Reflect

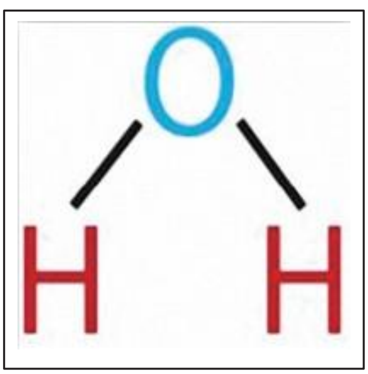
Have you ever listened to people speak a language that you can't speak? Did you know what they were talking about?

Just as people from different cultures have trouble communicating if they don't share a language, scientists need a common language to communicate with each other. In the early 1900s, scientists were rapidly discovering new chemical substances. Chemists needed a method for naming these substances, so they developed a standard system, or nomenclature. Nomenclature refers to a system for naming things. The nomenclature used by all scientists to name and talk about chemicals was developed by the International Union of Pure and Applied Chemistry (IUPAC). In this companion, we will refer to the IUPAC rules for naming chemicals.

Why is it important that all scientists use the same nomenclature for naming and talking about chemical substances?

Chemical Formulas of Compounds

The name of each chemical element can be abbreviated as a unique chemical symbol. For example, the chemical symbol for the simplest element, hydrogen, is H. The chemical symbol for helium is He, and the chemical symbol for hafnium is Hf. During chemical reactions, elements come together to form different compounds. Scientists represent these compounds by writing *chemical formulas*. In a chemical formula, the chemical symbols indicate the types of elements that make up a compound, and **subscripts** represent the quantity of each type of element in the compound.



A water molecule (H_2O) contains two hydrogen atoms (H) and one oxygen atom (O).

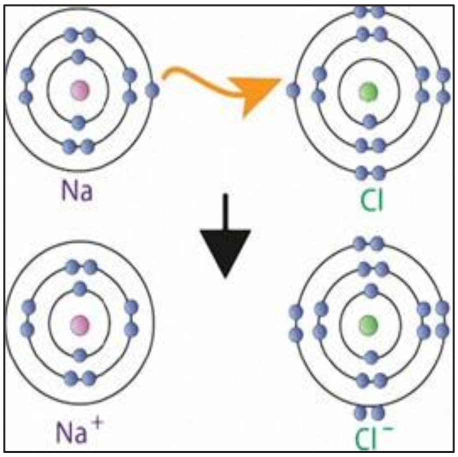
For example, the chemical formula for water is H_2O. This formula means that a water molecule contains both hydrogen (H) and oxygen (O). The subscript "2" means that each molecule of water contains two hydrogen atoms. There is no subscript beside the letter "O," so each water molecule contains only one oxygen atom.

Chemical formulas can be written for both ionic and covalent compounds.

subscript: a small number placed slightly below and to the right of a symbol that it describes

Ionic Compounds: An *ionic compound* forms when atoms bond by gaining or losing electrons. This type of compound usually forms between a metal and a nonmetal. A metal atom donates one or more electrons to a nonmetal. The result is a positively charged **ion,** called a *cation*, and a negatively charged ion, called an *anion*. The cation and anion are joined by an *ionic* bond. The total number of electrons lost by the cation (or cations) must equal the total number of electrons gained by the anion (or anions) to form a neutral ionic bond. The smallest unit of an ionic compound is called a *formula unit*.

Ion: an atom or a molecule with an electric charge



A sodium atom (Na) donates an electron to a chlorine atom (Cl). The result is an ionic bond between a positively charged sodium ion, or cation (Na^+), and a negatively-charged chlorine ion, or anion (Cl^-).

A familiar ionic compound is sodium chloride, which is commonly called table salt. Each formula unit of sodium chloride is made from one sodium cation and one chlorine anion. A neutral sodium atom (Na) has one valence electron, and a neutral chlorine atom (Cl) has seven valence electrons. The sodium atom donates one electron to the chlorine atom so that each ion now has a complete outer valence shell of electrons. The chemical formula is written NaCl. Notice that neither symbol has a subscript.

This means each formula unit of sodium chloride is composed of one atom of each element.

valence electron: an electron found in an atom's outer electron shell

An ionic bond can also form between atoms of magnesium (Mg) and chlorine (Cl). A magnesium atom has two valence electrons to donate, but chlorine needs only one electron to complete its outer valence shell. To create a neutral ionic compound, one magnesium atom must donate one electron each to two chlorine atoms. The chemical formula for this compound, magnesium chloride, is $MgCl_2$. In other words, each formula unit of magnesium chloride has one magnesium ion and two chlorine ions. No matter how large the sample of magnesium chloride, the ratio of magnesium to chlorine ions will always be 1:2.

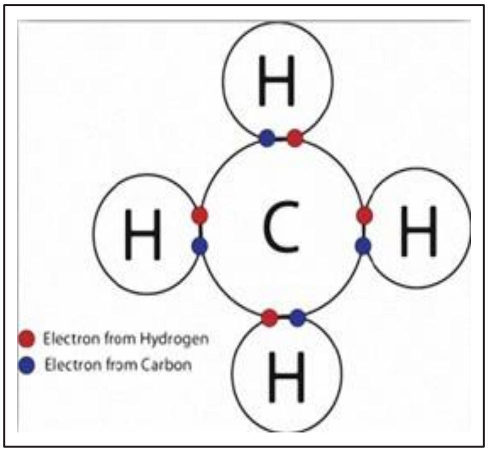
Balancing the charges in an ionic compound is not always simple. For example, an ionic compound can form between aluminum (Al) and oxygen (O). The aluminum cation has a 3+ charge, and the oxygen anion has a 2– charge. In order for the overall charge to be neutral, two aluminum cations and three oxygen anions must be present in each formula unit:

- For aluminum: 2 × (3+) = 6+
- For oxygen: 3 × (2–) = 6–

The resulting compound, aluminum oxide, has the chemical formula Al_2O_3.

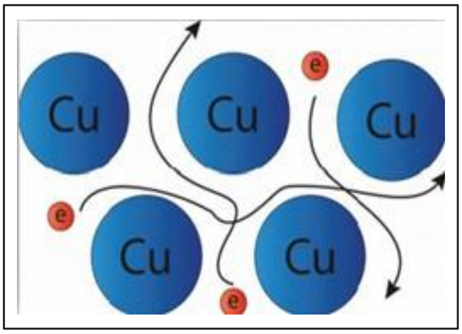
Covalent Compounds: A *covalent compound* forms when atoms bond by sharing electrons. This type of compound usually forms between two or more nonmetal elements. Most nonmetals are found on the upper-right side of the periodic table. (The exception is hydrogen, which is also a nonmetal and is found in many covalent compounds.) Each atom in a covalent compound shares one or more electrons with a neighboring atom, forming a *covalent bond*. The smallest unit of a covalent compound is called a *molecule*.

In covalent compounds, atoms share electrons to achieve a full valence shell. For example, a molecule of methane (shown at right) is composed of one atom of carbon (C) and four atoms of hydrogen (H). A carbon atom has four valence electrons, and a hydrogen atom has one valence electron. The carbon atom shares one of its electrons with each hydrogen atom, and each hydrogen atom shares its one electron with the carbon atom. This completes the valence orbitals for the carbon atom and each hydrogen atom. The chemical formula of methane is CH_4.



Look Out!

In addition to covalent and ionic bonds, a third type of chemical bond exists called a *metallic bond*. This type of bond exists between metals. In metallic bonds, electrons are not held tightly by one atom's nucleus. Instead, the electrons are free to move from one nucleus to another. Because the atom does not hold on to its valence electrons, the metal atoms are actually positively charged ions. Do not confuse metallic bonds with ionic bonds. Although ions form in each bond type, metallic bonds form only among metal atoms, while ionic bonds form between metal and nonmetal atoms.



In this metallic bond among copper (Cu) atoms, valence electrons can move from one nucleus to another.

Naming Ionic Compounds

The IUPAC rules for naming all chemical compounds have been established so that a particular compound can be clearly identified. When naming ionic compounds, the cation is named first, followed by the anion. The following rules can be applied for naming the ions.

- **Monatomic Ions**: Monatomic ions are formed from one atom. The table at right lists some common monatomic ions. In most cases, the name of a monatomic cation is the same as the name of the atom. An anion's suffix, however, is changed to "–ide." The ionic compound NaCl is therefore named sodium chloride. The rule for naming ionic compounds that contain more than one of the same type of ion is similar. For example, $CaCl_2$ is formed from one calcium cation and two chloride anions. It is named calcium chloride.
- **Monatomic Ions of Metals That Form More Than One Type of Ion**: Many transition metals and metals on the right of the periodic table can form cations with different charges. When naming these cations, it is important to differentiate between the ions with different charges. Roman numerals are placed in the chemical name to indicate the correct charge per ion of the cation. The table below shows common examples.

Common Monatomic Ions	
Ion	**Name**
Na^+	sodium
Mg^{2+}	magnesium
Al^{3+}	aluminum
F^-	fluoride
Cl^-	chloride
O^{2-}	oxide
S^{2-}	sulfide

Common Monatomic Ions for Metals with More Than One Ion			
Ion	**Name**	**Ion**	**Name**
Cr^{2+}	chromium(II)	Pb^{2+}	lead(II)
Cr^{3+}	chromium (III)	Pb^{4+}	lead(IV)
Cu^+	copper(I)	Hg_2^{2+}	mercury(I)
Cu^{2+}	copper(II)	Hg^{2+}	mercury(II)
Fe^{2+}	iron(II)	Sn^{2+}	tin(II)
Fe^{3+}	iron(III)	Sn^{4+}	tin(IV)

- **Polyatomic Ions**: An ion formed from multiple atoms is known as a *polyatomic ion*. In polyatomic ions, nonmetal atoms form covalent bonds that satisfy the **octet rule**. The group of atoms, however, has a net positive or negative charge because the number of electrons in the overall structure does not equal the number of protons. The following rules are helpful for identifying polyatomic ions:

octet rule: the tendency of elements to form compounds by gaining, losing, or sharing electrons so that each atom has eight electrons in its valence shell

1. If *two* ions are composed of the same nonmetal and different numbers of oxygen atoms, the ion with more oxygen atoms is named the root of the nonmetal with the suffix *-ate*. The other ion is named the root of the nonmetal with the suffix *-ite*.
2. If *four* ions are composed of the same nonmetal and different numbers of oxygen atoms, they all are named with the root of the nonmetal, but the ion with the greatest number of oxygen atoms has the prefix *per-* and the suffix *-ate*.
   a. The ion with one fewer oxygen atoms has no prefix but has the suffix *-ate*.
   b. The ion with two fewer oxygen atoms has no prefix but has the suffix *-ite*.
   c. The ion with the least number of oxygen atoms has the prefix *hypo-* and the suffix *-ite*.

Common Polyatomic Ions			
Ion	**Name**	**Ion**	**Name**
CH_3COO^-	acetate	H_3O^+	hydronium
NH_4^+	ammonium	NO_2^-	nitrite
CN^-	cyanide	NO_3^-	nitrate
OH^-	hydroxide	ClO_4^-	perchlorate
SO_3^{2-}	sulfite	ClO_3^-	chlorate
SO_4^{2-}	sulfate	ClO_2^-	chlorite
CO_3^{2-}	carbonate	ClO^-	hypochlorite

One or both of the ions in an ionic compound may be polyatomic. As usual, the cation is written first followed by the name of the anion. Because the ionic compound must be neutral, more than one polyatomic ion may be needed to balance the charges. In this case, parentheses are used around the entire ion, and a subscript indicates the number of ions. For example, the formula for ammonium sulfate is $(NH_4)_2SO_4$. Each molecule includes two ammonium ions and one sulfate ion.

Naming Covalent Compounds

IUPAC rules also exist for naming covalent compounds. In formulas for covalent compounds, the chemical symbols usually follow the order of elements—from left to right or top to bottom—on the periodic table. When naming covalent compounds containing two or more elements, the element that appears first in the chemical formula is named first. The suffix -*ide* is added to the root of the last element's name, just as it is for ionic compounds.

A prefix is also added to each elemental name to denote the number of atoms of each element in the molecule. The table at right lists these prefixes. However, if the molecule contains only one atom of an element, the prefix mono- is often omitted.

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

For example, a covalent compound containing five atoms of oxygen and two atoms of nitrogen in each molecule is N_2O_5. There are two atoms of the first element (nitrogen) and five atoms of the second element (oxygen). The compound's chemical name is dinitrogen pentoxide. It is important to remember that some compounds have common names that are used more often. For example, H_2O—dihydrogen monoxide (or simply dihydrogen oxide)—is almost always called water.

Naming Acids and Bases

In addition to ionic and covalent compounds, IUPAC has established rules for naming acids and bases. An acid is a substance that donates positive hydrogen ions (H+), and a base is a substance that accepts hydrogen ions. The naming of acids and bases follows a set of rules similar to the nomenclature rules of other types of compounds.

First, let's investigate the nomenclature rules for two different types of acids.

- **Binary Acids**: A *binary acid* contains a hydrogen atom and a nonmetal. HCl (hydrogen and chlorine) and HI (hydrogen and iodine) are examples of binary acids. When naming these acids, the prefix *hydro*- is added to the root of the nonmetal, followed by the suffix *-ic*. The word "acid" is then added. So the name of the binary acid HCl is hydrochloric acid, and the name of HI is hydroiodic acid.
- **Oxyacids**: An *oxyacid* is an acid that contains at least one hydrogen atom and a polyatomic ion containing oxygen. Common examples of oxyacids are H_2SO_4 and HNO_2. If name of the polyatomic ion contains an *-ate* suffix, the suffix is changed to *-ic*. If the name of the polyatomic ion contains an *-ite* suffix, the suffix is changed to *-ous*. The word "acid" is then added. For example, H_2SO_4 contains a sulfate ion (SO_4^{2-}), so it is named sulfuric acid. HNO_2 contains a nitrite ion (NO_2^-), so its name is nitrous acid. The prefix *hydro*- is not used in naming oxyacids.

Finally, let's describe the naming conventions of substances that are bases. Bases are named according to the nature of the base.

- **Bases That Are Ionic Compounds**: Commonly, bases contain hydroxide ions (OH^-). These bases are *metal hydroxides*. They are named in the same way that ionic compounds are named. The cation is named first, followed by the anion, with a suffix *-ide*. Sodium hydroxide (NaOH) and magnesium hydroxide ($Mg(OH)_2$) are examples of bases that are also ionic compounds.

- **Bases That Are Covalent Compounds**: Not all bases include a hydroxide ion. These bases are named in the same way that covalent compounds are named. Prefixes that denote the number of atoms are used for each element, and the suffix -*ide* is added to the second element in the formula. For example, you may be familiar with ammonia, a base with the chemical formula NH_3. Using IUPAC nomenclature rules, NH_3 is called trihydrogen mononitride, or simply trihydrogen nitride.

Reflect

Take a look at the following formulas. Which formula represents carbonic acid? Which represents calcium hydroxide? Which represents carbonous acid? You can check your answers before the What Do You Know? section of this companion.

$Ca(OH_2)$ $H_2CO_2H_2CO_3$

Scientists in the Spotlight:
International Union of Pure and Applied Chemistry
In the late 1800s and early 1900s, scientists in both industry and academia were discovering new elements and compounds at a rapid pace. A standardized nomenclature was needed to name these compounds. In 1919, a group of chemists formed the International Union of Pure and Applied Chemistry (IUPAC) to create a method of standardization in chemistry. This organization created not only the chemical nomenclature system to describe elements and compounds, but it also served to standardize methods for weights and measurements.

Today, the IUPAC is an organization made of chemists from all parts of the world. More than 85% of the world's chemical industries and research facilities are affiliated with IUPAC. IUPAC publishes a series of books that describe the naming system for different areas of specialty in chemistry: inorganic, organic, and biochemistry. Because newly discovered compounds may fall into more than one area of naming system, IUPAC may propose the naming system or a modified naming system in which these compounds should be named. IUPAC encourages the exchange of chemical information and knowledge among scientists in different areas of specialization.

What Do You Think?

Did you correctly identify the compounds? $Ca(OH)_2$ is calcium hydroxide, H_2CO_2 is carbonous acid, and H_2CO_3 is carbonic acid.

Try Now

What do you know?
Take a look at the chemical formula for each of the compounds in the table below. First, determine whether each formula represents an ionic compound or a covalent compound. Write your answer in the middle column. If the formula represents an acid or a base, include that information in the middle column also. Then using the IUPAC naming conventions, determine the name of each compound. Write the name of each compound in the third column.

Compound	Type of Compound	Name of Compound
$CaBr_2$		
ICl		
FeO		
CCl_4		
SO_3		
HNO_3		
$Al(OH)_3$		
Fe_2O_3		
P_2O_5		
K_2O		
$Cu(OH)_2$		
$NaNO_3$		
H_2CO_3		

Connecting With Your Child

Chemical Nomenclature Around the Home
To help your child learn more about chemical nomenclature, find at least five household products made from ionic or covalent compounds that can be named from the rules described in this lesson. Examples of possible household chemicals include table salt (sodium chloride:

- NaCl), Epsom salt (magnesium sulfate: $MgSO_4$), baking soda (sodium bicarbonate: $NaHCO_3$), and bleach (sodium hypochlorite:
- NaClO). The chemical compounds can also be one or many of the ingredients in household products. Possible sources for chemical compounds include soap, shampoo, conditioner, cleaning supplies, and toothpaste. Encourage your child to research the identified compounds using books or the Internet (the website of the IUPAC is a good place to begin). Record the chemical formula and the chemical name of each compound. Make sure to follow the IUPAC naming system of the compounds.

Here are some questions to discuss with your child:

1. How do you know which elements are present in the compound?
2. How do you know how many of each type of element are present in the compound?
3. How can you identify the name of the compound?
4. Is the compound ionic or covalent? Is it acidic or basic?
5. Do the chemical compounds you have identified have more common names? (For example, the common name of sodium bicarbonate is baking soda.)