Introduction to Inorganic Chemical Nomenclature

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Purpose of the Worksheet

- Learn to recognize elements vs. compounds and to classify compounds as ionic, molecular or acids based on their chemical formulas
- Learn the naming rules for each category of compounds and be able to write the correct chemical name when given a formula and determine the correct formula when given a compound name.

Background Required:

In order to name compounds successfully, you will need to be familiar with the periodic table, including the location of metals, metalloids and nonmetals and the Group 1A element families. You will also need to understand the notation used for chemical formulas and ions.

Background Information:

Water, vinegar, bleach, Epsom salts, baking soda, salt, sugar. These are the common names of everyday household substances. We have learned some of the properties of these substances and many of their uses from our personal experience, but their names do not give us any hint of their chemical composition. The use of many common names for compounds was typical of the alchemist's experience until late in the 18th century. As the study of chemistry developed, scientists began to realize that a consistent *or systematic* approach to naming elements and compounds was needed. The ultimate goal of a systematic approach would be set of rules that ensured a compound name would unambiguously reflect the chemical composition (chemical formula) of a compound. In other words, reading the name of a substance would allow a scientist to correctly write the chemical formula; the scientist also would be able to write the correct name for the substance from the chemical formula.

The most significant early attempts to develop a system of chemical nomenclature were instigated by the French scientist Louis-Bernard Guyton and consolidated into a written work by Lavosier, with his colleagues Berthollet and de Fourcroy in 1787. This work covered a limited number of elements and compounds that had been characterized at the time, introducing standardized names such as copper sulfate and iron sulfate to replace the alchemist's common names of "vitriol of Venus" and "vitriol of Mars". From 1919 to the present, the International Union of Pure and Applied Chemistry (IUPAC) has acted as the world authority for developing standards for the naming of the chemical elements and compounds. The system we use today still includes echoes of Lavosier's "*Method of Chemical Nomenclature*", but has been altered for clarity and consistency as the science of chemistry has exploded to include inorganic chemistry, organic chemistry and biochemistry.

We will focus on naming four categories of inorganic substances: elements, ionic compounds, molecules and acids. Each of these categories has slightly different rules for naming, so our first goal in learning nomenclature is to recognize what type of substance we are naming. The first step is determining whether the substance is a pure element or a compound from a given formula.

Elements: A pure element consists of only one *kind* of atom, although multiple atoms of that element may be bonded together. For example, the element oxygen is most commonly found as the diatomic molecule O_2. In our approach to naming, we will simply name elements as their element name.

Compounds: Compounds consist of more than one element held together by chemical bonds. Once we have decided that a formula represents a compound, we must determine whether the compound is an ionic compound, a molecular compound or an acid before we can name it.

Ionic compounds: Ionic compounds are composed of positive and negatively charged ions held together by the attraction of the opposite charges for each other, forming an ionic bond. The *cation* in an ionic compound is usually a *metal ion* that has lost one or more electron, giving it a *positive charge*. The *anion* will be a *negatively charged non-metal ion*, either a *single non-metal element anion* or a *polyatomic anion*. Polyatomic ions are groups of atoms bonded together that have an overall charge. Ionic compounds are neutral, so the total number of positive cation charges must equal the total number of negative anion charges.

Ionic compound example: Na^+Cl^-

The simplest way to recognize an *ionic compound* is to note whether the *formula starts with a metal or* the ammonium ion, NH_4^+.

Molecular compounds: Molecular or covalent compounds are composed of all non-metal elements held together by electron-sharing bonds. This type of bond is called a covalent bond. Molecular compounds are not composed of ions. Carbon dioxide, CO_2, is a good example of a covalent molecule. The oxygen atoms each share two electrons with the carbon atom and the carbon atom shares two electrons with each of the oxygen atoms.

Carbon dioxide: O::C::O

The simplest way to identify a *molecule* is to note that the formula is composed of *only non-metal elements* and the formula does *not* start with NH_4^+.

Acids: Acids are a subcategory of molecules, but have their own rules for naming because of their behavior in water. By the simplest definition, acids are molecules which partially or completely ionize in water, producing the hydrogen ion (H^+) and their acid anion. Since these molecules become acids when dissolved in water, we will write the state (aq) after the formula.

We will be able to recognize *inorganic acids* from their formulas because their *formulas will start with H*. We will also write the formula for any organic acids we encounter, such as acetic acid ($HC_2H_3O_{2\,(aq)}$), with the number of acidic hydrogens shown at the beginning of the formula.

Practice: Classify the substances below as elements, ionic or molecular compounds, or acids.

Formula	Classification	Formula	Classification
$MgCl_2$		O_2	
P_2O_{10}		$H_2CO_{3\,(aq)}$	
$HCl_{(aq)}$		Al_2O_3	
NH_4Cl		SF_6	

Once we've classified a compound as ionic, molecular or an acid, we follow the rules for that category to name the compound.

Naming Ionic Compounds: Since ionic compounds are composed of ions, we name them by naming the cation and the anion. We also include the charge on metal cation in the name, if the metal can form more than one ion. Metal cations are simply given their element name with their charge in parentheses (if necessary) and polyatomic cations are given their ion name. Single element anions are named with the stem of their name and an "ide" ending, while polyatomic anions are given their name. The "ide" endings for the non-metals are shown by groups below:

Nonmetal Atoms and Their "ide" Forms

Group 4A		Group 5A		Group 6A		Group 7A	
carbon	carbide	nitrogen	nitride	oxygen	oxide	fluorine	fluoride
		phosphorus	phosphide	sulfur	sulfide	chlorine	chloride
				selenium	selenide	bromine	bromide
						iodine	iodide

These rules are simple, but to apply them, we need to do some memorization. The first task is to learn the charges for the metal cations and non-metal anions that only form 1 ion. Luckily, we can do this by using the periodic table. Almost all of the Group 1A – 3A metals form only one ion and the charge on that ion equals their group number (See chart below). There are a few transition metals that also form only one ion, so we need to memorize these: Ag^{+}, Ni^{2+} and Zn^{2+}. These metals are named with just their element name. All the other metals will need a Roman numeral after their name to indicate the charge on the metal in the particular compound we are naming. We find the metal's charge by determining the total number of negative charges from the anion(s) and dividing that total by the subscript for the metal. Note that the ion charges for the *non-metal anions* equal their group number minus 8.

Metal Cation and Non-metal Anion Charges for Elements That Form Only One Ion

1A 1+	2A 2+											3A 3+	4A 4-	5A 3-	6A 2-	7A 1-	8A 0
H																	He
Li													C	N	O	F	Ne
Na	Mg											Al		P	S	Cl	Ar
K	Ca										Zn^{2+}	Ga			Se	Br	Kr
Rb	Sr									Ag^{1+}	Cd^{2+}	In				I	Xe
Cs	Ba																Ra

We also need to memorize the names, formulas and charges for common polyatomic ions in order to name ionic compounds. As mentioned above, polyatomic ions are groups of atoms that are bonded together with electron sharing (covalent) bonds, but the group has an overall charge. Most of the polyatomic ions have gained one or more electrons, so they have a negative charge. The only positive polyatomic ion we will memorize is NH_4^+, the ammonium ion. The names, formulas and charges for the ions we will be using in this naming worksheet are given in the next table.

Common Polyatomic Ions to Memorize

Ions with -1 charge *Halogen family (except F)*		**Ions with -1 charge**	
perchlorate	ClO_4^{1-}	nitrate	NO_3^{1-}
chlorate	ClO_3^{1-}	nitrite	NO_2^{1-}
chlorite	ClO_2^{1-}	hydroxide	OH^{1-}
hypochlorite	ClO^{1-}	cyanide	CN^{1-}
		acetate	$C_2H_3O_2^{1-}$
periodate	IO_4^{1-}	bicarbonate	HCO_3^{1-}
iodate	IO_3^{1-}	**Ions with a 2- charge**	
iodite	IO_2^{1}	carbonate	CO_3^{2-}
hypoiodite	IO^{1-}	sulfate	SO_4^{2-}
		sulfite	SO_3^{2-}
perbromate	BrO_4^{1-}	**Ions with a 3- charge**	
bromate	BrO_3^{1-}	phosphate	PO_4^{3-}
bromite	BrO_2^{1-}	phosphite	PO_3^{3-}
hypobromite	BrO^{1-}	**Ions with a 1+ charge**	
		ammonium	NH_4^+

Practice: Name or determine the formula for the following ionic compounds. Be sure to check whether the metal forms only one ion using the ion chart above and, if necessary, include its charge in the name. When writing formulas for ionic compounds, the sum of the positive and negative charges must be equal. If a formula contains more than one of a polyatomic ion, then the polyatomic ion formula is put in parentheses with a subscript outside the parentheses indicating how many of the polyatomic ion are in the formula.

Formula	**Name**	**Formula**	**Name**
NaCl		Ca_3N_2	
$AgNO_3$		Fe_2O_3	
$CuSO_4$		$Mg(OH)_2$	
	Potassium phosphate		Iron (III) carbonate

Naming Molecular Compounds:
Molecules are formed when two or more non-metal atoms form an electron sharing bond. We will focus on naming only *binary* molecular compounds, which are molecules which contain only *two different non-metal elements*. The first element is named with its element name, while the second element is named using its stem plus the "ide" ending as shown in the previous chart. Since molecular compounds do not contain ions and we cannot use ion charges to indicate how many of each element are present, we use counting prefixes in molecule names to indicate how many atoms of each element are present. The first element gets a prefix only if more than one atom of the element is present in the formula. We will always use a prefix for the second element. For example, the gas SO_2 is named sulfur dioxide, while N_2O_3 is named dinitrogen ~~tet~~ tri roxide. Notice the "a" is dropped from the prefix "tetra" before adding the word oxide. This is commonly done when oxygen is the second element.

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

It is easy to recognize a molecular compound from its name because *only molecular names will contain prefixes.* Since the prefixes tell us how many of each atom are present, it is also easy to write the formula from the name. There are a few molecules that are always named with their common names because the common names have been used for so long. We will memorize these few exceptions to our naming system: *water (H_2O), ammonia (NH_3) and methane (CH_4).*

Practice: Name or determine the formula for the following molecular compounds.

Formula	Name	Formula	Name
S_2Cl_2			Nitrogen triiodide
	tetraphosphorus hexasulfide	PBr_3	

Naming Acids: Acids are easy to recognize from their name or formula because the first element in the formula will be H (hydrogen) and the name will end in the word "acid". Once we have identified a compound as an acid, we must determine its subcategory before we can name it. There are two types of acids we will be naming:

Binary acids: composed of hydrogen and ***one*** *other non-metal element*
Oxyacids: composed of hydrogen and a *polyatomic ion containing oxygen*

Binary Acids: The names for binary acids start with the prefix "*hydro*" followed by the *stem of the other nonmetal element with an "ic" ending* and the word *"acid"*. For example, the HCl (aq) is named *hydro* + *chlor* (from chlorine)+ *ic acid* or hydrochloric acid. We can recognize a binary acid from a name because *only binary acids start with the prefix "hydro".*

Oxyacids: Oxyacids are easy to recognize because the formula begins with H and they contain oxygen as part of a polyatomic ion. Oxyacids are named using the name of their polyatomic ion, so it is important to memorize the ions to be able to name ionic compounds and oxyacids. Look at the polyatomic ion chart and notice that the polyatomic ions that form oxyacids all end in "ite" or "ate". To name the acid, we change the "ate" and "ite" ending of the polyatomic ion name to "ic" and "ous", respectively, and add the word acid. For example:

HNO_3 (aq): The polyatomic ion is nitr*ate*; change the ending to *ic* and add *acid*: *nitric acid*
HNO_2 (aq): The polyatomic ion is nitr*ite*; change the ending to *ous* and add *acid*: *nitrous acid*

From Acid Name to Formula: When given the name of an acid, we first determine if the acid is a binary acid or oxyacid. Binary acid names start with the prefix "hydro" and oxyacids will not. The formula of a binary acid is simply H and the symbol for the other non-metal. The subscript for H will equal the charge on the other nonmetal ion. For example: hydrosulfuric acid will contain H and S. Since sulfur forms a 2- ion, the formula will be H_2S (aq).

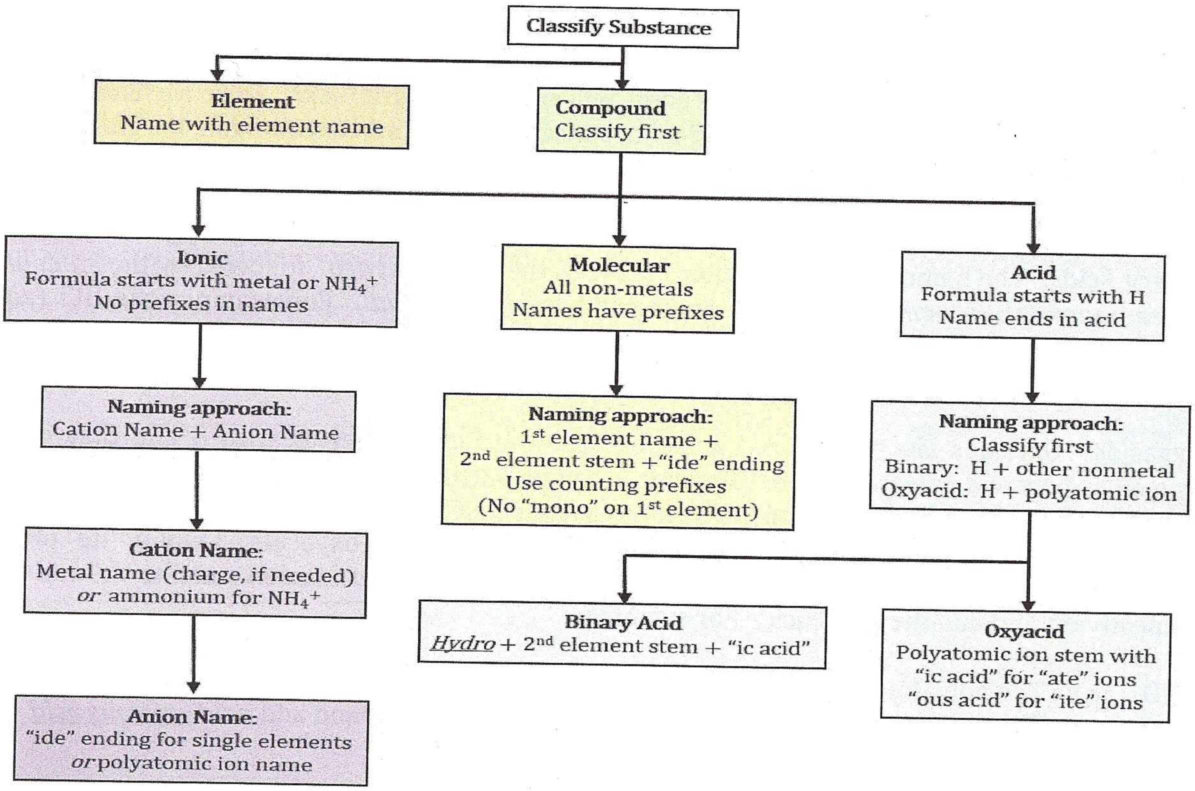
For oxyacids, we identify the name of the polyatomic ion from the "ic" or "ous" ending. The subscript for the H in the formula will equal the charge on the polyatomic ion. For example, hypochlor*ous* acid contains the hypochlor*ite* ion which has a charge of 1-. The formula for hypochlorous acid is $HClO$(aq). The "ous" and "ic" ending for the sulfate/sulfite and phosphate/phosphite ions are irregular, using the stems "sulfur" and "phosphor", respectively.

Practice: Classify the acid type (binary or oxyacid), then write the missing name or formula.

Formula	Type of Acid	Name
H_2SO_4 (aq)		
HBr (aq)		
		Phosphoric acid

Summary: The naming process for compounds is summarized on the flow chart below. The set of rules we are using is consist with the IUPAC rules for naming simple inorganic compounds and allows us to unambiguously link names to formulas. As you continue to study chemistry, you will realize these rules only cover a tiny fraction of the compounds that have been discovered and are continually being updated and revised.

Flowchart for Naming Compounds



Practice Problems: Classify each substance as an element, an ionic or molecular compound or an acid. Then, follow the rules for that class to complete the table by naming each substance or writing its formula. Don't forget to balance the positive and negative charges for ionic compounds and determine the correct number of hydrogens from the anion for acids.

	Category	Formula	Name
1.			Lithium carbonate
2.		H_2O	
3.		S_6	
4.			calcium oxide
5.		S_4N_4	
6.		$NaClO$	
7.			acetic acid
8.			Aluminum nitrate
9.		$NaOH$	
10.		H_2SO_4 (aq)	
11.		N_2O	
12.			perchloric acid
13.			magnesium sulfate
14.			Iron (III)fluoride
15.		$NaHCO_3$	
16.		$CoBr_2$	
17.			sulfurous acid
18.			carbon tetraiodide
19.		NH_3	ammonia
20.		$Cu(BrO_2)_2$	
21.		N_2O_3	
22.			selenium hexafluoride
23.			hydrobromic acid
24.			dinitrogen pentoxide
25.		ZnS	

Can you correct the errors? The following substances are named incorrectly. Fill in the correct name (classify first!) and explain your correction.

	Formula	Incorrect Name	Correction and Explanation
1.	$SnCl_4$	tin tetrachloride	
2.	CH_4	carbon tetrahydride	
3.	$HClO_3$ (aq)	hydrochloric acid	
4.	S_2F_{10}	sulfur decafluoride	
5.	Na_3N	sodium nitrate	
6.	SO_3	sulfite ion	
7.	$Ba(C_2H_3O_2)_2$	barium diacetate	

Can you correct the errors? The following substances are given an incorrect formula. Fill in the correct formula and explain your correction.

	Incorrect Formula	Name	Correction and Explanation
1.	CsS	cesium sulfide	
2.	HCO_3	carbonic acid	
3.	HIO_3 (aq)	hydroiodic acid	
4.	$CoNO_3$	cobalt (III) nitrate	
5.	P_4SO_3	tetraphosphorus trisulfide	

Reference: *Nomenclature of Inorganic Chemistry,* IUPAC Recommendations 2005, prepared by Neil G. Connelly, Ture Damhus, Richard M. Hartshorn and Alan T. Hutton, 2005