EXPERIMENT 3
Naming Inorganic Compounds

Introduction

Currently, there are over 20 million known chemical compounds. The names and formulas of these compounds are an essential vocabulary in chemistry. To alleviate the impossible task of memorizing the names of chemical compounds scientists have devised a systematic strategy for naming chemical substances. This process is termed ***chemical nomenclature***, from the Latin words *nomen* (name) and *calare* (to call). The rules for naming chemicals are universally accepted worldwide; what is known as sodium chloride in America is also sodium chloride in India, China, and Dubai. *It is important to master the rules for naming chemical compounds* at the very beginning of your study of chemistry as chemical nomenclature is the vocabulary you will use to identify and discuss an overwhelming variety of substances.

The rules for chemical nomenclature are based on the division of substances into categories. The first division separates chemicals substances into two categories, *organic* and *inorganic* compounds. **Organic compounds** contain carbon, usually in combination with elements such as hydrogen, oxygen, nitrogen and sulfur. All other compounds are referred to as **inorganic compounds**, and usually do not contain carbon. For convenience some carbon containing compounds, such as carbon monoxide (CO), carbon disulfide (CS_2), compounds containing the cyanide group (CN), and carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) groups are considered to be inorganic compounds. The rules for naming organic and inorganic compounds are different. This lab will focus on learning to name inorganic compounds, as these will be used regularly throughout chemistry 101.

Inorganic compounds are divided into four categories:
1. Ionic compounds
2. Molecular compounds
3. Acids and bases
4. Hydrates

Each of these categories have specific chemical nomenclature rules.

1. **Naming Ionic compounds:** Ionic compounds are made up of **cations** (positive ions) and **anions** (negative ions). Most of the cations of interest in this course are derived from metal atoms. Metal atoms are located in groups I and II in the periodic table (See figure of periodic table). *Metal cations take their names from the elements*.

For example:

Element	Name	Cation	Name
Na	Sodium	Na^+	Sodium ion
K	Magnesium	K^+	Magnesium ion
Al	Aluminum	Al^{3+}	Aluminum ion

Adapted from
1. Van Koppen, P. A. M. *General Chemistry Laboratory Manual Second Edition*. McGraw-Hill: New York, 2007, 15-26.
2. Chang, R. *Chemistry Tenth Edition*. McGraw-Hill: New York, 2010, 59-70.

Anions are mostly nonmetals. *Anions are named by taking the first part of the element name (fluorine) and adding "**-ide**" (fluoride)*. Other examples are shown below.

Element	Name	Cation	Name
Cl	Chlorine	Cl^-	Chlor**ide** ion
Br	Bromine	Br^-	Brom**ide** ion
S	Sulfur	S^{2-}	Sulf**ide** ion

It is important to become familiar with the names of the first 54 elements in the periodic table as these make up the most common chemical compounds. Knowing the names of the elements will greatly increase your ability to name chemical compounds.

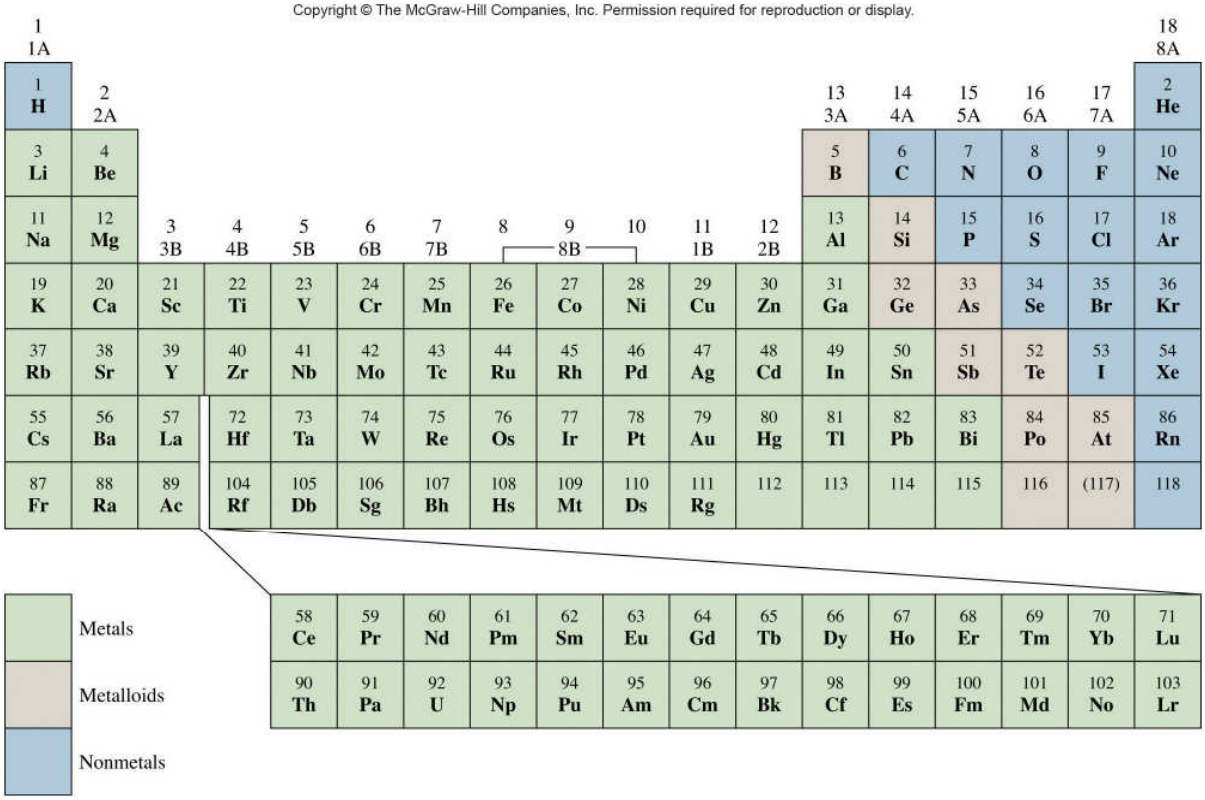

Figure 1: Periodic Table of Elements. Metals are shown in green, nonmetals in blue, and metalloids in pink.

Certain metals, especially among the **transition metals**, groups 3B to 2B in the periodic table, *can form more than one type of cation*. Iron, Fe, for example, can form two cations, Fe^{2+} and Fe^{3+}. The rules for naming atoms that form cations with variable charges is the same as for naming any cation, except that the charge of the metal must be specified using a roman numeral. An older nomenclature system, still in limited use, assigns the ending *–ous* to the cation with fewer positive charges, and the ending of *–ic* to the cation with more positive charges.

Cation	Name	Older Name
Fe^{2+}	iron (II) cation	ferrous cation
Fe^{3+}	iron (III) cation	ferric cation

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2. Chang, R. *Chemistry Tenth Edition*. McGraw-Hill: New York, 2010, 59-70.

Polyatomic anions are ions that are composed of more than one element. Polyatomic anions containing oxygen have names ending in ***–ate*** or ***-ite***. The ending –ate is used for the most common ion. The ending –ite is used for an ion that has same charge but one fewer O atoms. Table 1 shows a list of common polyatomic ions. See also Table 2.3 in Chang, 10th ed.

Table 1. Common Polyatomic Ions

NH_4^+	ammonium	PO_4^{3-}	phosphate
H_3O^+	hydronium	HPO_4^{2-}	hydrogen phosphate
OH^-	hydroxide	$H_2PO_4^{2-}$	dihydrogen phosphate
CN^-	cyanide	ClO^-	hypochlorite
SCN^-	thiocyanate	ClO_2^-	chlorite
NO_2^-	nitrite	ClO_3^-	chlorate
NO_3^-	nitrate	ClO_4^-	perchlorate
SO_3^{2-}	sulfite	MnO_4^-	permanganate
SO_4^{2-}	sulfate	CrO_4^{2-}	chromate
HSO_4^-	hydrogen sulfate (or bisulfate)	$Cr_2O_7^{2-}$	dichromate
CO_3^{2-}	carbonate	$C_2O_4^{2-}$	oxalate
HCO_3^-	hydrogen carbonate (or bicarbonate)	O_2^{2-}	peroxide
$CH_3CO_2^-$	acetate		

lf you memorize the names and charges of all the ions ending in *–ate*, then the suffixes and prefixes are changed in a systematic way to account for the number of oxygens in the ions:

-ite	corresponds to the ion with one fewer oxygen atom,
hypo- and *–ite*	with two fewer oxygen atoms,
per- and *–ate*	with one more oxygen atom than the ion ending in *-ate*

For example:

chlor**ate**	ClO_3^-
chlor**ite**	ClO_2^-
hypochlor**ite**	ClO^- least number of oxygens
perchlor**ate**	ClO_4^- greatest number of oxygens

NOTE:
1) adding or subtracting oxygen atoms does not change the charge on the ion
2) adding a hydrogen atom reduces the negative charge by one (e.g. sulfate, SO_4^{2-} and hydrogen sulfate HSO_4^-)

Most ionic compounds are ***binary compounds***, compounds formed from just two elements.
An ionic bond is formed by the attraction between ions of opposite charge. Cations, which are positively charged, are attracted to anions, which are negatively charged.

Adapted from
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For binary compounds, the first element named is the metal cation, followed by the nonmetallic anion. For example, NaCl is named by first naming the cation Na^+ using the element name, *sodium*. Then the anion Cl^- is named using the element stem and the suffix *–ide*: *chloride*. NaCl is thus called *sodium chloride*. Table 2 shows examples of how to name binary ionic compounds.

Table 2. Names of common binary ionic compounds.

Compound	Cation	Anion	Name
NaCl	Na^+	Cl^-	sodium chloride
Li_3N	Li^+	N^{3-}	lithium nitride
Na_3PO_4	Na^+	$H_2PO_4^-$	sodium phosphate
Na_2HPO_4	Na^+	HPO_4^{2-}	sodium hydrogen phosphate

Note that when a polyatomic ion is present, its name is given after the cation name.

For the following compounds, $FeCl_2$ contains the Fe^{2+} ion and $FeCl_3$ contains the Fe^{3+} ion. The corresponding name indicates the charge on the metal ion.

$FeCl_2$ iron **(II)** chloride or ferr**ous** chloride
$FeCl_3$ iron **(III)** chloride or ferr**ic** chloride

Exception: For Zn^{2+}, Cd^{2+},and Ag^+ in compounds, no Roman numeral is required to specify the charge because Zn, Cd, and Ag generally form only one type of ion with a fixed charge. Examples of common transition metals and their names are shown in table 3.

Table 3. Common transition metal atoms that form cations with variable charges

Ion	Name	Alternative name
Fe^{3+}	iron (III)	ferric
Fe^{2+}	iron (II)	ferrous
Cu^{2+}	copper (II)	cupric
Cu^+	copper (I)	cuprous

Ion	Name	Alternative name
Co^{3+}	cobalt (III)	cobaltic
Co^{2+}	cobalt (II)	cobaltous
Pb^{4+}	lead (IV)	plumbic
Cu^+	lead (II)	plumbous

2. Naming molecular compounds (two nonmetal atoms bound).

Name the first element in the chemical formula first, using the element name. Name the second element in formula as if it were an anion, element stem plus the suffix *-ide*. Number of atoms must be indicated using the prefixes: *mono-*, *di-*, *tri-*, *tetra-*,*penta-* , *hexa-*, *hepta-* , *octa-*, etc. but *mono-* is never used to name the first element. The table below shows a list of the prefixes and their meanings.

Table 4. Greek Prefixes

Greek Prefixes Used in Naming Molecular Compounds	
Prefix	**Meaning**
mono-	1
di-	2
tri-	3
tetra-	4
penta-	5
hexa-	6
hepta-	7
octa-	8
nona-	9
deca-	10

NO nitrogen monoxide
N_2O dinitrogen monoxide
N_2O_4 dinitrogen tetroxide
CO carbon monoxide
CO_2 carbon dioxide
NH_3 ammonia (or nitrogen trihydride)

Adapted from
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2. Chang, R. *Chemistry Tenth Edition*. McGraw-Hill: New York, 2010, 59-70.

3. Naming Acids and Bases

Acids:

An acid is defined as a substance that produces hydrogen ions, H^+, in solution. For example, HCl dissociates to produce H^+ and Cl^- in aqueous solution. Formulas for acids contain one or more hydrogen atom as well as an anionic group. The name assigned to the compound depends on its physical state. In the gaseous or pure liquid state, HCl is a molecular compound called *hydrogen chloride*. When it is dissolved in water, the molecules break up into the respective ions and in this state the substance is called *hydrochloric acid*.

1) Naming Binary Acids

Anions whose names end in -ide form acids with a hydro- prefix and an -ic ending. For example to name the acid HBr, first identify the anion (Br^-) then add *-ic* to the stem of the element , in place of *-ide* for the ion (bromic) and precede the stem by the prefix *hydro- (hydrobromic acid).* Table 5 shows this process for some simple acids.

Table 5. Naming Binary Acids

Anion	Corresponding Acid
F^- (fluoride)	HF (hydrofluoric acid)
Cl^- (chloride)	HCl (hydrochloric acid)
Br^- (bromide)	HBr (hydrobromic acid)
I^- (iodide)	HI (hydroiodic acid)
CN^- (cyanide)	HCN (hydrocyanic acid)
S^{2-} (sulfide)	H_2S (hydrosulfuric acid)

2) Naming Oxyacids

Oxyacids are acids that contain hydrogen, oxygen, and another element. When naming oxyacids:

Add *-ic* to the stem of the element if the anion ends in *-ate*

Add *-ous* to the stem of the element is the anion ends in *-ite*

For example, the stem of the element nitrogen is nitr:

nitr**ate** ion (NO_3^-) nitr**ic** acid (HNO_3)

nitr**ite** ion (NO_2^-) nitr**ous** acid (HNO_2)

In cases where an element forms more than two oxyacids, the prefixes *per-* (for the largest number of oxygen atoms in the oxyacid) and *hypo-* (for the smallest number of oxygens) are used, just as for the oxyanions. Table 6 below shows some examples for naming oxyacids.

Table 6. Names of Oxoacids and Oxoanions that contain Chlorine

TABLE 2.6 Names of Oxoacids and Oxoanions That Contain Chlorine

Acid	Anion
$HClO_4$ (perchloric acid)	ClO_4^- (perchlorate)
$HClO_3$ (chloric acid)	ClO_3^- (chlorate)
$HClO_2$ (chlorous acid)	ClO_2^- (chlorite)
HClO (hypochlorous acid)	ClO^- (hypochlorite)

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2. Chang, R. *Chemistry Tenth Edition*. McGraw-Hill: New York, 2010, 59-70.

3) Naming Organic Acids

The stems for the common organic acids are nonsystematic and must be memorized. The same relation as for oxoacids holds between the names of the ion and the acid. For example,

acetate ion (CH_3COO^-) acetic acid (CH_3COOH)

Bases:

A **base** can be described as a substance that yields *hydroxide* ions (OH^-) when dissolved in water. To name the base, first name the element of the cation, then follow it with *hydroxide* to identify the OH^- anion. Some examples:

Base	Cation	Anion	Name of base
NaOH	Na^+	OH^-	sodium hydroxide
KOH	K^+	OH^-	potassium hydroxide
$Ba(OH)_2$	Ba^{2+}	OH^-	barium hydroxide

4) Naming Hydrates

Hydrates are compounds that have a specific number of water molecules attached to them. For example, in its normal state *lithum chloride* has one water molecule associated with it. The systematic name for this compound is *lithium chloride monohydrate*, and its formula is written as $LiCl \cdot H_2O$. To name hydrate compounds, first name the ionic compound (*lithium chloride*) then name the specific number of water molecules attached using the Greek prefixes shown in Table 4. Below are some common examples for naming hydrates.

Hydrates	**Ionic compound**	**Water molecules**	**Name of Hydrate**
$BaCl_2 \cdot 2H_2O$	barium chloride	dihydrate	barium dihydrate
$MgSO_4 \cdot 7H_2O$	magnesium sulfate	heptahydrate	magnesium sulfate heptahyrate

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Procedure:

Naming Inorganic compounds:

1. Using what you have learned about naming inorganic compounds, work in teams to complete the nomenclature worksheet.
2. Be sure to complete all the examples in the worksheet.
3. Go to the computer room and practice naming more compounds:
   Use the following web address and start doing the exercises:

   http://jchemed.chem.wisc.edu/JCEDLib/WebWare/collection/open/JCE2005WWOR002/nom/nomrandom.html

   Instructions for website:
   a. Press the red arrow to begin, a chemical name or formula should appear on the screen.
   b. Name the compound or write out the chemical formula.
   c. Press the blue button to reveal if you have answered correctly.

4. Practice the computer drill for at least 20 different compounds and make a note of what compounds were used.

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Inorganic Nomenclature Worksheet

Name _____ *Section*_____
Date _____
This worksheet is to be completed in lab.

1. Ionic Compounds

Write the symbol and charge of the cation, the symbol and charge of the anion, and the chemical formula for each of the following compounds.

Compound	Cation	Anion	Chemical Formula
lithium fluoride			
potassium oxide			
magnesium iodide			
calcium nitride			
barium sulfide			
aluminum oxide			

Transition metals

Compound	Cation	Anion	Chemical Formula
lead (IV) oxide			
chromium (III) oxide			
copper (I) chloride			
iron (II) sulfide			
silver iodide			

Polyatomics

Compound	Cation	Anion	Chemical Formula
zinc sulfate			
barium nitrite			
chromium(II) phosphate			
potassium permanganate			
manganese(II) hydroxide			
calcium carbonate			
potassium hydrogen phosphate			
ammonium sulfate			

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Write the name of each of the following compounds.

$(NH_4)_2CO_3$	
$Zn(OH)_2$	
$Co(NO_3)_3$	
K_2SO_4	
Cr_2O_3	
K_2SO_3	
$Pb(CH_3COO)_2$	
K_2S	
Na_3P	
Na_3PO_4	
$LiNO_2$	

2. Molecular Compounds

Write the chemical formula or name for each of the following compounds.

carbon tetrachloride	
N_2O_4	
ammonia	
dinitrogen trioxide	
P_2O_5	
SF_6	
carbon disulfide	
NO	

3. Acids and Bases

Write the formula for the following acids.

nitric acid	
acetic acid	
barium sulfate	
hydrobromic acid	
carbonic acid	
nitrous acid	
phosphoric acid	
sulfurous acid	

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For each of the following formulas, write the name and whether it's an acid or a base.

Formula	Name	Acid or Base?
HCl		
H_2SO_4		
NaOH		
CH_3COOH		
H_3PO_4		
$Ba(OH)_2$		
HCN		
HNO_3		

4. Mixed Review. For each name, give the correct formula. Note that this list includes ionic compounds, molecular compounds, and acids. Decide first which of these categories the compound belongs to, then give the formula.

	Category (ionic, molecular, acids)	Formula
hydrochloric acid		
sodium bicarbonate		
aluminum chloride		
lithium sulfite		
dinitrogen monoxide		
iron (III) hydroxide		
magnesium nitrate		
xenon tetrafluoride		
hydrofluoric acid		
nitrogen dioxide		
phosphorous pentoxide		
zinc dichromate		

III. Give the category and name for each of the following compounds.

	Category (ionic, molecular, acids)	Formula
$(NH_4)_2CO_3$		
$Zn(OH)_2$		
$Co(NO_3)_3$		
NO_3		
PCl_5		
CrO		
N_2O_4		
H_2SO_4		

Adapted from
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