Chapter 5.9 - Rev.

5.9

Polyatomic Compounds

You have investigated such compounds as calcium carbonate, sodium bicarbonate, calcium hydroxide, and copper(II) sulfate. These names do not seem to fit the naming pattern we have been examining so far. What are these compounds?

Such compounds are pure substances that involve combinations of metals with polyatomic ions (**Table 1**). **Polyatomic ions** are groups of atoms that tend to stay together and carry an overall ionic charge. An example of a polyatomic ion is the nitrate ion (**Figure 1**). When a compound containing this ion is dissolved in water, the positive metal ion and the nitrate ion separate from each other, but the nitrate ion itself stays together as a unit surrounded by water molecules.

Table 1 Common Polyatomic Compounds

Compound	Formula	Use or source
calcium carbonate	$CaCO_3$	chalk and building materials
magnesium hydroxide	$Mg(OH)_2$	stomach antacids
sulfuric acid	H_2SO_4	car battery acid
sodium hypochlorite	$NaClO$	clothing bleach
copper(II) sulfate	$CuSO_4$	fungicide
sodium carbonate	Na_2CO_3	laundry detergents
ammonium nitrate	NH_4NO_3	fertilizer

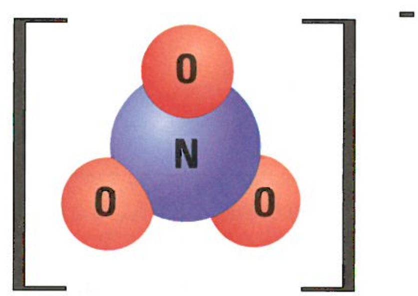


Figure 1
The nitrate ion contains one nitrogen atom tightly bonded to three oxygen atoms. The overall ionic charge on the ion is 1−.

Writing Formulas for Polyatomic Compounds

The ionic charges of polyatomic ions make it possible for them to form ionic compounds. **Table 2** lists some common polyatomic ions and their ionic charges.

When a polyatomic ion such as nitrate or sulfate combines with other elements, we follow the same rules for writing formulas that we learned in section 5.8, just as if it were an individual nonmetal ion. Consider the following example.

What is the formula for the ionic compound formed by sodium and a sulfate ion?

Rule 1: Write the symbols of the metal and of the polyatomic group.

$Na \quad SO_4$

Table 2 Common Polyatomic Ions and Their Ionic Charges

Name of polyatomic ion	Ion formula	Ionic charge
nitrate	NO_3^-	1−
hydroxide	OH^-	1−
bicarbonate (hydrogen carbonate)	HCO_3^-	1−
chlorate	ClO_3^-	1−
carbonate	CO_3^{2-}	2−
sulfate	SO_4^{2-}	2−
phosphate	PO_4^{3-}	3−

Did You Know?

Acid spills in the laboratory can be safely neutralized by sprinkling solid sodium bicarbonate ($NaHCO_3$, or baking soda) on them. The bicarbonate ion (HCO_3^-) combines with the acid to form harmless carbon dioxide gas and water.

Rule 2: Write the ionic charges.

1+ 2–
Na SO_4

Rule 3: Choose the number of ions to balance the charge.

Two Na^+ ions will balance the charge of one SO_4^{2-} ion.

Rule 4: Write the formula using subscripts.

The formula is Na_2SO_4.
The total ionic charge is $2(1+) + (2-) = 0$

Did You Know?

Calcium phosphate is the compound in eggshells that is responsible for the shells' hardness. Unfortunately, it also makes eggshells brittle, which was a problem for Humpty Dumpty. What is the formula for calcium phosphate?

As an alternative, you can use the "crisscross" rule.

Rule 1: Write the symbols of the metal and of the polyatomic group.

Na SO_4

Crisscross Rule: Write the ionic charges above the symbols and crisscross them.

1+ ╳ 2–
Na SO_4

The formula is Na_2SO_4.
Note that polyatomic ions do not "reduce." For example, the formula Na_2SO_4 cannot be simplified to Na_1SO_2 because the SO_4 is a group.

Naming Polyatomic Compounds

The name of the ionic compound in the previous example is simply sodium sulfate. This stable compound is shown in **Figure 2**. The names for polyatomic compounds are relatively straightforward. The name is simply a combination of the name of the metal and the name of the polyatomic ion.

For example, the compound formed by a carbonate ion (CO_3^{2-}) and a potassium ion (K^+) has the formula K_2CO_3 and its name is potassium carbonate. You will note that the positive part of the compound is always written first in both the formula and the name. Ammonium (NH_4^+) and nitrate (NO_3^-) combine to form ammonium nitrate (NH_4NO_3).

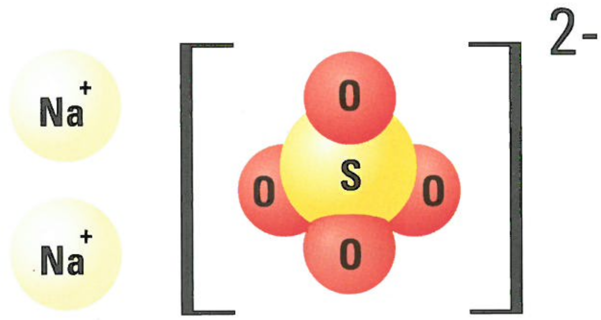


Figure 2
Sodium sulfate is made up of two sodium ions (each with an ionic charge of 1+) combined with a sulfate ion (one sulfur atom tightly bonded to four oxygen atoms, with a total ionic charge of 2-). The overall compound is neutral.

Polyatomic ions make it possible to have an even wider range of ionic compounds, especially when they combine with metals that may have more than one ionic charge.

Consider the following example.

What is the formula of lead(IV) carbonate? Note that lead has two different valences, but the Roman numeral tells you which one to use.

Rule 1: Write the symbols of the metal and of the polyatomic group.

Pb CO_3

Crisscross Rule: Write the ionic charges above the symbols and crisscross them.

4+   2–

Pb ✕ CO_3

The formula is $Pb_2(CO_3)_4$, which must be reduced to $Pb(CO_3)_2$. Note that parentheses are included in the formula to show the number of CO_3 ions in the formula.

Oxyacids

There are many types of polyatomic ions, but one special group should be mentioned. **Oxyacids** are compounds formed when hydrogen combines with polyatomic ions that contain oxygen. The hydrogen has an ionic charge of 1+ in these compounds. **Table 3** describes and names some common oxyacids.

Table 3 Common Oxyacids

Ion name	Ion formula	Ionic charge	Oxyacid formula	Oxyacid name
nitrate	NO_3^-	1–	HNO_3	nitric acid
nitrite	NO_2^-	1–	HNO_2	nitrous acid
chlorate	ClO_3^-	1–	$HClO_3$	chloric acid
carbonate	CO_3^{2-}	2–	H_2CO_3	carbonic acid
sulfate	SO_4^{2-}	2–	H_2SO_4	sulfuric acid
sulfite	SO_3^{2-}	2–	H_2SO_3	sulfurous acid
phosphate	PO_4^{3-}	3–	H_3PO_4	phosphoric acid

Understanding Concepts

1. In your own words, explain what is meant by the term "polyatomic ion." Give two examples.

2. What happens to the ions in the compound sodium nitrate when it dissolves in water?

3. Write the formulas for the following compounds:

(a) sodium phosphate

(b) calcium sulfate

(c) potassium chlorate

(d) aluminum hydroxide

(e) beryllium nitrate

(f) magnesium hydrogen carbonate (magnesium bicarbonate)

(g) nickel carbonate

4. Write the names for the following compounds:

(a) K_2CO_3

(b) Na_2SO_4

(c) $Al(HCO_3)_3$

(d) $AgNO_3$

5. (a) What pattern do you see in the formulas of the oxyacids and the original ionic charge of the polyatomic ion? Explain, with two examples.

(b) Why does this pattern make sense?

6. Why is ammonium nitrate (NH_4NO_3) not written as $N_2H_4O_3$?

7. Some polyatomic ions have a positive charge. The ammonium ion (NH_4^+) is an example. Give the names and formulas of the compounds formed by this ion with:

(a) a chloride ion

(b) a sulfate ion

5.10 Investigation

INQUIRY SKILLS MENU

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

Testing for Ions

What kinds of substances are present in a glass of water? We know that there are molecules of water (H_2O) present, but are there other substances as well? People often say that water from a different area has a different taste. Could there be small amounts of substances dissolved in a water sample from one area that gives it a different composition from another sample of water?

In fact, drinking water does contain many different substances (**Figure 1**). Some are added deliberately during the process of water purification. But many substances in water occur naturally. As rainwater passes through the ground, minerals dissolve into the water. These minerals are ionic compounds that may contain ions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), iron (Fe^{3+}), chloride (Cl^-), nitrate (NO_3^-), or sulfate (SO_4^{2-}).

One method of detecting these ions is to use chemical tests. Such tests can also be used to identify unknown ions. A **positive test** for a substance is one that clearly indicates the substance is present. A positive test for a dissolved ion may produce an insoluble precipitate or it may produce a coloured product. In this investigation, you will use chemical tests to investigate the ions that are dissolved in water.

Question

How can samples of water be tested for the presence of chloride ions (Cl^-), sulfate ions (SO_4^{2-}), and iron ions (Fe^{3+})?

Design

In this investigation you will test solutions containing three known ions with various testing solutions. You will then test some unknown solutions with the same testing solutions and compare your observations to determine which ions are present in the unknown solutions.

(a) Plan a table to record your observations. Write the names of the testing solutions along the top and the names of the known solutions and the codes for the unknown ones on the side.

Figure 1
Water quality technicians test water for dissolved substances.

Materials

- apron
- safety goggles
- testing solutions:
  - silver nitrate solution (0.5% or 0.03 mol/L)
  - barium chloride solution (2% or 0.1 mol/L)
  - potassium thiocyanate solution (1% or 0.1 mol/L)
- sample solutions:
  - potassium chloride solution (3% or 0.4 mol/L)
  - sodium sulfate solution (3% or 0.2 mol/L)
  - iron(III) nitrate solution (3% or 0.1 mol/L)
- unknown solutions:
  - teacher-provided solutions containing one or more ions
  - samples of water from various sources (tap water, bottled waters, etc.)
- labelled microdroppers
- microtrays

Silver nitrate solution is toxic and can stain skin and clothing. Barium chloride and potassium thiocyanate are toxic. Iron (III) nitrate is an irritant. Any spills on the skin, in the eyes, or on clothing should be washed immediately with cold water.

Part 1: Testing Known Solutions

Procedure

1. Put on your apron and safety goggles.

2. Obtain a microdropper containing potassium chloride solution (source of chloride ion) and a second microdropper containing silver nitrate solution.

3. Add one or two drops of the first solution to one of the wells on the microtray. Add one or two drops of the second solution to the same well (**Figure 2**). Record your observations, particularly noting the appearance and colour of both starting materials and any product.

4. Obtain a microdropper containing sodium sulfate solution (source of sulfate ion) and a microdropper containing barium chloride solution. Repeat step 3 in another well on the microtray. Record your observations.

Figure 2

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

5. Obtain a microdropper containing iron(III) nitrate solution (a source of iron(III) ions) and a microdropper containing potassium thiocyanate solution. Repeat step 3 in another well on the microtray. Record your observations.

Part 2: Testing Unknown Solutions

6. Obtain a microdropper containing one of the unknown solutions provided by your teacher. Use the testing solutions in separate microtray cells to determine whether chloride, sulfate, or iron(III) ions are present in the solution. Record your observations.

7. Repeat step 6 for other unknown solutions.

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

Analysis

(b) Make a table to summarize the observations that indicate a positive test for chloride, sulfate, and iron(III) ions. Possible headings could be: *Type of ion, Reagent solution added,* and *Observation for positive test.*

(c) Make a table to summarize your analyses of the unknown solutions.

Understanding Concepts

1. **(a)** Explain what is meant by a positive test for an ion.

(b) Describe two types of changes that demonstrate a positive test.

2. Write chemical formulas for the following substances:

(a) silver nitrate

(b) barium chloride

(c) sodium sulfate

(d) iron(III) nitrate

3. Why do you think chemical tests, similar to the tests used in this investigation, are called qualitative analyses?

4. If a silver nitrate solution is added to a potassium chloride solution and a precipitate forms, what are the names and formulas of the possible products?

Exploring

5. Suppose that you were asked to determine whether an ion was present in a solution and how much ion was present.

(a) Compare the amounts of precipitate that you would expect if you added barium chloride to two solutions that contained different amounts of sulfate ion.

(b) Compare the colour intensity that you would expect if you added potassium thiocyanate to two solutions that contained different amounts of iron(III) ion.

(c) Design an experiment to compare the amount of chloride, sulfate, or iron(III) ion present in a solution. (K4)

SKILLS HANDBOOK: (K4) Creating the Design

Molecular Compounds

Imagine that you find an unlabelled container of solid white crystals in the kitchen. You are sure that the crystals are either salt or sugar. A simple taste test will tell you what the crystals are. But imagine that you find the same crystals in the lab. A taste test is too dangerous, so you dissolve the crystals in water and test for conductivity. If the solution conducts electricity, the compound must contain ions. Salt, or sodium chloride, is an ionic compound. In ionic compounds, metals with one, two, or three electrons in their outer shell lose electrons to nonmetals, which often have five, six, or seven electrons in their outer shell. If the solution does not conduct electricity, it must be a different kind of compound.

Most of the compounds you encounter every day do not contain ions. Rather, they contain neutral groups of atoms called molecules. Sugar is a molecular compound. It is made up of molecules in which nonmetal atoms, such as hydrogen and oxygen, share electrons to form stable arrangements. Water and carbon dioxide are also molecular compounds, whether in a gas, a liquid, or a solid state. The particles in ionic and molecular compounds are different, as shown in **Figure 1**.

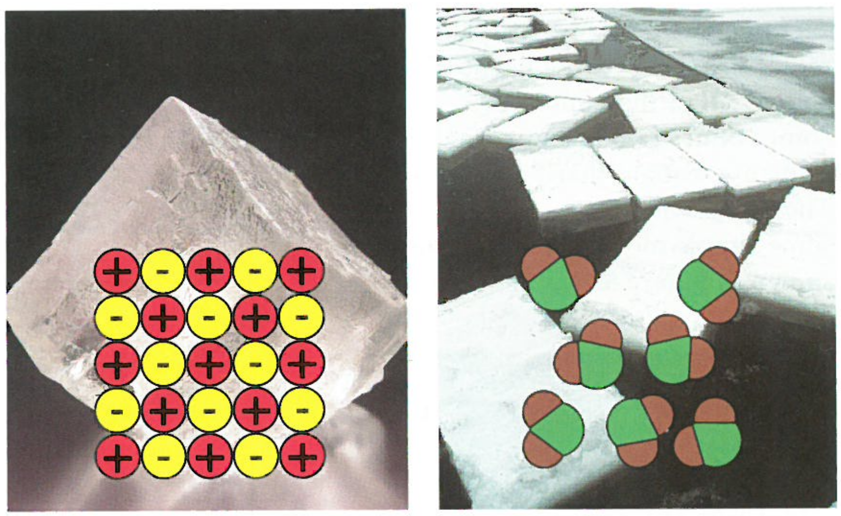


Figure 1
Salt (NaCl) is an example of an ionic compound made up of ions of opposite charge. Ice (H_2O) is an example of a molecular compound made up of neutral molecules.

Hydrogen gas is a molecule formed when two hydrogen atoms combine. Each hydrogen atom has one electron. Helium is the nearest noble gas with a stable electron arrangement — it has two electrons in the first orbit. For the two hydrogen atoms to become stable, both must gain an electron. They do this by sharing a pair of electrons, one from each atom, as shown in **Figure 2**.

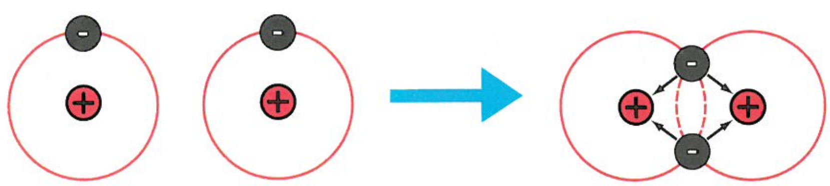


Figure 2
Two hydrogen atoms share a pair of electrons to form a covalent bond. Both negative electrons are attracted by the positive nuclei of both atoms.

The result is a **covalent bond** — a shared pair of electrons held between two nonmetal atoms that holds the atoms together in a molecule. Many nonmetals form molecules in this way. For example, chlorine gas is a molecule that consists of two chlorine atoms held together with a covalent bond. Each chlorine atom has seven electrons in its outer orbit and needs to gain one electron to become stable. The atoms share electrons to form a stable arrangement, as shown in **Figure 3**.

Many nonmetallic elements exist as covalently bonded molecules. **Table 1** lists elements that form diatomic molecules (molecules made of two atoms). This table includes only molecules made up of two identical atoms, but atoms of different elements can also form covalent bonds.

Molecular compounds are all around us (**Figure 4**). A bottle of soda pop contains water molecules, sugar molecules (usually compounds called sucrose, glucose, or fructose), and other molecules that provide flavour and colour. All of these molecular compounds are made up of nonmetal elements that are sharing electrons. The models and electronic structure of some simple molecular compounds are shown in **Figure 5**.

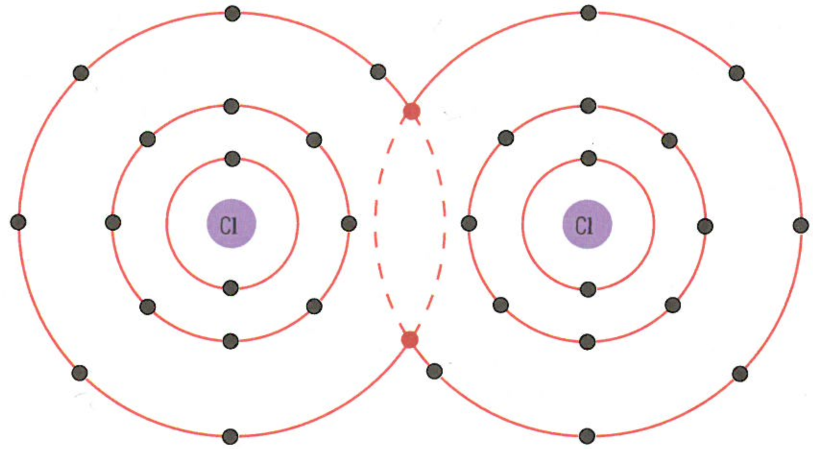


Figure 3
Two chlorine atoms share a pair of electrons to form a covalent bond. Each chlorine atom now has eight electrons in its outer orbit.

Table 1 **Elements That Form Diatomic Molecules**

Name of element	Chemical symbol	Formula (and state at room temperature)
hydrogen	H	H_2 (gas)
oxygen	O	O_2 (gas)
nitrogen	N	N_2 (gas)
fluorine	F	F_2 (gas)
chlorine	Cl	Cl_2 (gas)
bromine	Br	Br_2 (liquid)
iodine	I	I_2 (solid)

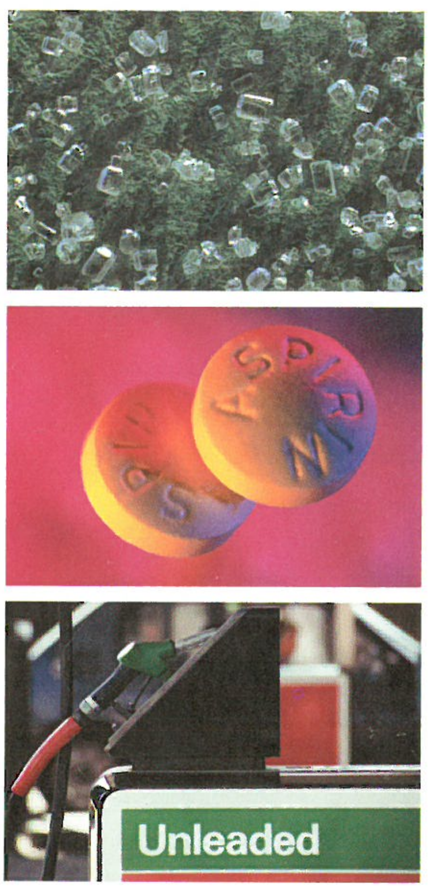


Figure 4
Sugar, Aspirin, and gasoline are all examples of molecular compounds.

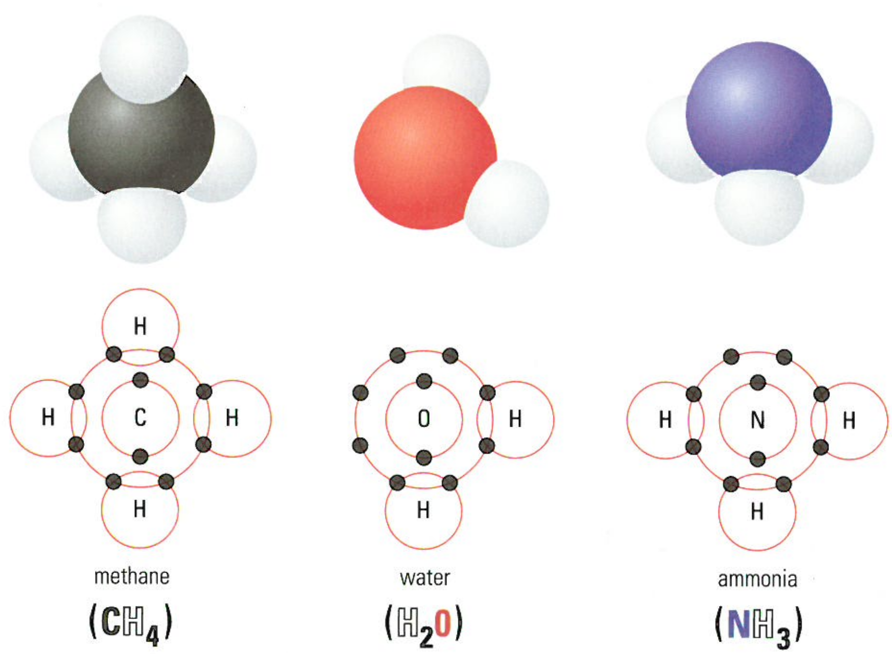


Figure 5
Methane, water, and ammonia are all covalently bonded molecules.

Writing Formulas for Molecular Compounds

The formulas of many molecular compounds can be predicted using a method similar to the one you used for ionic compounds. The number of electrons that metals and nonmetals transfer to become stable ions can be a clue to the formula of an ionic compound. Similarly, the number of electrons that a nonmetal needs to share to become stable is a clue to the number of covalent bonds it can form. The **combining capacity** of a nonmetal is a measure of the number of covalent bonds that it will need to form a stable molecule. These combining capacities are listed in **Table 2**.

Carbon (element 6) has four electrons in its outer (or valence) orbit. If it lost four electrons, it would have the electron arrangement of helium (element 2) and would form a positive ion. If it gained four electrons, it would have the electron arrangement of neon (element 10) and would form a negative ion. It turns out that carbon cannot form either ion. Instead it "gains" four electrons by sharing; carbon has a combining capacity of four. For example, when carbon shares one of its outer orbit electrons with each of four different hydrogen atoms, as shown in **Figure 5**, the result is methane (CH_4), the major component of natural gas. As a result of forming covalent bonds through sharing electrons, the atoms end up with a stable electron arrangement in their outer orbit similar to that of a noble gas.

You can use the combining capacity to write the formulas of molecular compounds without having to consider electronic structure. Consider the following example.

How would you write the formula for a compound formed between carbon and sulfur?

Rule 1: Write the symbols, with the left-hand element from ***Table 2*** *first, with the combining capacities.*

4 2
C S

Rule 2: Crisscross the combining capacities to produce subscripts.

4 ╳ 2
C S

The formula is C_2S_4.

Rule 3: Reduce the subscripts if possible.

The formula C_2S_4 can be reduced to C_1S_2.

Rule 4: Any "1" subscript is not needed.

The correct formula is CS_2.

Naming Molecular Compounds

Many molecular compounds have simple names. The compound H_2S is called hydrogen sulfide, much as if it were ionic. Other molecular compounds have names that are familiar to us, even though they do not follow a system.

Did You Know?

Most of the compounds in our bodies and in the food we eat are molecules. The basic building blocks in the human body — amino acids and proteins, sugars and carbohydrates, and fatty acids and fats — are all molecules held together with covalent bonds.

Table 2 **Combining Capacities of Nonmetal Atoms**

4	3	2	1
			H
C	N	O	F
Si	P	S	Cl
	As	Se	Br
			I

Common names have been used for centuries for water (H_2O); ammonia (NH_3), which is used in many cleaning products; hydrogen peroxide (H_2O_2), used in antiseptic solutions; and methane (CH_4), found in natural gas.

The names of molecular compounds often contain prefixes. These prefixes are used to count the number of atoms when the same two elements form different combinations. For example, the gas that you exhale is carbon dioxide (CO_2), while the poisonous combination of carbon and oxygen that can be formed in automobile engines is carbon monoxide (CO). The prefixes "di" and "mono" differentiate between the two molecules. When there is only one atom of the first element in the molecular compound, the prefix "mono" is not necessary. The prefixes that you will commonly encounter in molecular compounds are listed in Table 3.

Table 3 Prefixes in Molecular Compounds

Prefix	Number	Example (formula)
mon(o)-	1	carbon monoxide (CO)
di-	2	carbon disulfide (CS_2)
tri-	3	sulfur trioxide (SO_3)
tetra-	4	carbon tetrafluoride (CF_4)
pent(a)-	5	phosphorus pentabromide (PBr_5)

Challenge

1 Are there any molecular compounds in your product? What are their names?

Understanding Concepts

1. How can you tell the difference between an ionic compound and a molecular compound?
2. **(a)** What kinds of atoms form molecular compounds?
   (b) How do the atoms in molecular compounds form stable electron arrangements?
   (c) What type of bond holds atoms together in molecules?
3. **(a)** How many valence electrons are there in a fluorine atom?
   (b) How many electrons does a fluorine atom need to share to become stable?
   (c) Draw a sketch to show how two fluorine atoms could form a stable molecule.
4. Some elements exist in the form of diatomic molecules. Where are these elements generally located in the periodic table?
5. Name the following compounds (use prefixes):
   (a) CBr_4
   (b) NI_3
   (c) OF_2
   (d) $SiCl_4$
6. Write chemical formulas for and name the molecular compounds formed by the following pairs of elements:
   (a) silicon and oxygen
   (b) nitrogen and hydrogen
   (c) phosphorus and chlorine
   (d) sulfur and bromine
   (e) oxygen and fluorine
   (f) carbon and chlorine

Making Connections

7. Sugars were described as molecular compounds.
   (a) Name three sugar molecules.
   (b) What do you notice about the names of these substances?
   (c) Find five foods that contain different types of sugar molecules and examine the labels to name the types of sugar molecules.
8. **(a)** Chlorine has a combining capacity of one. How many electrons does it need to share to have the same electron arrangement as the nearest noble gas?
   (b) What is the combining capacity of oxygen? How many electrons does it need to share in order to have the same electron arrangement as the nearest noble gas?
   (c) Investigate the relationship between combining capacity and the number of electrons needed for stability in a number of other nonmetals.
   (d) Make a general statement to summarize your findings.

Reflecting

9. Could a pair of metal atoms form a covalent bond? Explain.

5.12

Hydrocarbons: A Special Group of Molecules

What do gasoline, dynamite, a plastic toy, aspirin pain reliever, and sugar have in common? They are all substances that are made of organic molecules. **Organic compounds** are molecular substances that contain carbon atoms as basic building blocks. The simplest organic compound is methane (chemical formula CH_4), and there are literally tens of thousands of different organic compounds.

In fact, carbon is contained in more compounds than all of the other elements put together. Why are there so many organic compounds? The answer is the remarkable combining capacity of carbon, which has a combining capacity of four. It has the ability to combine with other nonmetals, especially hydrogen, oxygen, and nitrogen, to form very stable compounds. Most of the food that we eat, whether from plants or animals, is made up of organic compounds. For example, table sugar (**Figure 1**) is an organic molecule. It is not surprising that food is organic because most of the human body is organic as well. Another important source of organic compounds is through chemical changes. Chemists use chemical reactions to make new substances from existing organic molecules. For example, plastics are made from crude oil.

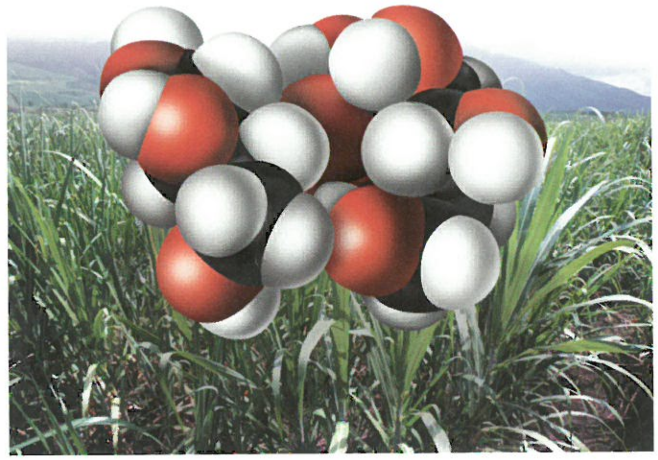


Figure 1
Table sugar, or sucrose, is an example of an organic compound. Its chemical formula is $C_{12}H_{22}O_{11}$. In the molecular model, black carbon atoms form the core of the molecule, with red oxygen and white hydrogen atoms attached.

Sources of Organic Compounds

Where do naturally occurring organic compounds come from? Many are produced by plants during the process of photosynthesis. Plants take in carbon dioxide from the air and water from the ground, and then build organic molecules — sugars, carbohydrates, proteins, and fats. Animals consume these organic molecules and make new molecules in more chemical reactions. Humans consume plants and animals, and the carbon-containing molecules are eventually recycled into the soil.

Another major source of organic molecules also has its origin in photosynthesis. In this case, though, the photosynthesis occurred millions of years ago. Crude oil petroleum and natural gas are obtained from under the ground, as shown in **Figure 2**. The main components in these mixtures are **hydrocarbons**, which are compounds of hydrogen and

Did You Know?

All food contains organic molecules. Plants and animals must all take in nutrients from their environment. However, some people use the term "organic" to describe food that has been grown without having any pesticides or other chemicals deliberately added by the farmer. Ironically, pesticides are organic molecules.

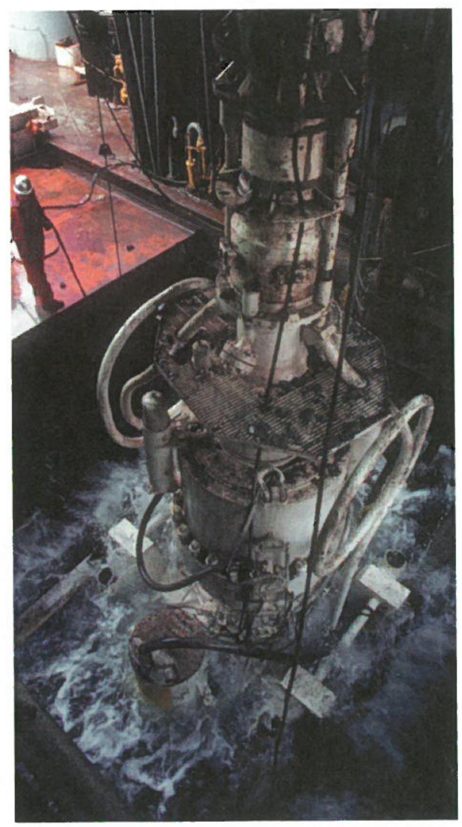


Figure 2
Oil wells produce oil and natural gas, which are mixtures of hundreds of different organic molecules.

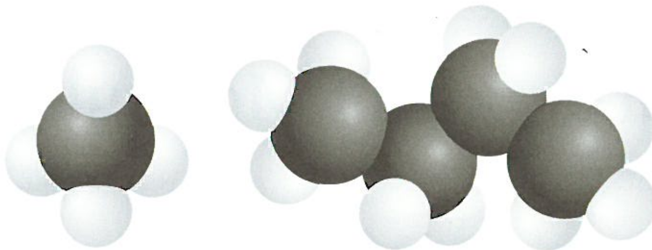


Figure 3
Hydrocarbons contain carbon and hydrogen atoms. Methane (CH_4) is found in natural gas and butane (C_4H_{10}) in lighter fuel.

Figure 4
Fractional distillation towers separate the components in petroleum according to their boiling points.

carbon found in various combinations. These mixtures of organic molecules were produced over millions of years as once-living plants and animals decayed and were changed by heat and pressure under the surface of Earth. These substances are also called **fossil fuels** because of their origin in living matter. Some examples of hydrocarbons are shown in **Figure 3**.

Petroleum and natural gas are transported across North America and around the world. Petroleum is generally moved by rail, road, or ship in tankers (**Figure 5**). Natural gas is transported across North America by pipeline and overseas by tanker as LNG (liquefied natural gas).

Crude oil and natural gas have become very important materials to people. For example, the energy released from burning these natural fuels is used to heat homes, produce electricity, and power automobiles and other machines. To the industrial chemist, however, crude oil and natural gas are more than just sources of fuel. The different types of molecules, or petrochemicals, present in these mixtures can be used to make industrial chemicals and consumer products, including plastics, synthetic fibres, and pharmaceuticals (**Figure 6**). The manufacture of chemical products consumes about 16% of the total petrochemical production.

Did You Know?

Gasoline mixtures are tested for their "octane rating." A higher-octane gasoline burns more efficiently and produces less engine "knock." Pure isooctane is given a rating of 100. Other fuel mixtures are assigned numbers by comparison with this standard.

The crude oil that comes out of the ground is a thick black "soup" of molecules. To make useful mixtures, the liquid crude oil and natural gas mixtures are separated into their components in a process called fractional distillation: the mixture passes into a distillation tower (**Figure 4**) that separates the components according to their boiling points.

Figure 5
The safe transport of petroleum products is a serious concern. Each year oil spills from tankers cause damage to plants and animals.

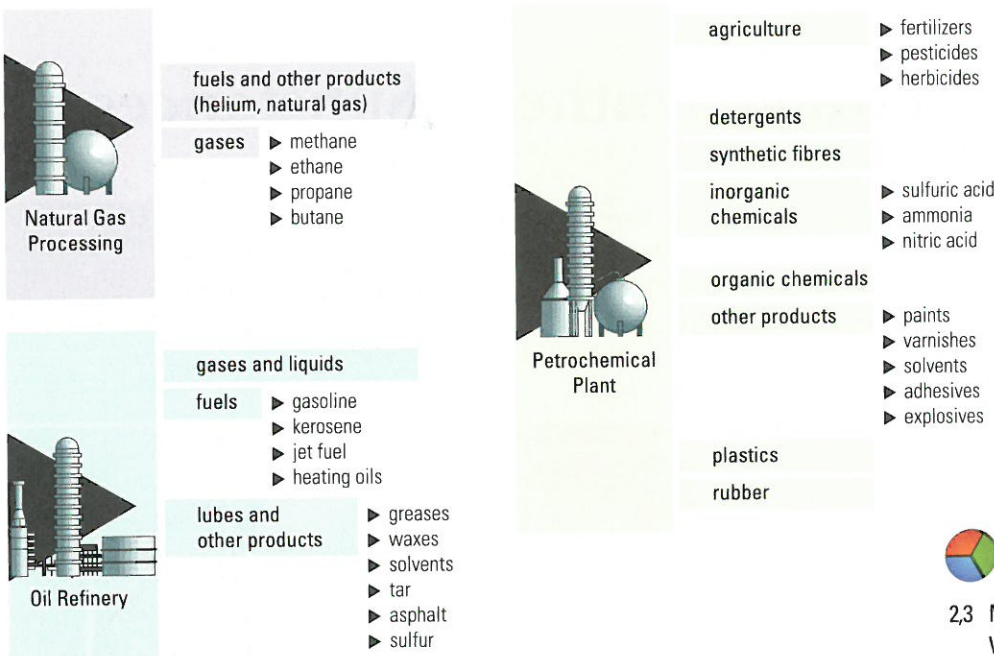


Figure 6
Some of the hundreds of substances obtained from crude oil and natural gas

Challenge

2,3 Most fuels are hydrocarbons. What are the names and formulas of these molecules?

3 What pollutants are produced when fossil fuels burn?

Try This Activity — Teacher Demo

Organic compounds, such as table sugar or sucrose ($C_{12}H_{22}O_{11}$) contain considerable amounts of stored energy. What would happen if the "H_2O" was removed from the sugar?

- Place about 1 cm depth of sugar in a 250-mL beaker.
- Add about 30 mL of concentrated sulfuric acid to the sugar. Wait and observe.

This demonstration should be done under a fume hood. Concentrated sulfuric acid is very dangerous. Wear safety goggles and stand back from the reaction. Be careful in cleaning up the products. Use sulfuric acid only in a well-ventilated area.

Understanding Concepts

1. **(a)** What are organic compounds?
   (b) What are the most common elements present in organic compounds?
   (c) What is the combining capacity of carbon?
   (d) Why is carbon called the backbone of organic molecules?
2. What are two sources of different kinds of organic compounds?
3. **(a)** What elements are present in hydrocarbon molecules?
   (b) How are hydrocarbons produced naturally?
4. **(a)** What is meant by the term "fossil fuel"?
   (b) Name three examples of fossil fuels.
5. Give five uses for natural gas and petroleum products.

Exploring

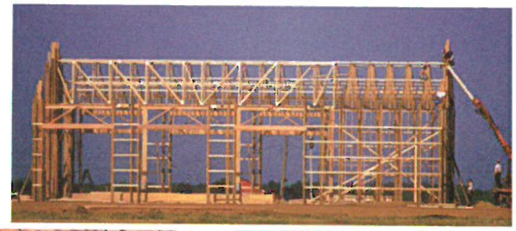
6. Research the mixture of substances found in gasoline. List (I) each molecular compound.
7. Find out about the geological process through which petroleum and natural gas are formed as plants and animals decay. Report on your reserach in a series of diagrams.

SKILLS HANDBOOK: (I) General Research

5.13

Chemical Wizardry: Synthetic Substances

Every hour of every day, people buy or use products that have become part of their way of living. Few people think about how these products have been produced using the application of chemistry. These substances include the fabrics in clothing, detergents for cleaning, plastics used to wrap food, and paints that decorate homes. Some chemicals prevent moisture loss and decay, and are used as preservatives in foods. Other substances give cosmetics their colours and textures. All of these are the products of applied chemistry and most of them are produced from hydrocarbons.



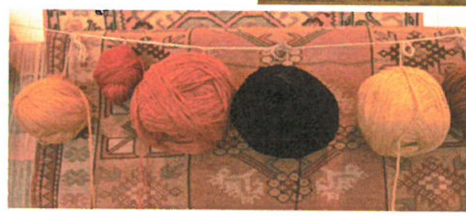


Figure 1
What natural substances are in these products?

Natural or Synthetic?

What do we mean when we describe a product as natural? **Natural products** are obtained from natural sources — animals, plants, or minerals (**Figure 1**). For example, leather and wool come from animals. Cotton, rubber, and wood are derived from plants. Mineral sources provide hydrocarbon fuels, metals, fertilizers, and cement. Many of these materials may be mixed with other substances or reshaped, but they all come from natural sources.

Many other products are made of **synthetic**, or artificially made, materials that have been manufactured in the chemical industry. Chemical changes are used to make these new substances with new properties. For example, natural crude rubber is obtained from the sap of trees; it is made up of molecules that are long and springy. This rubber stretches easily, but tends to become sticky when warm, and brittle when cold. Over a century ago, Charles Goodyear discovered a process he called vulcanization. In this process, natural rubber reacts with sulfur to form a new synthetic product called "vulcanized rubber." This substance is neither too hard nor too soft when the temperature changes. Today, car tires are made from completely synthetic molecules that are manufactured from petroleum (**Figure 2**). Such synthetic rubber is more resistant to acids and other chemicals, including gasoline.

Synthetic substances are used in most areas of daily life, as shown in **Table 1**. They are normally manufactured from petrochemicals. For example, polyethylene, used to make plastic bottles, is formed from ethene (C_2H_4), which has been separated from other hydrocarbon molecules in crude oil. Pharmaceutical chemists manufacture synthetic drugs, such as Aspirin. Other industrial chemists develop synthetic materials that are used to make products ranging from clothing to videotapes to computer chips.

Figure 2
The vulcanized rubber used in the tires on antique cars was an early example of a synthetic substance. Today's car tires are composites, or mixtures, of synthetic molecules. The composition of tires can be adjusted to make tires that perform better on wet roads or even high-speed racetracks.

Table 1 **Some Synthetic Substances Made from Petrochemicals**

Substance	Chemical name	Use
PVC	polyvinyl chloride	plastic pipe for plumbing
Teflon	polytetrafluoroethylene	coatings for frying pans
BHA	butylated hydroxyanisole	food additive
polypropylene	polypropene	carpet fibres
Aspirin (ASA)	acetylsalicylic acid	pain killer
vinyl	polyvinyl chloride	upholstery
TNT	trinitrotoluene	explosive
Plexiglas	polymethylmethacrylate	transparent car reflectors
PABA	para-aminobenzoic acid	sunscreen
Styrofoam	polystyrene	insulation
neoprene	polybutadiene	synthetic "rubber" hoses

Did You Know?

Polymers are not only produced in the chemical industry. Some polymers are naturally produced in living organisms. Starch, found in potatoes and other foods, is a natural polymer made up of hundreds of sugar molecules joined together in a long chain. Digestion breaks the polymer apart.

Polymers

Many synthetic substances, like polyethylene and Kevlar (**Figure 3**), are formed when tens or hundreds of smaller molecules link together to form long, thin molecules called **polymers**, shown in **Figure 4**. These polymers have very different properties from the reactants. For example, small styrene molecules are colourless, strong-smelling, and liquid at room temperature. They react to form the polymer polystyrene, which is used as insulation (Styrofoam).

Polymers that are shaped by flow at some point in their manufacture are called **plastics**. For example, a plastic spoon is formed by melting the polymer material into a mould and allowing it to cool in the desired shape. Fibres are made by drawing out the polymer into a thread as it forms.

Figure 3

Kevlar is an extremely strong, flexible polymer that is used in applications from ropes to skis to bulletproof vests.

Challenge

1 What are the names and formulas of the synthetic substances in your product?

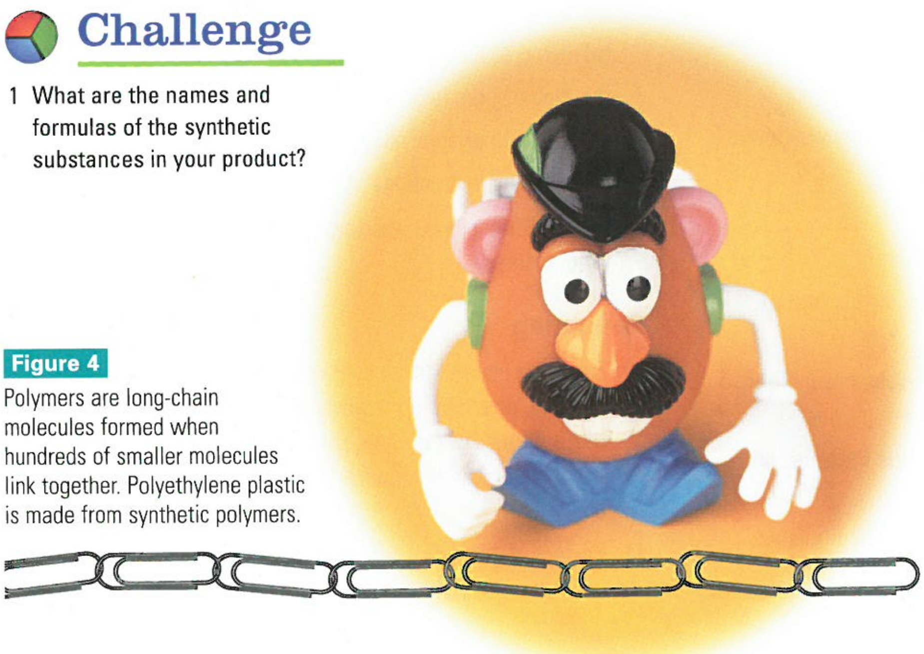


Figure 4

Polymers are long-chain molecules formed when hundreds of smaller molecules link together. Polyethylene plastic is made from synthetic polymers.

Did You Know?

Synthetic polymers can be formed into different types of plastics. Thermoplastic polymers, such as those used to make plastic cutlery, may be remelted with heat and reshaped. Thermosetting polymers become hard when they are heated and cannot be reheated and reshaped. They are baked in moulds to produce car battery and telephone casings, and electrical switches and fittings.

Fibres and Fabrics

Fibres are thin, hairlike strands of material that can be spun into thread or yarn. There are synthetic fibres and natural fibres (**Figure 5**). Fabrics are made when fibres are woven together.

Natural fibres have been used for thousands of years, and have many advantages over synthetic fibres. The structure of the natural fibre gives the fabric special properties. For example, wool fibres readily trap air when spun or woven. The trapped air pockets make wool a good heat insulator, even when wet. Silk fibres are like long, smooth tubes which give the silk fabric its satiny texture. Cotton fabrics allow good air circulation and absorb moisture, and are therefore excellent for hot weather use. By contrast, synthetic fibres generally do not "breathe" as well as natural fibres and tend to lose their insulating ability when wet. Moreover, natural fibres come from renewable sources — plants and animals that can produce more raw materials each year. Synthetic fibres, on the other hand, come from nonrenewable petroleum resources.

Synthetic fibres do have some advantages over natural fibres. Synthetics like polyester and nylon are becoming less and less expensive as the technology for making them from petrochemicals improves. The synthetic fibres used to make the fleece used in winter clothing are sometimes even made from recycled pop bottles! Research chemists are constantly working to produce new synthetic molecules with new properties. As a result, today there is a much greater variety of synthetic fibres from which to choose.

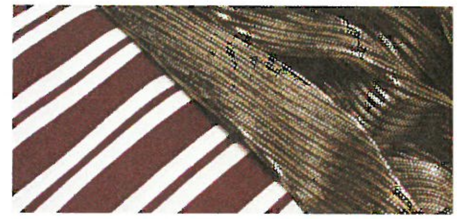


Figure 5
Which fabrics are made from natural fibres and which are made from synthetic fibres?

Did You Know?

Linen is one of the oldest and strongest natural fibres used in making fabrics. Egyptian mummies have been discovered still wrapped in linen thousands of years old.

Understanding Concepts

1. Name five natural materials found in the home. List two products that contain each material (e.g., cement: basement floor, sidewalk).
2. Name five synthetic substances found in the home. List two products that contain each material (e.g., nylon: windbreaker, socks).
3. Give two examples of useful properties of synthetic materials.
4. What are the raw materials used to make many synthetic substances?
5. **(a)** What is a polymer?
   (b) What are three examples of polymers?
   (c) What is the difference between a polymer and a plastic?
6. Examine the chemical names of the substances in **Table 1**. Which of the substances do you think are polymers?
7. **(a)** What are the advantages of synthetic fibres as compared to natural fibres?
   (b) What are the disadvantages of synthetic fibres as compared to natural fibres?

Making Connections

8. The tag on an article of clothing describes it as 65% polyester and 35% cotton. Suggest reasons why this blend of fibres might have been used.
9. Find examples of as many different fibres as possible at home. (Hint: Clothing tags and washing machine instructions will be useful.) Make a table to summarize the following:
   (a) name of fibre (e.g., cotton)
   (b) type of fibre (e.g., natural)
   (c) example of application (e.g., rug)
   (d) washing instructions

   What differences do you see in washing instructions for various fibres?

Reflecting

10. (I) Research and report on synthetic fibres used in athletic clothing. Investigate the advantages and disadvantages of these fibres. For example, consider their ability to stretch, washability, and resistance to bleaching by chemicals or light.
11. Can you think of any examples of synthetic materials that have changed how people live? Explain.

SKILLS HANDBOOK: (I) General Research

5.14 Explore an Issue

DECISION-MAKING SKILLS

- ● Define the Issue
- ○ Identify Alternatives
- ● Research
- ● Analyze the Issue
- ● Defend a Decision
- ○ Evaluate

Is "Natural" Better than Synthetic?

What types of chemical substances should people be using? You have already looked at some of the differences between natural and synthetic substances. In particular, you compared the advantages and disadvantages of synthetic and natural fibres, such as those used in clothing. But comparisons of synthetic and natural substances go far beyond fibres and clothing.

Some people believe that our society has become too dependent on synthetic materials over the last 50 years. As much as they can, they try to use natural products made from plants and animals, rather than synthetic products, which have been made by the chemical industry. But is it really better to use natural products than synthetic ones? Natural products often come from animals or plants raised with the assistance of chemicals. And land must be cleared for farms. On the other hand, natural products are more likely than synthetic products to be biodegradable.

After researching this question, two groups of students came up with the following lists of reasons for favouring either the "prosynthetic" (**Figure 1**) or the "pronatural" (**Figure 2**) position.

1. Synthetic antibiotics save thousands of lives every year. They are more effective and faster to produce than natural products. Without synthetic antibiotics, there would be worldwide epidemics.
2. Styrofoam coffee cups actually use up fewer resources than cardboard cups when you consider the trees that are cut down to make cardboard. Disposable cups may even be more environmentally friendly than china cups, when you consider the large amounts of hot water and detergent needed to clean china cups after each use.
3. Synthetic vitamins are cheaper, more convenient, and more effective than natural vitamins. Many people eat processed foods, which may have lost many of the minerals and vitamins necessary for health.
4. Synthetic diapers are better than cotton because they keep the baby's skin drier. They contain a super-absorbent polymer that effectively absorbs the moisture. They are also more convenient to use, and do not require hot water for washing.
5. Plastics are used in almost every kind of transportation. Synthetic canoes and other boats are lighter, more durable, and easier to repair than any craft made out of wood. Parts of snowmobiles are made out of plastic.
6. Synthetic fertilizers can be made to exact specifications for particular crops. They can be delivered in precise amounts more easily than natural fertilizers, and there is less waste.
7. Development of synthetic materials has allowed us to invent new devices. Artificial limbs and prosthetic devices, computers, and cellular phones are all made out of plastics and other synthetic materials.
8. The use of synthetic materials saves our forests. Trees are a renewable resource; however it takes decades for a tree to be replaced. Clearcutting of forests to meet our demand for wood and paper products is destroying our environment.
9. Sports equipment made of synthetics is superior to that made from natural products. Aluminum baseball bats, graphite composite tennis racquets, and metal-alloy golf clubs are all superior to their wooden counterparts.
10. The production of items using natural materials damages the environment. The production of leather requires the death of the animal, and the production of wool, cotton, and linen requires the use of large amounts of land that could otherwise be used for recreation or food crops.

Figure 1
"Prosynthetic" Viewpoint

1. Natural drugs, such as herbal extracts, are safer and often more effective than synthetic drugs. As a society, we consume too many drugs. The overprescription of antibiotics is producing "super bugs" that may eventually cause epidemics.
2. Cardboard containers, such as those used in fast food restaurants, do not use up valuable petroleum resources. They are made from trees, a renewable resource.
3. Losing weight by simply cutting back on food is healthier than taking synthetic diet pills. Diet pills are expensive and may cause long-term health problems.
4. Cotton diapers are better than synthetic diapers, because they are reusable and do not take up valuable space in landfills. If people have concerns over the time required for cleaning, they can use a diaper service that picks up and delivers.
5. Natural foods contain the nutrients that our bodies need. A well-balanced diet provides all the vitamins and other molecules needed for health.
6. Organic fertilizers, such as manure, allow farmers to recycle animal wastes and provide crops with a natural source of nutrients. Synthetic fertilizers are expensive, and crops become dependent on them.
7. Paper products are better than plastics because paper is easier to recycle. There are so many different kinds of synthetic plastics that they have to be sorted before they can be recycled — a process that is expensive and time-consuming.
8. Wood frames for houses are superior to metal or plastic frames. Wood is biodegradable, reusable, and recyclable. Natural cellulose insulation in houses is superior to fibreglass because it is a better insulator and does not irritate the skin.
9. Natural materials are safer to produce. They do not require huge chemical factories that generate large amounts of toxic air and water pollutants.
10. Natural wool carpets stabilize the relative humidity in a house by absorbing or releasing atmospheric moisture.

Figure 2
"Pronatural" Viewpoint

]DEBATE[Natural Products are Better than Synthetic

Proposition

Natural products are made from renewable resources and are therefore better than synthetic products.

- (C) (E) Your teacher will place you in a group of four students. One pair of students will be assigned the "pronatural" position, and the other pair will be assigned the "prosynthetic" position. Whichever your assigned position (and regardless of your own personal opinion), conduct further research to support that position. Remember to investigate the issue from a variety of perspectives. Keep notes as you research and form your evidence into supportive arguments.
- Share your findings with your partner and decide who will present which points.
- (S) Carry out a debate, with the two "pronatural" speakers presenting first.
- After all four students have spoken for 2 min each, reverse your positions: the "prosynthetic" students now take the "pronatural" position, and vice versa. Argue your new viewpoint for 2 min each.
- Finally, in your group of four, discuss the issue and arrive at a position. Produce a 20- to 50-word statement that summarizes your group's feelings on the issue. The group must all show your agreement by signing this consensus statement.

Work the Web

Synthetic materials tend to be extremely durable and long-lived. This is an advantage when we are using them, but a problem when we want to get rid of them. What are chemists doing to try to reduce this problem? Visit www.science.nelson.com and follow the links from Science 10, 5.14 to investigate the development of biodegradable plastics.

Understanding the Issue

1. What is the source of most natural products?
2. Write a paragraph outlining the arguments for and against using disposable diapers.
3. (D) List two pronatural and two prosynthetic arguments made from an ecological perspective.

 SKILLS HANDBOOK: (C) Defining the Issue (E) Researching Alternatives (S) Oral Presentations (D) Identifying Alternatives

Chapter 5 Summary

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Recognize the relationships between chemical formulas, composition, and names. (all)
- Use appropriate apparatus and apply WHMIS safety procedures for handling, storage, disposal, and recycling of materials in the lab. (5.1, 5.3, 5.10)
- Select and integrate information from many sources including electronic, print, and community resources, and personally collected data. (5.2, 5.13, 5.14)
- Explain how environmental challenges can be addressed through an understanding of chemical substances. (5.2)
- Conduct chemical tests to identify common gases (oxygen, hydrogen, carbon dioxide). (5.3)
- Analyze experimental data, evaluate evidence and sources of information, and identify errors and bias. (5.3, 5.10, 5.12, 5.14)
- Write lab reports. (5.3, 5.10)
- Explore careers based on technologies that use chemical reactions. (5.4)
- Write the names and formulas for common ionic, polyatomic, and molecular compounds using the periodic table. (5.7, 5.8, 5.9, 5.11)
- Ask questions about practical problems and issues involving chemical processes. (5.10, 5.14)
- Describe how an understanding of chemical reactions has led to new consumer products and technological processes. (5.12, 5.13, 5.14)

Key Terms

alkali metals
alkaline earth metal
Bohr diagram
chemical change
chemical family
chemical property
chemical test
chemistry
combining capacity
compound
covalent bond
electrolyte
electron
element
fossil fuel
halogens
hydrocarbon
ion
ionic charge
ionic compound
matter
molecular compound
natural product
neutron
noble gases
organic compound
oxyacid
periodic table
physical change
physical property
plastics
polyatomic ion
polymers
positive test
product
proton
pure substance
reactant
synthetic
valence
valence shell

Make a Summary

Make a concept map to summarize the material that you have studied in this chapter. Start with the word "chemicals" and try to use as many of the terms in the Key Term list as possible in your map.

Reflect on your Learning

Revisit your answers to the Reflect on your Learning questions, page 171, in the Getting Started.

- How has your thinking changed?
- What new questions do you have?

Chapter 5 Review

Understanding Concepts

1. Explain the difference between the following pairs of terms. Give an example for each term:
   (a) physical property and chemical property
   (b) element and compound
   (c) metal and nonmetal
   (d) ionic compound and molecular compound
   (e) natural substance and synthetic substance

2. For each of the following, replace the description with one or two words:
   (a) a sample of matter that contains only one kind of atom;
   (b) a characteristic of matter that involves the formation of a new substance;
   (c) the starting material in a chemical reaction;
   (d) a family of elements that includes sodium and potassium;
   (e) the positively charged particle in the atom;
   (f) an electrically charged atom;
   (g) artificially made.

3. The sentences below contain errors or are incomplete. Write complete, correct versions.
   (a) Elements and solutions are examples of pure substances.
   (b) The melting point of a substance is an example of a chemical property.
   (c) The chemical test for hydrogen gas is to use a glowing splint.
   (d) Fluorine, chlorine, and iodine are members of the alkaline earth metals family.
   (e) Negative particles called neutrons circle the nucleus of the atom.
   (f) An atom with more electrons than protons will be a positive ion.
   (g) A molecular compound is held together with ionic bonds.
   (h) The chloride ion is an example of a polyatomic ion.
   (j) Cotton, leather, and wool are examples of synthetic substances.

4. Use the periodic table at the back of this book to determine the atomic numbers and to draw Bohr diagrams for the following elements:
   (a) aluminum
   (b) fluorine
   (c) magnesium
   (d) phosphorus

5. For each of the elements in question 4:
   (a) Draw a Bohr diagram of the stable ion that it would form.
   (b) Write the symbol and ionic charge of the stable ion.

6. Write the name of the compound that would be formed by combining each of the following pairs of elements:
   (a) magnesium and chlorine
   (b) sodium and bromine
   (c) magnesium and oxygen
   (d) aluminum and phosphorus
   (e) aluminum and sulfur

7. Write the formula for each of the compounds in question 6.

8. Examine the Bohr diagram in **Figure 1**. This diagram could represent the electronic structure of a noble gas or a stable ion. What would be the chemical symbol and ionic charge if the nucleus of the atom contained:

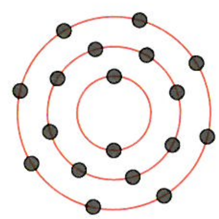


Figure 1

   (a) 16 protons
   (b) 18 protons
   (c) 19 protons

9. For each of the following compounds that involve elements with more than one ionic charge, write the corresponding name or chemical formula:
   (a) CuCl
   (b) FeI_2
   (c) tin(IV) oxide
   (d) lead(II) bromide

10. For each of the following compounds that involve polyatomic ions, write the corresponding name or chemical formula:
   (a) $CuCO_3$
   (b) $FeSO_4$
   (c) tin(IV) phosphate
   (d) lead(II) nitrate

11. For each of the following molecular compounds, write the corresponding name or chemical formula:
(a) carbon monoxide
(b) nitrogen triiodide
(c) SCl_2
(d) CCl_4

Applying Inquiry Skills

12. Describe four safety procedures that you followed during your investigations.

13. A student performs an experiment in which a solid white substance is added to a solution and produces a gas. When a sample of the gas is tested with limewater, the solution turns cloudy.
(a) What is the name and chemical formula of the gas?
(b) What would be the effect of the gas on a glowing or blazing splint?
(c) Suggest a reasonable possible formula for the original white solid.

14. A group of students performs an investigation to test an unknown solid. They dissolve the solid in water and then, using small samples of this solution, do separate tests for the presence of ions. **Figure 2** shows their experimental results.

Procedure	Observations
examined original solution	solution was clear and very pale yellow
added some silver nitrate solution	solution turned milky white
added some barium nitrate solution	no change in solution
added some potassium thiocyanate	solution turned reddish brown

Figure 2

(a) What ion(s) were present in the solution? Explain.
(b) What ion(s) were not present in the solution? Explain.
(c) Give a possible name and formula for the unknown solid.

15. An unknown element X forms an oxide with the formula X_2O_3.
(a) What is the ionic charge or valence of element X? Explain.
(b) What would be the formula of the compound that element X would form with chlorine?

16. Natural and synthetic fibres have different properties (see **Figure 3**). Design and perform a controlled experiment to compare the characteristics of various natural and synthetic fibres. Some possible areas of study might be
(a) the effect of heating the fibres with an iron;
(b) the fibres' solubility in solvents (e.g., acetone);
(c) the fibres' ability to absorb moisture;
(d) the effect of bleach on the fibres;
(e) the fibres' insulating ability.

Figure 3

Making Connections

17. Choose a category of household hazardous products and design a poster to be displayed in your home to encourage people to handle and dispose of these materials safely. Include HHPS or WHMIS symbols.

18. Research and report on environmentally friendly alternatives to hazardous household products.

19. Contact an oil company to obtain information about gasoline. Report on (a) the types of molecules present in unleaded and leaded gasoline; or (b) octane-rating and "knocking."

20. What natural and synthetic materials are used in modern tires? Contact a company that makes tires, and report on the substances that they use.

Understanding Chemical Reactions