Chemical Nomenclature
Naming and Writing Chemical Formulas

VOCABULARY

Ion — an atom or group of atoms that has gained or lost electrons
Monatomic ion — an atom that has gained or lost electrons and has a charge
Polyatomic ion — a group of covalently bound atoms that has a charge
Anion — a negatively charged ion
Cation — a positively charged ion
Charge — the positive or negative value assigned to an ion as a result of having lost or gained electrons
Oxidation number — hypothetical charge a covalently bound atom would have IF its bonds were ionic
Acid — a compound that donates a H^+ ion during a reaction
Ionic compound — a compound made of positively and negatively charged ions
Molecular compound — a compound held together by shared pairs of electrons
Hydrocarbon — a compound composed of carbon and hydrogen
Alcohol — a hydrocarbon that has had one or more of its hydrogens replaced with –OH groups
Complex ion — a metal ion that has been surrounded by ligands to form a large polyatomic ion
Ligand — a neutral or charged molecule that covalently bonds to a metal ion to form a complex ion
Coordination compound — a neutral ionic compound formed between a complex ion and another ion

INTRODUCTION

Writing chemical formulas will open your eyes to the chemical world. Once you are able to write correct chemical formulas there are four naming systems you will need to master. The trick lies in recognizing *which* naming system to use! Use the following guidelines when making your decisions about how to name compounds.

- If the chemical formula for the compound starts with H, it is an acid. Use the Naming Acids rules.
- If the chemical formula for the compound starts with C and contains quite a few H's and perhaps some O's, it is organic. Use the Naming Organic Compounds rules.
- If the chemical formula for the compound starts with a metal it is most likely ionic. Use the Naming Binary Ionic Compounds rules.
- If the chemical formula for the compound starts with a nonmetal other than H or C, use the Naming Binary Molecular Compounds rules.

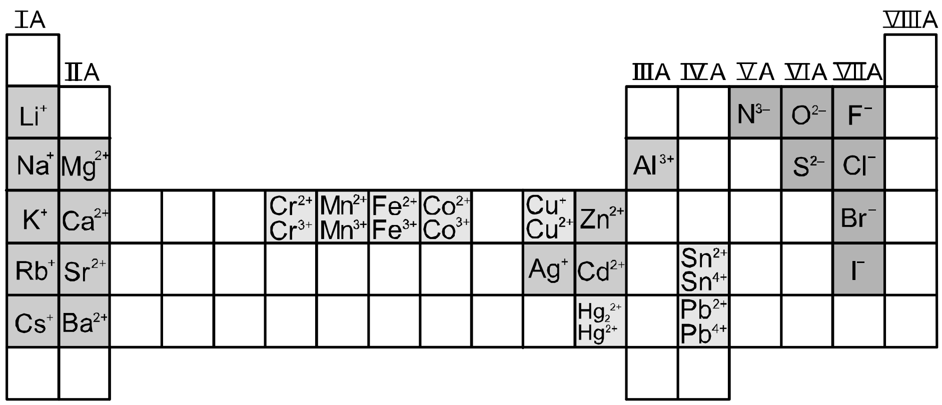
It is *essential* that you memorize at least 9 common polyatomic ions. Polyatomic ions are groups of atoms that behave as a unit and possess an overall charge. *If more than one copy of a polyatomic ion is needed to create a chemical formula, the ion must be enclosed in parentheses before adding the subscripts***.** You need to know their names, formulas and charges. If you learn the nine that follow, you can determine the formula and charges for many others from applying two simple patterns.

Name of Polyatomic Ion:	Formula & Charge:
Ammonium ion	NH_4^+
Acetate ion	$C_2H_3O_2^-$
Cyanide ion	CN^-
Hydroxide ion	OH^-
Nitrate ion	NO_3^-
Chlorate ion	ClO_3^-
Sulfate ion	SO_4^{2-}
Carbonate ion	CO_3^{2-}
Phosphate ion	PO_4^{3-}

Pattern 1: The -ates "*ate*" one more oxygen than the -ites **however,** their charge does not change as a result. For instance, if you know nitrate is NO_3^-, then nitrite must be NO_2^-. If you know phosphate is PO_4^{3-}, then phosphite must be PO_3^{3-}. You can also use the prefixes *hypo-* and *per-* with the chlorate series. Perchlorate, ClO_4^-, was really "*hy**per** and -ate yet another oxygen*" when compared to chlorate, ClO_3^-. Hypochlorite is a double whammy. It is -ite and therefore "*ate*" one less oxygen than chlorate **and** it is hypo- which means "below" so it "*ate*" even one less oxygen than plain chlorite so its formula must be ClO^-. You can substitute the other halogens for chlorine and make similar sets of this series.

Pattern 2: The -*ates* with charges less than negative one, meaning ions with charges of −2, −3, etc., can have an H added to them to form new polyatomic ions. For each H added the charge is increased by a +1. For instance, CO_3^{2-} can have an H added and become HCO_3^-. HCO_3^- is called either the bicarbonate ion or the hydrogen carbonate ion. Since phosphate is negative three, you can add one or two hydrogens to make new polyatomic ions, HPO_4^{2-} and $H_2PO_4^-$. The names are hydrogen phosphate and dihydrogen phosphate, respectively. If you continue adding hydrogen ions until you reach neutral, you've made an acid! That means you need to see the Naming Acids rules.

Pattern 3: Use of the following periodic table will also come in handy. Notice the simple patterns for determining the most common oxidation states of the elements based on their family's position on the periodic table. Notice the IA family is +1 while the IIA family is +2. Skip across to the IIIA family, and notice that aluminum is +3. Working backwards from the halogens, or VIIA family, they are most commonly −1 while the VIA family is −2 and the VA family is −3. The IV A family is "wishy-washy," and can be several oxidation states, the most common being ± 4.



NAMING ACIDS

How do I know it is an acid? The compound's formula begins with a hydrogen, H, and water doesn't count. Naming acids is extremely easy, if you know your polyatomic ions. There are three rules to follow:

- H + *element*: If the acid has only one element following the H, then use the prefix hydro- followed by the element's root name and an -ic ending. HCl is hydrochloric acid. H_2S is hydrosulfuric acid. When you see an acid name beginning with "hydro", think "Caution, element approaching!" (HCN is an exception since it is a polyatomic ion without oxygen, and it is named hydrocyanic acid.)
- H + *-ate polyatomic ion*: If the acid has an "-ate" polyatomic ion after the H, then it makes an "-ic" acid. H_2SO_4 is sulfuric acid.
- H + *-ite polyatomic ion*: If the acid has an "-ite" polyatomic ion after the H, then it makes an "-ous" acid. H_2SO_3 is sulfurous acid.

When writing formulas for acids you must have enough H^+ added to the anion to make the compound neutral. Also note that *-ate* and *-ite* polyatomic ions contain oxygen so, their acids are often referred to as *oxyacids*.

NAMING ORGANIC COMPOUNDS

How do I know it is organic? The chemical formula will start with a C followed by hydrogens and may even contain some oxygen. Most of the organic carbons you will encounter will be either hydrocarbons or alcohols. These are the simplest of all to name. Memorize the list of prefixes in Table B found in the conclusion questions. The prefixes correspond to the number of carbons present in the compound and will be the stem for each organic compound. Notice that the prefixes are standard geometric prefixes once you pass the first four carbons. This silly statement will help you remember the order of the first four prefixes: "Me Eat Peanut Butter." This corresponds to meth-, eth-, prop-, and but- which correspond to 1, 2, 3, and 4 carbons, respectively. Now that we have a stem, we need an ending. There are three common hydrocarbon endings that you will need to know as well as the ending for alcohols. The ending changes depending on the structure of the molecule.

- **-ane** - alkane (all single bonds & saturated) C_nH_{2n+2}; The alkanes are referred to as saturated hydrocarbons because they contain only single bonds and thus, the maximum number of hydrogen atoms.
- **-ene** = alkene (contains one double bond & unsaturated) C_nH_{2n}; The alkenes are referred to as unsaturated hydrocarbons because a pair of hydrogens have been removed to create the double bond.
- **-yne** ≡ alkyne (contains one triple bond & unsaturated) C_nH_{2n-2}; The alkynes are also referred to as unsaturated, because two pairs of hydrogens have been removed to create the triple bond. The term polyunsaturated means that the compound contains more than one double or triple bond.
- **-ol** – alcohol (one H is replaced with a hydroxyl group, -OH group, to form an alcohol) $C_nH_{2n+1}OH$; Do not be fooled—this looks like a hydroxide ion, but is not! It does not make this hydrocarbon an alkaline or basic compound. Do not name these as a hydroxide! C_2H_6 is ethane while C_2H_5OH is ethanol.

NAMING BINARY IONIC COMPOUNDS

How do I know it is ionic? The chemical formula will begin with a metal cation (+ ion) or the ammonium cation. The ending is often a polyatomic anion. If only two elements are present, they are usually from opposite sides of the periodic table, like KCl. If the metal can have more than one oxidation state, be prepared to use a Roman numeral indicating which oxidation state the metal is exhibiting. Group IA alkali metals, Group IIA alkaline earth metals, aluminum (Al), silver (Ag), cadmium (Cd) and zinc (Zn) are exceptions to the Roman numeral rule because their charges are constant. Group IA metals are always +1, Group IIA metals are always +2, Al is always +3, Ag is always +1, and Cd and Zn are always +2 in chemical compounds.

In order to name these compounds, first name the ions.

Naming positive ions: Metals commonly form cations.

- Monatomic positive ions in Group A are named by simply writing the name of the metal from which it is derived. Al^{3+} is the aluminum ion.
- Metals often form more than one type of positive ion so Roman numerals (in parentheses) follow the ion's name. Cu^{2+} is the copper(II) ion. Remember the exceptions — IA, IIA, Al, Ag, Cd, Zn.
- NH_4^+ is the ammonium ion. It is the only positive polyatomic ion that you will encounter.

Naming negative ions: Nonmetals commonly form anions (− ions). Most of the polyatomic ions are also negatively-charged.

- Monatomic negative ions are named by adding the suffix -ide to the stem of the nonmetal's name. Group VIIA, the Halogens are called the halides. Cl^- is the chloride ion.
- Polyatomic anions are given the names of the polyatomic ion. You must memorize these as instructed. NO_2^- is the nitrite ion.

Naming the Compound: The + ion (cation) name is given *first* followed by the name of the negative ion (anion). Remember, to include the Roman numeral that indicates a metal's charge for the many metals that have more than one oxidation state. **No prefixes are used in naming ionic compounds**.

NAMING BINARY MOLECULAR COMPOUNDS

How will I know it is a molecular compound? The chemical formula will contain a combination of nonmetals, both lying near each other on the periodic table. No polyatomic ions will be present. Use the following set of prefixes when naming molecular compounds.

Subscript	Prefix
1	Mono- [usually used only on the second element; such as carbon monoxide or nitrogen monoxide]
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-

Naming the Compound: The name of the element with the positive oxidation state is given *first*, followed by the name of the element with the negative oxidation state. Use prefixes to indicate the number of atoms of each element. Don't forget the -ide ending. If the second element's name begins with a vowel, then the "a" at the end of the prefix is usually dropped. N_2O_5 is dinitrogen pentoxide not dinitrogen pentaoxide. PCl_5 is phosphorous pentachloride not phosphorous pentchloride.

FORMULA WRITING

Naming is the trickiest part! Once you have been given the name, the formula writing is easy *as long as you have memorized the formulas and charges of the polyatomic ions*. The prefixes of a molecular compound make it really easy to write the formula since the prefix tells you how many atoms are present for each element. Roman numerals are your friend; they tell you the charge of the metal ions that can have more than one oxidation state and thus form positive ions with different charges. Remember that Group IA, Group IIA, Al, Ag, Cd, & Zn are usually not written with a Roman numeral; you must know their charges. The most important thing to remember is that, the sum of the charges must add up to zero in order to form a neutral compound. The *crisscross method* is very useful—the charge on one ion becomes the subscript on the other. *If you use this method, you must always check to see that the subscripts are in their lowest whole number ratio!* Here are some examples:

potassium oxide → K^{1+} O^{2-} → K^{1} O^{2} → K_2O

iron(III) chlorate → Fe^{3+} ClO_3^{1-} → Fe^{3} ClO_3^{1} → $Fe(ClO_3)_3$

tin(IV) sulfite → Sn^{4+} SO_3^{2-} → Sn^{4} SO_3^{2} → $Sn_2(SO_3)_4$ → $Sn(SO_3)_2$

zinc acetate → Zn^{2+} $C_2H_3O_2^{1-}$ → Zn^{2} $C_2H_3O_2^{1}$ → $Zn(C_2H_3O_2)_2$

COORDINATION CHEMISTRY NOMENCLATURE

These are actually quite fun! The rules are simple and you will really feel like you are speaking chemistry. Square brackets are used to enclose a complex ion or neutral coordination species. A complex ion is composed of a single central atom or ion with other atoms or molecules attached. The atoms or molecules attached are known as **ligands**. The number of ligands attached is called the coordination number of the complex ion. The naming of complex cations and complex anions is similar, except that anions are always made to end in **-ate**. Coordination compounds, like other ionic compounds, are named with the cation preceding the anion regardless of which (if either) one of them is a complex ion.

The rules for naming complex ions or compounds are as follows:

- As with any ionic compound, the cation is named before the anion.
- In naming a complex ion, the ligands are named before the central metal ion.
- In naming ligands, an "-o" is added to the root name of any anion. For example, the halides as ligands are called fluoro, chloro, bromo, and iodo; hydroxide is hydroxo; cyanide is cyano; nitrite is nitrito, etc. If the ligands are neutral, omit the "-o" ending. Neutral ligands take the name they normally use as neutral molecules. There are four exceptions which must be memorized: H_2O as a ligand is known as aqua, NH_3 is named ammine [note the "mm" in the spelling so it is not confused with the functional group $–NH_2$, an amine group], CO is named carbonyl, and NO is nitrosyl.
- The number of each kind of ligand is specified by the usual Greek prefix: mono-, di-, tri-, tetra-, penta-, and hexa-.
- The oxidation number of the central metal atom is designated by a Roman numeral in parentheses.

- When more than one type of ligand is present, they are named in alphabetical order with no regard for the Greek (numerical) prefix.
- If the complex has a negative charge, the suffix **-ate** is added to the name of the metal. When a Latin symbol is used for the element, the element takes the Latin name in complex **anions** but **not in** complex **cations**. For example, $[Cu(NH_3)_4]^{2+}$ is called the tetraamminecopper(II) ion but $[Cu(CN)_6]^{4-}$ is called the hexacyanocuprate(II) ion. Likewise $[Al(NH_3)_6]^{3+}$ is called the hexaamminealuminum(III) ion but $[Al(OH)_4]^{-}$ is called the tetrahydroxoaluminate(III) ion.

Common Neutral Ligands	
Formula	**Name**
H_2O	aqua
NH_3	ammine
CO	carbonyl
NO	nitrosyl
Common Anion Ligands	
Formula	**Name**
F^-	fluoro
Cl^-	chloro
Br^-	bromo
I^-	iodo
OH^-	hydroxo
CN^-	cyano
SCN^-	thiocyano
$S_2O_3^{2-}$	thiosulfato
$C_2O_4^{2-}$	oxalato
Latin Names Used for Some Metal Ions in Anionic Complex Ions	
iron	ferrate
copper	cuprate
lead	plumbate
silver	argentate
gold	aurate
tin	stannate

PURPOSE
To master the skill of writing and naming chemical formulas.

MATERIALS

Each lab group will need the following:

bag, zipper-lock, quart
copy of student formula manipulatives
scissors

PROCEDURE

Safety Alert
Use care when handling scissors.

1. Carefully cut out the models on Template 1. Group them by similar charge or oxidation state.

2. Trace over the symbol and oxidation state of each element using colored markers and apply the color scheme below:

Color	Oxidation State
Blue	+1
Red	−1
Yellow	+2
Green	−2
Purple	+3
Pink	−3

3. Notice how the models fit together. If an element has a +3 oxidation state, it requires three elements with a −1 oxidation state to create a complete compound and the subscripts would reflect a 1:3 ratio.

4. Review the rules for naming acids and complete Table A on your student answer page. Use the models you created from Template 1 as needed. Supply either the acid's name or its formula to complete Table A.

5. Review the rules for naming binary ionic **and** molecular compounds. Use the models you created from Template 1 as needed. Supply the compound's **formula and name** to complete Table C. If the charge or oxidation state is missing from the table, it is because you should already know them or be able to determine them due to their position in the periodic table.

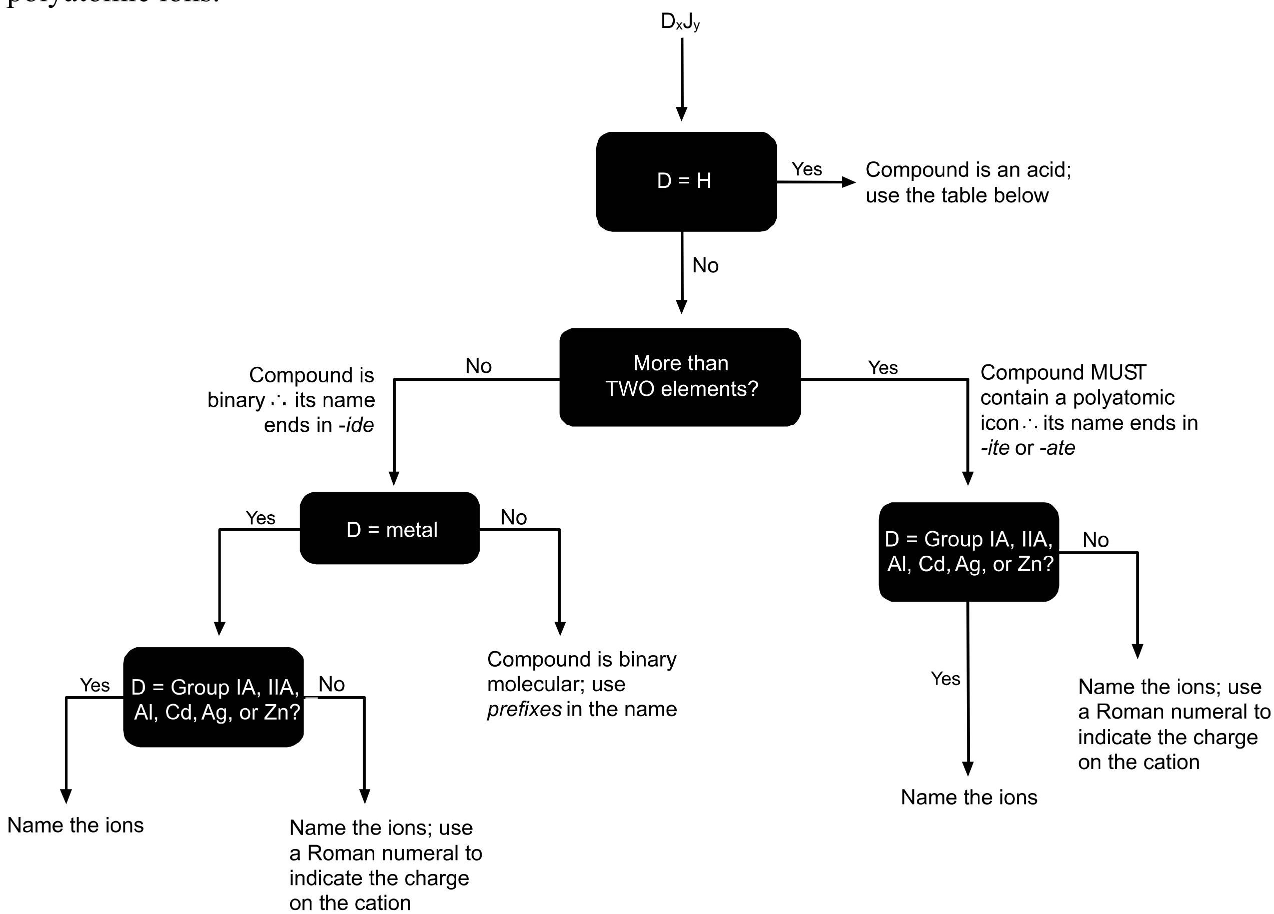
6. Carefully cut out the shapes on Template 2. Each carbon model has 4 inward notches. The model "bonds" found on Template 2 are for connecting the carbons. These shapes will be used to help you with organic compounds. There is no need to color them.

7. Review the rules for naming organic hydrocarbons and alcohols. Use your models from Template 2 as needed. Fill in the missing formulas **and** names for each compound in Table B.

Chemical Nomenclature
Naming and Writing Chemical Formulas

All You Really Need to Know About Chemical Names and Formulas SUMMARIZED

In this flowchart, D and J in the general formula D_xJ_y can represent atoms, monatomic ions, or polyatomic ions.



Naming Acids			
Anion ending	Example	Acid name	Example
–ide	S^{2-} sulfide	Hydro-(stem)-ic acid	hydrosulfuric acid
–ite	SO_3^{2-} sulfite	(stem)-*ous* acid	sulfurous acid
–ate	SO_4^{2-} sulfate	(stem)-*ic* acid	sulfuric acid

CONCLUSION QUESTIONS

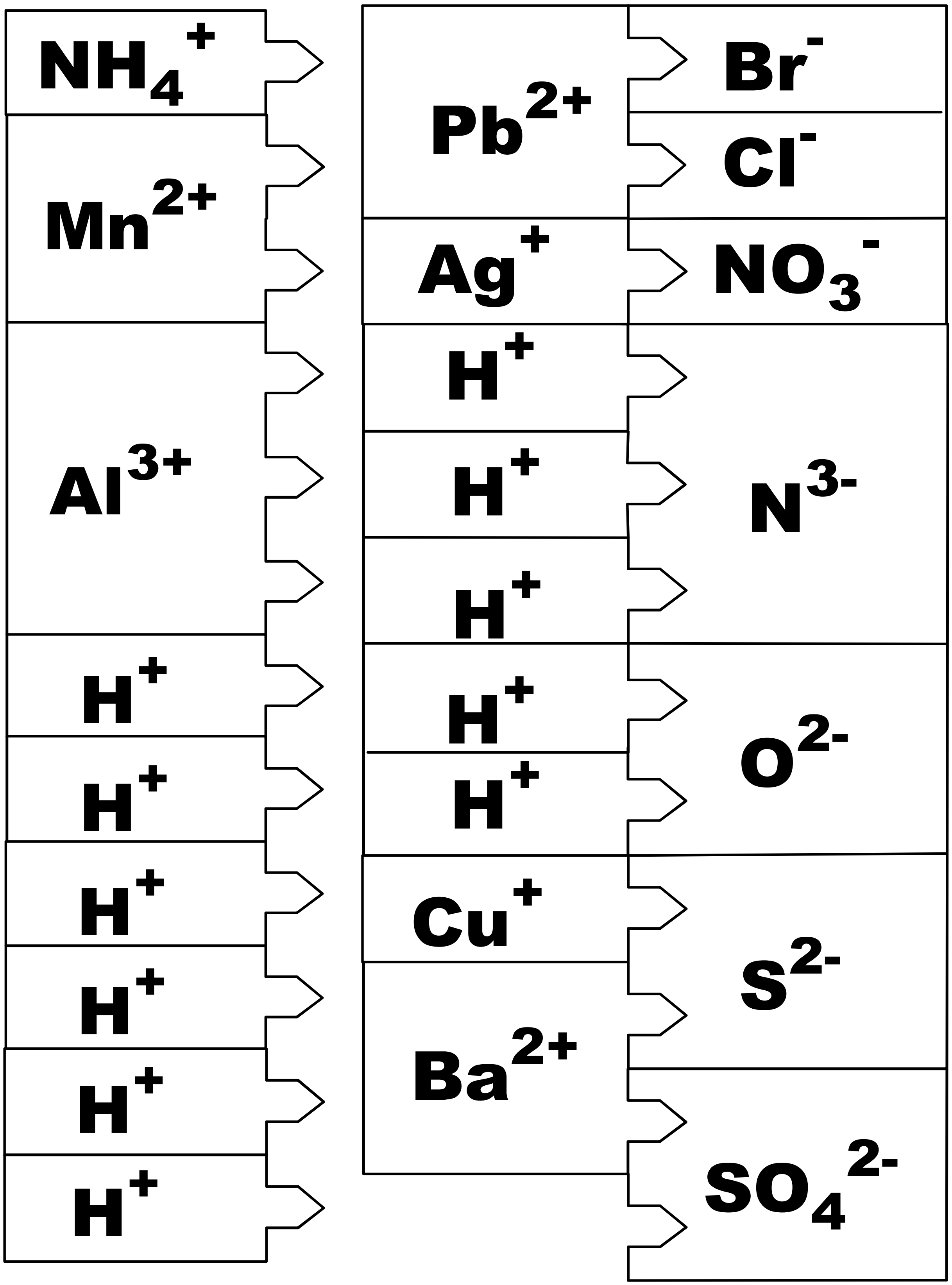
Table A	
Acid Formula	**Acid Name**
HCl	
	hypochlorous acid
	chlorous acid
	chloric acid
	perchloric acid (“hyperchloric” acid)
HNO_3	
	hydrobromic acid
H_3PO_4	
H_3PO_3	
	hydrocyanic acid
$HC_2H_3O_2$	
	carbonic acid
	hydroiodic acid
HF	

Table B					
# of carbon atoms = n	prefix or stem	-ane C_nH_{2n+2}	-ene C_nH_{2n}	-yne C_nH_{2n-2}	-anol $C_nH_{2n+1}OH$
1	meth-		None here because you must have at least 2 carbons for multiple bonding		CH_3OH methanol
2	eth-				
3	prop-		C_3H_6 propene		
4	but-				
5	pent-	C_5H_{12} pentane			
6	hex-				
7	hept-				$C_7H_{15}OH$ heptanol
8	oct-			C_8H_{14} octyne	
9	non-				
10	dec-				

Table C							
	Ag^{+}	Pb^{2+}	Cu^{+}	Ba^{2+}	NH_4^{+}	Al^{3+}	Mn^{2+}
N^{3-}							
O^{2-}							
Br^{-}							
S^{2-}							
SO_4^{2-}							
ClO_2^{-}							
PO_3^{3-}							

Table D	
Formula	**Name**
	tetrahydroxoaluminate(III) ion
$[Ag(NH_3)_2]^+$	
	tetrahydroxozincate(II) ion
$[Zn(NH_3)_4]^{2+}$	
	tetramminecopper(II) ion
$[FeSCN]^{2+}$	
$[FeSCN]Cl_2$	
	tetramminecadmium(II) ion
$[Ag(CN)_2]^-$	
$Mg[Ag(CN)_2]_2$	
	dibromodichlorodiiodocuprate(II) ion
$[Co(NH_3)_5Cl]Cl_2$	
	potassium hexacyanoferrate(III)
	triamminebromoplatinum(II) chloride
$[Cu(Cl_2Br_2INH_3)]^{4-}$	
$K_3[CoF_6]$	
$[Co(NH_3)_6]Cl_2$	
	hexacyanoferrate(II)

Template 1



ClO^-

ClO_2^-

ClO_3^-

ClO_4^-

$C_2H_3O_2^-$

PO_3^{3-}

S^{2-}

CO_3^{2-}

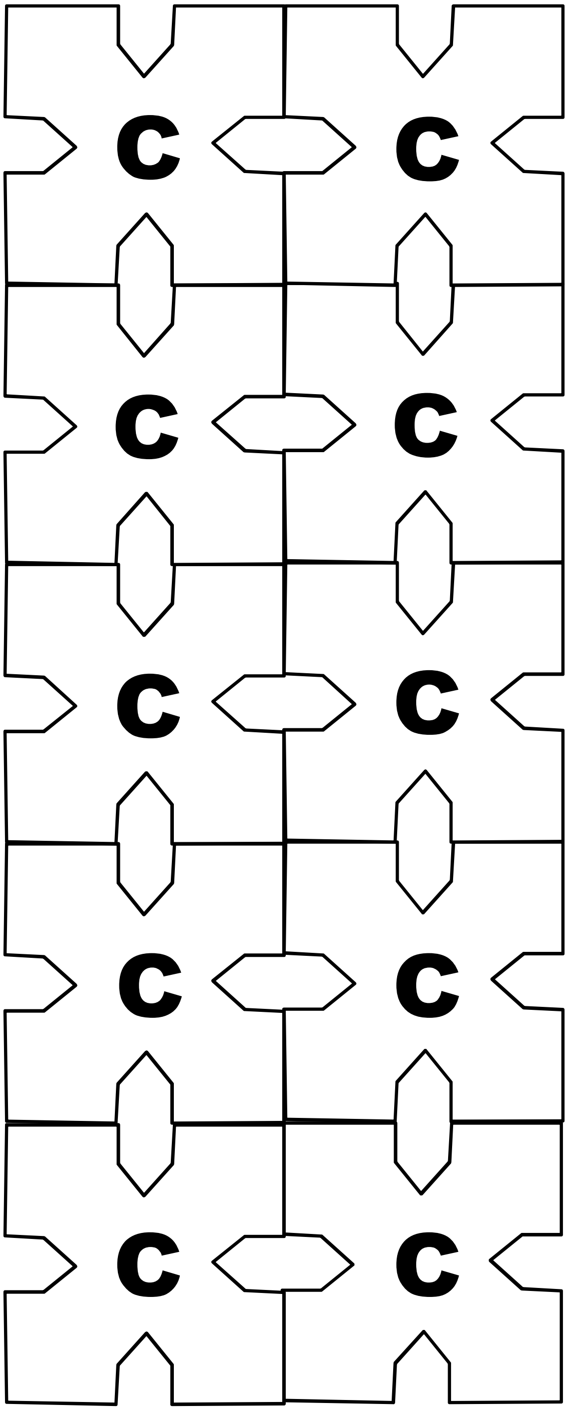
PO_4^{3-}

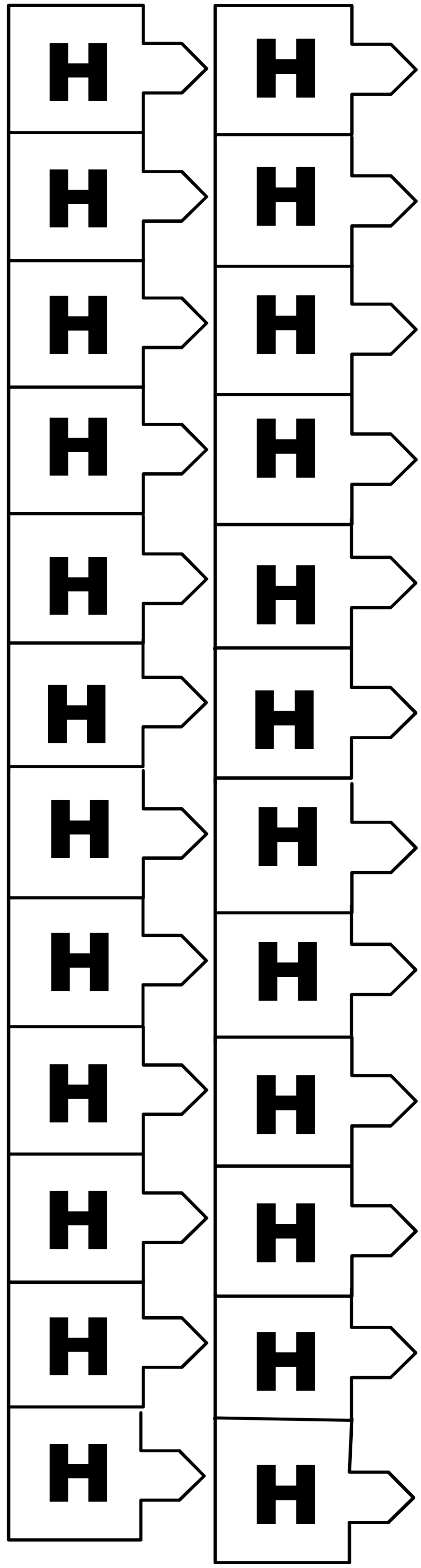
CN^-

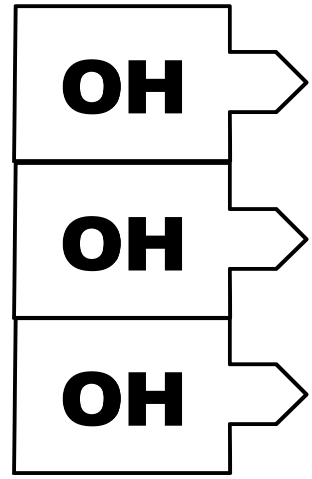
F^-

I^-

Template 2







Use the models below as single, double and triple bonds for connecting carbons.
Remember, DO NOT allow C to have more than FOUR total bonds!