Chemical Nomenclature and Formula Writing

Chemical nomenclature is the system that chemists use to identify and name compounds. Compounds can have two types of names: *systematic names* (names that identify the chemical composition of a chemical compound) and *common names* (traditional names based on historical discovery or reactivity behavior). For example, N_2O has both a systematic name (dinitrogen monoxide) and a common name (laughing gas).

If every substance were assigned a common name, chemists would be expected to memorize over nine million names! This is why chemists generally prefer systematic names for identifying compounds. The International Union of Pure and Applied Chemistry (IUPAC, see http://www.iupac.com) was founded in 1921 to provide a system of chemical nomenclature for scientists. IUPAC nomenclature rules can provide valuable structural and reactivity information. On the other hand, most people would be hard pressed to call dihydrogen monoxide by any other name but water, so both types of nomenclature have their place.

Nomenclature leads naturally to formula writing. Compounds exist in distinct combinations of elements, and knowing the proper combinations of elements is essential in chemistry. We expect sodium chloride to be NaCl and not Na_2Cl or $NaCl_2$; knowing which combination or combinations exist in nature is crucial.

The following sections will guide you through the rules of *inorganic nomenclature* and formula writing. Later you may experience the nomenclature for organic chemistry or transition metal chemistry, but most of the compounds observed in first year chemistry will fall in this category.

Part A: Nomenclature of Elemental Ions

The first step in learning nomenclature is to learn the names of the elemental ions you might see in compounds. We make a distinction between the following:

- **fixed charge cations** (metal positive ions from groups IA, IIA and all of IIIA except Tl)
- **variable charge cations** (positive ions which do not have a fixed charge; this includes ***all*** transition metals, lanthanides, actinides, Tl, Pb, Sn, and Bi)
- **anions** (negative ions which are generally nonmetals)

Why two types of cations? Many metals have, for all practical purposes, only one ionic charge observed in nature. Lithium is only observed as Li^+ naturally, and even though gas phase studies of lithium ions have produced Li^{2+} and even Li^- ions, they are not observed in most settings. Many metals (such as iron) have many different *oxidation states* or *ionic charges* associated with them. The ions Fe^{2+}, Fe^{3+} and Fe^{6+} can be observed and manipulated quite readily (even at Mt. Hood Community College!); therefore, we need a method to distinguish between the various ions (namely iron(II), iron(III) and iron(VI), respectively).

Fixed Charge Cations use their elemental name.

Example:

Na^+ is the sodium ion
Mg^{2+} is the magnesium ion
Al^{3+} is the aluminum ion
Cs^+ is the cesium ion
Sr^{2+} is the strontium ion
In^{3+} is the indium ion

Variable Charge Cations use their elemental name followed by their ionic charge in parentheses. Use *Roman numerals* to distinguish the charge of the ion.

Example: Fe^{2+} is the iron(II) ion
Fe^{3+} is the iron(III) ion
Mn^{7+} is the manganese(VII) ion
U^{4+} is the uranium(IV) ion
Pb^{2+} is the lead(II) ion
Pb^{4+} is the lead(IV) ion
Co^{9+} is the cobalt(IX) ion
Zn^{2+} is the zinc(II) ion

Anions use their elemental name with the ending changed to *-ide*.

Example: Cl^- is the chloride ion
O^{2-} is the oxide ion
N^{3-} is the nitride ion
I^- is the iodide ion
Te^{2-} is the telluride ion
As^{3-} is the arsenide ion

Part B: Nomenclature of Polyatomic Ions

Certain combinations of atoms result in stable configurations that are not easily destroyed; these are called *polyatomic ions*. Polyatomic ions can be either positive or negative, but most of them are anions (i.e. they have a negative charge.) Recognizing polyatomic ions in formulas is one of the most difficult concepts to master when learning nomenclature, and it is *very important that you **memorize** the following list of polyatomic ions*.

A list of polyatomic ions is given below:

nitrate	NO_3^-	**hydroxide**	OH^-	**hypochlorite**	ClO^-
nitrite	NO_2^-	**cyanide**	CN^-	**chlorite**	ClO_2^-
sulfate	SO_4^{2-}	**thiocyanide**	SCN^-	**chlorate**	ClO_3^-
sulfite	SO_3^{2-}	**cyanate**	OCN^-	**perchlorate**	ClO_4^-
phosphate	PO_4^{3-}	**thiosulfate**	$S_2O_3^{2-}$	**hypobromite**	BrO^-
phosphite	PO_3^{3-}	**chromate**	CrO_4^{2-}	**bromite**	BrO_2^-
hydrogen phosphate	HPO_4^{2-}	**dichromate**	$Cr_2O_7^{2-}$	**bromate**	BrO_3^-
dihydrogen phosphate	$H_2PO_4^-$	**permanganate**	MnO_4^-	**perbromate**	BrO_4^-
carbonate	CO_3^{2-}	**acetate**	$C_2H_3O_2^-$	**hypoiodite**	IO^-
hydrogen carbonate	HCO_3^-	**ammonium**	NH_4^+	**iodite**	IO_2^-
hydrogen sulfide	HS^-	**hydrogen**	H^+	**iodate**	IO_3^-
oxalate	$C_2O_4^{2-}$	**hydride**	H^-	**periodate**	IO_4^-

Part C: Nomenclature of Ionic Compounds from Ions

Knowing the nomenclature rules for ions, we can begin the naming of ionic compounds. Ionic compounds involve a *cation* (either *fixed* or *variable charge*) combining with an *anion*. Naming ionic compounds is straightforward; simply combine the ionic names with the cation first followed by the anion.

Example: **sodium** ion + **chloride** ion give **sodium chloride**
iron(III) ion + **bromide** ion gives **iron(III) bromide**
ammonium polyatomic ion + **oxide** ion gives **ammonium oxide**
aluminum ion + **sulfate** polyatomic ion gives **aluminum sulfate**

Part D: Writing Formulas for Ionic Compounds Using Nomenclature

Another important concept to master is the ability to write a chemical formula using the compound's systematic name. This can be accomplished using the following protocol:

1. Identify the elemental ions and/or polyatomic ions in the compound using the systematic name.
2. Determine the magnitude of the ionic charge on each ion
3. Assume the compound is electrically neutral *unless* the term "ion" appears in the name
4. The sum of the cation charges plus the anion charges must equal zero; combine the ions until this condition is met
5. Write the resulting formula. If more than one polyatomic ion is present, write the polyatomic portion in parentheses with a subscript after it denoting the number of polyatomic ions present.

Example: Write the formula for **sodium chloride**.

1. Sodium chloride has Na^+ and Cl^- ions
2. Sodium has a +1 charge, chloride has a -1 charge
3. Assume sodium chloride is neutral (no "ion" is present in the name)
4. Charge on sodium + charge on chloride = (+1) + (-1) = 0; therefore, **one** sodium ion and **one** chloride ion was required for a neutral compound.
5. 1 Na^+ ion and 1 Cl^- ion gives the formula **NaCl**

Example: Write the formula for **aluminum sulfide**.

1. Aluminum sulfide has Al^{3+} and S^{2-} ions
2. Aluminum has a +3 charge, sulfide has a -2 charge
3. Assume aluminum sulfide is neutral (no "ion" is present in the name)
4. Charge on aluminum + charge on sulfide = (+3) + (-2) = +1; this would indicate that combining one aluminum ion with one sulfide ion would give an *ion*. We want a *neutral* compound (see step 3); this can be accomplished by multiplying aluminum by **2** and sulfide by **3**, which results in: 2(+3) + 3(-2) = 0. Therefore, a neutral compound would result by combing **two** aluminum ions with **three** sulfide ions.
5. 2 Al^{3+} ions and 3 S^{2-} ions give the formula $\mathbf{Al_2S_3}$**.**

Example: Write the formula for **magnesium nitrate**.

1. Magnesium nitrate has Mg^{2+} and NO_3^- ions
2. Magnesium has a +2 charge, nitrate has a -1 charge
3. Assume magnesium nitrate is neutral (no "ion" is present in the name)
4. Charge on magnesium + charge on nitrate = (+2) + (-1) = +1; this would indicate that combining one magnesium ion with one nitrate ion would give an *ion*. We want a *neutral* compound (see step 3); this can be accomplished by multiplying magnesium by **1** and nitrate by **2**, which results in: 1(+2) + 2(-1) = 0. Therefore, a neutral compound would result by combing **one** magnesium ion with **two** nitrate ions.
5. 1 Mg^{2+} ions and 2 NO_3^- ions give the formula $\mathbf{Mg(NO_3)_2}$**.** (Note there are *two* nitrate ions, so they are placed in parentheses with a subscript two after it.)

Example: Write the formula for **titanium(IV) oxalate**.

1. Titanium(IV) oxalate has Ti^{4+} and $C_2O_4^{2-}$ ions
2. Titanium(IV) has a +4 charge, oxalate has a -2 charge
3. Assume titanium(IV) oxalate is neutral (no "ion" is present in the name)
4. Charge on titanium(IV) + charge on oxalate = (+4) + (-2) = +2; this would indicate that combining one titanium(IV) ion with one oxalate ion would give an *ion*. We want a *neutral* compound (see step 3); this can be accomplished by multiplying titanium(IV) by **1** and oxalate by **2**, which results in: 1(+4) + 2(-2) = 0. Therefore, a neutral compound would result by combing **one** titanium(IV) ion with **two** oxalate ions.
5. 1 Ti^{4+} ions and 2 $C_2O_4^{2-}$ ions give the formula **$Ti(C_2O_4)_2$.** (Note there are *two* oxalate ions, so they are placed in parentheses with a subscript two after it.)

Part E: Finding Systematic Names for Ionic Compounds Using Formulas

Determining the systematic name of a compound from its formula is straightforward using these steps:

1. Identify the cation and anion in the formula. *Watch* for polyatomic ions.
2. Assume the compound is electrically neutral *unless* a charge appears in the formula
3. Determine the name of the anion and the charge on the anion
4. If a fixed charge cation is present, determine its name.
5. If a variable charge cation is present, determine its name and use this formula to find the charge on the metal: **$\text{charge}_{\text{metal}}$ = - (# anions)($\text{charge}_{\text{anion}}$) / (# metal cations)** (where # = "number of")
6. Combine the cation and anion names as per Part C. The cation goes first, followed by the anion; do not forget the Roman numeral charge in parentheses for variable charge cations.

Example: Determine the name for **NaCl**.

1. The cation is Na and the anion is Cl
2. NaCl is neutral (no charges are present in the formula)
3. The anion, the chloride ion, has a -1 charge
4. Na is a fixed charge cation, and its name is the sodium ion
5. There are no variable charge cations in NaCl
6. The name of this compound is **sodium chloride**.

Example: Determine the name for **$Sr(NO_3)_2$.**

1. The cation is Sr and the anion is NO_3.
2. $Sr(NO_3)_2$ is neutral (no charges are present in the formula)
3. The anion, the nitrate polyatomic ion, has a -1 charge
4. Sr is a fixed charge cation, and its name is the strontium ion
5. There are no variable charge cations in $Sr(NO_3)_2$
6. The name of this compound is **strontium nitrate**.

Example: Determine the name for **$Fe(NO_3)_3$.**

1. The cation is Fe and the anion is NO_3.
2. $Fe(NO_3)_3$ is neutral (no charges are present in the formula)
3. The anion, the nitrate polyatomic ion, has a -1 charge
4. There are no fixed charge cations in $Fe(NO_3)_3$
5. Iron is a variable charge cation; therefore, we must use the formula to calculate the charge on the iron atom. $charge_{Fe}$ = -(# nitrates)($charge_{nitrate+}$) / (# Fe atoms) = - (3)(-1) / (1) = **+3**; therefore, this is the **iron(III) ion**.
6. The name of this compound is **iron(III) nitrate**.

Example: Determine the name for **$Ru_3(PO_4)_2$.**

1. The cation is Ru and the anion is PO_4.
2. $Ru_3(PO_4)_2$ is neutral (no charges are present in the formula)
3. The anion, the phosphate polyatomic ion, has a -3 charge
4. There are no fixed charge cations in $Ru_3(PO_4)_2$
5. Ruthenium is a variable charge cation; therefore, we must use the formula to calculate the charge on the ruthenium atom. $charge_{Ru}$ = -(# phosphates)($charge_{phosphate}$) / (# Ru atoms) = - (2)(-3) / (3) = **+2**; therefore, this is the **ruthenium(II) ion**.
6. The name of this compound is **ruthenium(II) phosphate**.

Part F: Nomenclature for Binary Nonmetal Covalent Molecules

Not all compounds are ionic; indeed, many compounds *share* their electrons over the respective atoms. This class of compound is called *covalent*, and they are formed when two nonmetal elements combine.

The simplest covalent compounds are the elements that exist naturally in pairs; we refer to them as *diatomics*. These are crucial to a successful chemistry experience, and memorization is straightforward using the following acronym:

Name	Compound	Acronym
Hydrogen	H_2	*Have*
Nitrogen	N_2	*No*
Fluorine	F_2	*Fear*
Oxygen	O_2	*Of*
Iodine	I_2	*Ice*
Chlorine	Cl_2	*Cold* (or *Clear*)
Bromine	Br_2	*Beer* (or *Brew*)

In addition to the diatomics, two other nonmetals exist naturally in elemental form as combinations of more than one atom. **Phosphorus** exists naturally as P_4, and **sulfur** exists as S_8.

Most nonmetal covalent compounds have more than one type of element. Since there is no ionic charge present in these molecules, we cannot use the system developed above for ionic compounds, and a new method must be used. We will use the **Greek prefixes** for our compounds; they are:

1	*mono*	6	*hexa*
2	*di*	7	*hepta*
3	*tri*	8	*octa*
4	*tetra*	9	*nona*
5	*penta*	10	*deca*

The Greek prefixes refer to the number of atoms present in the molecule. For example, "dinitrogen" implies two nitrogen atoms since the prefix *di* stands for two.

When writing systematic names for binary nonmetal covalent compounds, use the *least electronegative atom first*. The topic of electronegativity will be discussed in Chem 222, but for now, the element listed first (either in the formula or the name) will be the least electronegative element.

Just as with cations in ionic compounds, use the normal element name for the least electronegative element. If more than one exist, use the Greek symbols to represent how many. The *most* electronegative element receives an *-ide* ending (as with anions in ionic compounds) as well as a Greek prefix, *even for single elements.* This is an important distinction between the most and least electronegative elements in binary compounds: the least electronegative element uses Greek symbols only if two or more atoms are present, while the more electronegative element gets an *-ide* ending *and* a Greek prefix *regardless* of the number of atoms present.

Examples:	**NO**	nitrogen monoxide
	$\mathbf{N_2O}$	dinitrogen monoxide
	$\mathbf{NO_2}$	nitrogen dioxide
	$\mathbf{P_2O_3}$	diphosphorus trioxide
	$\mathbf{P_2O_5}$	diphosphorus pentoxide

In addition, there are several common names of binary covalent compounds that you should be familiar with including the following:

Common Name	**Formula**	**Systematic Name**
water	H_2O	dihydrogen monoxide
ammonia	NH_3	nitrogen trihydride
laughing gas	N_2O	dinitrogen monoxide
nitric oxide	NO	nitrogen monoxide
phosphine	PH_3	phosphorus trihydride
hydrazine	N_2H_4	dinitrogen tetrahydride
hydrogen sulfide	H_2S	dihydrogen monosulfide

Part G: Nomenclature for Acids and Bases

Acid and base theory shall be discussed in detail during CH 223, but recognizing common acids and bases is important for all chemists. Acids and bases require water to become active; hence, Part G assumes all of the compounds mentioned have been dissolved in water.

Acids contain $\mathbf{H^+}$, the **hydrogen ion**. Acids are created when hydrogen ions combine with halogens. If no oxygen atoms are present, add the *hydro-* prefix and an *-ic acid* suffix to find the acid name.

Examples:	**HCl**	hydrochloric acid
	HBr	hydrobromic acid
	HI	hydroiodic acid

If oxygen atoms are present in the halogen acid, use the following table:

Prefix and/or Suffix	Name	Formula
hydro-, -ic	hydrochloric acid	HCl
hypo-, -ous	hypochlorous acid	$HClO$
-ous	chlorous acid	$HClO_2$
-ic	chloric acid	$HClO_3$
per-, -ic	perchloric acid	$HClO_4$

Similar rules apply to bromide or iodide, but not fluoride.

Other common names for acids include:

$\mathbf{HNO_3}$	nitric acid	$\mathbf{H_3PO_4}$	phosphoric acid
$\mathbf{HNO_2}$	nitrous acid	$\mathbf{H_3PO_3}$	phosphorous acid
$\mathbf{H_2SO_4}$	sulfuric acid	$\mathbf{H_2SeO_4}$	selenic acid
$\mathbf{H_2SO_3}$	sulfurous acid	**HCN**	hydrocyanic acid
$\mathbf{H_2CO_3}$	carbonic acid	**HF**	hydrofluoric acid

More assistance with naming acids can be found in the handout, "**Guide to Common Polyatomic Ions and the Corresponding Acids**" available in the CH 221 Companion or on the CH 221 website.

One final note about acids: *technically*, an acid is only an acid if dissolved in water (i.e. if *aqueous*, with an *aq* state. If not in water, the acidic properties are lost (at least for CH 221!), and the compound should probably be written as either a binary nonmetal covalent molecule (Section F) or, if the acid contains a polyatomic ion, as a fixed charge metal with a nonmetal. Consider the following examples:

HCl(aq)	hydrochloric acid	*This is truly an acid since HCl is dissolved in water*
HCl(g)	hydrogen monochloride	*This is not an acid - no water! - so name this compound as a covalent compound*
$\mathbf{HNO_2(aq)}$	nitrous acid	*This is a true acid, dissolved in water*
$\mathbf{HNO_2(g)}$	hydrogen nitrite	*This is not an acid - no water! - so name this compound as a fixed charge metal + nonmetal due to the polyatomic ion (nitrite) present*

If a designation of state (i.e. aqueous, gas, solid, etc.) is not provided, then the naming system used is up to the observer (i.e. take your pick! ☺)

Bases contain $\mathbf{OH^-}$, the **hydroxide ion**. Bases consist of a metal cation with the hydroxide anion; hence, their nomenclature will be similar to that of Parts C, D and E, above.

Examples:	**NaOH**	sodium hydroxide
	$\mathbf{Fe(OH)_3}$	iron(III) hydroxide
	$\mathbf{NH_4OH}$	ammonium hydroxide

Part H: Final Words

Understanding chemical nomenclature rules and being able to write formulas for compounds can be thought of as learning to read and write a language. At first, the symbols and rules do not make much sense, but as time progresses, you master the language and a moment of euphoric inspiration occurs when "it all falls into place." Regrettably, inspiration only occurs after time has been spent practicing the material. The more you practice, the faster you will master the material.

Remember that there are five general classes of compounds:

Compound Class	**Example**
Fixed charge cation + anion	Al_2O_3 - aluminum oxide
Variable charge cation + anion	Fe_2O_3 - iron(III) oxide
Nonmetal binary covalent compound	P_2O_3 - diphosphorus trioxide
Acid	HIO_3 - iodic acid
Base	$Al(OH)_3$ - aluminum hydroxide

Each has specific rules to learn and master. Determining the charge of variable charge cations can be difficult at first, but application of the formulas in Part D and Part E should alleviate the distress.

Nomenclature & Formula Writing Worksheet

Name:

Section One: Ion Names

Complete the chart using the appropriate elemental ion or polyatomic ion name or symbol. The first row has been filled in as an example.

Ion	Name	Ion	Name
Na^+	sodium ion	F^{-1}	fluoride ion
Li^+	____________________	____________________	hydride ion
____________________	gold(III) ion	____________________	hydroxide ion
Mo^{3+}	____________________	____________________	cyanide ion
W^{2+}	____________________	SCN^{-1}	____________________
____________________	gold(I) ion	BrO^{-1}	____________________
Mn^{2+}	____________________	____________________	bromite ion
____________________	platinum(IV) ion	____________________	acetate ion
____________________	zirconium(II) ion	CrO_4^{2-}	____________________
Mt^{3+}	____________________	____________________	dichromate ion
Mg^{2+}	____________________	____________________	phosphide ion
____________________	vanadium(II) ion	____________________	phosphate ion
Cr^{3+}	____________________	____________________	phosphite ion
Cr^{2+}	____________________	$S_2O_3^{2-}$	____________________
____________________	tantalum(V) ion	IO_4^{-1}	____________________
Ni^{2+}	____________________	____________________	iodate ion
____________________	silver(I) ion	____________________	hypoiodite ion
____________________	ammonium ion	MnO_4^{-1}	____________________

Section Two: Ions from Formulas

Write the ions that you would expect from the following compounds

Example: NaCl would give: Na^{+}, Cl^{-}

Example: $Fe_3(PO_4)_2$ would give: Fe^{2+}, PO_4^{3-}

LiBr would give:

$MgCl_2$ would give:

Na_2O would give:

VCl_2 would give:

$Fe(NO_3)_3$ would give:

$U(ClO_3)_4$ would give:

Section Three: Nomenclature from Ion Names

Complete the chart using the appropriate compound name using the ions given. The first row has been filled in as an example.

Cation	Anion	Compound Name
Potassium	Iodide	potassium iodide
Magnesium	Oxide	____________________
Rhodium(III)	Chloride	____________________
Lead(IV)	Chlorate	____________________
Gold(I)	Cyanide	____________________
Cobalt(II)	Nitrate	____________________
Barium	Hydroxide	____________________
Ammonium	Phosphate	____________________

Section Four: Writing Formulas Using Nomenclature

Complete the chart by providing the correct ion symbols (with the charge) and the correct formula for each compound. The first row has been filled in as an example.

Compound	Cation	Anion	Formula
Calcium nitrate	Ca^{2+}	NO_3^{-1}	$Ca(NO_3)_2$
Gallium bromide	______________	______________	________________________________
Silver(I) nitrate	______________	______________	________________________________
Bismuth(III) chloride	______________	______________	________________________________
Sodium acetate	______________	______________	________________________________
Titanium(II) hypochlorite	______________	______________	________________________________
Lithium permanganate	______________	______________	________________________________
Iron(III) oxalate	______________	______________	________________________________
Cesium chloride	______________	______________	________________________________

Section Five: Chemical Nomenclature Using Formulas

Complete the chart by providing the correct ion symbols (with the charge) and the correct name for each formula. The first row has been filled in as an example.

Formula	Cation	Anion	Name
$Ca(IO_3)_2$	Ca^{2+}	IO_3^-	Calcium iodate
ZnS	______________	______________	________________________
$Sr_3(PO_3)_2$	______________	______________	________________________
$Ga_2(SO_4)_3$	______________	______________	________________________
$V(SCN)_5$	______________	______________	________________________
$NaMnO_4$	______________	______________	________________________
$(NH_4)_2S$	______________	______________	________________________
NH_4NO_2	______________	______________	________________________
$CrCl_6$	______________	______________	________________________

Section Six: Nonmetal Binary Covalent Compounds

Complete the chart by providing either the correct formula or name. The first row has been filled in as an example.

Name	Formula	Name	Formula
nitrogen dioxide	NO_2	Phosphorus trichloride	PCl_3
______________________	SCl_4	sulfur hexachloride	______________
hydrogen monochloride	______________	______________________	$H_2S(g)$
______________________	PI_3	disulfur dichloride	______________
dinitrogen tetraoxide	______________	______________________	N_2O_3
antimony trichloride	______________	______________________	$SbCl_5$
______________________	SiO	carbon monoxide	______________
______________________	SiO_3	carbon dioxide	______________
phosphorus trihydride	______________	______________________	NO

Section Seven: Acids and Bases

Complete the chart by providing either the correct formula or name. The first row has been filled in as an example.

Name	Formula
Hydrobromic acid	HBr(aq)
Nitric acid	__________________
_________________________	$HIO_3(aq)$
Sulfuric acid	__________________
Phosphorous acid	__________________
Phosphoric acid	__________________
_________________________	HCN(aq)
Iron(III) hydroxide	__________________
_________________________	$Mg(OH)_2$

Section Eight: Combined Problems

Complete the chart by providing either the correct formula or name.

Name	Formula
____________________	HCl(aq)
____________________	HCl(g)
Potassium chloride	____________________
____________________	N_2O_4
Nitrogen disulfide	____________________
____________________	$LiClO_3$
Aluminum dichromate	____________________
____________________	$FeSO_4$
Carbonic acid	____________________
____________________	SO_3
____________________	$(NH_4)_2CO_3$
Potassium dihydrogen phosphate	____________________
Potassium hydrogen phosphate	____________________
____________________	P_4O_{10}
____________________	$TbBr_6$
____________________	$ThBr_3$
____________________	TlBr
____________________	$TiBr_4$
____________________	$TeBr_2$
tetrasulfur decaoxide	____________________
sodium hydrogen carbonate	____________________
____________________	$In(C_2H_3O_2)_3$