INORGANIC NOMENCLATURE

1. Introduction

Chemistry is divided into two main branches: organic chemistry and inorganic chemistry. Organic chemistry is the study of carbon compounds, although some of these are included in the study of inorganic chemistry. Among these compounds are carbon dioxide and its derivatives, the carbonates, cyanides, carbon monoxide, and carbon disulfide.

Organic chemists deal with compounds which are relatively large. The properties of these compounds depend on the spatial arrangement of the atoms within the molecules. Therefore, the system of nomenclature used for organic chemistry must be detailed and complex.

Inorganic compounds, on the other hand, are commonly named by simply specifying the proportions of the elements that make up the compound. The two branches of chemistry have distinctly different but compatible systems of nomenclature, but the objective of both systems is to name each compound in such a way that the chemical identity of the specific compound is known with certainty.

A. Nomenclature of Cations

Cations are formed when an atom loses one or more electrons. These ions will have a positive electrical charge, and are normally formed from the atoms of **metals**.

A cation, if present, is always listed first in both names and formulas of compounds. These ions have the same name as the elements from which they are derived, without any alteration. When writing the symbol of a cation, the number of electrons lost in its formation is indicated by a superscript Arabic numeral followed by a positive sign. (For those ions formed by losing one electron, thus with a charge of positive one, the numeral 1 is commonly omitted.)

Examples:	Na^+	"en ay positive"
	Ca^{2+}	"cee ay two positive"

Some elements, particularly those in the "d" block of the periodic table (transition elements) form more than one cation. This is because the atom may, under different circumstances, lose a different number of electrons. To name the cations of such an element, a system known as **Stock notation** is preferred. A Roman numeral, representing the number of electrons lost and thus the positive charge on the ion, is placed in parentheses immediately following the name of the element.

Examples:	Fe^{2+}	iron(II)	"iron two"
	Fe^{3+}	iron(III)	"iron three"
	Cu^{1+}	copper(I)	

Cu^{2+}	copper(II)
Hg_2^{2+}	mercury(I)
Hg^{2+}	mercury(II)

Note: The mercury(I) cation Hg_2^{2+} consists of two mercury atoms covalently bonded together and each of these atoms has lost one electron so that the total charge on the pair of 1+ ions is 2+.

In the IUPAC system, it is considered inappropriate to use a Roman numeral in naming the ion of a metal that forms only one cation. It is incorrect to omit the Roman numeral in the name of the ion of a metal that has more than one possible cation. Therefore, to correctly apply the rules of this system, it is necessary to know which metals fall into each category. The following relatively common metallic elements should **not** have a Roman numeral included as part of their names in as much as they have only one possible charge on their cations:

The alkali metals and silver (all form 1+ cations)
(Memorize) **The alkaline earths, zinc and cadmium (all form 2+ cations)**
Aluminum and scandium (form 3+ cations)
For all other metals, the use of Roman numerals is required.

The NH_4^+ cation, the **ammonium ion**, is a common inorganic cation. It is derived from the compound NH_3, **ammonia**, by the addition of a hydrogen ion to the NH_3 molecule. Because the chemistry of the NH_4^+ ion somewhat resembles that of metal ions having a 1+ charge, it is given a name with the "ium" ending common to the Group 1 metals.

B. Nomenclature of Simple Anions

The nomenclature of **all** anions depends on alterations of the ending of the name of the main element to indicate the exact nature of the anion. The simple anions are, for the most part, **single atoms** of the nonmetals which have gained one or more electrons. The ending which indicates the single atom nature of an anion is **-ide**. The elements which form this type of anion, the symbol and charge for the anion formed, and its name are given in the following table.

Table 1 - The Single Atom Anions

Element	Symbol for Anion	Name of Anion
fluorine	F^-	fluor**ide**
chlorine	Cl^-	chlor**ide**
bromine	Br^-	brom**ide**
iodine	I^-	iod**ide**
oxygen	O^{2-}	ox**ide**
sulfur	S^{2-}	sulf**ide**

Element	Symbol for Anion	Name of Anion
selenium	Se^{2-}	selen**ide**
tellurium	Te^{2-}	tellur**ide**
nitrogen	N^{3-}	nitr**ide**
phosphorus	P^{3-}	phosph**ide**
hydrogen	H^{-}	hydr**ide**

Other anions with names ending in **ide**:

CN^{-} cyan**ide** (a carbon and nitrogen atom covalently bonded, one electron added to the pair of atoms.)

OH^{-} hydrox**ide** (a hydrogen and an oxygen atom covalently bonded, one electron added to the pair of atoms.)

O_2^{2-} perox**ide** (two oxygen atoms covalently bonded, two electrons added to the bonded pair.)

C_2^{2-} carb**ide** (two carbon atoms covalently bonded, two electrons added to the bonded pair.)

The names and charges for these ions must be memorized. However, the charges on the single atom anions can be deduced from position in the periodic table.

The name of a binary compound formed from one or more cations and one or more single atom anions or cyanide, hydroxide, peroxide or carbide anions is simply the name of the cation followed by the name of the anion, separated by one space.

Table 2 - Some Compounds Formed from Metals with Only One Ion Charge

Name	Formula	Name	Formula
sodium chlor**ide**	$NaCl$	strontium hydroxide	$Sr(OH)_2$
barium chlor**ide**	$BaCl_2$	aluminum cyanide	$Al(CN)_3$

Since the above compounds contain metallic ions of only one possible charge, a Roman numeral indicating the charge is **not** included as part of its name.
However, if the cation is formed from a metal which can form cations with different charges, and for which the ion charge must be included as part of its name, the charge on the cation in the particular compound being named must be determined from the formula and the charge on the anion. Examples are discussed below.

Table 3 - Some Compounds Formed from Metals with More Than One Possible Ion Charge

Name	Formula
iron(II) iodide[a]	FeI_2
iron(III) iodide[b]	FeI_3
chromium(III) oxide[c]	Cr_2O_3

a. The formula, FeI_2, must represent a neutral compound, with no net charge. The iodide ion has a 1- charge. Two iodide ions represent a total of 2- charges. To be electrically neutral the iron ion must have a charge of 2+. This is the **iron(II)** cation.

b. Three iodide ions represent a total negative charge of 3-. For the formula, FeI_3, to represent a neutral compound the iron cation must have a charge of 3+. This is the **iron(III)** ion.

c. The oxide ions represent a total negative charge of 6-. Therefore, **two** chromium ions must have a total charge of 6+. This means each chromium ion has a charge of 3+ in the compound, and is the **chromium(III)** ion.

Exercise 1: Write the preferred IUPAC name for the compounds below.

a. CaO	f. Na_2O_2	k. Al_2O_3	p. AgI
b. KCl	g. $CrBr_3$	l. CrO_3	q. NiS
c. Hg_2O	h. $Au(CN)_3$	m. CuO	r. Hg_3N_2
d. ZnF_2	i. Sr_3P_2	n. PbO	s. Li_3N
e. $Ba(OH)_2$	j. CoS	o. $Cu(CN)_2$	t. CaC_2

C. Binary Compounds of Two Non-metals

For naming compounds containing two elements, both of which are nonmetals, the IUPAC system recommends the use of a series of prefixes to specify exactly how many atoms of each element there are in a molecule of the compound. These prefixes and their numerical meanings are:

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

Table 4 - Nomenclature of Binary Compounds Using Numerical Prefixes

Name	Formula	Name	Formula

carbon monoxide sulfur trioxide tetraphosphorus hexaoxide	CO SO_3 P_4O_6	carbon dioxide dinitrogen pentaoxide dibromine heptachloride	CO_2 N_2O_5 Br_2Cl_7

Note: When there is only one atom of the first element in the compound, the prefix "mono" is **not** used.

The IUPAC rules state that in the preferred system of nomenclature:

a. Binary compounds of two nonmetals should be named using the system of numerical prefixes.
b. Numerical prefixes should not appear in the name of binary compounds of metals with nonmetals.
c. The Stock system of using Roman numerals to indicate ion charges is not appropriate for naming binary compounds of two nonmetals.

Exercise 2: Name the following binary compounds using the system of numerical prefixes.

a. SiO_2	e. CCl_4	h. ClF_3
b. Cl_2O	f. NF_3	i. N_2O_3
c. S_2Cl_2	g. CS_2	j. XeF_6
d. SF_6		

Exercise 3: Name the following compounds using the preferred IUPAC nomenclature.

a. XeF_4	f. Cs_3N	k. N_2O_4
b. $CuCl$	g. $CrCl_3$	l. Ag_2O
c. $Mg(CN)_2$	h. CaO_2	m. MnO_2
d. $Au(OH)_3$	i. CuS	n. PbS_2
e. PCl_3	j. SO2	o. Hg_2O

D. Writing Formulas from Names of Compounds ending in -ide

All binary compounds end in –ide, but not all –ide compounds are binary

1. The charges on both the cation and anion must be known.
   Cation charge: If the name includes a Roman numeral, this numeral gives the number of positive charges on the cation. If the name does not include a Roman numeral, the charge on the cation must be inferred from the position of the element in the periodic table or have been memorized.
   Anion charge: The charge on the anion is never stated in the name of a compound, and therefore must be inferred from the position of the element in the periodic table, or have been memorized.
2. The formula for a compound must be electrically neutral. This means that the total number of positive (cation) charges must be exactly balanced by the total number of negative (anion) charges. More than one cation and/or more than one anion may be necessary to balance these charges. If so, the number of ions needed is indicated by a **subscript** written after the symbol for the ion.

Table 5 - Examples of Formulas from Names of Ionic Compounds ending in -ide

Name	Cation	Anion	Formula
sodium chloride	Na^{+}	Cl^{-}	$NaCl$
(one 1+ ion and one 1- ion result in a neutral compound.)			
iron(III) bromide	Fe^{3+}	Br^{-}	$FeBr_3$
(one 3+ ion and the three 1- ions result in a neutral compound.)			
silver sulfide	Ag^{+}	S^{2-}	Ag_2S
(two 1+ ions and 2- ion result in a neutral compound.)			
calcium oxide	Ca^{2+}	O^{2-}	CaO
(one 2+ ion and one 2- ion result in a neutral compound.)			
aluminum oxide	Al^{3+}	O^{2-}	Al_2O_3
(two 3+ ions and three 2- ions give a neutral compound.)			
gold(III) cyanide	Au^{3+}	CN^{-}	$Au(CN)_3$
(one 3+ ion and three 1- ions give a neutral compound. The cyanide ion is enclosed in parentheses to indicate that three CN^{-} ions, each consisting of one C and one N, are needed.)			
ammonium sulfide	NH_4^{+}	S^{2-}	$(NH_4)_2S$
(two 1+ ions are needed to balance the one 2- charge. Note that the ammonium ion is enclosed in parentheses to indicate that two multi-atom ions are required.)			

Exercise 4. Write the formulas for the following compounds ending in -ide	
a. magnesium iodide	k. gold (III) hydroxide
b. chlorine dioxide	l. aluminum nitride
c. chromium(III) sulfide	m. iron(II) phosphide
d. silver bromide	n. oxygen difluoride
e. mercury(II) hydride	o. potassium peroxide
f. ammonium sulfide	p. gold(I) cyanide
g. barium hydroxide	q. zinc oxide
h. strontium phosphide	r. selenium disulfide
i. carbon tetraiodide	s. uranium(III) oxide
j. iodine heptafluoride	

E. Nomenclature of Complex Anions

Complex anions are made up of several atoms. These anions are usually identified by their "trivial" or common names. For example, the SO_4^{2-} complex anion oxygen is commonly called the **sulfate** ion. Since the trivial names are the ones in almost universal use within the United States, the rules for forming these names are discussed here.

In the correct formula for a complex anion, the central atom will appear first. Sulfur is the central atom in the sulfate ion and it is covalently bonded to four oxygen ligands. This group of five atoms shares two electrons over and above the number of electrons normally belonging to one sulfur atom and four oxygen atoms. Thus, the ion has a charge of 2-.

The names of the majority of complex anions with oxygen as the only ligand are derived by altering the name of the central atom. The following rules set out the derivation of the anion name:

Rule 1: **The most common oxygen-containing anion has the name of the central atom altered to "ate."**

Rule 2: **Anions with one <u>fewer</u> oxygen atom than the most common anion have the name of the central atom altered to "ite."**

Rule 3: **Anions with two <u>fewer</u> oxygen atoms than the most common anion have the prefix "hypo" added to the name of the central atom and the ending altered to "ite."**

Rule 4: **Anions with one <u>more</u> oxygen atom than the most common anion have the prefix "per" added to the name of the central atom and the ending altered to "ate."**

When writing formulas for compounds containing complex anions, as usual the positive cation charges and the negative anion charges must be balanced so that the compound is neutral. When more than one complex anion is required in the formula, the entire anion is placed in parentheses.

The number of anions in the formula is indicated by a subscript outside and to the right of the parentheses.

If there is only one complex anion required in the formula, the anion is **not** placed in parentheses.

Table 7 - Examples of Formulas with Complex Anions

Compound	Cation	Anion	Formula
silver nitrate	Ag^+	NO_3^-	$AgNO_3$
calcium chlorate	Ca^{2+}	ClO_3^-	$Ca(ClO_3)_2$
aluminum sulfate	Al^{3+}	SO_4^{2-}	$Al_2(SO_4)_3$
tin(IV) nitrate	Sn^{4+}	NO_3^-	$Sn(NO_3)_4$

These formulas are read aloud as:

$AgNO_3$ - "ay gee en oh three"
$Ca(ClO_3)_2$ - "cee ay - cee ell oh three taken twice"
$Al_2(SO_4)_3$ - "ay ell two - ess oh four taken three times"
$Sn(NO_3)_4$ - "ess en - en oh three taken four times."

The formulas and charges of the complex anions ending in "ate" **<u>should be memorized</u>**. Rules 2-4 above can then be applied to the memorized formulas to derive the other complex anions formed from the same central atom. For example:

ClO_3^- = "chlorate ion"
ClO_2^- has one less oxygen atom than the chorate ion; therefore it is the "chlor<u>ite</u> ion." (Rule 2)
ClO^- has two fewer oxygen atoms than the chlorate ion; therefore it is the "<u>hypo</u>chlor<u>ite</u> ion." (Rule 3)
ClO_4^- has one <u>more</u> oxygen atom than the chlorate ion; therefore it is the "<u>per</u>chlor<u>ate</u> ion." (Rule 4)

Note that the charge on all of the complex anions formed from chlorine have the same ion charge of -1. This, generally, will be the case for all complex anions formed from the same central atom.

Because sulfur has the same outer electron configuration as oxygen, it can take the place of an oxygen ligand in a complex anion. The replacement of an oxygen atom by a sulfur atom is indicated by prefixing the name of the complex anion by "thio."

Examples:	sulfate	SO_4^{2-}	thiosulfate	$S_2O_3^{2-}$
	sulfite	SO_3^{2-}	thiosulfite	$S_2O_2^{2-}$
	cyanate	OCN^-	thiocyanate	SCN^-

There are many exceptions to the simplified nomenclature rules described here. The following list of complex ions ending in "ate" are commonly encountered in course and laboratory work. A few exceptions to the rules for naming complex anions are also noted. **These should be memorized**.

Table 8 - Common Complex Anions Ending in "ate" and Exceptions to Rules

Name	Formula	Exceptions to Rules
chlorate	ClO_3^-	
bromate	BrO_3^-	
iodate	IO_3^-	
sulfate	SO_4^{2-}	persulfate - $S_2O_8^{2-}$
thiosulfate	$S_2O_3^{2-}$	
selenate	SeO_4^{2-}	
tellurate	TeO_4^{2-}	
nitrate	NO_3^-	
phosphate	PO_4^{3-}	
arsenate	AsO_4^{3-}	
carbonate	CO_3^{2-}	
acetate	$C_2H_3O_2^-$ or CH_3COO^-	
oxalate	$C_2O_4^{2-}$	
cyanate	OCN^-	
thiocyanate	SCN^-	
chromate	CrO_4^{2-}	
dichromate	$Cr_2O_7^{2-}$	
manganate	MnO_4^{2-}	permanganate - MnO_4^-

Exercise 5: Name the following compounds containing complex anions.

a. $NaClO_3$
b. $Ca(ClO_4)_2$
c. $Fe(ClO_2)_3$
d. $Al(ClO)_3$
e. KNO_3
f. $(NH_4)_2SO_4$
g. $(NH_4)_2SO_3$
h. $(NH_4)_2S_2O_3$
i. $CsC_2H_3O_2$
j. $CuCrO_4$
k. $BaCO_3$
l. $KMnO_4$
m. $ZnCr_2O_7$
n. $Pb(BrO_3)_2$
o. $Hg_2(BrO_2)_2$
p. Na_3PO_4
q. KNO_2
r. Ag_2SeO_4
s. $Na_2C_2O_4$
t. $Au(OCN)_3$
u. AuSCN
v. $Ni_3(AsO_4)_2$

Exercise 6: Write formulas for the following compounds containing complex anions.

a. sodium iodate	l. copper(II) phosphite
b. zinc cyanate	m. cobalt(II) thiocyanate
c. ammonium carbonate	n. mercury(I) chlorite
d. iron(III) bromate	o. aluminum perchlorate
e. calcium arsenate	p. sodium oxalate
f. potassium persulfate	q. calcium manganate
g. nickel(IV) acetate	r. potassium dichromate
h. rubidium hypobromite	s. magnesium iodite
i. ammonium nitrate	t. silver chlorate
j. sodium thiosulfate	u. barium selenate
k. aluminum oxalate	v. potassium acetate

F. Nomenclature of Acids

Compounds containing hydrogen which can be ionized to produce hydrogen ions (H^+) when dissolved in water are named as acids **when they are dissolved in water.**
Note: All acids must include (aq) in their formulas.

1. Binary Acids

HCl, a binary compound which exists by itself as a gas, will dissolve in water and form H^+ ions and Cl^- ions. The pure gas will have the name hydrogen chloride; an aqueous (water) solution of HCl is called **hydrochloric acid**.

Rule for binary acids: If a hydrogen containing binary compound is dissolved in water and if the compound produces H^+ ions in solution the name for the solution will be formed by adding the prefix "hydro", changing the ending of the non-hydrogen element to "ic" and adding "acid" to the name.

Examples: HF(g) hydrogen fluoride
HF(aq) <u>hydro</u>fluor<u>ic</u> <u>acid</u>
Note: the (g) and (aq) are added to indicate pure gas and aqueous solution, respectively.

Formulas for this type of compound are easily recognized as hydrogen will be written as the **first** element. For example, NH_3 (ammonia) does not form an acid solution with water and does not have its component hydrogen written first in its formula.

2. Acids Containing Complex Anions (Ternary Acids)

Rule 1: **A compound containing hydrogen as the only cation and a complex anion with its name ending in "ate" will have the "ate" ending changed to "ic" and "acid" added to its name.**

Rule 2: **A compound containing hydrogen as the only cation and a complex anion with its name ending in "ite" will have the "ite" ending changed to "ous" and "acid" added to its name.**

Examples:

H_2SO_4 sulfuric acid, or hydrogen sulfate
HNO_3 nitric acid, or hydrogen nitrate
H_2SO_3 sulfurous acid, or hydrogen sulfite
HClO hypochlorous acid, or hydrogen hypochlorite
$HClO_4$ perchloric acid, or hydrogen perchlorate
$HC_2H_3O_2$ acetic acid, or hydrogen acetate

Note: The following is an exception – it is a ternary acid but it is named according to the binary acid rule.

HCN(aq) hydrocyanic acid

If (aq) is included to indicate a water solution of the compound, the acid form of the name must be used. However, since these compounds are not commonly, and in some cases never, available in the absence of water, the acid name is usually given even when there is no indication of the compound being in solution.

Exercise 7. Give the name or write the formula for the following.

a. HI(aq)	h hypochlorous acid
b. HNO_2(aq)	i. oxalic acid
c. H_2Se(aq)	j. phosphoric acid
d. H_2CrO_4(aq)	k. hydrobromic acid
e. $HBrO_4$(aq)	l. bromic acid
f. HSCN(aq)	m. phosphorous acid
g. $HBrO_2$(aq)	n. nitric acid

G. Answers to Exercises

Exercise 1

a.	calcium oxide	k.	aluminum oxide
b.	potassium chloride	l.	chromium(VI) oxide
c.	mercury(I) oxide	m.	copper(II) oxide
d.	zinc fluoride	n.	lead(II) oxide
e.	barium hydroxide	o.	copper(II) cyanide
f.	sodium peroxide	p.	silver iodide
g.	chromium(III) bromide	q.	nickel(II) sulfide
h.	gold(III) cyanide	r.	mercury(II) nitride
i.	strontium phosphide	s.	lithium nitride
j.	cobalt(II) sulfide	t.	calcium carbide

Exercise 2.

a.	silicon dioxide	f.	nitrogen trifluoride
b.	dichlorine monoxide	g.	carbon disulfide
c.	disulfur dichloride	h.	chlorine trifluoride
d.	sulfur hexafluoride	i.	dinitrogen trioxide
e.	carbon tetrachloride	j.	xenon hexafluoride

Exercise 3.

a.	xenon tetrafluoride	i.	copper(II) sulfide
b.	copper(I) chloride	j.	sulfur dioxide
c.	magnesium cyanide	k.	dinitrogen tetraoxide
d.	gold(III) hydroxide	l.	silver oxide
e.	phosphorous trichloride	m.	manganese(IV) oxide
f.	cesium nitride	n.	lead(IV) sulfide
g.	chromium(III) chloride	o.	mercury(I) oxide
h.	calcium peroxide		

Exercise 4.

a.	MgI_2	g.	$Ba(OH)_2$	n.	OF_2
b.	ClO_2	h.	Sr_3P_2	o.	K_2O_2
c.	Cr_2S_3	i.	CI_4	p.	AuCN
d.	AgBr	j.	IF_7	q.	ZnO
e.	HgH_2	k.	$Au(OH)_3$	r.	SeS_2
f.	$(NH_4)_2S$	l.	AlN	s.	U_2O_3
		m.	Fe_3P_2		

Exercise 5.

a.	sodium chlorate	l.	potassium permanganate
b.	calcium perchlorate	m.	zinc dichromate
c.	iron(III) chlorite	n.	lead(II) bromate
d.	aluminum hypochlorite	o.	mercury(I) bromite
e.	potassium nitrate	p.	sodium phosphate
f.	ammonium sulfate	q.	potassium nitrite
g.	ammonium sulfite	r.	silver selenate
h.	ammonium thiosulfate	s.	sodium oxalate
i.	cesium acetate	t.	gold(III) cyanate
j.	copper(II) chromate	u.	gold(I) thiocyanate
k.	barium carbonate	v.	nickel(II) arsenate

Exercise 6.

a.	$NaIO_3$	i.	NH_4NO_3	p.	$Na_2C_2O_4$
b.	$Zn(OCN)_2$	j.	$Na_2S_2O_3$	q.	$CaMnO_4$
c.	$(NH_4)_2CO_3$	k.	$Al_2(C_2O_4)_3$	r.	$K_2Cr_2O_7$
d.	$Fe(BrO_3)_3$	l.	$Cu_3(PO_3)_2$	s.	$Mg(IO_2)_2$
e.	$Ca_3(AsO_4)_2$	m.	$Co(SCN)_2$	t.	$AgClO_3$
f.	$K_2S_2O_8$	n.	$Hg_2(ClO_2)_2$	u.	$BaSeO_4$
g.	$Ni(C_2H_3O_2)_4$	o.	$Al(ClO_4)_3$	v.	$KC_2H_3O_2$
h.	RbBrO				

Exercise 7.

a.	hydroiodic acid	h.	HClO(aq)
b.	nitrous acid	i.	$H_2C_2O_4$(aq)
c.	hydroselenic acid	j.	H_3PO_4(aq)
d.	chromic acid	k.	HBr(aq)
e.	perbromic acid	l.	$HBrO_3$(aq)
f.	thiocyanic acid	m.	H_3PO_3(aq)
g.	bromous acid	n.	HNO_3(aq)