

## 2.8: Chemical Nomenclature

### Learning Objectives

- Derive names for common types of inorganic compounds using a systematic approach.
- Describe how to name binary covalent compounds including acids and oxyacids.

Nomenclature, a collection of rules for naming things, is important in science and in many other situations. This module describes an approach that is used to name simple ionic and molecular compounds, such as  $\text{NaCl}$ ,  $\text{CaCO}_3$ , and  $\text{N}_2\text{O}_4$ . The simplest of these are binary compounds, those containing only two elements, but we will also consider how to name ionic compounds containing polyatomic ions, and one specific, very important class of compounds known as acids (subsequent chapters in this text will focus on these compounds in great detail). We will limit our attention here to inorganic compounds, compounds that are composed principally of elements other than carbon, and will follow the nomenclature guidelines proposed by IUPAC. The rules for organic compounds, in which carbon is the principle element, will be treated in a later chapter on organic chemistry.

### 2.8.1: Ionic Compounds

To name an inorganic compound, we need to consider the answers to several questions. First, is the compound ionic or molecular? If the compound is ionic, does the metal form ions of only one type (fixed charge) or more than one type (variable charge)? Are the ions monatomic or polyatomic? If the compound is molecular, does it contain hydrogen? If so, does it also contain oxygen? From the answers we derive, we place the compound in an appropriate category and then name it accordingly. We will begin with the nomenclature rules for ionic compounds.

### 2.8.2: Compounds Containing Only Monatomic Ions

The name of a binary compound containing monatomic ions consists of the name of the cation (the name of the metal) followed by the name of the anion (the name of the nonmetallic element with its ending replaced by the suffix *-ide*). Some examples are given in Table 2.8.2.

Table 2.8.1: Names of Some Ionic Compounds

$\text{NaCl}$ , sodium chloride	$\text{Na}_2\text{O}$ , sodium oxide
$\text{KBr}$ , potassium bromide	$\text{CdS}$ , cadmium sulfide
$\text{CaI}_2$ , calcium iodide	$\text{Mg}_3\text{N}_2$ , magnesium nitride
$\text{CsF}$ , cesium fluoride	$\text{Ca}_3\text{P}_2$ , calcium phosphide
$\text{LiCl}$ , lithium chloride	$\text{Al}_4\text{C}_3$ , aluminum carbide

### 2.8.3: Compounds Containing Polyatomic Ions

Compounds containing polyatomic ions are named similarly to those containing only monatomic ions, except there is no need to change to an *-ide* ending, since the suffix is already present in the name of the anion. Examples are shown in Table 2.8.2.

CL, ammonium chloride, C a S O subscript 4 calcium sulfate, and M g subscript 3 ( P O subscript 4 ) subscript 2 magnesium phosphate." data-quail-id="54" data-mt-width="1246">

Table 2.8.2: Names of Some Polyatomic Ionic Compounds

$\text{KC}_2\text{H}_3\text{O}_2$ , potassium acetate	$(\text{NH}_4)\text{Cl}$ , ammonium chloride
$\text{NaHCO}_3$ , sodium bicarbonate	$\text{CaSO}_4$ , calcium sulfate
$\text{Al}_2(\text{CO}_3)_3$ , aluminum carbonate	$\text{Mg}_3(\text{PO}_4)_2$ , magnesium phosphate

## 📌 Ionic Compounds in Your Cabinets

Every day you encounter and use a large number of ionic compounds. Some of these compounds, where they are found, and what they are used for are listed in Table 2.8.3. Look at the label or ingredients list on the various products that you use during the next few days, and see if you run into any of those in this table, or find other ionic compounds that you could now name or write as a formula.

Table 2.8.3: Everyday Ionic Compounds

Ionic Compound	Name	Use
NaCl	sodium chloride	ordinary table salt
KI	potassium iodide	added to “iodized” salt for thyroid health
NaF	sodium fluoride	ingredient in toothpaste
NaHCO <sub>3</sub>	sodium bicarbonate	baking soda; used in cooking (and in antacids)
Na <sub>2</sub> CO <sub>3</sub>	sodium carbonate	washing soda; used in cleaning agents
NaOCl	sodium hypochlorite	active ingredient in household bleach
CaCO <sub>3</sub>	calcium carbonate	ingredient in antacids
Mg(OH) <sub>2</sub>	magnesium hydroxide	ingredient in antacids
Al(OH) <sub>3</sub>	aluminum hydroxide	ingredient in antacids
NaOH	sodium hydroxide	lye; used as drain cleaner
K <sub>3</sub> PO <sub>4</sub>	potassium phosphate	food additive (many purposes)
MgSO <sub>4</sub>	magnesium sulfate	added to purified water
Na <sub>2</sub> HPO <sub>4</sub>	sodium hydrogen phosphate	anti-caking agent; used in powdered products
Na <sub>2</sub> SO <sub>3</sub>	sodium sulfite	preservative

### 2.8.4: Compounds Containing a Metal Ion with a Variable Charge

Most of the transition metals can form two or more cations with different charges. Compounds of these metals with nonmetals are named with the same method as compounds in the first category, except the charge of the metal ion is specified by a Roman numeral in parentheses after the name of the metal. The charge of the metal ion is determined from the formula of the compound and the charge of the anion. For example, consider binary ionic compounds of iron and chlorine. Iron typically exhibits a charge of either 2+ or 3+, and the two corresponding compound formulas are FeCl<sub>2</sub> and FeCl<sub>3</sub>. The simplest name, “iron chloride,” will, in this case, be ambiguous, as it does not distinguish between these two compounds. In cases like this, the charge of the metal ion is included as a Roman numeral in parentheses immediately following the metal name. These two compounds are then unambiguously named iron(II) chloride and iron(III) chloride, respectively. Other examples are provided in Table 2.8.4.

Table 2.8.4: Names of Some Transition Metal Ionic Compounds

Transition Metal Ionic Compound	Name
FeCl <sub>3</sub>	iron(III) chloride
Hg <sub>2</sub> O	mercury(I) oxide
HgO	mercury(II) oxide
Cu <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	copper(II) phosphate

Out-of-date nomenclature used the suffixes *-ic* and *-ous* to designate metals with higher and lower charges, respectively: Iron(III) chloride,  $\text{FeCl}_3$ , was previously called ferric chloride, and iron(II) chloride,  $\text{FeCl}_2$ , was known as ferrous chloride. Though this naming convention has been largely abandoned by the scientific community, it remains in use by some segments of industry. For example, you may see the words *stannous fluoride* on a tube of toothpaste. This represents the formula  $\text{SnF}_2$ , which is more properly named tin(II) fluoride. The other fluoride of tin is  $\text{SnF}_4$ , which was previously called stannic fluoride but is now named tin(IV) fluoride.

#### ✓ Example 2.8.1: Naming Ionic Compounds

Name the following ionic compounds, which contain a metal that can have more than one ionic charge:

- $\text{Fe}_2\text{S}_3$
- $\text{CuSe}$
- $\text{GaN}$
- $\text{CrCl}_3$
- $\text{Ti}_2(\text{SO}_4)_3$

#### Solution

The anions in these compounds have a fixed negative charge ( $\text{S}^{2-}$ ,  $\text{Se}^{2-}$ ,  $\text{N}^{3-}$ ,  $\text{Cl}^-$ , and  $\text{SO}_4^{2-}$ ), and the compounds must be neutral. Because the total number of positive charges in each compound must equal the total number of negative charges, the positive ions must be  $\text{Fe}^{3+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Ga}^{3+}$ ,  $\text{Cr}^{3+}$ , and  $\text{Ti}^{3+}$ . These charges are used in the names of the metal ions:

- iron(III) sulfide
- copper(II) selenide
- gallium(III) nitride
- chromium(III) chloride
- titanium(III) sulfate

#### ? Exercise 2.8.1

Write the formulas of the following ionic compounds:

- chromium(III) phosphide
- mercury(II) sulfide
- manganese(II) phosphate
- copper(I) oxide
- chromium(VI) fluoride

#### Answer a

$\text{CrP}$

#### Answer b

$\text{HgS}$

#### Answer c

$\text{Mn}_3(\text{PO}_4)_2$

#### Answer d

$\text{Cu}_2\text{O}$

#### Answer e

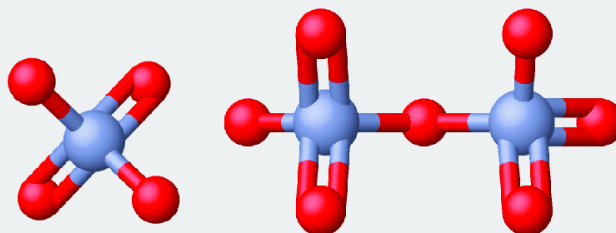
$\text{CrF}_6$

## Erin Brokovich and Chromium Contamination

In the early 1990s, legal file clerk Erin Brockovich (Figure 2.8.2) discovered a high rate of serious illnesses in the small town of Hinckley, California. Her investigation eventually linked the illnesses to groundwater contaminated by Cr(VI) used by Pacific Gas & Electric (PG&E) to fight corrosion in a nearby natural gas pipeline. As dramatized in the film *Erin Brokovich* (for which Julia Roberts won an Oscar), Erin and lawyer Edward Masry sued PG&E for contaminating the water near Hinckley in 1993. The settlement they won in 1996—\$333 million—was the largest amount ever awarded for a direct-action lawsuit in the US at that time.



(a)



(b)

Figure 2.8.2: (a) Erin Brockovich found that Cr(VI), used by PG&E, had contaminated the Hinckley, California, water supply. (b) The Cr(VI) ion is often present in water as the polyatomic ions chromate,  $\text{CrO}_4^{2-}$  (left), and dichromate,  $\text{Cr}_2\text{O}_7^{2-}$  (right).

Chromium compounds are widely used in industry, such as for chrome plating, in dye-making, as preservatives, and to prevent corrosion in cooling tower water, as occurred near Hinckley. In the environment, chromium exists primarily in either the Cr(III) or Cr(VI) forms. Cr(III), an ingredient of many vitamin and nutritional supplements, forms compounds that are not very soluble in water, and it has low toxicity. Cr(VI), on the other hand, is much more toxic and forms compounds that are reasonably soluble in water. Exposure to small amounts of Cr(VI) can lead to damage of the respiratory, gastrointestinal, and immune systems, as well as the kidneys, liver, blood, and skin.

Despite cleanup efforts, Cr(VI) groundwater contamination remains a problem in Hinckley and other locations across the globe. A 2010 study by the Environmental Working Group found that of 35 US cities tested, 31 had higher levels of Cr(VI) in their tap water than the public health goal of 0.02 parts per billion set by the California Environmental Protection Agency.

## 2.8.5: Molecular (Covalent) Compounds

The bonding characteristics of inorganic molecular compounds are different from ionic compounds, and they are named using a different system as well. The charges of cations and anions dictate their ratios in ionic compounds, so specifying the names of the ions provides sufficient information to determine chemical formulas. However, because covalent bonding allows for significant variation in the combination ratios of the atoms in a molecule, the names for molecular compounds must explicitly identify these ratios.

## 2.8.6: Compounds Composed of Two Elements

When two nonmetallic elements form a molecular compound, several combination ratios are often possible. For example, carbon and oxygen can form the compounds CO and  $\text{CO}_2$ . Since these are different substances with different properties, they cannot both have the same name (they cannot both be called carbon oxide). To deal with this situation, we use a naming method that is somewhat similar to that used for ionic compounds, but with added prefixes to specify the numbers of atoms of each element. The name of the more metallic element (the one farther to the left and/or bottom of the periodic table) is first, followed by the name of the more nonmetallic element (the one farther to the right and/or top) with its ending changed to the suffix *-ide*. The numbers of atoms of each element are designated by the Greek prefixes shown in Table 2.8.5.

Table 2.8.5: Nomenclature Prefixes

Number	Prefix	Number	Prefix

Number	Prefix	Number	Prefix
1 (sometimes omitted)	mono-	6	hexa-
2	di-	7	hepta-
3	tri-	8	octa-
4	tetra-	9	nona-
5	penta-	10	deca-

When only one atom of the first element is present, the prefix *mono-* is usually deleted from that part. Thus, CO is named carbon monoxide, and CO<sub>2</sub> is called carbon dioxide. When two vowels are adjacent, the *a* in the Greek prefix is usually dropped. Some other examples are shown in Table 2.8.6.

Table 2.8.6: Names of Some Molecular Compounds Composed of Two Elements

Compound	Name	Compound	Name
SO <sub>2</sub>	sulfur dioxide	BCl <sub>3</sub>	boron trichloride
SO <sub>3</sub>	sulfur trioxide	SF <sub>6</sub>	sulfur hexafluoride
NO <sub>2</sub>	nitrogen dioxide	PF <sub>5</sub>	phosphorus pentafluoride
N <sub>2</sub> O <sub>4</sub>	dinitrogen tetroxide	P <sub>4</sub> O <sub>10</sub>	tetraphosphorus decaoxide
N <sub>2</sub> O <sub>5</sub>	dinitrogen pentoxide	IF <sub>7</sub>	iodine heptafluoride

There are a few common names that you will encounter as you continue your study of chemistry. For example, although NO is often called nitric oxide, its proper name is nitrogen monoxide. Similarly, N<sub>2</sub>O is known as nitrous oxide even though our rules would specify the name dinitrogen monoxide. (And H<sub>2</sub>O is usually called water, not dihydrogen monoxide.) You should commit to memory the common names of compounds as you encounter them.

### ✓ Example 2.8.2: Naming Covalent Compounds

Name the following covalent compounds:

- SF<sub>6</sub>
- N<sub>2</sub>O<sub>3</sub>
- Cl<sub>2</sub>O<sub>7</sub>
- P<sub>4</sub>O<sub>6</sub>

#### Solution

Because these compounds consist solely of nonmetals, we use prefixes to designate the number of atoms of each element:

- sulfur hexafluoride
- dinitrogen trioxide
- dichlorine heptoxide
- tetraphosphorus hexoxide

### ? Exercise 2.8.2

Write the formulas for the following compounds:

- phosphorus pentachloride
- dinitrogen monoxide
- iodine heptafluoride
- carbon tetrachloride

**Answer a**

**Answer b**

**Answer c**

**Answer d**


### 2.8.7: Binary Acids

Some compounds containing hydrogen are members of an important class of substances known as acids. The chemistry of these compounds is explored in more detail in later chapters of this text, but for now, it will suffice to note that many acids release hydrogen ions,  $\text{H}^+$ , when dissolved in water. To denote this distinct chemical property, a mixture of water with an acid is given a name derived from the compound's name. If the compound is a binary acid (comprised of hydrogen and one other nonmetallic element):

1. The word "hydrogen" is changed to the prefix *hydro-*
2. The other nonmetallic element name is modified by adding the suffix *-ic*
3. The word "acid" is added as a second word

For example, when the gas  $\text{HCl}$  (hydrogen chloride) is dissolved in water, the solution is called *hydrochloric acid*. Several other examples of this nomenclature are shown in Table 2.8.7.

Table 2.8.7: Names of Some Simple Acids

Name of Gas	Name of Acid
$\text{HF}(g)$ , hydrogen fluoride	$\text{HF}(aq)$ , hydrofluoric acid
$\text{HCl}(g)$ , hydrogen chloride	$\text{HCl}(aq)$ , hydrochloric acid
$\text{HBr}(g)$ , hydrogen bromide	$\text{HBr}(aq)$ , hydrobromic acid
$\text{HI}(g)$ , hydrogen iodide	$\text{HI}(aq)$ , hydroiodic acid
$\text{H}_2\text{S}(g)$ , hydrogen sulfide	$\text{H}_2\text{S}(aq)$ , hydrosulfuric acid

### 2.8.8: Oxyacids

Many compounds containing three or more elements (such as organic compounds or coordination compounds) are subject to specialized nomenclature rules that you will learn later. However, we will briefly discuss the important compounds known as oxyacids, compounds that contain hydrogen, oxygen, and at least one other element, and are bonded in such a way as to impart acidic properties to the compound (you will learn the details of this in a later chapter). Typical oxyacids consist of hydrogen combined with a polyatomic, oxygen-containing ion. To name oxyacids:

1. Omit "hydrogen"
2. Start with the root name of the anion
3. Replace *-ate* with *-ic*, or *-ite* with *-ous*
4. Add "acid"

For example, consider  $\text{H}_2\text{CO}_3$  (which you might be tempted to call "hydrogen carbonate"). To name this correctly, "hydrogen" is omitted; the *-ate* of carbonate is replaced with *-ic*; and acid is added—so its name is carbonic acid. Other examples are given in Table 2.8.8. There are some exceptions to the general naming method (e.g.,  $\text{H}_2\text{SO}_4$  is called sulfuric acid, not sulfic acid, and  $\text{H}_2\text{SO}_3$  is sulfurous, not sulfous, acid).

Table 2.8.8: Names of Common Oxyacids

Formula	Anion Name	Acid Name
$\text{HC}_2\text{H}_3\text{O}_2$	acetate	acetic acid
$\text{HNO}_3$	nitrate	nitric acid
$\text{HNO}_2$	nitrite	nitrous acid
$\text{HClO}_4$	perchlorate	perchloric acid
$\text{H}_2\text{CO}_3$	carbonate	carbonic acid
$\text{H}_2\text{SO}_4$	sulfate	sulfuric acid
$\text{H}_2\text{SO}_3$	sulfite	sulfurous acid
$\text{H}_3\text{PO}_4$	phosphate	phosphoric acid

## Summary

Chemists use nomenclature rules to clearly name compounds. Ionic and molecular compounds are named using somewhat-different methods. Binary ionic compounds typically consist of a metal and a nonmetal. The name of the metal is written first, followed by the name of the nonmetal with its ending changed to *-ide*. For example,  $\text{K}_2\text{O}$  is called potassium oxide. If the metal can form ions with different charges, a Roman numeral in parentheses follows the name of the metal to specify its charge. Thus,  $\text{FeCl}_2$  is iron(II) chloride and  $\text{FeCl}_3$  is iron(III) chloride. Some compounds contain polyatomic ions; the names of common polyatomic ions should be memorized. Molecular compounds can form compounds with different ratios of their elements, so prefixes are used to specify the numbers of atoms of each element in a molecule of the compound. Examples include  $\text{SF}_6$ , sulfur hexafluoride, and  $\text{N}_2\text{O}_4$ , dinitrogen tetroxide. Acids are an important class of compounds containing hydrogen and having special nomenclature rules. Binary acids are named using the prefix *hydro-*, changing the *-ide* suffix to *-ic*, and adding “acid;”  $\text{HCl}$  is hydrochloric acid. Oxyacids are named by changing the ending of the anion (*-ate* to *-ic*, and *-ite* to *-ous*) and adding “acid;”  $\text{H}_2\text{CO}_3$  is carbonic acid.

## Glossary

### binary acid

compound that contains hydrogen and one other element, bonded in a way that imparts acidic properties to the compound (ability to release  $\text{H}^+$  ions when dissolved in water)

### binary compound

compound containing two different elements.

### oxyacid

compound that contains hydrogen, oxygen, and one other element, bonded in a way that imparts acidic properties to the compound (ability to release  $\text{H}^+$  ions when dissolved in water)

### nomenclature

system of rules for naming objects of interest

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