution, it is frequently shipped in a concentrated form to reduce the mass of the product. Every litre of water that does not have to be shipped reduces the load by 1 kg, helping keep transportation costs low.

25. Soft drinks served at many restaurants are dispensed from a "fountain." In this process, the concentrated form of the soft drink is taken from a pressurized canister and mixed with carbonated water. Explain the advantage of using a concentrated form of soft drink stored in a canister.

26. A fertilizer for flowers is sold as a dry, granular powder that must be mixed with water by the gardener before applying it to the flowering plants.

- **a.** Determine whether the dry, granular powder is the solute or the solvent of the liquid fertilizer solution.
- **b.** A 0.500-kg package of this dry powder is capable of making 189 L of liquid fertilizer solution. By approximately what factor would the shipping costs increase if the fertilizer was sold to consumers as a ready-to-use liquid?
- **c.** List some disadvantages of selling a dry powder that requires the gardener to mix the liquid fertilizer solution.

Observing the Effects of Reduced Concentrations

In the next investigation, "Repeated Dilutions," you will have an opportunity to observe the effects of concentration on a chemical reaction. Although the observations of this investigation focus on colour changes, the solution has its concentration reduced as measured by the number of moles per litre. The meaning of this unit will be explored fully in Lesson 1.5. For this investigation, you only need to know that a solution with a concentration of 4.00 mol/L has twice the concentration as a solution with 2.00 mol/L.

Investigation

Repeated Dilutions

Purpose

You will observe the effects of concentration on a chemical reaction.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 100-mL graduated cylinder
- 9, 100-mL beakers
- distilled water
- phenolphthalein solution in a bottle with an eyedropper
- 100 mL of 1.00-mol/L sodium hydroxide solution NaOH(aq)
- masking tape
- felt-tipped pen
- stirring rod

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Measure 50 mL of distilled water using the graduated cylinder, and pour it into a beaker. Label the beaker "Distilled Water."

step 2: Measure 100 mL of sodium hydroxide solution using the graduated cylinder. Pour this solution into another beaker. Label the beaker "1."

step 3: Pour 50 mL of the solution in beaker 1 into the graduated cylinder. Carefully add 50 mL of water so the graduated cylinder now has 100 mL of solution. Pour this diluted solution into another beaker, labelling it as beaker "2." Note that the solution in beaker 2 has only half the concentration of beaker 1 because the amount of solvent has been doubled. In other words, the concentration in beaker 2 is 50% of the concentration in beaker 1.

step 4: Repeat step 3 by halving the volume of the solution in beaker 2 and creating a new solution in beaker 3. Repeat this process by using the solution in beaker 3 to create a more dilute solution in beaker 4 and so on until you have eight beakers with successively more dilute concentrations. Each beaker will end up with a solution that is half the concentration of the previous beaker. All of the beakers will have 50 mL of solution except for the last beaker, which will have 100 mL.

step 5: Carefully add two drops of phenolphthalein solution to beakers 1 through 8 and to the beaker with the distilled water. Observe the effect of the phenolphathalein on the solution in each beaker. Stir the liquid using a clean stirring rod, rinsing it off between each beaker.

Analysis

1. Copy and complete the following table.

Beaker	Concentration of NaOH(aq) Relative to Beaker 1
1	100
2	50
3	
4	
5	
6	
7	
8	

2. Identify the manipulated variable and the responding variable.
3. State the process that you used to create the solutions in beakers 2 through 8.

Qualitative Properties of Solutions

You know the difference between concentrated juice and dilute juice because you can taste the difference. You should also see a difference in the colour and consistency. You can get a lot of information about a substance simply by observing its physical properties, like colour, taste, and odour. These are the **qualitative properties of a solution**.

4. How many times did you dilute the sodium hydroxide solution before you reached a point where the diluted solution no longer reacted with the phenolphthalein? Is it possible to dilute the solution to the point where it will have no sodium hydroxide left?
5. Imagine that the fluid you were diluting was sewage instead of sodium hydroxide. You repeated this experiment and produced eight beakers of sewage in decreasing concentrations.
   a. Would you feel comfortable drinking from beaker 8? Give a reason for your answer.
   b. List some substances that might affect the quality of the water.
   c. Use the Internet or other resources to obtain a copy of the drinking water standards for your local area or the *Guidelines for Canadian Drinking Water Quality* to determine what kinds of tests are performed on drinking water to ensure its safety. Are tests for the substances you listed in question 5.b. included in the standards?

Figure A1.15: Sewage must be processed thoroughly before returning to the environment.

Figure A1.16: The solution on the left has a higher concentration than the solution on the right.

qualitative property of a solution: a basic attribute of a solution you can observe with one or more of the five senses

Qualitative properties include a description of a solution's

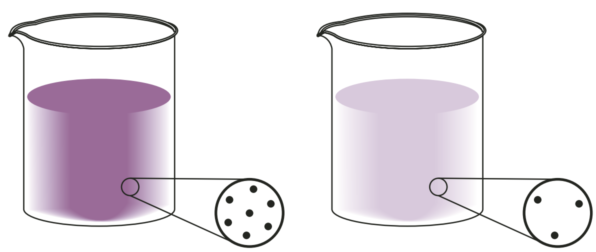
- colour
- colour intensity
- taste
- odour
- transparency

CAUTION!

Never taste or inhale any solution prepared in a laboratory.

Because the solute provides each solution with a new set of properties, qualitative tests can be used to detect the presence and, in some cases, identify the solute present in a solution. Often, the difference in the qualitative observations between concentrated and dilute solutions is directly related to the number of particles of solute dissolved within the solution. As shown in the "Repeated Dilutions" investigation, the greater the number of particles in the solution, the greater the specific effect. The beaker that had the lowest concentration of sodium hydroxide had the fewest particles to react with the drops of phenolphthalein to produce a colour change. A highly concentrated solution had a deeper colour because it contained more solute particles (sodium hydroxide) to react with the phenolphthalein.

Qualitative Characteristics of Solutions



A concentrated solution has many dissolved particles, resulting in a higher conductivity and in a more intense colour, taste, and scent.

A dilute solution has fewer dissolved particles, resulting in a weaker conductivity and a less intense colour, taste, and scent.

It is not always easy, however, to use qualitative properties to compare the concentrations of solutions. This is especially the case for colourless solutions. How could you determine which of the following solutions had the higher concentration?

Figure A1.17: Sometimes it is difficult to tell which solution has a higher concentration just by looking.

As you explored earlier, one method to accomplish this task would be to compare how the two different solutions conduct electricity. It is possible to place two electrodes into a solution and measure how easily an electrical current can pass through the solution from one electrode to another. Solutions with higher concentrations are more effective than dilute solutions at passing the current through the solution.

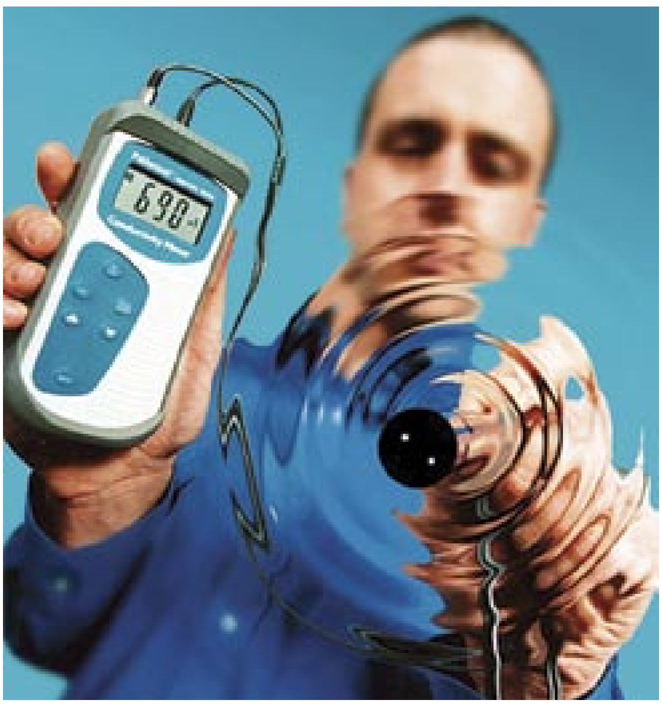


Figure A1.18: A conductivity meter provides numerical data for comparing solutions.

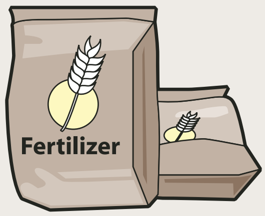
Another method to determine the relative concentrations of two solutions is to look at chemical characteristics, such as how readily each solution reacts.

Practice

27. Many fertilizers sold to gardeners have a non-staining dye to the ingredients. This dye has no beneficial effects on the plants, but it serves many purposes for the gardeners.

a. Suppose two gardeners each read the instructions on two bags of identical fertilizer and worked independently to prepare their solutions. Each gardener produced a solution of liquid fertilizer in identical 20-L pails. Although both solutions were blue, one has a much more intense blue colour than the other. Identify which pail has the more concentrated solution and suggest what these two gardeners should do next.

b. Many liquid fertilizers can be dispensed by a hose. Why is the presence of the dye in the fertilizer regarded by some gardeners as a useful safeguard?

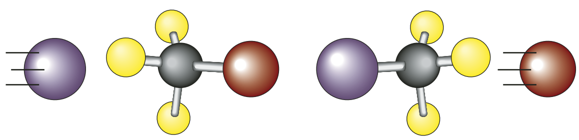


DID YOU KNOW?

All chemical reactions involve collisions between atoms, ions, and molecules. This idea is explained by the **collision-reaction theory**. This theory states that a chemical reaction will occur if the particles collide with a certain minimum energy and if they collide with a certain orientation. The rearrangement of particles that occurs after the collision is the chemical reaction.

collision-reaction theory: a theory stating that chemical reactions involve the collision and rearrangement of particles

Example of Collision Theory



$$I^-(g) + CH_3Br(g) \rightarrow CH_3I(g) + Br^-(g)$$

This reaction only occurs if the iodide ion, $I^-(g)$, collides with enough energy, travelling from the direction shown.

Concentration Affects the Speed of Chemical Reactions

A solution having a greater concentration of solute to solution reacts faster than a more dilute solution. This occurs for the following reasons:

- A chemical reaction is a result of collisions between particles.
- A concentrated solution has more particles of solute available for possible collisions than a dilute solution.
- The probability of collisions increases as the number of solute particles within a system increases.

Reactions of Concentrated Versus Dilute Solutions

Reactions with concentrated solutions occur more quickly because you have a greater number of collisions.

Reactions with dilute solutions occur at a slower rate because collisions are a little less probable.

1.4 Summary

Concentration is a description of the amount of solute dissolved within a solvent to form a solution. A concentrated solution has more solute particles dissolved in the solution than a dilute solution. The amount of solute in a solution can affect the qualitative characteristics of that solution, such as the intensity of colour and reactivity with other substances.

Concentrated solutions and dilute solutions have similar physical characteristics; but due to the number of particles in a concentrated solution, there tends to be an increased intensity of physical and chemical properties. These properties include greater colour intensity and an increased rate of chemical reactions.

Figure A1.19: Using only one of the five senses, it is very difficult to determine which solution is more concentrated.

1.4 Questions

Knowledge

1. Define the following terms.
   - **a.** concentration
   - **b.** concentrated solution
   - **c.** dilute solution
   - **d.** qualitative properties
   - **e.** collision-reaction theory
2. Describe how the qualitative characteristics of concentrated solutions compare with those of dilute solutions.
3. Explain why a chemical reaction appears to occur faster using a more concentrated solution versus a dilute solution.

Applying Concepts

4. A person accidentally swallows a poisonous compound. You immediately call the local poison control centre. They tell you that the person should drink at least three glasses of water and then go to the hospital. State a reason for the advice given.
5. State two situations when dilute solutions are used and two situations when concentrated solutions are used.
6. Explain why you must be much more aware of safety procedures when working with concentrated solutions than with dilute solutions.
7. Suggest appropriate safety procedures for shipping concentrated solutions by rail cars.

1.5 Calculating Concentration

Figure A1.20: Some insect repellents contain 25% DEET. Health Canada regulates that there should be no more than 0.010 ppm of lead in drinking water. A lab technician determines that a solution of cobalt(II) nitrate has a concentration of 0.200 mol/L.

Three Methods for Communicating Concentration

You can sometimes determine the relative concentrations of solutions by observing their qualitative properties; but it is often very useful to know specifically how much solute is dissolved in a particular solvent. In science and technology, a variety of ways are used to communicate the concentration of a solution. The table "Expressing Concentration" summarizes three common ways to express concentrations.

EXPRESSING CONCENTRATION

	Symbol	Formula	Use	Used By
Percent by Volume	% *V/V*	$\frac{\text{mL of solute}}{\text{mL of solution}} \times 100\%$	communicating the volume of a liquid solute dissolved in the total volume of a solution	manufacturers of consumer products
Parts Per Million	ppm	$\frac{\text{g of solute}}{\text{g of solution}} \times 10^6 \text{ ppm}$	communicating levels of a substance (like a pollutant) in very dilute aqueous solutions	agencies that set health and safety standards
Molar Concentration	*C*	$\frac{\text{mol of solute}}{\text{L of solution}}$	communicating the amount of moles of a pure substance dissolved in the total volume of a solution	scientists and lab technicians

In this lesson you will explore how and when to use these forms of communicating concentrations. By understanding how concentration is communicated, you should be better able to understand the labels of some of the consumer goods you purchase. You should also be able to make connections to environmental and scientific issues currently being debated.

Percent By Volume (% *V/V*)

Percent by volume is commonly used for liquids dissolved in liquids. This form of concentration is usually used for consumer products like drinks and cleaners. The equation for calculating percent by volume is as follows:

volume of solute dissolved in the solution (mL)

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

percent by volume concentration of the solution

total volume of the solution (mL)

Example Problem 1.6

A hair product requires you to combine 20.0 mL of hydrogen peroxide with enough water to produce a solution with a total volume of 120.0 mL. Determine the percent by volume concentration of the solution.

Solution

$V_{\text{solute}} = 20.0\ \text{mL}$

$V_{\text{solution}} = 120.0\ \text{mL}$

$(\%\ V/V) = ?$

$$\begin{aligned}(\%\ V/V) &= \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\% \\ &= \frac{20.0\ \cancel{\text{mL}}}{120.0\ \cancel{\text{mL}}} \times 100\% \\ &= 16.7\%\end{aligned}$$

The percentage by volume concentration of the solution is 16.7%.

Note: The rules of significant digits state that the final answer must be expressed to the same number of significant digits as the value with the least number of significant digits. Because the volume of the solute consists of only three significant digits, the final answer must consist of only three significant digits. For more information, refer to "Calculations with Significant Digits" on pages 534 to 536.

When problem-solving throughout this course, there are key points that you will want to remember:

- Mathematical solutions begin by listing the known and unknown values for this problem.
- The list of knowns and unknowns is used to choose the proper equation.
- The data, including units, is substituted into the equation.
- The final answer is expressed with the correct number of significant digits and with the proper units.

Sometimes, solving problems requires using algebra to rearrange the equation.

Example Problem 1.7

A mosquito repellent says that DEET makes up 45.0% of the total volume. If you have a 75-mL sample of this repellent, determine the volume of DEET within the sample.

Solution

List the knowns and the unknown.

$$(\%\ V/V) = 45.0\% \quad V_{\text{solution}} = 75\ \text{mL} \quad V_{\text{solute}} = ?$$

Rearrange the percent by volume equation so V_{solute} is isolated.

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\frac{(\%\ V/V)}{100\%} = \frac{\frac{V_{\text{solute}}}{V_{\text{solution}}} \times \cancel{100\%}}{\cancel{100\%}} \quad \leftarrow \text{Divide both sides by 100\%.}$$

$$\frac{(\%\ V/V)}{100\%} = \frac{V_{\text{solute}}}{V_{\text{solution}}}$$

$$\frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} = \frac{V_{\text{solute}}}{\cancel{V_{\text{solution}}}} \times \cancel{V_{\text{solution}}} \quad \leftarrow \text{Multiply both sides by } V_{\text{solution}}.$$

$$\frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} = V_{\text{solute}} \quad \leftarrow V_{\text{solute}} \text{ is now isolated.}$$

Substitute the values into the equation.

$$\begin{aligned}V_{\text{solute}} &= \frac{(\%\ V/V)}{100\%} \times V_{\text{solution}} \\ &= \frac{45.0\%}{100\%} \times 75\ \text{mL} \\ &= 33.75\ \text{mL} \\ &= 34\ \text{mL} \quad \leftarrow \text{two significant digits}\end{aligned}$$

The repellent sample contains 34 mL of DEET.

It is not necessary to show all of the algebra in your solutions. Most students simply write the basic equation and then write the rearranged version on the next line.

$$(\%\ V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\Downarrow$$

$$V_{\text{solute}} = \frac{(\%\ V/V)}{100\%} \times V_{\text{solution}}$$

The important thing to remember is that the second equation is simply a rearranged version of the basic equation; it is not a new equation.

Example Problem 1.8

Insecticidal soap is an environmentally friendly way to control insect pests on plants. A gardener needs a solution with a percent by volume concentration of insecticidal soap of 5.0%. If the total volume of the solution was 4000 mL, calculate the volume of insecticidal soap needed to make this solution.

Solution

$(\% \, V/V) = 5.0\%$

$V_{\text{solution}} = 4000 \text{ mL}$

$V_{\text{solute}} = ?$

$$(\% \, V/V) = \frac{V_{\text{solute}}}{V_{\text{solution}}} \times 100\%$$

$$\begin{aligned} V_{\text{solute}} &= \frac{(\% \, V/V)}{100\%} \times V_{\text{solution}} \\ &= \frac{5.0\%}{100\%} \times 4000 \text{ mL} \\ &= 200 \text{ mL} \\ &= 2.0 \times 10^2 \text{ mL} \end{aligned}$$

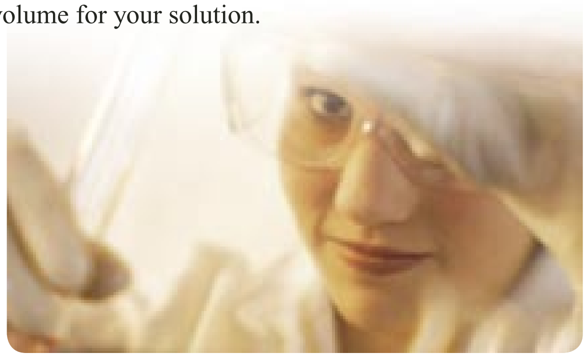
To make this solution, 2.0×10^2 mL of insecticidal soap is needed.

Note: Because the percent by volume has the least number of significant digits (two), the final answer must be expressed with only two significant digits. To do this, in this case, scientific notation is required.

DID YOU KNOW?

If you combined 50 mL of ethanol with 50 mL of water, you get a solution with a volume of 95 mL. How can this be? The molecules of ethanol and the molecules of water do not directly stack on top of each other. Instead, the two liquids intermingle with each other and, thus, fill in some of the spaces between each other's molecules. This causes them to occupy less volume.

For this reason, if you are making a solution a specific concentration, you first need to measure the volume of your liquid solute; then you need to add a sufficient amount of solvent to produce a final total volume for your solution.



Practice

28. To make a hand cleaner, a technician mixes 30 mL of antiseptic with enough liquid soap to make 70 mL of solution. Determine the percent by volume concentration of the antiseptic in the hand cleaner.

29. A solution of rubbing alcohol is labelled 60% (*V/V*). Determine the volume of rubbing alcohol present in a 200-mL sample of the solution.

30. A bottle of insect repellent states that it has a DEET percent by volume concentration of 25%. If you just bought a 250-mL container of this product, what volume of DEET have you purchased?

Parts Per Million (ppm)

Parts per million is a unit of concentration used for very dilute solutions. You will often come across this unit when you are investigating situations involving very small amounts of substances in contaminated water systems or food. The table "Allowable Toxic Levels in Drinking Water" lists the current guidelines established by Canada Health for some toxic elements in your drinking water.

ALLOWABLE TOXIC LEVELS IN DRINKING WATER

Substance	Maximum Acceptable Concentration (ppm)
arsenic	0.025
chromium	0.050
fluoride	1.5
lead	0.010
mercury	0.001
uranium	0.02

The term *1 part per million* means "one part solute for every million parts of solution." The details of the equation used to calculate parts per million is as follows:

mass of solute (g)

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^6 \text{ ppm}$$

parts per million concentration of the solution

mass of solution (g)

Remember that 1.000 mL of water has a mass of 1.000 g.

Example Problem 1.9

A 200-g sample from a bottle of water contains 5.4×10^{-3} g of mercury.

a. Calculate the concentration of mercury in the sample in parts per million.

b. Use the information in the table "Allowable Toxic Levels in Drinking Water" to determine if this water is safe to drink.

Solution

a. $m_{\text{solute}} = 5.4 \times 10^{-3}\ \text{g}$

$m_{\text{solution}} = 200\ \text{g}$

parts per million = ?

$$\begin{aligned}\text{parts per million} &= \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^{6}\ \text{ppm}\\ &= \frac{5.4 \times 10^{-3}\ \cancel{\text{g}}}{200\ \cancel{\text{g}}} \times 10^{6}\ \text{ppm}\\ &= 27\ \text{ppm}\end{aligned}$$

The concentration of mercury in this sample is 27 ppm.

Calculator Tip: You will be required to perform the calculations that involve entering values in scientific notation into your calculator. For most calculators, this requires using a special key labelled EXP or EE. Pressing these keys includes the "×10" part of the scientific notation. So, you only need to enter the exponent.

Value	Keystrokes on Calculator
5.4×10^{-3}	$\boxed{5}\ \boxed{\cdot}\ \boxed{4}\ \boxed{\text{EE}}\ \boxed{(-)}\ \boxed{3}$
$10^{6} = 1 \times 10^{6}$	$\boxed{1}\ \boxed{\text{EE}}\ \boxed{6}$

Consult the user's guide that came with your calculator for more information.

b. The mercury concentration in the water is well above the maximum acceptable concentration of 0.001 ppm. This water is not safe to drink.

Example Problem 1.10

Carbon monoxide, $CO(g)$, is a deadly gas that takes the place of oxygen molecules and binds to hemoglobin in blood. If you are smoking, the concentration of carbon monoxide that reaches your lungs is approximately 200 ppm. Determine the mass of $CO(g)$ that would be present in a sample of air having a mass of 9.6 g (approximately one breath). Express your answer in scientific notation.

Solution

parts per million = 200 ppm

$m_{\text{solution}} = 9.6\ \text{g}$

$m_{\text{solute}} = ?$

$$\text{parts per million} = \frac{m_{\text{solute}}}{m_{\text{solution}}} \times 10^{6}\ \text{ppm}$$

$$\begin{aligned}m_{\text{solute}} &= \frac{\text{parts per million}}{10^{6}\ \text{ppm}} \times m_{\text{solution}}\\ &= \frac{200\ \cancel{\text{ppm}}}{10^{6}\ \cancel{\text{ppm}}} \times 9.6\ \text{g}\\ &= 0.0019\ \text{g}\\ &= 1.9 \times 10^{-3}\ \text{g}\end{aligned}$$

There would be 1.9×10^{-3} g of $CO(g)$ present.

Note: In Example Problem 1.10, the answer displayed on the calculator is not in scientific notation. To write the answer in scientific notation, follow these steps:

step 1: Move the decimal to the right until it is on the right side of the first non-zero digit.

0.00192

step 2: Round the number to the specific number of significant digits. In this case, round the value to two significant digits.

1.9

step 3: Insert the power of ten the value should be multiplied by. Because the decimal moved three places to the right, the exponent in the power of 10 is –3.

1.9×10^{-3}

Alternatively, many calculators can be set to automatically display answers in scientific notation. This is a very useful feature because it reduces errors.

On many calculators, using the MODE key automatically causes the answers to be displayed in scientific notation. Check the user's guide that came with your calculator to learn how to set this up.

DID YOU KNOW?

If you put 4 drops of ink into a rain barrel that holds 210 L of water, the concentration of the ink would be approximately 1 ppm.

Practice

31. A 250-g sample of water contains 8.30×10^{-3} g of lead.
    a. Calculate the concentration of lead in the sample of water in parts per million.
    b. Determine if this water is safe to drink.
32. Canadian law prevents the sale of fish for consumption containing more that 2.00 ppm of PCBs. A 227-g sample of fish is tested and found to contain the maximum allowable concentration of PCBs. Determine the mass of PCBs in this sample of fish.
33. It is considered unsafe to have more than 50.0 ppm of arsenic in drinking water. If you have a bottle of water containing 250 g of water with this level of arsenic, what mass of arsenic would you ingest?

Molar Concentration, *C* (mol/L)

Earlier in this chapter you saw how diagrams of the atomic structure of a water molecule can communicate that two hydrogen atoms covalently bond to one oxygen atom. If you were to break up this molecule, you would expect to get twice as many molecules of hydrogen gas, $H_2(g)$, as you would oxygen gas, $O_2(g)$. The difficulty is that any sample of water contains so many atoms of hydrogen and oxygen that it is impossible to count them individually. Technologists and scientists, who need to know the amount of the substance, have solved this problem by counting particles in a very large group called a **mole**.

mole: a specific amount of a substance that consists of 6.022×10^{23} particles

molar concentration (molarity): the amount of solute, in moles, per litre of solution

The mole is a very useful quantity because it enables technologists to combine the precise amounts of substances so that all of the reactants are completely converted into products in a chemical reaction. Since many reactions occur in solutions, concentrations within the scientific community are most often communicated using **molar concentration** or **molarity**. The molar concentration of a solution can be calculated using the following relationship:

$$C = \frac{n}{V}$$

number of moles of solute dissolved in the solution (mol)

total volume of the solution (L)

concentration of the solution (mol/L)

This technique is very useful because it communicates the number of molecules or ions of solute dissolved or dissociated in a specified volume of a solution.

Example Problem 1.11

A sample of water taken from a nearby lake is found to have 0.0035 mol of salt in a 100-mL solution. Determine the concentration of the salt in the lake.

Solution

$n = 0.0035 \text{ mol}$

$V = 100 \cancel{\text{mL}} \times \dfrac{1 \text{ L}}{1000 \cancel{\text{mL}}}$

$= 0.100 \text{ L}$

$C = ?$

Note: Because the volume of the solution must be in litres (L), convert the original volume using a conversion factor.

$$C = \frac{n}{V}$$
$$= \frac{0.0035 \text{ mol}}{0.100 \text{ L}}$$
$$= 0.035 \text{ mol/L}$$
$$= 3.5 \times 10^{-2} \text{ mol/L}$$

The concentration of the salt in the lake is 3.5×10^{-2} mol/L.

Throughout this course, when you record measurements or do calculations, you should always include the units. In Example Problem 1.11, the volume of the solution was given in millilitres (mL) instead of litres (L). It is essential that you communicate, in a clear and concise way, how to convert one unit into another. One of the best ways to do this is by using a **conversion factor**.

conversion factor: a fraction used to convert one set of units into another

Conversion factors offer a concise and consistent way to sort out units. Conversion factors not only keep your solutions organized, they help keep your thinking clear by giving you a reliable way to handle units in all situations. For more information, refer to "Conversion Factors" on page 532.

Molar Mass

Sometimes it is necessary to first calculate the number of moles using the mass of the sample and information from the periodic table to determine the **molar mass**. The equation for calculating the number of moles in a substance is as follows:

molar mass: the mass of 1 mol of a substance

mass of the substance (g)

$$n = \frac{m}{M}$$

number of moles of a substance (mol)

molar mass of the substance (g/mol)

The process of finding the number of moles and then calculating the molar concentration is illustrated in Example Problem 1.12.

Example Problem 1.12

You dissolve 30.0 g of sodium sulfate, $Na_2SO_4(s)$, into 300 mL of water.

a. Determine the number of moles of sodium sulfate in this solution.

b. Calculate the molar concentration of this sodium sulfate solution.

Solution

a. First, determine the molar mass, M, of $Na_2SO_4(s)$.

11 Na	16 S	8 O
sodium 22.99	sulfur 32.06	oxygen 16.00
Na^+ sodium	S^{2-} sulfide	O^{2-} oxide

$$M = 2(M \text{ of Na}) + (M \text{ of S}) + 4(M \text{ of O})$$
$$= 2(22.99 \text{ g/mol}) + (32.06 \text{ g/mol}) + 4(16.00 \text{ g/mol})$$
$$= 142.04 \text{ g/mol}$$

Now, calculate the number of moles.

$m = 30.0 \text{ g}$

$M = 142.04 \text{ g}$

$n = ?$

$$n = \frac{m}{M}$$
$$= \frac{30.0 \text{ g}}{142.04 \text{ g/mol}}$$
$$= 0.211\,208\,110\,4$$
$$= 0.211 \text{ mol}$$

The solution contains 0.211 mol of sodium sulfate.

b. $n = 0.211\,208\,110\,4 \text{ mol}$

$V = 300 \cancel{\text{mL}} \times \dfrac{1 \text{ L}}{1000 \cancel{\text{mL}}}$

$= 0.300 \text{ L}$

$C = ?$

Note: Although the number of moles was rounded to three significant digits in part a., you should use the unrounded value in this calculation to get a more accurate answer to part b. Remember, the number of moles is still considered to have three significant digits in this calculation.

$$C = \frac{n}{V}$$
$$= \frac{0.211\,208\,110\,4 \text{ mol}}{0.300 \text{ L}}$$
$$= 0.704 \text{ mol/L}$$

The molar concentration of the sodium sulfate solution is 0.704 mol/L.

Practice

34. Determine the molar concentration for each solution.

a. 0.435 mol of sodium chloride, NaCl(s), dissolves in 200 mL of water.

b. 800 mL of water contains 0.674 mol of sodium hydroxide, NaOH(aq).

35. 30.0 g of NaCl(s) is added to water to make 800 mL of salt solution.

a. Use the periodic table on pages 554 and 555 to determine the number of moles in 30.0 g of NaCl(s).

b. Calculate the molar concentration of this salt solution.

36. In a science lab, 5.00 g of NaOH(s) is dissolved in 300 mL of water. What is the molar concentration of the resulting solution?

Standard Solutions

Technologists in a number of industries often need to make solutions with a specific concentration. In the field of health care, prescriptions can involve creams or liquids that require an exact amount of medicinal solute to be combined with the appropriate solvent. During manufacturing, specific solutions may have to be prepared. Each solution is an essential component, allowing for the precise control of a chemical reaction.

Why don't these facilities simply order the necessary solutions already mixed in the proper concentrations? As is the case with consumer goods, it is less expensive to ship highly concentrated solutions. Another reason is that sometimes the solutions need to be modified. This provides greater flexibility when it comes to mixing the specific solution needed for specific situations. Clearly, in many industries, technologists follow careful procedures to prepare **standard solutions**.

Making a standard solution requires practice and skill because the slightest error can cause the concentration of your standard solution to be less accurate. In the next investigation you will have an opportunity to produce a standard solution and a dilute solution.

standard solution: a solution having a precisely known concentration

Figure A1.21: In a number of industries, solutions need to be very specific.

Investigation

Developing Technological Skills with Solutions

Purpose

You will practise the skills for making a standard solution and for making a dilute solution.

Materials

- 50-mL beaker
- 2, 100-mL volumetric flasks
- anhydrous copper(II) sulfate, $CuSO_4(s)$
- distilled water
- eyedropper
- 10-mL volumetric pipette

Part A: Making a Standard Solution

In this part of the investigation you will make 100 mL of a 0.200 mol/L solution of copper(II) sulfate from anhydrous copper(II) sulfate.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation.

Pre-Lab Analysis

1. Complete the following calculation to determine the number of moles of solute you will need for your solution:

$$V = 100\ \cancel{\text{mL}} \times \frac{1\ \text{L}}{1000\ \cancel{\text{mL}}}$$
$$= 0.100\ \text{L}$$
$$C = 0.200\ \text{mol/L}$$
$$n = ?$$

$$C = \frac{n}{V}$$
$$n = CV$$
$$= (\qquad)(\qquad)$$
$$= \boxed{}$$

2. Complete the following calculation to determine the mass of the copper(II) sulfate, $CuSO_4$, you need.

$$n =$$
$$M = 1(M \text{ of Cu}) + 1(M \text{ of S}) + 4(M \text{ of O})$$
$$= (\qquad) + (\qquad) + 4(\qquad)$$
$$= \boxed{}$$
$$m = ?$$

$$n = \frac{m}{M}$$
$$m = nM$$
$$= (\qquad)(\qquad)$$
$$= \boxed{}$$

Procedure

step 1: Measure the appropriate mass of solute, $CuSO_4(s)$, and place it into a small beaker.

step 2: Dissolve the solute in the beaker with as little distilled water as possible.

step 3: Carefully transfer the dissolved solute into a volumetric flask. Be sure to rinse your beaker with a little water, and add this rinse to the volumetric flask as well.

step 4: Carefully fill the volumetric flask until the top of the meniscus reaches the 100-mL line.

step 5: Use an eyedropper to add water until the bottom of the meniscus touches the 100-mL line. This is the key step. Do not overshoot the line. If you do overshoot, discard the solution and start over.

step 6: Stopper the volumetric flask. Firmly hold the stopper in place, and invert the flask 15 times to mix the solution.

step 7: Show the solution to your teacher to check the accuracy of your work. Keep your solution. It will be used in Part B of this investigation.

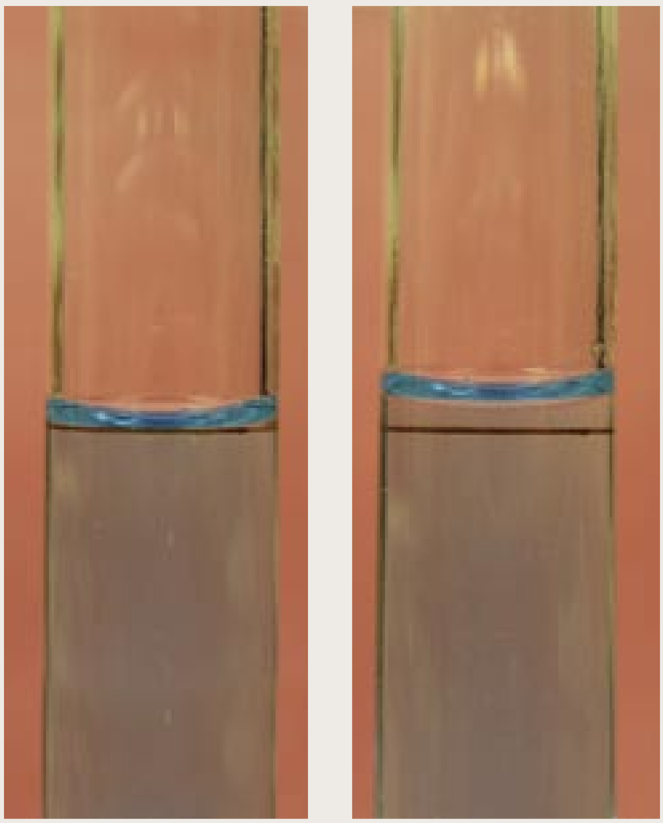


Figure A1.22: The correct measurement of 100 mL occurs when the bottom of the meniscus is even with the line on the volumetric flask. If the bottom of the meniscus is above the line on the volumetric flask, you have more than 100 mL of solution.

Part B: Diluting a Standard Solution

In this part of the investigation you will make 100 mL of a new solution that is a 10% dilution of your standard solution from Part A.

Procedure

step 1: Have your teacher demonstrate the proper technique for using a pipette.

step 2: Pipette 10 mL of your standard solution into another 100-mL volumetric flask.

step 3: Carefully fill the volumetric flask with water so the meniscus is just at the bottom of the 100-mL line.

step 4: Stopper the volumetric flask, and mix the contents of the flask by inverting and carefully shaking it.

step 5: Transfer the dilute solution to an appropriate storage container. Calculate the concentration of your dilute solution. Label the container with the name, chemical formula, and concentration. Also, indicate which WHMIS symbols should be placed on the label.

CAUTION!

Do not pour the remainder of your standard solution down the drain. Consult your teacher regarding the proper disposal of your solution.

Analysis

3. List the potential problems you may have encountered with each step of the procedure. Identify steps that could affect the accuracy of the concentration of your standard solution.
4. Are you confident that your standard solution is exactly 0.200 mol/L? Give a reason for your answer.
5. Do you think it would be easier or more difficult to make a standard solution that is colourless? Support your answer.
6. Explain the importance of knowing the exact concentration of a standard solution.
7. Explain how volumetric flasks and pipettes help you measure volumes with greater precision.

Evaluation

In this investigation you were instructed not to pour your standard solution down the drain. One reason for doing this is that once the water has evaporated, the crystals can be reconstituted and used by other classes. Another reason for not pouring the solutions down the drain has to do with the harmful effects of copper substances on the environment.

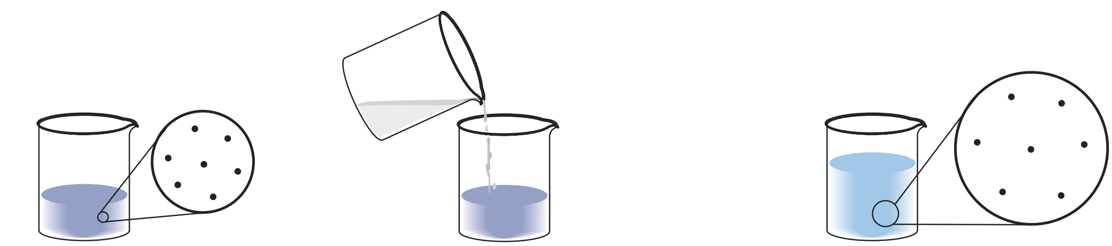
8. Use the Internet and other sources of information to determine the harmful effects of copper compounds released into the environment.

Diluting Solutions

Some chemical solutions are transported in concentrated form to save costs. It may be necessary to dilute such a solution to obtain a solution with a specifically desired concentration. There are also times when water is removed from a solution to make it more concentrated. In each case, the amount of solute is unchanged, but the amount of solvent changes.

Adding Solvent to a Solution

When solvent is added to a solution, the number of moles of solute, *n*, is unchanged.



initial solution

$$C_i = \frac{n}{V_i}$$

$$\boxed{n = C_i V_i}$$

number of moles of solute before dilution

final solution

$$C_f = \frac{n}{V_f}$$

$$\boxed{n = C_f V_f}$$

number of moles of solute after dilution

Since the number of moles of solute is constant,

$$\boxed{C_i V_i = C_f V_f}$$

initial concentration

initial volume

final volume

final concentration

Note: The final volume is the total volume of the solution, not the amount of solvent added.

Example Problem 1.13

You have 65.0 mL of a 0.759-mol/L solution of sodium chloride, NaCl(aq).

a. Calculate the final concentration of the solution if it is diluted to a final volume of 100.0 mL.
b. Calculate the final concentration of a solution prepared by adding 100.0 mL of water to the original solution.
c. How much water do you need to add to the original solution to obtain a solution with a concentration of 0.200 mol/L?
d. How much water needs to evaporate from the original solution to obtain a solution with a concentration of 0.890 mol/L?

Solution

a.
$V_i = 65.0 \text{ mL}$
$C_i = 0.759 \text{ mol/L}$
$V_f = 100.0 \text{ mL}$
$C_f = ?$

$$
\begin{aligned}
C_i V_i &= C_f V_f \\
C_f &= \frac{C_i V_i}{V_f} \\
&= \frac{(0.759 \text{ mol/L})(65.0 \cancel{\text{ mL}})}{100.0 \cancel{\text{ mL}}} \\
&= 0.493 \text{ mol/L}
\end{aligned}
$$

← **Note:** There is no need to convert millilitres to litres because they cancel each other out.

The final concentration of the solution is 0.493 mol/L.

b.
$V_i = 65.0 \text{ mL}$
$C_i = 0.759 \text{ mol/L}$
$V_f = 65.0 \text{ mL} + 100.0 \text{ mL}$
$\quad = 165.0 \text{ mL}$
$C_f = ?$

$$
\begin{aligned}
C_i V_i &= C_f V_f \\
C_f &= \frac{C_i V_i}{V_f} \\
&= \frac{(0.759 \text{ mol/L})(65.0 \cancel{\text{ mL}})}{165.0 \cancel{\text{ mL}}} \\
&= 0.299 \text{ mol/L}
\end{aligned}
$$

The final concentration of the solution is 0.299 mol/L.

c.
$V_i = 65.0 \text{ mL}$
$C_i = 0.759 \text{ mol/L}$
$C_f = 0.200 \text{ mol/L}$
$V_f = ?$
$V_{added} = ?$

$$
\begin{aligned}
C_i V_i &= C_f V_f \\
V_f &= \frac{C_i V_i}{C_f} \\
&= \frac{(0.759 \cancel{\text{ mol/L}})(65.0 \text{ mL})}{0.200 \cancel{\text{ mol/L}}} \\
&= 246.675 \text{ mL}
\end{aligned}
$$

The amount added can be found by subtracting the initial volume from the final volume.

$$
\begin{aligned}
V_{added} &= V_f - V_i \\
&= 246.675 \text{ mL} - 65.0 \text{ mL} \\
&= 181.675 \text{ mL} \\
&= 182 \text{ mL}
\end{aligned}
$$

You need to add 182 mL of water.

continued on next page

d. $V_i = 65.0\text{ mL}$

$C_i = 0.759\text{ mol/L}$

$C_f = 0.890\text{ mol/L}$

$V_f = ?$

$V_{\text{evaporated}} = ?$

$$C_i V_i = C_f V_f$$

$$V_f = \frac{C_i V_i}{C_f}$$

$$= \frac{(0.759\ \cancel{\text{mol/L}})(65.0\text{ mL})}{0.890\ \cancel{\text{mol/L}}}$$

$$= 55.432\ 584\ 27\text{ mL}$$

The amount evaporated can be found by subtracting the final volume from the initial volume.

$$V_{\text{evaporated}} = V_i - V_f$$

$$= 65.0\text{ mL} - 55.432\ 584\ 27\text{ mL}$$

$$= 9.567\ 415\ 73\text{ mL}$$

$$= 9.6\text{ mL}$$

The volume of water needed to evaporate is 9.6 mL.

Diluting Acids

In previous science courses you studied compounds that form solutions that turn blue litmus paper red because they produce hydrogen ions. These compounds are called **acids**.

acid: a substance that produces hydrogen ions when dissolved in water to form a conducting aqueous solution

Soft drinks, tomato sauce, and pickles are foods that are all slightly acidic. Acid content in food can be identified with a sour taste. While these products are relatively harmless, concentrated acids can be quite hazardous. Concentrated acids can cause acid burns on skin, blindness if splashed in the eyes, and death if swallowed.

The most common acid used in industry is sulfuric acid. In fact, more sulfuric acid is produced each year than any other industrial chemical. As you'll see in the next set of Practice questions, concentrated sulfuric acid is used in a wide variety of applications.

Safety Tip: When diluting an acid, always add the acid to the water in small amounts. The rearrangement of solute and solvent when an acid is diluted is exothermic and can be a safety risk.

Practice

Figure A1.23: A battery technician checks the concentration of sulfuric acid.

37. The battery is the primary source of electrical energy used in vehicles. Most automotive batteries produce electricity by using the chemical reaction between two different types of lead in a solution of sulfuric acid. This application is the reason why some people refer to sulfuric acid as battery acid. In one automotive battery, 360 mL of concentrated sulfuric acid, 17.8 mol/L, is combined with 640 mL of water to form the solution with the proper concentration.

- **a.** Determine the total volume of the solution in the battery.
- **b.** Calculate the molar concentration of the sulfuric acid solution in the battery.
- **c.** Determine the percent by volume concentration of the sulfuric acid solution in the battery.
- **d.** Consider your answers to questions 37.b. and 37.c. Which method of communicating concentration is likely used by scientists researching new designs for batteries, and which method is best for a brochure for customers explaining the features of a particular battery?

38. Sulfuric acid is used to make chlorine dioxide for bleaching in the pulp and paper industry. A technician in a pulp mill needs to make 275 L of a solution containing 4.25 mol/L of sulfuric acid.

- **a.** Calculate the volume of concentrated sulfuric acid (17.8 mol/L) that the technician must measure to make the required solution.
- **b.** Determine the volume of water needed to make the required solution.

39. Approximately two-thirds of all the sulfuric acid produced for industry is used in the production of fertilizers. Ammonium sulfate and potassium sulfate are both fertilizers that are manufactured using sulfuric acid. At a large fertilizer manufacturing plant, a technician begins to prepare some tests using a standard solution of sulfuric acid.

   a. The technician measures out 2.50 L of a standard solution of sulfuric acid with a concentration of 10.0 mol/L. Determine the amount of water that must be added to create a solution with a concentration of 3.75 mol/L.

   b. A large beaker contains 655 mL of a standard solution of sulfuric acid with a concentration of 10.0 mol/L. This beaker is placed in a fume hood where evaporation can occur. Determine the amount of water that would have to evaporate in order for the solution to have a concentration of 11.0 mol/L.

DID YOU KNOW?

Many natural compounds, such as the oils in onions, contain sulfur. When you slice an onion, a gas is released that rises upwards and combines with the water in your eyes. The result is that a dilute sulfuric acid solution forms in your eyes. In response to this irritation, your eyes automatically start to blink and tear to flush out the sulfuric acid.

Chemical Reactions and Electricity

If a vehicle's headlights are left on while the motor is shut off, the battery produces the electric current for the lights. The current is sustained by chemical reactions within the battery that decrease the concentration of sulfuric acid. If these reactions continue to the point that the sulfuric acid concentration drops below a critical level, the battery is said to be fully discharged or dead.

Figure A1.24: The voltage output of an automotive battery is checked.

When the engine is running, the vehicle's recharging system prevents this situation from occurring by supplying an electric current to the battery that flows in the opposite direction. As the electrons are forced into the battery, the chemical reactions are reversed, the concentration of sulfuric acid rises, and the battery is said to be fully charged.

The concentration of sulfuric acid in the battery is a good indicator of the state of charge of the battery. In the next chapter you will learn more about the role of electrons in chemical reactions and how all this relates to the batteries.

1.5 Summary

Having quantitative units for concentrations allows you to know specifically how much solute is dissolved in a solution. Percent by volume is a unit of concentration used to communicate what volume of liquid solute is dissolved in a solvent. Very dilute solutions are often expressed in parts per million (ppm). The method preferred by technologists and scientists is molar concentration (measured in mol/L). Volumetric flasks and pipettes are useful tools for making standard solutions. When you add more solvent to a solution, its volume is increased, thus lowering the concentration of the solvent and making it more dilute. The number of moles of solute dissolved in the solvent does not change. It is possible to calculate new volumes and concentrations when diluting or evaporating solvent from a solution.

1.5 Questions

Knowledge

1. Define the following.

- **a.** mole
- **b.** molar concentration
- **c.** conversion factor
- **d.** molar mass
- **e.** parts per million concentration
- **f.** percent by volume concentration
- **g.** standard solution
- **h.** volumetric flask
- **i.** pipette

2. Describe why making quantitative measurements of the concentration of a solution is useful.

3. Explain why there are many different units to measure concentration.

4. Explain how each property listed changes as you add more solvent to the solution.

- **a.** the concentration of the solution
- **b.** the volume of the solution
- **c.** the number of moles dissolved in the solution

5. Explain why it is necessary to make standard solutions.

Applying Concepts

6. A student takes 7.00 g of potassium permanganate, $KMnO_4(s)$, and dissolves it into 30.0 mL of water.

- **a.** Calculate the concentration of the resulting solution in mol/L.
- **b.** Calculate the concentration of the resulting solution in parts per million. (Remember, 30.0 mL of water is equal to 30.0 g of water.) Is this an appropriate way to communicate the concentration in this situation? Support your answer.
- **c.** If the student pours the original solution into a jar that contains 250 mL of water, find the concentration of the resulting solution in the jar in mol/L.
- **d.** If the student pours the original solute into a reservoir that contains 4.00×10^6 g of water, calculate the concentration of the resulting solution in parts per million. Is this an appropriate way to communicate the concentration in this situation? Support your answer.

7. A technician opens a jar that contains a concentrated disinfectant solution. The molar concentration of the disinfectant is 5.00 mol/L.

- **a.** What volume of this disinfectant is required to make a 2.00-L hand-soap solution that has a disinfectant concentration of 0.400 mol/L?
- **b.** If you take 20.0 mL of the disinfectant solution and add it to 150 mL of water, determine the percent by volume concentration of the resulting solution.
- **c.** A 50.0-mL sample of the original disinfectant solution is left in an open container overnight in a fume hood. You notice in the morning that the volume of the solution is now 40.0 mL. Assuming that no disinfectant evaporated, calculate the new molar concentration of the solution.

8. Design a flowchart describing the specific steps needed to make a standard solution of copper(II) sulfate from anhydrous copper(II) sulfate crystals. Include the types of calculations and equipment you would use.

9. Each of the following three photographs shows a different method for communicating concentration. Provide a reason for the form of communication used in each photograph.

Chapter 1 Review Questions

Knowledge

1. An atom has an atomic mass of 9.01 and an atomic number of 4.
   a. Determine the identity of the atom.
   b. Determine the number of neutrons the atom has.
   c. Draw a Bohr diagram for the atom.
   d. Draw a Lewis dot diagram for the atom.
   e. Determine the number of valence electrons this atom has.
   f. Write the symbol of the ion for this atom. Explain the reason for the net charge on this ion.
2. An atom has an atomic mass of 32.06 and an atomic number of 16.
   a. Determine the identity of the atom.
   b. Determine the number of neutrons in the most common form of the atom.
   c. Draw a Bohr diagram for the atom.
   d. Draw a Lewis dot diagram for the atom.
   e. Determine the number of valence electrons this atom has.
   f. Write the symbol of the ion for this atom. Explain the reason for the net charge on this ion.
3. Consider the following compounds.
   - carbon tetrachloride, $CCl_4(l)$
   - hydrogen fluoride, $HF(g)$
   - potassium iodide, $KI(s)$
   - magnesium oxide, $MgO(s)$

   a. Which compounds are ionic and which are molecular?
   b. Draw Lewis dot diagrams of the individual atoms that comprise these compounds.
   c. Draw diagrams to illustrate the bonding between particles in each of the four compounds.
4. A fireproof safe contains an ionic compound, $CaCO_3(s)$, between the inside and outside layers of metal. The particles of this compound do not respond to the heat released by a fire the same way the particles in the metal do. Explain how these different responses to heat are due to the different forms of chemical bonds in these materials. Describe how the presence of the $CaCO_3(s)$ in the safe's construction protects the contents against damage from the heat.

5. Classify each substance as being either a molecular compound or an ionic compound. Determine whether it will dissolve in water and whether it is classified as an electrolyte or a non-electrolyte.
   a. $NaF(s)$
   b. $CH_4(g)$
   c. $Li_2O(s)$
   d. $AlCl_3(s)$
   e. $C_5H_{12}(l)$
6. Define *dissociation*. Use a diagram to explain why $NaCl(s)$ will dissociate when placed in water.
7. Describe the differences between the changes that occur to solute particles that form a solution by undergoing dissociation and to the changes that occur to solute particles that form a solution but do not dissociate.
8. Give two reasons why a concentrated solution of sulfuric acid is more dangerous than a dilute solution of sulfuric acid.
9. Explain why it is a common safety procedure to flush skin with plenty of water when it comes into contact with a concentrated acid.

Applying Concepts

10. You dissolve 280 g of sucrose (table sugar), $C_{12}H_{22}O_{11}(s)$, in 2.00 L of water.

- **a.** Determine the number of moles of sugar in this solution.
- **b.** Calculate the molar concentration of this solution.

11. You dissolve 16.0 g of potassium sulfate, $K_2SO_4(s)$, in 500 mL of water.

- **a.** Determine the number of moles of potassium sulfate in this solution.
- **b.** Calculate the molar concentration of this solution.

12. A solution contains 100 ppm of lead. Determine the mass of lead present in 0.500 kg of the solution.

13. While visiting an ocean beach in Nova Scotia, you notice the following sign above the sinks in the changing room.

- **a.** If someone was to ignore this sign and drink 250 g of water, they would consume about 9.5×10^{-6} g of arsenic. Calculate the concentration of the arsenic in this water in parts per million.
- **b.** The maximum acceptable level of arsenic in drinking water is 0.025 ppm. Drinking water with an arsenic concentration of 60 ppm is lethal. Use this information and your answer to question 13.a. to determine if drinking a cup of water from this tap would be lethal.
- **c.** There are places on Earth where the only drinking water available to people contains high levels of arsenic. Use the Internet to locate a place where the arsenic contamination of drinking water creates major health problems for the population. What is the source of the arsenic contamination in this place?
- **d.** Arsenic has been used as a poison for centuries. Use the Internet to survey the evidence that suggests that Napoleon Bonaparte was poisoned with arsenic while imprisoned on the tiny island of St. Helena.

14. Determine how many moles of solute are dissolved in each of the following solutions.

- **a.** a 250-mL solution of sucrose, $C_{12}H_{22}O_{11}(aq)$, with a concentration of a 0.500 mol/L
- **b.** a 5.00-L solution of potassium sulfate, $K_2SO_4(aq)$, with a concentration of 0.0250 mol/L

15. Determine the number of moles of solute and the mass of the solute dissolved in each of the following solutions.

- **a.** a 250-mL solution of sucrose, $C_{12}H_{22}O_{11}(aq)$, with a concentration of 0.146 mol/L
- **b.** a 4.00-L solution of potassium sulfate, $K_2SO_4(aq)$, with a concentration of 0.150 mol/L

16. Determine the volume of solution required for the following situations.

- **a.** You wish to obtain 3.89 g of sucrose, $C_{12}H_{22}O_{11}(s)$, from a 0.0675-mol/L sugar solution.
- **b.** You wish to prepare a 6.26-g potassium sulfate solution, $K_2SO_4(aq)$, with a concentration of 0.0250 mol/L.

17. An amount of sucrose, $C_{12}H_{22}O_{11}(s)$, is needed to prepare 500 mL of a sugar solution with a concentration of 0.783 mol/L.

- **a.** Calculate the number of moles of sucrose that will be needed for this solution.
- **b.** Calculate the mass of sucrose required to make this solution.

18. An amount of sodium chloride, NaCl(s), is needed to prepare 1.25 L of a salt solution with a concentration of 0.750 mol/L.

- **a.** Calculate the number of moles of sodium chloride that will be needed for this solution.
- **b.** Calculate the mass of sodium chloride required to make this solution.

19. While removing rust from the bumper of a vintage automobile, a can containing 95.0 mL of an acid-based rust remover is left out in the hot sun. After some time, 15.0 mL of the water evaporates from this can. If the acid's original concentration was 2.30 mol/L, determine the new concentration of the acid.

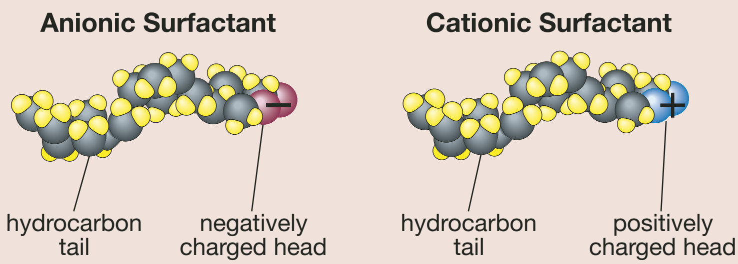
20. While cleaning a toilet, 150 mL of disinfectant solution is poured into a toilet containing 750 mL of water. If the initial concentration of the disinfectant was 3.40 mol/L, determine the new concentration of the solution.

Use the following information to answer questions 21 to 27.

Case Study: The Chemistry of Shampoo

Despite claims from the manufacturers, shampoo cannot enliven, nourish, or revive hair. This is because the part of hair that appears above the scalp is basically a shaft of protein molecules produced by cells in the scalp. Individual hairs are lubricated and protected by a natural oil, called sebum, which is produced by tiny glands located at the base of each hair. Unfortunately, sebum naturally tends to collect dirt as well as residues from hair-care products. The goal of shampoo is to remove the oily layer of sebum and any dirt that this layer may have accumulated on the shafts of the hairs. The challenge is that this oily layer must be removed in the watery environment of the shower. Water is a poor solvent for oil.

Shampoo manufacturers have solved this problem by including detergent substances in their products. Detergents are a type of surfactants—short for "surface active agents." The detergent property of the solutions removes the oil, and the surfactant property means that the shampoo will rinse out of the hair easily in water.



Surfactants work because one end of these long molecules consists of a tail of hydrocarbons that can attach itself to oily substances. At the other end of these molecules is a head that can be ionized and, therefore, be attracted to water molecules. If the head of the surfactant carries a negative charge, it is called anionic. If the head carries a positive charge, the surfactant is called cationic. Shampoos usually consist of a group of anionic surfactants mixed with other ingredients in a water-based solution.

INGREDIENTS IN BRAND X SHAMPOO

Name of Ingredient	Volume (mL)	Function
water	109.3	acts to dissolve other ingredients
ammonium lauryl sulfate solution	109.0	anionic surfactant
ammonium laureth sulfate solution	106.5	anionic surfactant
ammonium dodecylbenzene sulfonate solution	12.0	anionic surfactant
lauramide DEA solution	10.5	high-foaming surfactant
dimethicone solution	2.0	a coating that replaces the sebum, providing shine and easy combing
disodium EDTA solution	0.7	preservative to keep shampoo from "spoiling"
Total	350.0	

Shampoos work because the tail of the surfactant molecule secures itself to the oily layer of sebum while the anionic head attracts water molecules. When you rinse out the shampoo, the sebum is also washed away.

21. Identify an ingredient in the shampoo that could be classified as the solvent.

22. Identify an ingredient in the shampoo that could be classified as a solute.

23. Explain how neutral water molecules could be attracted to the charged head of an anionic surfactant. Draw a diagram to support your answer.

24. Calculate the percent by volume concentration of the following ingredients in the shampoo.

    a. ammonium lauryl sulfate solution
    b. ammonium laureth sulfate solution
    c. ammonium dodecylbenzene sulfonate solution
    d. dimethicone solution

25. The main protein in hair is keratin. An interesting property of keratin in hair is that its molecular structure tends to have a high percentage of negative charges on its outer surface. This means that the outer surface of each shaft of hair tends to have a slightly negative charge.

    a. Explain how the slightly negative charge along the length of a hair actually assists in the rinsing of the anionic surfactants from the hair after shampooing.

    b. Explain why dry hair tends to stand up and "fly away" after it has been combed.

26. Use your understanding of the properties of different groups of molecules to explain the following statement from the information box: "Water is a poor solvent for oil."

27. Manufacturers are required to list the ingredients in shampoo in order of decreasing concentration. However, they are not required to state numerical values for the concentration of each ingredient because this would reveal the exact recipe of the shampoo—something considered to be a trade secret. Locate a bottle of shampoo in your home.

    a. List the first three ingredients on your bottle of shampoo.

    b. How many ingredients are listed in total?

    c. Suggest some of the tests that would have to be performed on each of these ingredients before they could be approved for use in shampoo.

Chapter 2 The Reduction and Oxidation of Metals

The ’69 Chevelle was marketed to a boisterous generation of young people as an affordable performance car. The year 1969 saw the first person step on the surface of the moon, the Woodstock Music and Arts Fair made rock music history, and a powerful car was ready to assert itself on the road.

Christine first saw a ’69 Chevelle when she was just a little girl. The car she saw, though, had fallen into disrepair. The once powerful sprinter was rusting on a pile of hay bales. It was purchased as a salvage vehicle by Christine’s father. Over the years, Christine watched her father meticulously work to restore the vehicle to its former glory. Since Christine shared her father’s passion for this restoration, she was given the car. Years later, she hired professionals to complete the work.

The most expensive and time-consuming work in restoration is rust repair and panel replacement. To a car, rust is like a cancer that must be completely cut out to prevent it from spreading. Bumpers usually need to be removed, chemically cleaned, and put through a process that puts a new coating of chrome on the surface. Restoration also extends to the mechanical and electrical systems. The battery would be depleted of the reactants that enable it to produce an electric current. The copper in most of the electrical switches and contacts would most likely be corroded and have to be replaced.

The process of corrosion, the production of electricity in a battery, and the plating of chrome over steel all have something in common. What is it? You might be surprised to know that chemistry is at the heart of each one. Each process is explained by the exchange of electrons between different metals and metal ions.

In this chapter you will learn how metals are mined, protected from corrosion, used to generate an electric current, and plated onto the surface of other metals. Throughout this chapter, your knowledge of valence electrons, solutions, and bonding from Chapter 1 will be used to support your new learning.

Try This Activity

Observing the Reactivity of Zinc

In some chemical reactions, one type of ion replaces another type of ion in a solution. The ion that is replaced often precipitates out of the solution. In this activity you will observe the reaction between zinc metal and a solution of silver nitrate, $AgNO_3(aq)$.

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting
✓ Communication and Teamwork

Materials

- small samples of plastic
- small samples of zinc metal
- 0.500-mol/L silver nitrate solution
- eyedropper
- multi-well dish (or 2 Petri dishes)
- dissecting microscope

CAUTION!
Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Take a small piece of plastic and a small piece of zinc metal, and place each in a separate well of the multi-well dish (or in separate Petri dishes).

step 2: Place the dish containing the plastic under a dissecting microscope, and focus the microscope so you have a clear image of the edge of the plastic piece.

The next steps involve one partner observing changes through the microscope as the other partner adds a few drops of solution. Organize your group so that each person will have an opportunity to make observations through the microscope.

step 3: Have one of your partners add a few drops of silver nitrate solution, and observe any changes that occur to the plastic or to the solution while looking through the microscope.

step 4: Repeat steps 2 and 3 for the piece of zinc.

step 5: Clean your equipment, and dispose of the waste materials as directed by your teacher.

Analysis

1. Which substance is more reactive—the strip of plastic or the zinc? Please give a reason for your answer.
2. Infer what you think occurs to the zinc during the chemical reaction.
3. Infer which material is produced during the chemical reaction.
4. Describe the change by completing the following word chemical equation:

   zinc + silver nitrate →
5. Describe what you saw while looking at the zinc and silver nitrate solution through the microscope.
6. Use the word equation from question 4 to write a balanced chemical equation that describes the reaction between zinc metal and aqueous silver nitrate.

2.1 Compounds and Chemical Change

Figure A2.1: Copper bracelets were among the items found in an ancient site near Prince Rupert Harbour.

The objects in Figure A2.1 were found hidden in an ancient site near Prince Rupert Harbour. Archaeologists suspect that these objects were a cache of weapons and other objects that once belonged to a warrior who lived approximately 1800 years ago. Of particular interest are the copper bracelets and the copper-wrapped cedar cylinders that were a form of rod armour. The source of the copper was likely 1200 km north of Prince Rupert in the Copper River area of Alaska, where copper occurs as nuggets in the gravel of the river bed.

This evidence suggests that the ancestors of the First Nations people in Canada were not only identifying, collecting, and trading copper metal, they were also applying metallurgy—heating and hammering copper into shapes.

In Alberta, First Nations people also made use of copper; but, in this case, the source of the copper was likely from the area around Lake Superior—over 1500 km east of Alberta—which also has excellent deposits of copper. Archaeologists have dated some of the manufactured copper artifacts from this area to be nearly 7000 years old. This suggests that the ancestors of the First Nations people may have been among the first metal workers in the world. The technological details about how the copper was heated and hammered into shape remain a mystery because archaeologists have not located kilns or crucibles capable of melting or smelting copper needed for the manufacturing process.

Archaeologists studying artifacts, like the copper bracelets in Figure A2.2, often use chemical analysis to help determine the likely source of the copper. This can provide insights into the extent of trade routes among different regions.

Figure A2.2: The copper bracelets were found at a site along the Columbia River.

Practice

1. Ancient copper artifacts are rarely unearthed in shiny or lustrous condition. Usually, these objects tend to have a dull green surface. The change in colour of the copper artifacts indicates that a process has occurred. Identify the name of this process.

2. Archaeological evidence suggests that the ancient ancestors of the First Nations people in Alberta had access to copper from the Lake Superior area, sea shells from the Gulf of Mexico, and obsidian (a type of volcanic glass) from Wyoming. What does this evidence suggest about the movement of goods and materials on the North American continent in ancient times?
3. When copper artifacts were first discovered in eastern North America over a hundred years ago, it was assumed by archaeologists of the day that these objects were created by First Nations people using copper obtained through trade with European settlers.
   - **a.** Explain how this assumption led to the mistaken conclusion that some archaeological sites were hundreds of years old when, in reality, many sites were thousands of years old.
   - **b.** Copper nuggets from the Lake Superior area have exceptional purity: about 99.9%. The purest copper from Europe is only about 98% pure. Explain how a chemical analysis of ancient artifacts could determine the original source of the copper.

Tarnishing of Metal Jewellery

Ancient copper artifacts often have a dull green appearance when they are discovered. Even jewellery from modern times can sometimes start to tarnish and lose its lustre. Silver, in particular, has a tendency to turn black over time. Why does this happen?

Figure A2.3: Silver sulfide is the black substance that coats silverware.

When metal begins to tarnish, the colour change is evidence of a chemical reaction occurring. Silver has the tendency to react with molecules in the air, such as hydrogen sulfide in the presence of oxygen. The products of this reaction are silver sulfide, Ag_2S, and water. Silver sulfide is what gives tarnished silverware its black colour. The process of developing a balanced chemical equation for this reaction from a word description is as follows.

Writing a Balanced Chemical Equation

$$\left(\begin{array}{c}\text{solid}\\\text{silver}\end{array}\right) + \left(\begin{array}{c}\text{hydrogen}\\\text{sulfide}\\\text{gas}\end{array}\right) + \left(\begin{array}{c}\text{oxygen}\\\text{gas}\end{array}\right) \rightarrow \left(\begin{array}{c}\text{solid}\\\text{silver}\\\text{sulfide}\end{array}\right) + \left(\begin{array}{c}\text{liquid}\\\text{water}\end{array}\right)$$

Translate the words into chemical formulas.

$$\square\ Ag(s) + \square\ H_2S(g) + \square\ O_2(g) \rightarrow \square\ Ag_2S(s) + \square\ H_2O(l)$$

Add coefficients to balance the equation.

$$\boxed{4}\ Ag(s) + \boxed{2}\ H_2S(g) + \boxed{1}\ O_2(g) \rightarrow \boxed{2}\ Ag_2S(s) + \boxed{2}\ H_2O(l)$$

Coefficients of 1 are not recorded.

$$4\ Ag(s) + 2\ H_2S(g) + O_2(g) \rightarrow 2\ Ag_2S(s) + 2\ H_2O(l)$$

The coefficients ensure that the equation is balanced. Even though new products were produced, these new compounds were formed by simply rearranging the atoms that were available in the reactants. Atoms were not created nor destroyed—they were simply rearranged. You can use a table similar to the following to check whether chemical equations are, in fact, balanced.

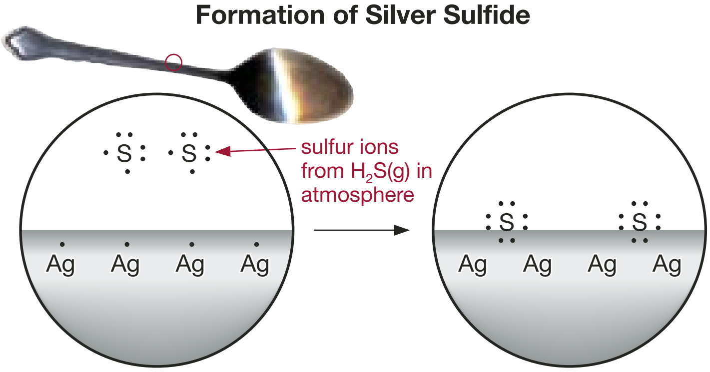
CHECKING A BALANCED CHEMICAL EQUATION

Atom	Number of Atoms Before Reaction	Number of Atoms After Reaction
Ag	4	4
H	4	4
S	2	2
O	2	2

Since the total of each kind of atom before the reaction is equal to the total of each kind of atom after the reaction, this equation is balanced. Matter is conserved.

In addition to balancing the equation, the coefficients indicate the relative ratios of one compound to another. For example, when silver reacts to form silver sulfide, for every four atoms of silver, there are only two units of silver sulfide crystal produced. The reasons for this 4-to-2 ratio lie within the silver sulfide crystal.

Lewis Dot Diagram Showing Formation of Silver Sulfide



Each sulfur atom acquires two electrons to fill its outer energy level to become an ion with a charge of 2–. To obtain a full outer energy level, each silver atom loses one electron to become an ion with a charge of 1+. As the graphic illustrates, it will always take four silver atoms to produce two units of silver sulfide. The ratio of these coefficients in the balanced chemical equation describing this reaction is called the **mole ratio**.

mole ratio: the ratio of the coefficients in a balanced chemical equation

number of moles of required substance

coefficient of required substance

$$\frac{n_r}{n_g} = \frac{coefficient_r}{coefficient_g}$$

coefficient of given substance

number of moles of given substance

It is called a ratio because it communicates proportion. Whether it is 8 dozen to 4 dozen, 600 to 300, or 4 mol to 2 mol, there will always be double the number of silver atoms to units of silver sulfide. Mole ratios are very useful because they can be used to solve problems.

Example Problem 2.1

Determine the amount of silver required to make 0.876 mol of silver sulfide.

Solution

$n_{Ag_2S} = 0.876 \text{ mol}, n_{Ag} = ?$

First, determine the mole ratio.

Balanced chemical equation

$$4\,Ag(s) + 2\,H_2S(g) + O_2(g) \rightarrow 2\,Ag_2S(s) + 2\,H_2O(l)$$

Mole ratio

$$\frac{n_{Ag}}{n_{Ag_2S}} = \frac{coefficient_{Ag}}{coefficient_{AgS}}$$
$$= \frac{4}{2}$$

Now, calculate the number of moles of silver required.

$$\frac{n_{Ag}}{n_{Ag_2S}} = \frac{4}{2}$$
$$n_{Ag} = \frac{4}{2} \times n_{Ag_2S}$$
$$= \frac{4}{2} \times 0.876 \text{ mol}$$
$$= 1.75 \text{ mol}$$

The amount of silver required is 1.75 mol.

Note: When no coefficient is written, the coefficient is assumed to be 1. Since a ratio can be stated a number of different ways, it is convenient to place the required substance in the numerator.

Practice

4. Determine the amount of oxygen required to react with 0.533 mol of silver in the formation of silver tarnish.
5. Determine the amount of hydrogen sulfide required to produce 1.45 mol of silver sulfide.
6. If you use a silver spoon to eat a hard-boiled egg, the spoon will develop tarnish on its surface much sooner than usual. Suggest a reason for this effect.

Ratios in Balanced Chemical Equations and Recipes

In Example Problem 2.1, the solution was separated into two steps. The first step was to determine the mole ratio for two of the chemicals in the reaction. Many students do not record this step because they are able to do this mentally. This cuts the length of the solution in half. If you think of a balanced chemical reaction like a recipe, you might be able to do this step in your head.

In the recipe for homemade iced tea, what is the ratio of tea bags to lemons? What is the ratio of granulated sugar to lemon juice? If you immediately said 24 tea bags to 4 lemons and 600 mL of sugar to 60 mL of lemon juice, you may want to start answering the next Practice questions by simply stating the ratio. As before, to keep the calculation straightforward, continue to set up the mole ratio with the required substance in the numerator.

Example Problem 2.2

When aluminium metal is exposed to air, the metal reacts with oxygen in the air to form aluminium oxide.

$$4\,\mathrm{Al(s)} + 3\,\mathrm{O_2(g)} \rightarrow 2\,\mathrm{Al_2O_3(s)}$$

a. If you react 6.25 mol of aluminium with a sufficient amount of oxygen, determine how many moles of aluminium oxide will be formed.

b. Determine the number of moles of oxygen required to react with 6.25 mol of aluminium.

Solution

a. $n_{\mathrm{Al}} = 6.25\ \mathrm{mol}$

$n_{\mathrm{Al_2O_3}} = ?$

$$\frac{n_{\mathrm{Al_2O_3}}}{n_{\mathrm{Al}}} = \frac{\mathit{coefficient}_{\mathrm{Al_2O_3}}}{\mathit{coefficient}_{\mathrm{Al}}}$$

$$\frac{n_{\mathrm{Al_2O_3}}}{n_{\mathrm{Al}}} = \frac{2}{4}$$

$$\begin{aligned} n_{\mathrm{Al_2O_3}} &= \frac{2}{4} \times n_{\mathrm{Al}} \\ &= \frac{2}{4} \times 6.25\ \mathrm{mol} \\ &= 3.13\ \mathrm{mol} \end{aligned}$$

There will be 3.13 mol of aluminium oxide formed.

b. $n_{\mathrm{Al}} = 6.25$

$n_{\mathrm{O_2}} = ?$

$$\frac{n_{\mathrm{O_2}}}{n_{\mathrm{Al}}} = \frac{\mathit{coefficient}_{\mathrm{O_2}}}{\mathit{coefficient}_{\mathrm{Al}}}$$

$$\frac{n_{\mathrm{O_2}}}{n_{\mathrm{Al}}} = \frac{3}{4}$$

$$\begin{aligned} n_{\mathrm{O_2}} &= \frac{3}{4} \times n_{\mathrm{Al}} \\ &= \frac{3}{4} \times 6.25\ \mathrm{mol} \\ &= 4.69\ \mathrm{mol} \end{aligned}$$

The reaction will require 4.69 mol of oxygen.

Practice

Use the following information to answer questions 7 and 8.

The Coppermine River in Nunavut has many copper deposits along its banks that were used by the ancestors of the Inuit people who live there. The copper was used to make jewellery, knives (such as the one shown in Figure A2.4), and other tools. Prior to restoration, the copper blade of this knife had the characteristic green colour of weathered copper metal.

The process of corrosion for copper artifacts is a complex one that involves many stages. The following description is a simplified version of the key steps in this process:

Figure A2.4: The Inuit people made tools from copper found along the Coppermine River.

step 1: The process usually involves carbon dioxide dissolved in atmospheric moisture to form carbonic acid.

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$$

step 2: The carbonic acid then reacts with the copper to form basic copper(II) carbonate (an ionic crystal), which gives the artifact its green colour. The following equation is a simplification of this process:

$$H_2CO_3(aq) + 2\ Cu(s) + 2\ H_2O(l) \rightarrow Cu_2(OH)_2CO_3(s) + 2\ H_2(g)$$

This same process is what often gives the copper roof of Canada's Parliament buildings their renowned green colour. When new pieces are added to the Parliament buildings' copper roofs, they start off with their characteristic reddish-brown lustre. It takes about 15 years for the chemical reaction to convert the copper in the roof to basic copper carbonate. The process can also be seen on the roof of the University of Calgary's MacEwan Hall. Recent additions are not the same colour as the original portions of the roof.

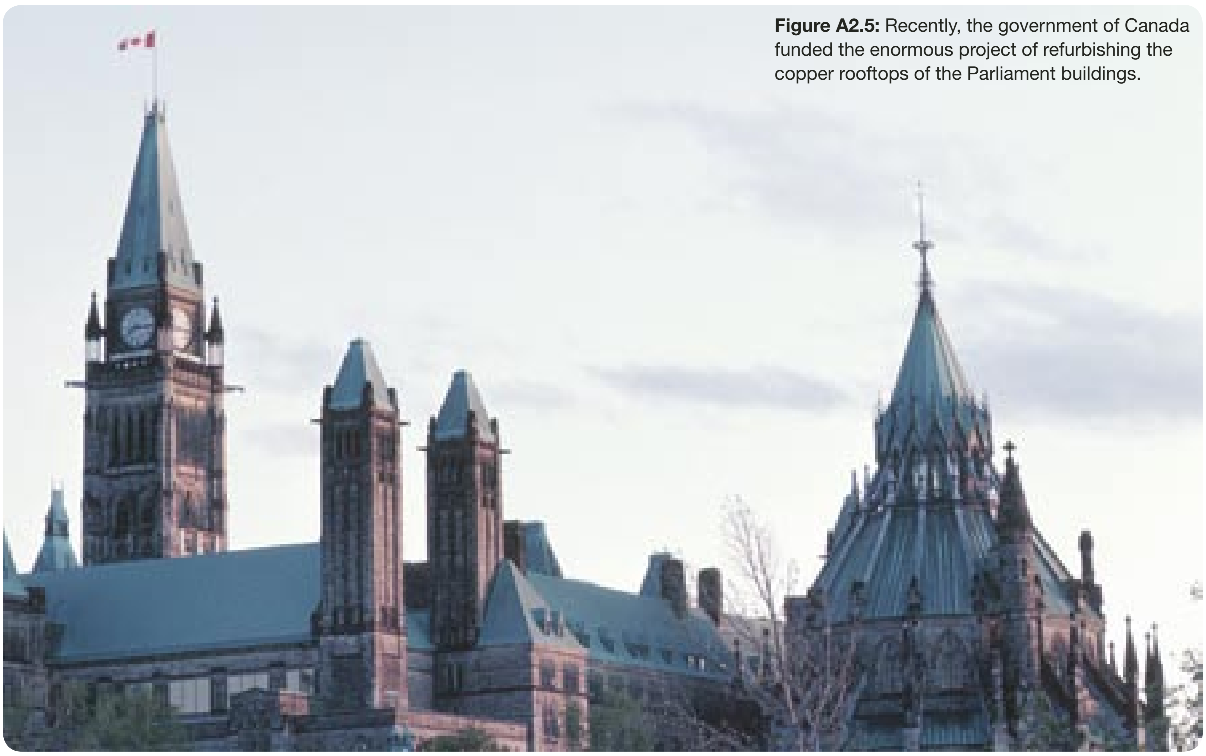


Figure A2.5: Recently, the government of Canada funded the enormous project of refurbishing the copper rooftops of the Parliament buildings.

7. Consider the reaction that produces the carbonic acid.

a. If the reaction involved 3.87 mol of carbon dioxide, how many moles of carbonic acid is expected to be produced?

b. Explain why a copper roof obtains its outer coating of basic copper carbonate in less time if the surrounding environment is humid and rich with the emissions from the burning of fossil fuels.

8. Consider the reaction that produces basic copper(II) carbonate. Suppose this reaction involves 3.89 mol of copper.

a. How many moles of carbonic acid will be used in the chemical reaction?

b. How many moles of basic copper carbonate will be produced?

Use the following information to answer questions 9 to 11.

If the amount of tarnish is light, you can make silver items shiny again by removing the thin, dark coating of silver sulfide. One way to do this is by reversing the chemical reaction that produced the silver sulfide. This simple process can be done at home.

step 1: Line the bottom of a large pan with aluminium foil, shiny side up.

step 2: Carefully pour boiling water into the pan from a kettle.

step 3: Add about 125 mL of baking soda, $NaHCO_3(s)$ (sodium bicarbonate), for every litre of water.

step 4: Use tongs to place the tarnished silver item in the pan so it is touching the aluminium foil and is submerged in the solution of hot water and baking soda.

step 5: Wait a few minutes for the tarnish to be removed.

step 6: Remove the silver item with tongs, rinse under cool water, and dry thoroughly.

The balanced chemical equation for this process is

$$3\ Ag_2S(s) + 2\ Al(s) + 3\ H_2O(l) \rightarrow 6\ Ag(s) + Al_2O_3(s) + 3\ H_2S(aq)$$

The baking soda, $NaHCO_3(aq)$, acts to remove impurities on the surface of the aluminium foil and to improve the conductivity of the solution. The baking soda also reacts with the hydrogen sulfide from the first chemical equation (as shown in the following equation).

$$NaHCO_3(aq) + H_2S(aq) \rightarrow NaHS(aq) + H_2O(l) + CO_2(g)$$

Figure A2.6: Removing tarnish from silver is a very simple process.

9. You have 4.29×10^{-3} mol of silver tarnish, $Ag_2S(s)$, on a spoon.

a. How many moles of aluminium are necessary to change these moles of $Ag_2S(s)$ back into silver?

b. How many moles of water are required in the reaction that converts the tarnish back into silver?

c. How many moles of silver will be produced during the reaction?

d. How many moles of aluminium oxide will be produced during the reaction?

10. During the process of removing tarnish from a fork, 5.76×10^{-3} mol of hydrogen sulfide, $H_2S(aq)$, completely reacts with the baking soda.

a. How many moles of baking soda, $NaHCO_3(aq)$, are required for this reaction?

b. How many moles of sodium hydrosulfide, NaHS, are produced in this reaction?

c. Explain how an understanding of mole ratio eliminates the need for calculations.

11. Tiny bubbles of gas can be observed leaving the silver piece during the tarnish-removal process. Consider both chemical equations in the tarnish-removal process as you answer the parts of this question.

a. Hydrogen sulfide gas has a distinctive rotten-egg odour. Why isn't this odour noticeable during the tarnish-removal process?

b. Identify the compound forming the tiny gas bubbles on the silver item during the process.

Investigation

Mole Ratios in Chemical Reactions

Purpose

You will collect data for the following chemical reaction:

$$2\ NaOH(aq) + CaCl_2(aq) \rightarrow 2\ NaCl(aq) + Ca(OH)_2(s)$$

The data you collect will allow you to compare the theoretical number of moles of calcium hydroxide produced to the actual number of moles produced.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 1.50 g of sodium hydroxide, $NaOH(s)$
- 2.10 g of calcium chloride, $CaCl_2(s)$
- distilled water
- 2, 100-mL beakers
- filter paper
- funnel
- ring stand
- drying oven
- analytical balance

CAUTION!

Exercise extreme caution to minimize exposure to the solids or solutions produced in this investigation. Use gloves, safety glasses, and lab aprons for this investigation.

Pre-Lab Analysis

1. Use the periodic table to determine the molar mass of sodium hydroxide, calcium chloride, and calcium hydroxide.
2. Using the masses given in the materials, calculate the number of moles of sodium hydroxide and calcium chloride that will be used in this experiment.
3. Use the mole ratio of calcium hydroxide to sodium hydroxide to predict the theoretical number of moles of calcium hydroxide that should be produced.
4. Use the mole ratio of calcium hydroxide to calcium chloride to predict the theoretical number of moles of calcium hydroxide that should be produced.
5. Consider your answers to questions 3 and 4. Explain which value is the best estimate of the amount of calcium hydroxide that will be produced.

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet. Insert the values from the pre-lab analysis to your data sheet.

Predicted/Theoretical Value

Moles of Calcium Hydroxide Produced = ________________

Measured/Experimental Values

Mass of Filter Paper and Calcium Hydroxide = ________________

Mass of Filter Paper = ________________

Chemical	Molar Mass (g/mol)	Mass (g)	Amount (mol)
sodium hydroxide $NaOH(s)$			
calcium chloride $CaCl_2(s)$			
calcium hydroxide $Ca(OH)_2(s)$			

step 2: Use an analytical balance to determine the mass of the filter paper. Record this mass on your data sheet.

step 3: Dissolve 1.50 g of sodium hydroxide, $NaOH(s)$, into a sufficient amount of water that just dissolves the crystals (no more than 20 mL). Record this mass on your data sheet.

step 4: Dissolve 2.10 g of calcium chloride, $CaCl_2(s)$, into a sufficient amount of water that just dissolves the crystals (no more than 20 mL). Record this mass on your data sheet.

step 5: Combine the solutions from steps 3 and 4. Gently swirl the solutions to encourage thorough mixing. A precipitate should be observable.

step 6: Support the funnel on the ring stand, and line the funnel with the filter paper.

step 7: Pour the solution from step 5 through the filter paper to collect all of the precipitate. Rinse any remaining precipitate into the funnel.

step 8: Dry the resulting precipitate overnight in a drying oven. (If no drying oven is available, you may leave it to air dry.)

step 9: Use an analytical balance to determine the mass of the filter paper and calcium hydroxide. Record your results.

Analysis

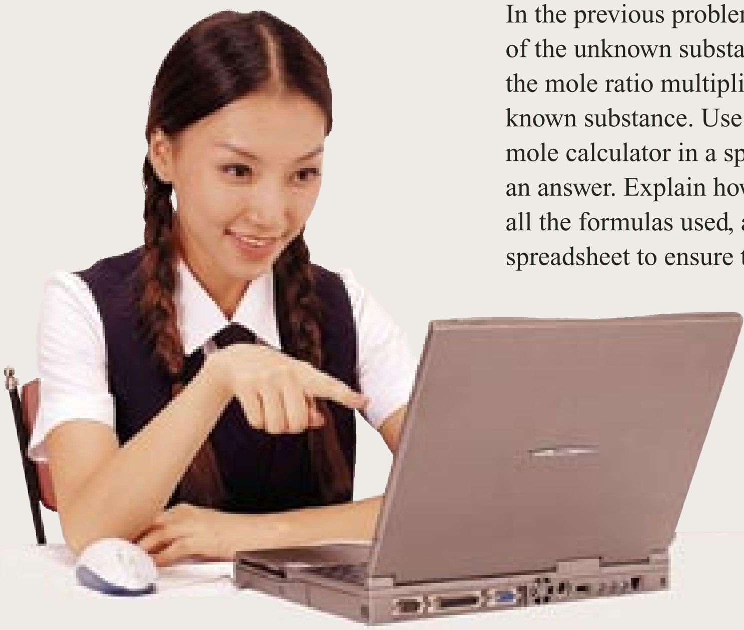
6. Calculate the mass of calcium hydroxide produced by this reaction. Record this value in your data sheet.
7. Calculate the number of moles of calcium hydroxide that were produced in this investigation. Record this value in your data sheet.

Evaluation

8. Compare your experimental value for the number of moles of calcium hydroxide to the theoretical value you calculated in the pre-lab analysis.
9. What difficulties did you encounter that may have affected the accuracy of your results?
10. Describe some steps you could take to minimize difficulties and make this investigation more accurate.

Utilizing Technology

Building an Automatic Mole Calculator Spreadsheet



In the previous problems, calculating the number of moles of the unknown substance always ended up being the same: the mole ratio multiplied by the number of moles of the known substance. Use this fact to construct an automatic mole calculator in a spreadsheet that will convert entered data into an answer. Explain how you constructed the spreadsheet. Include all the formulas used, and provide an example of how you tested the spreadsheet to ensure that it works appropriately.

Science Skills

✓ Initiating and Planning
✓ Analyzing and Interpreting

Using Chemistry to Preserve Artifacts

The warrior cache described at the beginning of the lesson represents a special discovery. It is rare for objects like the bone tools and copper artifacts to be so well preserved in a heavily forested area. Decaying forest vegetation normally creates an acidic soil environment that results in the rapid deterioration of these objects. In this case, the artifacts were surrounded by layers of shells. The shells represented hundreds of years of debris from the First Nations people who inhabited this site. As rainwater dissolved the shells, it created a solution that neutralized the effects of the acid. Thankfully, the naturally acidic soil chemistry was altered by the layers of shells, helping prevent further deterioration of these objects.

Chemistry is also used by experts who preserve and display these valuable artifacts. An understanding of chemical reactions ensures that these objects are maintained under optimum conditions. Such conditions include

- handling artifacts with gloves to prevent the transfer of sweat and oils from the skin
- packing, shipping, and storing artifacts in special acid-free tissue and acid-free boxes
- displaying artifacts in climate-controlled cabinets, ensuring stable temperatures, low humidity, and an environment free of harmful substances

2.1 Summary

Chemical reactions occur due to a rearrangement of atoms—the number of each atom involved in a chemical reaction is conserved. The balanced chemical equation is the result of this principle and provides the key values for determining the mole ratio. Mole ratio is useful because it allows you to determine the amount of reactants or products that will be involved in a chemical reaction.

2.1 Questions

Knowledge

1. Define *mole ratio* and *mass*.

2. Provide a step-by-step outline describing how to use the concept of mole ratio to determine the following.

a. the amount of a reactant required to produce a specific amount of a product

b. the amount of a product that will be produced given a certain amount of a reactant

3. Describe a useful situation for predicting the amount of product in a chemical reaction.

4. Describe a useful situation for calculating the amount of reactant required for a specific amount of product.

Applying Concepts

5. To make pure iron metal from its ore, iron(III) oxide must react with carbon monoxide. The products of this reaction are iron metal and carbon dioxide gas. The balanced chemical equation for this reaction is

$$Fe_2O_3(s) + 3\ CO(g) \rightarrow 2\ Fe(s) + 3\ CO_2(g)$$

Answer the following if 1.5×10^3 mol of iron(III) oxide reacted with a sufficient amount of carbon monoxide.

a. How many moles of pure iron metal will be produced?

b. How many moles of carbon dioxide will be released into the air?

c. How many moles of carbon monoxide will be required to fully change the ore into its metal?

6. Many fertilizers are formed from chemical reactions involving nitric acid because the nitrate within the acid helps make plants green. Several different reactions are required to make nitric acid within an industry. The first step is to react ammonia, $NH_3(g)$, with oxygen from the air. This will produce nitrogen monoxide gas and water. The balanced chemical equation for this reaction is

$$4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(l)$$

You need to make 2.8×10^3 mol of nitrogen monoxide.

a. How many moles of ammonia will you need?

b. How many moles of oxygen will you need?

c. How many moles of water will be produced?

7. During photosynthesis, carbon dioxide and water react in the presence of light energy to form glucose and oxygen.

$$6\ CO_2(g) + 6\ H_2O(g) \rightarrow C_6H_{12}O_6(aq) + 6\ O_2(g)$$

In a particular reaction, 9.00 mol of glucose are produced.

a. How many moles of water were required?

b. How many moles of oxygen were produced?

c. Without using pencil and paper, predict the number of moles of carbon dioxide needed. Explain.

2.2 The Gain and Loss of Electrons

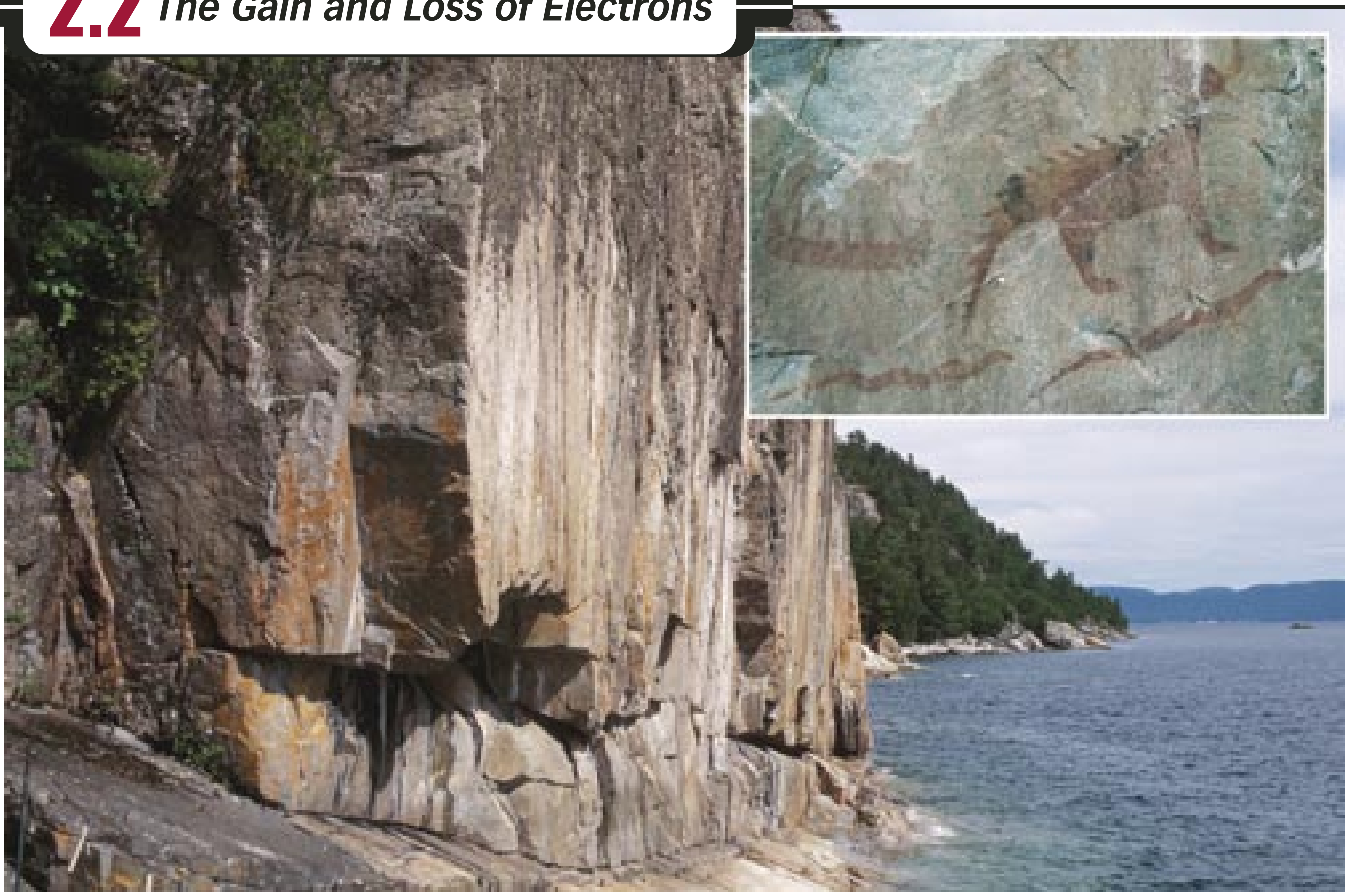


Figure A2.7: These rock paintings are found on the face of Agawa Rock on the shores of Lake Superior. They were painted hundreds of years ago by the ancestors of Anishinabe people.

One great holiday adventure is exploring the eastern shoreline of Lake Superior by kayak or canoe. One of the highlights of such a trip is to visit Agawa Rock, the site of centuries-old paintings by ancestors of Anishinabe, or Ojibway, people. Painted by using a paste of red ochre, $Fe_2O_3(aq)$, the images shown in Figure A2.7 include a canoe, two serpents, and Mishipeshu, a great "horned," underwater lynx that symbolizes the treacherous nature of dark and turbulent waters. Elders from the nearby community have explained that images like these serve many purposes: recounting important events (such as a great battle), as symbols for the clan or family group that lived nearby, or as symbols of spiritual significance. In the language of the Anishinabe people, *Agawa* means "sacred place." So, if you are able to visit this site, it is important to treat it with respect and recognize that it is an important place in Canada's national heritage.

By canoeing to other sites along the lakeside, you can encounter even older archaeological evidence left by the ancestors of the Anishinabe people. The most noteworthy would be abandoned copper mines that are thousands of years old. Natural outcroppings of very pure copper—about 99%—were mined long ago and were the source of most of the copper that was traded across North America by First Nations people for thousands of years.

Copper artifacts, similar to those described in Lesson 2.1, have been found at sites along the Clearwater River in northern Alberta and Saskatchewan. Archaeologists have determined these artifacts to be between 3500 and 5000 years old. The high purity of the copper in these objects, as well as the identification of tiny amounts of specific trace elements, has enabled archaeologists to establish that the copper originated from deposits along the shores of Lake Superior.

Today, mining operations extract copper from rock that may have less than 2% copper in the **ore**. These deposits are frequently contaminated with significant quantities of iron and other minerals. This means that vast quantities of rock have to be mined, crushed into a fine powder, and heated in huge furnaces to separate the copper from the unwanted minerals.

ore: a rock that contains a useful metal in a sufficient concentration that makes it economical to mine

The copper that emerges from the first set of furnaces is in the form of copper(I) sulfide. The molten copper(I) sulfide is then treated in another furnace by blowing air over it to remove the sulfur. This process results in a product called blister copper, because its surface appears blistered due to escaping sulfur dioxide gas while it is solidifying. Blister copper is 97% to 99% pure. The following two reactions occur as air is blown over molten copper sulfide to produce blister copper:

Reaction 1: $2\ Cu_2S(l) + 3\ O_2(g) \rightarrow 2\ Cu_2O(l) + 2\ SO_2(g)$
Reaction 2: $2\ Cu_2O(l) + Cu_2S(l) \rightarrow 6\ Cu(l) + SO_2(g)$

Figure A2.8: Blister copper is poured after being removed from a furnace.

Practice

12. Ores containing less than 2% copper are being mined because rock formations with higher concentrations of copper have already been removed. Even if over 98% of the ore is waste rock, all of this waste material must still be mined, crushed, ground up into a very fine powder, and subjected to extreme heat in furnaces to recover the copper.

- **a.** The mining industry in Canada accounts for over 9% of electricity used in Canada. Explain why this sector of the economy is such a major consumer of energy.
- **b.** If a mine produces 150 000 t of blister copper every year, approximately how many tonnes of finely ground waste rock are produced every year?
- **c.** Approximately 50% of the copper being manufactured is processed from recycled copper. Suggest reasons why recycled copper is likely to become an even more important source of copper in the future.

13. Refer to Reaction 2 above. A copper-refining operation produces about 74.8 mol of copper metal every second.

- **a.** Determine the number of moles of copper(I) sulfide required every second.
- **b.** Determine the number of moles of sulfur dioxide produced every second.

Copper: Essential for Using Electricity and Water

In Canada and across the world, more than half of the copper produced is used for wiring in a wide variety of applications: household wiring, electric motors, transformers, and generators to name a few. The second largest use of copper is the brass mill industry that makes copper pipes and fixtures for plumbing and other applications. So, every time you take a shower or use a small motor in a tool or appliance, you are using technologies that directly depend on the production of copper.

Figure A2.9: Copper plays a big part in home construction, from wiring to plumbing.

Ores Containing Other Metals

Like copper, most metals are not found naturally in a pure form. Instead, they are usually found in rock formations as ores. The metal atoms in an ore are bonded to non-metal atoms—often oxygen or sulfur—in ionic compounds. As you discovered in Chapter 1, metal ions in compounds have lost electrons and, therefore, have positive charges.

Figure A2.10: This sample is almost entirely made up of pure copper.

Practice

14. Copy and complete the following table. A copy of this table is available as a handout on the Science 20 Textbook CD.

METAL IONS

Ore Compound	Chemical Formula	Metal Ion	Number of Electrons Lost by Metal Ion
aluminium oxide	$Al_2O_3(s)$	$Al^{3+}(aq)$	
iron(III) oxide	$Fe_2O_3(s)$		3
silver oxide	$Ag_2O(s)$	$Ag^{+}(aq)$	
silver sulfide	$Ag_2S(s)$		1
iron(II) sulfide	$FeS(s)$	$Fe^{2+}(aq)$	
zinc nitrate	$Zn(NO_3)_2(s)$		2
calcium carbonate	$CaCO_3(s)$	$Ca^{2+}(aq)$	
potassium phosphate	$K_3PO_4(s)$		1

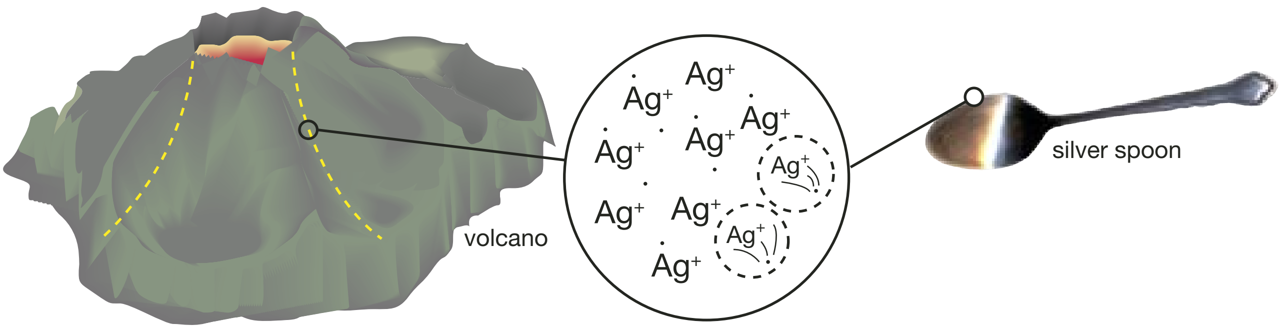
The Transfer of Electrons

Why is it that metals are usually found locked up in ionic compounds in ore deposits? Why are outcrops of pure metal so rare? Recall from Chapter 1 that the most stable arrangement for metals is to have their outer energy levels resemble those of noble gases. This stability can be achieved by a metal combining with a non-metal.

Silver atoms, for example, can combine with sulfur atoms under a variety of conditions: as extreme as inside a volcano or as ordinary as a silver spoon sitting on a kitchen counter. As shown in Figure A.2.11, in both cases, this process involves a transfer of electrons from the metal to the non-metal.

How a Metal Becomes an Ionic Compound

A metal is made up of positively charged particles within a “sea” of free-floating electrons.

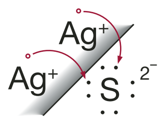


Occasionally, some of the free-floating electrons are lost to other atoms in the environment. The loss of these electrons turns the metal atoms into positively charged ions.

$$2\times\left[Ag(s) \rightarrow Ag^{+}(aq) + 1e^{-}\right]$$

Ag(s)	Ag^{+}(aq)	$1e^{-}$
silver metal	silver ion	one electron

The positive metal ions are then attracted to negative ions that have received the electron.



This ionic compound forms a crystal structure that is the black tarnish on a silver surface.

Figure A2.11: The process of forming an ionic crystal involves the exchange of electrons.

Oxidation: The Loss of Electrons

When an atom loses electrons it undergoes a process called **oxidation**. Originally, *oxidation* meant any reaction involving oxygen, but the term has been expanded to include any chemical process in which one substance transfers electrons to another substance.

oxidation: a chemical process involving the loss of electrons

Examples of Oxidation Reactions

Neutral atoms lose electrons and become positively charged ions.

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^{-}$$

Fe(s)	Fe^{2+}(aq)	$2e^{-}$
metal atom	metal ion	two electrons

Negatively charged ions lose electrons to become neutral atoms.

$$Cl^{-}(aq) \rightarrow Cl(g) + 1e^{-}$$

Cl^{-}(aq)	Cl(g)	$1e^{-}$
non-metal negative ion	non-metal atom	one electron

Positively charged ions lose electrons to become even more positively charged.

$$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + 1e^{-}$$

Fe^{2+}(aq)	Fe^{3+}(aq)	$1e^{-}$
positive metal ion	a more positive metal ion	one electron

Practice

15. Examine Figure A2.11.

a. Identify the substance that was oxidized.

b. Explain why this is called oxidation even though oxygen was not involved.

c. If the magma within a volcano remains liquid for a long time, the metallic elements may settle in layers according to density within the magma chamber—the heavier the element, the deeper it is found. This settling of magma acts to concentrate the metals into valuable ores. Why are the geological remains of ancient volcanoes often the sites of copper mines?

16. Consider the examples of oxidation reactions.

a. Identify the common feature on the right side of each reaction.

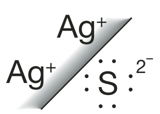
b. Why does the term *oxidation* have the potential to be misleading?

Reducing Large Amounts of Ore to Pure Metal

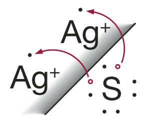
It takes 1000 kg of ore to produce less than 20 kg of pure copper. The essential task of the process is to reverse the oxidation reaction that has locked the copper metal into compounds like copper sulfide. Processing silver is also a matter of reversing oxidation. But, in this case, the task of reducing the amount of material is even greater: 1000 kg of ore usually yields about 0.1 kg of pure silver.

Purifying Metals from Metal Compounds

In ore deposits, metals are frequently locked up in ionic compounds.



In the process of refining the ore, the metallic ions are given back the electrons they lost.



This process purifies the metal since it is no longer part of the ionic compound.

$$2 \times \left[\underset{\text{silver ion}}{Ag^{+}} + \underset{\text{one electron}}{1e^{-}} \rightarrow \underset{\text{silver metal}}{Ag(s)} \right]$$

Figure A2.12: Purifying metals involves giving back electrons to metal ions.

Reduction: The Gain of Electrons

In Figure A2.12, silver ions gained electrons to form pure silver. When atoms gain electrons, they are undergoing a process called **reduction**. At first glance, the name seems to have things backward. How can a gain of electrons be a reduction? Historically, the name *reduction* comes from the metal-refining industry, where the application of this process involves reducing very large amounts of ore to smaller amounts of pure metal. As the following examples indicate, the term *reduction* has been expanded to include any reaction in which there is a gain of electrons.

reduction: a chemical process involving a gain of electrons

Practice

17. Examine Figure A2.12.
    - **a.** Identify the substance that is reduced.
    - **b.** Recall the process of silver tarnishing and the process of chemically removing the tarnish. Which of these two processes is an example of reduction?

Examples of Reduction Reactions

Neutral atoms gain electrons to become ions.

$$\underset{\text{non-metal molecule}}{Cl_2(g)} + \underset{\text{two electrons}}{2e^{-}} \rightarrow \underset{\text{non-metal negative ion}}{2Cl^{-}(aq)}$$

Positively charged ions gain electrons to become neutral atoms.

$$\underset{\text{positive metal ion}}{Na^{+}(aq)} + \underset{\text{one electron}}{1e^{-}} \rightarrow \underset{\text{metal atom}}{Na(s)}$$

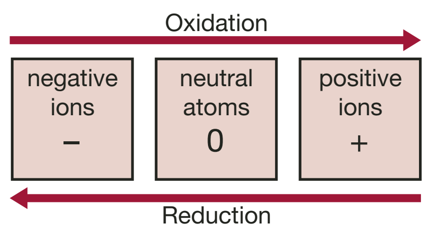
Positively charged ions gain electrons to become less positively charged.

$$\underset{\text{positive metal ion}}{Fe^{3+}(aq)} + \underset{\text{one electron}}{1e^{-}} \rightarrow \underset{\text{a less positive metal ion}}{Fe^{2+}(aq)}$$

Hints for Keeping It All Straight

You can use the following hints to remember the definitions and circumstances of oxidation and reduction reactions:

- **OIL RIG**: These two words are a memory device to help you remember the definitions.
  "**O**xidation **i**s the **l**oss of electrons. **R**eduction **i**s the **g**ain of electrons."
- The following may help you identify a process as an oxidation or a reduction.



Practice

18. For each of the following reactions, determine whether it is an oxidation or a reduction. Also, determine the number of electrons gained or lost.

a. A silver ion, $Ag^{+}(aq)$, becomes a silver atom, $Ag(s)$.

b. An iron metal atom, $Fe(s)$, becomes an iron(III) ion, $Fe^{3+}(aq)$.

c. $Cl_2(g) \rightarrow 2\ Cl^{-}(aq)$

d. $Au^{3+}(aq) \rightarrow Au(s)$

e. $Sn(s) \rightarrow Sn^{4+}(aq)$

f. $2\ F^{-}(aq) \rightarrow F_2(g)$

g. $Fe^{2+}(aq) \rightarrow Fe^{3+}(aq)$

h. $O_2(g) \rightarrow 2\ O^{2-}(aq)$

i. $Sn^{4+}(aq) \rightarrow Sn^{2+}(aq)$

j. $Na^{+}(aq) \rightarrow Na(s)$

19. Recall the activity on page 59 where you observed the reaction between zinc and silver nitrate in which pure silver was produced at the site of the reaction. Was the silver in this reaction oxidized or reduced?

Single Replacement Reactions

Refining copper ore to produce the pure copper metal that can be made into useful products involves reduction. Clearly, if reduction is a chemical process that involves a gain of electrons, another substance must lose electrons.

In the activity at the beginning of this chapter, you observed a chemical reaction. In Example Problem 2.3, each substance that participates in the reaction must be carefully analyzed to determine whether oxidation or reduction occurred.

Figure A2.12: This magnified photo shows evidence of chemical change as silver nitrate reacts with solid zinc.

Example Problem 2.3

A silver nitrate solution reacts with solid zinc to produce zinc nitrate solution and solid silver.

a. Write a balanced chemical reaction that describes this reaction.

b. Carefully examine each substance before and after the reaction to determine whether oxidation or reduction occurred. Use half-reactions to support your answers.

Solution

a. $2\ AgNO_3(aq) + Zn(s) \rightarrow Zn(NO_3)_2(aq) + 2\ Ag(s)$

b. **Silver**

Before reaction: $Ag^{+}(aq)$

After reaction: $Ag(s)$

Since the silver started as a silver ion and became a pure metal atom, it must have gained an electron. Therefore, the silver was reduced.

$$2 \times \left[Ag^{+}(aq) + 1e^{-} \rightarrow Ag(s) \right]$$

Zinc

Before reaction: $Zn(s)$

After reaction: $Zn^{2+}(aq)$

Since the zinc started as a pure metal atom and became a zinc ion, it must have lost electrons. Therefore, the zinc was oxidized.

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$$

Nitrate Ion

Before reaction: $NO_3^{-}(aq)$

After reaction: $NO_3^{-}(aq)$

Since the nitrate ion remained the same, it did not undergo oxidation or reduction.

In Example Problem 2.3, the zinc replaced the silver ions in the silver nitrate, resulting in the production of solid silver. This reaction is an example of a **single replacement reaction**. Since the nitrate ion did not change, remaining an ion in the solution, it is called a **spectator**. Keep these terms in mind as you attempt the next Practice questions.

single replacement reaction: a reaction in which an element reacts with a compound to produce a new element and a new compound

spectator: an atom or polyatomic ion that does not change in a chemical reaction

Practice

20. Examine each balanced chemical equation, and identify the chemical substance being oxidized, the chemical substance being reduced, and any spectators.
    a. $Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
    b. $3\ MnO_2(s) + 4\ Al(s) \rightarrow 3\ Mn(s) + 2\ Al_2O_3(s)$
    c. $2\ Al(s) + 3\ I_2(s) \rightarrow 2\ AlI_3(s)$
    d. $2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$
    e. $Ca(s) + 2\ HOH(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
21. Look at the reaction side of each equation in question 20. How many electrons are gained or lost by each atom or ion?

Redox Reactions

Reduction and oxidation reactions are the most common type of chemical reaction. In fact, the term *reduction-oxidation reaction* is used so frequently that it is often shortened to just **redox reaction**.

redox reaction: reduction-oxidation reaction

2.2 Summary

Most metals naturally exist as ores because they tend to lose electrons to form ionic compounds with non-metal ions. A loss of electrons by an atom is called oxidation. The metal ions within an ore can be extracted (removed from the ore) by giving the metal ions electrons. A gain of electrons by an atom is called reduction.

Single replacement reactions can involve oxidation and reduction processes if one reactant gains electrons while another reactant loses electrons. A spectator ion does not lose or gain electrons.

2.2 Questions

Knowledge

1. Define *oxidation*, *reduction*, and *spectator ion*.
2. Explain how single replacement reactions can involve an oxidation and a reduction reaction.
3. Determine whether the following could undergo oxidation, reduction, or both.
   a. an oxygen molecule, $O_2(g)$
   b. an iron(III) ion, $Fe^{3+}(aq)$
   c. an iron(II) ion, $Fe^{2+}(aq)$
   d. an iron atom, $Fe(s)$
   e. a chloride ion, $Cl^-(aq)$
   f. a nitrogen molecule, $N_2(g)$

Applying Concepts

4. When zinc metal is placed into a solution of silver nitrate, silver metal and zinc nitrate are produced.

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

   a. State the chemical substance that is gaining electrons. Give a reason for your choice.
   b. State the chemical substance that is losing electrons. Give a reason for your choice.
   c. State the chemical substance that is neither gaining nor losing electrons. Give a reason for your choice.
   d. State the atom or ion that is oxidized.
   e. State the atom or ion that is reduced.
   f. State the atom or ion that is a spectator ion.
   g. Determine the number of electrons transferred in the reaction.
   h. If 35.0 mol of zinc react with silver nitrate, how many moles of silver metal will form?
5. When iron metal is exposed to air, it slowly turns into iron(III) oxide. The following equation is a simplification of this process.

   $$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$$

   a. State the atom or ion that is oxidized.
   b. State the atom or ion that is reduced.
   c. Determine the number of electrons being transferred.
   d. How many moles of oxygen gas would it take to oxidize 127 mol of iron?
6. Silver atoms react with sulfur atoms found in the air to form silver sulfide (tarnish), $Ag_2S(s)$.

   $$4\ Ag(s) + 2\ H_2S(g) + O_2(g) \rightarrow 2\ Ag_2S(s) + 2\ H_2O(l)$$

   Identify the chemical substance being oxidized and the chemical substance being reduced. Determine the number of electrons transferred in the reaction.

2.3 The Reactivity of Metals

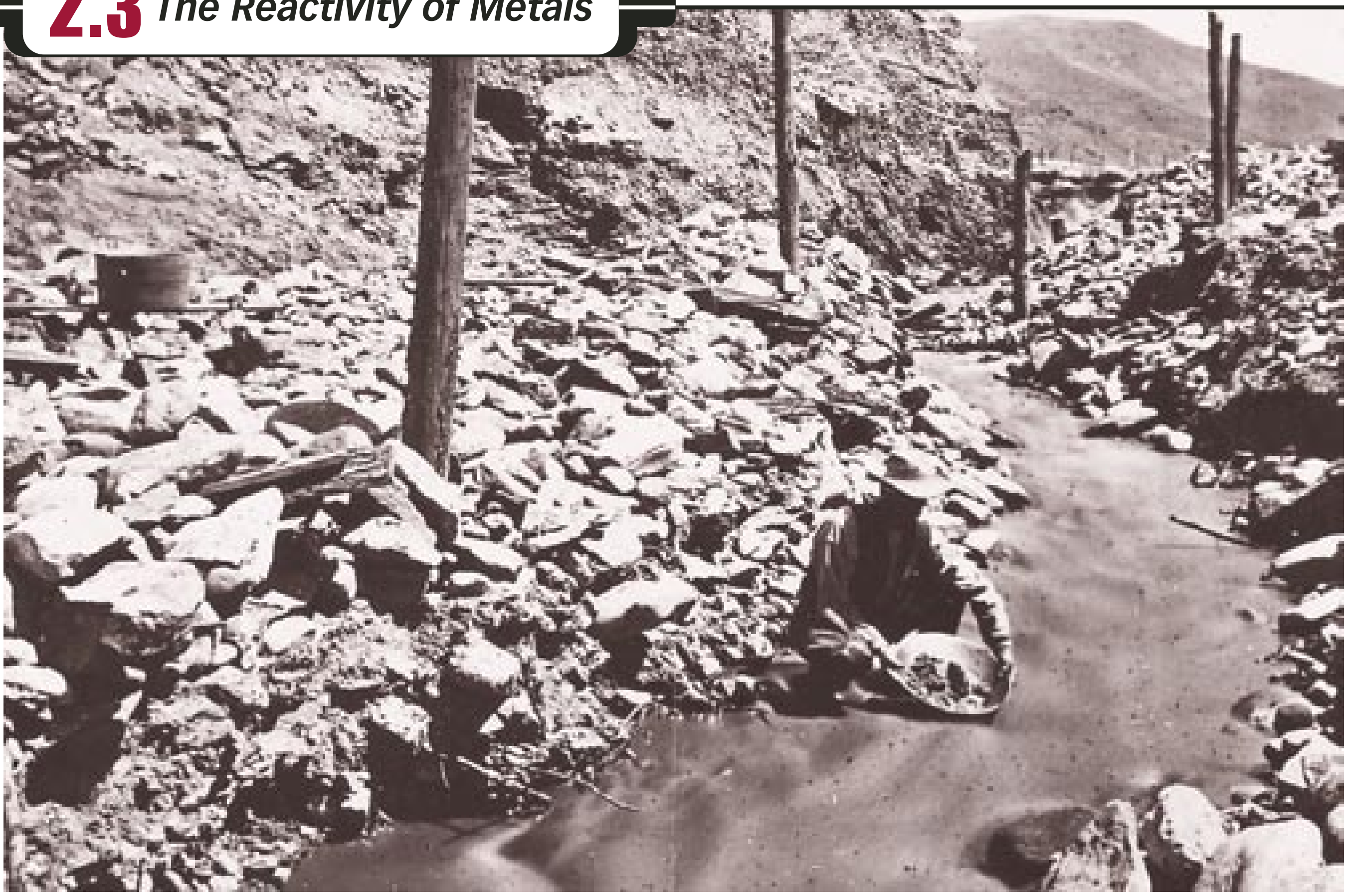


Figure A2.13: Prospectors like this one may have travelled to the Yukon on the Edmonton Overland Trail.

Klondike Gold Rush

In August 1896, gold was discovered in the gravel of a small creek that flowed into the Yukon River. The news of this discovery reached the outside world on July 17, 1897, when the first successful prospectors arrived in Seattle. Within a month, the Klondike Gold Rush had begun. Some historians estimate that over 100 000 people—nicknamed stampeders—participated in this gold rush. Due to the difficulties of travelling through the mountains and the wilderness terrain, only about 30 000 prospectors made it all the way to Dawson City by 1898.

Most prospectors entered the Yukon through the treacherous mountain passes along the border of Alaska. About 2000 people travelled from Edmonton, through Fort Assiniboine, and then on to Peace River Crossing and Fort St. John. This route was called the Edmonton Overland Trail. These people travelled by dogsled in the winter and by pack horses and burros in the summer. During this time Edmonton prospered as an essential supply base and outfitting centre.

The Unique Properties of Gold

Clearly, the prospectors stampeding toward the Yukon were willing to risk all that they owned and even their very lives to strike it rich. Even relatively small amounts of gold can make a person very wealthy. The price of gold can fluctuate. In December of 2005, a small coffee cup filled with fine grains of gold would have been worth over $80 000. What makes gold such a valuable metal? Although gold has an attractive appearance, it is the physical and chemical properties of gold that make it a precious metal.

Figure A2.14: Panning for gold is still a hobby for many people today.

Figure A2.15: Gold has been used for many purposes throughout history.

Gold is the most malleable and ductile metal known. The fact that gold is soft means that it can be easily hammered and stretched into desired shapes. This makes gold ideally suited for making jewellery and other elaborate and intricate objects.

DID YOU KNOW?

A gram of gold can be beaten into a sheet that is 1 m by 1 m, or it can be stretched into an ultrathin wire—thinner than a human hair—that is 3.5 km long.

Unlike metals such as iron and copper, gold does not readily react with other elements. Gold is a very stable metal. Because gold atoms have a strong tendency to keep their electrons, objects made from gold do not tarnish or undergo **corrosion**. At the atomic level, a metal corrodes as its atoms are being oxidized to form metal ions.

Gold is so stable that it can resist the action of most strong acids. From a chemical point of view, gold is almost indestructible. It can be used and reused for centuries.

corrosion: the oxidation of a metal

These properties alone do not totally explain why gold is a precious metal. Another factor to consider is that gold is quite rare. It has been estimated that all the gold in the world that has ever been refined could form a single cube with each side measuring 20 m.

Practice

22. In nature, gold is almost always found as tiny particles that are mixed with stream-bed deposits of sand and gravel. These particles are usually 85% to 95% pure gold.

a. Explain why gold is rarely found in nature in ores where it is combined with other elements.

b. Explain how the tendency of gold to not react with other substances would be helpful to a prospector looking for particles of gold in a stream bed.

23. Gold has been used to make coins for over 2500 years. Identify the properties of gold that make it suitable as a raw material for coins.

Figure A2.16: Long ago, gold was commonly used for currency.

Investigating the Reactivity of Metals

If gold is one of the least reactive metals, which metals are the most reactive? Is there a way to compare the reactivity of one metal relative to another? In the next investigation you will have an opportunity to compare the reactivity of a few metals and their corresponding metal ions in solution.

Investigation

Ranking the Reactivity of Metals and Metal Ions

Purpose

You will collect data to rank the reactivity of copper, zinc, and silver metal. You will also have an opportunity to rank the reactivity of copper ions, zinc ions, and silver ions in solutions.

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- small strip of copper
- small strip of zinc
- small strip of silver
- 3, 50-mL beakers
- 20.0 mL of 0.100-mol/L copper(II) sulfate solution, $CuSO_4(aq)$
- 20.0 mL of 0.100-mol/L silver nitrate solution, $AgNO_3(aq)$
- 20.0 mL of 0.100-mol/L zinc nitrate solution, $Zn(NO_3)_2(aq)$
- wax pencil
- several sheets of paper towel
- steel wool

CAUTION!
Use gloves, safety glasses, and a lab apron for this investigation.

Procedure

step 1: Take a strip of copper, zinc, and silver and place each one on a tabletop. Label each strip with the wax pencil.

step 2: Pour 20.0 mL of 0.100-mol/L copper(II) sulfate solution into a 50.0-mL beaker. Label the beaker $Cu^{2+}(aq)$.

step 3: Pour 20.0 mL of 0.100-mol/L silver nitrate solution into a 50.0-mL beaker. Label the beaker $Ag^{+}(aq)$.

step 4: Pour 20.0 mL of 0.100-mol/L zinc nitrate solution into a 50.0-mL beaker. Label the beaker $Zn^{2+}(aq)$.

step 5: Copy the following table into your notebook.

Metal	Solution		
	$Cu^{2+}(aq)$	$Zn^{2+}(aq)$	$Ag^{+}(aq)$
copper			
zinc			
silver			

step 6: Place the copper strip into the $Cu^{2+}(aq)$ solution for 30.0 s.

step 7: Remove the copper strip from the solution, and wipe it dry with a clean paper towel.

step 8: Look for a precipitate on the copper strip and the paper towel—evidence that a chemical change occurred while the strip was in the solution.

step 9: If you see evidence of a chemical change, enter “reaction” in the table. If you do not see evidence of a chemical reaction, enter “no reaction.”

step 10: Remove any residue from the copper strip with steel wool. Wipe clean with a paper towel.

step 11: Repeat steps 6 to 10 by placing the copper strip into the other two solutions.

step 12: Repeat steps 6 to 11 for the zinc and the silver.

step 13: Clean the equipment, and dispose of the waste materials as directed by your teacher.

Analysis

1. According to your observations, list the metals from least reactive to most reactive.
2. According to your observations, prepare a list of the metal ions from least reactive to most reactive.
3. Refer to your answers to questions 1 and 2. Write down any trends you may see with regards to the reactivity of the metal and the reactivity of the metal ion.
4. You need to store a solution that contains copper ions, $Cu^{2+}(aq)$, and have the choice to store it in a container made up of copper, zinc, or silver. In which container would no reaction occur between the copper ions in the solution and the metal atoms of the container? Explain why a reaction between the container and its contents is not desirable.

Comparing the Reactivity of Metals and Metal Ions

One of the properties that makes gold a precious metal is that it tends to not participate in chemical reactions. The data collected from the activity you just completed indicates that silver, too, is not chemically reactive. At the atomic level, chemical reactions occur when electrons are exchanged. Since gold and silver atoms tend to not be chemically reactive, these atoms must not readily lose their electrons to become metal ions. By holding on to their electrons, gold and silver tend not to participate in chemical reactions like corrosion. Gold and silver are very stable metals.

Silver ions, $Ag^{+}(aq)$, on the other hand, were the most reactive of the three metal ions tested in the previous investigation. Because of their tendency to react, you can conclude that silver ions must be able to gain electrons and use them in order to increase stability.

There is a general trend regarding the reactivity of metals and their metal ions.

The more stable a metal atom is, the more reactive it is as an ion.

This trend makes sense because atomic species naturally move to states that have greater stability. If the metallic atom is more stable than a nearby metallic ion, the ions will tend to react to gain electrons and become metal atoms.

Figure A2.17: Iron readily corrodes if it isn't sufficiently protected from the environment.

Is it possible for a metal to be more stable in its ionic form than in its uncharged form? If this were the case, the metallic atom would readily oxidize and easily undergo corrosion. One particular metal, iron, exemplifies this trend in stability. Unless protected, iron readily corrodes. It is estimated that 20% of the iron produced each year is used to replace existing iron that has undergone corrosion!

In the previous investigation, which of the three metals tested was the most reactive? Does the reactivity of this metal suggest that it is also more stable in its ionic form? Does the data you collected support this? Your observations should support a second general trend.

The more stable a metal ion is, the more reactive it is as a metal.

Practice

24. For headphones to reproduce great sound, a good contact must be made between the headphone jack and the source of the tunes—whether it be your stereo or MP3 player. Many manufacturers use a thin coating of gold on the end of the headphone jack to improve the electrical connection between the devices.

Figure A2.18: A thin layer of gold is often used in headphone jacks to improve the electrical connection.

a. Iron is a reasonably good conductor, and it is much cheaper than gold. Explain why iron would be a poor choice as the material to construct headphone jacks? Refer to the stability of iron atoms and iron ions in your answer.

b. The three metals that are the best conductors of electricity are silver, copper, and gold, in that order. Even though copper and silver are better conductors than gold, they have some significant disadvantages. Explain the disadvantages of these conductors compared to gold.

25. State the relationship that exists between the reactivity of a metal and the reactivity of its metal ion.

Ordering Reactivity: The Activity Series

Remember the general rules that govern the reactivity of metal atoms and their metallic ions:

The more stable a metal atom is, the more reactive it is as an ion.
The more stable a metal ion is, the more reactive it is as a metal.

If you create a list that organizes metal ions from most reactive to least reactive, you end up creating a list that organizes metal atoms from least reactive to most reactive. Refer to the following table.

Metal Ions		Metals	
Reactivity in Solutions	**Metal Ion**	**Metal**	**Reactivity in Solutions**
most reactive	$Ag^{+}(aq)$	Ag(s)	least reactive
⋮	$Cu^{2+}(aq)$	Cu(s)	⋮
least reactive	$Zn^{2+}(aq)$	Zn(s)	most reactive

This table can be adjusted to show that gaining electrons changes the metal ions to their other form. The resulting table is a table of reduction half-reactions based on the reactivity of the atoms or ions, or an **activity series**.

activity series: a list of substances in order of reactivity with one another

Metal Ions		Half-Reaction	Metals	
Reactivity in Solutions	**Metal Ion**		**Metal**	**Reactivity in Solutions**
most reactive	$Ag^{+}(aq)$	$+ 1e^{-} \rightarrow$	$Ag(s)$	least reactive
⋮	$Cu^{2+}(aq)$	$+ 2e^{-} \rightarrow$	$Cu(s)$	⋮
least reactive	$Zn^{2+}(aq)$	$+ 2e^{-} \rightarrow$	$Zn(s)$	most reactive

This comprehensive listing of metals based on their reactivity also appears on page 556 and in the Science Data Booklet.

Activity Series for Metals and Metal Ions

Reactions Read as Reductions

Reduction Half-Reaction

most reactive metal ion on the list	$Au^{3+}(aq)$	+	$3e^{-}$	$\rightarrow$	$Au(s)$	most stable metal atom on the list
	$Hg^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Hg(l)$	
	$Ag^{+}(aq)$	+	e^{-}	$\rightarrow$	$Ag(s)$	
	$Cu^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Cu(s)$	
	$2\ H^{+}(aq)$	+	$2e^{-}$	$\rightarrow$	$H_2(g)$	
	$Pb^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Pb(s)$	
	$Sn^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Sn(s)$	
	$Ni^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Ni(s)$	
	$Cd^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Cd(s)$	
	$Fe^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Fe(s)$	
	$Zn^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Zn(s)$	
	$Cr^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Cr(s)$	
	$Al^{3+}(aq)$	+	$3e^{-}$	$\rightarrow$	$Al(s)$	
	$Mg^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Mg(s)$	
	$Na^{+}(aq)$	+	e^{-}	$\rightarrow$	$Na(s)$	
	$Ca^{2+}(aq)$	+	$2e^{-}$	$\rightarrow$	$Ca(s)$	
most stable metal ion on the list	$Li^{+}(aq)$	+	e^{-}	$\rightarrow$	$Li(s)$	most reactive metal atom on the list

Reactions Read as Oxidations

DID YOU KNOW?

Lithium is used in the rechargeable batteries found in many MP3 players. Lithium is used because of its low molar mass and because the oxidation of lithium is such a strong reaction.

Using the Activity Series

The activity series for metals and metal ions is a valuable tool that can be used in a number of different ways. Like any other tool, it works best if you understand all of its features.

Comparing the Relative Reactivity of Metal Ions—Using the Left Side

According to the listing on the left side of the activity series, the $Cu^{2+}(aq)$ ion is more reactive than the $Zn^{2+}(aq)$ ion. This is indicated by the $Cu^{2+}(aq)$ ion appearing above the $Zn^{2+}(aq)$ ion in the series. This is consistent with the results of the investigation on page 78, as is the placement of $Ag^{+}(aq)$, which appears above the other two ions. The ranking of the reactivity of metal ions is shown on the left-hand side of this table, with the most reactive metal ions placed above the least reactive metal ions.

Comparing the Relative Reactivity of Metals—Using the Right Side

The right side of the series lists the metals in ascending order of reactivity. Metals that appear lower in the series are more reactive than those listed higher in the series. For example, copper metal, Cu(s), is more reactive than silver, Ag(s), and less reactive than zinc, Zn(s). Again, this matches the observations in the investigation on page 78.

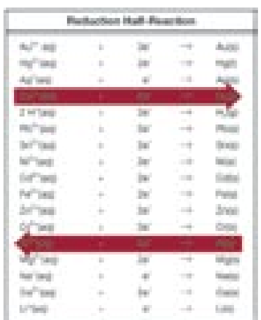
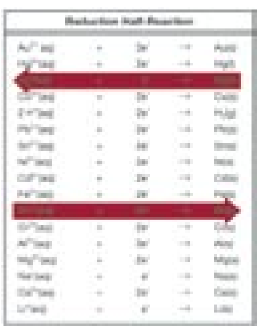
Determining Whether a Reaction will Occur—Using the Half-Reactions

Perhaps the most useful feature of this table is in determining whether a reaction will occur between a metal and a metal ion in solution. A reaction that occurs without the addition of external energy is called a **spontaneous reaction**. You witnessed a spontaneous reaction in the investigation on page 78 when you placed a strip of zinc metal in the solution containing silver ions. You also observed cases where no reaction occurred (when a strip of silver metal was placed in a solution of zinc ions). These reactions are called **non-spontaneous reactions**.

spontaneous reaction: a chemical reaction that occurs without the addition of external energy

non-spontaneous reaction: a chemical reaction that does not occur without the addition of external energy

How is the activity series able to make these predictions? The left side of this series compares the ability of metal ions to gain electrons—the stronger reduction reactions are written nearer the top of the series. The right side of this series compares the ability of metal atoms to donate electrons—the stronger oxidation reactions are written closer to the bottom of the series. So, a spontaneous reaction will occur if a metal ion has a stronger tendency to gain electrons than a metal atom. In this case, the reduction half-reaction for the ion is found closer to the top of the chart. Since reduction cannot occur without oxidation, the metal atom must have a stronger tendency to lose electrons than the metal ion. In this case, the oxidation half-reaction for the metal is found closer to the bottom of the series. Refer to the following table.

Type of Reaction	Activity Series	Position of Half-Reactions	Description
spontaneous		The reduction half-reaction is written above the oxidation half-reaction.	• A stronger tendency to gain electrons (reduction) is combined with a stronger tendency to donate electrons (oxidation). • Electrons are transferred. • A reaction occurs.
non-spontaneous		The oxidation half-reaction is written above the reduction half-reaction.	• A weaker tendency to donate electrons (oxidation) is combined with a weaker tendency to gain electrons (reduction). • Electrons are not transferred. • No reaction occurs.

Example Problem 2.4

A piece of zinc metal is placed in a solution containing $Cu^{2+}(aq)$.

a. Write the reduction and oxidation half-reactions that describe this situation.

b. Locate these half-reactions on the activity series for metals and metal ions. Determine whether the reaction will be spontaneous. Concisely describe what you might observe.

Solution

a. **Reduction half-reaction:** $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$

Oxidation half-reaction: $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$

b. Because the reduction half-reaction is above the oxidation half-reaction, the reaction will be spontaneous. Copper ions would precipitate out of the solution as copper metal, and the zinc metal would enter the solution in the form of zinc ions. A precipitate would be visible, and the solution would start to change colour.

Example Problem 2.5

A piece of gold jewellery is dipped into an acid solution containing $H^{+}(aq)$.

a. Write the reduction and oxidation half-reactions that describe this situation.

b. Locate these half-reactions on the activity series for metals and metal ions. Determine whether the reaction will be spontaneous. Concisely describe what you might observe.

Solution

a. **Reduction half-reaction:** $2\ H^{+}(aq) + 2e^{-} \rightarrow H_2(g)$

Oxidation half-reaction: $Au(s) \rightarrow Au^{3+}(aq) + 3e^{-}$

b. Because the oxidation half-reaction is above the reduction half-reaction, the overall reaction would be non-spontaneous. There is no transfer of electrons and, thus, no evidence of chemical change. No precipitate will form, and the solution will not change colour.

Practice

26. Describe how you would construct an activity series from data collected during an experiment where a variety of metals were combined with acids.

27. Explain the uses of activity series.

28. Use the activity series to organize the following ions in order of most reactive to most stable.

$Mg^{2+}(aq)$, $Ni^{2+}(aq)$, $Sn^{2+}(aq)$, $Li^{+}(aq)$, $Cr^{2+}(aq)$, $Ag^{+}(aq)$

29. Use the activity series to organize the following metals in order of most reactive to most stable.

Cu(s), Zn(s), Cd(s), Sn(s), Pb(s), Fe(s), Ca(s)

30. Copy the following table into your notebook or into a spreadsheet. You will need to add more rows.

Reduction Half-Reaction	Oxidation Half-Reaction	Half-Reaction That First Appears in Activity Series	Reaction Type

Complete the table for each of the following situations.

a. A brick of gold is placed into a silver nitrate solution.
b. A piece of iron is placed into a copper(II) sulfate solution.
c. A piece of zinc is placed into a solution of sodium chloride.
d. An aluminium fishing boat is floating on a lake with a very high concentration of iron(II) ions.
e. A piece of nickel metal is placed into a lead(II) nitrate solution.
f. Acid, containing hydrogen ions, falls onto some iron metal.
g. A piece of silver is placed into a solution of zinc nitrate.
h. Bubbles of hydrogen pass through a solution of gold(III) nitrate.
i. Water that is contaminated with mercury(II) ions is placed in a zinc container.

Oxidizing and Reducing Agents

As you have seen, oxidation and reduction always occur together. This is because if one substance is going to gain electrons, another must lose electrons. As an example, consider the following equation:

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

In this reaction, silver gains electrons and the zinc loses them. In other words, the zinc acts as a **reducing agent** because it promotes the reduction of the silver nitrate. Notice that the reducing agent—zinc—lost electrons. So, the reducing agent is oxidized. Some students find this confusing. Focus on the word *agent*. Just as a travel agent makes it possible for other people to travel, a reducing agent makes it possible for something else to be reduced.

Similar thinking can be applied to the process of oxidation. In the previous balanced chemical equation, silver nitrate is the **oxidizing agent** because it promotes the oxidation of the zinc. Again, focus on the word *agent* to remind you that the term is describing what the substance does. Since the oxidizing agent—silver nitrate—is gaining electrons, it is being reduced.

reducing agent: a substance that makes the reduction process possible by losing electrons

oxidizing agent: a substance that makes the oxidation process possible by gaining electrons

Practice

31. The following reaction describes the process of removing silver tarnish, $Ag_2S(s)$, by soaking the item in a hot baking-soda solution in which the container is lined with aluminium foil.

$$3\ Ag_2S(s) + 2\ Al(s) + 3\ H_2O(l) \rightarrow 6\ Ag(s) + Al_2O_3(s) + 3\ H_2S(aq)$$

The baking soda acts to remove impurities on the surface of the aluminium foil and to improve the conductivity of the solution.

a. Identify the substance that is oxidized. Copy the oxidation half-reaction shown on the activity series for this substance to support your answer.
b. Identify the substance that is reduced. Copy the reduction half-reaction shown on the activity series for this substance to support your answer.
c. Refer to the activity series for metals and metal ions. Explain why this is a spontaneous reaction.
d. Identify the oxidizing agent in this reaction.
e. Identify the reducing agent in this reaction.

32. Refer to the activity series for metal and metal ions on page 556.

a. Explain why lithium metal, Li(s), is the strongest reducing agent in the table.
b. Explain why the gold ion, $Au^{3+}(aq)$, is the strongest oxidizing agent in the table.

Investigation

Planning an Experiment Using the Activity Series

Science Skills
✓ Initiating and Planning

It is time for you to be the scientist and design an experiment to further investigate the theory used to construct the activity series.

Purpose

Locate the hydrogen ion in the activity series, and design an investigation that will allow you to test the accuracy of the position of four metals in the activity series relative to hydrogen. For each of the four metals you select, the source of hydrogen ions is a solution of hydrochloric acid. In this test, the evidence of a spontaneous reaction would be the production of a gas (hydrogen), as indicated by bubbling and the disappearance of the metal. A temperature change may also be detected.

Pre-Lab Analysis

1. Concisely describe the circumstances that would allow a spontaneous reaction to occur between the hydrogen ions and one of the metals used in your experiment. Refer to electron transfer and to the terms *oxidation* and *reduction* in your answer.
2. Write the reduction and oxidation half-reactions that describe a spontaneous reaction in this experiment. Use the symbol M(s) to represent one of the metals in the experiment. Assume this metal produces ions with a charge of 2+, represented by the symbol $M^{2+}(aq)$.

Prediction

3. Generate two predictions about which metals in the activity series would spontaneously react with the hydrogen ions and which would not spontaneously react.

Procedure

4. Outline a simple procedure that would allow you to test the predictions in question 3.
5. Describe the safety procedures that should be followed throughout this investigation.

Gold—From Jewellery to High Technology

Consider what you have learned about gold thus far:

- Gold is the least chemically reactive metal in the activity series for metals and metal ions.
- Gold is an excellent conductor that can be stretched into tiny wires that are smaller in diameter than a human hair.

These facts have made gold even more precious than it was before because now, in addition to the jewellery trade, gold has become an essential element for high-tech industries. In personal computers, gold plays a vital role in forming the microthin wires that connect components on a motherboard. Gold is used in the contacts beneath the keys of most computer keyboards and in the contacts at the end of cables that connect external devices, like printers. Because gold does not degrade over time and because it is an excellent conductor, gold is now an essential industrial metal.

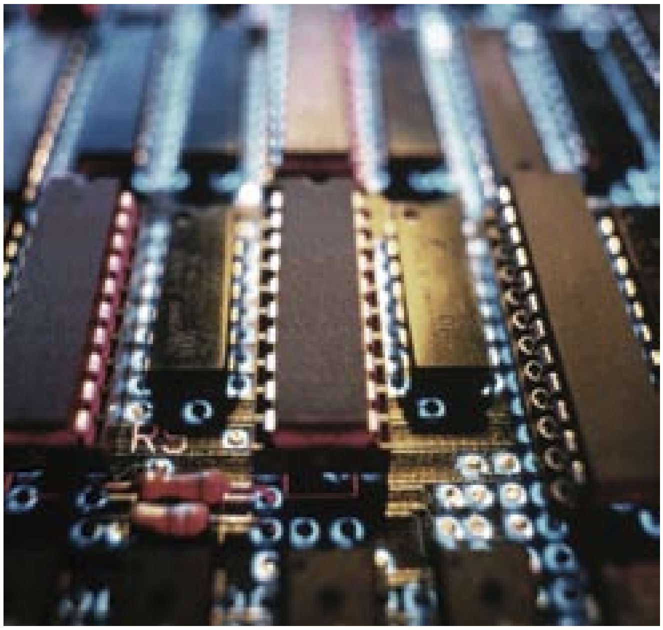
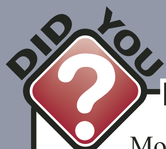


Figure A2.19: Bonding wire is 99.999% pure gold. It is used to connect computer chips to other components.

As high-tech electronics industries continue to grow, the worldwide demand for gold as an industrial metal will increase as well. In 2001, it is estimated that the world used approximately 200 t (tonnes) of gold for electronic applications. Some experts predict that annual demand may reach 300 t (tonnes) in the near future. Given these trends, it will be essential for all waste electronic equipment to be recycled so that the gold can be recovered.



DID YOU KNOW?

Motorized wheelchairs help provide a control over movement and a sense of independence for people with disabilities. These devices could not operate as reliably without gold. The microprocessor—the brains of the computerized control system—is attached with gold wires and gold-coated connectors. Manufacturers use gold because of its resistance to corrosion and because of its excellent electrical conductivity.

2.3 Summary

Some metal atoms are more stable than others. The more stable a metal atom is, the more reactive it is as a metal ion. The reverse is also true. The more stable a metal ion is, the more reactive it is as a metal.

The activity series for metals and metal ions lists metal ions from most reactive to least reactive and metals from least reactive to most reactive. You can use the activity series to predict whether a reaction between a metal and a metal ion will be spontaneous or non-spontaneous.

2.3 Questions

Knowledge

1. Define each of the following terms, and provide an example.

- **a.** metal atom
- **b.** metal ion
- **c.** activity series
- **d.** spontaneous reaction
- **e.** non-spontaneous reaction

2. Explain the relationship between the reactivity of a metal atom and the reactivity of its metal ion.

3. Describe three observations that would lead you to conclude that a reaction is spontaneous.

4. Describe three observations that would lead you to conclude that a reaction is non-spontaneous.

Applying Concepts

5. You have been given a contract by an employer to design an inexpensive metal container that will be used to store large amounts of water contaminated with lead(II) ions, $Pb^{2+}(aq)$. The solution will need to be stored for a long period of time. Describe suitable materials required to build this kind of container.

6. Describe the properties that make gold such a precious metal to society.

7. Use the activity series to explain why silver is a precious metal, but not as precious as gold.

2.4 Using Voltaic Cells

Figure A2.20: Gold is ideal for jewellery because it will never tarnish.

In this chapter you have seen many examples of the role metals play in the lives of humankind. You have also seen how the different rates of chemical reactivity make some metals more susceptible to the effects of corrosion than others. For example, silver jewellery can tarnish, whereas gold jewellery does not. While corrosion is usually seen as an unwanted effect, it is sometimes helpful. Copper artifacts that were made thousands of years ago by the ancient ancestors of the First Nations people in Canada, for example, were preserved by a protective surface layer of green corrosion—basic copper carbonate.

In each of these cases, oxidation and reduction play a key role in describing the reaction. In this lesson, the focus shifts from corrosion on a metal surface to applications that make use of the flow of electrons between different metals.

You know from your own experiences that many modern devices operate using **voltaic cells**. Most people call one of these devices a **battery**. However, a battery actually refers to a group of cells that are connected together.

A battery of voltaic cells in a graphing calculator provides a continuous flow or current of electrons when the calculator is operating. The different components within the calculator convert the energy from the current into other work. This transfer of energy allows each component to accomplish its designed task. As one set of electrons leaves the battery of voltaic cells, another group enters to keep the device working. A graphing calculator operates because the components can access the energy within the current of electrons that continuously loops through the circuits.

What causes this river of electrons to flow in the first place? Why do electrons leave one end of a voltaic cell and return to the other end? Answers to these questions involve reduction and oxidation reactions—combining metals that have a tendency to lose electrons with metal ions that have a tendency to gain electrons.

voltaic cell: a device that spontaneously produces electricity by redox reactions

battery: a set of voltaic cells joined to produce an electric current

Figure A1.21: This calculator is powered by a battery of four voltaic cells.

Practice

33. Use the terms *voltaic cell* and *battery* to describe the process shown in Figure A2.22.
34. Construct a simple flowchart showing the energy transformations necessary for a flashlight to produce light energy.
35. Hundreds of years ago, before the invention of electrical devices, the word *battery* was a military term that referred to a collection of cannons. Suggest a reason why this military term was adapted by people using electricity.

Figure A2.22: It's a good idea to have a fully charged flashlight handy.

Inside a Voltaic Cell

A voltaic cell uses the transfer of electrons between its chemical components to create an electric current that can flow through an external circuit. The connection to the external circuit is made through wires that contact each **electrode** of the voltaic cell.

As one substance in the cell is oxidized—losing electrons—another substance in the cell is reduced—gaining electrons. In the next investigation you will have an opportunity to explore the oxidation and reduction reactions that occur inside a voltaic cell.

electrode: a solid electrical conductor in a cell that connects a cell to an external circuit

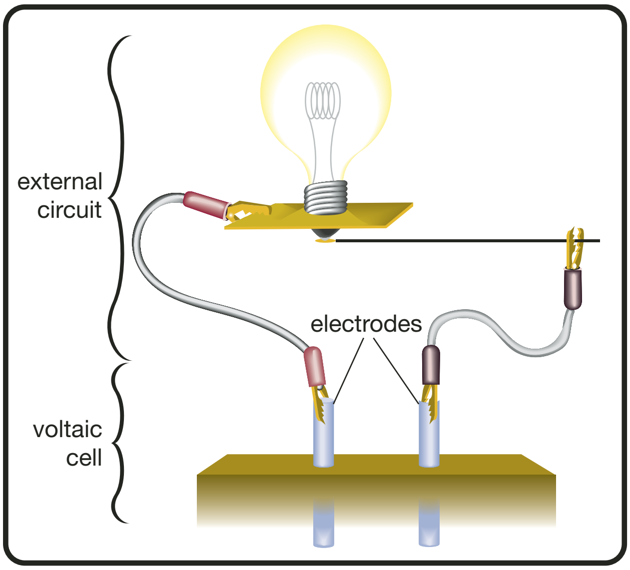


Figure A2.23: The electrodes of a voltaic cell connect to an external circuit.

Investigation

Building a Voltaic Cell

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

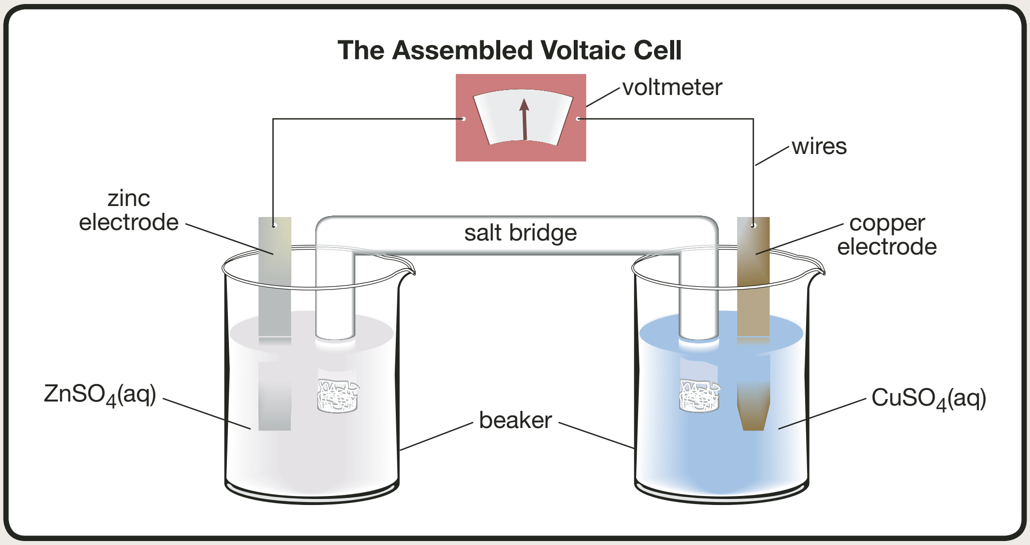
Purpose

You will build a working voltaic cell.

Materials

- 2 beakers
- voltmeter (or digital multimeter)
- electrical leads with alligator clips
- salt bridge
  - glass U-tube
  - cotton plugs
  - aqueous electrolyte with low reactivity (e.g., 0.500-mol/L sodium sulfate, $NaSO_4(aq)$)
- copper metal strips
- zinc metal strips
- 0.500-mol/L copper(II) sulfate $CuSO_4(aq)$
- 0.500-mol/L zinc sulfate $ZnSO_4(aq)$

CAUTION!
Use gloves, safety glasses, and a lab apron for this investigation.



Pre-Lab Analysis

1. List the two metals used in the cell. Use the activity series to determine which is the more reactive metal and which is the more reactive metal ion.
2. Use the activity series to determine the oxidation half-reaction and reduction half-reactions that could occur in the voltaic cell illustrated.
3. Use your knowledge of spontaneous reactions to determine whether the more reactive metal and metal ion will react spontaneously in the cell you have constructed.
4. Use your half-reactions to determine which metal is losing electrons and which metal ion is gaining electrons.
5. Use your spontaneous half-reactions to make a prediction as to what will happen to each metal strip if you were to leave the voltaic cell on for a long time.
6. If the voltaic cell kept operating indefinitely, would any part of the cell labelled in the diagram need to be replaced? Explain your reasoning.
7. Hypothesize which metal strip is the negative electrode of the voltaic cell and which metal strip is the positive electrode of the voltaic cell. Provide a reason for your choice.

Procedure

step 1: Add the copper(II) sulfate solution to one beaker and the zinc sulfate solution to the other beaker. Ensure that there will be enough of each solution to submerge the ends of the salt bridge.

step 2: While working over a sink or basin, assemble the salt bridge by filling the glass U-tube with sodium sulfate. Carefully pack the ends of the U-tube with cotton wool to form plugs. Hold the U-tube upright and carry it to a point above the two beakers. Place gloved fingers over the ends so that the solution does not leak out. Adjust the position of the beakers to prepare for the placement of the U-tube. Turn the U-tube upside down and place it in the beakers so that the ends with the cotton plugs are submerged.

step 3: Refer to the diagram to assemble the rest of the voltaic cell from the materials provided.

step 4: Record the reading of the voltmeter. If the reading is zero, refer to the diagram of the voltaic cell and make adjustments to the apparatus until an output reading appears.

step 5: Carefully lift the salt bridge out of the beakers. Quickly observe the effect this has on the output of the voltmeter. After you have made your observations, return the salt bridge to the solution. Record your results.

step 6: Reverse the leads from the voltmeter so that they are connected to the opposite electrodes. Observe the effect this has on the output of the voltmeter. Record your results.

step 7: Let the voltaic cell continue to operate while you answer the rest of the analysis questions. Periodically check the apparatus for any evidence of change on the electrodes or in the solutions. Record any changes you see.

Analysis

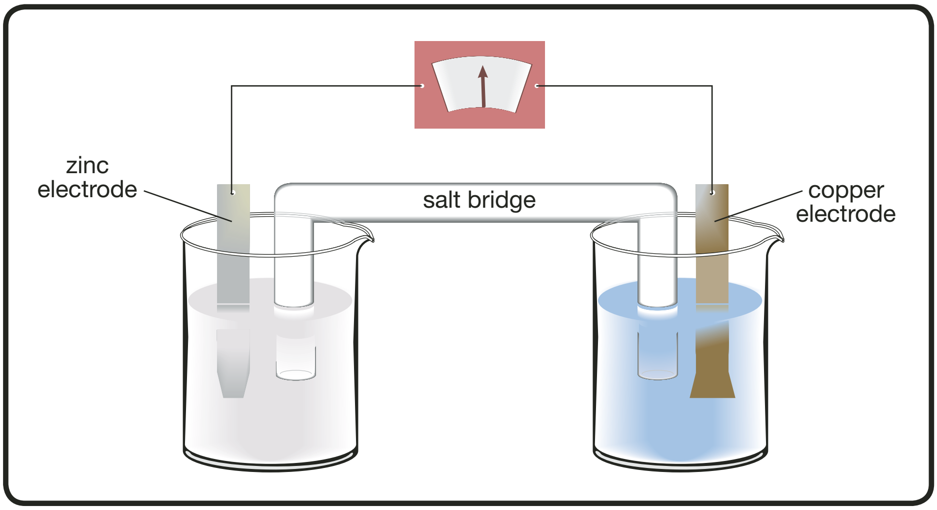
8. Describe the effect on the output of the voltmeter when you lifted the salt bridge out of the cell.
9. Hypothesize why the salt bridge is necessary for the voltaic cell to work.
10. Explain what happened to the output of the voltmeter when you connected the leads from the voltmeter to the opposite electrodes in the voltaic cell.
11. Describe the changes you observed to the electrodes or to the solutions. Use the half-reactions stated earlier to assist you in suggesting reasons for the changes you observed.

Analyzing How a Voltaic Cell Works

Earlier in this chapter you investigated the activity series for metals and metal ions. This series describes oxidation reactions, where metal atoms lose electrons to become metal ions. The chart also describes reduction reactions, where metal ions gain electrons to become metal atoms. Placing a metal that readily loses electrons into a solution that contains metal ions that readily gain electrons results in a spontaneous reduction-oxidation (redox) reaction.

The voltaic cell featured in the "Building a Voltaic Cell" investigation used these principles to transform chemical energy into the electrical energy measured by the voltmeter. The following analysis shows how a voltaic cell can produce a steady electric current to an external circuit.

step 1: Identify the electrode where oxidation occurs, and label it.



Locate each metal used in the electrodes in the activity series. These metal atoms are located on the right side of the series. Recall that the metal atoms located closest to the bottom of the chart have the greatest tendency to be oxidized or lose electrons. In this case, zinc is located below copper; so, the zinc electrode is the one that loses electrons or is oxidized. This electrode is called the **anode**.

The copper electrode is the one that will be receiving electrons, or is reduced. This electrode is called the **cathode**.

Here's a memory device you can use to help remember the labelling of the electrodes:

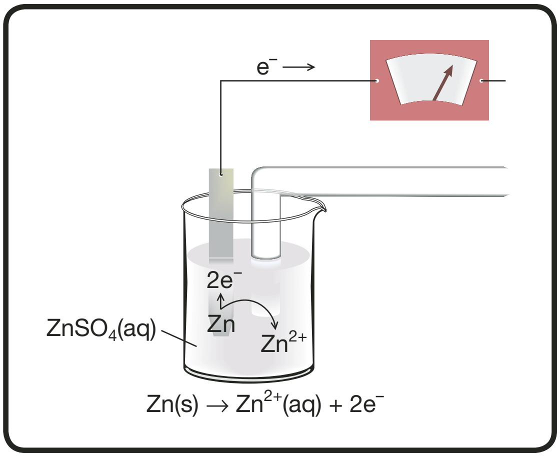
Anode and *oxidation* both begin with vowels.

Cathode and *reduction* both begin with consonants.

anode: the electrode in a cell where the oxidation half-reaction occurs

cathode: the electrode in a cell where the reduction half-reaction occurs

step 2: Describe the oxidation process at the anode.



Write the half-reaction that describes the oxidation process at the anode.

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

The zinc strip will decrease in mass and become smaller over time because the zinc atoms are turning into zinc ions.

Electrons lost by the zinc electrode travel to the external circuit. From the point of view of the voltmeter, the zinc electrode is the negative electrode because it is a source of electrons.

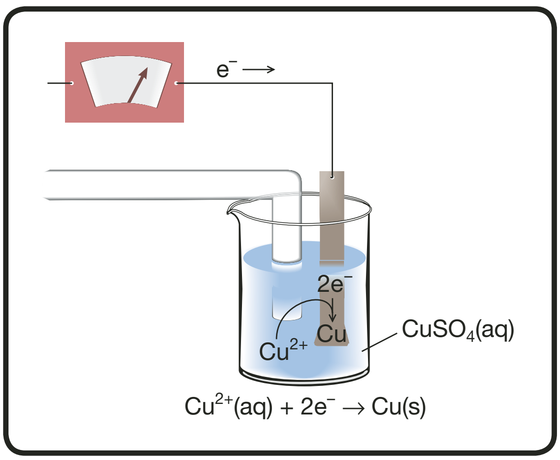
Here's a memory device to help you remember the charge of the anode as seen by the external circuit:

A_node **is negative**.
(Read as: "A no is negative.")

Here's another memory device to help you remember which way the electrons flow in the external circuit:

Electrons flow from Anode **to C**athode.
(Read as: "Electrons flow from A to C.")

step 3: Describe the reduction process at the cathode.



Write the half-reaction that describes the reduction process at the cathode.

$Cu^{2+} + 2e^- \rightarrow Cu(s)$

The copper(II) ions in the surrounding solution are attracted to the electrons, thus gaining electrons to become reduced copper atoms.

Copper(II) ions precipitate on the copper metal strip, causing the mass of the Cu(s) to increase.

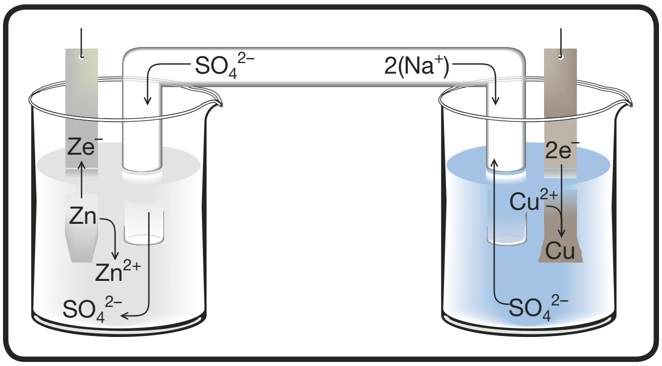
As the cell operates, the intensity of the blue colour of the copper(II) ion solution in the beaker decreases as copper(II) ions are being reduced.

Electrons are conducted from the external circuit to the copper cathode. From the point of view of the voltmeter, the cathode is the positive electrode because it is attracting the electrons.

Here's a memory device to help you remember the charge of the cathode as seen by the external circuit:

A cathode **is pos**itive.
(Read as: "A cat's paws.")

step 4: Describe how the salt bridge completes the circuit.



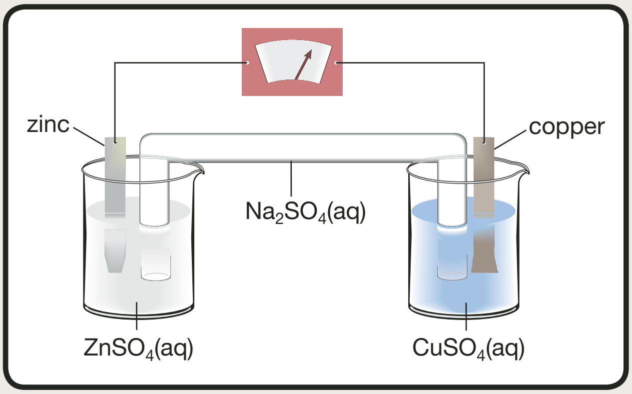
The previous steps described the flow of negative charge in the form of electrons from the zinc anode to the copper cathode. This situation is not sustainable because electrons cannot be produced at the anode without limit. The charges must be replenished. The salt bridge provides a path for ions to complete the circuit.

The salt bridge allows the SO_4^{2-}—negative ions or anions—to move to the solution containing the zinc anode. The negative ions are attracted to the excess positive zinc ions accumulating in this solution. Sodium ions will migrate to the cathode side, where the solution has lost positive ions as the $Cu^{2+}(aq)$ ions are reduced. This closes the loop and completes the circuit.

The absence of a salt bridge to balance the charges on both sides of the voltaic cell inhibits the reduction and oxidation reactions, thus not allowing the voltaic cell to function.

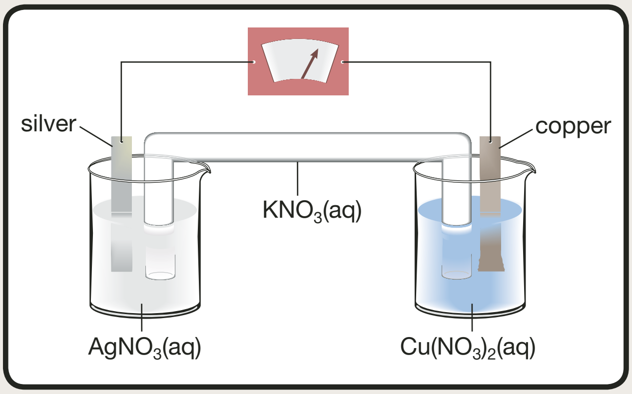
Practice

36. Copy the following diagram into your notebook or obtain the handout “Voltaic Cell Diagram” from the Science 20 Textbook CD.



Add labels to this diagram that illustrate how this voltaic cell works. Attempt to do this without looking at the four steps outlined previously. Then use the four steps to check your diagram.

37. Study the following diagram carefully; then answer questions 37.a. to 37.d.



a. Identify the electrode where oxidation occurs.

b. Describe the oxidation process at the anode.

c. Describe the reduction process at the cathode.

d. Describe how the salt bridge completes the circuit.

38. Explain the statement, “In simple terms, a voltaic cell is an electron pump.”

39. A voltaic cell cannot run forever. In time, the cell begins to lose its ability to supply electrical energy to an external circuit. Identify some of the circumstances that would cause a cell to eventually stop circulating electrons through an external circuit.

A Concise Way to Represent Voltaic Cells

The detailed diagram showing a voltaic cell is useful for explaining all of the components of the cell’s operation. However, sometimes it is useful to communicate the essential features of a voltaic cell in a more abbreviated format. This is concisely illustrated as follows.

$$\underbrace{\underset{\text{anode}}{Zn(s)}\ |\ Zn^{2+}(aq)}_{\text{oxidation}}\ \overbrace{||}^{\text{salt bridge}}\ \underbrace{Cu^{2+}(aq)\ |\ \underset{\text{cathode}}{Cu(s)}}_{\text{reduction}}$$

This format, $Zn(s)|Zn^{2+}(aq)||Cu^{2+}(aq)|Cu(s)$, is called **cell notation**. In this arrangement, one electrode is always put on the left side and the other electrode is put on the right side. The vertical line | represents a boundary between a metal and its ion in the solution. The double lines || represent the salt bridge.

cell notation: a concise description of a voltaic cell

Example Problem 2.6

A voltaic cell is assembled using a copper electrode in a copper(II) nitrate solution, a silver electrode in a silver nitrate solution, a salt bridge containing potassium nitrate, and a number of connecting wires attached to a voltmeter. Describe this voltaic cell using cell notation.

Solution

According to the activity series for metals and metal ions, copper metal has a greater tendency to lose electrons compared to silver—copper appears closer to the bottom of the series. This means that the copper is oxidized and will form the anode.

The silver ions are the most reactive of the two metal ions listed. Therefore, the solid silver, $Ag(s)$, placed in the solution of silver ions, $Ag^{+}(aq)$, will be the cathode. The two electrodes can then be written on either side of the equation. It does not matter which is written first.

$Cu(s)$ $\qquad$ $Ag(s)$

Add the metal ions and the salt bridge to complete the cell notation.

$Cu(s)|Cu^{2+}(aq)||Ag^{+}(aq)|Ag(s)$

Example Problem 2.7

A salt bridge containing potassium nitrate is used in the following voltaic cell:

$$Zn(s)|Zn^{2+}(aq)||Al^{3+}(aq)|Al(s)$$

a. Identify the substance being oxidized and the substance being reduced.

b. Identify the anode and the cathode in this cell.

c. Identify the anions, and describe the motion of these particles within the cell.

d. If wires and a voltmeter were connected to this voltaic cell, describe the direction of electron flow between the two electrodes.

Solution

a. Aluminium appears below zinc in the activity series, indicating that aluminium has a greater tendency to oxidize than zinc. Therefore, the aluminium is being oxidized and the zinc ion is being reduced.

b. Because the aluminium is being oxidized, it is the anode. The zinc ions are the most reactive of the two metal ions listed. Therefore, the solid zinc, Zn(s), placed in the solution of zinc ions, $Zn^{2+}(aq)$, will be the cathode.

c. The anions are the nitrate ion, $NO_3^-(aq)$. They complete the circuit by flowing to the solution containing the anode.

d. If wires and a voltmeter were connected to this voltaic cell, the electrons would flow from the aluminium anode, where they are produced by oxidation, to the zinc cathode, where they complete the process of reduction.

DID YOU KNOW?

A 9-volt battery is made up of a series of six connected voltaic cells that are connected anode to cathode in series. These batteries go dead when a cell loses a reactant. Voltaic cells are a closed system and will cease to function unless more reactants are added.

Practice

40. Study the following voltaic cell closely. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$.

$$Au(s)|Au^{3+}(aq)||Pb^{2+}(aq)|Pb(s)$$

a. Identify which metal would be oxidized and which metal ion would be reduced.

b. Identify the anode and the cathode.

c. Write the half-reactions that will occur in the cell.

d. Draw the voltaic cell. Label the direction of the flow of electrons and anions within the cell.

Note: Feel free to use the handout "Voltaic Cell Diagram" on the Science 20 Textbook CD whenever you need to draw a voltaic cell.

41. Study the following voltaic cell closely. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$.

$$Zn(s)|Zn^{2+}(aq)||Ni^{2+}(aq)|Ni(s)$$

a. Identify which metal would be oxidized and which metal ion would be reduced.

b. Identify the anode and the cathode.

c. Write the half-reactions that will occur in the cell.

d. Draw the voltaic cell. Label the direction of the flow of electrons and anions within the cell.

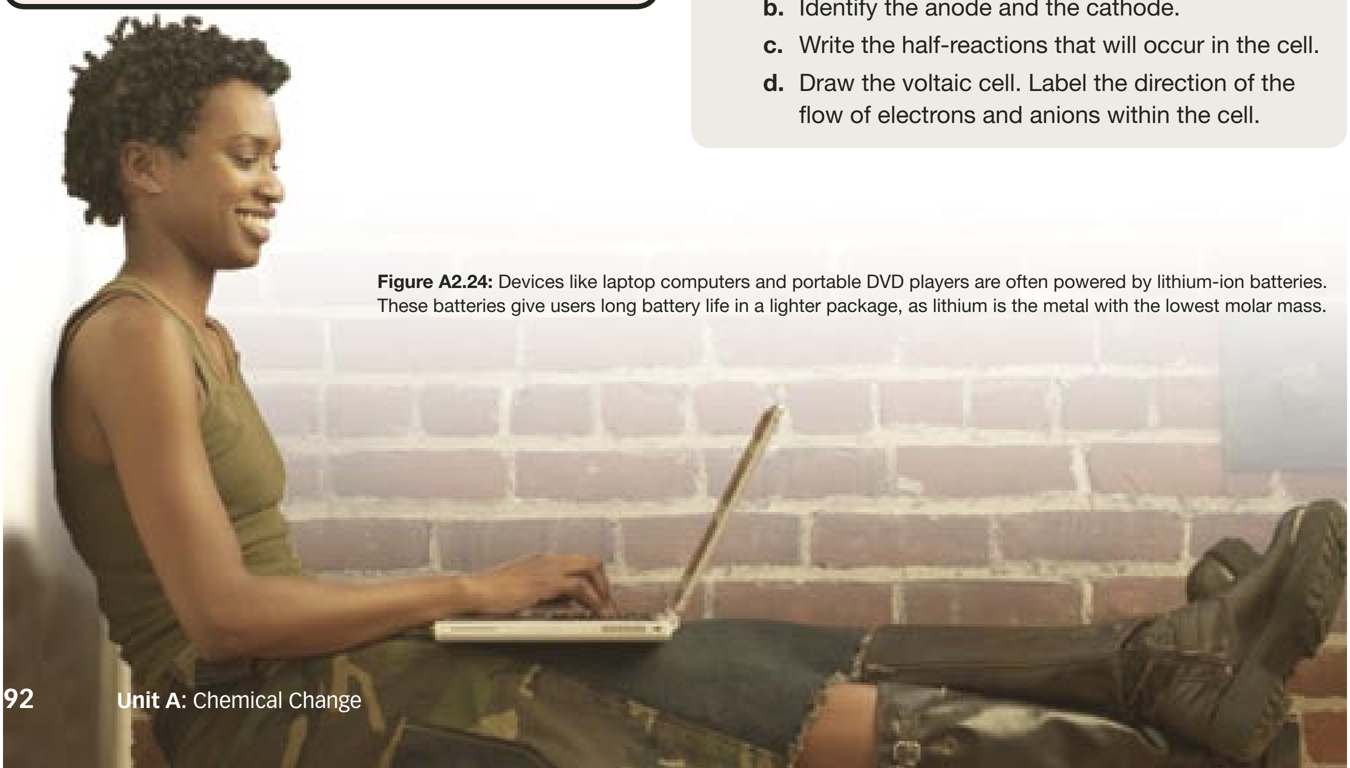


Figure A2.24: Devices like laptop computers and portable DVD players are often powered by lithium-ion batteries. These batteries give users long battery life in a lighter package, as lithium is the metal with the lowest molar mass.

Investigation

Designing Voltaic Cells

Science Skills

✓ Initiating and Planning

Given a list of metals and solutions containing metal ions, it is possible to design a number of voltaic cells using different combinations of materials. Which combination would you select to build a cell that creates the maximum output on a voltmeter? Which would create the minimum output?

Metal Electrode	Solution
$Fe(s)$	$Fe(NO_3)_2(aq)$
$Cu(s)$	$Cu(NO_3)_2\ (aq)$
$Mg(s)$	$Mg(NO_3)_2\ (aq)$
$Zn(s)$	$Zn(NO_3)_2\ (aq)$

Purpose

You will design voltaic cells that create the maximum and minimum output on a voltmeter.

Procedure

Consider the list of metals and solutions that could be used for this experiment. Consider the position of each of these metals and metal ions in the activity series. You will choose substances from the materials list to build a voltaic cell that produces the maximum output on a voltmeter. To ensure that your design, in fact, provides the maximum output, you should include plans to build three other voltaic cells, including the voltaic cell that provides the minimum output. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$.

Designs

1. Using the list of materials, describe the voltaic cell that will produce the maximum output on the voltmeter. Provide a concise explanation and a diagram to support your answer.
2. Using the list of materials, describe the voltaic cell that will produce the minimum output on the voltmeter. Provide a concise explanation and a diagram to support your answer.
3. Using the list of materials provided, describe a possible voltaic cell that will produce neither the maximum nor the minimum output on the voltmeter.

Voltaic Cells for Consumer Use

Although the set-up with the two beakers and the salt bridge is ideal for learning about the operation of a voltaic cell, this apparatus is not suitable for everyday use. Most people use voltaic cells that are conveniently packaged in small, sealed containers like the consumer cell shown in Figure A2.25. Even though these cells are called "dry cells," they actually contain a moist paste as the electrolyte—if these cells were completely dry, they would not work.

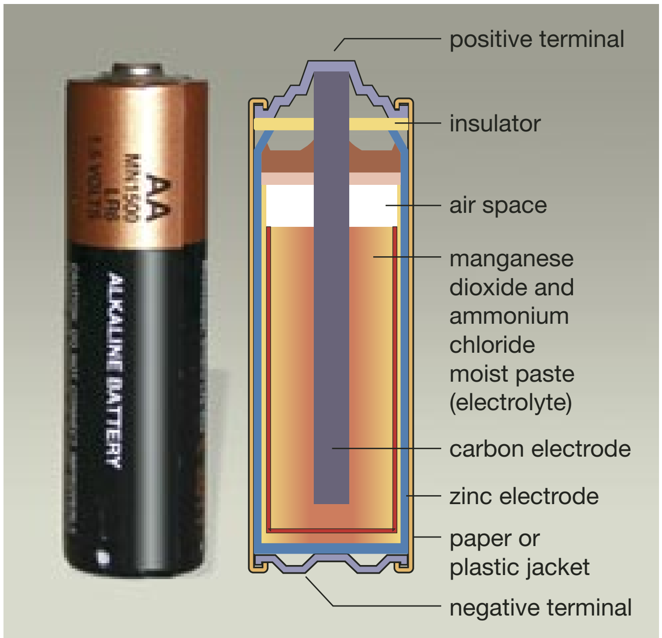


Figure A2.25: This is an artist's diagram of the inside of a standard consumer cell.

The small cells consumers use operate on the same principles of oxidation and reduction that you have been applying throughout this lesson. The oxidation reaction is straightforward and can be found in the activity series for metals and metal ions. The reduction reaction is more complex, requiring a number of interconnected steps.

Oxidation and Reduction in a Standard Consumer Cell

Oxidation

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

Reduction

$$2\ NH_4^+(aq) + 2\ MnO_2(s) + 2e^- \rightarrow Mn_2O_3(s) + NH_3(g) + H_2O(l)$$

In North America, about three billion consumer cells are purchased every year. The metals and electrolytes that enable these cells to produce an electric current are harmful if released into the environment. You can help keep these substances out of landfills by sending spent cells to local recycling centres. Another strategy is to use rechargeable cells, which dramatically reduces the number of cells needed over a product's lifetime.

Practice

42. Consider the oxidation reaction that occurs in a standard consumer cell.

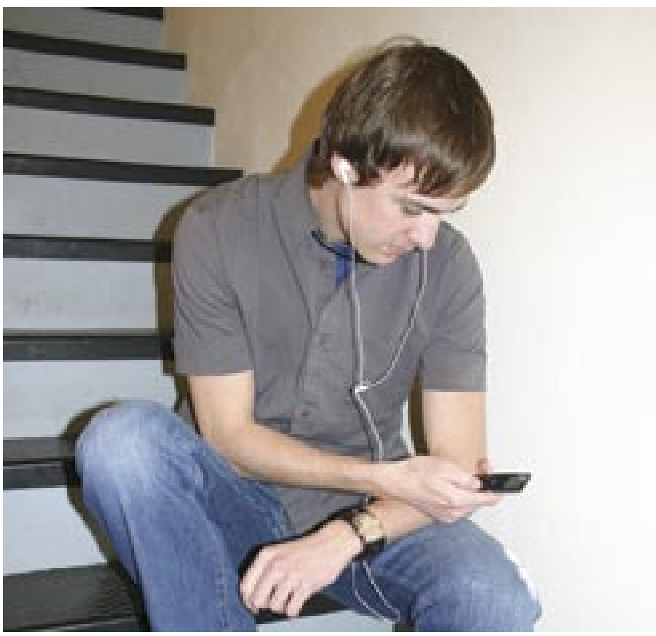
- **a.** Explain how this reaction indicates that the zinc electrode is the anode.
- **b.** Carefully examine the diagram of the standard consumer cell in Figure A2.24. Explain how this diagram verifies your answer to question 42.a.

43. Consider the reduction reaction that occurs in a standard consumer cell.

- **a.** Explain why both the manganese and the ammonium are considered to be reduced in this reaction.
- **b.** If the reduction-half reaction for the manganese dioxide were to be placed in the activity series for metals and metal ions, would it be placed above or below the reaction for zinc? Explain.

2.4 Summary

Electrical devices, like MP3 players and portable CD players, require energy from electrons in order to function. A voltaic cell uses spontaneous oxidation and reduction reactions to create an electrical current. The activity series for metals and metal ions can be used to predict which electrode will be the anode and which will be the cathode. Oxidation occurs at the anode, which is the source of electrons for an external circuit. The electrons flow from the anode, through the external circuit, to the cathode, where reduction occurs. To keep a voltaic cell working, the reactants need to be replenished.



2.4 Questions

Knowledge

1. Define the following terms.

a. battery	**b.** voltaic cell	**c.** electrode
d. anode	**e.** cathode	**f.** anion
g. cation		

2. Draw a detailed diagram of a voltaic cell that uses zinc and copper electrodes, a solution of sodium sulfate in the salt bridge, and other materials. Label all the essential parts that explain how the operation of the cell is based upon oxidation and reduction.

3. Explain the importance of the salt bridge in a voltaic cell.

4. Outline the path of electrons within an external circuit connected to a voltaic cell.

Applying Concepts

5. Answer the following questions regarding the following voltaic cell. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$

$$Mg(s)\,|\,Mg^{2+}(aq)\,||\,Ag^{+}(aq)\,|\,Ag(s)$$

- **a.** Identify which metal is oxidized and which metal ion is reduced.
- **b.** Identify the anode and the cathode of the voltaic cell.
- **c.** Write the half-reactions that will occur in the cell.
- **d.** The solutions in this cell are magnesium nitrate in the beaker on the left, silver nitrate in the beaker on the right, and potassium nitrate in the joining salt bridge. Draw the voltaic cell and label the direction of the flow of electrons and anions within the cell.

6. Lithium voltaic cells are very common today. Use the activity series for metals and metal ions to explain why lithium metal would be a useful metal for voltaic cells, especially for one producing a high voltage.

7. You notice that the voltaic cells running your portable stereo have "died." Explain why your voltaic cells are no longer able to provide your device with the energy it needs to operate. Use the terms *metal*, *metal ion*, *anode*, *cathode*, *oxidation*, and *reduction* in your explanation.

8. Obtain the handout "Voltaic Cell Diagram" from the Science 20 Textbook CD.

- **a.** Explain how this cell works by adding detailed labels and a description of the chemical reactions to the illustration on the handout.
- **b.** Check your answer to question 8.a. by watching "The Voltaic Cell" applet on the Science 20 Textbook CD. Be sure to use the pause button if you need to make additions or changes to your work.

2.5 The Electrolytic Cell

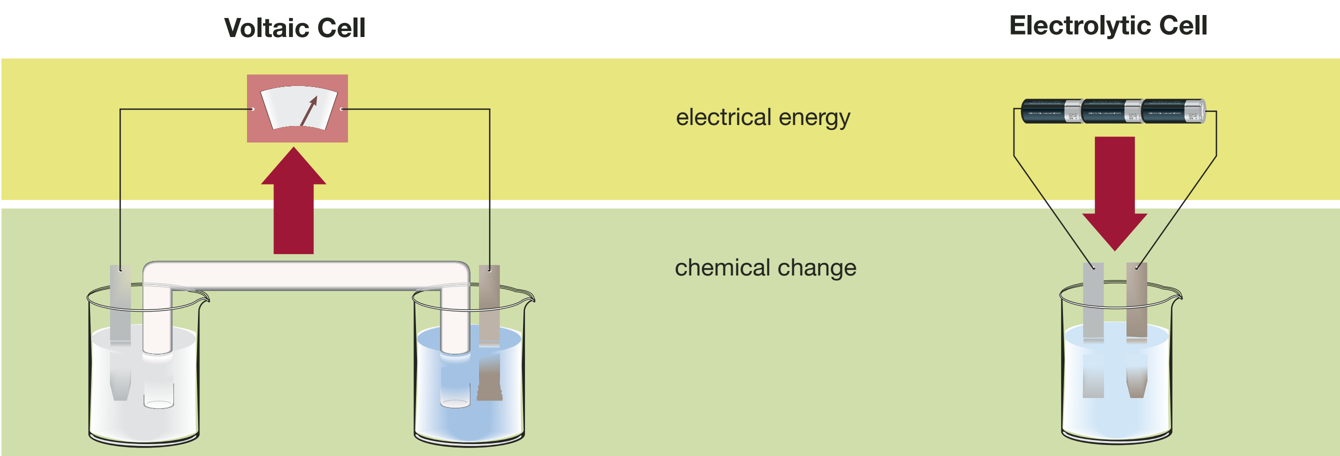
Figure A2.26: Iron is an easy victim for corrosion if left unprotected.

electrolytic cell: a chemical system in which non-spontaneous oxidation and reduction reactions are made to occur by the application of electrical energy

You use metals every day. However, most metals are reactive and will oxidize to produce metal ions. With this reaction, they will eventually return to the earth, combining with other substances to reform the ionic compounds from which they came.

As indicated by their position in the activity series, gold and silver are two metals that do not oxidize as easily as other metals. This makes them extremely valuable because objects made from these metals will resist corrosion and probably last a long time. Unfortunately, it is usually too expensive to make an object entirely of these precious metals.

A cost-effective alternative is to apply a very thin coating of a corrosion-resistant metal to the surface of a susceptible metal. These protective coatings are applied using a variation of the voltaic cell called the **electrolytic cell**. Both cells involve chemical change and electrical energy.



The difference between these cells is that a voltaic cell uses chemical change to produce electrical energy, whereas an electrolytic cell uses electrical energy to produce a chemical change.

You can observe a very simple electrolytic cell in operation in the next activity.

Try This Activity

Using Electrical Energy to Force Chemical Change

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will observe the effect of an electric current through water. A small amount of sodium sulfate is added to the water as an electrolyte to improve its ability to conduct electricity.

Materials

- 500-mL beaker
- 9-V battery
- matches
- wood splints
- stirring rod
- 28.0 g of sodium sulfate, $Na_2SO_4(s)$
- 400 mL of distilled water
- 2 test tubes (15 mm × 150 mm)
- test tube rack

CAUTION!

Use gloves, safety glasses, and a lab apron for this activity.

Procedure

step 1: Add 28.0 g of sodium sulfate, $Na_2SO_4(s)$, into a beaker containing 400 mL of water, and stir to dissolve the solute.

step 2: Once the sodium sulfate has dissolved, fill each test tube to the very top with the solution and place it in a test tube rack.

step 3: Place a new 9-V battery into the remaining solution in the beaker. The battery should be sitting on the bottom of the beaker, completely submerged in the solution, with the terminals facing upward.

step 4: Observe each terminal of the battery for evidence of chemical change. You should see some gas bubbles appearing at each terminal. Can you predict the gases that are produced?

step 5: To collect the gas produced at each terminal, take the two test tubes filled with the electrolyte solution and cover the tops with your thumbs. Carefully tip the test tubes over, and slowly remove your thumb once they are under the surface of the solution. Position each test tube so the opening covers one of the battery terminals.

step 6: After a few minutes, note whether one tube is filling with gas faster than the other.

step 7: Given that the chemical formula for water is $H_2O(l)$, determine which of the test tubes contains hydrogen gas and which contains oxygen gas.

step 8: Remove the test tube you think contains hydrogen gas. Do this by placing your thumb over the open end of the test tube and carefully removing each test tube without losing the gas collected. While pointing the open end of the test tube in a safe direction, use a **burning** splint to confirm your prediction.

step 9: Remove the test tube you think contains oxygen gas using the same method stated in step 8. While pointing the open end of the test tube in a safe direction, use a **glowing** splint to confirm your prediction in this case.

Analysis

1. In this activity, you assembled a simple electrolytic cell.

a. Identify the source of electrical energy for this cell.

b. Describe the evidence that indicates that this electrolytic cell caused a chemical change.

2. Consider the gas collected in the test tube positioned over the positive terminal of the battery. What does the splint test indicate about the identity of this gas?

3. Consider the gas collected in the test tube positioned over the negative terminal of the battery. What does the splint test indicate about the identity of this gas?

4. More gas accumulated in one of the test tubes than in the other. State the identity of this gas, and use the following chemical reaction to help you explain why a larger amount of it was produced.

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$$

5. In this activity you added a salt, sodium sulfate, to act as an electrolyte so that the distilled water could conduct electricity. Concisely explain why both voltaic and electrolytic cells require electrolytes to properly function.

Using Electrical Energy to Produce Metal Coatings

Many metal products manufactured today have a thin coating of a less corrosive metal added to their surface. In this process, the object to be coated is submerged in a solution containing metal ions that will eventually form the corrosion-resistant surface. An external source of electrical energy supplies energy to electrons that flow through two electrodes: one electrode connects to the object to be coated and the other to a second electrode in the conducting solution to complete the circuit. This process is called **electroplating**.

You will have an opportunity to build an electrolytic cell that can electroplate copper onto a carbon electrode in the next investigation.

electroplating: the process of depositing a metal at the cathode of an electrolytic cell

Figure A2.27: Large-scale industrial electroplating facilities use banks of electrolytic cells to produce metal coatings.

Investigation

Electroplating Copper

Purpose

You will assemble an electrolytic cell that will add a thin coating of copper to a carbon electrode. You will observe changes to the electrodes that will verify that chemical change has occurred.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Materials

- 150 mL of 0.250-mol/L copper(II) sulfate solution, $CuSO_4(aq)$
- 2 electrical leads with alligator clips
- 9-V battery (or direct current power supply)
- carbon electrode
- copper electrode
- 250-mL beaker
- electronic balance

CAUTION!

Use gloves, safety glasses, and a lab apron for this investigation. Copper(II) sulfate solution, $CuSO_4(aq)$, is toxic and an irritant.

CAUTION!

Proceed with caution if you are using a direct current power supply. An ammeter should be used to ensure that the current does not exceed 2.0 A. The power supply should be protected by a fuse or circuit breaker in case the electrodes accidentally touch.

Procedure

step 1: Before starting this investigation, carefully read over the entire investigation. Design a data table to record the qualitative and quantitative observations you will make during the investigation.

step 2: Pour 150 mL of 0.250-mol/L copper(II) sulfate solution into the beaker.

step 3: Measure the initial masses of the carbon and copper electrodes, and record each value in your data table.

step 4: Take the carbon electrode and attach an alligator clip to one of its ends. Take the other end of the alligator clip and attach it to the negative terminal of the 9-V battery (or to the negative terminal of the power supply).

step 5: Take the copper electrode and attach an alligator clip to one of its ends. Take the other end of the alligator clip and attach it to the positive terminal of the 9-V battery (or to the positive terminal of the power supply).

step 6: Carefully place the electrodes into the copper(II) sulfate solution. Do not immerse the alligator clips or let the electrodes touch each other.

step 7: Let the electrodes sit in the solution for approximately 10 min. During this time, look at the electrodes and note any changes you see.

step 8: Disconnect the alligator clips from the battery and the electrodes. Observe any changes to the electrodes that have occurred.

step 9: Allow the electrodes to dry thoroughly, and measure the final mass of each electrode. Record the values in your data table.

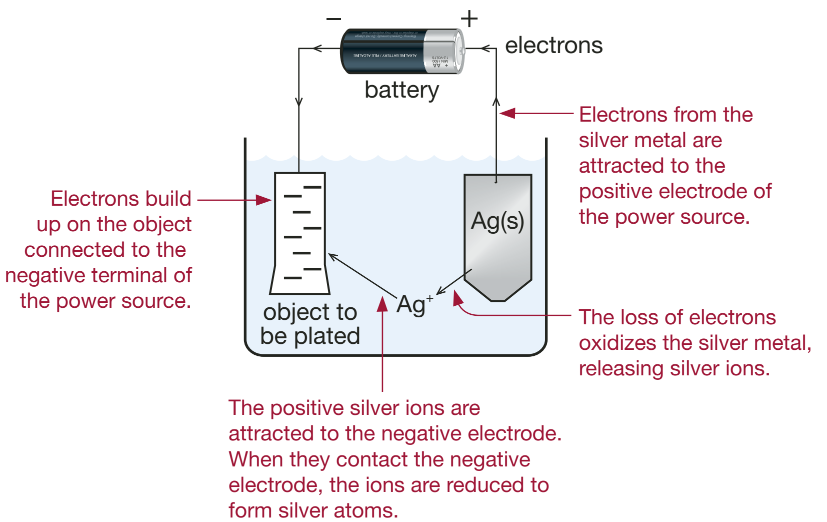
Analysis

1. Describe any changes that occurred at the carbon electrode.
2. Describe any changes that occurred at the copper electrode.
3. Identify the evidence that indicates a reduction half-reaction occurred during the operation of the electrolytic cell. Write the half-reaction that describes this reaction.
4. Identify the evidence that indicates an oxidation half-reaction occurred during the operation of the electrolytic cell. Write the half-reaction that describes this reaction.
5. Draw a diagram of the apparatus. Label the anode, the cathode, the electrolyte, and the direction of electron flow provided by the power source.

A Look into Electroplating—The Mechanics of an Electrolytic Cell

Earlier, you explored the idea that batteries make use of spontaneous oxidation and reduction reactions. Energy is released as relatively reactive metals lose electrons to relatively reactive ions. The resulting current of electrons is guided through a wire so that their energy can be captured and used by your electronic devices.

The Mechanics of Electroplating



Electroplating, however, is a process that forces non-spontaneous oxidation and reduction reactions to occur. Energy is used to remove electrons from the metal located at the anode of the cell and transfer them to metal ions within the electrolyte near the cathode of the cell. The cell you constructed in the last activity forced copper(II) ions in the solution to gain electrons and become copper metal. Cells like this can be used to electroplate one metal over another metallic substance. Can you think of a reason why this process is an effective way to protect metals that tend to be easily oxidized?

Electroplating is commonly used to protect metals from other elements in the environment that might cause corrosion. Iron and other metals are often electroplated with chromium, platinum, silver, or gold to protect them from substances in the atmosphere that oxidize them. Electroplating a metal can increase the life span of the consumer good without having to actually make the entire object out of an expensive metal.

Practice

Use the following information to answer questions 44 to 46.

Gold Used in Jewellery

If an object is made entirely from pure gold, it is described as being made from 24-karat gold. However, because gold is such a soft metal, it is often combined with other metals, like brass (copper and zinc) and nickel, to make the object more durable. A piece of jewellery made from 18-karat gold is 75% pure gold, and a piece that is 12-karat gold is only 50% pure gold. By law, every piece of jewellery has to be stamped with the karat or (k) mark, along with the manufacturer's trademark.

Gold-filled jewellery is also called gold overlay or gold clad. These pieces have a layer of at least 10-karat gold that has been permanently welded to a less expensive metal underneath. The karat gold must make up at least 1/20 of the total mass of the piece in order to qualify as gold-filled. Gold-filled items, like designer frames for eyeglasses, have many of the advantages of a gold surface without the excessive weight characterized by 24-karat gold.

Jewellery that is gold-plated means that an electrolytic cell was used to coat the surface with a plating of at least 10-karat gold. The coating on the surface is much thinner than it is for rolled gold, so these pieces are not as durable. This process is ideal for pieces that have intricate designs or are very large.

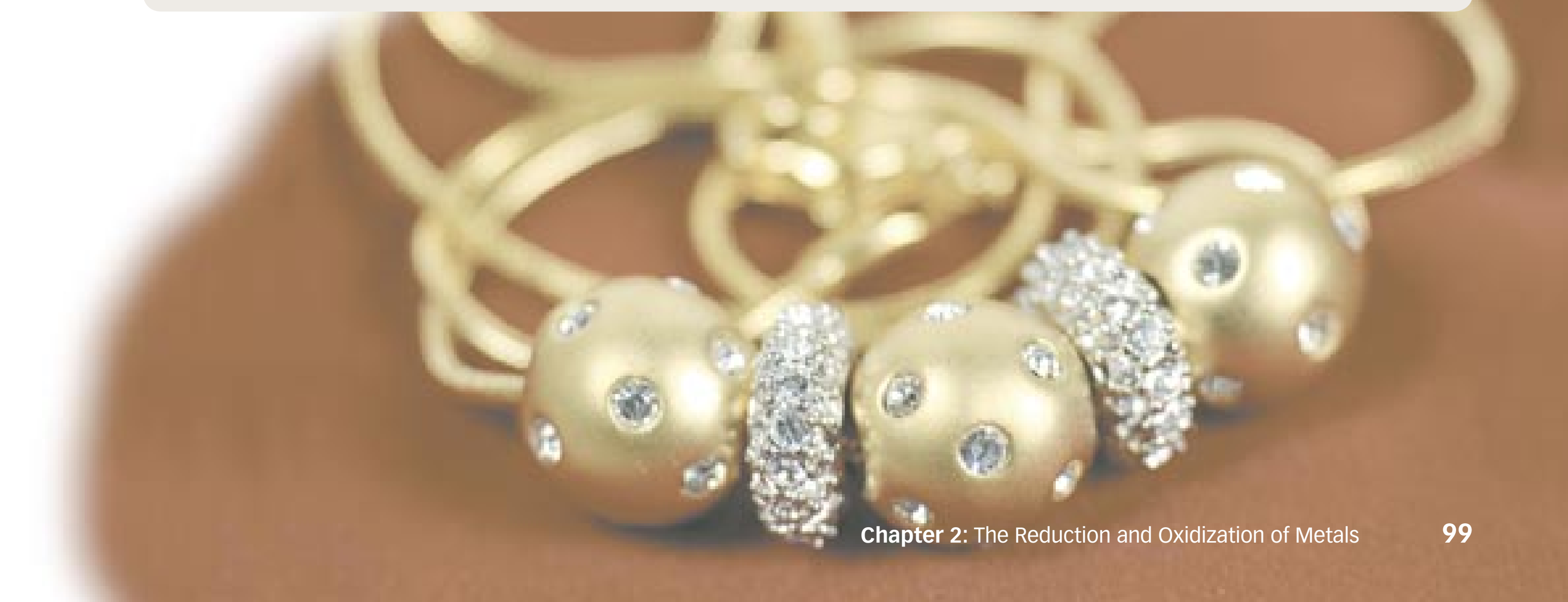
44. Consider the following description of a bracelet being sold:

"For Sale: One gold bracelet, 15 cm long, $200."

If you were interested in buying this item, what questions should you ask the seller?

45. In a commercial gold-plating operation, would you expect the piece of jewellery to be electroplated to be in contact with the negative terminal of the power supply or with the positive terminal? Explain your reasoning.

46. Gold-plating is a cost-effective alternative to the other types of gold jewellery because the gold can be applied sparingly to the surface. However, care must be taken not to scratch this thin layer. Explain the problems created by deep scratches on the surface of gold-plated objects.



Other Uses for Electrolytic Cells

Refining Metals

Recall that when copper is extracted from its ores, blister copper is produced from molten copper sulfide. Blister copper is 97% to 99% pure copper. Although this grade of copper is fine for many applications, it is still not pure enough for use in copper wires. Copper wire must be 99.99% pure copper. Further refinement is done using an electrolytic cell.

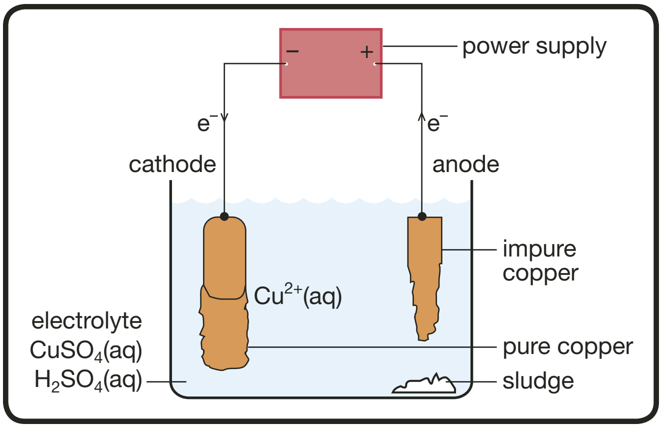


Figure A2.28: This electrolytic cell shows purifying copper.

In Figure A2.28, a very thin electrode of already pure copper is connected to the cathode. The blister copper is attached to the anode. As the copper in the blister copper is oxidized at the anode, copper ions, $Cu^{2+}(aq)$, are released and enter the solution. The free-floating, positive copper ions diffuse in the solution and are eventually attracted to the electrons at the cathode. They move toward the cathode and gain two electrons when they come into contact with it. By gaining two electrons, the copper ions are reduced to pure copper metal. Over time, the anode of impure copper shrinks while the cathode of pure copper grows.

Electrolysis

electrolysis: the decomposition of a substance by means of an electric current

Earlier in this lesson you saw how electrolytic cells can be used to divide water molecules to form hydrogen gas and oxygen gas. This process is called **electrolysis**.

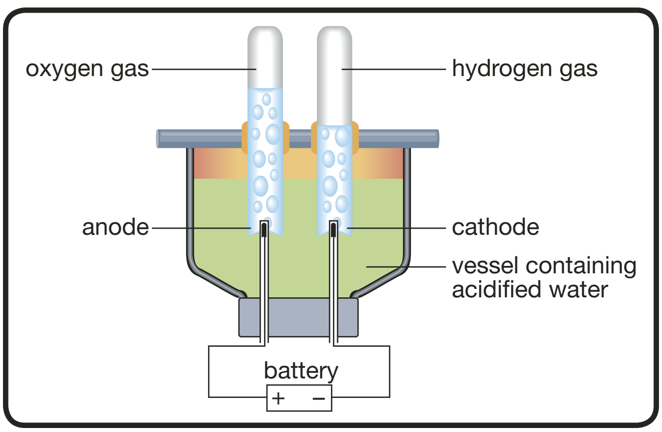


Figure A2.29: Electrolysis is actually a simple process.

In Figure A2.29, the oxygen in water molecules loses electrons at the anode to become oxygen gas, $O_2(g)$. At the same time, hydrogen in water molecules gain electrons at the cathode to become hydrogen gas, $H_2(g)$. The overall equation for this process is

$$2\ H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$$

Producing Non-Metals

Electrolytic cells are not limited to purifying only metals, they can also be used to produce non-metals.

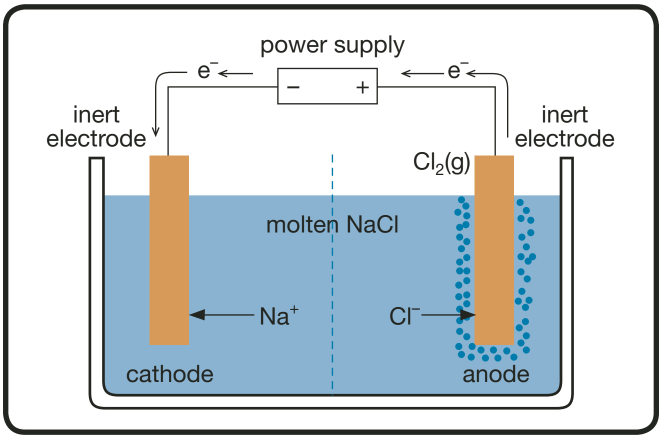


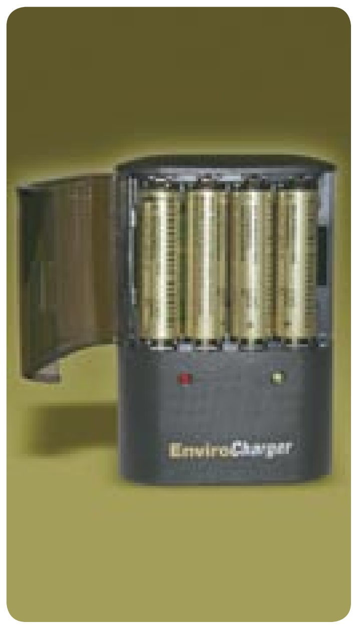
Figure A2.30: This diagram shows how an electrolytic cell produces non-metals.

In Figure A2.30, the chloride ions have electrons taken away from them at the anode to make chlorine gas. Meanwhile, the sodium ions are reduced at the cathode to produce sodium metal. Both chlorine gas and sodium metal have a large variety of industrial uses.

Chlorine is used to kill micro-organisms in both drinking water and waste-water treatment. Sodium is used as a reducing agent in refining metals like titanium.

Rechargeable Voltaic Cells

A rechargeable voltaic cell functions as an electrolytic cell when it is recharging. As mentioned earlier, a voltaic cell (or commercial cell) contains reactants that spontaneously undergo oxidation and reduction. When a cell no longer produces energy, the reactants need to be re-made. When you recharge one of these cells, you use an electric current to force the oxidation and reduction of the contents in the cell to reproduce the original reactants.



2.5 Summary

Non-spontaneous reactions require electrical energy in order for a reaction to occur. Electrolytic cells make use of non-spontaneous oxidation and reduction reactions. Electroplating is a process where you reduce metal atoms onto an object acting as an electrode. This process will give that object an outer protective layer consisting of another metal. One example is the Canadian penny. Since 1997, this coin has been made with a small percentage of copper plated over less-expensive metals. Electrolytic cells are also used to purify metals from their ores and to remove elements from compounds to produce gases.

2.5 Questions

Knowledge

1. Define the following terms.

  a. electrolytic cell
  b. electroplating
  c. electrolysis

2. Outline the similarities and differences between an electrolytic cell and a voltaic cell.

3. Explain the benefits of electroplating one metal with another metal.

Applying Concepts

4. Design an electrolytic cell that uses silver metal as one of the electrodes to plate a house key with silver. Be certain to include a diagram with your design that has the following components:

- electrolyte
- cathode
- anode
- loss of electrons
- gain of electrons
- negative terminal
- positive terminal
- electron flow
- products of the electrolytic cell
- power source
- oxidation half-reaction
- reduction half-reaction

5. Explain how you can purify a metal from its ore with an electrolytic cell.

6. Explain the difference between regular and rechargeable batteries.

7. Electrolysis uses an electrolytic cell to break down water molecules to form oxygen gas and hydrogen gas.

  a. Draw and label the important structures and products of an electrolytic cell that will complete the electrolysis of water.

  b. Explain why it is necessary to have an ionic compound dissolved in the water of the cell.

  c. Use the overall equation of electrolysis to explain how this process supports the idea that water is made up of two hydrogen atoms and one oxygen atom.

Chapter 2 Review Questions

Knowledge

1. For each of the following reactions, state whether oxidation or reduction will occur, determine the number of electrons gained or lost, and write a balanced half-reaction.
   a. $Sn^{4+}(aq) \rightarrow Sn^{2+}(aq)$
   b. $Na^{+}(aq) \rightarrow Na(s)$
   c. $S(s) \rightarrow S^{2-}(aq)$
   d. $2\ F^{-}(g) \rightarrow F_2(aq)$
   e. $As(s) \rightarrow As^{3-}(aq)$
   f. Gold atoms convert into gold ions.
   g. Nitride ions convert into nitrogen gas.
2. Using the activity series, write the oxidation half-reaction that describes each of the following changes.
   a. An atom of lithium reacts to form a lithium ion.
   b. An atom of copper reacts to form a copper(II) ion.
3. Examine the following balanced chemical equations:
   - $Mg(s) + Cl_2(g) \rightarrow MgCl_2(s)$
   - $2\ Ni(s) + O_2(g) \rightarrow 2\ NiO(s)$
   - $Ag_2S(s) + Ca(s) \rightarrow CaS(s) + 2\ Ag(s)$

   a. Identify the chemical substances being oxidized.
   b. Identify the chemical substances being reduced.
   c. Identify any ions that do not undergo oxidation or reduction during the reaction (spectators).
4. Refer to the balanced chemical equations in question 3.
   a. Determine the number of electrons gained by each atom or ion.
   b. Determine the number of electrons lost by each atom or ion.
5. Determine whether the following substances could undergo oxidation, reduction, or both.
   a. lithium atom, $Li(s)$
   b. hydride ion, $H^{-}(aq)$

Applying Concepts

6. If you place a strip of aluminium metal into hydrochloric acid, you will obtain hydrogen gas. The balanced chemical equation that describes this process is

   $$2\ Al(s) + 6\ HCl(aq) \rightarrow 2\ AlCl_3(aq) + 3\ H_2(g)$$

   a. State the chemical substance that is gaining electrons. Provide a reason for your choice.
   b. State the chemical substance that is losing electrons. Provide a reason for your choice.
   c. State the chemical substance that is neither gaining nor losing electrons. Provide a reason for your choice.
   d. State the atom or ion that is being oxidized.
   e. How many moles of aluminium metal are required to make 300 mol of hydrogen gas?
   f. How many moles of hydrochloric acid are required to make 300 mol of hydrogen gas?
7. Balance the following reactions.
   a. $HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$
   b. $Pb(NO_3)_2(aq) + Cu(s) \rightarrow Cu(NO_3)_2(aq) + Pb(s)$
   c. $AgNO_3(aq) + Cu(s) \rightarrow Cu(NO_3)_2(aq) + Ag(s)$
   d. $AuCl_3(aq) + Zn(s) \rightarrow ZnCl_2(aq) + Au(s)$
8. Aspirin, $C_9H_8O_4(s)$, is easily made by reacting salicylic acid, $C_7H_6O_3(aq)$, and acetic anhydride, $C_4H_6O_3(s)$. This is described by the chemical reaction

   $$2\ C_7H_6O_3(aq) + C_4H_6O_3(s) \rightarrow 2\ C_9H_8O_4(s) + H_2O(l)$$

   You have 3.56 mol of acetic anhydride.
   a. How many moles of aspirin could you produce?
   b. How many moles of water will this reaction produce?
   c. How many moles of salicylic acid will you need?
9. Cement is primarily made up of a substance called quicklime, $CaO(s)$. Quicklime is created by using heat to decompose limestone, $CaCO_3(s)$. A by-product of this reaction is carbon dioxide, $CO_2(g)$. The balanced chemical reaction that describes this process is

   $$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

   In the process of making quicklime, a factory releases 7.13×10^5 mol of carbon dioxide into the air every day.
   a. How many moles of quicklime is the factory producing every day?
   b. How many moles of limestone is the factory using every day?
   c. Explain how your answer makes sense by describing what is occurring to the limestone at the atomic scale.

Use the following information to answer questions 10 to 13.

> The process of producing copper metal from ores containing copper involves a step in which air is blown over molten copper(I) sulfide in a conversion furnace. The product that emerges from this furnace is called blister copper, because its surface is blistered by the escaping sulfur dioxide gases as the sulfur solidifies. The equations describing the reactions that occur as air is blown over the molten copper(I) sulfide to produce pure copper are as follows:
>
> **Reaction 1:** $2\ Cu_2S(l) + 3\ O_2(g) \rightarrow 2\ Cu_2O(l) + 2\ SO_2(g)$
>
> **Reaction 2:** $2\ Cu_2O(l) + Cu_2S(l) \rightarrow 6\ Cu(l) + SO_2(g)$

10. Consider each substance described in Reactions 1 and 2. Classify each substance as being an ionic compound, a molecular compound, or a pure metal.

11. Every 1000 kg of ore mined from Kidd Creek Mine in Ontario typically contains about 18 kg of copper and 58 g of silver.

a. Determine the percentage of the ore that contains copper.

b. Determine the concentration of the silver in the ore in parts per million.

c. Explain the statement, "Percentage and parts per million are actually very similar methods for communicating parts of a whole. In fact, percentage could also be called parts per hundred to help people see the similarities."

12. A copper refining operation uses about 34.4 mol of oxygen every second in the refining of copper(I) sulfide.

a. Determine the number of moles of copper(I) sulfide required for this reaction every second.

b. Determine the number of moles of copper(I) oxide produced by this reaction every second.

13. Sulfur dioxide has been shown to cause a number of health and environmental problems. The mining industry has responded by reducing their emissions of sulfur dioxide. This is done by capturing some of the sulfur dioxide produced and converting it into sulfuric acid. Despite these efforts, in Canada about 40% of all sulfur dioxide emissions come from the mineral sector. Use the Internet to determine any health and environmental problems caused by the release of sulfur dioxide.

14. A small coffee cup has a volume of 250 mL. The density of gold is 19.4 g/mL.

a. Use the density of gold as a conversion factor to determine the total mass of the fine grains of gold that could fill a coffee cup.

b. Use the Internet to find the current world price for a gram of gold. Use your answer from question 14.a. to calculate the current value (in Canadian dollars) of a small coffee cup filled with fine grains of gold.

c. As indicated by your answer to question 14.a., gold is a very dense substance. Explain how this property can be used to separate particles of gold from small grains of sand and other minerals when streambed deposits are swirled with water in a shallow container. This process is called panning for gold.

15. Describe how an activity series could be used to

a. determine the reactivity of various metals

b. determine the reactivity of various metal ions

c. determine whether a particular combination of a metal and a solution containing a metal ion would spontaneously react

16. Use the activity series for metals and metal ions to complete the following table. Indicate whether a spontaneous reaction or a non-spontaneous reaction will occur with each combination.

Metal	Metal Ion		
	$Al^{3+}(aq)$	$Zn^{2+}(aq)$	$Sn^{2+}(aq)$
Al(s)			
Zn(s)			
Sn(s)			

17. Use your knowledge of reduction and oxidation to explain what occurs to a metal when it corrodes and the techniques that protect metals from corrosion.

18. Draw a voltaic cell that consists of nickel and magnesium electrodes, each within a solution of its metal ion. Label the cathode, anode, positive and negative electrodes, electrolytes, flow of electrons through the external circuit, and flow of ions through the salt bridge. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$.

19. A voltaic cell is described by the following cell notation:

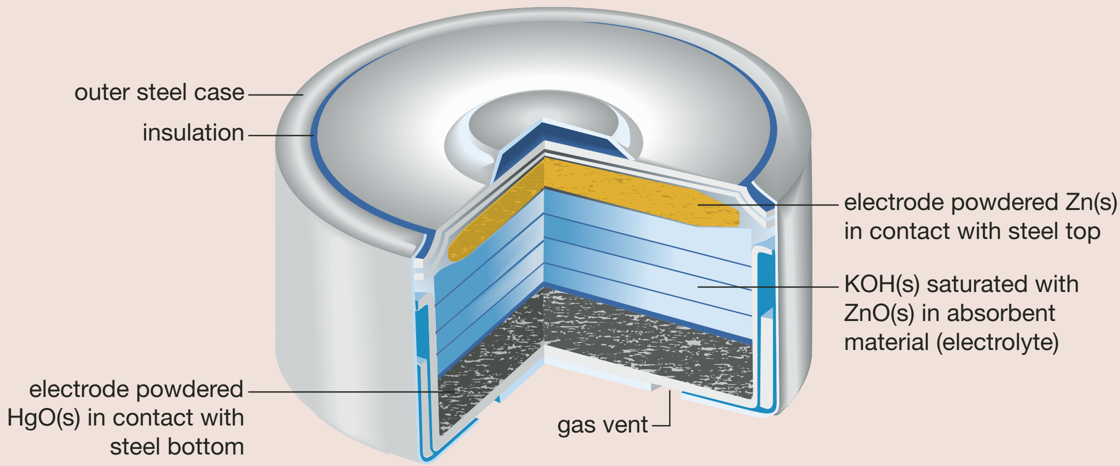
$$Al(s)|Al^{3+}(aq)||Fe^{2+}(aq)|Fe(s)$$

Draw a detailed diagram of this voltaic cell. Include labels for the direction of the flow of electrons, anions, and cations within the cell. Assume the salt bridge contains a solution of potassium nitrate, $KNO_3(aq)$.

20. Compare the voltaic cells in questions 18 and 19. Identify which voltaic cell would produce the higher output on the voltmeter. Concisely explain your reasoning.

21. Devices like watches, pacemakers, and hearing aids require cells that are very small. In these applications, a miniature mercury button cell is often used.

Mercury Button (Miniature) Cell



Although the chemical reactions within these cells are complex, they can still be categorized as oxidation and reduction:

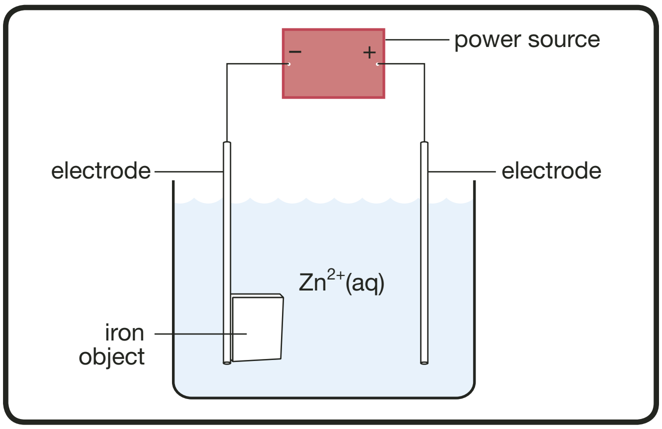
Reaction 1: $Zn(s) + 2\,OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$
Reaction 2: $HgO(s) + H_2O(l) + 2e^- \rightarrow Hg(l) + 2\,OH^-(aq)$

a. Classify Reaction 1 as being either an oxidation or a reduction reaction. Support your answer.
b. Is the powdered zinc in contact with the steel top acting as the anode or the cathode in this cell?
c. Classify Reaction 2 as being either an oxidation or a reduction reaction. Support your answer.
d. Is the powdered HgO(s) in contact with the steel bottom acting as the anode or the cathode in this cell?
e. Would electrons leave the top or the bottom of this cell to flow through an external circuit.

22. Zinc is electroplated over iron metal to prevent the corrosion of iron nails. This process is called galvanizing. Explain how the zinc acts to protect the iron.

23. Refer to the diagram on the right.

a. Identify the type of cell depicted as either voltaic or electrolytic.
b. Describe the importance of the power source to the chemical change that occurs in the cell.
c. Determine the direction of electron flow in this cell.
d. Identify the half-reaction that occurs at the cathode of this cell.



Chapter 3 Organic Chemistry

Take a close look at the oil well pumping petroleum out of the earth. What thoughts come to mind? Most people think of fuel and cars, and they would be right in doing so because fossil fuels are burned for energy.

Petroleum, however, is not only used for energy. In fact, most of the products you purchase contain compounds that are a direct result of developments in the field of organic chemistry—the study of compounds made of carbon atoms. Petroleum is a mixture of many carbon-based compounds and, therefore, acts as the raw material for these processes. Plastics, cosmetics, medicines, and even some food products are made by taking petroleum, refining it, and changing it to into a large variety of human-made (artificial) compounds.

In this chapter you will examine carbon-based molecules that are the building blocks for materials made from petrochemicals. You will investigate the processes used to get these molecules, methods used to classify them, and reactions used to change them. You will be blending science and technology as you look at representations of molecules produced by natural processes and investigate how they can be manipulated into forms people use every day.

The next time you look at an oil well, don't only think about the fuel obtained from it. Think about the multitude of products and goods around you that are made from molecules contained in petroleum. It is important to consider that there is a limited supply of petroleum in the world and that there may be consequences associated with the unwise use of this resource.

Try This Activity

Making an Organic Compound

Organic chemistry involves taking carbon-based compounds, like oil, and reacting them with other reagents to form products with unique and usable properties.

Purpose

You will use chemical reactions to produce a useful substance from a carbon-based material.

Materials

- 30 mL of white glue (This is your carbon-based raw material.)
- 3 mL of powdered borax (This is the reagent that will chemically change the carbon-based raw material.)
- plastic cup (or plastic resealable lunch bag)
- spoon
- source of running water

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Procedure

step 1: Pour 30 mL of white glue into a plastic cup or plastic bag.

step 2: Add 3 mL of powdered borax to the glue.

step 3: Use a spoon to stir the mixture until it becomes sticky.

step 4: Take the sticky product into your hands and run it under water. Use your hands to shape the sticky material into a ball.

step 5: Gently dry the ball.

step 6: You just made your first organic compound. Explore the properties of the compound you just created. Consider flexibility, ductility, elasticity, conductivity, adhesiveness, cohesiveness, tensile strength, and permeability.

Analysis

Copy the following table into your notebook. You will need more room than what is shown here. Complete the table by choosing a few of the properties listed in step 6 of the procedure or any property you can think of that is not listed.

PROPERTIES OF AN ORGANIC COMPOUND

Property of Compound	Use as a Finished Product	Potential Drawbacks	Tests to Further Assess Possible Development

3.1 Carbon Chains

Figure A3.1: A vehicle burns more fuel in the winter than in the summer.

For many people, getting up at 5:00 a.m. on a Saturday morning is not exactly the best way to start a weekend; but if you play hockey, you have to practise when your team is able to get ice time. In the winter, this can mean getting up hours before the Sun rises and hopping into a cold vehicle to drive to the arena.

Although this does not sound like a story about chemistry, many of the products involved in an early morning hockey practice are made up of a large number of **carbon-based compounds**. The gasoline used to fuel the car, the plastic used to manufacture the hockey equipment, the synthetic material used to make the uniforms, the medications (like Aspirin, Tylenol, and Advil) players use to treat minor injuries, the breakfasts quickly eaten by players on the way, and even the molecules that make up the body are all carbon-based compounds.

carbon-based compound: a compound primarily made up of carbon atoms

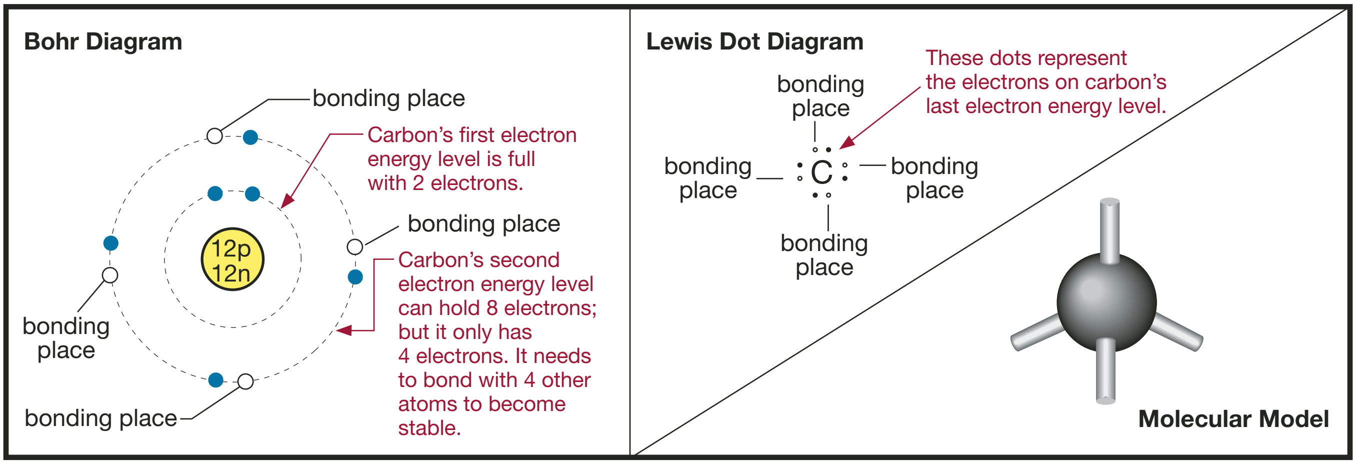
organic chemistry: the study of compounds composed of carbon

Most of the molecules in all living things on Earth are carbon based. This strong presence of carbon-based compounds in organic matter is why the study of these compounds was originally called **organic chemistry**.

Figure A3.2: Molecules in all living things are mostly carbon-based.

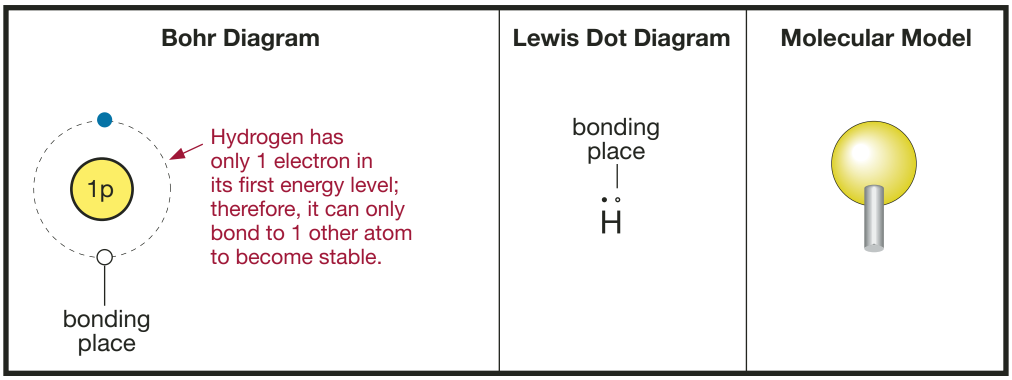
Fats, proteins, and sugars are all made of carbon chains. Why is carbon such an important building block of living and non-living things on Earth? To answer this question, you need to look at the carbon atom itself.

The Carbon Atom



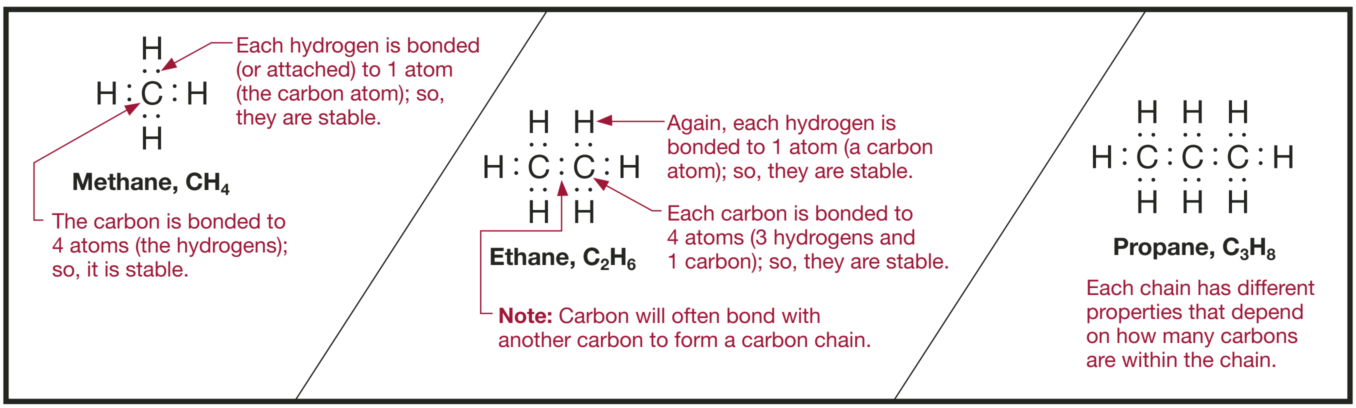
Recall that an atom is most stable when its outer electron energy level is filled with electrons. Carbon has four valence electrons and four empty spots in its outer electron energy level. Carbon needs to form four bonds with other atoms to become stable. Compare a carbon atom to another atom like hydrogen.

The Hydrogen Atom



Hydrogen only requires one electron to fill its outer electron energy level. This means that it bonds to only one other atom to become stable. Because carbon needs to form four bonds to be stable, it is able to form many bonds with other atoms. This gives carbon the ability to produce a large variety of compounds.

Carbon Chains



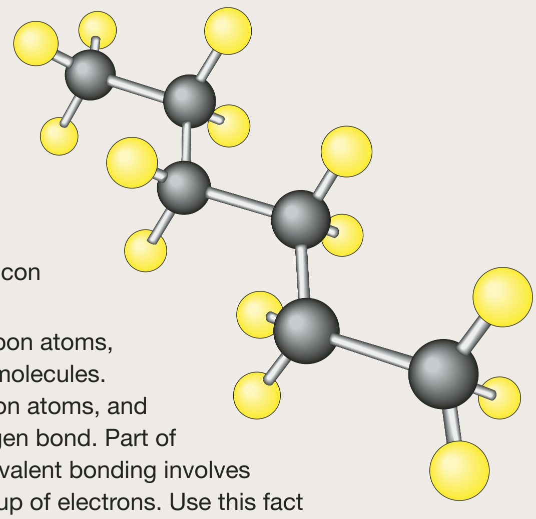
By adding another carbon to the chain, you get a new compound with slightly different properties. The carbon chains in products made from plastics consist of thousands of carbon atoms.

DID YOU KNOW?

Not all carbon-based compounds are considered to be organic. Carbonates, carbides, and oxides of carbon are carbon-based compounds that are inorganic.

Practice

1. Draw Lewis dot diagrams of the following atoms. Determine the number of bonds each atom needs to form to become stable.
   a. carbon **b.** oxygen **c.** fluorine **d.** nitrogen
2. Of the atoms in question 1, hypothesize which atom is capable of producing the largest variety of compounds. State a reason for your choice.
3. Of the atoms in question 1, hypothesize which atom is the most limited in its ability to produce a large variety of compounds. State a reason for your choice.
4. Closely study the molecular model on the right. The black balls represent carbon, and the yellow balls represent hydrogen.



   a. Draw the Lewis dot diagram of this molecule.
   b. How many hydrogen atoms does it take to stabilize all of the carbon atoms in this molecule?
   c. Write the chemical formula for this compound.
5. **a.** Draw a Lewis dot diagram of the silicon atom.
   b. Make a list of the similarities and the differences between the silicon atom and the carbon atom.
   c. There are many more silicon atoms within Earth's crust than carbon atoms, yet there are more carbon-based molecules than silicon-based molecules. Long chains of silicon atoms are not as stable as chains of carbon atoms, and the silicon-hydrogen bond is not as strong as the carbon-hydrogen bond. Part of the reason for these observations has to do with the fact that covalent bonding involves the mutual attraction of the nuclei of two atoms for a shared group of electrons. Use this fact and the answers to the preceding questions to suggest why there are many more carbon-based molecules on Earth than silicon-based molecules.

DID YOU KNOW?

The term *organic* refers to substances that are created by living things, and the term *chemistry* refers to the study of matter. If you put these together, then *organic chemistry* must refer to the study of matter created by living things. This was the original definition of organic chemistry; but it was changed because of a scientific discovery.

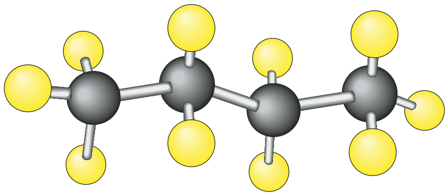
Scientists believed for a very long time that carbon compounds were too complex for scientists to produce in the laboratory. However, in 1828, a chemist named Friedrich Wöhler discovered a way to artificially make a carbon compound, called urea, in a laboratory. This discovery resulted in the production of more complex carbon compounds, and it forced scientists to change the meaning of the term *organic chemistry*. It is now defined as the study of carbon-based molecules rather than the study of matter created by living things.

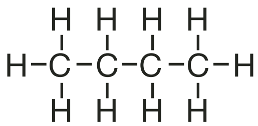
Figure A3.3: Friedrich Wöhler (1800–1882)

The Simplest Carbon Compounds—Hydrocarbons

Since Wöhler's discovery, scientists and technologists have dedicated an immense amount of time and effort in investigating and designing synthetic organic molecules to develop products. Take a look at these molecules and their associated products.

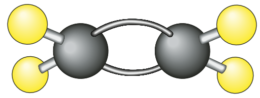
Butane

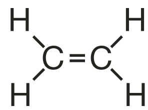




Butane is used as a fuel in barbecue lighters.

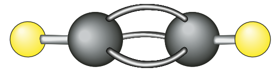
Ethene





Ethene is the starting compound used to produce polyethylene, which is used to make plastic bags.

Ethyne



H−C≡C−H

Ethyne is the starting compound for polyvinyl chloride (PVC), which is used to make rain gear.

A few observations you might make while looking at these compounds are as follows:

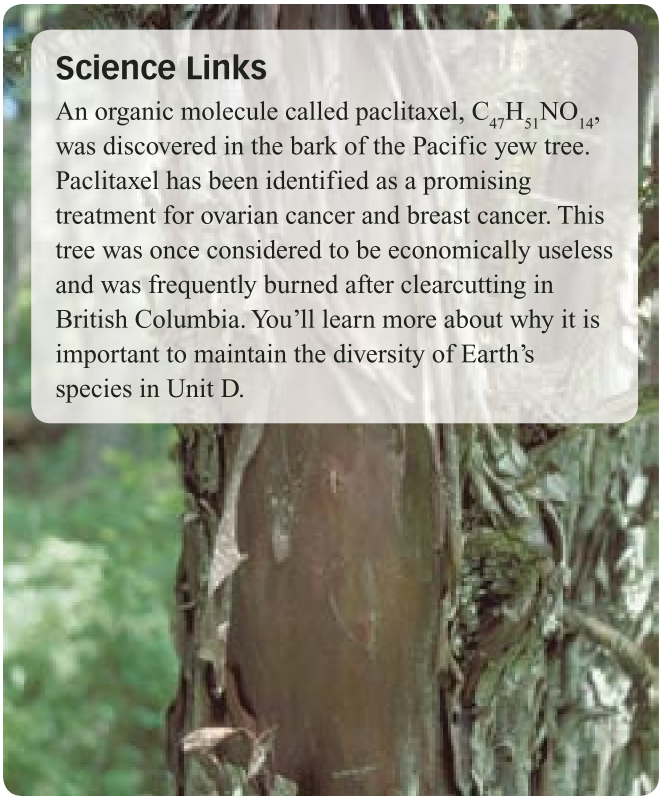
- The only atoms involved are carbon and hydrogen.
- The organic molecules contain single, double, or triple bonds.

hydrocarbon: an organic molecule containing only carbon and hydrogen atoms

The organic molecules you will be exploring in this chapter are all part of a class of organic molecules called the **hydrocarbons**. This name appropriately describes the molecules that belong to this category because they all are made up of only carbon and hydrogen atoms. Hydrocarbons are the simplest group of organic compounds. To understand organic chemistry, you first need to have a good grasp of hydrocarbons because all other organic molecules are very similar.

DID YOU KNOW?

During the winter months, hydrocarbons in the form of fluids leaking from vehicles tend to accumulate on roadways. When the snow and ice melt, these hydrocarbons can find their way into lakes and rivers during the spring run-off. This sudden increase in pollutants every spring creates extra challenges for the facilities that supply Albertans with fresh drinking water.

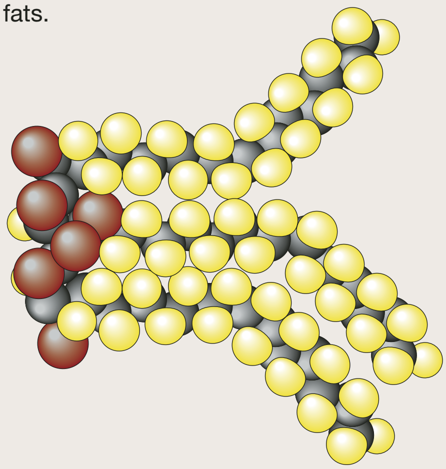


Science Links

An organic molecule called paclitaxel, $C_{47}H_{51}NO_{14}$, was discovered in the bark of the Pacific yew tree. Paclitaxel has been identified as a promising treatment for ovarian cancer and breast cancer. This tree was once considered to be economically useless and was frequently burned after clearcutting in British Columbia. You'll learn more about why it is important to maintain the diversity of Earth's species in Unit D.

Practice

6. Explain how a scientific discovery resulted in the need to change the definition of organic chemistry.
7. Define *hydrocarbon*.
8. A plant has the ability to produce a large variety of complex organic molecules such as oils, proteins, and fats.

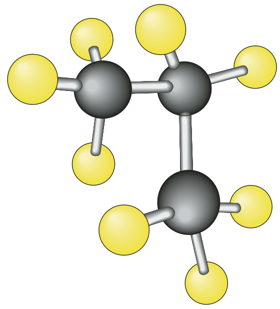


   a. Hypothesize why it is difficult today to make molecules like the one pictured.
   b. About 40% of the world's medicines are organic compounds that were discovered in natural species. This trend is continuing. Every day, new medicines are developed from organic molecules. Why is it important to prevent species from becoming extinct?

Alkanes

Propane, commonly used for barbecuing, is an example of the simplest group of hydrocarbons. These compounds have only single bonds between carbon atoms. This family of molecules is called **alkanes**.

Propane, C_3H_8

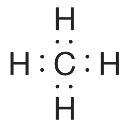
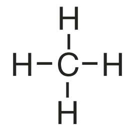
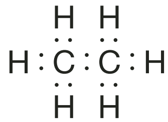
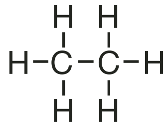
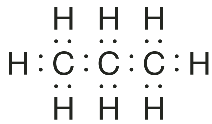
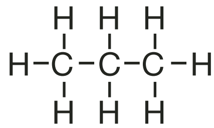
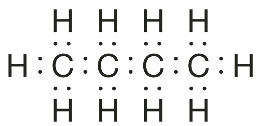
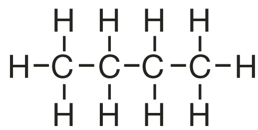


alkane: a hydrocarbon that contains only carbon-carbon single bonds; C_nH_{2n+2}

Each carbon in an alkane is bonded to four other atoms. As a result of the number of hydrogen atoms bonded to the carbon atoms in a hydrocarbon, alkanes have the general chemical formula C_nH_{2n+2}, where n represents the number of carbon atoms in the hydrocarbon.

Figure A3.4: Propane is a gas sold to consumers in refillable cylinders. Many barbecues use propane as a fuel.

ALKANES

Compound	Chemical Formula	Lewis Dot Diagram	Complete Structural Diagram	Condensed Structural Diagram
methane	CH_4			CH_4
ethane	C_2H_6			CH_3-CH_3
propane	C_3H_8			$CH_3-CH_2-CH_3$
butane	C_4H_{10}			$CH_3-CH_2-CH_2-CH_3$

The alkanes depicted are called **continuous-chain alkanes** because the carbon atoms form one chain of consecutive carbon atoms. These hydrocarbons can be represented in several ways:

- a chemical formula—shows the number of carbon and hydrogen atoms in the molecule; includes chemical symbols
- a Lewis dot diagram—shows the sharing of valence electrons between hydrogen and carbon atoms as a pair of dots; includes chemical symbols
- a **complete structural diagram**—shows covalent bonds between atoms as a short line; includes chemical symbols
- a **condensed structural diagram**—shows carbon-carbon bonds but omits carbon-hydrogen bonds; includes chemical symbols

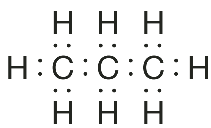
continuous-chain alkane: an alkane consisting of one simple chain of carbon atoms

complete structural diagram: a diagram of a molecule that uses a short line to show the bonds that exist due to the sharing of a pair of electrons between atoms

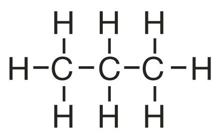
condensed structural diagram: a diagram of a molecule that uses a short line to show carbon-carbon bonds but uses the chemical formula for carbon-hydrogen bonds

Here are examples of the diagrams.

Various Diagrams of Propane, C_3H_8



Lewis Dot Diagram



Complete Structural Diagram

$CH_3-CH_2-CH_3$

Condensed Structural Diagram

Naming Continuous-Chain Alkanes

There are under half a million compounds that do not contain carbon. By comparison, there are in excess of ten million compounds that do contain carbon. Each day, new organic compounds are added to this huge list. Just as each new compound has its own unique structure and set of properties, each compound needs its own characteristic name. People such as pharmacists need a systematic way to name these compounds.

As a result, scientists use a system that allows them to accurately describe the size and structure of each organic molecule. The International Union of Pure and Applied Chemistry (also known as IUPAC) has developed a system for naming organic compounds. This system involves the use of a **prefix** and a **suffix** to convey specific meaning.

Prefixes indicate the number of carbons within a carbon chain, and suffixes indicate the family the molecule belongs to. Different families have different molecular structures.

prefix: the first syllable in the name of an organic molecule that indicates the number of carbon atoms in the molecule

suffix: the second syllable in the name of an organic molecule that indicates the family of the organic molecule

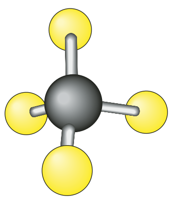
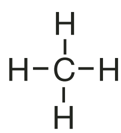
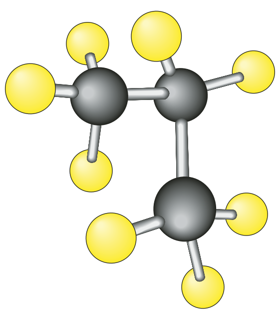
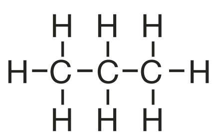
PREFIXES FOR CONTINUOUS CHAINS

Number of Carbons Within the Chain	Prefix
1	meth
2	eth
3	prop
4	but
5	pent
6	hex
7	hept
8	oct
9	non
10	dec

Figure A3.5: Many medicines dispensed by pharmacists are carbon-based compounds.

To name an alkane, you need to match the correct prefix that describes the number of carbon atoms in the longest continuous chain to the suffix for the group. Alkanes have single bonds between the carbon atoms and are described by the suffix *-ane*.

Examples of Naming Continuous Alkanes

Molecular Model	Complete Structural Diagram	Naming Procedure
		This molecule has only **1** carbon atom. Therefore, it is named **meth**ane.
		This molecule has **3** carbon atoms in the chain. Therefore, it is named **prop**ane.

Note: All of the prefixes you need to know are summarized for you on page 556 and in the Science Data Booklet.

COMMON ALKANES AND THEIR APPLICATIONS

Name	Formula	Applications
*meth*ane	$CH_4(g)$	gaseous fuel
*eth*ane	$C_2H_6(g)$	gaseous fuel, starting compound for plastics
*prop*ane	$C_3H_8(g)$	gaseous fuel
*but*ane	$C_4H_{10}(g)$	gaseous fuel
*pent*ane	$C_5H_{12}(l)$	solvents
*hex*ane	$C_6H_{14}(l)$	solvents, liquid fuel
*hept*ane	$C_7H_{16}(l)$	solvents, liquid fuel
*oct*ane	$C_8H_{18}(l)$	solvents, liquid fuel
*non*ane	$C_9H_{20}(l)$	liquid fuel
*dec*ane	$C_{10}H_{22}(l)$	liquid fuel

primary ingredients in gasoline

ingredients for jet fuel and diesel fuel

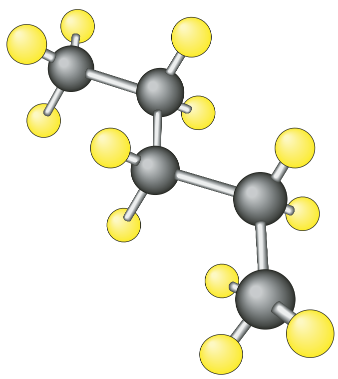
Simplified Structural Diagrams

The structural diagrams of many compounds can become very complex and difficult to draw. Scientists have developed shortcuts to make drawing and reading these structures easier. The following shows increasing simplification starting with the molecular model and ending with the **line structural diagram**.

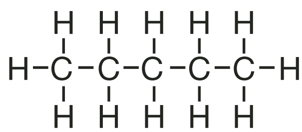
line structural diagram: a diagram of a molecule that only uses a short line to show the bonds between carbon atoms

Simplifying the Diagrams for Pentane, C_5H_{12}

Molecular Model



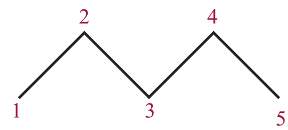
Complete Structural Diagram



Condensed Structural Diagram

$CH_3-CH_2-CH_2-CH_2-CH_3$

Line Structural Diagram



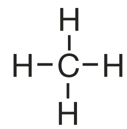
The end of each segment in the line structural diagram represents a carbon atom. Each of the five carbon atoms have been numbered for you.

This diagram assumes that a sufficient number of hydrogen atoms are attached to each carbon, so you do not have to add hydrogens to this diagram.

The diagram for the molecular model of pentane, C_5H_{12}, communicates the most information; but it is the most difficult to draw. The line structural diagram is the easiest to draw; but it communicates the least amount of detail. Most students prefer the complete structural diagram or the condensed structural diagram because they provide a compromise between detail and ease of drawing.

Practice

9. Define each term.
   - **a.** alkane
   - **b.** continuous-chain alkane
   - **c.** Lewis dot diagram
   - **d.** complete structural diagram
   - **e.** condensed structural diagram
   - **f.** line structural diagram
10. Earlier, you were shown examples of three hydrocarbons: butane, ethene, and ethyne. Which of these compounds is classified as an alkane?
11. Draw the Lewis dot diagram, the complete structural diagram, and the line structural diagram for ethane. Explain the differences and similarities that exist between each type of diagram.
12. Explain how a continuous-chain alkane is named.
13. Copy and complete the following table:

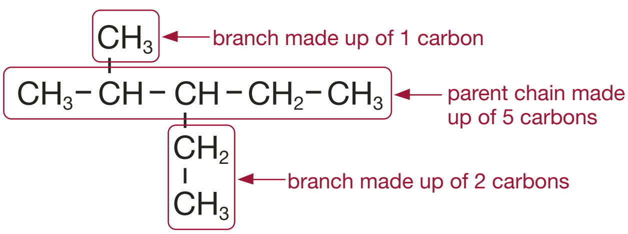
Chemical Formula	Name	Lewis Dot Diagram	Complete Structural Diagram	Application
	ethane			
C_5H_{12}				
	hexane			
				

14. Describe why it is sometimes necessary to simplify the representation of hydrocarbon molecules with line structural diagrams.

Branched Alkanes

Hydrocarbons do not always form continuous-chain alkanes. Carbon atoms are like building blocks, and there are a variety of ways they can be arranged. They often form a long chain with smaller carbon branches attached to them. This kind of hydrocarbon is called a **branched alkane**.

branched alkane: an alkane consisting of a long chain with smaller carbon branches attached to it



Branched alkanes can become complex. Each new branch attached to the parent chain contributes to a molecule's uniqueness and to its own set of properties. The main reason so many organic compounds exist is that there are so many possible locations for branches.

DID YOU KNOW?

While alkanes are important, they do not usually occur in living systems. One exception to this trend is methane. Methane is released by cows and other animals in the form of burps, flatulence, and the decomposition of their wastes. The methane released by livestock accounts for nearly 50% of the methane emissions due to human activity. Since methane is a greenhouse gas that contributes to global warming, many people regard this as cause for concern. One solution is to harvest the methane from animal wastes and use it as a fuel in agricultural operations.

Naming Branched Alkanes

IUPAC has also developed a system for naming branched alkanes. To name a branched alkane, follow these steps:

step 1: Find the longest continuous chain of carbon atoms in the molecule. Circle this chain and label it the parent chain. Name the parent chain as though it is a continuous-chain alkane. For example, a parent chain containing six carbons is called hexane.

step 2: Find all of the branches and circle them individually. Each branch is called an **alkyl group**. Name each group with the prefix that corresponds to the number of carbons within the group; then end its name with the suffix *-yl*. For example, one carbon in the branch is called methyl and two carbons in the branch is called ethyl.

alkyl group: a branch of a larger molecule consisting of an alkane with one hydrogen removed

step 3: To communicate where each branch is on the parent chain, number the carbons on the parent chain starting at the end nearest the first branch. Assign each branch the appropriate number. For example, *2-methyl* means that there is a methyl group on carbon 2.

step 4: Communicate how many of each branch type exists in the molecule. To do this, refer to the following table.

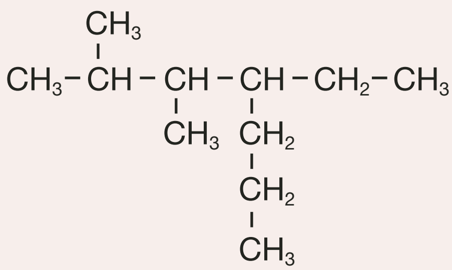
Number of Branches in the Chain	Prefix
1	no prefix
2	di
3	tri
4	tetra
5	penta
6	hexa
7	hepta
8	octa

For example, *dimethyl* means you have two methyl branches in the chain.

step 5: Put the name together, starting with the alkyl groups (in alphabetical order) and ending with the parent chain.

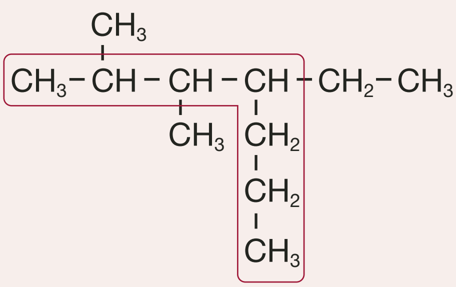
Example Problem 3.1

Name the following compound.



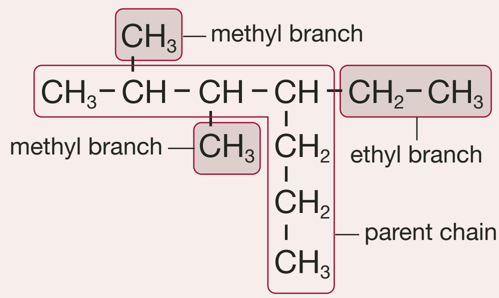
Solution

step 1: Find the longest chain and name it. Be aware that the longest chain may not be in a straight line.



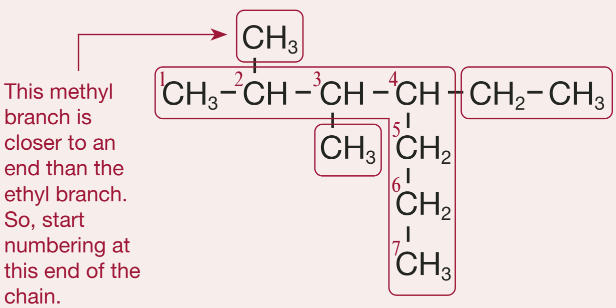
The longest chain has seven carbons. Therefore, the parent molecule is heptane.

step 2: Find all branches and name them.



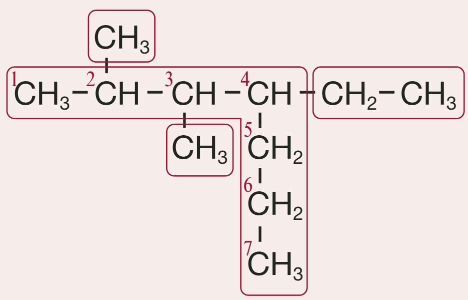
This molecule has two methyl branches and one ethyl branch.

step 3: Number the parent chain.



This molecule has a methyl branch on carbon 2, a methyl branch on carbon 3, and an ethyl branch on carbon number 4.

step 4: Organize branch types and numbers.



Because there are two methyl branches (one on carbon 2 and one on carbon 3), this becomes 2,3-dimethyl. Because there is one ethyl branch on carbon 4, this becomes 4-ethyl. (No *mono* prefix is required.)

step 5: Put the name together.

Parent chain: heptane
Branches: 2,3-dimethyl and 4-ethyl

Place the branches in alphabetical order and end with the parent chain. Do not include the prefixes (e.g., *di* and *tri*) when alphabetizing. Therefore, the name of the compound is **4-ethyl-2,3-dimethylheptane**.

Note that there are commas between numbers and hyphens between numbers and letters.

The Importance of the IUPAC Naming System

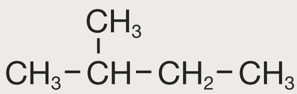
As you saw in Example Problem 3.1, a systematic approach is required to properly name an organic compound. You may wonder why so much effort is put into this process. Why not just use the simple chemical formula for this compound?

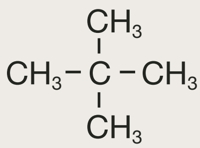
The answer is that the simple chemical formula of the compound in Example Problem 3.1 is $C_{10}H_{22}(l)$. This could mislead you into thinking that this compound was decane, a continuous-chain alkane with a much simpler structure. Due to the fact that carbon atoms can form four single bonds, there are many possible arrangements for a given number of carbon and hydrogen atoms. The IUPAC naming system makes sure that you correctly identify the compound.

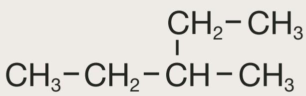
Figure A3.6: A systematic approach for naming organic compounds is essential in the health-care industry.

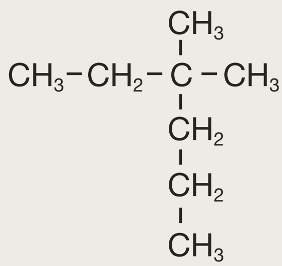
Practice

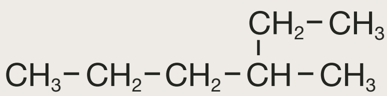
15. Provide the IUPAC name for each compound given.

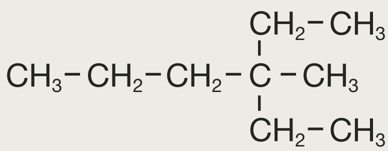
a. 

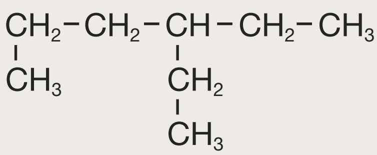
b. 

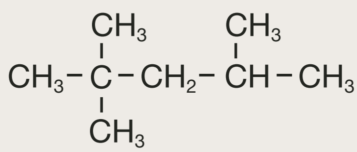
c. 

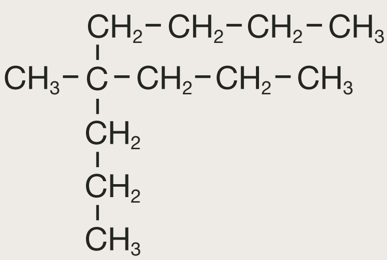
d. 

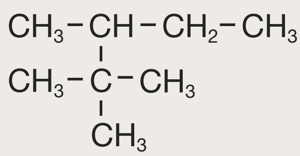
e. 

f. 

g. 

h. 

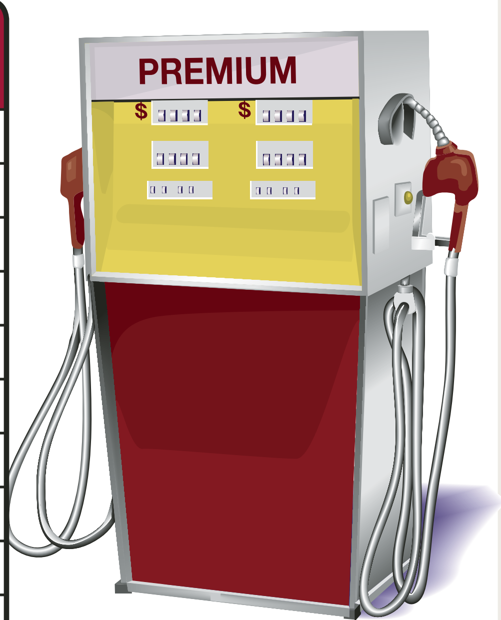
i. 

j. 

Use the following information to answer questions 16 to 18.

Gasoline is a complex mixture of over 500 hydrocarbons. The alkanes, either straight chain or branched, make the greatest contribution to this mixture. The following table lists the most common alkanes that occur in gasoline

Compound	Complete Structural Diagram	Line Structural Diagram	Chemical Formula
butane			
pentane			
hexane			
heptane			
2-methylbutane			
2,2-dimethylpropane			
2,2-dimethylbutane			
2,2-dimethylpentane			
2,2,3-trimethylpentane			
2,2,4-trimethylpentane			



16. Copy and complete the table in your notebook.

17. Check your answers to question 16 by finding images of the molecular model for each compound on the Internet. One possible search strategy is to enter the name of the compound and restrict your search to images. In each case, print an image of the molecular model for the compound and compare it to your complete structural diagram. Remember, the model may need to be rotated to match the orientation you chose for your answers.

18. Carefully examine the chemical formula for each of your answers in question 16.

a. Does each compound have a unique chemical formula?

b. Explain why the IUPAC name of a compound is a better description of the compound than the chemical formula.

3.1 Summary

The basic unit for organic chemistry is a chain of carbon atoms. There are a large variety of carbon compounds, and each compound has its own unique properties. Scientists have created a system to name organic compounds that uses prefixes and suffixes to convey information about the molecule's structure.

The simplest organic molecules are hydrocarbons because they consist of only carbon and hydrogen atoms. The simplest hydrocarbons are called alkanes. These hydrocarbons contain only single bonds between the carbon atoms. There are two types of alkanes: continuous-chain alkanes and branched alkanes.

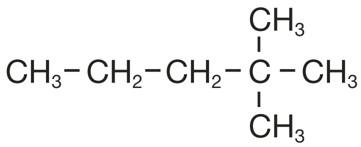
3.1 Questions

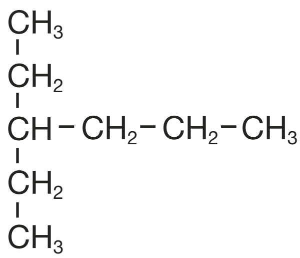
Knowledge

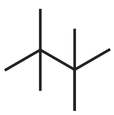
1. Define each of the following terms.
   a. carbon chain
   b. branched alkane
   c. condensed structural diagram
   d. line structural diagram
   e. parent chain
   f. alkyl group
2. Explain why there are a large variety of carbon compounds on Earth.
3. Explain the importance of systems and standards such as the IUPAC rules regarding the naming of hydrocarbons.

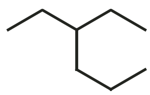
Applying Concepts

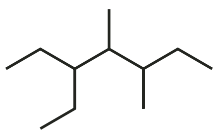
4. Name the following compounds.

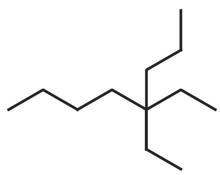
a.


b.


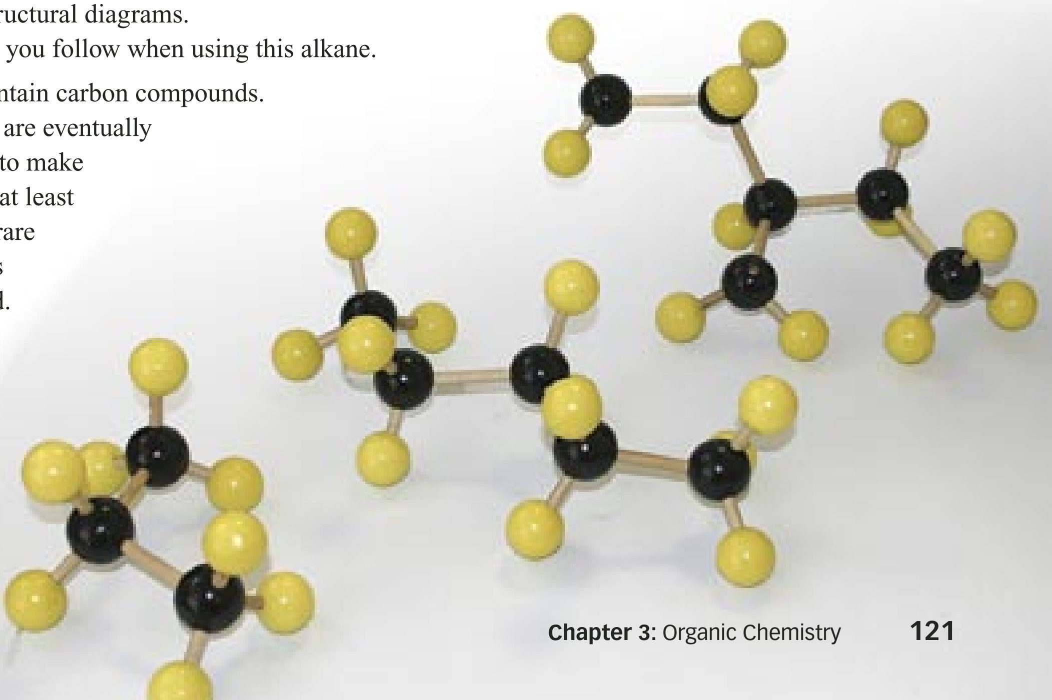
c.


d.


e.


f.


5. Draw a condensed structural diagram and line structural diagram for each of the following compounds.
   a. 3-ethylhexane
   b. 2,2-dimethylbutane
   c. 3-ethyl-2-methylpentane
   d. 3,4,5-trimethylheptane
   e. 3,4-dimethyl-4-propylheptane
   f. 2,4,6-trimethyloctane
   g. 3-ethyl-4,6-dimethyl-5-propyloctane
6. a. Identify an alkane used in your home.
   b. Draw its complete and line structural diagrams.
   c. Describe any safety measures you follow when using this alkane.
7. Many of the products you use contain carbon compounds. If the world's petroleum reserves are eventually depleted, it will be very difficult to make these compounds. Make a list of at least ten products that would become rare and quite expensive if the world's petroleum reserves were depleted.



3.2 Saturated and Unsaturated Hydrocarbons

Figure A3.7: Many popular snack foods contain saturated fats and trans fats.

Many people turn to greasy foods when they want a snack or a quick way to re-energize themselves on a busy day. The reason these foods are known to be a source of energy is that they all contain significant amounts of fat. Gram for gram, fat contains more food energy than does any other type of nutrient. These foods also share something else in common: it is likely that they all contain saturated fats and industrially produced trans fatty acids.

Food	Amount of Industrially Produced Trans Fatty Acids (g)
doughnut	1 to 3.2
large portion of French fries	2 to 6.8
bag of microwave popcorn	1 to 10.0

How does the arrangement of hydrogen atoms around the double bond in a trans fatty acid influence its properties? Why is Health Canada working with the food-service and food-processing industries to limit the content of trans fatty acid in foods sold in Canada? How are trans fatty acids made? Why did many manufacturers deliberately start adding trans fatty acids to processed foods in the 1980s?

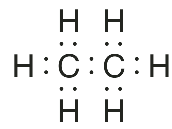
Fats and oils are both organic molecules that are rich in carbon and hydrogen atoms. To answer the preceding questions, once again you need to look at carbon compounds and their bonds.

Saturated Hydrocarbons

You already know that each carbon atom needs to have four bonds to be stable. For example, each carbon atom in an ethane molecule has stability because it is attached to three hydrogen atoms and another carbon atom. This makes a total of four bonds for each carbon atom. As a result of having the maximum number of bonds, carbon atoms are stable and no other atoms can be added to the molecule. Since each carbon in ethane has four bonds to four individual atoms, it is called a **saturated hydrocarbon**.

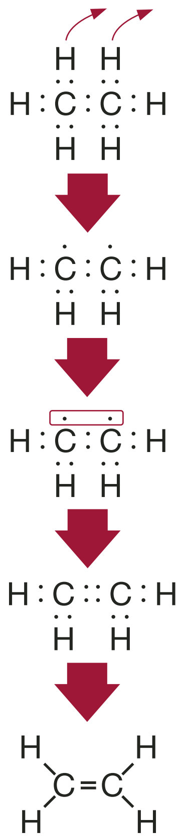
It is possible for a two-carbon molecule, like ethane, to exist with fewer hydrogen atoms. Look at what happens to a molecule when this occurs. If these two neighbouring carbon atoms each lose one hydrogen atom, they can form a double bond. If they each lose an additional hydrogen atom, a triple bond can form.

Ethane



All atoms in this molecule are stable because they each have a full outer energy level.

Making a Double Bond



Two hydrogen atoms leave the carbon chain.

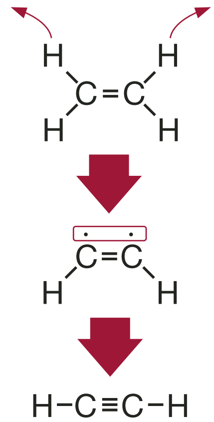
Both carbons have an unbonded electron. So, they are not stable until these unbonded electrons form a bond.

The closest thing to bond with is the electron from the other carbon.

Both carbons bond with each other to form a double bond. All carbon atoms are again stable.

The complete structural diagram shows the twisting that occurs to accommodate the double bonds.

Making a Triple Bond



Two hydrogen atoms leave the carbon chain on either side of a double bond.

The carbons are not stable until they form a bond. So, they bond, yet again, with each other to form a triple bond.

Each atom is stable in this molecule. The carbons each have four bonds: three from the other carbon and one from a hydrogen.

Note: Hydrocarbons with double and triple bonds are less stable than those with single bonds.

saturated hydrocarbon: a hydrocarbon containing only single covalent bonds between carbon atoms

unsaturated hydrocarbon: a hydrocarbon containing double or triple covalent bonds between carbon atoms

Molecules with double and triple bonds are called **unsaturated hydrocarbons**. They are given this name because they are missing their maximum number of bonds to hydrogen atoms. Because there are fewer hydrogen atoms in unsaturated hydrocarbons, they have a general chemical formula different from saturated hydrocarbons like alkanes.

Practice

19. Explain how the formation of a carbon-carbon double bond from a carbon-carbon single bond enables both of the carbon atoms to remain stable.

20. Explain how a hydrocarbon can have a triple bond.

21. Define the terms *saturated hydrocarbon* and *unsaturated hydrocarbon*.

The Difference Between Animal Fats and Plant Oils

Have you ever wondered why many foods containing fats and oils are so popular? In addition to being a rich source of food energy, these ingredients provide taste, consistency, and stability, and they help you feel full. Although many fats and oils help to maintain good health, others do not. To sort this out, you have to look at the shape of the molecules.

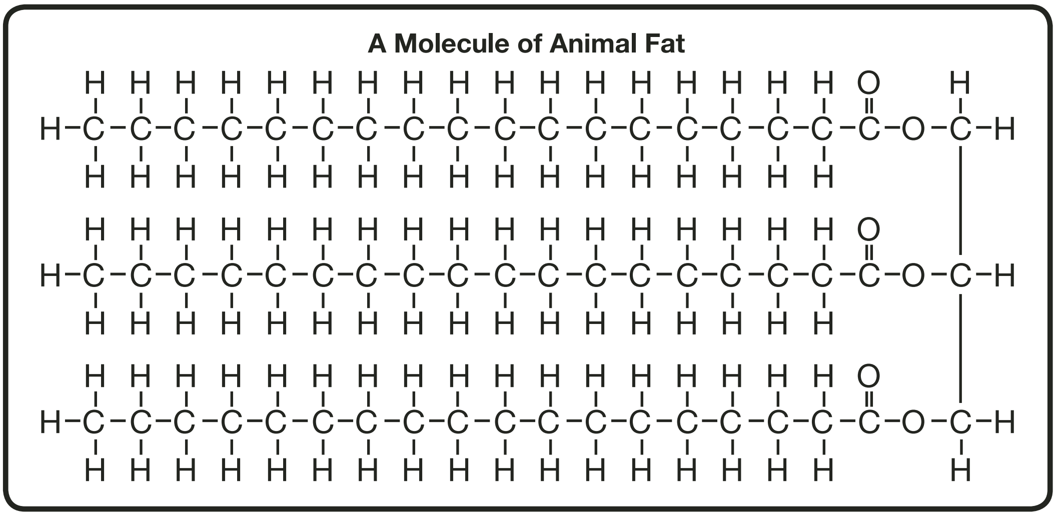


Figure A3.8: A molecule of animal fat contains three fatty acid chains.

The molecules of fats and oils found in foods consist of three connected chains of **fatty acids**. The properties of a fat or oil are determined by the particular fatty acids in these chains.

fatty acid: an organic molecule consisting of a long chain of carbons with a COOH group at one end and a methyl group at the other end

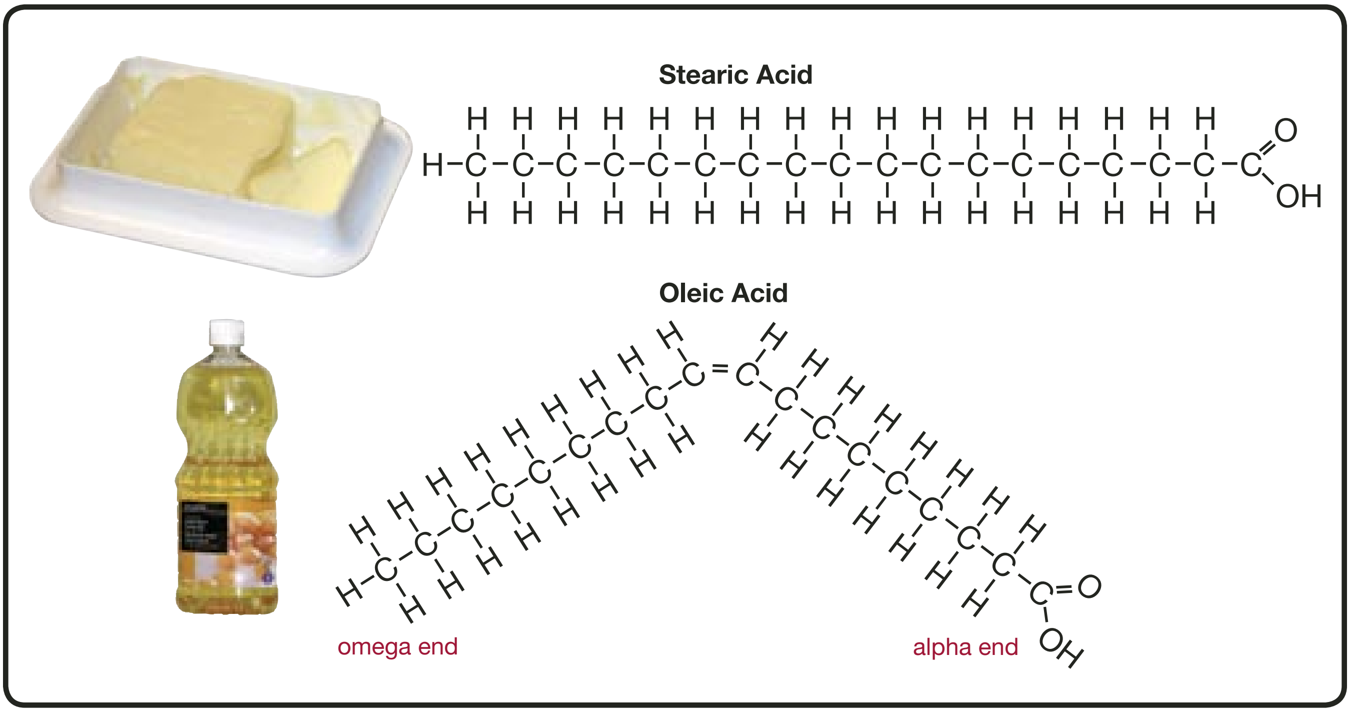


Figure A3.9: Butter is made from saturated fats, which contain saturated fatty acids. Corn oil is made from unsaturated fats, which contain unsaturated fatty acids.

What accounts for the different shapes of these two molecules? Looking closely, you should notice that the carbon chain in the stearic acid is a saturated hydrocarbon, whereas the oleic acid from the plant oil has a double bond and is an unsaturated hydrocarbon. That is, the carbon chain in the stearic acid contains only single bonds between carbon atoms and the carbon chain in the oleic acid contains at least one double bond.

Notice that the unsaturated oleic acid has a bend in the chain at the location of the double bond. The two missing carbon atoms on each side below the double bond create a gap that allows the molecule to bend.

This bend means that groups of oleic acid molecules are like crooked twigs. They don't pack together as closely as the straight chains of stearic acid. Since the oleic acid molecules are further apart, the forces of attraction between adjacent molecules are weaker; therefore, it takes less energy to separate these molecules so that they can move freely over one another. This helps explain why oleic acid is a component of an oil, which is a liquid at room temperature. The closer packing and greater forces of attraction between molecules helps explain why stearic acid is a component of a fat, which is a solid at room temperature.

Oleic acid is an omega-9 fatty acid. The end of the molecule with the COOH group is called the alpha end; the part that terminates with a methyl group is called the omega end. Since the double bond occurs after the ninth carbon, counting from the omega end, this is an omega-9 fatty acid. Your body can produce small amounts of omega-9 fatty acids, but you can also get it from your diet—through olive oil, almonds, and other nuts.

It is the bent shape of this molecule—due to the arrangement of the double bond—that accounts for many of the healthy properties of this nutrient. In general, unsaturated fats and oils are healthier choices than saturated fats. On food labels, unsaturated fats and oils are often called **monounsaturated fats** and **polyunsaturated fats**.

The first part of each word has been added to describe the number of double bonds present in the molecules of each substance. *Mono* refers to one double bond, and *poly* refers to more than one double bond.

monounsaturated fat: a fat molecule that includes fatty acids having only one double bond

polyunsaturated fat: a fat molecule that includes fatty acids having more than one double bond

essential fatty acid: a fatty acid that the body cannot synthesize itself and must obtain from food

Essential Fatty Acids

Although it has become quite popular for people to reduce the amount of fat in their diets, not all fats are health hazards. In fact, some fats are essential to good health. That's why some fat is often included as an ingredient in an energy bar.

It is important to ensure that you eat foods with fats and oils that contain **essential fatty acids**. You need these nutrients for the formation of healthy cell membranes, for the proper development of the brain and the nervous system, and for the production of hormone-like substances that regulate body functions (e.g., blood pressure).

The essential fatty acids are the omega-3 and omega-6 fatty acids. Most people have no trouble getting enough omega-6 fatty acids, but it can be a challenge to get an adequate supply of omega-3 fatty acids. Sources for these include flaxseeds, salmon, and sardines.

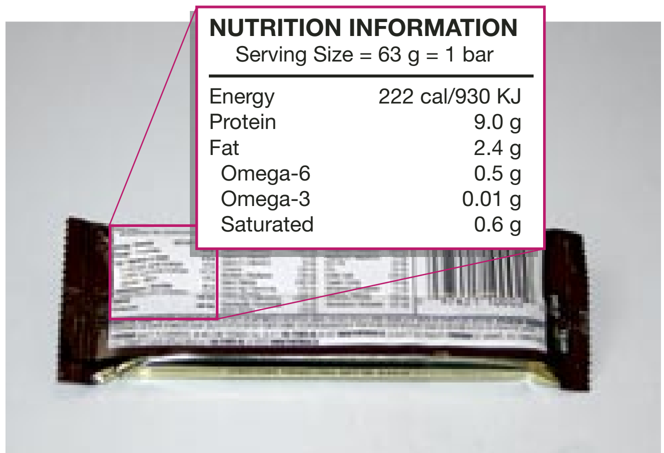


Figure A3.10: Nutrition information is printed on the package of every energy bar.

Practice

22. Explain why saturated fats tend to be solids at room temperature.

23. Sketch a diagram showing the omega end of an omega-3 fatty acid.

24. Sketch a diagram showing the omega end of an omega-6 fatty acid.

25. Explain the flaw in the statement, "A diet high in fat is very unhealthy. So, it is much better to have no fat in your diet."

26. Consider the list of ingredients shown in the energy bar in Figure A3.10.

- **a.** Identify the ingredient that is normally considered to be an unhealthy component in a food.
- **b.** Suggest reasons why a small amount of this ingredient has been added to an energy bar.

Try This Activity

Building Models of Hydrocarbons

Purpose

You will use a molecular kit to make models of the hydrocarbons listed in the procedure. Use the models to determine if the hydrocarbons contain only single bonds or if they contain double or triple bonds.

Materials

- molecular model kit

Science Skills
✓ Analyzing and Interpreting

Procedure

step 1: Copy the following table into your notebook.

Chemical Formula	Complete Structural Diagram	Only Single Bonds, a Double Bond, or a Triple Bond	Saturated or Unsaturated
C_5H_{12}			
C_5H_{10}			
C_5H_8			
C_8H_{14}			
C_4H_{10}			
C_7H_{16}			
C_6H_{12}			
C_4H_8			
C_7H_{12}			
C_3H_8			

step 2: For each compound, build a model of the molecule. Use your model kit to determine whether there are enough hydrogen atoms to saturate the molecule.

step 3: Complete the table for each molecule. Draw a complete structural diagram; and determine whether the molecule has only single bonds, whether it has at least one double or triple bond, and whether it is saturated or unsaturated. Since there is more than one way to construct each molecule, there are a number of possible responses for each of the structural diagrams.

Analysis

1. Earlier, you discovered that the general formula for an alkane was C_nH_{2n+2}. Alkanes have only single bonds between the carbon atoms. Use this information to verify the results of your work with the models.
2. Consider the compounds in your table that have a double bond. Use the chemical formula for each of these compounds to develop a general formula for a hydrocarbon with a double bond.
3. Consider the compounds in your table that have a triple bond. Use the chemical formula for each of these compounds to develop a general formula for a hydrocarbon with a triple bond.

Naming Hydrocarbons with a Double or Triple Bond

You already know that an alkane is a hydrocarbon that contains only single bonds. A compound that has at least one double bond between two neighbouring atoms in its longest continuous chain of carbon atoms is called an **alkene**. A compound that has at least one triple bond along the longest continuous chain of carbon atoms is called an **alkyne**.

The rules for naming alkenes and alkynes are similar to naming alkanes, except for the following differences:

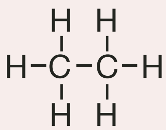
- If the compound is an alkene, the suffix *-ene* is used. If the compound is an alkyne, the suffix *-yne* is used.
- The double or triple bond must appear in the longest continuous chain of carbon atoms.
- Number the chain so that the carbons with the double or triple bond receive the lowest possible number.
- The location of the double or triple bond is communicated by a number, placed before the name of the longest continuous carbon chain.

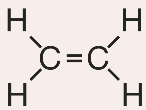
alkene: a hydrocarbon that has at least one carbon-carbon double bond; C_nH_{2n}

alkyne: a hydrocarbon that has at least one carbon-carbon triple bond; C_nH_{2n-2}

Example Problem 3.2

Name each hydrocarbon given.

a. 

b. 

c. H−C≡C−H

Solution

Each compound has a continous chain of two carbons. So, the prefix *eth-* is used.

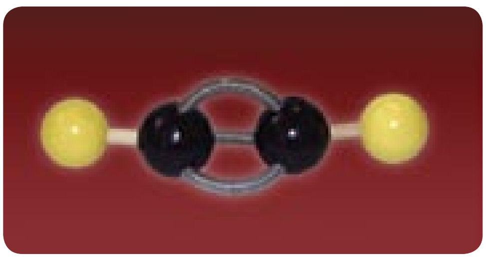
a. This hydrocarbon uses the suffix *-ane* because it is an alkane; it has only single bonds between the carbon atoms. Therefore, this is **ethane**.

b. This hydrocarbon uses the suffix *-ene* because it is an alkene; it has a double bond between the carbon atoms. Therefore, this is **ethene**.

c. This hydrocarbon uses the suffix *-yne* because it is an alkyne; it has a triple bond between the carbon atoms. Therefore, this is **ethyne**.

DID YOU KNOW?

Using the IUPAC naming system, the following molecule is called ethyne. The common name is acetylene.



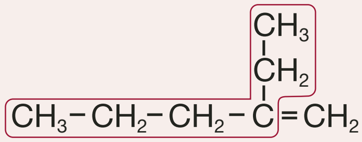
When acetylene is burned alone, it can produce temperatures of 2200°C; but when it is burned with oxygen, the flame temperature can approach 3300°C—hot enough to melt all commercial metals.

Oxy-acetylene welding uses this very hot flame to melt the edges of two pieces of metal that are brought together. The oxy-acetylene process can also be used to cut metal.

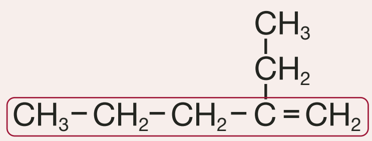
Example Problem 3.3

Identify which diagram correctly identifies the parent chain of an alkene molecule.

A.



B.



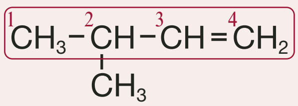
Solution

Diagram A is incorrect. Even though diagram A identifies the longest chain, this chain does not include the double bond. Diagram B is correct because the parent chain includes the double bond.

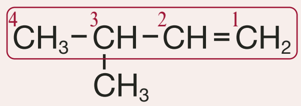
Example Problem 3.4

Identify which diagram correctly numbers the carbons in the parent chain.

A.



B.

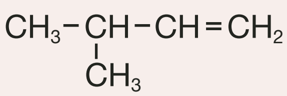


Solution

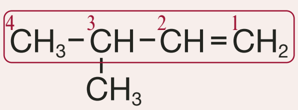
Diagram A shows the double bond occurring after carbon number 3. This is not the lowest number. Diagram B shows the double bond occurring after carbon number 1. Because 1 is less than 3, diagram B is correct.

Example Problem 3.5

Correctly name the following hydrocarbon.



Solution



The double bond for this molecule is between carbon 1 and carbon 2. Use the smaller number to communicate its position. Therefore, the name of this hydrocarbon is

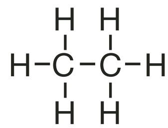
3-methyl-1-butene

methyl branch on carbon 3

double bond after carbon 1

Practice

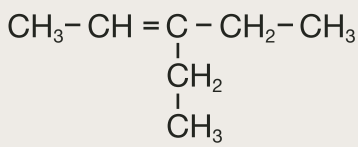
27. Copy and complete the following table into your notebook. The first line has been completed for you.

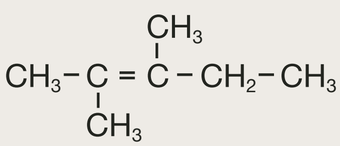
	Type of Hydrocarbon	Bond Between Carbon Atoms in Longest Chain	General Chemical Formula	Example
Saturated	alkane	single bonds	C_nH_{2n+2}	Ethane: C_2H_6 
Unsaturated		one double bond	C_nH_{2n}	
		one triple bond	C_nH_{2n-2}	

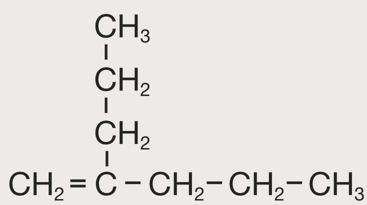
n = 2
2n + 2 = 2(2) + 2
= 6

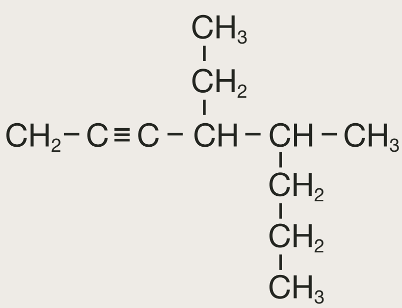
28. Name the following compounds.

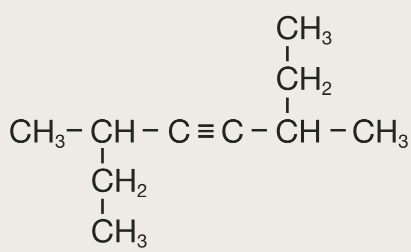
a. $CH_3-CH_2-CH=CH-CH_2-CH_3$

b. 

c. 

d. 

e. 

f. 

29. Draw condensed structural diagrams for the following compounds.

a. 1-hexene
b. 2-pentyne
c. 2-methyl-2-pentene
d. 2,5-dimethyl-3-heptyne

30. The following compounds are named incorrectly. Draw a complete structural diagram of the compound; then name it correctly.

a. 3-butene
b. 2-methyl-4-pentene
c. 2-ethyl-2-pentene
d. 2,3-diethyl-2-hexene

Saturated and Unsaturated Compounds in Food

You have just finished exploring many of the different hydrocarbons that exist. You know that there are alkanes, alkenes, and alkynes. As stated earlier, butter is produced from fats containing saturated carbon chains and, therefore, has properties more like an alkane. Margarine, on the other hand, is produced from oils containing primarily unsaturated carbon chains and, therefore, has properties more like an alkene. So, which is the healthier food choice—butter or margarine?

Part of the answer to this question lies in the differences in the physical and chemical properties of saturated and unsaturated compounds. Remember that the physical properties of a substance include a substance's state at room temperature, solubility, colour, melting point, and boiling point. The chemical properties of a substance explain how stable and reactive the substance is.

Is there a relationship between the properties of the different groups of hydrocarbons and their chemical structure? In the next investigation, you have an opportunity to identify any trends and explain why they may exist.

Investigation

Connecting Chemical and Physical Properties to Structure

Purpose

You will use molecular models to represent various hydrocarbons and suggest how their structure might influence their properties.

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

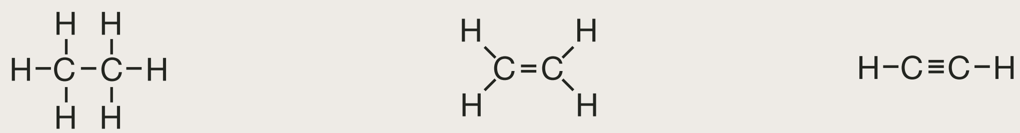
Materials

- molecular model kit

Procedure

step 1: Read through the analysis questions so you know what to look for as you build your models.

step 2: Use the molecular kit to construct each of the following molecules:



Remember that the black balls in your model kit represent carbon atoms, the yellow balls represent hydrogen, and the connectors between the balls represent the bonds between the atoms.

Analysis

Use your models to answer the following questions:

1. Which model is the most rigid?
2. Which model is the most flexible?
3. On which model are the bonds under the most stress?
4. On which model are the bonds under the least stress?
5. Which model has the largest mass? Which has the smallest?
6. Choosing between hydrocarbons with single, double, or triple bonds, which group will have bonds that are the easiest to break? Support your answer.
7. Choosing between hydrocarbons with single, double, or triple bonds, which group will have bonds that are the most difficult to break? Support your answer.
8. Which of the three hydrocarbons will have the greatest reactivity? Support your answer.
9. Order the molecules from most reactive to least reactive. Explain how you came to your conclusion.
10. Predict which molecule will require the most energy to make it move around. Support your answer.
11. Particles in a liquid move freely over one another, taking the shape of their container. This is due to the fact that the particles in a liquid have a greater energy of motion than particles in a solid. Suggest another reason why saturated fats tend to be solid at room temperature and unsaturated fats tend to be liquid at room temperature.

Try This Activity

Investigating Hydrocarbon Boiling Points

Science Skills
✓ Analyzing and Interpreting

Purpose

You will graph data for the boiling points of both alkanes and alkenes. You will then analyze the graphs to find trends in the data.

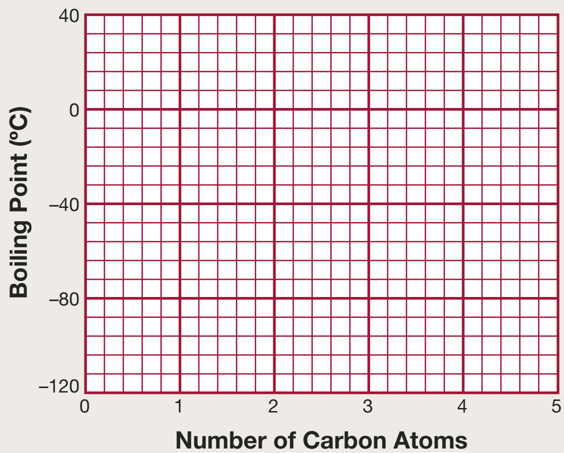
Procedure

1. Copy and complete the following table in your notebook.

	Name of Compound	Chemical Formula	Number of Carbon Atoms	Boiling Point (°C)
Alkanes	ethane			−88.6
	propane			−42.0
	butane			−0.5
Alkenes	ethene			−103.7
	propene			−47.5
	1-butene			−6.0

2. Graph the data in the table. Draw one best-fit line for alkanes and another best-fit line for alkenes. Include a legend. Set up your graph similar to the following.

Comparing Boiling Points of Alkanes and Alkenes



Analysis

3. State the relationship between the boiling point of a hydrocarbon and the number of carbon atoms within the molecule. Give an explanation for this relationship.
4. Predict which compound would have a higher boiling point—pentane or hexane. Give a reason for your choice.
5. Generally describe how the boiling points of alkanes compare with the boiling points of alkenes. Suggest an explanation.
6. Predict which compound would have a higher boiling point—pentane or 2-pentene. Give a reason for your choice.
7. Predict how the melting point of pentane would compare to the melting point of octane.
8. Predict how the melting point of octane would compare to the melting point of 2-octene.
9. Most saturated fats are solid at room temperature, whereas unsaturated fats are liquids (oils). Explain how this statement agrees with the data you analyzed.

The Melting Points and Boiling Points of Hydrocarbons

Generally speaking, the boiling points and melting points of hydrocarbons increase as the number of carbons in the molecule increases. There are two reasons for this:

- The attraction between molecules increases as the number of atoms within those molecule increases. If the attraction between molecules is strong, more energy (or heat) is required to break those attractions to cause a change in state.
- More energy is required to move something with greater mass. If the molecule is bigger, more energy (or heat) is required to make it move.

Therefore, a larger number of carbons in a molecule results in higher melting and boiling points for the compounds because of the stronger attractions between molecules and the greater mass. Smaller hydrocarbons, such as methane, $CH_4(g)$, and ethane, $C_2H_6(g)$, have weaker attractions between molecules and exist as gases at room temperature. Pentane, $C_5H_{12}(l)$, and octane, $C_8H_{18}(l)$, have more carbons, so these compounds tend to be liquids. Waxes tend to have 20 carbons or more in their molecules and are solid at room temperature.

Practice

31. Explain why pentane has a higher boiling point than butane.

32. Explain how a double bond affects the stability of a molecule.

33. For each group, order the compounds from highest boiling point to lowest boiling point.

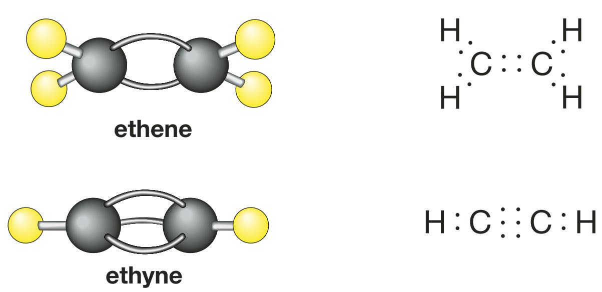
- **a.** pentane, propane, hexane
- **b.** 1-pentene, pentane, 1-butene
- **c.** 2-hexene, 2-heptene, 2-octene

The Reactivity of Hydrocarbons

The reactivity of hydrocarbons depends on other molecules around them. As a general rule, unsaturated hydrocarbons are more reactive than saturated hydrocarbons, due to the bond strain associated with the double or triple bond between carbons.

If you make a molecular model of a double bond or triple bond, you will notice some stress or tension in the bond. Recall that each spring in your model kit represents a pair of electrons shared by the two atoms with double and triple bonds. Carbon atoms joined by double and triple bonds have a greater number of electrons between the carbons than singly bonded carbons. The larger number of electrons results in a greater force of repulsion between them. As a result, hydrocarbons with double or triple bonds are more reactive than those with single bonds.

The Reactivity of Hydrocarbons



Recall that all electrons have a negative charge and, therefore, have a tendency to repel each other.

The close proximity of the electrons within double and triple bonds will increase the repulsion forces between the electrons. This repulsion force increases the stress within the bond and, therefore, increases the reactivity of the molecule.

The reactivity of unsaturated hydrocarbons is useful, especially when you look at industrial processes that use chemical reactions to produce different products. Many plastics and artificial rubbers are produced from chemical reactions involving unsaturated hydrocarbons. As you will see later, the breaking of double or triple bonds in short, unsaturated hydrocarbons can be used to form long carbon chains with single bonds.

Practice

34. For each group, order the compounds from most reactive to least reactive.

- **a.** 2-hexene, 2-hexyne, hexane
- **b.** propane, ethene, 2-butyne
- **c.** 3-octyne, heptane, 2-hexene

The Origins of Industrially Produced Trans Fatty Acids

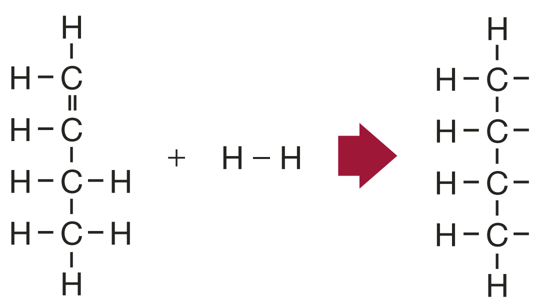
Since butter tends to be expensive and vegetable oils less expensive, it seems to be a good idea to make a spreadable fat from vegetable oil. However, it was not easy to manufacture a new fat that was soft enough to be spread smoothly on a piece of bread. Early attempts produced a product that was too hard. Eventually, food scientists developed a process that could produce an artificial fat from vegetable oil.

Figure A3.11: Industrially produced toppings should be able to spread as smoothly as butter.

Margarine is made by bubbling hydrogen gas through hot vegetable oil under pressure in a special metal vat. The result is that the carbon double bond is broken and is replaced with two single bonds to hydrogen atoms. Since two more hydrogen atoms can be added to the molecule for every double bond that is broken, the process is called **hydrogenation**.

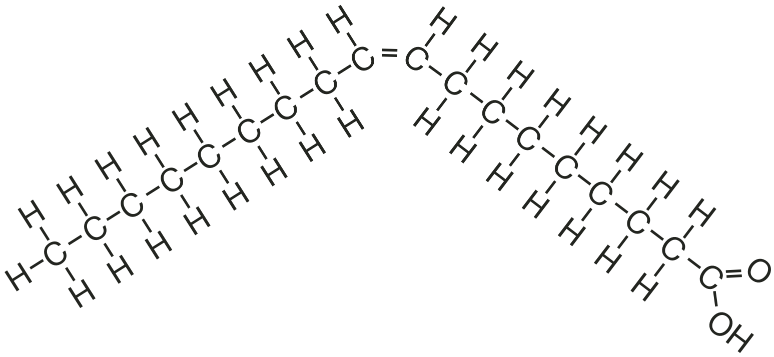
hydrogenation: a reaction that converts carbon-carbon double and triple bonds in unsaturated compounds into carbon-carbon single bonds of saturated compounds

A Hydrogenation Reaction



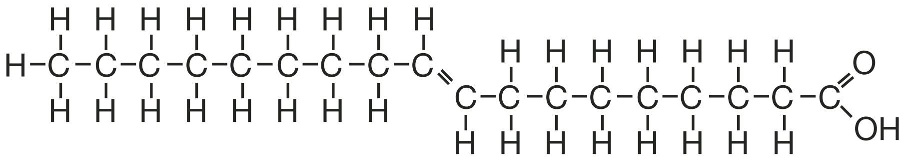
If the hydrogenation is complete, then all the double bonds have been broken. The result is a fat that is so hard that it cannot be spread like butter. To solve this problem, the oil is only partially hydrogenated. This produces a soft, spreadable fat called margarine. The high temperatures needed for the partial hydrogenation process seem to have an unintended effect on some of the unsaturated molecules that remain in the vegetable oils. See if you can spot the difference in Figure A3.12.

Before Being Subjected to High Temperatures and Pressures



oleic acid: a fatty acid that is a component of plant oils

After Being Subjected to High Temperatures and Pressures



elaidic acid: a trans fatty acid produced by the hydrogenation process

Figure A3.12: Can you spot the difference in the bonding within these two fatty acids that causes the difference in shape?

Although it may be obvious that the molecule after being subjected to high temperatures and pressures is no longer bent, it is not as obvious why this occurred. Look at the position of the hydrogen atoms on either side of the double bond. In the original oleic acid molecule, the hydrogen atoms are on the same side of the double bond, providing a gap so the molecule can bend. In the elaidic acid molecule, the hydrogen atoms are on either side of the double bond, making the molecule more symmetrical so the carbon chain remains straight. The position of the two hydrogen atoms is what makes the elaidic acid molecule an **industrially produced trans fatty acid**. The word *trans* means "across" in Latin. Trans fatty acids produced by this process can combine with other fatty acids to make an **industrially produced trans fat**. You might be surprised to know that this industrial hydrogenation process generates a family of trans fatty acids that are completely different than what tends to be produced naturally by plants and animals.

industrially produced trans fatty acid: a synthetic molecule that has the hydrogen atoms on either side of the double bond, resulting in a straighter carbon chain

industrially produced trans fat: a fat molecule produced by partial hydrogenation that contains at least one trans fatty acid chain

COMPARING MOLECULES

Most Fatty Acids Produced Naturally by Plants and Animals	Industrially Produced Trans fatty Acids Manufactured Through Hydrogenation
• Hydrogen atoms are always on the same side of the double bond, resulting in bent molecules. • The double bond occurs after carbon 3, 6, or 9 when counting from the omega end. This accounts for omega-3, omega-6, and omega-9 fatty acids. • The number of carbon atoms in the fatty acid chain is always an even number.	• Hydrogen atoms are on opposite sides of the double bond, resulting in straight molecules. • The double bond can occur after almost any carbon in the chain, but especially after carbons 8, 9, 10, 11, 12, and 13. • The number of carbon atoms in the fatty acid chain could be an odd or even number.

Biochemists and nutritionists are concerned because the molecules of trans fatty acids are so different from the natural fatty acids that our bodies need to stay healthy. Nobody knows all the effects that these substances will have on the human body.

One known property is linked to the fact that trans fatty acids have a straight chain of carbon atoms. This means that these molecules have some properties in common with saturated fatty acids found in butter, cheese, beef, and coconut oil. Because these molecules tend to be solid at room temperature, they have a greater likelihood of clogging up your arteries. Eating foods rich in saturated fats or trans fats should be avoided for the same reason that bacon fat shouldn't be poured down the drain: it will "clog up the pipes." Deposits that develop inside arteries that lead to the heart and brain can cause heart attacks and strokes. Another component of food that also contributes to the buildup of fat deposits in blood vessels is **dietary cholesterol**.

dietary cholesterol: a substance found in food from animal sources

Studies from all over the world are indicating that industrially produced trans fats pose an even greater risk for heart disease than saturated fats. A study in Denmark indicates that, gram for gram, industrially produced trans fats contribute to a more than ten times greater risk of developing heart disease than do naturally produced saturated fats.

Practice

35. Consider Figure A3.12 on page 134. Explain why oleic acid is an oil at room temperature with a melting point of 4°C, whereas elaidic acid is a solid at room temperature with a melting point of 46.5°C.

36. A theme you will encounter throughout Science 20 is how technological solutions to societal problems often create new, unintended problems. Concisely describe how the industrial production of cholesterol-free, spreadable fats (like margarine) illustrates this theme.

37. Consider the statement, "Dietary cholesterol is found in butter but not in margarine."

- **a.** Explain this statement.
- **b.** Does this statement automatically mean that margarine is a healthier food choice?

38. Although the human body has no need for industrially produced trans fats, food manufacturers began to deliberately add trans fats to foods in the 1980s. Use the Internet to determine why this was done.

Making Healthy Food Choices

Fats and oils are a major source of energy for the body. These substances play key roles in the operation of the nervous system and in other essential body functions. However, it is important to choose foods that have moderate amounts of unsaturated fatty acids, such as the monounsaturated fatty acids found in olive oil or the omega-3 fatty acids found in fish oils and flax seeds.

Saturated fats, industrially produced trans fats, and dietary cholesterol are all substances that can significantly increase your risk of heart disease. It is best to choose foods that have the lowest amounts of these substances.

3.2 Summary

In this lesson you discovered that carbon atoms have the ability to form double and triple bonds. The molecules that contain only single carbon-carbon bonds are called saturated compounds; molecules that contain double or triple carbon-carbon bonds are called unsaturated compounds. Unsaturated compounds can be further subdivided into compounds with double carbon-carbon bonds, called alkenes, and compounds with triple carbon-carbon bonds, called alkynes. Scientists and industries have created a system to name unsaturated compounds.

In terms of properties, as you increase the number of carbons within a carbon chain, the compound's melting point and boiling point also increases. Since double and triple carbon-carbon bonds experience bond strain, these bonds are less stable than single bonds. This is why unsaturated compounds are more chemically reactive than saturated compounds.

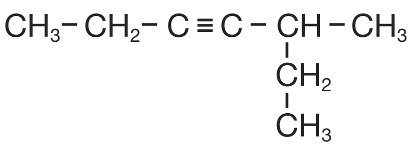
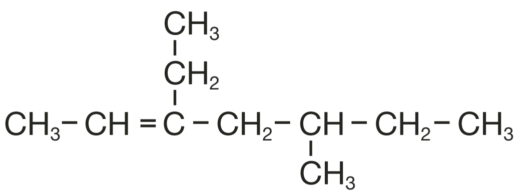
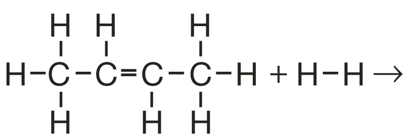
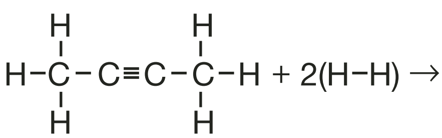
It is important to choose foods that contain the least amount of saturated fats, industrially produced trans fatty acids, and cholesterol. People who eat foods that contain high amounts of these substances have been shown to have a significantly high risk for heart disease.

3.2 Questions

Knowledge

1. Define and provide an example for the following terms.
   a. saturated compound
   b. unsaturated compound
   c. alkane
   d. alkene
   e. alkyne
2. Describe how the number of carbon atoms within a compound affects the melting point and boiling point of that compound.
3. Why are alkenes more reactive than alkanes?
4. Why are alkynes more reactive than alkenes?

Applying Concepts

5. Name the following compounds.
   a. 
   b. 
6. Looking at physical properties, explain why it is more convenient to use octane as a fuel for cars than methane or ethane.
7. Provide a condensed structural diagram for each compound.
   a. 2,3-dimethyl-1-pentene
   b. 3-ethyl-4-methyl-1-pentyne
   c. 3-methyl-3-octene
   d. 4-ethyl-2,3-dimethyl-3-hexene
8. Complete each reaction by drawing the complete structural diagram of the product.
   a. 
   b. 
9. Refer to your answer to question 8. Identify which type of reaction is illustrated by all of these reactions.
10. The following nutrition facts describe the contents of butter, margarine sold in tubs, and margarine sold in rectangular blocks.

NUTRITION FACTS FOR BUTTER
(per serving, 14 g)

Energy	100 cal (419 kJ)
Total fat	11 g
Saturated fat	7 g
Trans fat	0 g
Cholesterol	30 g

NUTRITION FACTS FOR TUB MARGARINE
(per serving, 14 g)

Energy	60 cal (251 kJ)
Total fat	7 g
Saturated fat	1 g
Trans fat	0 g
Cholesterol	0 g

NUTRITION FACTS FOR BLOCK MARGARINE
(per serving, 14 g)

Energy	100 cal (419 kJ)
Total fat	11 g
Saturated fat	2 g
Trans fat	3 g
Cholesterol	0 g

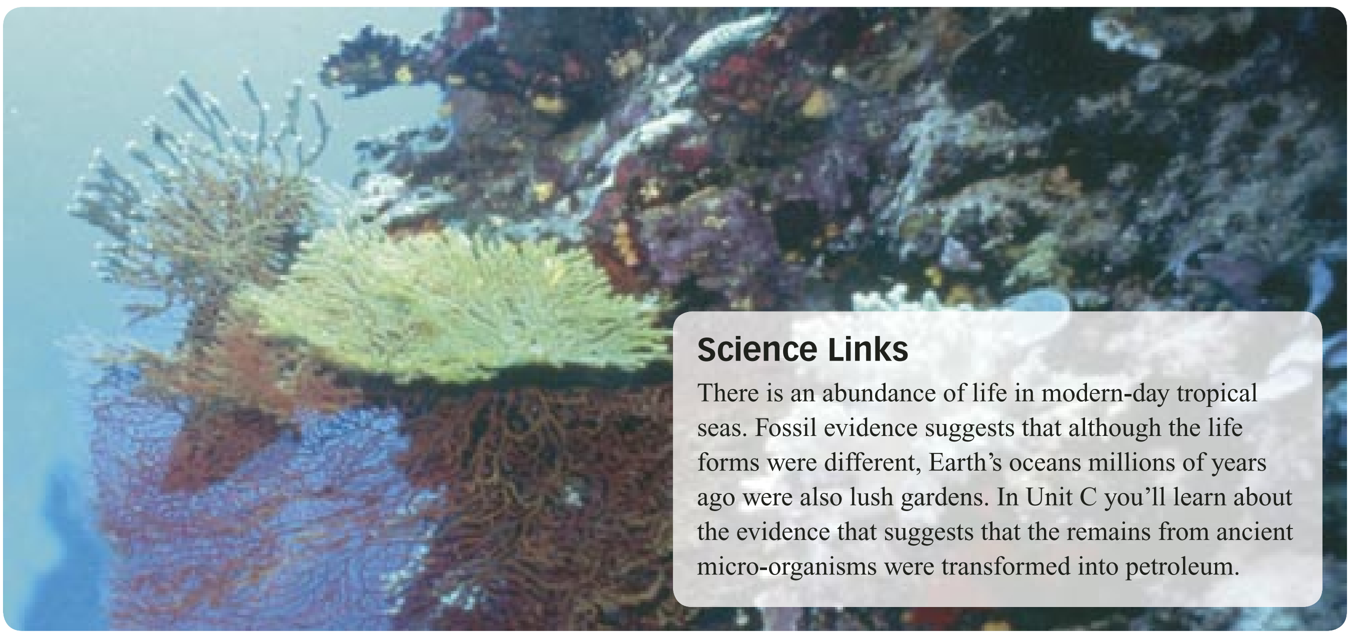
Which of these three foods would be the healthiest choice if you wanted to reduce the risks associated with heart disease? Concisely support your answer.

3.3 Petroleum Is the Source

Figure A3.13: Each of these products has one thing in common—petroleum.

Scientists suspect that atoms in plastics were once part of microscopic plants and animals that lived in oceans millions of years ago. If this theory is correct, that means many of the atoms in any plastic item were once in the cells of ancient micro-organisms that lived in shallow tropical seas. What is the connection between marine life from millions of years ago and plastics? The answer is **petroleum**.

petroleum: liquid hydrocarbons formed over millions of years from the remains of ancient microscopic marine organisms



Science Links

There is an abundance of life in modern-day tropical seas. Fossil evidence suggests that although the life forms were different, Earth's oceans millions of years ago were also lush gardens. In Unit C you'll learn about the evidence that suggests that the remains from ancient micro-organisms were transformed into petroleum.

Petroleum contains a large variety of hydrocarbons of different sizes. It might be easier to think of petroleum as a soup of hydrocarbon molecules.

After locating the resource, the petroleum is pumped out of the ground and is separated into different components. Each component is a mixture of smaller molecules, called a **fraction**. The process of separating and processing petroleum into different fractions is called **refining**.

How is a refinery able to separate groups of molecules from the large and diverse mixture of hydrocarbons that is petroleum? How does this process work? To answer these questions, you need to look at the physical properties of the substances you are trying to separate.

Figure A3.14: An oil refinery separates petroleum into its component molecules.

fraction: a group of compounds found in petroleum with similar properties and uses

refining: an industrial process that separates, purifies, and alters raw materials

Try This Activity

Separating Components of a Mixture

Science Skills

✓ Initiating and Planning

Purpose

You will design a procedure for separating the components of a mixture.

Materials

- 50 mL of salt
- 50 mL of wood chips
- 50 mL of sand
- 50 mL iron filings
- glass beaker (or jar)

CAUTION!

Iron filings can be very messy. If you get these filings on your fingers, they can be quickly transferred to your clothing where they may leave permanent stains, especially if they get wet.

Procedure

step 1: Combine the salt, wood chips, sand, and iron filings in the plastic bucket. Stir the components to make the mixture as uniform as possible.

step 2: Use your knowledge of the properties for each substance to design a procedure that will allow you to separate the mixture into its individual components.

Analysis

1. For each component of the mixture, describe the properties you would use to separate that component from the mixture.
2. Is the order in which you separate the fractions from the mixture important? Give a reason for your answer.
3. Imagine you are on a deserted island in the middle of the ocean and there is no source of fresh water on the island. The only water available to you is the salt water from the ocean. Devise a procedure you could use to separate the salt from the water to obtain fresh water.

Separating Petroleum into Its Fractions

The properties of each substance—salt, sand, iron filings, and woodchips—were used to determine the methods for separation. For example, a magnet was used to separate the iron filings because only the filings were attracted to the magnet. In the case of petroleum, the property used to separate the components of the mixture is the unique boiling point for each group of hydrocarbons. You can explore this process by using a computer applet in the next activity.

Figure A3.15: Magnets are so effective at attracting iron filings that the filings can be difficult to remove from the surfaces of the magnets.

Utilizing Technology

From Petroleum to Gasoline

Purpose

You will use the "Fractional Distillation" applet on the Science 20 Textbook CD to explore the process of separating petroleum into its components.

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Background

Before starting this activity, read through the procedure and the analysis to get a sense of what information you will need to record and what questions you will need to answer. This applet uses the term *crude oil* interchangeably with *petroleum*. Throughout this textbook, you can consider these two terms to mean the same thing.

Procedure

step 1: Obtain the handout "Atmospheric Distillation Tower" from the Science 20 Textbook CD. Add labels to this graphic as you complete the applet.

step 2: Work through the applet by completing all the activities on each page.

step 3: Return to the various pages of the applet as you answer the analysis questions.

Analysis

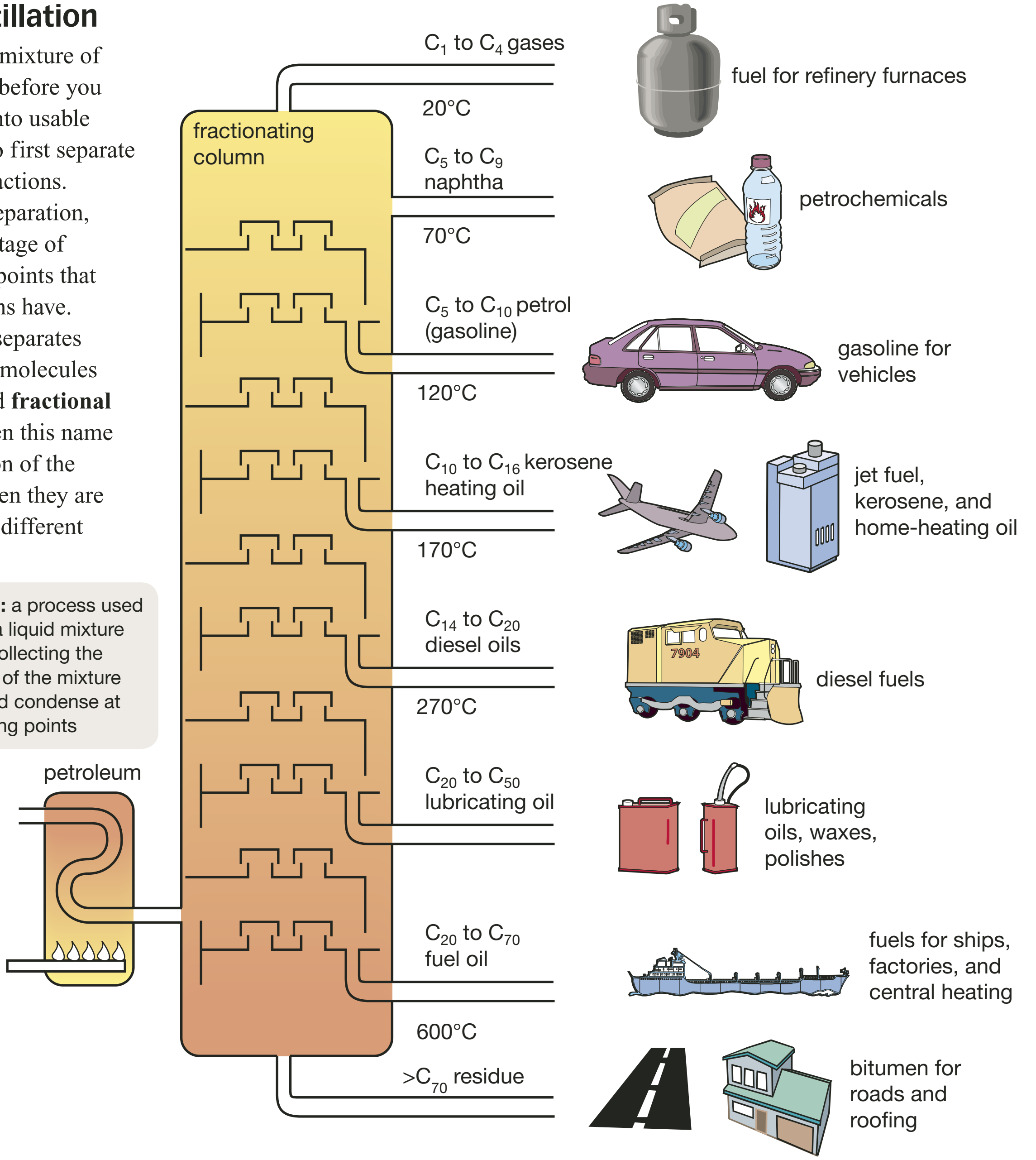
1. Add the missing labels to the "Atmospheric Distillation Tower" handout.
2. Define *isomers*. Provide an example that illustrates its meaning.
3. Cracking is a process used in the refining of petroleum.
   a. Define *cracking*. Provide a balanced chemical equation to illustrate its meaning.
   b. Suggest a reason why the word *cracking* was applied to this chemical process.
4. Alkylation is a process used to make 2,2,4-trimethylpentane, a key component in gasoline.
   a. Identify the other name for 2,2,4-trimethylpentane.
   b. Describe *alkylation*. Use the balanced chemical equation for the production of 2,2,4-trimethylpentane to illustrate your answer.
   c. Earlier, you learned that an alkyl group is an alkane with one hydrogen atom removed that acts as a branch in a larger molecule. Use this information to suggest why the process of making 2,2,4-trimethylpentane is called alkylation.
5. The performance rating of gasoline is improved by adding hydrocarbons that have undergone a reforming reaction.
   a. Define *reforming*, and use a balanced chemical equation to illustrate your answer.
   b. Suggest a reason why the term *reforming* was applied to this process.

Fractional Distillation

Since petroleum is a mixture of many hydrocarbons, before you can turn petroleum into usable products, you need to first separate it into its different fractions. To accomplish this separation, refineries take advantage of the different boiling points that different hydrocarbons have.

The process that separates the different sizes of molecules in petroleum is called **fractional distillation**. It is given this name because the separation of the molecules occurs when they are gases and can rise to different levels in the tower.

fractional distillation: a process used for the separation of a liquid mixture by vaporizing it and collecting the different components of the mixture as they cool down and condense at their appropriate boiling points



In Lesson 3.2 you discovered that the boiling point of a hydrocarbon increases as the number of carbons within the hydrocarbon increases. Here is a quick summary of how the petroleum industry uses fractional distillation:

step 1: The petroleum is vaporized in a hot furnace.

step 2: The petroleum vapour is placed into a tall column.

step 3: The hot vapours rise inside the column. As the vapour moves away from the heat source, it cools.

step 4: As the vapour cools, it not only drops in temperature, but the molecules condense to form liquids at different places in the tower. By condensing at different locations in the tower, the fractions can be collected separately.

step 5: Fractions with high boiling points—the largest molecules in the mixture—will condense first at the bottom of the column. Fractions with lower boiling points—the smallest molecules in the mixture—condense higher in the column. Those fractions that are gaseous at normal temperatures are collected at the top of the column as gases.

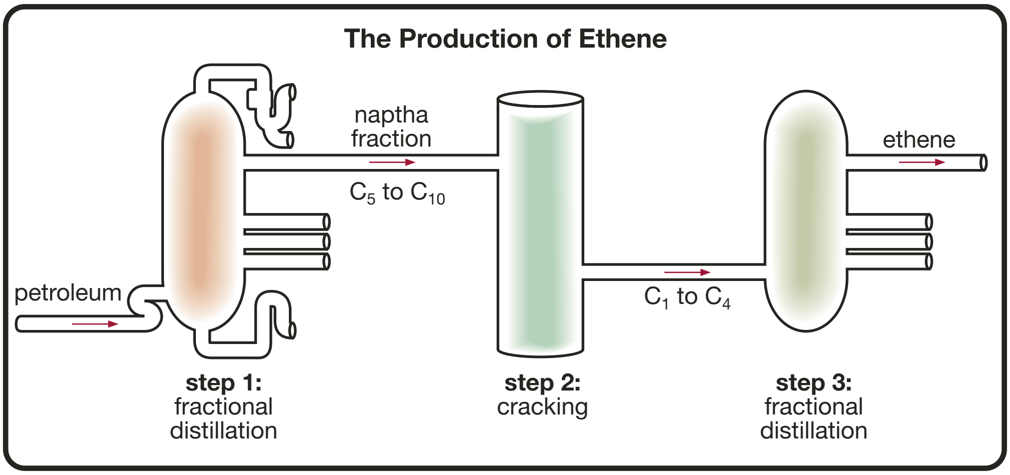
Processing Hydrocarbons

Smaller hydrocarbons are often more useful than larger hydrocarbons because they can easily be reacted to construct new molecules used to make products. Because smaller molecules are easier to manipulate in a chemical reaction, larger hydrocarbon molecules are often used as a source of smaller molecules. It is much easier to use smaller molecules as the building blocks to create larger molecules.

The breaking up of larger hydrocarbons to form smaller molecules is called **cracking**. A hydrocarbon can be cracked by catalytic cracking—a process that uses a catalyst and lower pressure and temperature—or by thermal cracking—a process that uses high pressure and temperature.

cracking: a reaction in which hydrocarbons are broken down into smaller molecules by means of heat (thermal cracking) or catalysts (catalytic cracking)

"The Production of Ethene" diagram shows how the naphtha fraction from a fractional distillation tower is passed to another pressurized tower where high-pressure steam is used to crack the molecules that form the naphtha mixture into smaller molecules.



The naphtha fraction shown between steps 1 and 2 contains a mixture of hydrocarbons containing between 5 and 10 carbon atoms. One molecule that could be in this naphtha fraction is $C_8H_{18}(g)$. The following equation shows how $C_8H_{18}(l)$ undergoes cracking in step 2 to produce ethene, $C_2H_4(g)$.

$$C_8H_{18}(l) \rightarrow 2\ C_2H_4(g) + C_3H_6(g) + CH_4(g)$$

The ethene is separated from the other products of the cracking reaction in step 3, where fractional distillation is used again. The ethene produced from cracking reactions is used to make polyethylene. This plastic is produced in larger quantities than any other plastic; approximately 50 million tonnes of polyethylene are produced worldwide every year.

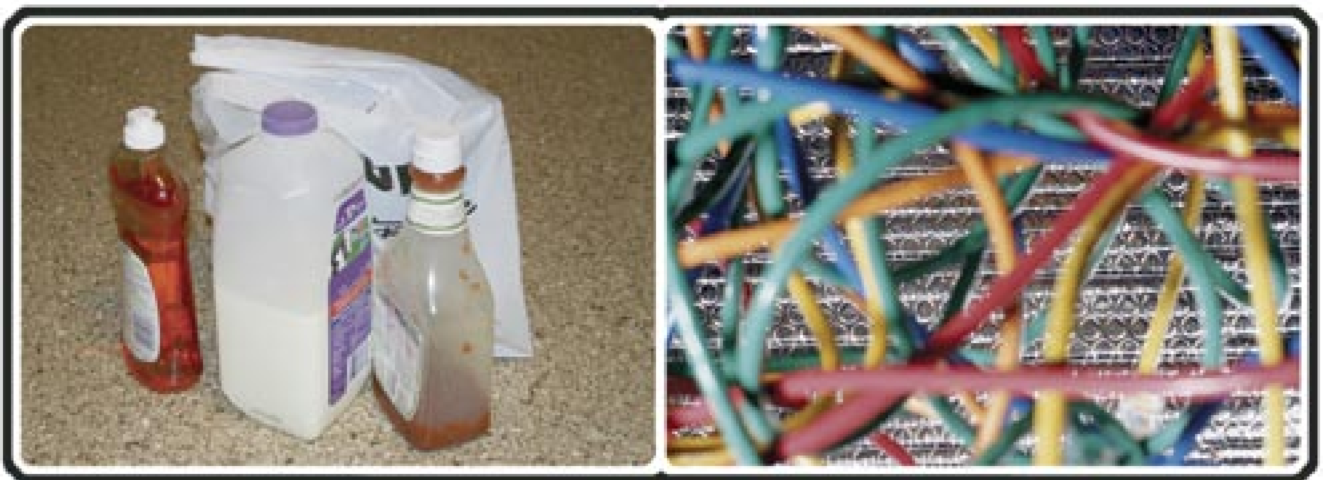


Figure A3.16: Polyethylene is used to make many products.

Most polyethylene is used to manufacture the thin plastic used in grocery bags, freezer bags, and cling wrap. It is also used to make plastic food containers and insulation for electrical cables and wire.

Practice

39. Outline the steps involved in the fractional distillation process.

40. Refer to the diagram and equation on page 141 that shows the production of ethene from the naphtha fraction. Assume that the compounds are unbranched hydrocarbons.

- **a.** Translate this chemical equation into a word equation that properly names each reactant and product.
- **b.** Identify each reactant and product as being an alkane, alkene, or alkyne.
- **c.** If this reaction generates 152.5 mol of ethene every second, how many moles of $C_8H_{18}(l)$ are required?

41. Ethene can also be produced by cracking ethane. In this reaction, another substance is produced in addition to ethene. Write a balanced chemical equation to describe this reaction.

DID YOU KNOW?

A ripe banana can speed up the ripening process of a bowl of unripe tomatoes. How does this happen? Does the banana signal the tomatoes that its time to ripen? As astonishing as this may sound, the banana does send a signal to the tomatoes, in the form of an invisible, odourless gas—ethene. This gas is naturally produced by fruit as it ripens, and its presence can trigger the ripening process in other fruit. Some plants are so sensitive to this effect that they can detect ethene at a concentration of only 1 ppm in air.

Try This Activity

Get Cracking

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will complete a pencil-and-paper exercise that has a surprising number of correct answers. You will take a saturated hydrocarbon chain with 15 carbon atoms and crack it to produce three smaller hydrocarbon molecules.

Procedure

Using a pencil, paper, and an eraser, try to write a balanced chemical equation to summarize a possible cracking reaction. Remember to add states of matter and to check that the equation is balanced. It may take a few attempts to make this work because even though a compound like CH_6 might help to balance your equation, you know that carbon has four bonds and each hydrogen has one. So, a compound like CH_6 is chemically impossible.

Analysis

1. Write the balanced chemical equation for your cracking reaction.
2. Draw the complete structural diagram of the original molecule with the 15 carbon atoms.
3. Draw the complete structural diagram of the three products of the cracking reaction. Add the names of each of the products of the cracking reaction.
4. Are any of your products unsaturated hydrocarbons? Explain why unsaturated compounds form during hydrocarbon cracking.
5. Describe how you could separate the resulting mixture of smaller hydrocarbons produced by the reaction.
6. Compare your results with those of your classmates. Why are there so many possible outcomes even though you all began with the same substance?

Cracking Is a Random Reaction

As was shown by the results of the "Get Cracking" activity, when you crack a single, large saturated hydrocarbon chain, a number of possible combinations of products can be produced. This is because the cracking action can occur at many places along the carbon chain.

Also, notice that you produce unsaturated hydrocarbons during this process. This is because the original molecule had only two carbon atoms at the end position, accommodating three hydrogen atoms each. If the result of cracking is three smaller molecules, that gives a total of six carbons in the end position. Now, there are not enough hydrogen atoms to have all of these new compounds become saturated. So, unsaturated hydrocarbons are produced since there is an insufficient number of hydrogen atoms to completely saturate the products of the reaction.

3.3 Summary

Petroleum is a complex mixture of many different hydrocarbons that can be separated using fractional distillation. This process uses the different boiling points of each group of hydrocarbons to separate the mixture into different fractions. Each fraction that results from this process contains compounds that have a surprisingly large number of applications. Sometimes hydrocarbons are broken into smaller hydrocarbon chains by the process called cracking.

3.3 Questions

Knowledge

1. Define each of the following terms.

- **a.** petroleum
- **b.** fraction
- **c.** refining
- **d.** separation
- **e.** fractional distillation
- **f.** cracking

2. Explain why it is often useful to subject larger hydrocarbons to cracking.

3. State two methods that industries use to break a large hydrocarbon to form smaller chains.

4. Draw the complete structural diagram of a saturated hydrocarbon chain that contains 12 carbons. Use your drawing to create a balanced chemical equation of a cracking reaction.

Applying Concepts

5. "All of our products come from Earth." Use ideas presented in this chapter to explain the accuracy of this statement.

6. Describe uses for the compounds found in the lower sections of a fractional distillation column.

7. Describe uses for the compounds found in the higher sections of a fractional distillation column.

8. You have a solution composed of two molecules with different boiling points. Describe a method in which you can separate the mixture into the two fractions.

9. Explain why it is important for industry to have effective and efficient ways of separating petroleum into different fractions.

3.4 Everyday Use of Hydrocarbons

Figure A3.17: Most people use hydrocarbons as fuel for basic transportation.

Previous periods in human history have been identified as the Stone Age, the Bronze Age, and the Iron Age. The name of each of these periods is based upon the primary raw material that was the basis for making the culture's most advanced tools. What name would you give to the period of human history in which you live?

Figure A3.18: Items purchased at a grocery store are packaged using hydrocarbons.

petrochemical: a chemical made from petroleum

Some would argue that we are still in the Iron Age, since iron is the main ingredient of steel—an essential raw material for the tools used in modern society. If you broaden the definition to include the materials that power the tools, it could be argued that you are currently living in the Hydrocarbon Age. Virtually every human activity in modern society is somehow dependent upon **petrochemicals**.

Practice

42. Carefully examine all the objects shown in Figures A3.17 and A3.18.

  a. List specific examples that illustrate the use of hydrocarbons in each photograph.

  b. Consider the items you identified in question 42.a. Which of these items would be difficult to substitute with materials that were not petrochemicals?

43. What is meant if someone were to say that we were entering the Silicon Age?

Tracing the Path of Petrochemicals

In Lesson 3.3 you studied the processes used to separate specific types of hydrocarbons from the hydrocarbon soup that is petroleum. The petrochemical industry pumps hydrocarbons from deep in the ground and sends them to a refinery. Using fractional distillation, the petroleum is vaporized and the individual fractions are separated from the large mixture of other hydrocarbons they have been mixed with for millions of years. What happens next to the individual fractions?

In some ways, the answer to this question lies in the hands of consumers. What products from this process are in demand? In general, there are two possible outcomes for hydrocarbons once they have been refined:

- They may be combusted or burned for energy.
- They may become the raw material for making products (e.g., plastics, synthetic fabrics, cosmetics, medicines).

In this lesson you will explore both of the outcomes for refined hydrocarbon molecules. You will also explore some of the benefits and risks associated with each of these outcomes.

Hydrocarbons as Fuel

As a consumer, you primarily use hydrocarbons as fuel. Whenever you ride in a car or bus, cook on the barbecue, or turn up the furnance in your house, the energy you use comes from the burning of hydrocarbons. Hydrocarbons make excellent fuels because they

- are relatively stable and easily transported
- have bonds that store much energy
- are readily available (for the time being)

combustion: a rapid reaction with oxygen that produces energy and oxides

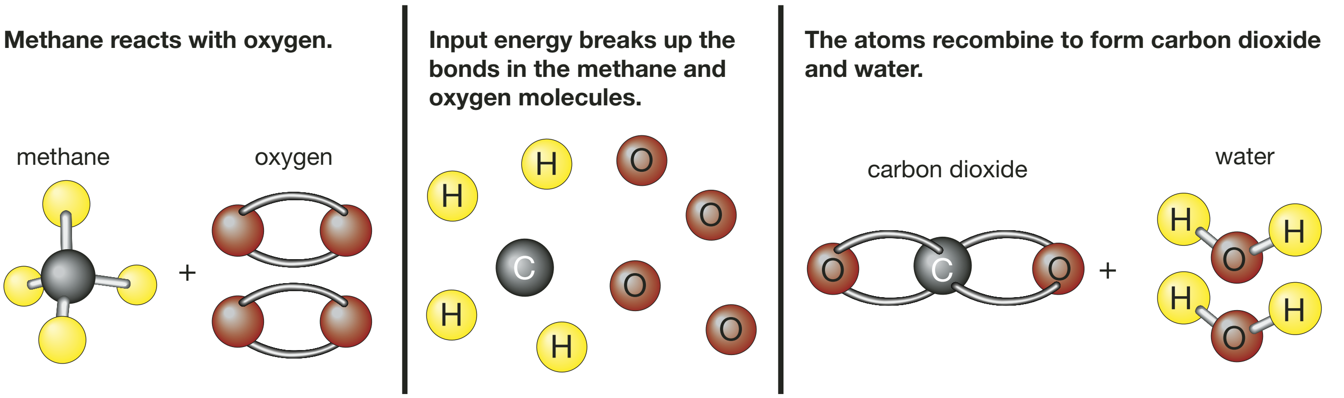
Figure A3.19: When the ratio of oxygen to fuel is right, hydrocarbons burn with a blue flame.

When something burns, it is reacting with oxygen. Another term for burning is **combustion**. When hydrocarbons are combusted, carbon dioxide and water are the most common oxides formed. During a hydrocarbon combustion reaction, oxygen reacts with the hydrocarbon fuel to produce carbon dioxide and water vapour. Here is the combustion reaction for methane:

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$$

This reaction happens in nearly every home in Alberta during the winter, as most homes are heated by the combustion of natural gas in a furnace. Since natural gas is mostly methane, the simplest hydrocarbon, this combustion reaction is a good place to begin.

For these molecules to react, energy has to be added to break the carbon-hydrogen single bonds and the oxygen-oxygen double bonds. In more modern furnaces, this is provided by the spark from an electronic igniter; in older models, the initial energy is provided by the spark of a pilot light. With this input energy, the bonds are broken and the individual atoms temporarily move into an unstable and energized state. When the atoms recombine to form carbon dioxide and water, they become more stable and energy is released.



Since the output energy from forming bonds of carbon dioxide and water is greater than the input energy to break the bonds of methane and oxygen, the overall effect of this reaction is to release energy to the environment. A furnace captures as much of this energy as possible, making a home comfortable for people on cold days.

When natural gas comes out of the ground, in addition to methane, it also contains ethane, propane, and butane. Impurities—such as nitrogen, sulfur, water, oil, and carbon dioxide—may also be present in the natural gas; but these impurities are removed before the natural gas is delivered to homes in Alberta. This helps make natural gas one of the cleanest hydrocarbon fuels.

Practice

44. Explain why it takes energy to separate the atoms joined by a covalent bond.

45. Explain why energy is released when atoms join and form a covalent bond.

Comparing Combustion Reactions

The concepts that explained the combustion of the simplest hydrocarbon can also be applied to the combustion of larger hydrocarbons. Longer hydrocarbon chains have more bonds than shorter hydrocarbon chains; therefore, longer hydrocarbon chains

- store a greater amount of energy than shorter hydrocarbon chains
- require greater amounts of oxygen to be combusted than shorter hydrocarbon chains
- will produce a greater amount of carbon dioxide, water vapour, and energy when combusted than shorter hydrocarbon chains

Example Problem 3.6

Propane and octane are both hydrocarbons that are used as fuels. Propane is used to cook food, and octane is a component of gasoline for automobiles.

a. Write the balanced chemical equation for the hydrocarbon combustion of propane.

b. For every mole of propane, determine the number of moles of oxygen required and the number of moles of carbon dioxide produced.

c. Write the balanced chemical equation for the hydrocarbon combustion of octane.

d. For every mole of octane, determine the number of moles of oxygen required and the number of moles of carbon dioxide produced.

e. Which combustion reaction uses more oxygen and produces more carbon dioxide per mole of fuel?

f. Energy is required to break chemical bonds, and energy is released when bonds are formed. Given this information, would you expect more energy to be released by the combustion of a mole of propane or a mole of octane?

Solution

a. $\_\_\_\_ \; C_3H_8(g) + \_\_\_\_ \; O_2(g) \rightarrow \_\_\_\_ \; CO_2(g) + \_\_\_\_ \; H_2O(g)$

↓ Add coefficients to balance the carbon atoms.

$\underline{\;\mathbf{1}\;} \; C_3H_8(g) + \_\_\_\_ \; O_2(g) \rightarrow \underline{\;\mathbf{3}\;} \; CO_2(g) + \_\_\_\_ \; H_2O(g)$

↓ Add a coefficient to balance the hydrogen atoms.

$\underline{\;1\;} \; C_3H_8(g) + \_\_\_\_ \; O_2(g) \rightarrow \underline{\;3\;} \; CO_2(g) + \underline{\;\mathbf{4}\;} \; H_2O(g)$

↓ Add a coefficient to balance the oxygen atoms.

$\underline{\;1\;} \; C_3H_8(g) + \underline{\;\mathbf{5}\;} \; O_2(g) \rightarrow \underline{\;3\;} \; CO_2(g) + \underline{\;4\;} \; H_2O(g)$

Recall that coefficients of 1 are normally not shown. Therefore, the balanced chemical equation is

$$C_3H_8(g) + 5\,O_2(g) \rightarrow 3\,CO_2(g) + 4\,H_2O(g)$$

continued on next page

b. Every mole of propane requires 5 mol of oxygen and produces 3 mol of carbon dioxide.

c. ___ $C_8H_{18}(l)$ + ___ $O_2(g)$ → ___ $CO_2(g)$ + ___ $H_2O(g)$

↓ Add a coefficient to balance the carbon atoms.

__1__ $C_8H_{18}(l)$ + ___ $O_2(g)$ → __8__ $CO_2(g)$ + ___ $H_2O(g)$

↓ Add a coefficient to balance the hydrogen atoms.

__1__ $C_8H_{18}(l)$ + ___ $O_2(g)$ → __8__ $CO_2(g)$ + __9__ $H_2O(g)$

↓ Add a coefficient to balance the oxygen atoms.

__1__ $C_8H_{18}(l)$ + __12.5__ $O_2(g)$ → __8__ $CO_2(g)$ + __9__ $H_2O(g)$

↓ Multiply all coefficients by 2.

__2__ $C_8H_{18}(l)$ + __25__ $O_2(g)$ → __16__ $CO_2(g)$ + __18__ $H_2O(g)$

The balanced chemical equation is

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$$

d. Every mole of octane requires 12.5 mol of oxygen and produces 8 mol of carbon dioxide.

e. The combustion of octane uses more oxygen and produces more carbon dioxide per mole of fuel.

f. Octane is a larger molecule with a longer carbon chain than propane and more covalent bonds in itself and in the products formed. Since the number of bonds is greater, it is reasonable to expect more energy to be released from the combustion of 1 mol of octane than 1 mol of propane.

Practice

46. Write balanced chemical equations for each reaction.

a. the combustion of pentane

b. the combustion of 2-pentene

c. the combustion of 2,2-dimethylheptane (**Hint:** Use a condensed structural diagram.)

d. the combustion of glucose, $C_6H_{12}O_6(s)$

e. the combustion of sucrose, $C_{12}H_{22}O_{11}(s)$

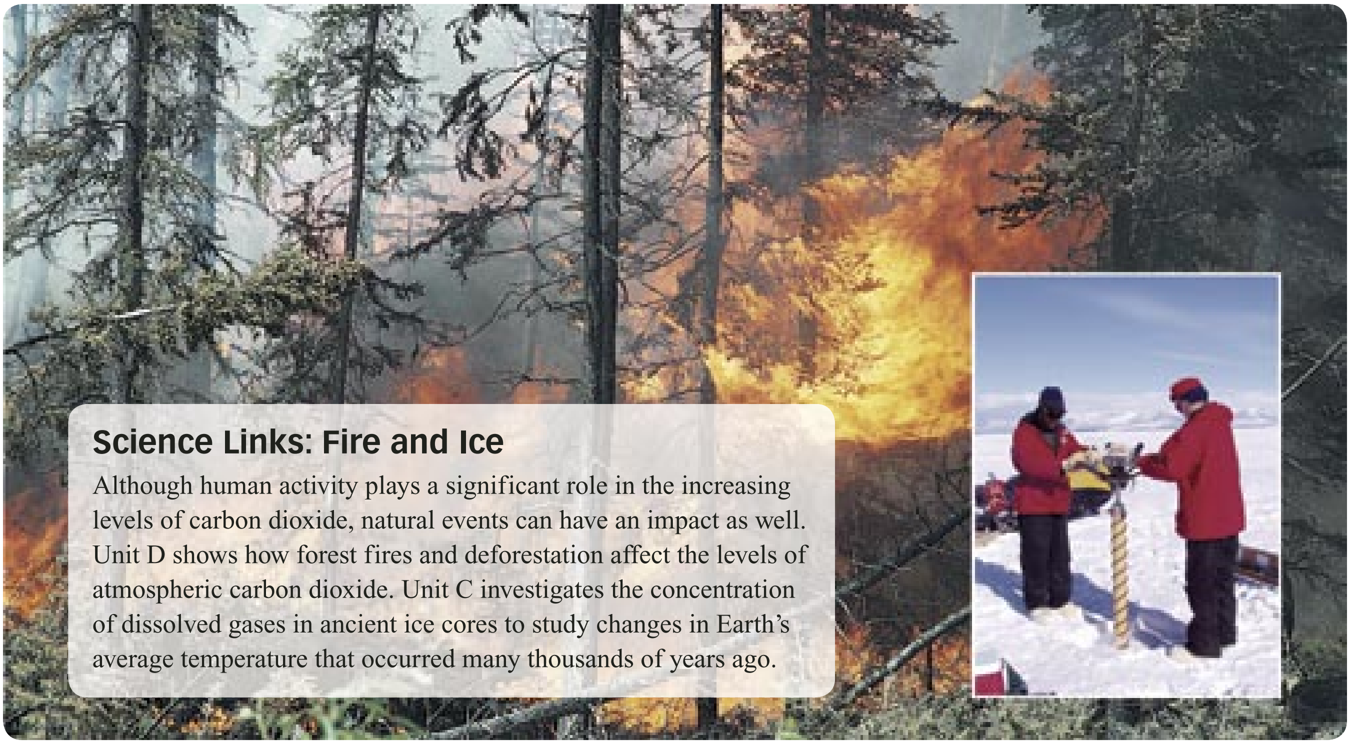
47. Carbon monoxide gas, CO(g), can reach hazardous levels if a vehicle is left to idle inside a garage. This occurs because hydrocarbons do not completely combust. Write a balanced chemical equation for the incomplete combustion of octane that produces carbon monoxide and water vapour.

The Environmental Impact of Burning Hydrocarbons

It is a fact that the combustion of hydrocarbons by humans has increased significantly in the last 200 years. Out of the exhaust of a vehicle you can usually see the water vapour produced by combustion. Even though you cannot see the carbon dioxide, it should not be surprising that the concentration of carbon dioxide in the atmosphere has increased.

Figure A3.20: It is the condensed water vapour in the exhaust from a vehicle that makes it visible.

Recall from previous science courses that carbon dioxide is a molecule that has unique properties. When it is present in the atmosphere, it helps trap heat near Earth's surface, contributing to the greenhouse effect. Many scientists believe that the increased levels of carbon dioxide are enhancing the natural greenhouse effect, warming Earth to the point that the average global temperature is rising. Evidence is mounting that increasing levels of carbon dioxide will eventually result in global climate change.



Science Links: Fire and Ice

Although human activity plays a significant role in the increasing levels of carbon dioxide, natural events can have an impact as well. Unit D shows how forest fires and deforestation affect the levels of atmospheric carbon dioxide. Unit C investigates the concentration of dissolved gases in ancient ice cores to study changes in Earth's average temperature that occurred many thousands of years ago.

Try This Activity

Voluntarily Reducing Hydrocarbon Consumption

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

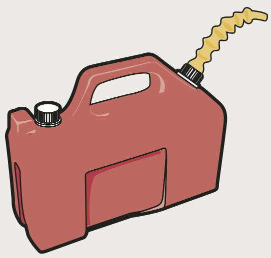
Purpose

You will apply the chemistry you covered earlier in this chapter to investigate the impact of voluntary reduction in the use of gasoline.

Background

Gasoline is a complex mixture of over 500 hydrocarbons. For the purpose of this activity, you will assume that gasoline only consists of iso-octane (2,2,4-trimethylpentane). Iso-octane is a major component of gasoline.

Analysis



1. Write a balanced chemical equation for the combustion of iso-octane.
2. The average car uses 28.0 kg of gasoline every week. Assuming that gasoline is made up of only iso-octane, calculate the number of moles of octane present in one week's worth of gas.
3. Using the balanced chemical equation, determine the number of moles of carbon dioxide released into the atmosphere after the combustion of 28.0 kg of gasoline.
4. There are 52 weeks in a year.
   a. Calculate the number of moles of carbon dioxide a typical car would release into the atmosphere each year.
   b. Calculate the mass (in grams) of carbon dioxide a typical car would release into the atmosphere in one year.
   c. If 1000 kg = 1 t, how many tonnes of carbon dioxide would a car release into the atmosphere in one year?
5. A small city may have as many as 70 000 cars on the road. Calculate the number of tonnes of carbon dioxide all the cars in the small city would release into the atmosphere each year.
6. Suppose the citizens of the small city described in question 5 voluntarily agreed to reduce their consumption of gasoline by 10% for one year.
   a. Calculate the number of tonnes of carbon dioxide this would prevent from entering the atmosphere.
   b. Describe the benefits that this pledge could have on the economic, social, and environmental aspects of the city.
   c. Identify why it might be difficult for some people in the city to purchase less gasoline.

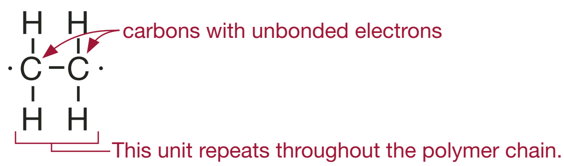
From Hydrocarbons to Polymers

Many of the products you buy result from changing hydrocarbons chemically. Products made from plastics, for example, are often made up of long carbon chains formed by joining many short, unsaturated hydrocarbon molecules.

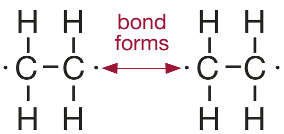
Creating Polyethylene

First, start with an ethene molecule.

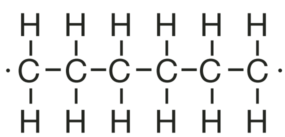
Carbons have unbonded electrons and look to bond with something else.



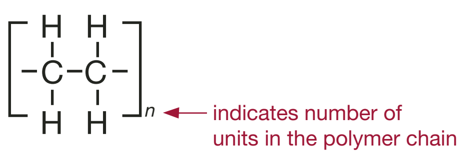
Another "broken" ethene molecule comes and forms a bond.



Many "broken" ethene molecules join together to make very long chains called polyethylene.



This results in the molecular formula of polyethylene.



polymerization: a reaction where many short hydrocarbon molecules join together to form very long hydrocarbon chains

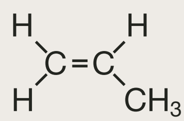
polymer: a large hydrocarbon molecule formed by a polymerization reaction

The process of joining many short, unsaturated hydrocarbon molecules is called **polymerization**. The resulting plastic is called a **polymer** (*poly* means "many," *mer* means "units"). The plastic in the preceding example is called polyethylene. It is given this name because it is created by joining many ethene molecules together. Polyethylene is the soft plastic used to make many products, including plastic bottles, plastic bags, and many toys.

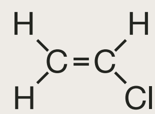
Practice

48. For each starting compound, determine the complete structural diagrams for both the repeating polymer unit and a segment of the resulting polymer chain. Use the reaction for polyethylene as a guide.

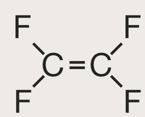
a. This is the starting compound used to make polypropylene. Polypropylene is used to make indoor-outdoor carpeting and bottles.



b. This starting compound is used to make polyvinylchloride (PVC). Plastic wrap, synthetic leather, and garden hoses are all made with PVC.



c. This starting compound is used to make polytetrafluoroethylene, also known as Teflon. Teflon is used for non-stick coatings on frying pans, cooking utensils, and electrical insulation.



Exploring Polymers

There are many different polymers, each with their own unique properties and, therefore, different uses. In the "Making an Organic Compound" activity on page 107, you made a polymer and linked its properties to possible applications. The matching of a polymer's characteristics to a useful application is done in industry as well.

The properties of polymers are a result of their chemical structure. Longer polymer chains will have different properties than shorter polymer chains. Polymers with branches will have different properties than polymers without branches. Even mixtures of polymers have different properties. The development of new types of polymers to produce plastics with unique properties is extensive.

Science Links: Helmet Design

In Unit B you will investigate helmets by designing and testing a helmet of your own design. Polymers will play a large role in this work because some types are light, hard, and make an ideal outer shell; others are soft and provide padding for the inner liner.

The Environmental Impact of Polymers

People use polymers every day. Polymers like rubbers and plastics for example, are often used either as materials for products or as a coating to protect products from other compounds in the environment. They are stable substances, which means they do not react readily with compounds they are exposed to on a daily basis.

The greatest problem associated with polymers is that they take a long time to decompose or degrade. Industry has become very good at using natural resources to produce goods that suit people's needs, but it is difficult for natural processes to return these consumer products back to Earth where they can be used again. Carbon atoms become locked in polymers for hundreds of years because polymers are resistant to natural processes that decompose or break down matter. As a result, society is facing problems with the accumulation of discarded polymers.

Countries around the world have developed many different practices to deal with the accumulation of disposed plastics. One option is to bury polymers underground in the hopes that someday they will decompose. Other countries have decided to burn disposed plastics in order to release the carbon into the air as carbon dioxide. In some places, there are recycling programs for polymers so they can be reused in their locked form. Other communities have even decided to ban the use of disposable, plastic grocery bags.

In Alberta, there is a province-wide goal to reduce the amount of polymers and other materials sent to landfills. In 2005, approximately 800 kg of municipal solid waste for every person living in the province was sent to landfills. The goal is to reduce this average to 500 kg per person by 2010.

One way that every Albertan can contribute to the goal of waste reduction is to apply the three Rs: Reduce, Re-use, and Recycle. Here are some specific things that you can do to reduce the amount of polymer waste that you produce.

Reduce

Buy products that do not have excessive packaging. Try to look for a similar product that is available with no packaging or re-usable containers.

Vote with your wallet—buy products from retailers and manufacturers who are making an effort to use less packaging.

Take re-usable shopping bags to the store so you don't need disposable bags.

Re-use

Margarine containers, ice cream pails, and other containers could be re-used around your home as storage bins.

Toys, sporting goods, and other plastic items can be used by someone else instead of being thrown away. You can take them to the donation centre for a local charity, give them to a neighbour, or have a yard sale.

Recycle

Choose materials that can be recycled or that are made from recycled materials, such as glass and metal. Unfortunately, less than 5% of plastics are currently recycled. Because there are so many different types of plastics, these plastic items have to be sorted and separated before the plastic can be reprocessed. However, the plastics that can be recycled should be diverted away from garbage cans.

As you'll learn in Unit D, an even more powerful approach to solving these problems is to **rethink** many of your basic assumptions. Is it really necessary for our entire society to be so focused on the consumption of goods?

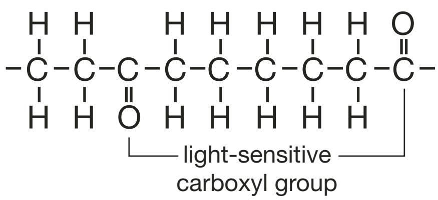
Practice

Beverages in aluminium cans are sometimes sold in sets of six that are held together by a plastic collar.

This form of plastic packaging is not only a litter problem, but birds and small animals have snared themselves in the plastic rings. Several solutions have been proposed to deal with this problem.

Option 1: Consumers should cut each of the plastic rings with scissors before discarding this form of packaging.

Option 2: Manufacturers should make this form of packaging from biodegradable polyethylene. This polymer has light-sensitive carboxyl groups inserted into the polymer chain.



When this polymer is exposed to light, the long chains break at each carboxyl group. The remaining shorter sections can then be effectively broken down by natural processes.

49. Explain why Option 1 does not address all of the environmental concerns regarding this form of packaging.
50. Although two options were outlined in the information box, there are other approaches to solving the environmental problems associated with this form of packaging. Describe two additional options that could be used. In each case, list the positive and negative aspects of your proposal.
51. Reread your answers to questions 42, 49, and 50. Given what you learned about the environmental impact of hydrocarbons in this lesson, what recommendations would you make regarding the use of petrochemicals?

3.4 Summary

Hydrocarbons produced from the fractional distillation of petroleum are used either as fuels in combustion reactions or as starting compounds to produce polymers. Hydrocarbon combustion is a reaction with oxygen that produces carbon dioxide and water vapour. As the hydrocarbon chain gets longer, larger amounts of oxygen are required, more carbon dioxide and water are produced, and more energy is released. Since carbon dioxide is a greenhouse gas, the combustion of hydrocarbons has raised concerns about the links to global warming and climate change.

A polymer is a very long carbon chain produced by linking together smaller units in a polymerization reaction. The structure of the polymer chain determines the properties of the molecule, which, in turn, indicates the particular applications that are best suited to that particular polymer. The fact that polymers tend to be quite resilient compounds means that products made from these materials decompose very slowly and become a disposal problem.

3.4 Questions

Knowledge

1. Define the following terms.
   - **a.** hydrocarbon combustion
   - **b.** polymerization
   - **c.** polymer
2. Describe the steps that occur during a hydrocarbon combustion reaction.
3. Describe the steps that occur during a polymerization reaction.

Applying Concepts

4. Write the balanced chemical equations for the combustion of each hydrocarbon listed.
   - **a.** hexane
   - **b.** 2-methylhexane
5. Refer to question 4 as you answer the following.
   - **a.** Which hydrocarbon molecule requires more oxygen to combust? Provide a reason to support your choice.
   - **b.** Which hydrocarbon molecule produces more carbon dioxide and water vapour? Support your choice.
   - **c.** Which hydrocarbon molecule releases more energy? Provide a reason to support your choice.
6. Show the structures of the polymers that will be produced with the polymerization of each of the following compounds: 1-butene and 2-butene.
7. Explain why each country should use hydrocarbons wisely.

Chapter 3 Review Questions

Knowledge

1. Complete the following table.

Name of Compound	Chemical Formula	Condensed Structural Diagram	Alkane, Alkene, or Alkyne
3,4-diethylhexane			
3-methyl-4-propyloctane			
2,2-dimethylbutane			
	C_5H_8(l) (unbranched)		
3-ethyl-1-pentene			
3-hexene			
3-octyne			
2-ethyl-4-methyl-1-pentene			
	C_7H_{14}(l) (unbranched)		

2. Compare and contrast a continuous-chain alkane with a branched alkane.
3. **a.** Draw complete structural diagrams for 2-methyl-2-butene and 3-methyl-2-pentene.
   b. Show how the name describes the features and structure of these two molecules.
   c. Which molecule would have the higher boiling and melting point?
4. Draw a diagram of a fractional distillation column. Label the following items on your diagram.
   - furnace
   - residue
   - fractions with higher boiling points
   - fractions with lower boiling points
   - long-chained hydrocarbons
   - small-chained hydrocarbons
   - gaseous hydrocarbons
5. Outline the changes that occur to the molecules of petroleum that undergo the process of fractional distillation.

Applying Concepts

6. The following compounds are named incorrectly. Draw a complete structural diagram of the compound, and name it correctly.
   a. 1-methylbutane
   b. 2-ethylpentane
   c. 2-ethyl-2-propylhexane
   d. 4-butyl-2-methylhexane
   e. 2-propyl-butane
   f. 3-ethyl-2-propyl-5-hexyne
   g. 2-ethyl-3,4-dimethyl-3-octene

7. Explain why the compound 2-methyl-1-propyne cannot exist.

8. Write the balanced chemical equation for the following reactions.

a. the combustion of 2-pentyne
b. the combustion of 5,5-diethyl-2,2-dimethyloctane
c. the hydrogenation of 2-butene
d. the hydrogenation on 2-methyl-3-hexyne
e. the cracking of octane to produce two-carbon and three-carbon molecules
f. the cracking of hexene into two three-carbon molecules

9. Draw a series of structural diagrams to illustrate the polymerization of each of these starter compounds.

a. ethene
b. propene

Use the following information to answer questions 10 and 11.

Each of these foods could be used as a dessert in a typical "brown bag" lunch.

The following labels describe the contents of the granola bar, the two chocolate cookies with vanilla filling, and a small rolled cake with filling.

NUTRITION FACTS GRANOLA BAR per serving (1 bar, 33 g):		**NUTRITION FACTS FOR COOKIES** per serving (2 cookies, 28 g)		**NUTRITION FACTS FOR A ROLLED CAKE WITH FILLING** per serving (1 cake, 28 g)	
Energy	140 cal(587 kJ)	Energy	130 cal(545 kJ)	Energy/	119 cal(499 kJ)
Total fat	5 g	Total fat	5 g	Total fat	5.3 g
Saturated fat	1 g	Saturated fat	1 g	Saturated fat	1.2 g
Trans fat	0 g	Trans fat	1.5 g	Trans fat	1.5 g
Cholesterol	0 mg	Cholesterol	0 mg	Cholesterol	3.5 mg

10. Identify which of these foods would be the healthiest choice if you want to reduce the risks associated with heart disease? Concisely support your answer.

11. One of the ingredients listed on these labels is trans fat.

a. Describe the process of how industrially produced trans fat is made.
b. Describe the similarities in terms of structure and in terms of properties between saturated fat and trans fat.
c. What recommendation do most nutritionists make in terms of the amount of trans fat you should have in your diet?

Case Study: The Life Cycle of a 2-L Pop Bottle

12. The starting point in the life cycle of a 2-L pop bottle is petroleum. During the refining processes, the naptha fraction from a fractional distillation tower is passed on to another pressurized tower where the molecules from the naptha fraction are broken down into smaller molecules. Further fractional distillation is used to produce ethene.

a. Sketch a labelled diagram illustrating the production of ethene from petroleum.

b. Sketch a diagram of an ethene molecule, and write its molecular formula.

13. The ethene is shipped to a manufacturing facility where it is polymerized into polyethylene terephthalate, which is often shortened to PET or PETE. This is the material used to make 2-L pop bottles. The first step in making the bottles involves heating PETE and pouring it into a mould to make a small, plastic tube called a parison or a preform.

a. Use the Internet to determine how a parison or preform is made into a 2-L pop bottle.

b. How do preforms help reduce the costs of shipping empty bottles to the factories where the beverages are made?

1 PETE

Every product made from PETE is identified with the code on the left. This code is used to identify the type of plastic so recyclers can properly sort the plastics before the plastics are reclaimed and made into the next generation of products.

There are, in fact, a total of six plastics that are commonly used in packaging, each identified with its own plastic recyling code. Each of these plastics has properties that determine the type of packaging applications to which it is best suited.

14. Copy the following table into your notebook. Add as many rows as necessary.

Plastic Recycling Code	Full Name of Plastic	Properties	Packaging Applications	Products Made from Recycling This Plastic
1 PETE	polyethylene terephthalate			

a. Use the Internet to collect information to complete the first row of the chart for PETE. Repeat this process to complete the five other rows with information for each of the other types of common plastic packaging.

b. Look around your home and find specific products that are packaged in each of the six types of plastic packaging. Look on the bottom of plastic containers for the plastic recycle code that will be stamped on the bottom. Add your results to the second last column.

15. Although it is possible to recycle most types of plastics, in reality only items marked with recycling codes 1 and 2 are actively recycled. Since there is no market for plastic packages marked with numbers 3 through 6, these items end up in landfills. This is part of the reason why less than 5% of all plastics are recycled, compared to 34% for paper, 22% for glass, and 30% for metals. In addition, these three materials can be recycled into similar products many times over, while plastics usually have only a single re-use.

a. Why is it especially important for recycled plastics to be made into items that will have a relatively long, useful life?

b. In the ecological slogan, “Reduce, Re-use, Recycle,” it is the last word that tends to get the most attention. Explain why reducing the consumption of plastic is the most effective way to help the environment in the long term. You will explore these ideas in more detail in Unit D.

Unit A Review Questions

1. Which term—*solution*, *solute*, or *solvent*—best matches each of the following substances?
   - **a.** sucrose (table sugar)
   - **b.** water
   - **c.** sports drink
2. Use the following list to answer questions 2.a. and 2.b.
   - I. hydrogen peroxide, $H_2O_2(aq)$
   - II. hydrochloric acid, $HCl(aq)$
   - III. salt water, $NaCl(aq)$
   - IV. ammonia, $NH_3(aq)$

   - **a.** The two electrolyte solutions are ___________ and ___________.
   - **b.** The two non-electrolyte solutions are ___________ and ___________.
3. At the particle level, describe how water molecules act to change the structure of the crystals of a solid ionic compound to form an electrolytic solution.
4. Use a simple, labelled diagram to highlight the main features of each of the following types of solutions.
   - **a.** an electrolytic solution
   - **b.** a non-electrolytic solution
   - **c.** a concentrated solution
   - **d.** a dilute solution
5. Read the following descriptions of four chemical reactions.

   Reaction A: Copper sheets oxidize and lose their shine.
   Reaction B: Hydrogen ions in solution react to form a molecule of hydrogen gas.
   Reaction C: Iron metal rusts to form iron(II) oxide.
   Reaction D: A nickel(II) ion is electroplated at the cathode of an electrolytic cell.

   Complete the following chart for each of the reactions.

Reaction	Half-Reaction for the First Element Mentioned	Oxidation or Reduction	Number of Electrons Gained or Lost
A			
B			
C			
D			

6. In this unit you made an extensive use of the activity series for metals and metal ions. Summarize the uses of this activity series.

7. Examine the following balanced chemical equation:

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s)$$

a. Identify the chemical substance being oxidized.
b. Identify the chemical substance being reduced.
c. Identify any spectators.
d. Determine the number of electrons gained by each atom or ion.
e. Determine the number of electrons lost by each atom or ion.

8. Examine the following balanced chemical equation:

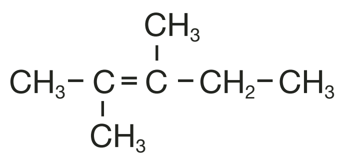
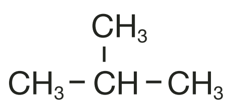
$$2\ Ag(s) + H_2SO_4(l) \rightarrow Ag_2SO_4(aq) + H_2(g)$$

a. Identify the chemical substance being oxidized.
b. Identify the chemical substance being reduced.
c. Identify any spectators.
d. Determine the number of electrons gained by each atom or ion.
e. Determine the number of electrons lost by each atom or ion.

9. Determine whether the following species could undergo oxidation, reduction, or both.

a. a hydrogen ion, $H^+(aq)$
b. a gold ion, $Au^+(aq)$
c. a silver ion, $Ag^+(aq)$

10. Complete the following table.

Name of Compound	Chemical Formula	Condensed Structural Diagram	Alkane, Alkene, or Alkyne	Saturated or Unsaturated
2,2-dimethylpentane				
4-propyloctane				
3-octene				
	$C_7H_{12}(l)$			
2-ethyl-1-hexene				
	$CH_4(g)$			
				
				

11. Draw the condensed structural diagram for 4,4-diethyl-2-hexyne. Describe the process used to draw the diagram.

12. Complete each of the following calculations by showing all of your steps.

a. Calculate the molar concentration of a solution prepared by adding 150 mL of water to 25.4 g of silver nitrate, $AgNO_3(aq)$.

b. Calculate the number of moles of solute dissolved in 0.050 L of a 0.392-mol/L silver nitrate solution, $AgNO_3(aq)$.

c. The maximum concentration of lead in drinking water is 0.010 ppm. A 4.00-kg sample of contaminated well water was found to have twice this concentration of lead. Calculate the mass of the lead dissolved in the water.

d. In addition to copper, trace amounts of other metals are often recovered at copper mines. The concentration of silver found in the ore of a copper mine is 58 ppm. Calculate the mass of ore that would have to be mined to yield 1.00 kg of silver.

13. Ammonia is a very useful reagent for many reactions. One way of making ammonia is to react nitrogen gas with hydrogen gas.

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

You have 20.0 mol of nitrogen.

a. How many moles of ammonia could you make?

b. How many moles of hydrogen gas would you require to react with the nitrogen?

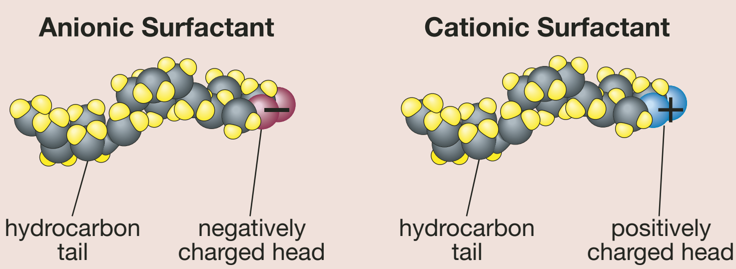
Use the following information to answer questions 14 to 18.

Case Study: The Chemistry of Hair Conditioners

When you rinse shampoo out of your hair, you also remove oils that act to protect your hair. A hair conditioner replaces these oils with a protective coating. Although some hair conditioners are applied and then left on wet hair, most conditioners are also rinsed out of the hair. How can the protective coating be left on the hair when the other ingredients of the conditioner are rinsed away?

Part of the answer to this question is found in the structure of hair itself. The main protein in hair is keratin. An interesting property of the keratin in hair is that its molecular structure tends to have a high percentage of negative charges on its outer surface. This means that the outer surface of each shaft of hair tends to have a slightly negative charge, even after it's been washed with shampoo.

This is why the manufacturers of hair conditioners use substances in their products called surfactants—short for "surface active agents."



Surfactants work because one end of these long molecules consists of a tail of hydrocarbons that can attach itself to oily substances. At the other end of these molecules is a head that can be ionized. If the head of the surfactant carries a negative charge, it is called anionic. If the head carries a positive charge, the surfactant is called cationic.

As the following example indicates, conditioners usually consist of a group of cationic surfactants mixed with other ingredients in a water-based solution.

INGREDIENTS IN BRAND Y HAIR CONDITIONER

Ingredient	Volume (mL)	Function
water	465.5	acts to dissolve the other ingredients
cyclomethicone and dimethiconol solution	10.5	an oil soluble blend of compounds that holds silicone in solution until it can be released onto the hair
distearyldiammonium chloride solution	7.0	cationic surfactant—helps second ingredient attach to hair
cetyl alcohol solution	6.0	ingredients work to keep the oil-based and water-based parts of the solution from separating
sorbitan oleate solution	5.0	
stearyl alcohol solution	4.0	
polysorbate-85 solution	2.0	
Total	500.0	

The cationic surfactants play a key role in hair conditioners. The charged head of the surfactant is attracted to the hair while the long tail helps carry the oil-based ingredients that give the hair its shine.

14. Identify the ingredient in the hair conditioner that could be classified as the solvent.

15. Identify an ingredient in the hair conditioner that could be classified as a solute.

16. Explain how neutral water molecules could be attracted to the charged head of a cationic surfactant. Sketch and label a diagram to support your answer.

17. As explained in the information, the outer surface of a hair has a slight negative charge.

- **a.** Explain the significance of the charge along the length of the hair to the action of the cationic surfactants in bringing a new protective coating to a hair.
- **b.** Explain why conditioned hair is less likely to stand on end and "fly away."

18. Calculate the percent by volume concentration of the following ingredients in the hair conditioner.

- **a.** distearyldiammonium chloride
- **b.** cetyl alcohol
- **c.** polysorbate-85

19. Balance each of the following reactions.

- **a.** $SnCl_2(aq) + Al(s) \rightarrow AlCl_3(aq) + Sn(s)$
- **b.** $Au(NO_3)_3(aq) + Ag(s) \rightarrow AgNO_3(aq) + Au(s)$
- **c.** $HNO_3(aq) + Cu(s) \rightarrow Cu(NO_3)_2(aq) + H_2(g)$
- **d.** $Zn(s) + H_2SO_4(aq) \rightarrow H_2(g) + ZnSO_4(aq)$

20. If you react chlorine gas with sodium metal, you can produce sodium chloride.

$$Cl_2(g) + 2\ Na(s) \rightarrow 2\ NaCl(s)$$

- **a.** State the chemical substance that is being oxidized.
- **b.** State the chemical substance that is being reduced.
- **c.** Determine the number of electrons transferred in the reaction.
- **d.** If 75.0 mol of sodium reacted with a sufficient amount of chlorine gas, how many moles of chlorine gas will be required?

21. A student performed an experiment on platinum metal and collected the following data:

$Pt(s) + Ag^{+}(aq) \rightarrow$ no reaction

$Pt(s) + Fe^{2+}(aq) \rightarrow$ no reaction

According to the data, where should solid platinum, Pt(s), and its ion, $Pt^{2+}(aq)$, appear in the activity series for metals and metal ions?

22. Use the activity series to predict whether each combination of reactants will result in a spontaneous reaction.

a. copper metal and chromium(II) ion
b. zinc metal and hydrochloric acid
c. silver metal and nitric acid
d. silver ion and nickel metal

23. List some of the methods used to prevent the corrosion of metals. Briefly explain how these methods prevent the oxidation of the metal being protected.

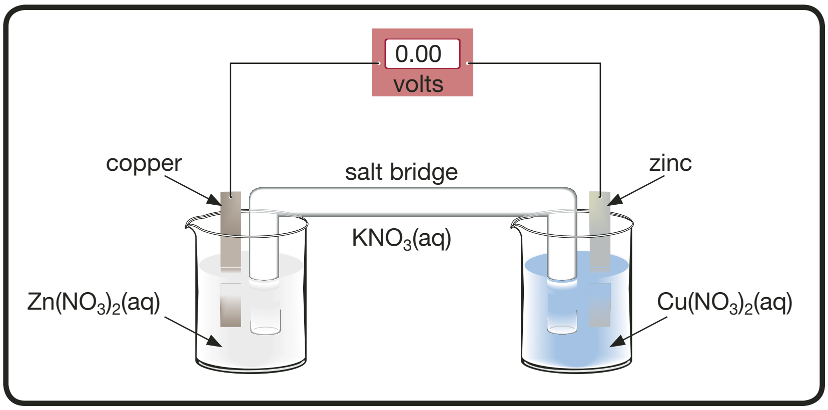
24. An automobile manufacturer plans to build a corrosion-proof body for a car. The car's body will be made entirely from plastic. Will the use of plastic in the car's body prevent damage from corrosion? Suggest advantages and disadvantages of this design.

25. The following cell notation describes a voltaic cell:

$Mg(s) \mid Mg^{2+}(aq) \mid\mid Ag^{+}(aq) \mid Ag(s)$

Draw a diagram of this voltaic cell. Label the anode, cathode, voltmeter, and salt bridge. Also label the direction of the flow of electrons, anions, and cations within the cell. Assume that potassium nitrate, $KNO_3(aq)$, is used in the salt bridge.

26. The following diagram shows a voltaic cell that a student set up in a lab.



Observations from this cell:

- The voltage output is zero.
- The solution of $Cu(NO_3)_2(aq)$ is becoming less blue as time goes by.
- The mass of the zinc electrode has increased since the experiment began.

a. Suggest a reason for the change in the mass of the zinc electrode in the cell.
b. Suggest a reason why the cell was not able to produce a voltage.

27. Locate the video clip called "Career Profile: Ceramic Artist" on the Science 20 Textbook CD. This segment describes how chemistry is used by a potter to create works of art. Watch this video, and then answer the following questions.

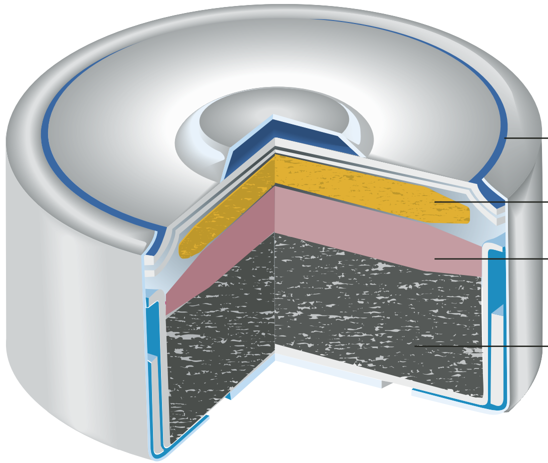
a. Describe the chemical composition of the clay used by a ceramic artist.

b. List the compounds used to give colour to a glaze.

c. Consider the list that you generated in 27.b. Identify the category of matter that applies to all the compounds on your list.

d. Describe how the compounds used in glazes are prepared to be applied to the clay body.

28. Some specialized electrical devices, such as pacemakers, require a miniature cell that can maintain a constant voltage throughout its useful lifetime. In these devices, silver-zinc button cells are often used.



Although the chemical reactions within these cells are complex, they can still be categorized as oxidation and reduction.

Oxidation and Reduction in a Miniature Silver-Zinc Button Cell
Reaction 1: $Ag_2O(s) + H_2O(l) + 2e^- \rightarrow 2\ Ag(s) + 2\ OH^-(aq)$
Reaction 2: $Zn(s) + 2\ OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$

a. Classify Reaction 1 as being either an oxidation or a reduction reaction. Support your answer.

b. Is the powdered Ag_2O(s) in contact with the steel bottom acting as the anode or the cathode in this cell?

c. Classify Reaction 2 as being either an oxidation or a reduction reaction. Support your answer.

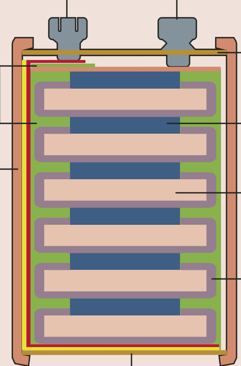
d. Is the powdered zinc, Zn(s), in contact with the steel top acting as the anode or the cathode in this cell?

e. Would electrons leave the top of this cell and flow through an external circuit or would they leave the bottom of this cell?

Use the following information to answer questions 29 to 31.

Although a single zinc chloride cell can provide 1.5 V, smoke detectors require a higher voltage. For applications such as this, the six cells are combined in a single package to provide 9.0 V of output. Refer to the cross sectional diagram given.

Each cell within this device adds energy to the current of electrons that flows to the circuitry of the smoke detector. The chemical reactions that occur within each cell are summarized as follows:



Oxidation and Reduction Within Each Cell
Oxidation Reaction: $Zn(s) \rightarrow Zn^{2+} + 2e^-$
Reduction Reaction: $2\ NH_4^+(aq) + 2\ MnO_2(s) + 2e^- \rightarrow Mn_2O_3(s) + 2\ NH_3(g) + H_2O(l)$

29. Identify the proper name for the type of device shown in the illustration.

30. Consider the oxidation reaction that occurs within each cell.

a. Use this reaction to determine whether the zinc electrode is acting as the anode or the cathode.
b. Carefully examine the cross sectional diagram. Explain how this diagram verifies your answer to question 29.a.

31. Consider the reduction reaction that occurs within each cell.

a. Explain why both the manganese and the ammonium are considered to be reduced in this reaction.

b. If the reduction half-reaction for the manganese(IV) oxide were to be placed in the activity series for metals and metal ions, would it appear above or below the reduction half-reaction for zinc? Explain.

32. Draw an electrolytic cell that would be able to plate nickel onto an iron drill bit. In your diagram include the following:

- electrolyte solution and label its contents
- anode
- cathode
- power source
- direction for electron flow

33. The compound 3-ethyl-3-methyl-2-pentyne cannot exist. Use the name of the compound to draw a condensed structural diagram that will explain why this compound could never exist.

34. **a.** Write a balanced chemical equation to show one possibility in the cracking of decane.
b. Properly name the products of your cracking reaction.

35. Write a balanced chemical equation to describe each reaction.

a. the combustion of butane
b. the combustion of 2,2-dimethylhexane
c. the hydrogenation of 3-hexene

36. Draw a series of diagrams to illustrate the polymerization of 2-butene.

37. Many nutritionists recommend sardines as a healthy food. Although this food is a good source of many important nutrients, it is not a perfect food due to the presence of some less desirable substances.

a. Saturated and unsaturated fats are listed in the nutrition facts. Explain what these terms mean in terms of the carbon chains that make up these substances.

b. Identify at least two items listed in the nutrition facts that indicate that this is a healthy food choice.

c. Identify at least two items listed in the nutrition facts that are less desirable because they are not associated with good health.