

Chemical Names and Formulas

3

Key Terms

monatomic ion
binary compound
nomenclature

oxyanion
salt

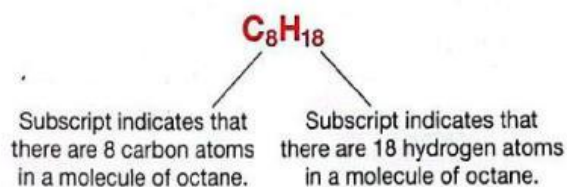
The total number of natural and synthetic chemical compounds runs in the millions. For some of these substances, certain common names remain in everyday use. For example, calcium carbonate is better known as limestone, and sodium chloride is usually referred to simply as table salt. And everyone recognizes dihydrogen monoxide by its popular name, water.

Unfortunately, common names usually give no information about chemical composition. To describe the atomic makeup of compounds, chemists use systematic methods for naming compounds and writing chemical formulas. In this chapter, you will be introduced to some of the rules used to identify simple chemical compounds.

MAIN IDEA

Formulas tell the number and kinds of atoms in a compound.

Recall that a chemical formula indicates the relative number of atoms of each kind in a chemical compound. For a molecular compound, the chemical formula reveals the number of atoms of each element contained in a single molecule of the compound, as shown below for the hydrocarbon octane. (*Hydrocarbons* are molecular compounds composed solely of carbon and hydrogen.)

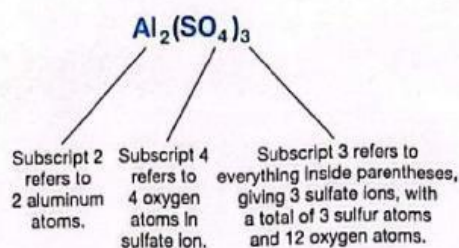


Unlike a molecular compound, an ionic compound consists of a lattice of positive and negative ions held together by mutual attraction. The chemical formula for an ionic compound represents one formula unit—the simplest ratio of the compound's positive ions (cations) and its negative ions (anions). The chemical formula for aluminum sulfate, an ionic compound consisting of aluminum cations and polyatomic sulfate anions, is written as shown on the next page.

SECTION 1

Main Ideas

- ▶ Formulas tell the number and kinds of atoms in a compound.
- ▶ Monatomic ions are made of only one type of atom.
- ▶ Binary compounds contain atoms of two elements.
- ▶ Some covalent compounds are a network with no single molecules.
- ▶ Acids are solutions of water and a special type of compound.



Note how the parentheses are used. They surround the polyatomic anion to identify it as a unit. The subscript 3 refers to the entire unit. Notice also that there is no subscript written next to the symbol for sulfur. When there is no subscript written next to an atom's symbol, the value of the subscript is understood to be 1.

MAIN IDEA

Monatomic ions are made of only one type of atom.

CHECK FOR UNDERSTANDING

Describe What characteristic atoms determines whether they exchange valence electrons (form an ionic compound) or share them (form a covalent compound)? Describe how this happens. Refer to the chapter "Chemical Bonding" for help.

By gaining or losing electrons, many main-group elements form ions with noble-gas configurations. For example, Group 1 metals lose one electron to give 1+ cations, such as Na^+ . Group 2 metals lose two electrons to give 2+ cations, such as Mg^{2+} . **Ions formed from a single atom are known as monatomic ions.** The nonmetals of Groups 15, 16, and 17 gain electrons to form anions. For example, in ionic compounds, nitrogen forms the 3- anion N^{3-} . The three added electrons plus the five outermost electrons in nitrogen atoms give a completed outermost octet. Similarly, the Group 16 elements oxygen and sulfur form 2- anions, and the Group 17 halogens form 1- anions.

Not all main-group elements readily form ions, however. Rather than gain or lose electrons, atoms of carbon and silicon form covalent bonds in which they share electrons with other atoms. Other elements tend to form ions that do not have noble-gas configurations. For instance, it is difficult for the Group 14 metals tin and lead to lose four electrons to achieve a noble-gas configuration. Instead, they tend to lose the two electrons in their outer *p* orbitals but retain the two electrons in their outer *s* orbitals to form 2+ cations. (Tin and lead can also form molecular compounds in which all four valence electrons are involved in covalent bonding.)

Elements from the *d*-block form 2+, 3+, or, in a few cases, 1+ or 4+ cations. Many *d*-block elements form two ions of different charges. For example, copper forms 1+ and 2+ cations. Iron and chromium each form 2+ cations as well as 3+ cations. And vanadium forms 2+, 3+, and 4+ cations.

Examples of Cations

K^+
Potassium cation

Mg^{2+}
Magnesium cation

Naming Monatomic Ions

Monatomic cations are identified simply by the element's name, as illustrated by the examples at left. Naming monatomic anions is slightly more complicated. First, the ending of the element's name is dropped. Then the ending *-ide* is added to the root name, as illustrated by the examples on the next page.

The names and symbols of the common monatomic cations and anions are organized according to their charges in Figure 1.1. The names of many of the ions in the table include Roman numerals. These numerals are part of the *Stock system* of naming chemical ions and elements. You will read more about the Stock system and other systems of naming chemicals later in this chapter.

Examples of Anions

Element	Anion
F Fluorine	F ⁻ Fluoride anion
N Nitrogen	N ³⁻ Nitride anion

FIGURE 1.1

SOME COMMON MONATOMIC IONS

Main-group elements

1+		2+		3+	
lithium	Li ⁺	beryllium	Be ²⁺	aluminum	Al ³⁺
sodium	Na ⁺	magnesium	Mg ²⁺		
potassium	K ⁺	calcium	Ca ²⁺		
rubidium	Rb ⁺	strontium	Sr ²⁺		
cesium	Cs ⁺	barium	Ba ²⁺		
1-		2-		3-	
fluoride	F ⁻	oxide	O ²⁻	nitride	N ³⁻
chloride	Cl ⁻	sulfide	S ²⁻	phosphide	P ³⁻
bromide	Br ⁻				
iodide	I ⁻				

d-Block elements and others with multiple ions

1+		2+		3+		4+	
copper(I)	Cu ⁺	vanadium(II)	V ²⁺	vanadium(III)	V ³⁺	vanadium(IV)	V ⁴⁺
silver	Ag ⁺	chromium(II)	Cr ²⁺	chromium(III)	Cr ³⁺	tin(IV)	Sn ⁴⁺
		manganese(II)	Mn ²⁺	iron(III)	Fe ³⁺	lead(IV)	Pb ⁴⁺
		iron(II)	Fe ²⁺	cobalt(III)	Co ³⁺		
		cobalt(II)	Co ²⁺				
		nickel(II)	Ni ²⁺				
		copper(II)	Cu ²⁺				
		zinc	Zn ²⁺				
		cadmium	Cd ²⁺				
		tin(II)	Sn ²⁺				
		mercury(II)	Hg ²⁺				
		lead(II)	Pb ²⁺				

Chemical Formulas and Chemical Compounds

CAREERS IN CHEMISTRY

Pharmacist

STEM

Pharmacists work in many areas of health care. Traditionally, they have dispensed medications in pharmacies. Today, pharmacists work with other health professionals to develop and implement customized drug treatment plans. They advise medical professionals on the side effects of and interactions between medicines. Increasingly, pharmacists are working in nontraditional settings, such as in managed-care companies, pharmaceutical companies, and governmental agencies. In these settings, pharmacists establish drug guidelines, conduct drug reviews, and assist in the research and development of new drugs.

CHECK FOR UNDERSTANDING

Describe In your own words, describe how to determine the subscripts of a binary ionic compound by using the oxidation numbers of the ions.

MAIN IDEA

Binary compounds contain atoms of two elements.

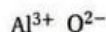
Compounds composed of two elements are known as **binary compounds**. In a binary ionic compound, the total numbers of positive charges and negative charges must be equal. Therefore, the formula for such a compound can be written given the identities of the compound's ions. For example, magnesium and bromine combine to form the ionic compound magnesium bromide. Magnesium, a Group 2 metal, forms the Mg^{2+} cation. Note that the $^{2+}$ in Mg^{2+} is written as a superscript. Bromine, a halogen, forms the Br^- anion when combined with a metal. In each formula unit of magnesium bromide, two Br^- anions are required to balance the $2+$ charge of the Mg^{2+} cation. The compound's formula must therefore indicate one Mg^{2+} cation and two Br^- anions. The symbol for the cation is written first.

Ions combined: Mg^{2+} , Br^- , Br^- *Chemical formula:* MgBr_2

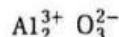
Note that the $_2$ in Br_2 is written as a subscript. The charges of the ions are not included in the formula. This is always the case when writing formulas for binary ionic compounds.

As an aid for determining subscripts in formulas for ionic compounds, the positive and negative charges can be "crossed over." Crossing over is a method of balancing the charges between ions in an ionic compound. For example, the formula for the compound formed by the aluminum ion, Al^{3+} , and the oxide ion, O^{2-} , is determined as follows.

1. Write the symbols for the ions side by side. Write the cation first.



2. Cross over the charges by using the absolute value of each ion's charge as the subscript for the other ion.



3. Check the subscripts and divide them by their greatest common factor to give the smallest possible whole-number ratio of ions. Then write the formula.

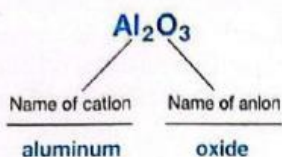
Multiplying the charge by the subscript shows that the charge on two Al^{3+} cations ($2 \times 3+ = 6+$) equals the charge on three O^{2-} anions ($3 \times 2- = 6-$). The greatest common factor of the subscripts is 1. The correct formula is therefore written as follows.



Naming Binary Ionic Compounds

The **nomenclature, or naming system**, of binary ionic compounds involves combining the names of the compound's positive and negative ions. The name of the cation is given first, followed by the name of the anion. For most simple ionic compounds, the ratio of the ions is not indicated in the compound's name, because it is understood based on the relative charges of the compound's ions.

The naming of a simple binary ionic compound is illustrated below for aluminum oxide. Notice that the known relative charges of each ion make specifying ratios in the name unnecessary.



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Writing Formulas For Ionic Compounds

Sample Problem A Write the formulas for the binary ionic compounds formed between the following elements:

- a. zinc and iodine b. zinc and sulfur

SOLVE

Write the symbols for the ions side by side. Write the cation first.

- a. $\text{Zn}^{2+} \text{I}^-$
b. $\text{Zn}^{2+} \text{S}^{2-}$

Cross over the charges to give subscripts.

- a. $\text{Zn}_1^2+ \text{I}_2^-$
b. $\text{Zn}_2^2+ \text{S}_2^{2-}$

Check the subscripts, and divide them by their greatest common factor to give the smallest possible whole-number ratio of ions. Then write the formula.

- a. The subscripts are mathematically correct because they give equal total charges of $1 \times 2+ = 2+$ and $2 \times 1- = 2-$. The greatest common factor of the subscripts is 1.

The smallest possible whole-number ratio of ions in the compound is therefore 1:2.

The subscript 1 is not written, so the formula is ZnI_2 .

- b. The subscripts are mathematically correct because they give equal total charges of $2 \times 2+ = 4+$ and $2 \times 2- = 4-$. The greatest common factor of the subscripts is 2.

The smallest whole-number ratio of ions in the compound is therefore 1:1.

The correct formula is ZnS .

Practice

Answers in Appendix E

1. Write formulas for the binary ionic compounds formed between the following elements:

- a. potassium and iodine d. aluminum and sulfur
b. magnesium and chlorine e. aluminum and nitrogen
c. sodium and sulfur

2. Name the binary ionic compounds indicated by the following formulas:

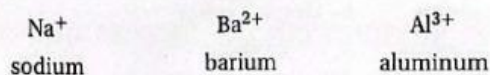
- a. AgCl d. SrF_2
b. ZnO e. BaO
c. CaBr_2 f. CaCl_2

The Stock System of Nomenclature

Some elements, such as iron, form two or more cations with different charges. To distinguish the ions formed by such elements, scientists use the Stock system of nomenclature. It is useful for distinguishing two different compounds formed by the same elements, as the lead oxides in Figure 1.2. This system uses a Roman numeral to indicate an ion's charge. The numeral in parentheses is placed *immediately* after the metal name.

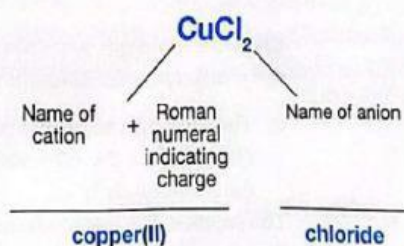


Names of metals that commonly form only one cation do *not* include a Roman numeral.



No element forms more than one monatomic anion.

Naming a binary ionic compound according to the Stock system is illustrated below.



1.2

Two Different Cations of a Metal

Two different cations of the same metal form two different compounds even when they combine with the same anion.

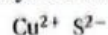


Naming Ionic Compounds

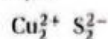
Sample Problem B Write the formula and give the name for the compound formed by the ions Cu^{2+} and S^{2-} .

SOLVE

Write the symbols for the ions side by side. Write the cation first.



Cross over the charges to give subscripts.



Check the subscripts, and write the formula.

The subscripts are correct because they give charges of $2 \times 2+ = 4+$ and $2 \times 2- = 4-$. The greatest common factor of the subscripts is 2, so the smallest whole-number ratio of the ions is 1:1. The formula is therefore CuS . As

Figure 1.1 shows, copper forms more than one ion. Therefore, the name of the 3+ copper ion must be followed by a Roman numeral indicating its charge.

The compound's name is **copper(II) sulfide**.

Practice

Answers in Appendix E

- Write the formula and give the name for the compounds formed between the following ions:
 - Cu^{2+} and Br^-
 - Fe^{2+} and O^{2-}
 - Pb^{2+} and Cl^-
 - Hg^{2+} and S^{2-}
 - Sn^{2+} and F^-
 - Fe^{3+} and O^{2-}
- Give the names for the following compounds:
 - CoI
 - FeS
 - Cu_2Se
 - PbO_2

Compounds Containing Polyatomic Ions

Figure 1.3 on the next page lists some common polyatomic ions. Most are negatively charged, and most are **oxyanions**—polyatomic ions that contain oxygen. Some elements can combine with oxygen to form more than one type of oxyanion. For example, nitrogen can form NO_3^- or NO_2^- . The name given a compound containing such an oxyanion depends on the number of oxygen atoms in the oxyanion. The name of the ion with the greater number of oxygen atoms ends in *-ate*. The name of the ion with the lesser number of oxygen atoms ends in *-ite*.



Chemical Formulas and Chemical Compounds

FIGURE 1.3

SOME POLYATOMIC IONS

1+		2+			
ammonium	NH_4^+	dimercury*	Hg_2^{2+}		
1-		2-		3-	
acetate	CH_3COO^-	carbonate	CO_3^{2-}	arsenate	AsO_4^{3-}
bromate	BrO_3^-	chromate	CrO_4^{2-}	phosphate	PO_4^{3-}
chlorate	ClO_3^-	dichromate	$\text{Cr}_2\text{O}_7^{2-}$		
chlorite	ClO_2^-	monohydrogen phosphate	HPO_4^{2-}		
cyanide	CN^-	oxalate	$\text{C}_2\text{O}_4^{2-}$		
dihydrogen phosphate	H_2PO_4^-	peroxide	O_2^{2-}		
hydrogen carbonate (bicarbonate)	HCO_3^-	sulfate	SO_4^{2-}		
hydrogen sulfate	HSO_4^-	sulfite	SO_3^{2-}		
hydroxide	OH^-				
hypochlorite	ClO^-				
nitrate	NO_3^-				
nitrite	NO_2^-				
perchlorate	ClO_4^-				
permanganate	MnO_4^-				

*The mercury(I) cation exists as two Hg^+ ions joined together by a covalent bond and is written as Hg_2^{2+} .

Sometimes, an element can form more than two types of oxyanions. In this case, the prefix *hypo-* is given to an anion that has one fewer oxygen atom than the *-ite* anion. The prefix *per-* is given to an anion that has one more oxygen atom than the *-ate* anion. This nomenclature is illustrated by the four oxyanions formed by chlorine.

ClO^-	ClO_2^-	ClO_3^-	ClO_4^-
hypochlorite	chlorite	chlorate	perchlorate

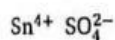
Compounds containing polyatomic ions are named in the same manner as binary ionic compounds. The name of the cation is given first, followed by the name of the anion. For example, the two compounds formed with silver by the nitrate and nitrite anions are named *silver nitrate*, AgNO_3 , and *silver nitrite*, AgNO_2 , respectively. When multiples of a polyatomic ion are present in a compound, the formula for the polyatomic ion is enclosed in parentheses.

Writing Formulas for Ionic Compounds

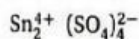
Sample Problem C Write the formula for tin(IV) sulfate.

SOLVE

Write the symbols for the ions side by side.
Write the cation first.



Cross over the charges to give subscripts. Add parentheses around the polyatomic ion if necessary.



Check the subscripts, and write the formula.

The total positive charge is $2 \times 4+ = 8+$. The total negative charge is $4 \times 2- = 8-$. The charges are equal. The greatest common factor of the subscripts is 2, so the smallest whole-number ratio of ions in the compound is 1:2. The correct formula is therefore $\text{Sn}(\text{SO}_4)_2$.

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Practice

- Write formulas for the following ionic compounds:
 - sodium iodide
 - calcium chloride
 - potassium sulfide
 - lithium nitrate
 - copper(II) sulfate
 - sodium carbonate
 - calcium nitrite
 - potassium perchlorate
- Give the names for the following compounds:
 - Ag_2O
 - $\text{Ca}(\text{OH})_2$
 - KClO_3
 - NH_4Cl
 - $\text{Fe}_2(\text{CrO}_4)_3$
 - KClO

Naming Binary Molecular Compounds

Unlike ionic compounds, molecular compounds are composed of individual covalently bonded units, or molecules. Chemists use two nomenclature systems to name binary molecules. The newer system is the Stock system for naming molecular compounds, which requires an understanding of oxidation numbers. This system will be discussed in Section 2.

The old system of naming molecular compounds is based on the use of prefixes. For example, the molecular compound CCl_4 is named carbon *tetrachloride*. The prefix *tetra-* indicates that four chloride atoms are present in a single molecule of the compound. The two oxides of carbon, CO and CO_2 , are named carbon *monoxide* and carbon *dioxide*, respectively. These prefix-based names are often the most widely recognized names for some molecular compounds. However, either naming system is acceptable, unless specified otherwise.

FIGURE 1.4

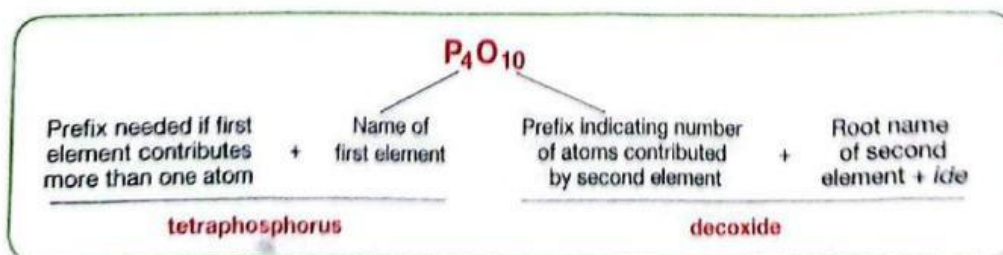
NUMERICAL PREFIXES	
Number	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

In these names, the prefix *mon-* (from *mono-*) indicates one oxygen atom, and the prefix *di-* indicates two oxygen atoms. The prefixes used to specify the number of atoms in a molecule are listed in Figure 1.4.

The rules for the prefix system of nomenclature of binary molecular compounds are as follows.

1. The element that has the smaller group number is usually given first. If both elements are in the same group, the element whose period number is greater is given first. The element is given a prefix only if it contributes more than one atom to a molecule of the compound.
2. The second element is named by combining (a) a prefix indicating the number of atoms contributed by the element, (b) the root of the name of the element, and (c) the ending *-ide*. With few exceptions, the ending *-ide* indicates that a compound contains only two elements.
3. The *o* or *a* at the end of a prefix is usually dropped when the word following the prefix begins with another vowel. For example, one would write *monoxide* and *pentoxide* instead of *mono-oxide* and *penta-oxide*.

The prefix system is illustrated below.



In general, the order of nonmetals in binary compound names and formulas is C, P, N, H, S, I, Br, Cl, O, and F.

FIGURE 1.5

BINARY COMPOUNDS OF NITROGEN AND OXYGEN

Formula	Prefix-system name
N_2O	dinitrogen monoxide
NO	nitrogen monoxide
NO_2	nitrogen dioxide
N_2O_3	dinitrogen trioxide
N_2O_4	dinitrogen tetroxide
N_2O_5	dinitrogen pentoxide

The prefix system is illustrated further in Figure 1.5, which lists the names of the six oxides of nitrogen. Note the application of rule 1, for example, in the name *nitrogen dioxide* for NO_2 . No prefix is needed with *nitrogen* because only one atom of nitrogen is present in a molecule of NO_2 . On the other hand, according to rule 2, the prefix *di-* in *dioxide* is needed to indicate the presence of two atoms of oxygen. Take a moment to review the prefixes in the other names in Figure 1.5.

 CHECK FOR UNDERSTANDING

Explain You have learned several ways to name compounds. Explain why it is necessary to have so many different methods of nomenclature.

Naming Binary Molecular Compounds

- Sample Problem D**
- Give the name for As_2O_5 .
 - Write the formula for oxygen difluoride.

 SOLVE

- A molecule of the compound contains two arsenic atoms, so the first word in the name is *diarsenic*. The five oxygen atoms are indicated by adding the prefix *pent-* to the word *oxide*. The complete name is *diarsenic pentoxide*.
- The first symbol in the formula is that for oxygen. Oxygen is first in the name because it is less electronegative than fluorine. Since there is no prefix, there must be only one oxygen atom. The prefix *di-* in *difluoride* shows that there are two fluorine atoms in the molecule. The formula is OF_2 .

Practice

Answers in Appendix E

- Name the following binary molecular compounds:
 - SO_3
 - ICl_3
 - PBr_5
- Write formulas for the following compounds:
 - carbon tetraiodide
 - phosphorus trichloride
 - dinitrogen trioxide

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▶ MAIN IDEA

Some covalent compounds are a network with no single molecules.

Some covalent compounds do not consist of individual molecules. Instead, each atom is joined to all its neighbors in a covalently bonded, three-dimensional network. There are no distinct units in these compounds, just as there are no such units in ionic compounds. The subscripts in a formula for a covalent-network compound indicate the smallest whole-number ratio of the atoms in the compound. Naming such compounds is similar to naming molecular compounds. Some common examples are given below.

SiC	SiO ₂	Si ₃ N ₄
silicon carbide	silicon dioxide	trisilicon tetranitride

▶ MAIN IDEA

Acids are solutions of water and a special type of compound.

An *acid* is a distinct type of molecular compound. Most acids used in the laboratory can be classified as either binary acids or oxyacids. *Binary acids* are acids that consist of two elements, usually hydrogen and one of the halogens— fluorine, chlorine, bromine, iodine. *Oxyacids* are acids that contain hydrogen, oxygen, and a third element (usually a nonmetal).

Acids were first recognized as a specific class of compounds based on their properties in solutions of water. Consequently, in chemical nomenclature, the term *acid* usually refers to a solution in water of one of these special compounds rather than to the compound itself. For example, *hydrochloric acid* refers to a water solution of the molecular compound hydrogen chloride, HCl. Some common binary and oxyacids are listed in Figure 1.6. Figure 1.7 shows some common laboratory acids.

Many polyatomic ions are produced by the loss of hydrogen ions from oxyacids. A few examples of the relationship between oxyacids and oxyanions are shown below.

sulfuric acid	H ₂ SO ₄	sulfate	SO ₄ ²⁻
nitric acid	HNO ₃	nitrate	NO ₃ ⁻
phosphoric acid	H ₃ PO ₄	phosphate	PO ₄ ³⁻

1.6

COMMON BINARY ACIDS AND OXYACIDS

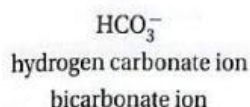
hydrofluoric acid	HNO ₂	nitrous acid	HClO	hypochlorous acid
hydrochloric acid	HNO ₃	nitric acid	HClO ₂	chlorous acid
hydrobromic acid	H ₂ SO ₃	sulfurous acid	HClO ₃	chloric acid
hydriodic acid	H ₂ SO ₄	sulfuric acid	HClO ₄	perchloric acid
phosphoric acid	CH ₃ COOH	acetic acid	H ₂ CO ₃	carbonic acid

FIGURE 1.7

Common Acids Some common laboratory acids are nitric acid, hydrochloric acid, and sulfuric acid. Acids should always be handled with care and according to instructions. They can burn holes in skin or clothing.



An ionic compound composed of a cation and the anion from an acid is often referred to as a **salt**. Table salt, NaCl , contains the anion from hydrochloric acid. Calcium sulfate, CaSO_4 , is a salt containing an anion from sulfuric acid. Some salts contain anions in which one or more hydrogen atoms from the acid are retained. Such anions are named by adding the word *hydrogen* or the prefix *bi-* to the anion name. The best known such anion comes from carbonic acid, H_2CO_3 .



SECTION 1 FORMATIVE ASSESSMENT

Reviewing Main Ideas

- What is the significance of a chemical formula?
- Write formulas for the compounds formed between the following:
 - aluminum and bromine
 - sodium and oxygen
 - magnesium and iodine
 - Pb^{2+} and O^{2-}
 - Sn^{2+} and I^-
 - Fe^{3+} and S^{2-}
 - Cu^{2+} and NO_3^-
 - NH_4^+ and SO_4^{2-}

- Name the following compounds by using the Stock system:

- | | | |
|-----------------|-------------------------|--------------------|
| a. NaI | c. CaO | e. CuBr |
| b. MgS | d. K_2S | f. FeCl_2 |

- Write formulas for each of the following compounds:

- | | |
|--------------------------|----------------------|
| a. sodium hydroxide | e. carbon diselenide |
| b. lead(II) nitrate | f. acetic acid |
| c. iron(II) sulfate | g. chloric acid |
| d. diphosphorus trioxide | h. sulfurous acid |

Critical Thinking

- RELATING IDEAS** Draw the Lewis structure, give the name, and predict VSEPR geometry of SCl_2 .