Inorganic Chemical Nomenclature

(Naming the common compounds)

Bob Widing 9/89, 8/93, 8/94, 8/95, 8/96, 8/97
Department of Chemistry, Univ. of Ill. at Chgo.
modified from notes of
Dr. Marlene Kolz and Dr. David Parrish

Nomenclature outline

(A) Prerequisite skills for learning nomenclature of inorganic compounds:

Elements to know on web-site

1. When given the chemical symbol, from memory, write the correctly spelled names of the first twenty elements (H to Ca), and Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Kr, Sr, Mo, Ag, Cd, Sn, Sb, I, Xe, Ba, W, Pt, Au, Hg, Pb, Bi, Rn, Ra, U, Pu
2. Identify the correct chemical symbols when given the names.
3. Be able to quickly locate these elements on a periodic table.

Objectives:

After reading and answering the questions in this set of handout notes, you should be able to:
(while using a Periodic Table, using the elements listed above)

1. Write from memory, the formulas and trivial names of methane, ammonia, and water.
2. Distinguish inorganic compounds from organic compounds when given their formulas (or their names).
3. Be able to distinguish metals from non-metals (and metalloids) by their position in the periodic table or by their names.
4. Label compounds as ionic or covalent, given their formulas.
5. For any of these elements, list their possible valences in compounds (charges in ionic compounds or number of bonds formed in covalent compounds)
6. Given its name, write the formula of any binary (ie. two-element) ionic compound composed of representative elements (U.S. Group A). eg. magnesium chloride = $MgCl_2$
7. Name any binary ionic compound when given its name. eg. Na_2S = sodium sulfide

Ions to know on website

8. From memory, write the names and formulas of any of these twelve polyatomic ions:
NO_3^{-1}, NO_2^{-1}, SO_4^{-2}, SO_3^{-2}, CO_3^{-2}, HCO_3^{-1}, PO_4^{-3}, OH^{-1}, CN^{-1}, NH_4^{+1}, MnO_4^{-1}, CrO_4^{-2} eg. NH_4^+ ⇔ ammonium
9. Write the formulas and names of compounds containing any of those 12 polyatomic ions.
eg. $(NH_4)_3PO_4$ ⇔ ammonium phosphate
10. Given their formulas, use the Stock system for naming compounds containing ions of variable charge.
eg. $Fe(OH)_3$ ⇒ iron(III) hydroxide
11. Given their names, determine the formulas of compounds containing metal ions of variable charge.
eg. tin(IV) sulfate = $Sn(SO_4)_2$

OMIT

12. Given name of any compound having metals of variable charge that have been named by the old -ous, -ic system, find the formula and the modern Stock system name. eg. ferrous sulfate ⇒ $FeSO_4$ and ⇒ iron(II) sulfate
13. Know the Greek numerical prefixes from one to ten.
14. Name the covalent compound (ie. compounds made from two non-metals) given their formulas and find the formula when given any such name. eg. N_2O_5 ⇔ dinitrogen pentoxide
15. write the names and formulas of the common acids and bases: HCl, HNO_3, H_2SO_4, H_3PO_4, NaOH, KOH, $Ca(OH)_2$ HCl ⇔ hydrochloric acid H_2SO_4 ⇔ sulfuric acid
16. Identify the elements that occur as diatomic molecules under normal conditions:
They are hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine
Mnemonics: 1.) All the elements that end in -gen or -ine suffixes, 2.) FONClBrIH (pronounce: fonklebree), 3.) These elements are located in an (up-side-down) L-shaped pattern in the periodic table.
17. When provided with the names and symbols of elements that you did not have to memorize in the lists above (Prerequisite skills 1 & 2), use the periodic table to generalize and assign names or formulas.
eg. rubidium selenide ⇔ Rb^+ like Na^+ and Se^{2-} like S^{2-}, so Rb_2Se is the formula.
eg. Cs_3AsO_4 ⇔ cesium ion, Cs^+ like Na^+ and AsO_4^{3-} like PO_4^{3-}, so cesium arsenate is the name.
18. Be able to assign names and/or formulas in a general mixture of compounds that fit into any of the three naming systems.

(B)

In ancient Rome, a nomenclator was the person who stood at the door of gatherings, such as the Roman Senate, and announced the names of guests as they arrived. (Etymology of nomenclature) Today, chemical nomenclature is name assignment (and understanding of names and formulas).

The word nomenclature is itself apparently difficult, if one may judge by the different ways of mispronouncing it. I have attended seminars of visiting chemists, sometimes famous chemists, who pronounced this word as nŏm' men klā' cher, nŏm men' klā cher, nō menk' klā' cher, nō' men clĕt cher, and others. Mispronunciations are a sign of a self-taught person, one who learned only from reading. But, if usage is the judge, then I do not know who is correctly pronouncing nomenclature. According to my two dictionaries, nō' men klā' cher is the correct pronunciation; with the first o, as a long o as in go, the first e pronounced as in agent, the a , a long a as in ape, and the -ture ending pronounced as cher with this e sound pronounced as in agent.

How would* Chemical Abstracts *handle it
If you just called it "an ooky mess"?

Trivial names (Common names, non-systematic names)

When chemistry (and alchemy) was a new science, a relatively small number of substances were known. It was possible to memorize all their names.
So, new substances were named haphazardly as were the elements.
Some were named for their **appearance** (milk of lime, Venetian red, fool's gold).
Some were named for their **chemical properties** (caustic soda, aqua fortis, fixed air)
Some were named for other properties (magnetite, laughing gas) or their **origin** (Chilean saltpeter) or their **use** (baking soda, washing soda) or for their **discoverer** (Zeise's salt) or other incidentals.
(See page 12 at the end of these notes.)

Trivial names are sometimes used like nicknames, for brevity and familiarity.
Chemists still use trivial names for some types of compounds, such as these non-metal hydrides.

CH_4 is methane	**NH_3 is ammonia**	**H_2O is water**
SiH_4 is silane	PH_3 is phosphine	
GeH_4 is germane	AsH_3 is arsine	
SnH_4 is stannane	SbH_3 is stibine	

Exercise #1 Write the name for these three formulas.

H_2O _____ NH_3 _____ CH_4 _____

It would be a hopeless task to learn the names of all the millions of known compounds if they had all been named by trivial names assigned by the caprice of those who discovered or first described each compound.

The goal of systematic chemical nomenclature is to describe **COMPOSITION**, unambiguously, but briefly.

Element	**Compound**
use a symbol (one or two letters) example: Mg	use a formula example: $MgSO_4$
use a one-word name example: magnesium	use a two-word name example: magnesium sulfate
elements are mostly solids (often gray metals)	inorganic compounds are usually white solids (often powders or colorless crystals)

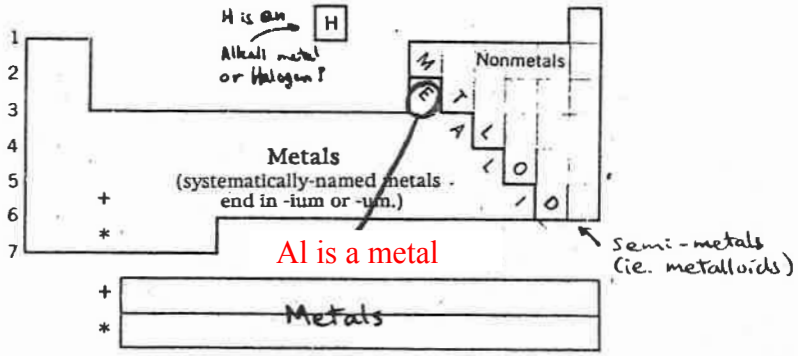
Both an element and a compound are pure substances (i.e., chemicals).
See "Classification of Matter" notes for definitions.

Our modern inorganic chemical nomenclature uses two names to describe the two parts of most compounds. A first name describes the positively charged part and a second name describes the negatively charged part. The positive part is usually a metal or hydrogen or the less negative nonmetal. The negative part is usually a nonmetal or an oxygen-containing negatively-charged ion.

Covalent compounds are described differently than ionic compounds, so we must be able to distinguish between covalent and ionic to properly assign names. **Ionic** compounds have a positive ion (cation) and a negative ion (anion). The positive ion is usually a metal ion, since metals tend to lose electrons to form cations. The negative ion is often a nonmetal anion since nonmetals tend to gain electrons to complete their outer-electron level. Some examples of ionic compounds are NaCl, $MgCl_2$, and $FeCl_3$.

Metals can be distinguished from nonmetals by their position in the periodic table. For the purposes of nomenclature, metalloids (that is, the borderline elements between metals and nonmetals) are classed with and named like the nonmetals.

The location of metal, non-metal, and metalloid elements on the periodic table



When a nonmetal forms a compound with another nonmetal, they share electrons to form a **covalent** compound. Below we separate the compounds by an arbitrary division, this is necessary because the compounds actually grade continuously from ionic to covalent.

Metal - nonmetal compound
(eg. NaCl, or $CaBr_2$)
has **ionic** bonds (cations attract anions)
(metal loses e^- to form cation, and
the nonmetal gains e^- to form anion

Nonmetal - nonmetal compound
(eg. CCl_4, or H_2O)
has **covalent** bonds
(electrons are shared between atoms
that have similar attraction for electrons
ie. similar electronegativity)

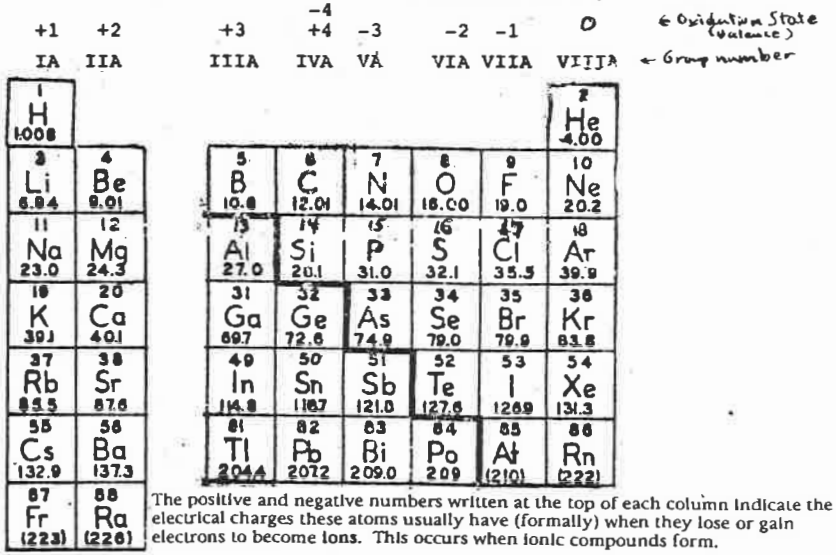
Use an **-ide** suffix for the ions that have gained enough electrons to reach a noble-gas configuration.

C^{4-} carbide	N^{3-} nitride	O^{2-} oxide	F^- fluoride	(H^- hydride) like a halide
(Note: C_2^{2-} is also called "carbide")	P^{3-} phosphide	S^{2-} sulfide	Cl^- chloride	
	As^{3-} arsenide	Se^{2-} selenide	Br^- bromide	
		Te^{2-} telluride	I^- iodide	
			halides	

These are the common states for non-metallic elements when only one non-metal constitutes the negative part of the compound. So, -ide indicates one negative element. Compare this to -ite or -ate which indicate the presence of additional oxygen.

Periodic Table and Ions (Oxidation Number)

(a simplified periodic table, omitting the transition metals)



The positive and negative numbers written at the top of each column indicate the electrical charges these atoms usually have (formally) when they lose or gain electrons to become ions. This occurs when ionic compounds form.

Ionic bonding occurs when the bonded partners come from opposite ends of the periodic table, such as when potassium, a left-winger, bonds with fluorine, a right-wing reactionary.
Here is a mnemonic device from politics: the far-left are liberal at giving away electrons.
The far-right are conservative and collect things (old flags in the attic?). The extreme far-right (noble gases) are isolationists and aristocrats. The metalloids are undecided, independent.

There are several exercises found throughout this set of notes. For each exercise, a dashed line separates the problem from the answer. To get the most benefit from these exercises, cover up the answers with a piece of paper. Write down your answers in the space provided, and compare your answers with those given.

Exercise #4 Label each of these compounds as ionic or covalent.

$CaCl_2$ $NiBr_2$ SO_2 ClF_3 NaI B_2O_3

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ionic (metal-nonmetal) ionic (metal-nonmetal) covalent (nonmetal-nonmetal) covalent (nonmetal-nonmetal) ionic (metal-nonmetal) covalent (nonmetal-nonmetal)

Exercise #5a For each formula listed below, write the charge on each ion, the total positive charge, the total negative charge, and the net charge on the compound. The first two have been done for you as examples.

Compound	Ions				Net Charge
NaCl	Na	+1	Cl	−1	0
$MgBr_2$	Mg	+2	2Br	−2	0 = 1(+2) + 2(−1)
AlI_3	Al	___	3I	___	___
Li_2O	2Li	___	O	___	___
Al_2O_3	2Al	___	3O	___	___
Li_3N	3Li	___	N	___	___
Na_4C	4Na	___	C	___	___

The positive and negative parts must combine in a ratio so as to make a neutral compound, so in all cases the total positive charges should equal the total negative charge, since the net charge on any compound is zero.

Al^{3+}, 3 I^- Net charge of $AlI_3 = 0$; 2 Li^+, O^{2-} Net charge of $Li_2O = 0$;

2 Al^{3+}, 3 O^{2-} Net charge of $Al_2O_3 = 0$; 3 Li^+, N^{3-} Net charge of $Li_3N = 0$

The fact that compounds are neutral helps us to correctly write the formulas of most ionic compounds when given only the charges of their constituent ions. For example, the compound sodium oxide consists of Na^{+1} ions and O^{2-} ions. In order for the compound to be neutral, there must be two Na^{+1} ions for every one O^{2-} ion. Therefore, the formula of sodium oxide is Na_2O.

By convention we write the metal (or positive ion) first. Thus, we write Na_2O, not ONa_2 (and NaCl, never ClNa)

Exercise #5b Write the formula of the simplest compound formed between:

potassium and fluorine _____
calcium and oxygen _____
magnesium and iodine _____
aluminum and bromine _____
sodium and sulfur _____
aluminum and sulfur _____
calcium and nitrogen _____
hydrogen and oxygen _____

KF, CaO, MgI_2, $AlBr_3$, Na_2S, Al_2S_3, Ca_3N_2, H_2O

Note the order of the ions in the formulas you have just finished writing.

Which ion is first? [positive? or negative?] (Circle one.)

(D1) Simple Binary Ionic Compounds

(from Whitten, Galley, & Davis)

Metal (General symbol, M)		Nonmetal (General symbol, X)		General Formula of Compound (and the ions present)	Example	Melting Point ‡ Temperature
M (Group IA)*	+	X (Group VIIA)	→	MX (M^+, X^-)	LiBr	547°C
M (Group IIA)	+	X (Group VIIA)	→	MX_2 (M^{2+}, 2 X^-)	$MgBr_2$	708°C
M (Group IIIA)	+	X (Group VIIA)	→	MX_3 (M^{3+}, 2 X^-)	GaF_3	800°C
M (Group IA)*	+	X (Group VIA)	→	M_2X (2 M^+, X^{2-})	Li_2O	1750°C
M (Group IIA)	+	X (Group VIA)	→	MX (M^{2+}, X^{2-})	CaO	2580°C
M (Group IIIA)	+	X (Group VIA)	→	M_2X_3 (2 M^{3+}, 3 X^{2-})	Al_2O_3	2045°C
M (Group IA)*	+	X (Group VA)	→	M_3X (3 M^+, X^{3-})	Li_3N	840°C
M (Group IIA)	+	X (Group VA)	→	M_3X_2 (3 M^{2+}, 2 X^{3-})	Ca_3P_2	1600°C
M (Group IIIA)	+	X (Group VA)	→	MX (M^{3+}, X^{3-})	AlP	very high

* Hydrogen is considered a nonmetal, and all binary compounds are covalent except the metal hydrides such as NaH and CaH_2.

Naming a Binary Compound (i.e., a compound having only two elements.)

A.) **Binary compounds in which there is a metal having only one possible charge.**
(eg. Group IA metal ions, Group IIA metal ions, Zn^{2+}, Cd^{2+}, or Al^{3+})

The name of a binary (ie. two-element) compound consists of two parts:
1.) the name of the first element (usually a metal or the more positive atom), and
2.) the stem name of the second (more negative) element with an -ide suffix.
[Stem names are listed in the tables on the right side of this page.]

‡ Compounds formed from ions having a higher charge (M^{+large} with X^{-large}) will have a stronger attractive force and thus higher melting point temperature. [See Coulomb's law of electrostatic attraction (Physics) which states that the attractive force is directly proportional to the size of the two charges.]

Calcium chloride, $CaCl_2$, is a binary compound composed of one atom of calcium for every two atoms of chlorine. The name of the positive element, "Ca" , is written first and is not modified. The name of the negative element, "Cl", is derived from the stem, "Chlor-", by adding the ending "-ide"; so, it is named "chloride". The compound name is "calcium chloride". Because, calcium is **always** +2 in all of its compounds, we do not write "calcium(II) chloride". Also, since calcium is a metal, we do not write "calcium dichloride".

Examples of binary compounds where the metal has **only one** possible oxidation state.

Formula	Name
$MgBr_2$	Magnesium bromide
Na_2O	Sodium oxide
NaH	Sodium hydride
K_3P	Potassium phosphide
CaS	Calcium sulfide
Al_2Se_3	Aluminum selenide
Mg_3N_2	Magnesium nitride
$ZnCl_2$	Zinc chloride

Ordering of elements in formula of binary compounds (generally follows electronegativity) - see CH1,2 lecture notes

B	Si	C	Sb	Ar	P	N	H	Te	Se	S	I	Br	Cl	O	F
Group #	III	IV	V	VI	VII

A part of a word is called an affix, such as a prefix, suffix, or infix (ie. stem).
("beginnings, endings, and middles")

The table below lists the stems for the non-metallic elements that become negative. So these stems are the foundation for the second name in the binary compound.

Symbol	Element	Stem (ie. infix)	Binary name ending
B	boron	bor-	boride
Br	bromine	brom-	bromide
C	carbon	carb- (or carbon-)	carbide
Cl	chlorine	chloro-	chloride
F	fluorine	fluoro-	fluoride
H	hydrogen	hydr-	hydride
I	iodine	iod-	iodide
N	nitrogen	nitr-	nitride
O	oxygen	ox-	oxide
P	phosphorus	phosph- (or phosphor-)	phosphide
S	sulfur	sulf- (or sulfur-)	sulfide

sulfuric acid but sulfate (not sulfurate!) however, we use carbonic acid and carbonate

Below these stem names are reorganized by their elements' positions in the periodic table.

Group → (in Periodic Table)	IIIA	IVA	VA	VIA	VIIA
	B bor	C carb(on)	N nitr	O ox	F fluor
		Si silic	P phosph(or)	S sulf(ur)	Cl chlor
			As arsen	Se selen	Br brom
			Sb antimon	Te tellur	I iod

Exercise #7a Name the seven compounds listed below (from Exercise #5a)

$NaCl$ _____

$MgBr_2$ _____

AlI_3 _____

Li_2O _____

Al_2O_3 _____

Li_3N _____

Na_4C _____

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sodium chloride, magnesium bromide, aluminum iodide, lithium oxide, aluminum oxide, lithium nitride, sodium carbide

Exercise #7b Name the eight compounds listed below (from Exercise #5b)

KF _____

CaO _____

MgI_2 _____

$AlBr_3$ _____

Na_2S _____

Al_2S_3 _____

Ca_3N_2 _____

H_2O _____

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potassium fluoride, calcium oxide, magnesium iodide, aluminum bromide, sodium sulfide, aluminum sulfide, calcium nitride, hydrogen oxide (water!)

Formulas of binary hydrogen, oxygen, and chloride compounds of Group A elements (i.e., representative elements) showing periodic patterns in valence.

Group in the periodic table:	IA	IIA	IIIA	IVA	VA	VIA	VIA
Hydrogen compound :	NaH	CaH_2	AlH_3	CH_4	NH_3	H_2S	HCl
Oxygen compound :	Na_2O	CaO	Al_2O_3	CO_2	N_2O_5	SO_3	Cl_2O_7
Chlorine compound : (see Table on p.3, too)	$NaCl$	$CaCl_2$	$AlCl_3$	CCl_4	NCl_3	SCl_2	Cl_2

Polyatomic Ions

Certain combinations of atoms behave like ions during compound formation. They are called polyatomic ions. Each consists of more than one atom and each has a net electrostatic charge. For example, NO_3^- is the nitrate ion.

Exercise #8a What is the formula of sodium nitrate? _____

What is the formula of calcium nitrate? _____

What is the formula of aluminum nitrate? _____

$NaNO_3$, $Ca(NO_3)_2$, $Al(NO_3)_3$ [We describe this last compound by saying "Al(nitrate)taken three times"]

Note **parentheses** are required when there is **more than one** polyatomic ion in the compound. However, no parentheses are used when there is only **one** polyatomic ion in the compound. For example, we do not write Na(OH) but NaOH. Also, note that parentheses are never used for a single element. For example, we never write $(Na)_2SO_4$, but rather Na_2SO_4. As a general rule, do not use parentheses unless they are needed to make the formula unambiguous.

Here is a list of the most common polyatomic ions. These ions are used so much in chemistry, that chemistry students must MEMORIZE the NAMES, FORMULAS, and CHARGES of each of these twelve polyatomic ions. *

OH^-	hydroxide	SO_4^{2-}	sulfate	PO_4^{3-}	phosphate
CN^-	cyanide	SO_3^{2-}	sulfite	NH_4^+	ammonium
NO_3^-	nitrate	CO_3^{2-}	carbonate	MnO_4^-	permanganate
NO_2^-	nitrite	ClO_3^-	chlorate	CrO_4^{2-}	chromate

Note that -ate and -ite suffixes are used to indicate the presence of **oxygen** as a third element in the compound (with greater or lesser amounts of oxygen Mnemonic: Think of -ite as having a mite less oxygen.). Contrast the -ide suffix which indicates only one element in the negative portion of the compound.

Exercise #8b Write out form memory the names, charges, and formulas of these twelve polyatomic ions.

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ammonium, NH_4^+; carbonate, CO_3^{2-}; chlorate, ClO_3^-; chromate, CrO_4^{2-}; etc.

* And all ions in IONS_TO_KNOW on website

Exercise #8b Write out form memory the names, charges, and formulas of these twelve polyatomic ions.

Here is another set of six polyatomic ions which are not quite as frequently used as the twelve above, but these will be used many times in this coming year's class. Some of these you will learn later.

O_2^{2-}	peroxide	ClO_4^-	perchlorate	$C_2H_3O_2^-$	acetate
$Cr_2O_7^{2-}$	dichromate	$S_2O_3^{2-}$	thiosulfate	HCO_3^-	hydrogen carbonate (bicarbonate)

This list has the less common polyatomic ions.
Use this for reference, **do not memorize.**
(The oxidation number of the central, main element is in parentheses.)

AsO_4^{3-}	arsenate (V)	ClO_2^-	chlorite (III)	$C_2O_4^{2-}$	oxalate
AsO_3^{3-}	arsenite (III)	$Fe(CN)_6^{3-}$	ferricyanide (III)	HPO_3^{2-}	phosphite
N_3^-	azide	$Fe(CN)_6^{4-}$	ferrocyanide (II)	PO^+	phosphoryl
BiO_3^-	bismuthate (V)	ClO^-	hypochlorite (I)	SCN^-	thiocyanate
BiO^+	bismuthyl (III)	Hg_2^{2+}	mercury (I)	I_3^-	triiodide
BO_3^{3-}	borate (III)	MoO_4^{2-}	molybdate (VI)	UO^{2+}	uranyl (IV)
C_2^{2-}	carbide (acetylide)	NO^+	nitrosyl (III)	VO^{2+}	vanadyl
OCN^-	cyanate	NO_2^+	nitryl (V)	WO_4^{2-}	tungstate

The rules for naming compounds having polyatomic ions are the same as for naming binary ionic compounds, except you must use the name of the polyatomic ion whether it occurs first or second in the formula. Its name is first if the polyatomic ion is a positive ion (cation), and its name is second if the polyatomic ion is a negative ion (anion). Examples are:

NH_4Cl	ammonium chloride
$NaHCO_3$	sodium hydrogen carbonate [old name: sodium bicarbonate]
$Mg_3(PO_4)_2$	magnesium phosphate

Exercise #9a Name these pseudo-binary compounds:

NaOH	_____
$CaCO_3$	_____
$Al(ClO_3)_3$	_____
Li_2SO_4	_____
KCN	_____
$(NH_4)_3PO_4$	_____
$ZnSO_4$	_____

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sodium hydroxide, calcium carbonate, aluminum chlorate, lithium sulfate, potassium cyanide, ammonium phosphate, zinc sulfate.

To write formulas involving polyatomic ions, you must remember that all compounds are neutral; therefore the net charge of all of the ions in the compound must be zero. For example, aluminum carbonate is composed of Al^{3+} ions and CO_3^{2-} ions. The lowest common multiple of 3 and 2 is 6. So, in order to have a neutral compound, there must be 6 positive charges and 6 negative charges. This is accomplished by two Al^{3+} ions and three CO_3^{2-} ions. Thus the formula of aluminum carbonate must be $Al_2(CO_3)_3$

Exercise 9b Determine the formula of each of these compounds.

calcium hydroxide	_____
potassium phosphate	_____
aluminum nitrate	_____
potassium permanganate	_____
calcium phosphate	_____
ammonium iodide	_____
hydrogen cyanide	_____
sodium chromate	_____
ammonium phosphate	_____
ammonia	_____

$Ca(OH)_2$, K_3PO_4, $Al(NO_3)_3$, $KMnO_4$, $Ca_3(PO_4)_2$, NH_4I, HCN, Na_2CrO_4, NH_3 [Note that the compound ammonia (NH_3) and the ammonium ion (NH_4^+) are often confused by beginners.]

(D3a) Ions that have Variable Charge

Several elements, especially in the transition metals, can form more than one type of positive ion. For example, copper ions may have a charge of +1 or +2. The officially approved system used for naming compounds containing such ions is known as the **Stock System#**. In this system the positive charge of an ion is designated by a Roman numeral in parentheses written immediately after the name of that metallic element. Some of the elements that have more than one possible ion are:

Fe^{2+}	iron(II)	Fe^{3+}	iron(III)
Cu^+	copper(I)	Cu^{2+}	copper(II)
Hg_2^{2+}	mercury(I) *	Hg^{2+}	mercury(II)
Sn^{2+}	tin(II)	Sn^{4+}	tin(IV)

* Mercury(I) ions have a covalent bond between two Hg^+, so they make the polyatomic ion: Hg_2^{2+}

Here are examples of compounds containing such ions (and the names of those compounds):

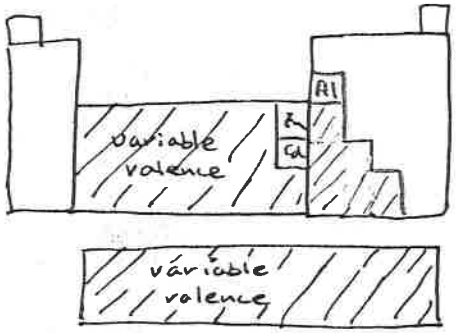
$FeCl_3$	iron(III) chloride	[Read as "iron-three chloride"]
$Hg(NO_3)_2$	mercury(II) nitrate	
CuO	copper(II) oxide	

From the formula, the charge of the positive ion can be determined by calculating the total charge of the negative ions and remembering that any compound must be neutral. For example, in $FeCl_3$, the three chloride ions have a total charge of -3; therefore, the iron ion must have a charge of +3.

Make note of this pitfall (a common mistake on examinations by beginners): Lead(II) means Pb^{2+} in the compound, **not** Pb_2 . . . The Roman numeral is not the subscript.

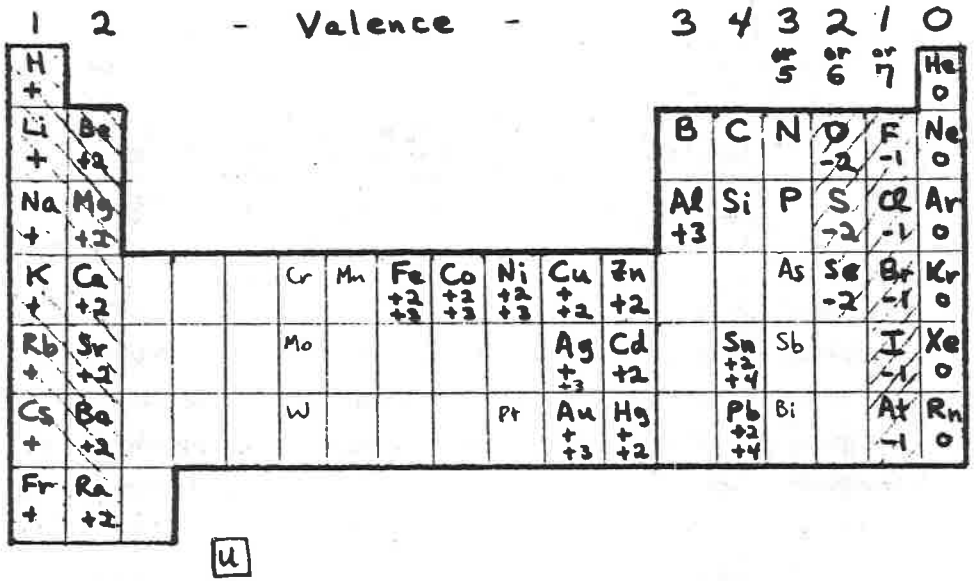
The Stock System is named after Alfred Stock (1876-1946). He was a German chemist who researched the synthesis and properties of boron, beryllium, and silicon compounds. He was also the first scientist to realize the dangers of mercury poisoning (toxicity of mercury compounds).

All metals have variable valence except Group I, Group II, Al(+3), Zn(+2), Cd(+2) - we will treat silver as having one valence (+1)



Many elements form only **one** type of ion when they react to form compounds. Examples of such elements are in Group I A and Group IIA.

But some elements have **more than one** possible ion (variable valence). You must know which elements have variable valence and you must know the possible ions of the few elements listed in this table.



Roman numerals You must know I to VIII for this this course.

I 1	V 5	X 10	L 50	C 100	D 500	M 1000
I 1	II 2	III 3	IV 4	V 5	VI 6	VII 7	VIII 8	IX 9	X 10
XX 20	XXX 30	XL 40	L 50	LX 60	LXX 70	LXXX 80	XC 90	IC 99	C 100
CC 200	CCC 300	CD 400	D 500	DC 600	DCC 700	DCCC 800	CM 900	XM 990	M 1000

MCDXCVI 1496 MDCCCLXXXIII 1883 MCMIL 1949 MCMLXXIV 1974

Exercise #10: Name these compounds using the Stock system.

FeO _____
Fe_2O_3 _____
Cu_2O _____
Hg_2SO_4 _____
SnO_2 _____
$Hg(NO_3)_2$ _____
CuS _____
$FePO_4$ _____
$FeBr_2$ _____
$MgBr_2$ _____

---

iron(II) oxide, iron(III) oxide, copper(I) oxide, mercury(I) sulfate, tin(IV) oxide, mercury(II) nitrate, copper(II) sulfide, iron(III) phosphate, iron(II) bromide, magnesium bromide [Note that magnesium ions can have only have a charge of +2; therefore Roman numerals are not used.]

Exercise #11: Write the formula of each compound:

iron(III) sulfide _____
copper(II) oxide _____
mercury(II) carbonate _____
tin(II) fluoride _____

Fe_2S_3, CuO, $HgCO_3$, SnF_2

Are You Wondering . . .

Why we don't use names such as sodium(I) chloride for NaCl and magnesium(II) chloride for $MgCl_2$? Each proposed name does clearly indicate the compound in question, but as a general rule chemists always write the *simplest name possible*. The metals of periodic table Group 1A (including Na) and Group 2A (including Mg) have *only one ionic form*, one oxidation state. Roman numerals designating these oxidation states are superfluous. *

* The same is true for Al - +3
Zn - +2
Cd - +2
Ag - +1

(D3b)

An older system of nomenclature indicates the charge of these variable ions by the use of suffixes: -ous for the lower charge and -ic for the higher charge. For five of the seven ancient metals whose chemical symbols came from Latin, Latin names of the elements are used in combination with the -ous or -ic suffixes.

Examples: ferrous chloride - $FeCl_2$ ferric chloride - $FeCl_3$
stannous oxide - SnO stannic oxide - SnO_2
cuprous bromide - CuBr cupric bromide - $CuBr_2$

TABLE Metals with Variable Oxidation States

Metal	Stock Method	Classical Method	Metal	Stock Method	Classical Method
thallium	thallium(I)	thallous	lead	lead(II)	plumbous
	thallium(III)	thallic		lead(IV)	plumbic
iron	iron(II)	ferrous	tin	tin(II)	stannous
	iron(III)	ferric		tin(IV)	stannic
chromium	chromium(II)	chromous	copper	copper(I)	cuprous
	chromium(III)	chromic		copper(II)	cupric
cobalt	cobalt(II)	cobaltous	gold	gold(I)	aurous
	cobalt(III)	cobaltic		gold(III)	auric

This system has lost favor with chemists for three reasons:
1.) Several elements have more than two possible charges, so two suffixes are insufficient to name the possible variations.
2.) The suffixes do not indicate the number of the charge of the ion, but merely that two different states occur and which is higher.
So, while ferrous ion has a charge of +2, cuprous ion has a charge of +1.
Also, cupric is +2, ferric is +3, and stannic is +4. (no simple pattern).
3.) In the past, some assignments like titanous for Ti^{3+} and titanic for Ti^{4+}, when later, other states were discovered, such as Ti^{2+}.
This obviously produces confusion.

We shall try not to use this system. As a student in this class, you need never write these names yourself.

Exercise #12 What is the formula and modern (Stock) name for:

	Formula	Modern name (Stock system)
stannous fluoride	_____	_____
cupric sulfate	_____	_____

SnF_2, tin(II) fluoride; $CuSO_4$, copper(II) sulfate

(D4) Covalent Compounds

Covalent compounds generally are formed when atoms share electrons. This occurs when both elements in the binary compound are non-metals or when one element is a metalloid and the other is a non-metal. Remember, we treat metalloids as non-metals for the purposes of nomenclature. Some pairs of elements can combine in many different ways. For example, nitrogen and oxygen can form the compounds N_2O, NO, NO_2, N_2O_3, NO_2, N_2O_4, N_2O_5, and NO_3. To name these compounds, we do not pretend that they are ionic, instead the Greek numerical prefixes are used.

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

NUMERICAL PREFIXES

	Greek	Latin (for comparison; used later in this course)
one	mono-	uni-
two	di-	bi-
three	tri-	tri-
four	tetra-	quad-, quadra-
five	penta-	quinque-, quint-
six	hexa-	sex-, sexa-
seven	hepta-	septi-. septa-
eight	octa-	octa-
nine	nona- (ennea-)	nona-
ten	deca-, deka-	deci-
100	hecto-	centum
1000	kilo-	mille
many	poly-	multi-

* Electronegativity:

N O

I < Br < Cl < F

(know this)

The first element is usually the one of which there are fewer atoms.
* The second element in the chemical name is almost always the more electronegative of the two elements.
The prefix *mono-* is generally omitted unless there is a similar compound which must be distinguished.

see page 3 for ordering

Examples: NO_2 nitrogen dioxide (instead of mononitrogen dioxide)
NO nitrogen monoxide N_2O_3 dinitrogen trioxide

Nonmetal-nonmetal compounds (covalent compounds):
The more electronegative element is placed in the second word of the name.

ClF	chlorine **monofluoride**
SCl_2	sulfur **dichloride**
PI_3	phosphorus **triiodide**
$SiBr_4$	silicon **tetrabromide**
$AsBr_5$	arsenic **pentabromide**
SeF_6	selenium **hexafluoride**
IF_7	iodine **heptafluoride**
CO	carbon **monoxide**
B_2Se_3	diboron **triselenide**
CS_2	carbon **disulfide**
N_2O_5	dinitrogen **pentoxide**
SO_3	sulfur **trioxide**
Cl_2O_7	dichlorine **heptoxide**
XeO_4	xenon **tetroxide** (explosive: $XeO_4 \rightarrow Xe + 2\ O_2$)

Exercise #13a. What numbers do these prefixes stand for?

hexa- _____
nona- _____
mono- _____
tri- _____
deca- _____
penta- _____
di- _____
hepta- _____
tetra- _____
octa- _____

Exercise #13b. Write the numerical prefixes (Greek) used for these numbers.

1 _____
2 _____
3 _____
4 _____
5 _____
6 _____
7 _____
8 _____
9 _____
10 _____

Exercise #13c What is the Greek prefix meaning four? (Circle one)

a.) petra- b.) tentra- c.) mega- d.) tetra- e.) hexa-

Answer: d.) tetra-

Exercise #14a. Write the systematic name for these compounds

N_2O _____

N_2O_4 _____

P_2O_5 _____

NO_3 _____

CO_2 _____

CO _____

---

dinitrogen monoxide, dinitrogen tetroxide, diphosphorus pentoxide, nitrogen trioxide, carbon dioxide, carbon monoxide

In order to tell when to use numerical prefixes, you must categorize the elements as metals, metalloids, or non-metals. Review the periodic tables on page 2 of this set of notes. Notice the zig-zag (or stair-step) shaped line. This line separates the metals (to the left) from the non-metals (to the right of the line). Compounds requiring numerical prefixes have two non-metals, such as NO_2, or one metalloid and one non-metal, such as $GeCl_4$. Binary ionic compounds are formed from a metallic element and a non-metallic element; these compounds require NO numerical prefixes.

Exercise #4b (review of Goal 4): Circle the compounds that require numerical prefixes in their names.

Al_2O_3 As_2O_5 KF NBr_3 SF_6 $CuSO_4$ S_2F_{10}

As_2O_5, NBr_3, SF_6, S_2F_{10} (These compounds have two non-metals.)

Exercise #14b Write formulas for these compounds:

tetraphosphorus hexoxide _____

disulfur trioxide _____

carbon tetrachloride _____

phosphorus trichloride _____

Write names for these polyatomic ions and compounds:
(These formulas are often confused.)

SO_3^{2-} _____ SO_3 _____

NO_2^- _____ NO_2 _____

P_4O_{10}, S_2O_3, CCl_4, PCl_3, sulfite, sulfur trioxide,

nitrite, nitrogen dioxide

(D5) Acids and Bases

When dissolved in water, certain hydrogen compounds form solutions that have acidic properties. Because these acidic solutions are so common and important, they have been given names as acids. For example, HCl is called hydrogen chloride, but its water solution (i.e., aqueous solution) is known as "hydrochloric acid". Other examples follow. You must learn the formulas and names that are starred. and binary acids and oxyacids in lecture notes.

Formula	Name (substance by itself)	Name (in aqueous solution)
HCl *	hydrogen chloride *	hydrochloric acid *
HNO_3 *	hydrogen nitrate	nitric acid *
H_2SO_4 *	hydrogen sulfate	sulfuric acid *
H_3PO_4 *	hydrogen phosphate	phosphoric acid *
$HC_2H_3O_2$	hydrogen acetate	acetic acid

Exercise #15a Name these compounds as gases and as their aqueous solutions.

HF (g) _____ HF (aq) _____

H_2CO_3 (g) _____ H_2CO_3 (aq) _____

---

hydrogen fluoride, hydrofluoric acid, hydrogen carbonate, carbonic acid

Inorganic bases contain the hydroxide ion, OH^-, in combination with a positive ion. They have the same name when alone or when dissolved in a water solution. For example, the substance NaOH is named "sodium hydroxide". When NaOH is dissolved in water the resulting solution is called a "sodium hydroxide" solution.

Exercise #15b Name these bases:

$Ca(OH)_2$ _____

KOH _____

NH_4OH _____

$Al(OH)_3$ _____

$Fe(OH)_3$ _____

$Hg(OH)_2$ _____

---

calcium hydroxide. potassium hydroxide, ammonium hydroxide, aluminum hydroxide, iron(III) hydroxide, mercury(II) hydroxide

Diatomic Elements

The atoms of several elements combine naturally to form pairs. Consequently these elements usually exist as diatomic molecules (molecules made of two atoms). The following seven elements are the most common examples:

H_2 - hydrogen

N_2 - nitrogen

O_2 - oxygen

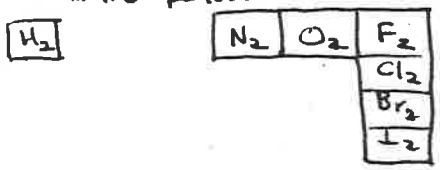
F_2 - fluorine

Cl_2 - chlorine

Br_2 - bromine

I_2 - iodine

Pattern of these elements in position in the periodic table:



Note that these are the elements whose names end in -ine or -gen suffixes. When the name of any of these seven elements is given, it is understood that the element is in its diatomic state (its most stable state at normal conditions).

Exercise #16 Locate the seven listed elements on the periodic table on page 2 of this notes.

(F) The following problems are intended to help you practise applying these rules of chemical nomenclature. These problems are general and unsorted. When you finish with the problems below, you will find the answers on the right → next page. If you feel you need more practise, you can use those answers as a second list of compounds and work backwards.

General Chemistry - Nomenclature Practise Problems (by M. Katz)

NAME THE FOLLOWING COMPOUNDS AND ELEMENTS:

1. K_2SO_4	11. Cu_2O	21. Fe_2O_3	31. H_2SO_4
2. $CaCO_3$	12. CuO	22. H_2O	32. Ca_2C
3. $CaCl_2$	13. AgBr	23. H_2O_2	33. NO
4. $NaNO_3$	14. NO_2	24. NH_4OH	34. $CuCO_3$
5. KOH	15. NH_4Cl	25. HCl	35. Cu_2CO_3
6. MgS	16. Na_2CO_3	26. $Mg(OH)_2$	36. NCl_3
7. Li_2O	17. P_2O_5	27. CS_2	37. SiF_4
8. MgF_2	18. Al_2O_3	28. Na_3N	38. I_2
9. $Ca_3(PO_4)_2$	19. CCl_4	29. $HgNO_3$	39. SO_2
10. $NaHCO_3$	20. FeO	30. $Hg(NO_3)_2$	40. SO_3

WRITE FORMULAS FOR THE FOLLOWING COMPOUNDS OR ELEMENTS

1. sodium fluoride	11. ammonium phosphate	21. potassium carbonate
2. calcium hydroxide	12. ammonia	22. iron (II) sulfide
3. potassium sulfate	13. phosphorus trichoride	23. tin (IV) oxide
4. ammonium sulfide	14. iron (III) chloride	24. lithium fluoride
5. magnesium carbonate	15. oxygen	25. iron (III) oxide
6. lithium iodide	16. mercury (II) oxide	26. ammonium sulfate
7. calcium nitrate	17. hydrogen phosphate	27. calcium phosphate
8. copper(II) nitrate	18. dinitrogen trioxide	28. copper (I) sulfate
9. copper (I) nitrate	19. magnesium phosphate	29. sodium nitrate
10. sodium hydroxide	20. aluminum sulfide	30. aluminum oxide

(more practice)

31. carbon tetrachloride	35. hydrogen sulfate	39. dinitrogen monoxide
32. bromine	36. silver nitrate	40. aluminum bicarbonate
33. magnesium carbide	37. carbon monoxide	
34. sodium phosphate	38. carbon dioxide	

ANSWERS:

1. potassium sulfate	14. nitrogen dioxide	27. carbon disulfide
2. calcium carbonate	15. ammonium chloride	28. sodium nitride
3. calcium chloride	16. sodium carbonate	29. mercury (I) nitrate
4. sodium nitrate	17. diphosphorus pentoxide	30. mercury (II) nitrate
5. potassium hydroxide	18. aluminum oxide	31. hydrogen sulfate
6. magnesium sulfide	19. carbon tetrachloride	32. calcium carbide
7. lithium oxide	20. iron(II) oxide	33. nitrogen monoxide
8. magnesium fluoride	21. iron (III) oxide	34. copper (II) carbonate
9. calcium phosphate	22. water	35. copper (I) carbonate
10. sodium bicarbonate	23. hydrogen peroxide	36. nitrogen trichloride
11. copper(I) oxide	24. ammonium hydroxide	37. silicon tetrafluoride
12. copper (II) oxide	25. hydrogen chloride	38. iodine
13. silver bromide	26. magnesium hydroxide	39. sulfur dioxide
		40. sulfur trioxide

---

1. NaF	11. $(NH_4)_3PO_4$	21. K_2CO_3	31. CCl_4
2. $Ca(OH)_2$	12. NH_3	22. FeS	32. Br_2
3. K_2SO_4	13. PCl_3	23. SnO_2	33. Mg_2C
4. $(NH_4)_2S$	14. $FeCl_3$	24. LiF	34. Na_3PO_4
5. $MgCO_3$	15. O_2	25. Fe_2O_3	35. H_2SO_4
6. LiI	16. HgO	26. $(NH_4)_2SO_4$	36. $AgNO_3$
7. $Ca(NO_3)_2$	17. H_3PO_4	27. $Ca_3(PO_4)_2$	37. CO
8. $Cu(NO_3)_2$	18. N_2O_3	28. Cu_2SO_4	38. CO_2
9. $CuNO_3$	19. $Mg_3(PO_4)_2$	29. $NaNO_3$	39. N_2O
10. NaOH	20. Al_2S_3	30. Al_2O_3	40. $Al(HCO_3)_3$

common name

N2O dinitrogen monoxide — nitrous oxide

NO nitrogen monoxide — nitric oxide

(D5)

Oxo-acids and their Salts

(ortho-acids)

(Valence patterns classified by periodic table position)

Periodic table Group	III	IV	V	VI	VII
	H_3BO_3 boric acid	H_2CO_3 carbonic acid	HNO_3 nitric acid		
	BO_3^- Na_3BO_3 sodium borate	CO_3^{2-} Na_2CO_3 sodium carbonate	NO_2^- $NaNO_3$ sodium nitrate		

Note that the pattern changes between the first and second long periods of the periodic table.
This pattern change is due to the size increase of the central atom which allows more oxygen atoms to bind.

	H_4SiO_4 silicic acid	H_3PO_4 phosphoric acid	H_2SO_4 sulfuric acid	$HClO_3$ chloric acid
	SiO_4^{4-} Na_4SiO_4 sodium silicate	PO_4^{3-} Na_3PO_4 sodium phosphate	SO_4^{2-} Na_2SO_4 sodium sulfate	ClO_3^- $NaClO_3$ sodium chlorate
	GeO_4^{4-} H_4GeO_4 germanic acid	H_3AsO_4 arsenic acid	H_2SeO_4 selenic acid	$HBrO_3$ bromic acid
	SnO_4^{4-} H_4SnO_4 stannic acid	AsO_4^{3-} Na_3AsO_4 sodium arsenate	SeO_4^{2-} Na_2SeO_4 sodium selenate	BrO_3^- $NaBrO_3$ sodium bromate
	PbO_4^{4-} H_4PbO_4 plumbic acid (unstable)	SbO_4^{3-} H_3SbO_4 antimonic acid	TeO_4^{2-} H_2TeO_4 telluric acid	
			NO_4^- (rare) pernitrate	ClO_4^- chlorate
			NO_3^- nitrate	ClO_3^- chlorate
			NO_2^- nitrite	ClO_2^- chlorite
			$N_2O_2^{2-}$ ($2NO^-$) hyponitrite	ClO^- hypochlorite

Valence patterns in oxo-anions (polyatomic ions containing oxygen):

Periodic table Group		IV A	V A	VI A	VII A	
		SiO_4^{4-} silicate	PO_4^{3-} phosphate	SO_4^{2-} sulfate	ClO_4^- perchlorate	
		GeO_4^{4-} germanate	AsO_4^{3-} arsenate	SeO_4^{2-} selenate	BrO_4^- perbromate	
		SnO_4^{4-} stannate	SbO_4^{3-} antimonate	TeO_4^{2-} tellurate	IO_4^- periodate	XeO_4 xenon tetroxide
Periodic table Group	III B	IV B	V B	VI B	VII B	
	ScO_3^{3-} scandate	TiO_3^{2-} titanate	VO_4^{3-} vanadate	CrO_4^{2-} chromate	MnO_4^- permanganate	
		ZrO_3^{2-} zirconate	NbO_3^- niobate	MoO_4^{2-} molybdate	TcO_4^- pertechnetate	
		HfO_3^{2-} hafnate	TaO_3^- tantallate	WO_4^{2-} tungstate	ReO_4^- perrhenate	OsO_4 osmium tetroxide

Red line denotes where oxyanion composition differs between the A and B series.

(G) The old trivial names (pre-systematic nomenclature) sometimes describe characteristic properties of the substance. Although they sometimes are evocative and have interesting patterns, do not memorize these old names.

Exercise #18: Write systematic names for these compounds from their modern formulas.

Acids

aqua fortis, HNO_3 _____
(Latin means "strong water")

oil of vitriol, H_2SO_4 _____
(or vitriolic acid, from vitreous, meaning glassy in appearance)
Today, vitriolic means extremely biting or caustic, from acid properties.

muriatic acid, HCl _____

prussic acid, HCN _____

vinegar, $HC_2H_3O_2$ _____

sulfuretted hydrogen, H_2S (g) _____
(also called rotten egg gas)

aqua regia, HNO_3 and HCl _____

and _____

Salts

baking soda, $NaHCO_3$ _____

washing soda, Na_2CO_3 _____
(or soda ash)

potash, K_2CO_3 _____

saltpeter, KNO_3 _____
(nitre)

Chilean saltpeter, $NaNO_3$ _____
(also called Bolivian saltpeter or cubic nitre)

brine, NaCl (aq) _____

muriate of potash, KCl _____

sal ammoniac, NH_4Cl _____

sal volatile, $(NH_4)_2CO_3$ _____

sal soda, Na_2CO_3 _____

green vitriol, $FeSO_4$ _____

blue vitriol, $CuSO_4$ _____

white vitriol, $ZnSO_4$ _____

plaster of paris, $(CaSO_4)_2 \bullet H_2O$ _____

Glauber's salt, $Na_2SO_4 \bullet 10\ H_2O$ _____
(also called sal mirabile)

Epsom salt, $MgSO_4 \bullet 7\ H_2O$ _____

sugar of lead, $Pb(C_2H_3O_2)_2$ _____
(extract of Saturn)

bleaching powder, $Ca(OCl)_2$ _____

calomel, Hg_2Cl_2 _____

corrosive sublimate, $HgCl_2$ _____

Bases

lime, CaO (i.e., quicklime) _____

limestone, $CaCO_3$ _____

slaked lime, $Ca(OH)_2$ (s) _____

limewater, $Ca(OH)_2$ (aq) _____
(milk of lime)

magnesia, $Mg(OH)_2$ _____
(magnesia alba)

milk of magnesia, $Mg(OH)_2$ _____

spirits of hartshorn, NH_4OH _____
(spiritis volatilis, or ammonia water)

caustic soda, NaOH _____
(also called lye)

caustic potash, KOH _____

Minerals

fluorite (fluorspar), CaF_2 _____

litharge, PbO _____

corundum, Al_2O_3 _____
(alumina, or emery when impure)

carborundum, SiC _____

pyrite (fool's gold), FeS_2 _____

hematite, Fe_2O_3 _____
(Venetian red, rust, rouge)

magnetite, Fe_3O_4 _____

galena, PbS _____

calamine, $ZnCO_3$ _____

marble, $CaCO_3$ _____
(limestone, pearl, chalk, are less pure)

titania, TiO_2 _____

silica (quartz or sand), SiO_2 _____

pyrolusite, MnO_2 _____

Gases

fixed air, CO_2 _____

carbonic oxide, CO _____

fire damp (marsh gas), CH_4 _____

laughing gas, N_2O _____
(nitrous oxide)

nitric oxide, NO _____

marine acid air, HCl _____

Elements

brimstone, S _____

quicksilver, Hg _____

diamond, C _____

dephlogisticated air, O_2 _____

mephitic air, N_2 _____

lampblack (soot), C _____