EXPERIMENT A2: NOMENCLATURE

Learning Outcomes

Upon completion of this lab, the student will be able to:

1) Predict the names of common ionic compounds and simple molecular compounds from their formulas.
2) Predict the formulas of common ionic compounds and simple molecular compounds from their names.
3) Distinguish between and give the names of common acids and bases.

Introduction

The ability to use nomenclature and chemical formulas to identify and discuss specific reagents is a key skill for a chemist. While molecules can be depicted in a variety of fashions, chemical nomenclature provides the shorthand vocabulary that chemists use to disseminate their findings and techniques. The ability to interconvert between chemical names and structure is essential to communicate substantively about topics in the field. As such, it is important to take the time to learn and understand the rules for naming chemicals so that one can continue to build a foundation of knowledge that will support future studies in chemistry.

Chemicals can be broken down into several broad categories for the purpose of organization. The first is the distinction between organic and inorganic molecules. Inorganic molecules are those that come from non-living sources, such as minerals or stone, while organic molecules were originally defined as those that came from living materials, such as living plants or decayed organic material. Today, organic molecules are referred to as those with carbon as a major constituent while inorganic chemicals are those without carbon. This lab focuses mainly on inorganic molecules. While some simple organic compounds are mentioned, the extent of the rules regarding organic nomenclature is beyond the scope of this class.

Inorganic molecules can be broken down further into two main groups: ionic and covalent compounds. This lab will focus on the systematic process of converting the formulas for binary ionic compounds to the corresponding chemical name and vice versa. Binary covalent compounds, inorganic acids, and hydrates are also discussed. A brief discussion of organic nomenclature and non-systematic names for ionic compounds is also included.

1. Binary Ionic Compounds

Binary ionic compounds are comprised of positively charged cations (metals) and negatively charged anions (nonmetals) held together by electrostatic forces. The charge on many ions can be predicted based on the group the element belongs to. Table 1 summarizes the group trends.

TABLE 1: GROUP TRENDS FOR ION FORMATION

Group	Trend	Notes
1A	+1 cations	
2A	+2 cations	
3A	+3 cations	Only Al. Others are variable or not ionic
4A	No overall trend	Mix of nonmetals and metals
5A	-3 anions	Only N. Others are variable.
6A	-2 anions	O, S, Se
7A	-1 anions	
8A	Does not form ions	Noble gases are generally non-reactive

There are three general rules for naming binary ionic compounds: 1) compounds must have an overall neutral charge, 2) the cation is named first, and 3) the nonmetal anion is named second and the suffix –*ide* is added to the root name of the element.

Some cations, including most of the transition metals, have two charge states that they commonly adopt. To denote which ion is present, the charge in roman numerals is added following the cation in the chemical name. Ex: $FeCl_3$ is iron (III) chloride. An older non-systematic naming system is sometimes applied to these compounds as well. For example, $FeCl_3$ would be ferric chloride. First, note that the root name for the cation is used in the nonsystematic names. Second, for the higher of the two common charge states the suffix –*ic* is added to the root name for the cation, while –*ous* is added to the lower charge state. As older chemical containers may still be labeled with these names, it is useful to be able to recognize them. Table 2 summarizes a few common metals that have multiple charge states and lists both the systematic (IUPAC) and nonsystematic (common) names.

TABLE 2: NOMENCLATURE FOR CATIONS WITH MULTIPLE CHARGES

Cation	Systematic name	Non-systematic name
Fe^{2+}	iron (II)	ferrous
Fe^{3+}	iron (III)	ferric
Co^{2+}	cobalt (II)	cobaltous
Co^{3+}	cobalt (III)	cobaltic
Cu^{+}	copper(I)	cuprous
Cu^{2+}	copper (II)	cupric
Sn^{2+}	tin(II)	stannous
Sn^{4+}	tin(IV)	stannic
Hg^{+} (as Hg_2^{2+})	mercury(I)	mercurous
Hg^{2+}	mercury(II)	mercuric
Pb^{2+}	lead(II)	plumbous
Pb^{4+}	lead(IV)	plumbic

2. Hydrates and Polyatomic Ions

Hydrates are ionic compounds that have a specific number of water molecules associated with each formula unit. The presence of associated water molecules is denoted by appending the word *hydrate* to the end of the ionic compound's name. Giving a numerical prefix to the "hydrate" portion of the name specifies the number of water molecules. These prefixes can be found below in Table 3. For example, $MgCl_2 \bullet 2H_2O$ is magnesium chloride dihydrate

TABLE 3: NUMERICAL PREFIXES FOR HYDRATES AND BINARY COVALENT COMPOUNDS

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

Polyatomic ions consist of two or more atoms bonded covalently and carry a net positive or negative charge. These ions always stay together as a charged unit, and do not break up further into individual atoms. Most polyatomic ions are anions. The only two common polyatomic cations are ammonium (NH_4^+) and mercury (I) (Hg_2^{2+}). Polyatomic anions are broken up into two main groups:

those that contain oxygen (often called oxoanions) and those that do not. While memorization is required for the polyatomic ions in general, there are two rules for oxoanions that help predict the appropriate name.

1. For oxoanions families with two members:

    a. The ion with more O atoms takes the nonmetal root and the suffix *–ate*
    b. The ion with fewer O atoms takes the nonmetal root and the suffix *–ite*

2. For oxoanion familes with four members:

    a. The ion with the most O atoms takes the nonmetal root, the prefix *per-* and the suffix *–ate*
    b. The ion with 1 fewer O atom takes the nonmetal root and the suffix *–ate*
    c. The ion with 2 fewer O atoms takes the nonmetal root and the suffix *–ite*
    d. The ion with the fewest O atoms (3 fewer) takes the nonmetal root, the prefix *hypo-* and the suffix *–ite*

TABLE 4: COMMON POLYATOMIC ANIONS

Ion	**Name**	**Ion**	**Name**
NO_2^-	Nitrite	CO_3^{2-}	carbonate
NO_3^-	Nitrate	HCO_3^-	hydrogen carbonate or bicarbonate
OH^-	Hydroxide	CN^-	cyanide
SO_3^{2-}	Sulfite	PO_4^{3-}	phosphate
SO_4^{2-}	Sulfate	HPO_4^{2-}	hydrogen phosphate
$H\ SO_4^-$	hydrogen sulfate	$H_2PO_4^-$	dihydrogen phosphate
CH_3COO^-	acetate	ClO_4^-	perchlorate
CrO_4^{2-}	chromate	ClO_3^-	chlorate
$Cr_2O_7^{2-}$	dichromate	ClO_2^-	chlorite
MnO_4^-	permanganate	ClO^-	hypochlorite
O_2^{2-}	peroxide	SCN^-	thiocyanate
BrO_3^-	Bromate	$S_2O_3^{2-}$	thiosulfate
NH_4^+	Ammonium		

3. Acids

Acids are an important class of chemical compounds that have been an integral part of the study of matter since alchemical times. In this type of compound, anions balance their negative charge via the addition of hydrogen atoms. There are two classes of acids: binary acids and oxoacids. Oxoacids are composed of oxoanions and hydrogen, while binary acids are composed of other anions and hydrogen. Each has their own rules for naming.

1. Binary Acids (no oxygen in anion):

    a. Prefix *hydro-* is added to nonmetal root plus suffix –*ic* plus "acid"
        i. $H_2S_{(aq)}$ is hydrosulfuric acid. [NOTE: $H_2S_{(g)}$ would however be called dihydrogen sulfide or simply hydrogen sulfide, based on the rules for binary covalent compounds discussed in the next section]

2. Oxoacids (based on oxoanion name)

    a. –*ate* suffix becomes –*ic* plus "acid
        i. H_2SO_4 is sulfuric acid

    b. –*ite* suffix becomes –*ous* plus "acid"
        i. H_2SO_3 is sulfurous acid

    c. oxoanion prefixes are retained
        i. $HClO_4$ is perchloric acid

4. Binary Covalent Compounds

Covalently bound compounds involving two nonmetals require a more specific nomenclature than ionic compounds. While magnesium and oxygen can combine in only one ratio, nitrogen and oxygen can combine in a variety of ways, including NO, NO_2, N_2O, N_2O_4, and others. To differentiate between these compounds, the following guidelines are used.

1. Name the most metallic atom first with its full name. The most metallic element is the one farthest to the left and down on the periodic table.

2. The second element uses its root name plus the suffix –*ide*.
    a. Example: N_2S_5 is dinitrogen pentasulfide

3. Each element gets a number prefix from Table 3 to denote how many atoms of that element are in each molecule.
    a. For the first named element only, the "mono-" prefix is omitted.
        i. Ex: BF_3 is boron trifluoride (not monoboron trifluoride)

    b. If the second element is oxygen, the "a" at the end of the number prefix is elided with the "o" in oxide.
        i. Ex: N_2O_5 is dinitrogen pentoxide, (not dinitrogen pentaoxide)

5. Simple Organic Compounds

As mentioned previously, organic chemistry has its own detailed and complex system of nomenclature. Much of this is beyond the scope of general chemistry, but it is worthwhile to explore the simplest of the organic molecules: hydrocarbons. Hydrocarbons are compounds that contain only carbon and hydrogen. This class of compounds is known collectively as **alkanes**. When all the carbons are attached to each other in a straight line, the most basic of organic compounds, the straight chain alkanes, or n-alkanes, are formed. For these compounds, the number of hydrogens always equals the 2*C+2. For example if there are 3 carbons, there are 3*2+2 = 8 hydrogens. The names for each of these compounds end in the suffix –*ane* while the remainder of the name corresponds to the number of carbons. As can be seen in Table 5, the first four alkanes have common or historical prefixes, while chains with five carbons or more use similar prefixes as those in Table 3. Chains that are branched or have non-carbon substituents have their own rules and are not covered here.

TABLE 5: ORGANIC NOMENCLATURE OF STRAIGHT CHAIN ALKANES

Number of carbons in chain	Number prefix
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-
9	non-
10	dec-

Reagents and Supplies

None

Procedure

Complete the following worksheets and the final review sheet.

Worksheet

1. USING THE GUIDELINES PROVIDED IN **SECTION 1** ABOVE, COMPLETE THE FOLLOWING TABLES.

   A. REFER TO TABLE 1

Formula	**Name**	**Name**	**Formula**
$MgCl_2$		Strontium nitride	
Al_2S_3		Lithium bromide	
K_3N		Calcium oxide	
NaF		Cesium selenide	

   B. REFER TO TABLE 2

Formula	**Name**	**Name**	**Formula**
$CoCl_3$		Ferric sulfide	
SnS_2		Chromium (II) iodide	
CuO		Manganese (IV) oxide	
Fe_2O_3		Stannic fluoride	
Pb_3N_4		Tin (II) nitride	

2. USING THE GUIDELINES PROVIDED IN **SECTION 2** ABOVE (**REFER TO TABLES 3 AND 4**), COMPLETE THE FOLLOWING TABLE.

Formula	**Name**	**Name**	**Formula**
KCN		Tin (II) phosphate	
$LiNO_3$		Iron (II) chlorite	
$Cd(CH_3COO)_2{\bullet}2H_2O$		Lead (IV) nitrite	
$Pb(MnO_4)_4$		Sodium carbonate	
NH_4ClO_4		Barium permanganate	
$SnSO_4$		Potassium hydroxide	
$Al(H_2PO_4)_3$		Calcium acetate	
MgO		Cesium perchlorate	
NaSCN		Aluminum cyanide	
$Ca(NO_2)_2$		Ammonium nitride	

3. USING THE GUIDELINES PROVIDED IN **SECTION 3** ABOVE (**ALSO REFER TO TABLE 4**), COMPLETE THE FOLLOWING TABLE.

Formula	**Name**	**Name**	**Formula**
$HBr_{(aq)}$		Nitrous acid	
HNO_3 $_{(aq)}$		Hydrocyanic acid	
H_3PO_4 $_{(aq)}$		Hydrofluoric acid	
H_2CO_3 $_{(aq)}$		Sulfurous acid	
$CH_3COOH_{(aq)}$		Sulfuric acid	
$HClO_{(aq)}$		Carbonic acid	
$HClO_3$ $_{(aq)}$		Hydroiodic acid	

4. USING THE GUIDELINES PROVIDED IN **SECTION 4** ABOVE (**ALSO REFER TO TABLE 3**), COMPLETE THE FOLLOWING TABLE.

Formula	**Name**	**Name**	**Formula**
N_2O_5		Sulfur hexafluoride	
NO_2		Iodine tribromide	
PCl_3		Sulfur trioxide	
SiO_2		Carbon monoxide	
S_2O_5		Diphosphorous pentoxide	
CCl_4		Diboron hexachloride	
As_2S_3		Iodine heptachloride	

5. USING THE GUIDELINES PROVIDED IN **SECTION 5** ABOVE (**ALSO REFER TO TABLE 5**), COMPLETE THE FOLLOWING TABLE.

Formula	Name	Name	Formula
C_3H_8		Ethane	
C_5H_{12}		Butane	
C_9H_{20}		Heptane	
C_6H_{14}		Methane	

6. FINAL REVIEW SHEET: COMPLETE THE FOLLOWING TABLE

Formula	**Name**	**Name**	**Formula**
$Hg_2(CH_3COO)_2$		Bromine pentafluoride	
H_2CrO_4		Copper (II) carbonate	
Na_2O		Antimony triiodide	
C_4H_{10}		Iron (III) nitride	
$H_2S_{(g)}$		Propane	
C_2H_6		Phosphoric acid	
$SrCl_2{\bullet}2H_2O$		Octane	
$SeCl_6$		Lithium sulfide	
$AgNO_3$		Sulfuric acid	
P_2F_4		Sodium hydrogen phosphate	