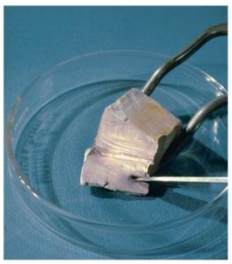
COMPOUNDS

- Compounds are pure substances that contain 2 or more elements combined in a definite proportion by mass.

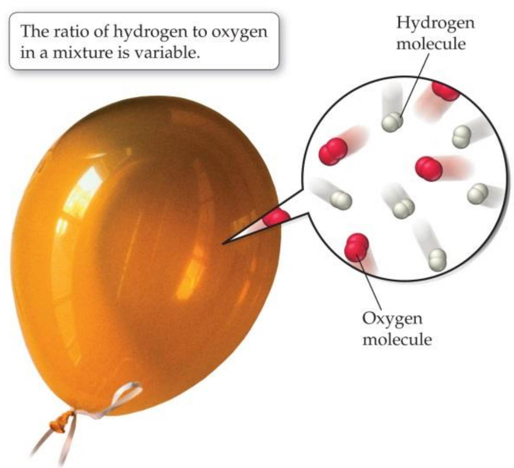
- Compounds have unique properties compared to their component elements. For example, although both Na and Cl are extremely reactive and poisonous substances, compound from combination of them, NaCl, is a relatively harmless flavor enhancer.

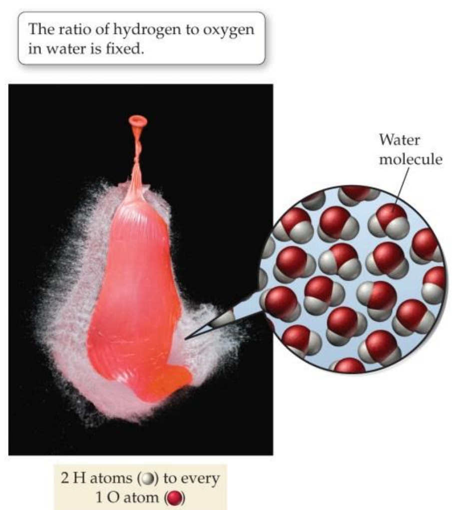
 +  → 

- Compounds are formed from elements by combining in a definite, fixed composition.

- The first chemist to formally state this relationship was ***Joseph Proust***, who developed the ***law of constant composition***, which states:

  All samples of a given compound have the same proportions of their constituent elements.





- The ratio of hydrogen to oxygen is ***variable in a mixture***, while it is ***fixed in a compound*** such as water.

LAW OF CONSTANT COMPOSITION

- In a ***pure compound***, the elements are always present in the same ***definite proportion*** by mass.

Two samples of NH_3 were analyzed for composition:

	Mass of sample	Mass of N	Mass of H
Sample 1	1.840 g	1.513 g	0.327 g
Sample 2	2.000 g	1.644 g	0.356 g

Calculating **% N** in each sample:

Sample 1

$$\%N = \frac{1.513\text{ g}}{1.840\text{ g}} \times 100 = 82.23\%$$

Sample 2

$$\%N = \frac{1.644\text{ g}}{2.000\text{ g}} \times 100 = 82.20\%$$

- Based on this law, the mass of an element can be determined from its ***mass percent*** in a compound.

Examples:

1. Barium iodide, BaI_2, contains 35.1% barium by mass. How many grams of barium does an 8.50 g sample of barium iodide contain?

$$8.50\ BaI_2 \times \frac{35.1\text{ g Ba}}{100\text{ g }BaI_2} = 2.98\text{ g Ba}$$

2. Mercuric sulfide, HgS, contains 82.6% mercury by mass. What mass of mercuric sulfide can be prepared from 60.0 g of mercury?

3. When 12.66 g of calcium are heated in air, 17.73 g of calcium oxide is formed. What is the percent of oxygen in this compound?

CHEMICAL FORMULAS

- A ***chemical formula*** is an ***abbreviation*** for a compound.
- It shows the ***symbols*** and the ***ratio*** of the ***atoms*** of the elements present in the compound.

$NaCl$

Indicates the element sodium (one atom)

Indicates the element chlorine (one atom)

H_2SO_4

Indicates the element hydrogen

Indicates two atoms of hydrogen

Indicates the element sulfur (one atom)

Indicates four atoms of oxygen

Indicates the element oxygen

$Ca(NO_3)_2$

Indicates the element calcium (one atom)

Indicates the nitrate group composed of one nitrogen atom and three oxygen atoms

Indicates two nitrate (NO_3) groups

Examples:

1. Which formula represents the greatest number of atoms?

   a) $Al(C_2H_3O_2)_3$

   b) $Al_2(Cr_2O_7)_3$

   c) $Pb_3(PO_4)_4$

   d) $(NH_4)_3PO_4$

TYPES OF FORMULAS

- Chemical formulas can be categorized into 3 types:

    1. Molecular formula
    2. Empirical formula
    3. Structural formula

- A ***molecular formula*** is the ***actual number*** of atoms of each element in a compound. For example, the molecular formula for hydrogen peroxide is H_2O_2, because a molecule of hydrogen peroxide actually contains 2 hydrogen and 2 oxygen atoms.

- An ***empirical formula*** is the ***simplest whole-number ratio*** of atoms of each element in a compound. For example, hydrogen peroxide would have an empirical formula of HO, since this is the smallest ratio of its atoms.

- A structural formula uses lines to represent chemical bonds and shows how atoms in a molecule are connected to each other. For example, hydrogen peroxide would have the structural formula shown below:

$$H-O-O-H$$

Examples:

1. Give the empirical formula that corresponds to each molecular formula shown below:

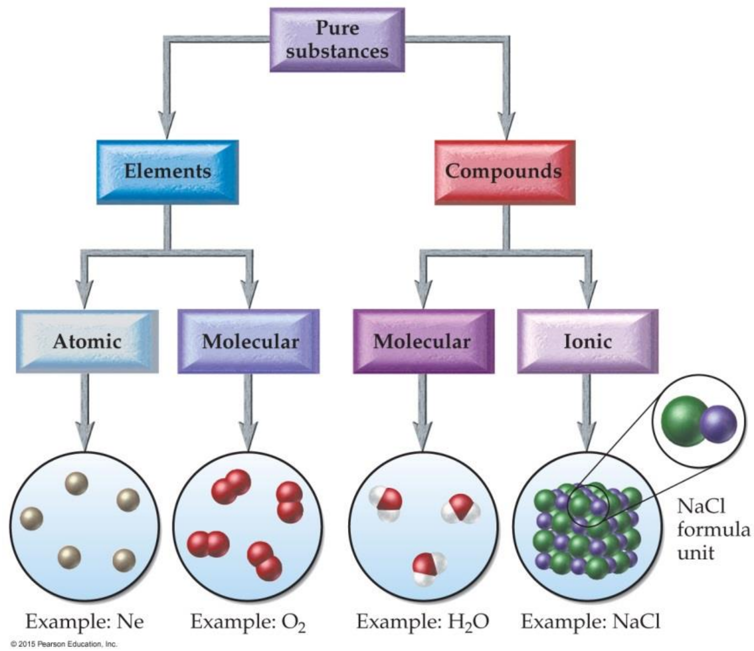
    a) C_2H_4

    b) CO_2

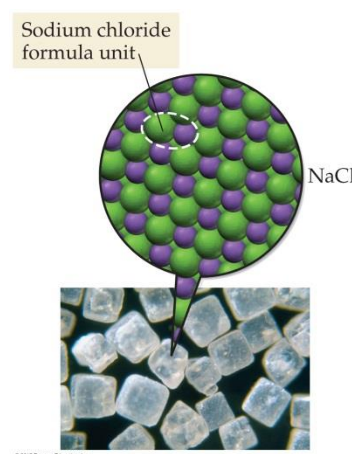
    c) $C_6H_{12}O_6$

    d) B_2H_6

MOLECULAR VIEW OF ELEMENTS & COMPOUNDS



- Recall that all pure substances can be classified as element or compound. We can further subcategorize elements and compounds according to the basic units that compose them.
- Elements may be either ***atomic or molecular***, while compounds can be either ***molecular or ionic***.
- The smallest particles of matter can be therefore ***atoms, molecules or ions.***
- ***Atomic elements*** are those that exist as single atoms. Most elements fall into this category.
- ***Molecular elements*** are those that exist naturally as diatomic molecules. Among these are hydrogen, nitrogen, oxygen as well as the four halogens: F_2, Cl_2, Br_2 and I_2.
- ***Molecular compounds*** are compounds of 2 non-metals. Two examples are water (H_2O) and dry ice (CO_2).
- ***Ionic compounds*** are composed of one or more cations paired with one or more anions. In most cases, the cations are metals and the anions are non-metals. The basic unit of ionic compounds is not a molecule, but a formula unit. Examples are sodium chloride, NaCl, which is composed of Na^+ and Cl^- ions.



<u>Examples:</u>

1. Classify each substance as atomic element, molecular element, molecular compound or ionic compound:

   a) NO

   b) Chlorine

   c) Au

   d) Na_2O

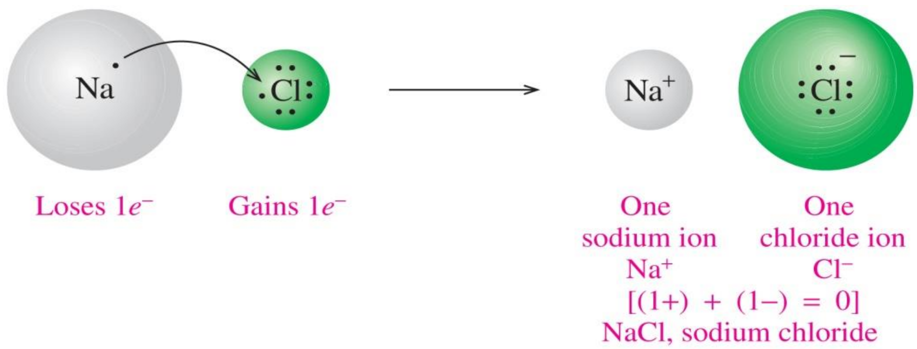
   e) KNO_3

IONIC CHARGES & FORMULAS

- The formula of an ionic compound indicates the number and kinds of ions that make up the ionic compound.

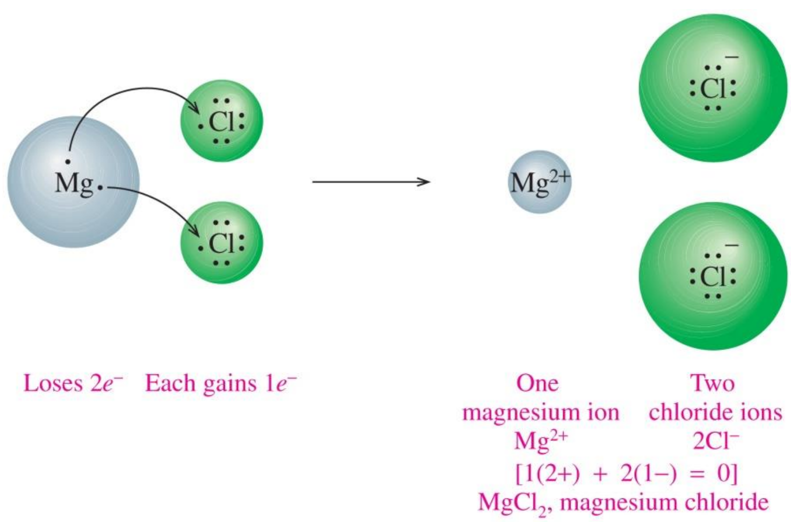
- The sum of the ionic charges in the formula is always zero, which indicates that the total number of positive charges is equal to the total number of negative charges.

- For example, the +1 charge on the sodium ion is cancelled by the –1 charge on the chloride ion, to form a net zero charge.



- When charges between the two ions do not balance, subscripts are used to balance the charges.

- For example, since each magnesium loses 2 electrons, and each chloride gains one electron, 2 chlorides are needed to balance the charge of the magnesium ion. Therefore, magnesium chloride is written as $MgCl_2$.

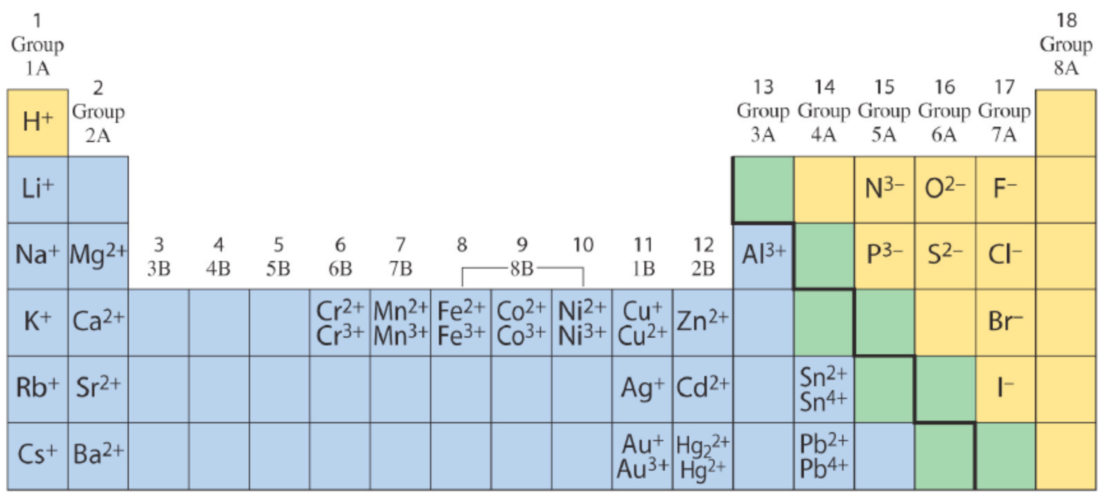


WRITING IONIC FORMULAS

- When writing ionic formula, knowing the charge of the ions are important since the net charge on the compound must be zero.

- Some elements produce only one ion (***Type I***) while others produce two or more ions (***Type II***).

- Differentiating between type I and II ions is important, since the naming system is different for each. Shown below are the common ions of each type:



- Note that most main-group elements are type I (except Sn and Pb), and most transition elements are type II (except Ag, Cd and Zn).

WRITING IONIC FORMULAS (TYPE I & II)

Binary Ionic Compounds:

- ***Binary*** compounds contain only ***two elements***.
- In these compounds, ***charges of the cations must equal the charges of the anions*** since the ***net charge is zero***.
- ***Subscripts*** are used to ***balance*** the charges between cations and anions.

Elements	Ions	Formula
sodium and bromine	Na^+, $Br^–$	NaBr
potassium and sulfur	K^+, $S^{–2}$	K_2S
aluminum and oxygen		
iron (II) and oxygen		

Examples:

1. Write formulas for ionic compounds formed from the following elements:

a) calcium & chlorine: _____________

b) sodium & sulfur: _______________

c) aluminum & nitrogen _______________

d) copper (I) & phosphorus ______________

e) iron (III) & sulfur _________________

WRITING IONIC FORMULAS (POLYATOMIC IONS)

- Some ionic compounds contain ***polyatomic ions***, an ion composed of ***several atoms bound together***.
- Some common polyatomic ions are:

TABLE 5.3 Some Common Polyatomic Ions

Name	Formula	Name	Formula
acetate	$C_2H_3O_2^-$	hypochlorite	ClO^-
carbonate	CO_3^{2-}	chlorite	ClO_2^-
hydrogen carbonate (or bicarbonate)	HCO_3^-	chlorate	ClO_3^-
hydroxide	OH^-	perchlorate	ClO_4^-
nitrate	NO_3^-	permanganate	MnO_4^-
nitrite	NO_2^-	sulfate	SO_4^{2-}
chromate	CrO_4^{2-}	sulfite	SO_3^{2-}
dichromate	$Cr_2O_7^{2-}$	hydrogen sulfite (or bisulfite)	HSO_3^-
phosphate	PO_4^{3-}	hydrogen sulfate (or bisulfate)	HSO_4^-
hydrogen phosphate	HPO_4^{2-}	peroxide	O_2^{2-}
ammonium	NH_4^+	cyanide	CN^-

- When writing formulas for compounds containing polyatomic ions, treat the polyatomic ion as one group.

potassium nitrate	1+ 1– $K_? (NO_3)_?$	KNO_3
calcium hydroxide	2+ 1– $Ca_? (OH)_?$	$Ca(OH)_2$
ammonium acetate	1+ 1– $(NH_4)_? (C_2H_3O_2)_?$	$NH_4C_2H_3O_2$
sodium sulfate	1+ 2– $Na_? (SO_4)_?$	Na_2SO_4
copper(II) nitrate	2+ 1– $Cu_? (NO_3)_?$	$Cu(NO_3)_2$

Examples:

1. Write formulas for the ionic compounds formed from the following ions:

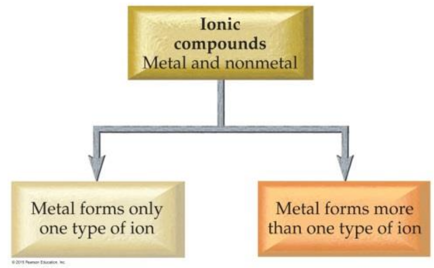
sodium & carbonate: ___________________

ammonium & sulfide: ___________________

magnesium & bicarbonate: ____________________

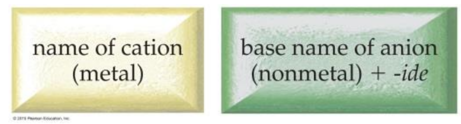
NAMING IONIC COMPOUNDS

- When naming ionic compounds, we must first identify it as one. Any formula that contains a metal and a non-metal can be categorized as an ionic compound.
- Ionic compounds must then be categorized by the type of cation they possess: Type I or Type II.



Binary Ionic Compounds (Type I):

- Type I cations are those that form only one ion. Most main-group cations are of this type (exceptions are Pb and Sn).
- These compounds are named by naming the cation (same as the atom), followed by the name of the anion with the ending –***ide***.



NaCl	sodium chlor***ide***
MgO	magnesium ox***ide***
$CaCl_2$	calcium chlor***ide***

Examples:

1. Name each of the following Type I ionic compounds:

ZnS ________________

Li_2O ________________

Ca_3N_2 ________________

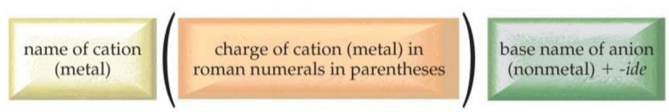
NAMING IONIC COMPOUNDS

Binary Ionic Compounds (Type II):

- ***Type II*** cations are those that ***form more than one ion***. Many transition metals are of this type (exceptions are Ag, Cd and Zn). A partial list of these cations is shown below:

Metal	Symbol Ion	Name	Older Name*
chromium	Cr^{2+}	chromium(II)	chromous
	Cr^{3+}	chromium(III)	chromic
iron	Fe^{2+}	iron(II)	ferrous
	Fe^{3+}	iron(III)	ferric
cobalt	Co^{2+}	cobalt(II)	cobaltous
	Co^{3+}	cobalt(III)	cobaltic
copper	Cu^{+}	copper(I)	cuprous
	Cu^{2+}	copper(II)	cupric
tin	Sn^{2+}	tin(II)	stannous
	Sn^{4+}	tin(IV)	stannic
mercury	Hg_2^{2+}	mercury(I)	mercurous
	Hg^{2+}	mercury(II)	mercuric
lead	Pb^{2+}	lead(II)	plumbous
	Pb^{4+}	lead(IV)	plumbic

- When naming compounds formed from these ions, include the ***ionic charge as Roman numeral***, in parentheses, after the metal's name.



- This method of nomenclature is called the "***stock***" system.

? –1 $FeCl_2$	+2 –1 $FeCl_2$	Iron(II) chloride
? –1 $FeCl_3$	+3 –1 $FeCl_3$	Iron(III) chloride
? –2 Cu_2O	+1 –2 Cu_2O	Copper(I) oxide
? –2 CuO	+2 –2 CuO	Copper(II) oxide

NAMING IONIC COMPOUNDS

- Type II cations can also be named by an ***older method (classical)***. In this system, cations with the ***higher charge*** end in ***–ic***, while cations with the ***lower charge*** end in ***–ous***. In this system, some cations are named based on their ***Latin*** roots.

+2 –1 $FeCl_2$	Ferrous chloride	+3 –1 $FeCl_3$	Ferric chloride
+1 –2 Cu_2O	Cuprous oxide	+2 –2 CuO	Cupric oxide

Examples:

2. Name each of the following compounds using the stock and classical nomenclature system:

   $SnCl_2$: ____________________ ______________________

   Cu_2S: _____________________ ______________________

Ionic Compounds containing Polyatomic ions:

- ***Polyatomic*** ionic compounds are named by naming the cation first, followed by the polyatomic ion.

Na_3PO_4	sodium phosphate
NH_4Br	ammonium bromide
$CuNO_3$	copper (I) nitrate or cuprous nitrate
$Pb(CO_3)_2$	lead (IV) carbonate or plumbic carbonate

Examples:

3. Name the following polyatomic compounds:

   $Mg(OH)_2$: __________________

   $NaNO_3$: ____________________

   $Fe_2(SO_4)_3$: __________________

NAMING & WRITING MOLECULAR FORMULAS

Binary Molecular Compounds:

- These compounds are named similar to ionic compounds, with the second element named based on its ***root*** and suffix ***"-ide".***

- ***Greek*** prefixes are used to indicate the ***number of atoms*** in these compounds:

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

CS_2	carbon ***di***sulf***ide***
PCl_5	phosphorus ***penta***chlor***ide***
N_2O_4	***di***nitrogen ***tetr***ox***ide***
P_4O_{10}	***tetra*****phosphorous** ***dec*****oxide**

- The ***first atom*** uses a prefix only when ***more than one*** atom is present.

- The ***second atom always*** uses a prefix.

Examples:

1. Name the following molecular compounds:

   P_2O_5: ________________________

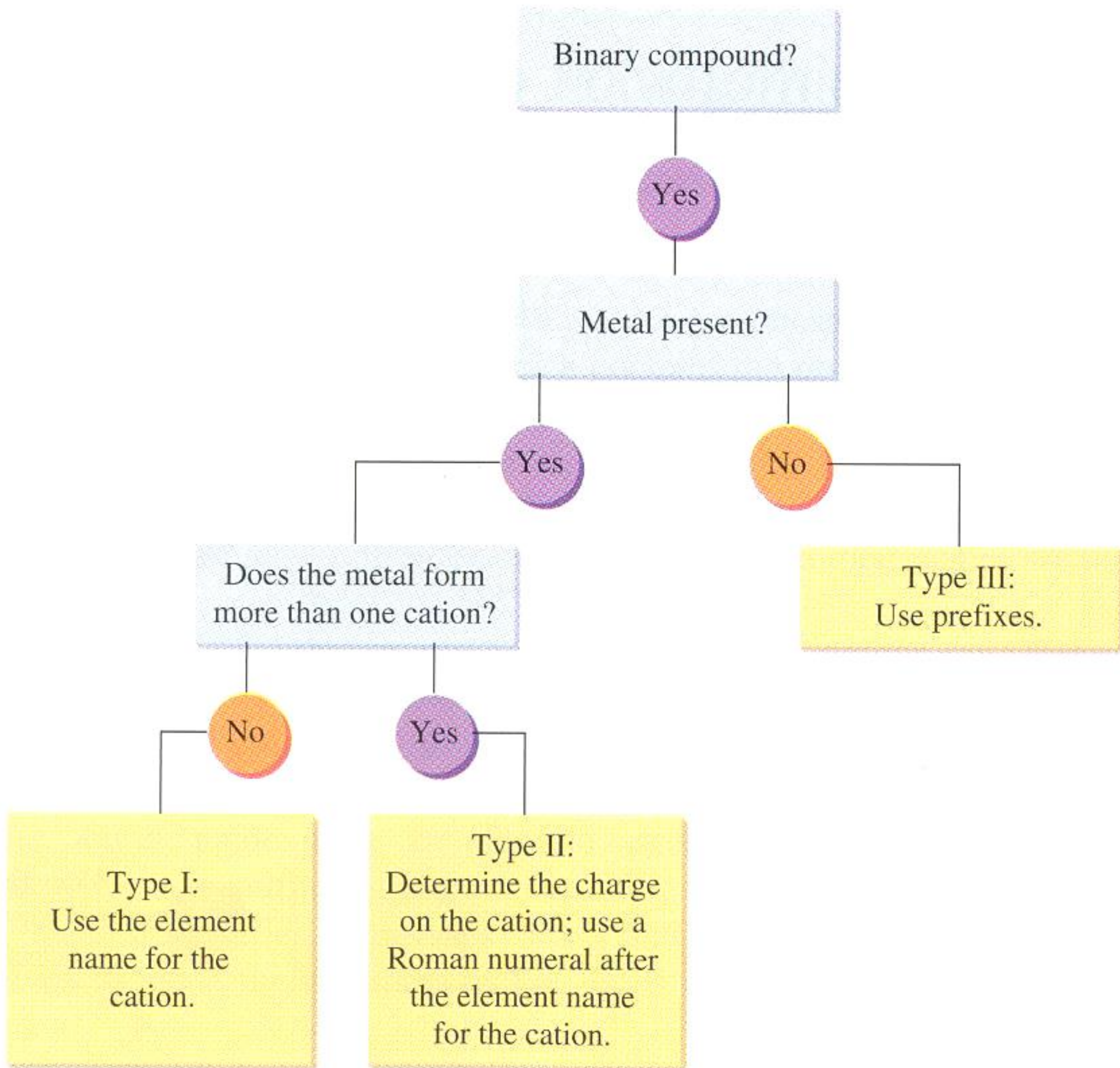
   IF_7: ________________________

2. Write formulas for the following molecular compounds:

   carbon tetrachloride: ________________

   dichlorine monoxide: ________________

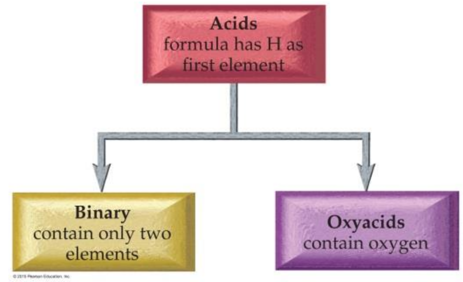
NOMENCLATURE FLOWCHART FOR BINARY COMPOUNDS



NAMING ACIDS

- Acids are molecular compounds that form ions when dissolved in water.

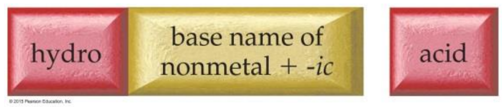
- Acids can be categorized into two groups: ***binary*** and ***oxyacids***.



Naming Binary Acids:

- Formulas are written similar to binary ionic compounds, assigning a +1 charge to hydrogen.

- When naming the acids, use **hydro**- prefix, followed by the name of the non-metal with an –**ic** ending, followed with the word **acid**.



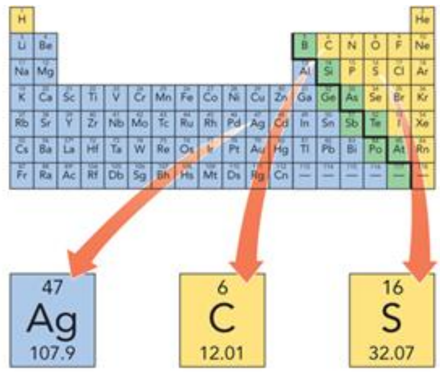
HCl	hydrochloric acid
H_2S	hydrosulfuric acid

Naming Oxyacids:

- Oxyacids are acids that contain oxyanions which are listed in the table of polyatomic ions. Some of the important acids in this group and the oxyanions they form are listed below.

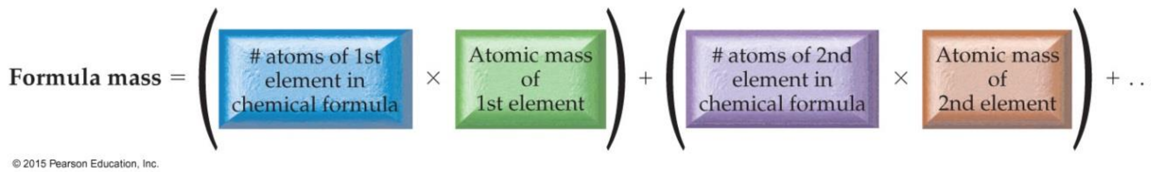
Acid Name	Acid Formula	Oxyanion formed from ionization of acid
Nitric acid	HNO_3	NO_3^- (nitrate)
Nitrous acid	HNO_2	NO_2^- (nitrite)
Sulfuric acid	H_2SO_4	SO_4^{2-} (sulfate)
Sulfurous acid	H_2SO_3	SO_3^{2-} (sulfite)
Chloric acid	$HClO_3$	ClO_3^- (chlorate)
Chlorous acid	$HClO_2$	ClO_2^- (chlorite)
Phosphoric acid	H_3PO_4	PO_4^{3-} (phosphate)
Carbonic acid	H_2CO_3	CO_3^{2-} (carbonate) HCO_3^- (bicarbonate)
Acetic acid	$HC_2H_3O_2$	$C_2H_3O_2^-$ (acetate)

FORMULA MASS



- Recall that the atomic mass of elements was defined as average atomic mass of the isotopes that compose that element and measured in atomic mass unit (amu).

- Similarly, the formula mass of molecules or formula units can be defined as the sum of the atomic masses of all the atoms in its formula.



Mass of one molecule of H_2O

2 atom H = 2 (1.01 amu) = 2.02 amu
1 atom O = 1 (16.00 amu) = <u>16.00 amu</u>
18.02 amu **Formula Mass**

Mass of one formula unit of $Ca(OH)_2$

1 atom Ca = 1 (40.08 amu) = 40.08 amu
2 atoms O = 2 (16.00 amu) = 32.00 amu
2 atoms H = 2 (1.01 amu) = <u>2.02 amu</u>
74.10 amu **Formula Mass**

<u>Examples:</u>
Calculate the formula mass of each compound shown below:

1. Lithium sulfide, Li_2S

2. Aluminum nitrate, $Al(NO_3)_3$