16-1 What is a chemical formula?

Objective ▸ Write chemical formulas for some simple compounds.

TechTerms

- **chemical formula:** way of writing the name of a compound using chemical symbols
- **subscript:** number written to the lower right of a chemical symbol

Chemical Symbols Scientists use symbols to represent elements. Each element has its own symbol. A symbol represents one atom of an element. Most symbols are made up of one letter. H is the symbol for hydrogen. Some symbols are made up of two letters. Fe is the symbol for iron.

Identify: What is the symbol for iron?

Chemical Formulas Molecules of compounds consist of two or more atoms joined together. Scientists use a **chemical formula** to represent one molecule of a compound. A chemical formula is a way of writing the name of a compound using chemical symbols. The compound water contains the elements hydrogen and oxygen. Each molecule of water contains two atoms of hydrogen and one atom of oxygen. The chemical formula for water is H_2O. The chemical formula includes the symbols for each element in the compound. Table 1 shows the chemical formulas of some compounds.

Describe: What is a chemical formula?

Subscripts Chemical formulas also indicate how many atoms of each type of element are in a compound. Numbers of atoms are shown by a **subscript.** A subscript is a number written to the lower right of a chemical symbol. The 2 in the chemical formula H_2O is a subscript. It indicates that there are two atoms of hydrogen in a molecule of water. There is also one atom of oxygen in a molecule of water. No subscript is written after the O in H_2O. This is because the subscript 1 is never written in a chemical formula. When no subscript appears after a symbol in a formula, you know that there is one atom of that element.

Infer: How many atoms of hydrogen are there in a molecule of sugar if the chemical formula for sugar is $C_{12}H_{22}O_{11}$?

Writing Chemical Formulas In many compounds, a metallic element is combined with a nonmetallic element. Sodium chloride is made up of the metal sodium and the nonmetal chlorine. In a chemical formula, the symbol for the metallic element is always written first. Table 2 shows some compounds and the metallic and nonmetallic elements that make them up.

Calculate: How many atoms are there in a molecule of aluminum chloride?

Table 1 **Chemical Formulas of Compounds**

COMPOUND	FORMULA	ELEMENTS
Sodium chloride	NaCl	sodium chlorine
Hydrochloric acid	HCl	hydrogen chlorine
Sodium hydroxide	NaOH	sodium oxygen hydrogen
Calcium oxide	CaO	calcium oxygen

Table 2 **Metallic and Nonmetallic Elements**

COMPOUND AND FORMULA		METALLIC ELEMENT	NONMETALLIC ELEMENT
Sodium chloride	NaCl	Na (sodium)	Cl (chlorine)
Aluminum chloride	$AlCl_3$	Al (aluminum)	Cl (chlorine)
Silver sulfide	Ag_2S	Ag (silver)	S (sulfur)
Aluminum oxide	Al_2O_3	Al (aluminum)	O (oxygen)

LESSON SUMMARY

- Every element has its own chemical symbol.
- Every compound has its own chemical formula.
- A chemical formula identifies the elements in a compound.
- Subscripts show how many atoms of an element are found in a molecule of a compound.
- The symbol for a metallic element is always written first in a chemical formula.

CHECK *Complete the following.*

1. The chemical symbol for hydrogen is _____ .
2. The chemical formula for water is _____ .
3. A _____ shows how many atoms of an element are contained in one molecule of a compound.
4. The nonmetallic element in sodium chloride is _____ .
5. In a chemical formula, the symbol for a _____ element is always written first.

APPLY *Complete the following.*

6. **Analyze:** Identify the elements and the number of each kind of atom in one molecule of the following compounds: ammonia (NH_3), barium chloride ($BaCl_2$).
7. **Contrast:** The chemical formula for water is H_2O. The chemical formula for hydrogen peroxide is H_2O_2. How does a molecule of water differ from a molecule of hydrogen peroxide?
8. What two things does a chemical formula tell you about a compound?

Skill Builder

Interpreting Chemical Formulas On a sheet of paper, list the names of the elements that make up each of the following compounds.

a. carbon dioxide (CO_2)
b. ammonia (NH_3)
c. calcite ($CaCO_3$)
d. potassium hydroxide (KOH)
e. baking soda ($NaHCO_3$)

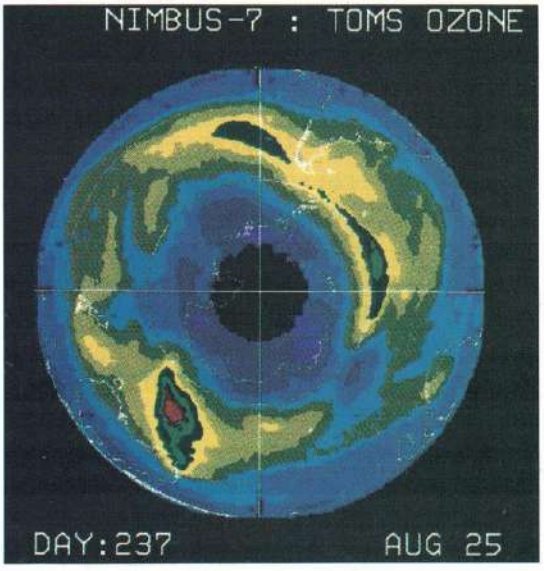
SCIENCE CONNECTION

DESTRUCTION OF THE OZONE LAYER

Ozone is a molecule made up of three atoms of oxygen. Ozone forms in the atmosphere when ultraviolet rays from the sun strike oxygen molecules in the air. A layer of ozone in the atmosphere absorbs about 99% of the sun's ultraviolet radiation.

Scientists have found that certain chemicals called CFCs destroy ozone molecules. CFCs are found in gases that are used in spray cans. CFCs also are used in some air conditioners, refrigerators, and aircraft engines. When used, CFCs may be released into the atmosphere. When the CFCs reach the ozone layer, ozone molecules are destroyed. As a result, more harmful ultraviolet radiation reaches the earth's surface. Exposure to increased levels of ultraviolet radiation can cause skin cancer in humans.

In the 1970s, the United States government banned the use of CFCs in spray cans. However, these chemicals are still being phased out in other products in the United States and in other countries.



16-2 What is an oxidation number?

Objective ▸ Describe how to use oxidation numbers to write the chemical formula of a compound.

TechTerms

- **oxidation number:** number of electrons an atom gains, loses, or shares when it forms a chemical bond
- **valence electrons:** electrons in an atom's outer energy level

Valence Electrons Electrons move around the nucleus of an atom in energy levels. The first energy level is complete when it holds two electrons. Other energy levels are complete when they hold eight electrons. Atoms tend to complete their outer energy levels when they bond with other atoms. The electrons in an atom's outer energy level are called **valence electrons.**

Identify: How many electrons are in a complete outer energy level?

Oxidation Number An **oxidation number** shows how many electrons an atoms gains, loses, or shares when it forms a chemical bond. A chlorine atom has seven valence electrons. In order to complete its outer energy level, the atom must gain one electron from another atom. An atom that gains electrons has a negative oxidation number. When it gains an electron, the chlorine atom has a negative charge. Therefore, the oxidation number of chlorine is 1−.

An atom that loses electrons has a positive oxidation number. The outer energy level of a sodium atom contains one electron. If sodium loses this electron, then the next energy level becomes its outer level. This level already has eight electrons, so it is complete. A sodium atom has one valence electron. When it loses this electron, sodium has a positive charge. Therefore, the oxidation number of sodium is 1+.

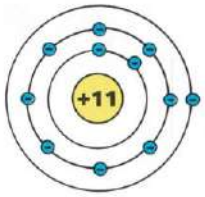
Infer: What is the oxidation number of an atom with six valence electrons?

Writing Chemical Formulas The oxidation number of an element tells you if it loses (+) or gains (−) electrons. Knowing the oxidation number of elements can help you predict the formula for a compound. To write the formula for a compound, remember that the oxidation numbers of the elements in a compound must add up to zero. For example, sodium chloride is a compound made up of sodium and chlorine. The oxidation number of sodium is 1+. The oxidation number of chlorine is 1−. The oxidation numbers of the elements cancel one another:

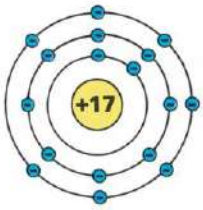
$$(1+) + (1-) = 0$$

In the compound sodium chloride, one atom of sodium combines with one atom of chlorine. The chemical formula for sodium chloride is NaCl.

Predict: The oxidation number of hydrogen is 1+ and of sulfur is 2−. What is the formula for hydrogen sulfide?

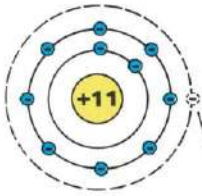


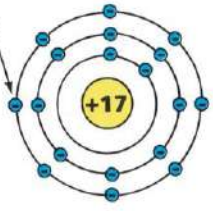
Sodium atom
1 valence electron



Chlorine atom
7 valence electrons

Sodium ion





Chloride ion

LESSON SUMMARY

- The number of electrons in an atom's outer energy level determines how the atom will combine with other atoms.
- Valence electrons are the number of electrons in an atom's outer energy level.
- Atoms that lose electrons have positive oxidation numbers.
- Atoms that gain electrons have negative oxidation numbers.
- Elements with positive oxidation numbers are written first in a chemical formula.

CHECK *Complete the following.*

1. What is the number of electrons an atom gains, loses, or shares when it forms a chemical bond called?
2. What determines how an atom will combine with other atoms?
3. Is the oxidation number of an atom that gains electrons positive or negative?
4. How many valence electrons does an atom of chlorine have?
5. What is the oxidation number of chlorine?
6. What is true about the oxidation numbers of the elements in a compound?

APPLY *Complete the following.*

7. **Infer:** The chemical formula for aluminum chloride is $AlCl_3$. Which atom in a molecule of aluminum chloride has a positive oxidation number? How do you know?
8. **Analyze:** What is the oxidation number of aluminum in $AlCl_3$? What is the oxidation number of chlorine? Explain how you arrived at your answers.

Ideas in Action

IDEA: Many household products are compounds. Each compound has its own chemical formula.

ACTION: Make a list of five compounds found in products used in your home. Write the chemical formula of each compound and identify the elements it contains.

ACTIVITY

WRITING CHEMICAL FORMULAS

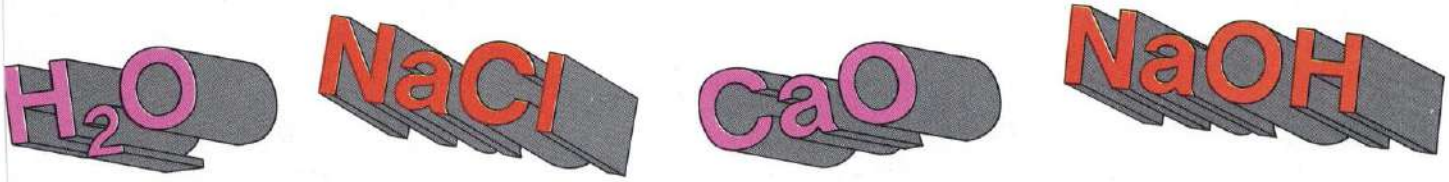
You will need a pencil and a sheet of paper.

1. Copy the table on a separate sheet of paper.
2. Use the oxidation numbers to find the formulas of the compounds that will be formed when each metal combines with each nonmetal. The first one has been done for you.

		NONMETALS				
		Cl^{1-}	Br^{1-}	I^{1-}	O^{2-}	S^{2-}
METALS	H^{1+}	HCl				
	Na^{1+}					
	Au^{1+}					
	K^{1+}					
	Fe^{3+}					
	Al^{3+}					

Questions

1. Which type of element, a metal or a nonmetal, did you write first in your chemical formulas?
2. Why is it possible to use oxidation numbers to write chemical formulas for compounds?



16-3 How are chemical compounds named?

Objective ▸ Explain how chemical compounds are named.

TechTerm

▸ **binary** (BY-nur-ee) **compound:** compound containing two elements

Binary Compounds A **binary** (BY-nur-ee) **compound** contains two different elements bonded together. The name of a binary compound tells which elements are found in a molecule of the compound. Sodium chloride is an example of a binary compound. It is formed from the elements sodium and chlorine. The name of the element with a positive oxidation number is written first. The name of the second element is changed to end in -ide and is written last. In sodium chloride, chlorine is changed to chloride.

Predict: What elements would you expect to find in the compound hydrogen chloride?

Different Oxidation Numbers Some elements have more than one oxidation number. For example, the oxidation number of iron can be either 2+ or 3+. Scientists indicate different oxidation numbers of an element by including a Roman number in parentheses in the name of the element. Iron (II) shows that an atom of iron has an oxidation number of 2+. Iron (III) shows that an atom of iron has an oxidation number of 3+.

Iron and chlorine can combine to form the compound $FeCl_2$. Iron and chlorine can also combine to form the compound $FeCl_3$. $FeCl_2$ and $FeCl_3$ are two different compounds. In one compound, the oxidation number of iron is 2+. In the other compound, the oxidation number of iron is 3+. Another way of identifying these compounds is iron (II) chloride and iron (III) chloride.

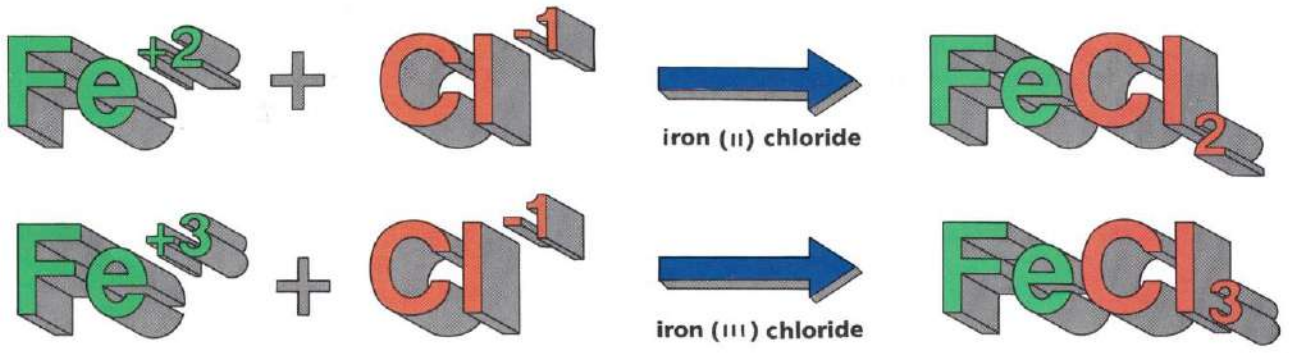
Infer: What is the oxidation number of an atom of gold (III)?

Other Elements Most elements have more than one oxidation number. Tin can have an oxidation number of 4+ or 2+. Gold can have an oxidation number of 3+ or 1+. Copper can have an oxidation number of 2+ or 1+. The Roman number in the name of the compound shows the oxidation number of the element in the compound.

Identify: What is the oxidation number of copper in the compound copper (II) chloride?

Table 1 **Oxidation Numbers of Some Metals**

METAL	HIGHER OXIDATION NUMBER	LOWER OXIDATION NUMBER
Iron	3+, iron (III)	2+, iron (II)
Mercury	2+, mercury (II)	1+, mercury (I)
Copper	2+, copper (II)	1+, copper (I)
Tin	4+, tin (IV)	2+, tin (II)
Nickel	3+, nickel (III)	2+, nickel (II)
Gold	3+, gold (III)	1+, gold (I)



LESSON SUMMARY

- A binary compound contains atoms of two different elements.
- An element can have more than one oxidation number.
- A Roman number in the name of a compound shows the oxidation number of an element in the compound.

CHECK *Complete the following.*

1. The oxidation number of iron (III) is _____ .
2. Iron (II) chloride and iron (III) chloride are different _____ .
3. In the compound hydrogen chloride (HCl) _____ has a positive oxidation number.
4. Since the compound water contains the elements hydrogen and oxygen, it is a _____ compound.
5. The name mercury (II) bromide indicates that the oxidation number of _____ is 2+.

APPLY *Complete the following.*

6. **Infer:** The chemical formula for oxygen gas is O_2. Is oxygen gas a binary compound?
7. Mercury can have two oxidation numbers, 1+ or 2+. Are mercury (I) chloride and mercury (II) chloride the same compound? Explain.

InfoSearch

Read the passage. Ask two questions about the topic that you cannot answer from the information in the passage.

Naming Compounds Some compounds contain two nonmetals. In naming compounds made up of two nonmetals, prefixes are used. For example, the compound carbon monoxide contains one atom of carbon and one atom of oxygen. The compound carbon dioxide contains one atom of carbon and two atoms of oxygen. The prefix "mono-" means "one," while the prefix "di-" means "two."

SEARCH: Use library reference to find answers to your questions.

CAREER IN PHYSICAL SCIENCE

CHEMICAL TECHNICIAN

Do you enjoy working in a science laboratory? Can you keep detailed records? Do you like putting complicated things together? If so, you may enjoy a career as a chemical technician. Chemical technicians help develop, test, and manufacture chemical products.

Chemical technicians work in many different settings. Some chemical technicians perform tests to check the quality of chemical products. Others assist in the design and production of food or drug products. Still others aid in the research and development of new products in the aerospace and automobile industries.

To become a chemical technician, you should attend a two-year college or technical school. You should take courses in mathematics, chemistry, and other sciences.

16-4 What is a polyatomic ion?

Objective ▸ Recognize the chemical formula for a polyatomic ion.

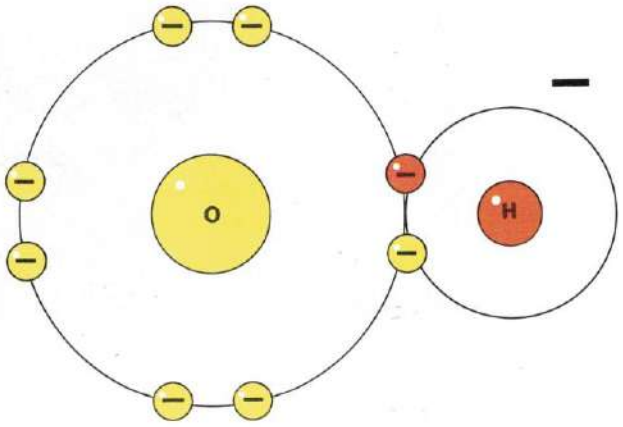
TechTerm

- **polyatomic** (PAHL-i-uh-tahm-ik) **ion:** group of atoms that acts as a single atom when combining with other atoms

Polyatomic Ions Sometimes, a group of atoms stays together when combining with other atoms. The group of atoms acts as one single atom. A group of atoms that acts as a single atom when combining with other atoms is called a **polyatomic** (PAHL-i-uh-tahm-ik) **ion.** The prefix "poly-" means "more than one." The group of atoms is called an ion because it has an electrical charge. The atoms in a polyatomic ion are joined by covalent bonds.

Define: What is a polyatomic ion?

Hydroxide Ions An example of a polyatomic ion is the hydroxide ion. A hydroxide ion is made up of one oxygen atom and one hydrogen atom. The oxygen atom and the hydrogen atom are joined by a covalent bond. A hydroxide ion has a negative electrical charge. The chemical formula for a hydroxide ion is OH^-. Compounds containing hydroxide ions are called bases.



Hydroxide ion $(OH)^-$

Identify: What is the formula for a hydroxide ion?

Ammonium Ions The ammonium ion is made up of one nitrogen atom and four hydrogen atoms. The ammonium ion has a positive electrical charge. The chemical formula for the ammonium ion is NH_4^+. The ammonium ion is the only common polyatomic ion with a positive charge. Table 1 shows some other polyatomic ions and their chemical formulas.

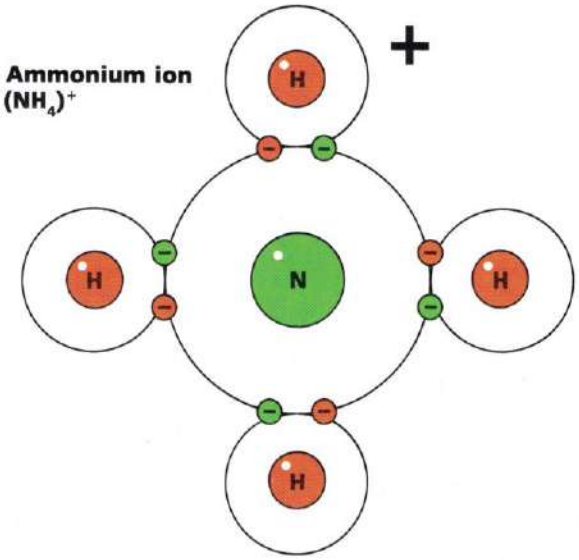


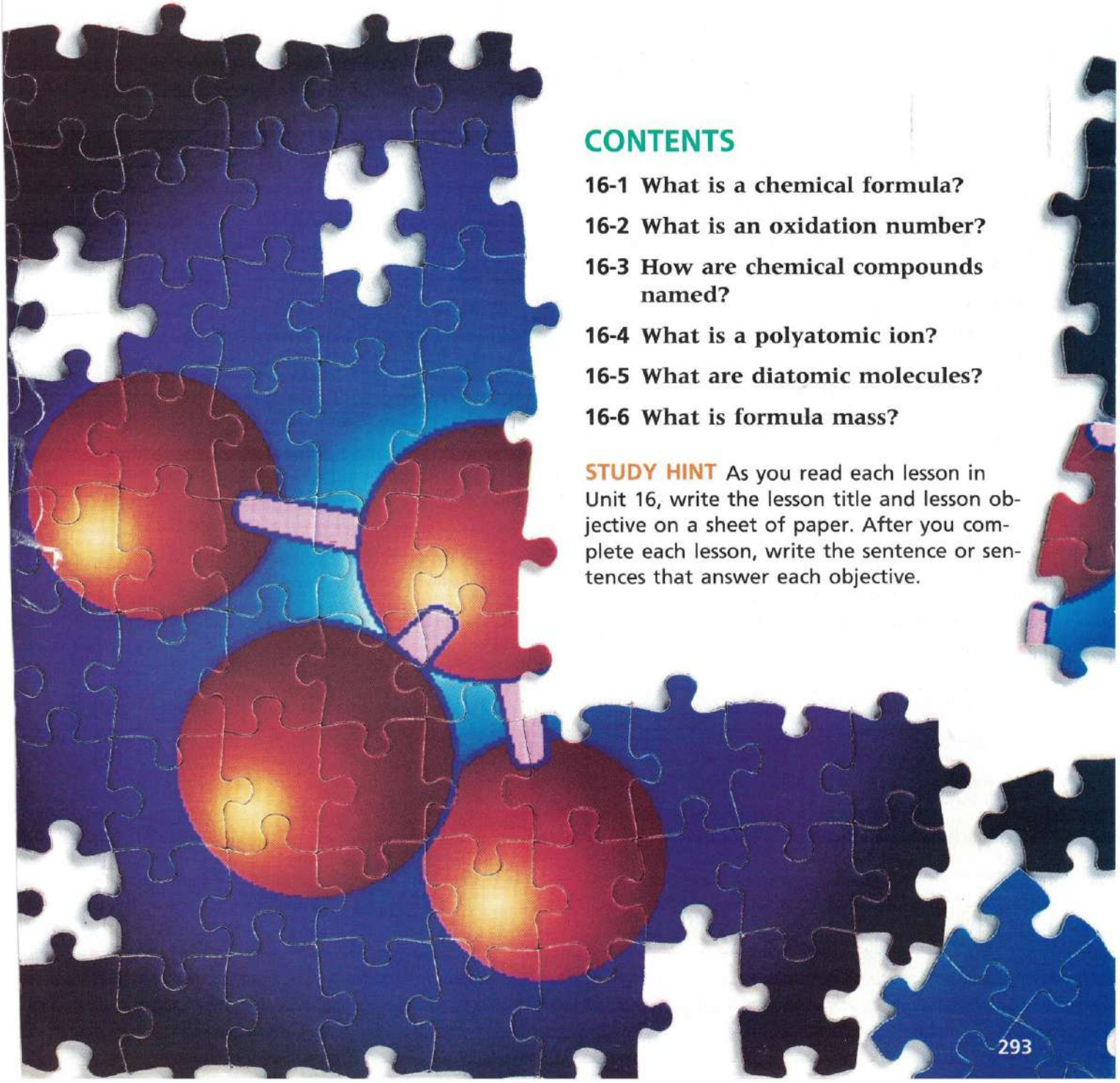
Table 1 **Common Polyatomic Ions**

POLYATOMIC ION	CHEMICAL FORMULA
Sulfate ion	SO_4^{-2}
Carbonate ion	CO_3^{-2}
Phosphate ion	PO_3^{-3}
Nitrate ion	NO_3^{-1}
Chlorate ion	ClO_3^{-1}

Analyze: What is the formula for a nitrate ion?

UNIT 16

CHEMICAL FORMULAS



CONTENTS

STUDY HINT As you read each lesson in Unit 16, write the lesson title and lesson objective on a sheet of paper. After you complete each lesson, write the sentence or sentences that answer each objective.