CHAPTER

3

Names, Formulas and Equations

Have you ever listened to people speaking a language you didn't understand? To you, it probably seemed just a collection of meaningless sounds, but, to the speakers, the language was perfectly intelligible. The language chemists use is much like a foreign language. An equation like

$$4\,Fe + 3\,O_2 \longrightarrow 2\,Fe_2O_3$$

probably won't mean much to you unless you already have some knowledge of chemical equations. But, if we translated the chemical symbols into English—"iron combines with oxygen (air) to form iron rust—you'd probably understand.

There are two ways to find out what is being said in a foreign language: you can hire a translator or you can learn to understand the language yourself. To enable you to learn the language of chemistry (so you won't have to depend on a translator), we offer in this chapter a short, intensive course. It won't make you a chemist, but it will make it possible for you to understand a little more of what those mysterious strangers—the chemists—are talking about.

One minor caution before we proceed: the language of chemists often is closely related to that spoken by mathematicians. Don't worry, though; the math that we use is much like the arithmetic you use in everyday life. So hang in there. Before you know it, you, too, will be able to speak the language of chemists.

SECTION

3.1 Names and Symbols for Simple Ions

In Chapter _, we introduced chemical symbols. A symbol of one or two letters is used to represent each of the chemical elements. If you have not yet memorized the list in Table , you should do so now. You will save time in the long run.

how certain metals (those from the left side of the periodic chart) react with nonmetals (those from the right side) to form ionic compounds. Recall that in forming compounds each atom of metal tends to give up the electrons in its outer shell, and each atom of nonmetal takes on enough electrons to complete its valence shell. For example, aluminum atoms with three electrons in their outermost energy levels give up three electrons to form triply charged ions. In electron-dot symbols this reaction may be written

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

Oxygen, with six electrons in its outermost energy level, tends to acquire two more.

$$:\ddot{O}\cdot + 2\,e^- \longrightarrow :\ddot{O}:^{2-}$$

Figure The use of symbols is not unique to chemistry. Symbols can be quite helpful—when you know what they mean.

Table Symbols and Names for Some Simple Ions

Group	Element	Name of Ion	Symbol for Ion
IA	Hydrogen	Hydrogen ion*	H^+
	Lithium	Lithium ion	Li^+
	Sodium	Sodium ion	Na^+
	Potassium	Potassium ion	K^+
IIA	Magnesium	Magnesium ion	Mg^{2+}
	Calcium	Calcium ion	Ca^{2+}
IIIA	Aluminum	Aluminum ion	Al^{3+}
VA	Nitrogen	Nitride ion	N^{3-}
VIA	Oxygen	Oxide ion	O^{2-}
	Sulfur	Sulfide ion	S^{2-}
VIIA	Fluorine	Fluoride ion	F^-
	Chlorine	Chloride ion	Cl^-
	Bromine	Bromide ion	Br^-
	Iodine	Iodide ion	I^-
IB	Copper	Copper(I) ion (cuprous ion)	Cu^+
		Copper(II) ion (cupric ion)	Cu^{2+}
	Silver	Silver ion	Ag^+
IIB	Zinc	Zinc ion	Zn^{2+}
VIIIB	Iron	Iron(II) ion (ferrous ion)	Fe^{2+}
		Iron(III) ion (ferric ion)	Fe^{3+}

*Does not exist independently in aqueous solution.

The charged atoms formed by the gain or loss of electrons are called *ions*. Table lists symbols and names for some simple ions formed in this manner. Note that the charge on an ion of a Group IA element is

1+ (usually written simply as +). The charge on an ion of a Group IIA element is 2+, and the charge on an ion of a Group IIIA element is 3+. You can calculate the charge on the negative ions in the table by subtracting 8 from the group number. For example, the charge on the oxide ion (oxygen is in Group VIA) is $6 - 8 = -2$. The charge on a nitride ion (nitrogen is in Group VA) is $5 - 8 = -3$.

There is no simple way to determine the most likely charge on ions formed from Group VIII elements and from those in B subgroups. Indeed, you may have noticed that these can form ions with different charges. In such cases, chemists use roman numerals with the names to indicate the charge. Thus, *iron(II) ion* means Fe^{2+} and *iron(III) ion* means Fe^{3+}. In an older system of terminology, Fe^{2+} was called a *ferrous ion* and Fe^{3+} was called a *ferric ion*. See similar terms for the two copper ions in Table .

Names of simple positive ions (*cations*) are derived from those of their parent elements by the addition of the word *ion*. A sodium atom (Na), upon losing an electron, becomes a *sodium ion* (Na^+). A magnesium atom (Mg), upon losing two electrons, becomes a *magnesium ion* (Mg^{2+}). Names of simple negative ions (*anions*) are derived from those of their parent elements by changing the usual ending to *-ide* and adding the word *ion*. A chlor*ine* atom (Cl), upon gaining an electron, becomes a chlor*ide ion* (Cl^-). A sulf*ur* atom (S), upon gaining two electrons, becomes a sulf*ide ion* (S^{2-}).

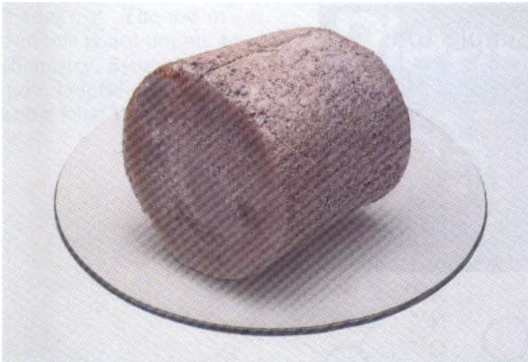


Figure Ions differ greatly from the atoms from which they are made. Sodium atoms are the constituents of a soft, highly reactive metal. Chlorine atoms—paired in chlorine molecules—make up a corrosive greenish yellow gas. Sodium ions and chloride ions make up ordinary table salt. [*Left photos copyright Richard Megna/Fundamental Photographs; above copyright Dr. E. R. Degginger.*]

We cannot emphasize too strongly the difference between ions and the atoms from which they are made. They are as different as a whole peach (an atom) and a peach pit (an ion). The names and symbols may look a lot alike, but the substances themselves are quite different. Unfortunately, the situation is confused because people talk about needing "iron" to perk up "tired blood" and "calcium" for healthy teeth and bones. What they really mean is iron(II) *ions* (Fe^{2+}) and calcium *ions* (Ca^{2+}). You wouldn't think of eating iron nails to get "iron." Nor would you eat highly reactive calcium metal. Although careful distinction is not always made by persons who are not chemists, we try to use precise terminology here.

SECTION 3.2

Formulas and Names for Binary Ionic Compounds

Simple ions of opposite charge can be combined to form **binary** (two-component) **compounds**. To get the correct formula for a binary compound, simply write each ion with its charge (positive ion to the left), then cross over the numbers (but not the plus or minus signs) and write them as subscripts. The process is best learned by practice.

EXAMPLE

Give the formula for calcium chloride.

SOLUTION

First, write the symbols for the ions.

$$Ca^{2+} \qquad Cl^{1-}$$

Then cross over the numbers as subscripts.

$$Ca^{2+} \quad Cl^{1-} \qquad \text{gives} \qquad Ca_1^{2+}Cl_2^{-}$$

Then rewrite the formula, dropping the charges. The formula for calcium chloride is

$$Ca_1Cl_2 \qquad \text{or} \qquad CaCl_2$$

Exercise

Give the formula for potassium oxide.

Note that the cross-over method works because it is based on the transfer of electrons and the conservation of charge. Two aluminum atoms lose three electrons each (that's six electrons lost), and three oxygen atoms gain two electrons each (that's six electrons gained). Electrons lost equal electrons gained, and all is well. Similarly, two aluminum ions have six positive charges (three each) and three oxide ions have six negative charges (two each). The net charge on aluminum oxide is 0, just as it should be.

EXAMPLE

Give the formula for aluminum oxide.

SOLUTION

Write the symbols for the ions.

$$Al^{3+} \qquad O^{2-}$$

Cross over the numbers as subscripts.

$$Al^{3+} \quad O^{2-} \qquad \text{gives} \qquad Al_2^{3+}O_3^{2-}$$

Then rewrite the formula, dropping the charges. The formula for aluminum oxide is

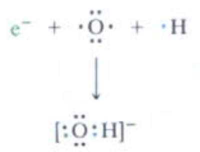
$$Al_2O_3$$

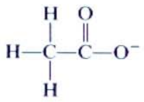
Exercise

Give the formula for calcium nitride.

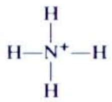
SECTION 3.3 Polyatomic Ions

Many compounds contain both ionic and covalent bonds. Sodium hydroxide, commonly known as lye, consists of sodium ions (Na^+) and hydroxide ions (OH^-). The hydroxide ion contains an oxygen atom covalently bonded to a hydrogen atom, plus an "extra" electron. Whereas the sodium atom becomes a cation by giving up an electron, the hydroxide group becomes an anion by gaining an electron.

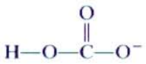




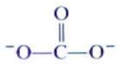
Acetate ion



Ammonium ion



Hydrogen carbonate ion
(Bicarbonate ion)



Carbonate ion

Nitrite ion

Figure Polyatomic ions have both covalent bonds (*dashes*) and ionic charges (+ or −).

Table Some Common Polyatomic Ions

Charge	Name	Formula
1+	Ammonium ion	NH_4^+
	Hydronium ion	H_3O^+
1−	Hydrogen carbonate (bicarbonate) ion	HCO_3^-
	Hydrogen sulfate (bisulfate) ion	HSO_4^-
	Acetate ion	$CH_3CO_2^-$ (or $C_2H_3O_2^-$)
	Nitrite ion	NO_2^-
	Nitrate ion	NO_3^-
	Cyanide ion	CN^-
	Hydroxide ion	OH^-
	Dihydrogen phosphate ion	$H_2PO_4^-$
	Permanganate ion	MnO_4^-
2−	Carbonate ion	CO_3^{2-}
	Sulfate ion	SO_4^{2-}
	Monohydrogen phosphate ion	HPO_4^{2-}
	Oxalate ion	$C_2O_4^{2-}$
	Dichromate ion	$Cr_2O_7^{2-}$
3−	Phosphate ion	PO_4^{3-}

The formula for sodium hydroxide is NaOH; for each sodium ion there is one hydroxide ion.

There are many groups of atoms that (like hydroxide ion) remain together through most chemical reactions. **Polyatomic ions** are charged particles containing two or more covalently bonded atoms (Figure 3). A list of common polyatomic ions is given in Table . You can use these ions, in combination with the simple ions in Table , to determine formulas for compounds that contain polyatomic ions.

SECTION 3.4

Names for covalent Compounds

Table Prefixes That Indicate the Number of Atoms of an Element in a Compound

Prefix	Number of Atoms
Mono-	1
Di-	2
Tri-	3
Tetra-	4
Penta-	5
Hexa-	6
Hepta-	7
Octa-	8
Nona-	9
Deca-	10

Many molecular compounds have common and widely used names. Examples are water (H_2O), methane (CH_4), and ammonia (NH_3). For other compounds, the prefixes *mono-*, *di-*, *tri-*, and so on, are used to indicate the number of atoms of each element in the molecule. A list of these prefixes for up to ten atoms is given in Table .

Simply use the prefixes to indicate the number of each kind of atom. For example, the compound N_2O_4 is called *dinitrogen tetroxide*. (The *a* often is dropped from tetra- and other prefixes when it precedes another vowel.) We often leave off the mono- prefix (NO_2 is nitrogen dioxide), but do include it to distinguish between two compounds of the same pair of elements (CO is carbon monoxide; CO_2 is carbon dioxide).

Exercises

What is the name for SCl_2? For SF_6?

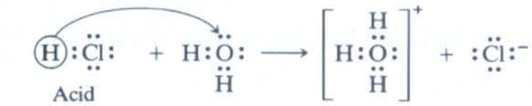
Give the formula for carbon tetrachloride.

SECTION 3.5 Acids: Hydronium Ions

It is nice to know that certain compounds are acids and others are bases and that each class has characteristic properties. It is more satisfying, however, to know *why* a certain compound is an acid and another a base. The search for meaning is central to science—and to life in general. We will not recount the history of the theory of acids and bases in this discussion, but we will list some of the more important concepts.

A wealth of experimental evidence indicates that, in water solution, the properties of acids are due to H_3O^+, the *hydronium ion*. This ion is a water molecule to which a hydrogen ion (H^+) has been added. Since a hydrogen atom with its electron removed is just a bare nucleus consisting of a single proton, H^+ often is called a *proton*.

Table lists a variety of common acids. Every acid contains one or more hydrogen atoms. When dissolved in water, acids transfer hydrogen nuclei to the water molecules. They are proton donors. For hydrogen chloride, the reaction is written



Acid
(proton donor)

Table Some Familiar Acids

Name	Formula	Classification
Sulfuric acid	H_2SO_4	Strong
Nitric acid	HNO_3	Strong
Hydrochloric acid	HCl	Strong
Phosphoric acid	H_3PO_4	Moderate
Hydrogen sulfate ion	HSO_4^-	Moderate
Lactic acid	$CH_3CHOHCOOH$	Weak
Acetic acid	CH_3COOH	Weak
Boric acid	H_3BO_3	Weak
Carbonic acid	H_2CO_3	Weak
Hydrocyanic acid	HCN	Weak

SECTION 3.6 Bases: Hydroxide Ions

Plenty of experimental evidence indicates that the properties of a base, in water, are due to OH^-, the *hydroxide ion*. Table lists several common bases. Ionic compounds contain two separate and distinct species. In sodium hydroxide, there are sodium ions (Na^+) and hydroxide ions (OH^-). In calcium hydroxide, there are calcium ions (Ca^{2+}) and hydroxide ions (OH^-). When either compound is dissolved in water, a basic solution is formed. The hydroxide ion is the base. Adding sodium hydroxide or calcium hydroxide to water simply supplies an excess of hydroxide ions.

Ammonia seems out of place in Table , because it contains no hydroxide ions. How can it be a base? The only way to get hydroxide ions from ammonia in water is for the ammonia molecule to accept a proton from water, leaving a hydroxide ion.

Table Common Bases

Name	Formula	Classification
Sodium hydroxide	$NaOH$	Strong
Potassium hydroxide	KOH	Strong
Lithium hydroxide	$LiOH$	Strong
Calcium hydroxide	$Ca(OH)_2$	(see text)
Magnesium hydroxide	$Mg(OH)_2$	(see text)
Ammonia	NH_3	Weak