Chemical Nomenclature

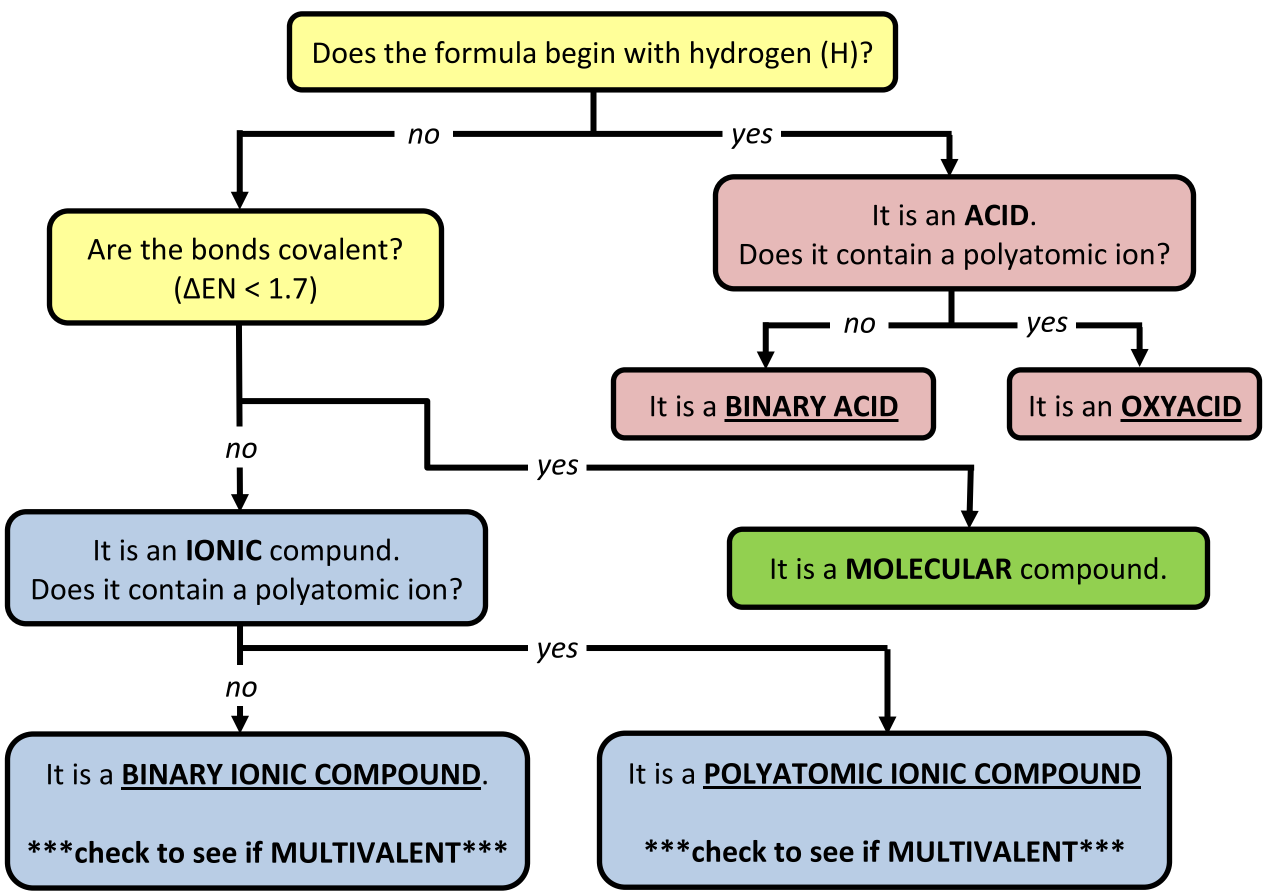
There are two main systems of nomenclature:

IUPAC ***International Union of Pure and Applied Chemistry***	***Classical***
IUPAC has created a standardized set of rules used to name chemical compounds. This system is used internationally and it is expected that you will use it exclusively to name all compounds.	No longer used, but it can be useful to be familiar with it as you may encounter it in older publications.

Being able to name compounds and to derive accurate chemical formulas given a chemical name are both critically important skills in the field of chemistry. Chemical formulas and chemical equations are the language of chemistry and you must become fluent in order to be successful in this field.

Overview of the IUPAC system

There are several sets of rules used to name different types of compounds. Before deciding which set to use you must identify what type of compound it is. You must determine if you are naming a binary ionic compound, a polyatomic ionic compound, a molecular compound, a binary acid, or an oxyacid. The flowchart below models the thought process one may go through when naming a chemical compound. A more detailed version of this flow chart can be found on page 81 of your textbook.



I: NAMING IONIC COMPOUNDS

There are two types of ionic compounds in the IUPAC system.

1) **Binary ionic compounds** contain only **two** different elements.
2) **Polyatomic ionic Compounds** contain a metal cation and a polyatomic ion.

A: Regular Binary Ionic Compounds

Regular binary ionic compounds always contain a metal element from group 1, 2 or 13, and a non-metal element.

<u>Writing Chemical Formulas:</u>

To write the **chemical formula** for a regular binary ionic compound, we must first determine the **charge** that each element will have when it forms a stable ion. This is referred to as the **oxidation number.** Remember, for most elements its **group** will tell us the most common oxidation number. Some elements may have more than one possible oxidation number. These will be discussed in the section of multivalent ionic compounds.

Once we know the oxidation number on each element, we then use the **crossover rule** to find the **chemical formula** of the compound they will form.

Eg. ***Find the formula of the compound formed from Li and P.***

Solution: Li is in group 1, so its oxidation number will be +1
P is in group 15, so its oxidation number will be –3

So: By convention, the cation is always listed first.
"Cross over" the charges to find the formula

$$Li^{+1}P^{-3}$$

$$Li_3P$$

* notice that we do not show the "1" it is understood to be there

Remember:
subscripts must be reduced to their lowest common denominator

It is good practice when you are learning to write chemical formulas to write out each oxidation number, then erase them after crossing over. When you become comfortable with this process, you will no longer need to write the oxidation numbers.

Now try the practice examples on the following page.

Practice Table #1: Finding Oxidation numbers on Ions

Element	Group #	Ion	Element	Group #	Ion
Li	**1**	**Li^{+}**	**F**	**17**	**F^{-}**
Mg			**S**		
Al			**N**		
Be			**Br**		
Na			**P**		

Practice Table #2: Writing Formulas of Regular Ionic Compounds

Leave space to fill in the name of the compound after reading the next section.

Metal	Non-metal	Compound	Metal	Non-metal	Compound
Na	**Br** *name:*		**Al**	**Cl** *name:*	
Mg	**Br** *name:*		**B**	**O** *name:*	
Al	**Br** *name:*		**Ca**	**N** *name:*	
Li	**S** *name:*		**K**	**O** *name:*	
Ca	**S** *name:*		**Na**	**P** *name:*	
B	**S** *name:*		**Al**	**O** *name:*	
K	**N** *name:*		**Mg**	**S** *name:*	
Be	**N** *name:*		**B**	**P** *name:*	
Al	**N** *name:*		**Na**	**Cl** *name:*	
Li	**O** *name:*		**Ca**	**F** *name:*	

Naming Ionic Compounds From Chemical Formulas:

A regular binary ionic compound has a very simple name. We simply take the name of the **metal element** and follow it with the name of the **non-metal element**, with the ending changed to **–ide**.

Eg.	NaCl = sodium and chlorine → sodium chlor**ide**

That's it! Go back to Practice Table #2 and write the NAME of each compound under its formula. Notice that NO capital letters are used in the name.

Practice Table #3: Chemical Names and Formulas of Regular Ionic Compounds

Chemical Name	Metal Ion	Non-metal Ion	Chemical Formula
sodium fluoride	Na^{+}	F^{-}	NaF
boron iodide			
calcium phosphide			
magnesium oxide			
potassium chloride			
beryllium sulfide			
barium nitride			
aluminum sulfide			
lithium phosphide			
potassium sulfide			
boron oxide			
calcium fluoride			

B: Multivalent Metals in Ionic Compounds

Some elements can form multiple different stable ions. This is particularly true of the **transition metals**. For example, iron may form an **Fe^{2+}** ion OR an **Fe^{3+}** ion, depending on what it is bonding with. This means that we cannot PREDICT the oxidation number of the metal when we see it in a compound.

We use a special system that allows us to know what charge is on the ion. We actually put the oxidation number into the name! We write the oxidation number as a **Roman numeral**, and put it in **brackets** after the name of the metal.

> ***Eg.*** iron (II) chloride - in this case, iron has formed an Fe^{2+} ion
> copper (I) oxide - here, copper has formed a Cu^{+} ion

Writing Chemical Formulas:

The bracket system makes it very easy to find the formulas of transition metal compounds, since we are given the oxidation number for the metal ion! We only have to predict the charge on the non-metal as usual, using the periodic table. We then use the crossover rule as usual to get the formula.

> ***Eg.*** copper (II) chloride - here, copper has a 2+ oxidation number, as indicated in the brackets
>
> So: Cu^{2+} Cl^{-} (predicted from the periodic table)
> Crossover!
> Formula: $CuCl_2$

Practice Table #4: Writing Formulas with Transition Metals

Compound Name	Metal Ion	Non-metal Ion	Formula
gold (I) chloride			
nickel (III) sulfide			
cobalt (II) oxide			
iron (III) phosphide			
mercury (IV) fluoride			
nickel (II) nitride			
gold (III) sulfide			
copper (I) oxide			

Naming Multivalent Compounds From Chemical Formulas:

When we name a multivalent ionic compound, we MUST include the oxidation number on the metal ion (in brackets). Because we cannot use the periodic table to predict the charge on transition metal cations, we need a way to figure out this charge, using the **formula** of the compound. This technique is called the **reverse crossover**.

Eg. Co_2O_3

- the two elements involved here are cobalt and oxygen, so the skeleton of the name will be **cobalt (?) oxide**
- **however**, we still need to find the **oxidation number** on the cobalt ion to put in the brackets

$Co_2 \quad O_3$

- if we put a bit of space between the two parts of the compound, it makes it easier to show the **reverse crossover**
- now, just cross the **subscript** of each element UP to become the **charge** of the opposite element

$Co^{3+} \quad O^{2-}$

- this gives you the charges on each ion. oxygen has a oxidation number of 2- , and **cobalt has an oxidation number of 3+** .
- we **must** check that the non-metal has the correct charge, and indeed according to the periodic table, oxygen will have a 2- charge

Therefore the name of this compound is **cobalt (III) oxide**.

Other than the brackets, all other naming rules for ionic compounds stay the same.

Why is it important to check the charge on the non-metal ion?

This is because the subscripts may have been reduced to their lowest common denominator.

Eg. Consider the chemical formula FeO

If we use the reverse crossover method to find the charge on the iron ion here, we see:

$Fe^{1+} \quad O^{1-}$ - the charge on iron appears to be 1+, and on oxygen is 1–

However, when we check the periodic table, we find that oxygen MUST have a 2- charge. This ratio must have been reduced, therefore we must **multiply** the oxidation number on the oxygen by 2 to bring it up to the necessary 2- value. BUT if multiply one oxidation number, we must multiply the other, bringing the iron ion up to an oxidation number of 2+.

Therefore the name of the compound is **iron (II) oxide**.

Practice Table #5: Naming Ionic Compounds with Transition Metals

Formula	Reverse Crossover Predicted Charges		Name
	Metal Ion	Non-Metal Ion	
CoS	**1+**	**1-**	**Cobalt (II) sulfide ****
NiO			
HgI_4			
FeF_2			
Fe_2O_3			
$CuCl_2$			
HgF_2			
CoN			
NiP			
FeS			
Cu_2O_3			

*** NOTE: The charges had to be corrected from 1 to 2, because the correct charge on a sulfur ion is 2-!!*

C: Polyatomic Ionic Compounds

Some **ionic compounds** are **NOT binary**. They contain AT LEAST three elements. In this situation, the compound contains one ion which is **polyatomic** (many atoms) or both polyatomic ions. You **must memorize** the names, formulas and charges of the list of polyatomic ions below.

Polyatomic Ions to Memorize:

Name	*Formula*	*related ions*	
ammonium	NH_4^+		
hydroxide	OH^-		
nitrate	NO_3^-	nitrite	NO_2^-
chlorate	ClO_3^-	hypochlorite chlorite perchlorate	ClO^- ClO_2^- ClO_4^-
bromate	BrO_3^-		
iodate	IO_3^-		
carbonate	CO_3^{2-}		
sulfate	SO_4^{2-}		
phosphate	PO_4^{3-}	phosphite	PO_3^{3-}
permanganate	MnO_4^-		
acetate	CH_3COO^-		
chromate	CrO_4^{2-}		
dichromate	$Cr_2O_7^{2-}$		
cyanide	CN^-	cyanate thiocyanate	OCN^- SCN^-
hydrogen carbonate	HCO_3^-		
hydrogen sulfate	HSO_4^-	hydrogen sulfite	HSO_3^-
hydrogen phosphate	HPO_4^{2-}	hydrogen phosphite	HPO_3^{2-}
dihydrogen phosphate	H_2PO_4	dihydrogen phosphite	$H_2PO_3^{2-}$

Writing Chemical Formulas:

Since these are ionic compounds, we use ALL the same rules that applied to the other ionic compounds, such as crossover and reverse crossover (for transition metal compounds). One NEW thing is the use of **brackets** whenever we need **more than one** of these polyatomic ions in the compound.

Eg 1 What is the formula of lithium hydroxide?

We know that lithium forms a 1+ ion, and hydroxide is OH^-, SO:

Li^+ OH^- The charges are equal but opposite -no crossover is needed.

LiOH is the correct formula for lithium hydroxide

Eg 2 What is the formula of copper (II) nitrate?

Cu^{2+} NO_3^- CROSSOVER!

$Cu(NO_3)_2$ is the correct formula for copper (II) nitrate

Notice the use of brackets around the **whole** nitrate ion. This is important, since we can then put the two **outside** the bracket to show that this compound needs two complete nitrate ions.

Practice Table #6: Writing Formulas with Polyatomic Ions

Compound Name	Positive Ion	Negative Ion	Formula
sodium carbonate	Na^+	CO_3^{2-}	Na_2CO_3
calcium nitrate			
manganese (V) sulfate			
aluminum hydrogen carbonate			
potassium phosphate			
beryllium hydroxide			
gold (I) hydrogen sulfite			
ammonium chloride			
ammonium permanganate			
mercury (I) chromate			
nickel (II) perchlorate			

Naming Polyatomic Compounds From Chemical Formulas:

Again, we use all the same rules for naming ionic compounds when we are using these polyatomic ions. Notice that other than ammonium (a positive ion), the other (negative ions) names all end in **–ate**.

Eg 1 What is the name of $Ca(NO_3)_2$?

Calcium is not multivalent, so we just call this compound **calcium nitrate**.

Notice that again, the positive ion name goes first, followed by the negative ion name. We **do not** change the ending to –ide, since **nitrate** is already the proper name for the ion.

Eg 2 What is the name of $CoPO_4$?

Cobalt is a multivalent transition metal, so we must use the reverse crossover method to determine its charge.

Co^{+} PO_4^{-}

We see only ONE phosphate ion, so the number that we cross up will be 1, NOT the 4 subscript on the oxygen.

This gives phosphate a charge of –1. BUT we know that it has a charge of –3, so we must **multiply** both charges by 3 to correct them.

This gives the name **cobalt (III) phosphate.**

Practice Table #7: Naming Compounds with Polyatomic Ions

FORMULA	NAME OF COMPOUND
$Fe(OH)_2$	
$CaCO_3$	
NH_4Cl	
$LiHCO_3$	
$Al(NO_3)_3$	
$Be_3(PO_4)_2$	
$Cu(HSO_4)_2$	
$(NH_4)_3N$	

I: NAMING MOLECULAR COMPOUNDS

Molecular compounds always contain two non-metal elements.

Writing Chemical Formulas:

The formulas of molecular compounds often cannot be predicted. We understand covalent bonding, but many non-metals bond in unexpected combinations. You will always be given the NAME or the FORMULA of the compound.

If you are given the name of the compound, you need to be able to write its formula. We use **prefixes** to indicate how many atoms of each element are in the compound.

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

NOTES:

1. The prefix **mono** is never used with the **first element** in the compound.
2. The prefixes **mono, tetra, penta, and hexa** LOSE their final o or a when placed in front of oxygen.
3. The ending of the second element is again changed to –**ide**.

Eg. What are the formulas of the following compounds?

carbon **mon**ox**ide** — **CO** (1 atom of carbon – see note 1, and 1 atom of oxygen – see note 2)

diphosphorus **penta**brom**ide** — $\mathbf{P_2Br_5}$ (2 atoms of phosphorus and 5 atoms of bromine)

Naming Molecular Compounds From Chemical Formulas:

To determine the name of a molecular compound, simply apply the prefixes to the two elements that make up the compound.

Eg. What are the names of the following compounds?

CO_2 carbon **di**ox**ide** (1 atom of carbon – see note 1, and 2 atoms of oxygen)

N_2O_3 **di**nitrogen **tri**ox**ide** (2 atoms of nitrogen and 3 atoms of oxygen)

Practice Table #8: Names and Formulas of Molecular Compounds

Complete the table with the names or formulas needed.

Chemical Name	Formula	Chemical Name	Formula
nitrogen monoxide	**NO**		SCl_2
silicon dioxide			SO_2
sulfur trioxide			**NO**
carbon tetrachloride			SiS_2
diarsenic trioxide			PO_3
phosphorus pentabromide			PF_3
nitrogen dioxide			CBr_4
sulfur hexafluoride			NCl_3
selenium dioxide			SiO_3
dinitrogen tetroxide			PCl_3
sulfur dioxide			CS_2

Review: Naming Chemical Compounds

Element #1 (or ion and charge)	Element #2 (or ion and charge)	Type of Compound	Formula	Name
Be^{2+}	F^{-}	ionic	BeF_2	beryllium fluoride
			NaCl	
				nickel (III) oxide
			Cl_2O	
Na	CO_3^{-2}			
			Na_3PO_4	
				calcium chloride
NH_4^{+}	F			
			NiS	
				calcium nitrate
				nitrogen trifluoride
				gold (III) iodide
			CoF_2	
K	HSO_4^{-}			
			KCl	
				copper (II) hydroxide
			$HgSO_4$	
			CO	
			Fe_2O_3	
				lead (IV) sulfate
				calcium iodate