Chemical Formulas and Equations

I. Elements
  I. Metals
    i. Form large crystals of many atoms.
    ii. Share electrons among all atoms in the crystal.
    iii. Bond is formed by common attraction of each nucleus for all nearby electrons and ease of electron mobility. This is why many metals are ductile. As one bends or shapes a metal bonds can break and reform fairly easily.
  II. Nonmetals
    i. Exist as monatomic or diatomic gasses or larger crystals formed through covalent bonds. Mostly we think of these as forming small molecular units.
    ii. Covalent bonds are formed when one or more electrons are shared between two specific atoms.
  III. Metalloids - these are somewhere between metals and nonmetals, possessing bonding patterns as well as other properties in common with both groups.

II. Compounds
  I. Ionic compounds
    i. Forms large crystals consisting of metals and nonmetals.
    ii. An ionic bond is formed between oppositely charged metals and nonmetals (oppositely charged ions).
    iii. The ionic bond is formed by the attraction between opposite charges.
    iv. When dissolved in solution the ions separate from each other. When in the dissolved state they are sometimes referred to as electrolytes.
  II. Molecular compounds
    i. Either form small molecules, long chains, or large networked crystals. We will primarily be talking about the small molecules.
    ii. Primarily formed from nonmetals
    iii. A covalent bond or the sharing of electrons between specific atoms is what bonds these nonmetals together.
    iv. When dissolved in solution the molecules stay whole retaining the covalent bonds between the atoms. The atoms don't separate from each other when dissolved.
  III. Acids
    i. These compounds fall somewhere in-between.
    ii. Many acids are molecular in pure form, but ionic when dissolved.

iii. The trademark quality of an acid is that it will produce H^{+1} ions when dissolved.

iv. For example, HCl in pure form is a gas formed of diatomic molecules. When dissolved in water it breaks up into separate ions: H^{+1} and Cl^{-1}.

III. Demo: Conductivity of various compounds.

IV. Homework: Discriminating between Substances sheet

V. Naming Substances and Writing Formulas

i. Elements

a. The names of the elements are given on the periodic table.

b. Formulas are written differently depending on the element.

1. The formula for most elements is just its symbol. For example, Na for sodium or Xe for xenon.

2. Some elements naturally come in diatomic molecules. When expressing this element in its pure form we would write a formula indicating this state. There are seven diatomic elements: H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2. You should memorize these.

ii. Compounds

a. Ionic Compounds

I. Ionic compounds are formed between oppositely charged ions.

II. An ion can be a single charged atom or a small group of atoms (molecule) with a charge.

III. Binary Ionic Compounds (compounds composed of two single atom ions)

i. Naming

a. We can form ionic compounds from choosing a metal and a nonmetal. This is best taught by example

b. Sodium and chlorine form Sodium Chloride.

c. Magnesium and oxygen form Magnesium Oxide.

d. Calcium and sulfur form Calcium Sulfide.

e. Binary ionic compounds are named by removing the end of the name from the nonmetal and adding -ide.

ii. Formula writing

a. To write the correct formula you must know the charges present on each ion. To determine this you would look on the periodic table or your common ion sheet.

b. The positive and negative charges must exactly balance each other in order to have the correct ratio of ions to form a neutral compound.

c. Sodium can form a +1 charged ion and is written: Na^{+1}

d. Sulfur can form a -2 charged ion and is written: S^{-2}

e. The formula for Sodium Sulfide is Na_2S

f. Some other common ions that you should memorize: K^{+1}, Ag^{+1}, Mg^{+2}, Zn^{+2}, Al^{+3}, Ca^{+2}, O^{-2}, Cl^{-1}

g. Try some examples below:

Calcium Fluoride = Potassium Chloride =

Lithium Oxide = Aluminum Sulfide =

IV. Polyatomic Ionic Compounds

i. Sometimes a group of atoms can have a charge. This is called a poly atomic ion.

ii. Some common poly atomic ions which you should memorize are: nitrate NO_3^{-1}, sulfate SO_4^{-2}, carbonate CO_3^{-2}, bicarbonate (or hydrogen carbonate) HCO_3^{-1}, and hydroxide OH^{-1}

iii. Notice that the names of these ions end in -ate.

iv. When you see a name ending in -ate it probably implies that it is a polyatomic ionic compound.

v. The groups of atoms can be thought of as a single entity with a charge, just like a single atom can have a charge. For example, Sodium Nitrate needs one +1 sodium ion to neutralize one -1 nitrate ion, so the formula is $NaNO_3$.

vi. If you need more than one polyatomic ion then you put parenthesis around it in the formula. For example, Calcium Nitrate needs one +2 calcium ion to neutralize two -1 nitrate ions, so the formula is $Ca(NO_3)_2$.

vii. Try some examples below:

Sodium Sulfate = Zinc Phosphate =

Barium Hydroxide = Ammonium Sulfate =

V. Ions with multiple charges

i. Some atoms can commonly form 2 or 3 different charges. These atoms are typically transition elements.

ii. Copper, for example, usually forms +1 or +2 charged ions.

iii. This can cause problems if a compound is named Copper Oxide. This could have the formula CuO or Cu_2O depending on the charge of the copper atom.

iv. To clear up this ambiguity we can name the ions by specifically adding on a number to their name. Cu^{+1} is Copper(I) and Cu^{+2} is Copper(II). So the names of the copper compounds listed above are Copper(II)Oxide for CuO and Copper(I)Oxide for Cu_2O.

v. Try some examples below:

Iron(II)Oxide = =$CuSO_4$

Iron(III)Oxide = = $Cr(NO_3)_3$

VI. Click here to see an applet which will help you in writing ionic formulas. This applet was created by University of Massachusetts at Amherst Chemistry System. Note: You may need to use Internet Explorer 4.5 or better to see this applet properly.

b. Handout: Solubility Rules and Common Ions

c. Homework: Binary Ionic Naming Sheet

d. Homework: Binary Ionic With Roman Numerals.

e. Homework: Polyatomic Ion Sheet.

f. Molecular Compounds

I. Molecular naming falls into two groups - organic and inorganic. We will talk about inorganic for now. Later this year an entire unit will be dedicated to the study of organic molecules

II. Prefixes which indicate the number of atoms of each element are used in the naming of inorganic molecular compounds. You should memorize the following:

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

III. When given a formula the prefixes above are applied to the words that would be used to name the compound as if it were ionic. For example, P_2O_3 would be named Phosphorous Oxide if it were ionic, but it consists of two nonmetals, so it would be named Diphosphorous Trioxide.

IV. Whenever there is only one atom of the first element in a formula we drop the term Mono-. For example CO is Carbon Monoxide, not Monocarbon Monoxide.

V. To write formulas you just interpret the prefixes on the names and write the appropriate symbolic representation. For example, Sulfur Dioxide is SO2.

VI. Try some of the following examples:

Carbon Tetrachloride = | =N_2O
Trinitrogen Pentoxide = | = CO_2

VII. There are special cases where we use common names for molecular compounds. The only two that I want you to memorize are: Water = H_2O and Ammonia = NH_3 (not to be confused with the amonium ion = NH_4^{+1}

g. Ban dihydrogen monoxide! DMHO Fact Sheet- Join the movement by clicking here.

h. Acids

I. Binary Acids

i. As a general rule the formula for an acid starts with hydrogen.

ii. If acid consists of just two elements, then it is named Hydro-_______-ic Acid.

iii. For example HCl is Hydrochloric Acid.

iv. And the formula for Hydrobromic Acid is HBr.

II. Other Acids

i. For all other acids common names are used that cannot be deduced from the formula and vise versa.

ii. You should memorize the following:

a. H_2SO_4 = Sulfuric acid

b. HNO_3 = Nitric Acid

c. $HC_2H_3O_2$ = acetic acid

i. Homework: Naming Various Chemicals Sheet

j. Get some extra practice on naming substances at the ChemTeam website.

iii. General naming and formula writing strategy

I. General naming strategy

i. Determine if the formula depicts an ionic compound (metal and nonmetal), a molecular compound (two nonmetals), or an acid (begins with hydrogen).

ii. If ionic determine the names of the ions and write the name putting the metal first.

iii. If molecular determine the names of the nonmetals and add the appropriate prefixes before writing the name.

iv.If an acid it is either in the form hydro-______-ic acid or it is one of the ones you memorized.

II.General formula writing strategy

i.Determine if the name depicts an ionic compound (metal and nonmetal), a molecular compound (two nonmetals), or an acid (has the word acid in its name).

ii.If ionic, determine the charges on the ions and write a formula that will yield a neutral compound.

iii.If molecular, write a formula using the prefixes in the name to determine the subscripts in the formula.

iv.If an acid, then it is either one of the ones you memorized or it's H__. (hydrogen followed by some single element)

VI.Writing Chemical Equations

I.A chemical equation is a symbolic representation of what happens during a chemical reaction.

II.To describe the reaction you did between baking soda and hydrochloric acid in words you would write: Sodium Bicarbonate reacts with Hydrochloric Acid to produce Carbon Dioxide, Water, and Sodium Chloride.

III.In symbolic form we would write: $NaHCO_3 + HCl \dashrightarrow CO_2 + H_2O + NaCl$

IV.Everything to the left of the arrow is called the reactants, everything to the right, the products.

V.One can even add the state of each substance in the reaction.

(s) = solid (l) = liquid

(g) = gas (aq) = aqueous (dissolved in water)

Using the above, the reaction becomes: $NaHCO_3(s) + HCl(aq) \dashrightarrow CO_2(g) + H_2O(l) + NaCl(aq)$

VI.Reactions with only ionic compounds as reactants.

i.Typically ionic compounds won't react with each other unless they are dissolved in water. Therefore, most of our reactions with ionic compounds will be in the aqueous phase.

ii.A reaction only occurs if one of the products formed would be insoluble in water. When an insoluble compound is formed from a reaction between two aqueous solutions, we call this compound a precipitate. See the Precipitation Rules Sheet to learn if an insoluble compound would form.

iii.When combining two aqueous ionic compounds you basically have four different ions floating around in solution. The positive and negative ions from each compound have the opportunity to come in contact and react. If the new compound formed is insoluble then a precipitate forms.

iv. We can write the reaction between Sodium Chloride and Lead(II)Nitrate in several ways.

a. In words it would be:

Sodium Chloride + Lead(II) Nitrate --> Sodium Nitrate + Lead(II) Chloride

b. In formulas it would be

$NaCl(aq) + Pb(NO_3)_2(aq) \rightarrow NaNO_3(aq) + PbCl_2(s)$

c. Notice that the NaNO3 is still dissolved. Basically, the sodium and nitrate ions did not really do anything. They were floating around dissolved in solution before and after the reaction. So, we have another way of writing this equation which is called the net ionic equation:

$Pb^{+}2(aq) + Cl^{-1}(aq) \rightarrow PbCl_2(s)$

VII. Reactions with all other substances utilize the "In formulas" method listed above.

VII. Lab: Predicting Precipitates

VIII. Homework: Seven Solution Practice

IX. Balancing Equations

I. Remember Lavoisier's Law of Conservation of Mass? So far the chemical equations we have written have not taken this law into consideration.

II. Let's recall the reaction between Sodium Chloride and Lead(II) Nitrate:

$NaCl(aq) + Pb(NO_3)_{2(aq)} \rightarrow NaNO_{3(aq)} + PbCl_{2(s)}$

Where did the second chloride ion come from, and where did the other nitrate ion go?

III. Every atom that appears on the left side of the arrow must also appear on the right side. It might be tempting to fix this problem by rewriting $PbCl_2$ as PbCl, but that would be the incorrect formula for Lead(II) Chloride. Pb^{+2} must pair up with two Cl^{-1}s.

IV. We resolve this by placing coefficients in front of the formulas indicating that you can have different ratios of the substances reacting to form different ratios of products. To fix the above reaction we would rewrite it as:

$2\ NaCl_{(aq)} + Pb(NO_3)_{2(aq)} \text{-->} 2\ NaNO_{3(aq)} + PbCl_{2(s)}$

V. The 2 in front of NaCl give you 2 Nas and 2 Cls. The 2 in front of the $NaNO_3$ gives you 2 Na, 2 N, and 6 O. If you count up all the atoms on the left and right of the arrows you will have the same number of each element. The equation is now balanced.

VI. An unbalanced equation is like having a recipe with no quantities for each ingredient.

VII. Click here to see a visual representation of balancing equations by C.H. Mak at Virginia Tech.

X. Homework: Balance Practice

XI. If you want even more practice on balance equations click here to see the ChemTeam's set of problems.

XII. Lab: Seven Solution Lab

XIII. Types of Reactions

I. Reactions can placed in broad categories.

i. Synthesis

a. This occurs when the number of products is fewer than the number of reactants.

b. In symbolic form: A + B --> AB

c. An example of this is the formation of water: $2\ H_{2(g)} + O_{2(g)} \text{-->} 2\ H_2O_{(l)}$

ii. Decomposition

a. This occurs when the number of products is more than the number of reactants.

b. In symbolic form: AB --> A + B

c. Concrete example: $2\ H_2O_{(l)} \text{-->} 2\ H_{2(g)} + O_{2(g)}$

iii. Single Replacement (or Displacement)

a. This occurs when one element replaces another element in a compound.

b. In symbolic form: A + BC --> AC + B or A + BC --> BA + C

c. Concrete example: $Zn_{(s)} + CuSO_{4(aq)} \text{->} ZnSO_{4(aq)} + Cu_{(s)}$

iv. Double Replacement (or Displacement)

a. This occurs when two sets of elements switch places in a reaction.

b.In symbolic form: AB + CD --> AD + CB

c.Concrete example: 2 $NaCl_{(aq)}$ + $Pb(NO_3)_{2(aq)}$ -->2 $NaNO_{3(aq)}$ + $PbCl_{2(s)}$

d.There are two special cases which have specific names given to them

1.When the reaction is between two ionic compounds and they form a precipitate, this reaction is also called a Precipitation. The example given above shows this.

2.When the reaction is between an acid and a base (any compound that forms hydroxide ions), water is formed as one of the products. This is called Neutralization. For example:

$H_2SO_{4(aq)}$ + 2 $NaOH_{(aq)}$ --> 2 $H_2O_{(l)}$ + $Na_2SO_{4(aq)}$

v.Combustion

a.Typically combustion occurs when a hydrocarbon reacts with oxygen to produce carbon dioxide and water. Hydrocarbons are a class of compounds that primarily consist of hydrogen and oxygen.

b.In symbolic form: C_xH_y + O_2 --> CO_2 + H_2O

c.Concrete example: 2 C_2H_6 + 7 O_2 --> 4 CO_2 + 6 H_2O

II.Some common chemical reactions that you should be familiar with:

a.acid + base ----> water + ionic compound

b.metal + oxygen ---> ionic compound

c.metal + acid ---> hydrogen gas + ionic compound

d.ionic compound1 + ionic compound2 ---> ionic compound3 + ionic compound4

e.acid + carbonate ---> carbon dioxide + water + ionic compound

f.metal1 + ionic compound1 ---> metal2 + ionic compound2

g.hydrocarbon + oxygen ---> carbon dioxide + water

XIV.Homework: Types of Reactions

XV.Lab: Common Chemical Reactions

XVI.Handout / Homework: Equation Review