$2Na + Cl_2 \Rightarrow 2NaCl$

♀☽☿♂♃℞♅♄

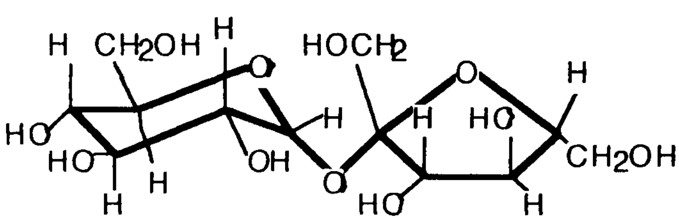
The Language of Chemistry

Χηεμιστρψ ισ εϖερψωηερε!

Die Chemistrie ist sehr gut!

Mg

sucrose



α-glucose and fructose units

Viva la Chemitry!

Habla Chemistry?

Unit 3

Is it time for Lunch, yet?

Unit 3: The Language of Chemistry

I. The Significance of Chemical Formulas

A **chemical formula** is a combination of symbols that represents the composition of a compound. Formulas indicate the elements that are present in the compound and the relative number of atoms of each element. For example, table salt is an ionic compound made up of 1 part sodium and 1 part chlorine, as indicated by its chemical formula, NaCl. The simple sugar glucose consists of carbon, hydrogen and oxygen and is represented by the formula, $C_6H_{12}O_6$. Note that the **subscripts** indicate that a molecule(formula unit) of glucose contains 6 carbon atoms, 12 hydrogen atoms and 6 oxygen atoms. There are also 7 elements (**HINClBrOF**) that usually exist in nature as diatomic molecules, written as H_2, I_2, etc. The subscript 2 indicates that two atoms of the same element are chemically attached together in this molecular form.

Coefficients are placed in front of chemical formulas in equations to indicate when more than one unit is involved. They act as a multiplier for the number of atoms present in the chemical formula. For the reaction of glucose burning in air, the chemical equation would be written as follows: $C_6H_{12}O_6$ + $\mathbf{6}O_2$ ---> $\mathbf{6}CO_2$ + $\mathbf{6}H_2O$

Since one glucose molecule contains 6 carbon atoms, it was necessary to place a coefficient of 6 in front of the CO_2 formula. (The total number of atoms of each element in the reactants <u>must equal</u> the total number of atoms of each element in the products.) $6CO_2$ indicates that there are 6 separate molecules(formula units) of CO_2 which would contain a total of 6 carbon atoms and
12(6 x 2) oxygen atoms. A **formula unit** is a generic term used to describe either one molecule of a compound or the smallest whole-number ratio of ions that make up an ionic substance.

Problem:
What is the <u>total</u> number of oxygen and hydrogen atoms on each side of the arrow in the equation above?

Some formulas can get quite complicated, as chemists try to represent the exact composition of various compounds. Parentheses are sometimes used around polyatomic ions(charged groups of atoms) found in the chemical formula. For example, the chemical formula that represents the compound calcium phosphate(known as the soap scum ring in your tub) is $Ca_3(PO_4)_2$. This formula shows that 3 Ca atoms combine with 2 of the PO_4(phosphate) groups, which gives a total of 2 P atoms and 8 O atoms.

Many solids have water molecules that are physically trapped within their crystal structures. They are said to be **hydrated solids**. To indicate the relative number of water molecules that are attached to each formula unit of the compound, the following notation is used: $CuSO_4 \bullet 5H_2O$ In this example, one molecule of $CuSO_4$ is combined with 5 molecules of water. Only a physical combination exists between the two compounds, and the water can be easily boiled off by heating the solid in the lab. A coefficient of 2 placed in front of this formula, $\mathbf{2}CuSO_4 \bullet 5H_2O$, indicates two separate formula units of $CuSO_4 \bullet 5H_2O$ are present. This means there are 2 Cu atoms, 2 S atoms, a total of 18 O atoms(8 from the two $CuSO_4$ units and 10 from the ten H_2O units) and 20 H atoms(from the 2 x $5H_2O$).

Problems:

Determine the total number of atoms of each element found in the following formulas:

Ag_2CO_3 $3H_3PO_4$ $6Fe(NO_3)_2$ $4BaCl_2 \bullet 2H_2O$ $AlK(SO_4)_2 \bullet 12H_2O$

II. Writing Chemical Formulas

Elements will gain, lose or share electrons to chemically combine together and form compounds. In the process, some of the elements will try to obtain a positive electrical charge by losing electrons, while others will try to become negatively charged by gaining electrons. Chemists believe that the number of electrons found in the atoms of the Inert Gases(He 2, Ne 10, Ar 18, Kr 36, Xe 54 and Rn 86) have a particularly stable arrangement, and the other elements react to obtain this same electron structure, too. Atoms or groups of atoms that are electrically charged are called **ions**. The real or apparent electrical charge formed by the loss or gain of electrons when the atoms make a compound are indicated by **oxidation numbers**. For compounds, the sum of all of the atoms' oxidation numbers must equal zero.

To write a chemical formula for a compound given its name, such as aluminum sulfate, complete the following steps:

1. Write the symbols of the positive and negative ions based on the compound's name. The positive ion is usually written first.
   EX: aluminum is Al sulfate, a polyatomic ion, is SO_4

2. List the electrical charges(oxidation numbers) for the positive and negative ions.
   EX: Al has a 3+ charge, Al^{3+} SO_4 has a 2- charge, SO_4^{2-}

3. Balance the charges by determining the least common multiple of the positive and negative charge, using the criss-cross method.
   EX: The least common multiple between 3+ and 2- is 6
   Two Al^{3+} ions will combine with three SO_4^{2-} ions.

   Al 3+ SO_4 2-
   2 3

4. Rewrite the formula using subscripts to indicate the number of positive and negative ions needed.
   EX: Rewrite the formula without showing the charges. $Al_{2}\ SO_{4}\ {}_{3}$

5. Place parentheses around any polyatomic ions that are used more than once.
   EX: The SO_4 ion needs parentheses to indicate 3 SO_4 groups. $Al_2(SO_4)_3$

Problems:

Look up the charges and formulas in your textbook for the ions used in the compounds below. Then write the correct chemical formulas for the following compounds:

1. calcium iodide ________________
2. potassium selenide ________________
3. sodium bromide ________________
4. copper (II) phosphide ________________
5. tin (IV) fluoride ________________
6. vanadium (V) oxide ________________
7. zinc chloride ________________
8. iron(III)oxide ________________
9. calcium nitrate ________________
10. ammonium hydroxide ________________

III. Learning the Common Ions

General patterns and tendencies exist for determining the charges and names of the ions formed when elements combine to make compounds. These generalizations can be used to predict the chemical formulas and names of the compounds. Refer to the periodic table below while examining the patterns that follow.

Common Oxidation Numbers of the Elements

(* indicates other oxidation numbers exist)

Metals (all elements left of the bold staircase) — Nonmetals — Inert Gases

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1+ H																	0 He
1+ Li	2+ Be											3+ B	±4 C*	3- N*	2- O*	1- F	0 Ne
1+ Na	2+ Mg											3+ Al	4+ Si*	3- P*	2- S*	1- Cl*	0 Ar
1+ K	2+ Ca	3+ Sc	4+ Ti*	5+ V*	3+ Cr*	2+ Mn*	3+ Fe*	2+ Co*	2+ Ni*	2+ Cu*	2+ Zn	3+ Ga	4+ Ge	3- As*	2- Se*	1- Br*	0 Kr*
1+ Rb	2+ Sr	3+ Y	4+ Zr	5+ Nb*	6+ Mo*	7+ Tc	4+ Ru*	3+ Rh*	2+ Pd*	1+ Ag	2+ Cd	3+ In	4+ Sn*	3- Sb*	2- Te*	1- I*	0 Xe*
1+ Cs	2+ Ba		4+ Hf	5+ Ta	6+ W*	4+ Re*	4+ Os*	4+ Ir*	4+ Pt*	3+ Au*	2+ Hg*	1+ Tl*	2+ Pb*	3+ Bi*	4+ Po*	1- At*	0 Rn*
1+ Fr	2+ Ra		? Rf	? Db	? Sg	? Bh	? Hs										

rare earth elements

3+ La	4+ Ce*	4+ Pr*	3+ Nd	3+ Pm	3+ Sm*	3+ Eu*	3+ Gd	3+ Tb*	3+ Dy	3+ Ho	3+ Er	3+ Tm*	3+ Yb*	3+ Lu
3+ Ac	4+ Th	5+ Pa*	6+ U*	5+ Np*	4+ Pu*	3+ Am*	3+ Cm	3+ Bk*	? Cf	3+ Es	3+ Fm	3+ Md	3+ No*	3+ Lr

A. Names and Charges of Metallic Ions

1. Metals in Groups IA, IIA, and IIIA will form ions that have charges of 1+, 2+, and 3+ respectively. These positive ions have only one possible charge and are named by using the name of the element. For example, a sodium atom loses 1 electron to have the same number as neon(10 electrons), but still has 11 protons. Therefore, the sodium ion = Na^{1+}. The Mg^{2+} magnesium ion also has 10 electrons, but 12 protons.

aluminum ion = __________ K^{1+} = ________________ zinc ion __________

2. Metals(or nonmetals) that have several positive oxidation states <u>must</u> indicate the charge of the ion by writing a Roman numeral in parentheses following the name of the element.
   EX: copper (II) ion = Cu^{2+} Sn^{4+} = tin (IV) ion iron (II) ion = Fe^{2+}

lead (IV) ion =__________ As^{5+} =______________ chromium (III) ion = ________

B. Names and Charges of Nonmetallic Ions

1. Negative, monatomic(one atom) ions are named by using the root word of the nonmetal and adding the suffix **-ide**. Nonmetals in Groups VIIA, VIA, VA and IVA will form ions that have charges of 1-, 2-, 3-, and 4- respectively in binary(two element) compounds. For example, a fluorine atom gains 1 electron to have the same number as neon(10 electrons), but still has only 9 protons. Therefore, the fluoride ion = F^{1-}. The oxide and nitride ions will also have 10 electrons, but only 8 and 7 protons, and are written as O^{2-} and N^{3-}.

   iodide ion = _______ S^{2-} = ______________ phosphide ion = _______

Exceptions: Not all -ide endings belong to binary compounds
EX: potassium cyanide = KCN NH$_4$OH = ammonium hydroxide

2. Negative polyatomic ions are formed by the combination of a nonmetal and varying numbers of oxygen atoms. The charge of the polyatomic ion is usually the same as the charge of the -ide ion. Prefixes and/or suffixes are added to the root word of the nonmetal to indicate the number of oxygen atoms in the ion. The following pattern is used:

per- ------ **-ate** (1 MORE oxygen atom than the **-ate** ion)
------ **-ate**
------ **-ite** (1 LESS oxygen atom than the **-ate** ion)
hypo- ------ **-ite** (2 LESS oxygen atom than the **-ate** ion)

The number of oxygens in the -ate ion can be determined by using the generalizations based on the "Slivka square" of elements on the periodic chart. Those elements outside of the square form -ate ions with an XO_3 formula. Those elements inside of the square form -ate ions with an XO_4 formula.

Slivka's Square

IIIA	IVA	VA	VIA	VIIA
B	C	N	O	F
Al	[Si]	[P]	[S]	Cl
Ga	[Ge]	[As]	[Se]	Br
In	[Sn]	[Sb]	[Te]	I
Tl	Pb	Bi	Po	At

Outside Square		Inside Square	
chlorate	ClO_3^{1-}	sulfate	SO_4^{2-}
bromate	BrO_3^{1-}	selenate	SeO_4^{2-}
iodate	IO_3^{1-}	phosphate	PO_4^{3-}
*nitrate	NO_3^{1-}	arsenate	AsO_4^{3-}
*carbonate	CO_3^{2-}	tellurate	TeO_4^{2-}

*charge is different than -ide ions

Once the formula and charge of the -ate ion is determined, the other polyatomic ions vary only in the number of oxygens.

chlor**ide**	Cl^{1-}	sulf**ide**	S^{2-}	nitr**ide**	N^{3-}
perchlor**ate**	ClO_4^{1-}	**per**sulf**ate**	SO_5^{2-}	**per**nitr**ate**	NO_4^{1-}
chlor**ate**	ClO_3^{1-}	sulf**ate**	SO_4^{2-}	nitr**ate**	NO_3^{1-}
chlor**ite**	ClO_2^{1-}	sulf**ite**	SO_3^{2-}	nitr**ite**	NO_2^{1-}
hypochlor**ite**	ClO^{1-}	**hypo**sulf**ite**	SO_2^{2-}	**hypo**nitr**ite**	NO^{1-}

This same pattern applies for a polyatomic ion of elements in group "A" or "B".
EX: chlorate, ClO_3^{1-} from group VIIA and manganate, MnO_3^{1-} from group VIIB

NOTE: Even though we can predict and write formulas and charges for these polyatomic ions, some might not actually exist in nature!

Negative polyatomic ions sometimes combine with hydrogen atoms(that have an oxidation number of 1+) to form a new ion. The word **hydrogen** is added to the original name of the polyatomic ion and the negative charge is decreased by one for each hydrogen atom present.

EX: hydrogen sulfate = HSO_4^{1-} HSO_3^{1-} = hydrogen sulfite

hydrogen phosphate = HPO_4^{2-} $H_2PO_4^{1-}$ = ***di**hydrogen phosphate

*note the "di" prefix indicates 2 hydrogen atoms

hydrogen carbonate = _________ $H_2AsO_3^{1-}$ = ___________________

Some ions have no simple rule and must be memorized.

EX: acetate = $C_2H_3O_2^{1-}$ cyanide = CN^{1-} hydroxide = OH^{1-}

There are eight common polyatomic ions that are found in hundreds of household chemicals. The names and formulas of these ions **should be memorized** to expedite formula writing. These are: **acetate $C_2H_3O_2^{1-}$** (also written as **CH_3COO^{1-}**)

ammonium NH_4^{1+} **carbonate CO_3^{2-}** **chlorate ClO_3^{1-}**

hydroxide OH^{1-} **nitrate NO_3^{1-}** **phosphate PO_4^{3-}** **sulfate SO_4^{2-}**

Other common polyatomic ions are included in the list below:

1+		**3-**	
hydronium	H_3O^{1+}	arsenate	AsO_4^{3-}
1-		arsenite	AsO_3^{3-}
bromate	BrO_3^{1-}	phosphite	PO_3^{3-}
bromite	BrO_2^{1-}	**2-**	
chlorite	ClO_2^{1-}	chromate	CrO_4^{2-}
cyanide	CN^{1-}	dichromate	$Cr_2O_7^{2-}$
dihydrogen phosphate	$H_2PO_4^{1-}$	hydrogen phosphate	HPO_4^{2-}
hydrogen carbonate	HCO_3^{1-}	molybdate	MoO_4^{2-}
hypobromite	BrO^{1-}	oxalate	$C_2O_4^{2-}$
hypochlorite	ClO^{1-}	peroxide	O_2^{2-}
hypoiodite	IO^{1-}	selenate	SeO_4^{2-}
iodate	IO_3^{1-}	silicate	SiO_3^{2-}
nitrite	NO_2^{1-}	sulfite	SO_3^{2-}
perbromate	BrO_4^{1-}	tellurate	TeO_4^{2-}
perchlorate	ClO_4^{1-}	thiosulfate	$S_2O_3^{2-}$
periodate	IO_4^{1-}	tungstate	WO_4^{2-}
permanganate	MnO_4^{1-}		
thiocyanate	SCN^{1-}		
vanadate	VO_3^{1-}		

IV. Naming compounds

The name of a chemical compound must provide enough information to specify exactly which elements have combined together and the number of atoms of each element present. The general rules for naming the ions(as previously described) are applied when determining the name from a given chemical formula.

To determine the name for a compound given its chemical formula, such as $Al_2(SO_4)_3$, complete the following steps:

1. Identify and write the names of any polyatomic ions.
   EX: SO_4 is the "sulfate" ion

2. Write the name(modified to end in -ide) of any negative monatomic ions.
   EX: The sulfate ion is the negative ion in this example. No -ide ion exists.

3a. Name any positive monatomic ions that have only 1 possible oxidation number.
   EX: Al always has a 3+ oxidation number, so it is simply named as "aluminum"

3b. Determine the charge of any positive monatomic ion that could have several possible oxidation numbers. Remember that the sum of all charges(oxidation numbers) MUST add up to zero. Write the name of the positive ion using a Roman numeral inside of parentheses to indicate its charge.
   EX: The aluminum in this example can only have a 3+ charge, so no Roman numeral is required.
   The name of this compound is **aluminum sulfate**.

Additional Examples:

Cu_2CO_3 — CO_3 is the carbonate polyatomic ion with a 2- charge
Cu is copper, which can have more than one charge. Since there are 2 Cu atoms combined with 1 carbonate ion, the charge of each Cu must be 1+
The name of this compound is **copper(I) carbonate.**

CO_2 — There are no polyatomic ions present. The carbon will have a positive oxidation number and the oxygen will be negative. Oxygen has a 2- charge and is called oxide. The charge of each C atom must be 4+ .
The name of this compound is **carbon (IV) oxide.**
A more common name is carbon dioxide.

Problems:
Write the correct names for each of the following compounds:

N_2O	$CuSO_4$	$Fe_3(PO_4)_2$
$FeBr_3$	Na_2S	$Pb(ClO_3)_2$
$CaCl_2$	NH_4NO_3	$HC_2H_3O_2$
$Mg(OH)_2$	$LiNO_2$	SF_6

V. Other Methods of Naming Compounds

Sometimes other methods can are used for naming specialized groups of compounds, such as acids and organic compounds. There are also some outdated methods that occasionally appear on labels or in the literature. A brief description of the other methods is included in this packet to provide an insight to their application and usage.

A. Binary ***Molecular*** compounds (***nonmetal*** combined with a ***nonmetal***) can be identified with an older naming system that uses Greek prefixes to indicate the number of atoms of each element that are present, as determined by the subscripts in formula. The prefixes used are:
mono- = 1 di- = 2 tri- = 3 tetra- = 4 penta- = 5 hexa- = 6 hepta- = 7 octa- = 8

Formula	Common Name	Preferred Name
CS_2	carbon disulfide	carbon (IV) sulfide
N_2O_5	dinitrogen pentoxide	nitrogen (V) oxide
CO	carbon monoxide	carbon (II) oxide

(note the prefix "mono-" is omitted from the name of the first element)

B. Binary ***Ionic*** compounds (***metal*** combined with a ***nonmetal***) can be identified with an older naming system that uses Latin root names for metallic ions with several oxidation states. An -ous suffix indicates a lower oxidation state, -ic a higher one.

iron (II) = ferrous Fe^{2+}	copper (I) = cuprous Cu^{1+}	tin (II) = stannous Sn^{2+}
iron (III) = ferric Fe^{3+}	copper (II) = cupric Cu^{2+}	tin (IV) = stannic Sn^{4+}

C. Binary aqueous ***acid*** compounds (recognized because ***hydrogen*** is the first element that is combined with an **-ide** ion) are named by using the pattern:

hydro- (root word of negative element) -ic acid

If the H-compound is dissolved in water(aqueous), it becomes an acid with acid properties.

EX: HCl(aq) **hydrochloric acid** HF(aq) **hydrofluoric acid**

HBr(aq) ______________ HI(aq) ______________

A+B

D. Three-element acid compounds (***hydrogen*** with a ***polyatomic ion***) are called ternary or oxyacid compounds. The name of the acid depends upon the name of the polyatomic ion that is combined with the hydrogen. Use these patterns to name the acids:

hydrogen per ------ ate	changes to	**per ------ ic acid**
hydrogen ------ ate	changes to	**------ ic acid**
hydrogen ------ ite	changes to	**------ ous acid**
hydrogen hypo ------ ite	changes to	**hypo------ ous acid**

EX:
- H_2SO_5(aq) hydrogen persulfate becomes persulfuric acid
- H_3PO_4(aq) hydrogen phosphate becomes phosphoric acid
- HNO_2(aq) hydrogen nitrite becomes nitrous acid
- HBrO(aq) hydrogen hypobromite becomes hypobromous acid

Problems:
Write the names of the following ternary acids:

$H_2SO_4(aq)$ ____________ $H_2CO_3(aq)$ ____________

$HIO(aq)$ ____________ $HClO_4(aq)$ ____________

$HC_2H_3O_2(aq)$ ____________ $H_3PO_3(aq)$ ____________

E. **Hydrated solids**, which have water molecules that are physically trapped within their crystal structures, are named in the usual manner based on which positive and negative ions are present. To indicate the relative number of water molecules that are attached to each formula unit of the compound, the appropriate prefix (mono- = 1, di- = 2, tri- = 3, etc.) with the word **hydrate** are added after the compound's name.

EX: $BaCl_2 \bullet 2H_2O$ is named as *barium chloride dihydrate*

$CuSO_4 \bullet 5H_2O$ is named as *copper (II) sulfate pentahydrate*

Problems:
Write the names or formulas of the following hydrated solids:

$MgSO_4 \bullet 7H_2O$ ____________ aluminum chloride hexahydrate ____________

$Hg(NO_3)_2 \bullet H_2O$ ____________ sodium carbonate decahydrate ____________

F. **Double & Triple Salts** can occur when two or three different positive ions are attracted to the same negative ion to form one single compound. The sum of the charges of all ions present must still add up to zero, and the compound name includes the names of all ions present.

EX: $AlK(SO_4)_2 \bullet 12H_2O$ is named as *aluminum potassium sulfate dodecahydrate*
Two SO_4^{2-} ions are needed to balance the charges of the Al^{3+} and K^{1+} ions.

Ferrous ammonium sulfate hexahydrate consists of Fe^{2+}, NH_4^{1+}, and SO_4^{2-} ions with six water molecules and has the formula of $Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$.

Problems:
Write the names or formulas of the following salts:

$CaMg(CO_3)_2$ ____________ $KMgF_3$ ____________

sodium ammonium hydrogen phosphate tetrahydrate ____________

G. Organic chemistry deals with the millions of compounds created by the combination of mainly carbon atoms. Naming these compounds is based upon the number of carbon atoms in the molecule and specific ways the carbon can attach to other atoms. This branch of chemistry will be studied in more depth later in the year.

Unit 3 Objectives

Having studied the unit notes and done the problems, you should be able to:

1. Differentiate between a chemical symbol and a chemical formula.
2. Explain the significance of subscripts and coefficients.
3. Distinguish between atoms, ions, and molecules.
4. Given a formula, state the number of atoms of each element present.
5. Define monatomic ion and polyatomic ion, and oxidation number.
6. Use the periodic table to predict the charge and formula of a monatomic ion.
7. Use the periodic table to predict the charge and formula of a polyatomic ion.
8. List the names, symbols, and oxidation numbers or charges of the most common ions as designated by your instructor.
9. Recognize and give examples of compounds containing polyatomic ions.
10. Write formulas for chemical compounds using oxidation numbers.
11. Name compounds from given chemical formulas, using Roman numerals where necessary.
12. Determine the formula of a compound based upon an older naming system with prefixes or Latin names.
13. Determine the name or formula of acids.
14. Determine the name or formula of hydrated compounds.
15. Determine the name or formula of double or triple salts.
16. Define and distinguish between molecular and ionic compounds.