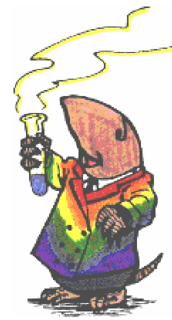
Chemistry 6A Fall 2007

Dr. J. A. Mack

Wednesday

9/19/07

Avogadro's Number and the Mole



The concept of a mole is defined so that we may equate the amount of matter (mass) to the number of particles (mole).

The Standard is based upon the C-12 isotope.

The atomic mass of ^{12}C is defined as exactly 12 u.

The atomic mass of ^{12}C is 1.99265×10^{-23} g.

1 amu = (the mass of one ^{12}C atom ÷12) = 1.66054×10^{-24}g
= 1.66054×10^{-27} kg

Avagagro's Number

Since one mole of ^{12}C has a mass of 12g (exactly), 12g of ^{12}C contains 6.022142 x 10^{23} ^{12}C-atoms.

But carbon exists as 3 isotopes: C-12, C-13 &C-14

The average atomic mass of carbon is 12.011 u.

From this we conclude that 12.011g of carbon contains 6.022142 x 10^{23} C-atoms

Is this a valid assumption?

Yes, since N_A is so large, the statistics hold.

Molar Masses

Since we can equate mass (*how much matter*) with moles (*how many particles*) we now have a ***conversion factor*** that relates the two.

mols × molar mass (g/mol) = grams

The Molar Mass of a substance is the amount of matter that contains one-mole or 6.022×10^{23} particles.

aka: Avogadro's number (N_A)

The atomic masses on the Periodic Table also represent the molar masses of each element in grams per mole (g/mol)

So if you have 12.011g of carbon…

and if you have 6.022×10^{23} avocados…

you have… ***a "guacamole"***

So if you have 12.011g of carbon…

you have 6.022×10^{23} carbon atoms!

So if you have 39.95g of argon…

you have 6.022×10^{23} argon atoms!

if you have a mole of dollar bills… you are Bill Gates…

you have 6.022×10^{23} bucks!

and if you have 6.022×10^{23} avocados…

you have… ***a "guacamole"***

Grams, moles and the number of atoms:

Since atoms are extremely small individual particles, even small masses (grams) will have huge quantities of them!

How many argon atoms are there in 0.00351g of argon?

Solution: Use the molar masses of the element and Avogadro's number as conversion factors.

$$0.00351\,\cancel{\text{g Ar}} \times \frac{1\ \cancel{\text{mole Ar}}}{39.95\,\cancel{\text{g Ar}}} \times \frac{6.022\times10^{23}\ \text{Ar atoms}}{1\ \cancel{\text{mole Ar}}}$$

$$= 5.29 \times 10^{19}\ \text{Ar atoms}$$

3 sf

How many chlorine atoms are there in 5.01g of elemental chlorine?

Solution: Use the molar masses of the element and Avogadro's number as conversion factors.

Recall that chlorine in its elemental state is diatomic!

$$Cl_2$$

The molar mass is therefore 2× the molar mass of atomic chlorine.

$$Cl_2 = 2 \times 35.45\ \text{g/mol} = 70.90\ \text{g/mol}$$

How many chlorine atoms are there in 5.01g of elemental chlorine?

Solution: Use the molar masses of the element and Avogadro's number as conversion factors.

What do you know!

Cl_2 = 70.90 g/mol

$N_A = 6.022 \times 10^{23}$ particles / mole

what else do we know?

for every one mole of Cl_2, there are 2 moles of Cl atoms

Conversion factor!

$$5.01\text{g } Cl_2 \times \frac{1 \text{ mole } Cl_2}{70.90 \text{ g } Cl_2} \times \frac{2 \text{ mole Cl}}{1 \text{ mole } Cl_2} \times \frac{6.022 \times 10^{23} \text{ Cl atoms}}{1 \text{ mole Cl}} =$$

8.51×10^{22} Cl-atoms *3 sf*

What mass of argon will have the same number of particles as 5.01 g of sodium?

Solution: Use the molar masses of the two elements as conversion factors.

Na = 22.99 g/mol Ar = 39.95 g/mol

$$5.01\text{g Cl} \times \frac{1 \text{ mol}}{22.99 \text{ g Na}} \times \frac{39.95\text{g Ar}}{1 \text{mol}}$$

= 8.71g Ar *(3 sf)*

How many protons are there in 1.205g of carbon?

Use the molar mass and atomic number and Avogadro's number to determine the result.

$$1.205\text{g C} \times \frac{1 \text{ mole C}}{12.011 \text{ g C}} \times \frac{6.022 \times 10^{23} \text{ C atoms}}{1 \text{ mole C}} \times \frac{6 \text{ protons}}{1 \text{ C atom}}$$

$= 3.625 \times 10^{23}$ protons

4 sf

Compounds:

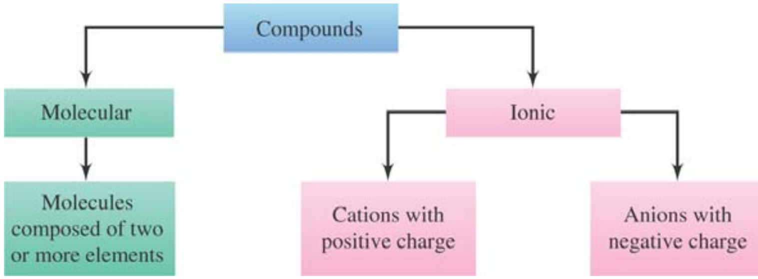
A compound is a distinct substance that contains two or more elements combined in a definite proportion by weight.

Atoms of the elements that constitute a compound are always present in simple whole number ratios.

They are never present as fractional parts.

Examples: AB A_2B AB_2

Never: $A_{1/2}B$



- Compounds can be classified as molecular or ionic.
- Ionic compounds are held together by attractive forces between their positive and negative charges.
- Molecular compounds are held together by covalent bonds.

Molecules and Ionic Compounds:

A molecule is the smallest uncharged individual unit of a compound formed by two or more atoms.

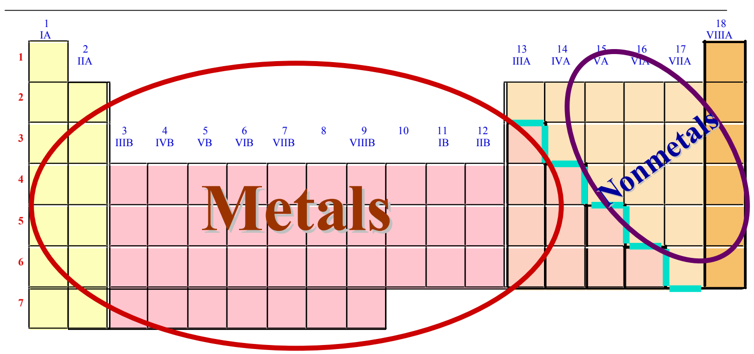
Ionic compounds are made of positively and negatively charged ions.

A molecule can exist as an entity on its own.

An ionic compound is represented by a formula unit that describes the simplest ratio of *cations* to *anions*.

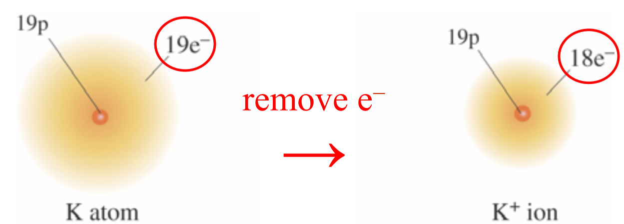
Inorganic Compounds:

Metals and Nonmetals



Ions:

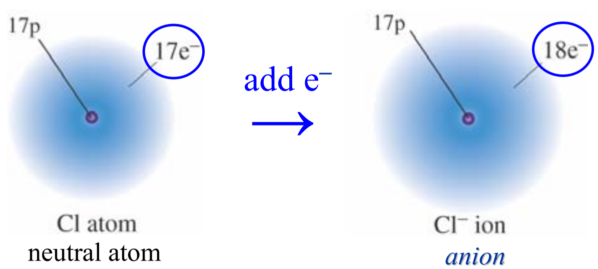
If one or more electrons are removed from a neutral atom a positive ion is formed. A positive ion is called a *cation*.



neutral atom

cation

If one or more electrons are added to a neutral atom a negative ion is formed. A negative ion is called an *anion*.



A positively charged ion is called a ***cation***.

Na^+

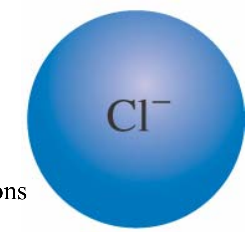
metals form cations

Sodium ion

An ***anion*** is a negatively charged ion.

Cl^-

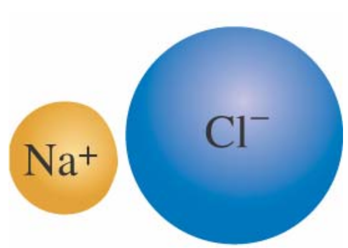
non-metals form anions



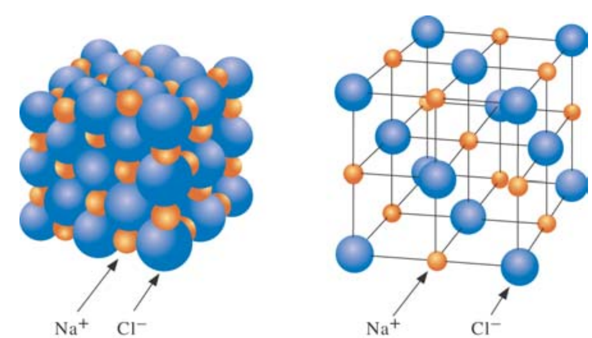
Chloride ion

Ionic Compounds

Ionic compounds consist of ions *(charged particles)*. The oppositely charged ions (positive and negative) are held together by strong electrostatic forces.



The crystalline structure of sodium chloride is held together by the attractive forces between the positive sodium ions and the negative chloride ions.



The actual chemical formulas of ionic compounds express the *smallest whole number ratio* that exists between these cations and the anions.

Na_2Cl_2	$NaCl$
Wrong!	Correct!

The more electrons lost, the more positive the cation becomes.

$$Na \rightarrow Na^{+} + e^{-}$$

$$Ca \rightarrow Ca^{2+} + 2e^{-}$$

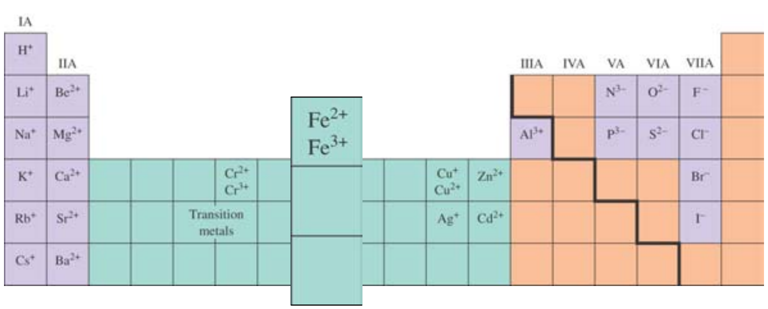
$$Al \rightarrow Al^{3+} + 3e^{-}$$

Naming ions: ***Cations***

All metal cations are named after there representative element followed by the word "ion".

sodium	Na ⟶	Na^{+} ⟶	sodium ion
barium	Ba ⟶	Ba^{2+} ⟶	Barium ion
silver	Ag ⟶	Ag^{+} ⟶	silver ion

The metals in the center of the periodic table (including the transition metals) often form more than one type of cation.



All variable ***transition metal cations*** are named by their element followed by the number of their oxidation (charge) state.

Example:

Cu ⟶ Cu^{+} ⟶ copper (I) ion

Cu ⟶ Cu^{2+} ⟶ copper (II) ion

All ***simple anions*** are named by the root name of the element followed by the suffix (ending) -***ide***.

Example:

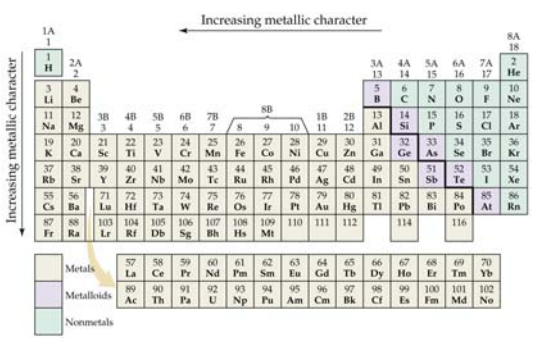
chlorine Cl ⟶ Cl^{-} ⟶ chlor***ide*** ion

oxygen O ⟶ O^{2-} ⟶ ox***ide*** ion

nitrogen N ⟶ N^{3-} ⟶ nitr***ide*** ion

Predicting Ion charges:

The charge on an ion can be predicted from its position in the periodic table.



All group 1A elements form +1 Cations

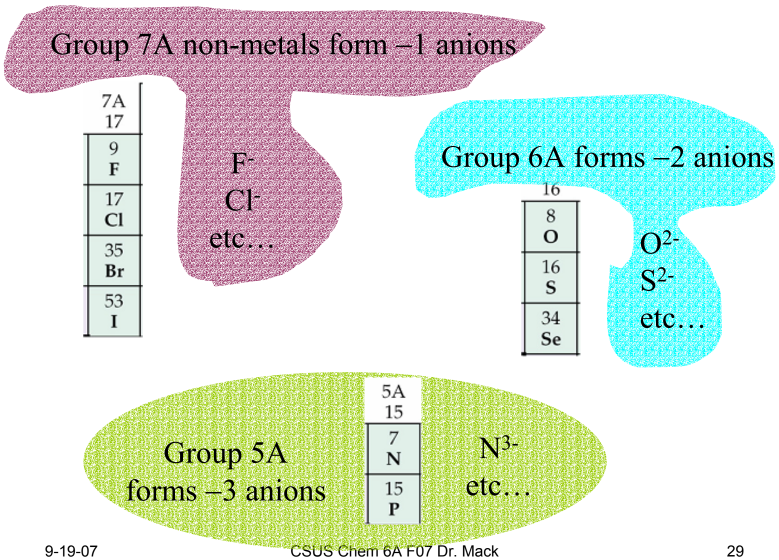
H^{+}
Li^{+}
Na^{+}
etc…

1A 1	2A 2
1 H	
3 Li	4 Be
11 Na	12 Mg
19 K	20 Ca
37 Rb	38 Sr
55 Cs	56 Ba
87 Fr	88 Ra

All group 2A elements form +2 Cations

Be^{2+}
Mg^{2+}
Ca^{2+}
etc…

Group 3A: Aluminum forms a +3 cation



All chemical compound must have a net charge of zero. ***(neutral)***

Since inorganic compounds (***metal and a non-metal***) contain ions, then the charge on the cations must cancel the charge on the anions. (***equal zero***)

charge from cation (+) + charge from anion (–) = 0

Chemical Formulas:

Since we are large (macroscopic) and atoms and compounds are small (microscopic), we need a symbolism to communicate the identity of an atom or compound.

A chemical formula tells us not only which elements make up a compound, but also their proportions.

A compound made of calcium and chlorine has the formula:

$CaCl_2$

The metal atom is written first followed by the anion.
The subscript indicates the number of each element (1's are not shown)

$CaCl_2$

The formula tells us that there are two chlorine ions for every calcium ion in the compound

We pronounce the name: "Calcium Chloride"

One does not use the prefixes "mono", "di", "tri" etcetera for ionic compounds

We'll get into that later…

Binary Compounds: Metal & non-Metal

Metal of fixed oxidation (charge) state combined with a non-metal.

Examples:

Cation	Anion	Formula	Name
K^+	Cl^-	KCl	Potassium chloride
Ca^{2+}	O^{2-}	CaO	Calcium Oxide
Na^+	S^{2-}	Na_2S	Sodium sulfide
Al^{3+}	S^{2-}	Al_2S_3	Aluminum sulfide

$$Al^{3+} + S^{2-} \longrightarrow Al_2S_3$$

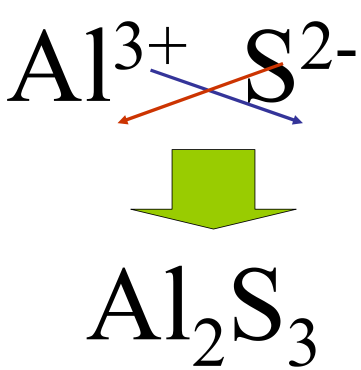
since the charges on the cation and anion don't match we must have multiples of both

$2 \times +3 = +6$ $\quad$ $3 \times -3 = -6$

$$Al_2S_3$$

$$+6 \quad + \quad -6 \quad = 0$$

Or one can use the "Chris-Cross" method:



Metals of variable charge with a non-metal

Examples:

Cation	Anion	Formula	Name
Pb^{2+}	Cl^-	$PbCl_2$	lead (II) chloride pronounced: *lead - two - chloride*
Pb^{4+}	Cl^-	$PbCl_4$	lead (IV) chloride
Fe^{3+}	O^{2-}	Fe_2O_3	Iron (III) oxide

Two ***complex anions*** are named like simple ions with the suffix (ending) -***ide***.

Example:

OH^- → hydrox***ide*** ion

CN^- → cyan***ide*** ion

Most other complex ions end in -***ate*** or -***ite*****.**

SO_4^{2-} → sulf***ate*** ion

SO_3^{2-} → sulf***ite*** ion

See table 6.6 page 117

More examples:

Ion:	Name:
NO_2^-	nitrite
SO_3^{2-}	sulfite
HCO_3^-	bicarbonate *or* *hydrogen carbonate*
MnO_4^-	permanganate

Ternary Compounds: Those with three different elements

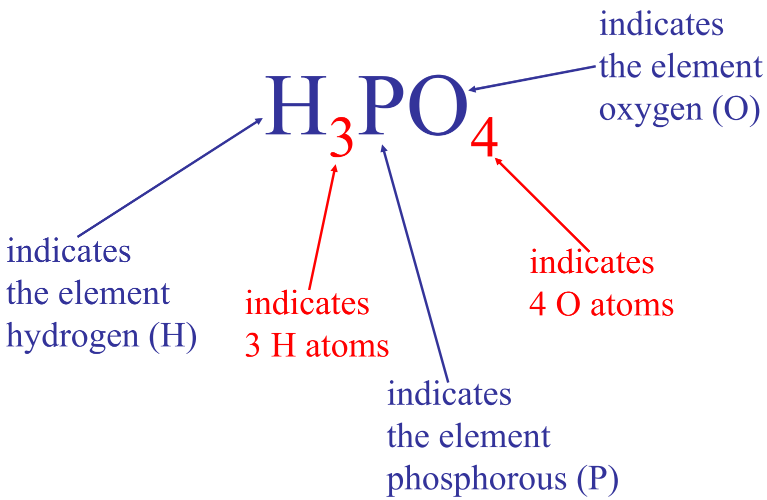
metal of fixed charge with a complex ion

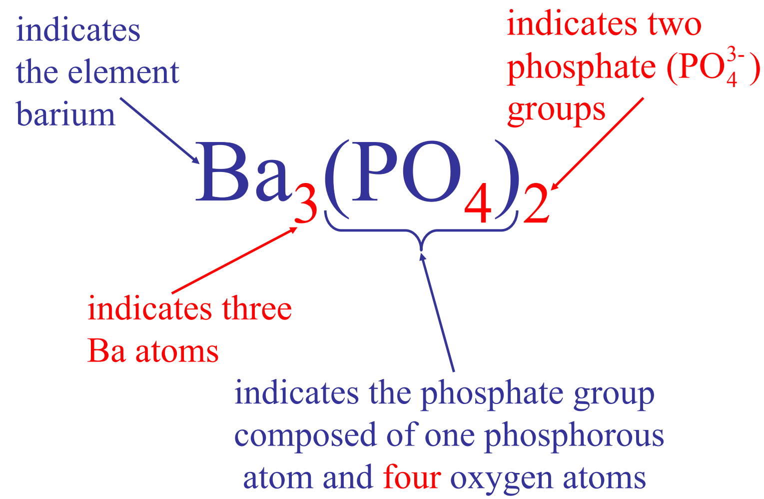
Cation	Anion	Formula	Name
K^+	OH^-	KOH	Potassium hydroxide
Ca^{2+}	OH^-	$Ca(OH)_2$	Calcium hydroxide
Na^+	SO_4^{2-}	Na_2SO_4	Sodium sulfate
Al^{3+}	SO_4^{2-}	$Al_2(SO_4)_2$	Aluminum sulfate

$$Al_2(SO_4)_3$$

spoken as: Al - two, sulfate, taken three times

or Al -two, parenthesis, sulfate, three





Metal of variable charge with a complex ion

Cation	Anion	Formula	Name
Pb^{2+}	SO_4^{2-}	$PbSO_4$	lead (II) sulfate
Pb^{4+}	SO_4^{2-}	$Pb(SO_4)_2$	lead (IV) sulfate
Fe^{3+}	NO_3^-	$Fe(NO_3)_3$	Iron (III) nitr***ate***
Fe^{2+}	NO_2^-	$Fe(NO_2)_2$	Iron (II) nitr***ite***

Type I Acids: Acids derived from *–ide* anions.

The names for these acids follows the formula:

"hydro" + the root of the ***ide*** anion + ***ic*** "acid"

Anion:	Acid:	Name:
chlor***ide***	HCl	***hydro***chlor***ic*** acid
fluor***ide***	HF	***hydro***fluor***ic*** acid

H^+ and S^{2-}

↓

it takes 2 H^+ to cancel one S^{2-}

H_2S

hydro sulfur***ic*** acid

An acid must be an ***aqueous*** (in water) species:

Later on will differentiate acids from molecules by:

HCN(aq) hydrocyanic acid

Vs.

HCN(g) hydrogen cyanide gas

Oxy-acids contain hydrogen, oxygen and one other element.

Example:

H_2SO_4

- The other element is usually a nonmetal, but it can be a metal.
- Its first element is hydrogen.
- Its remaining elements include oxygen in the form of a polyatomic ion.

Oxy Acids: Those derived from –***ate*** anions.

The names for these acids follows the formula:

root name of the anion with –***ic*** replacing the -***ate***

One student remembered it this way:

I ***ate*** something ***ic***ky!

Examples:

(anion)	Anion:	Acid:	Name:
(nitrate)	NO_3^-	HNO_3	nitr*ic* acid
(chlorate)	ClO_3^-	$HClO_3$	chlor*ic* acid
(sulfate)	SO_4^{2-}	H_2SO_4	sulfur*ic* acid
(acetate)	$C_2H_3O_2^-$	$HC_2H_3O_2$	acet*ic* acid *vinegar*

Additional Acids: Those derived from –*ite* anions.

root name of the anion with –***ous*** replacing the -*ite*

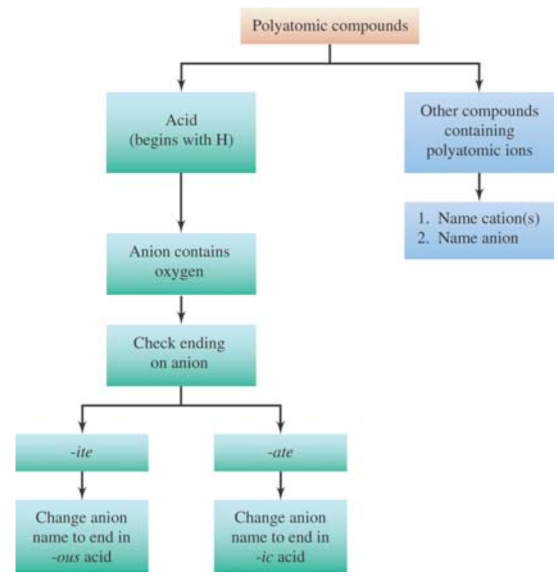
The ***–ite*** forma of a complex anion usually has one less oxygen atom than the *–ate* form.

NO_3^- nitr***ate***

NO_2^- nitr***ite***

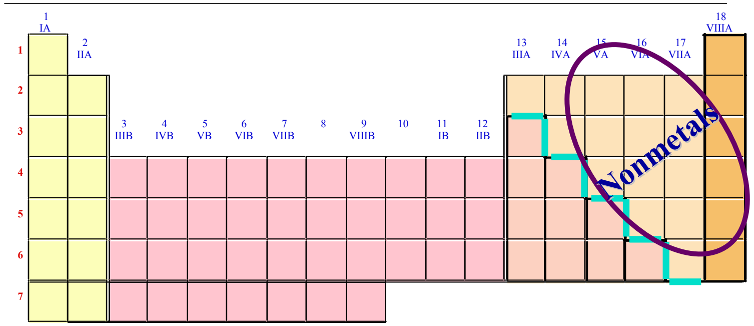
One can remember the ***–ous*** acids by:
"one less (oxygen atom) is the –ous acid."

(anion)	Anion:	Acid:	Name:
(nitrite)	NO_2^-	HNO_2	nitr***ous*** acid
(chlorite)	ClO_2^-	$HClO_2$	chlor***ous*** acid
(sulfite)	SO_3^{2-}	H_2SO_3	sulfur***ous*** acid

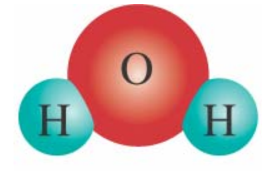


Molecular Compounds:

Nonmetals and Nonmetals



A water molecule consists of two hydrogen atoms and one oxygen atom.



If it is decomposed, the water molecule will be destroyed liberating hydrogen and oxygen.

A ***diatomic molecule*** contains exactly two atoms of the same or different elements.

Some elements exist in nature as diatomic molecules.

Table 3.6 Elements That Exist as Diatomic Molecules

Element	Symbol	Molecular formula	Normal state
Hydrogen	H	H_2	Colorless gas
Nitrogen	N	N_2	Colorless gas
Oxygen	O	O_2	Colorless gas
Fluorine	F	F_2	Pale yellow gas
Chlorine	Cl	Cl_2	Yellow-green gas
Bromine	Br	Br_2	Reddish-brown liquid
Iodine	I	I_2	Bluish-black solid

Molecular compounds: non-metal with a non-metal

When non-metals combine, they form molecules. They may do so in multiple forms:

CO CO_2

Because of this we need to specify the number of each atom by way of a prefix.

1 = mono 2 = di 3 = tri 4 = tetra

5 = penta 6 = hexa 7 = hepta

Examples:

Formula	Name:
BCl_3	boron ***tri***chlor***ide***
SO_3	sulfur ***tri***oxide
NO	nitrogen ***mon***oxide
we don't write:	nitrogen ***mono***oxide or ***mon***onitrogen ***mon***oxide
N_2O_4	***di***nitrogen ***tetra***oxide