AMSAT CHEM IH TOPIC #9
REACTION NOTES

TABLE OF CONTENTS

1. Describing Chemical Reactions
2. Types of Chemical Reactions
3. Activity Series of the Elements
4. Predicting Products of Reactions

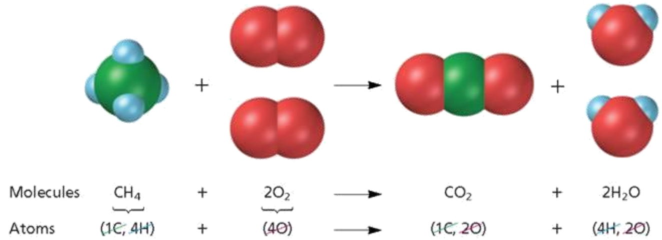
DESCRIBING CHEMICAL REACTIONS SECTION #1

- Intro
    - Chemical reaction
        - Process by which one or more substances are changed into different substances
    - Original substances (reactants)
    - Resulting substances (products)
    - Law of Conservation of Mass
        - Mass of products must equal the mass of reactants
    - Chemical equation
        - Represent with symbols and formulas, the identities and relative amounts of reactants and products in a chemical reaction: $(NH_4)_2Cr_2O_7(s) \rightarrow N_2(g) + Cr_2O_3(s) + 4H_2O(g)$
- Indicators of a Reaction
    - (1) heat released/absorbed
    - (2) production of light
    - (3) production of a gas
    - (4) formation of a precipitate
    - (5) color change
- Characteristics of Chemical Equations
    - The equation must represent known facts.
    - The equation must contain the correct formulas for the reactants and products.
    - The Law of Conservation of Mass must be obeyed.
        - Coefficients are used (in front of a chemical formula) to balanced out atoms of elements on the product and reactant side of the chemical equation.
            - Always a whole number
            - Must be in simplest ratio to other coefficients in chemical equation
            - All atoms in chemical formula are multiplied by the coefficient
    - Word and Formula Equations
        - First step in writing a chemical equation is identifying the facts to be represented.
        - Word equation
            - An equation in which the reactants and products I a chemical reaction are represented by words
            - When <u>methane</u> burns in air, it <u>combines</u> with <u>oxygen gas</u> to form <u>carbon dioxide</u> and <u>water vapor</u>.

                methane + oxygen → carbon dioxide + water
                - The → is read as "*react to yield*" or *"yields"*

- Formula Equation
  - Represents reactants/products of a chemical reaction with symbols/formulas.

$$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$



In a Bunsen burner, methane combines with oxygen in the air to form carbon dioxide and water vapor. The reaction is represented by both a molecular model and a balanced equation. Each shows that the number of atoms of each element in the reactants equals the number of atoms of each element in the products.

- Balancing an Equation
  - Using coefficients to equalize the number of each element on the product and reactant side of the equation
    - Satisfy the Law of Conservation of Mass

$CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$ (not balanced)

1C: 4H 2O 1C:2O 2H:1O

- Balance C's first, next balance H's, and balance O's last
  - All coefficients must be whole numbers in simplest ratio.

- **<u>Sample Problem 9.1</u>** – Balancing Equations — coefficients (mole ratio)

(1) __Fe + __$Cl_2 \rightarrow$ __$FeCl_3$ ___:___:___

(2) __$FeBr_3$ + __$H_2SO_4 \rightarrow$ __$Fe_2(SO_4)_3$ + __HBr ___:___:___:___

(3) __$C_4H_6O_3$ + __$H_2O \rightarrow$ __$C_2H_4O_2$ ___:___:___

(4) __C_7H_{16} + __$O_2 \rightarrow$ __CO_2 + __H_2O ___:___:___:___

Symbols Used in Chemical Equations

Symbol	Explanation
$\longrightarrow$	"Yields"; indicates result of reaction
$\rightleftarrows$	Used in place of a single arrow to indicate a reversible reaction
(s)	A reactant or product in the solid state; also used to indicate a precipitate
$\downarrow$	Alternative to (s), but used only to indicate a precipitate
(l)	A reactant or product in the liquid state
(aq)	A reactant or product in an aqueous solution (dissolved in water)
(g)	A reactant or product in the gaseous state

Symbol	Explanation
$\uparrow$	Alternative to (g), but used only to indicate a gaseous product
$\xrightarrow{\Delta}$ or $\xrightarrow{heat}$	Reactants are heated
$\xrightarrow{2\ atm}$	Pressure at which reaction is carried out, in this case 2 atm
$\xrightarrow{pressure}$	Pressure at which reaction is carried out exceeds normal atmospheric pressure
$\xrightarrow{0°C}$	Temperature at which reaction is carried out, in this case 0°C
$\xrightarrow{MnO_2}$	Formula of catalyst, in this case manganese dioxide, used to alter the rate of the reaction

- **<u>Sample Problem 9.2</u>** – Word/Formula Equations

Write the word and formula equations for the chemical reaction that occurs when solid <u>sodium oxide</u> is added to <u>water</u> at room temperature and forms <u>sodium hydroxide</u> (dissolves in the water). Include symbols for physical states in the formula equation. Then balance the formula equation to give a balanced equation.

- **<u>Sample Problem 9.3</u>** – Word/Formula Equations

  Translate the following chemical equation into a sentence:

  $$BaCl_2(aq) + Na_2CrO_4(aq) \rightarrow BaCrO_4(s) + 2NaCl(aq)$$

- Significance of a Chemical Equation
  - Chemical equations are very useful for doing quantitative chemical work.
  - The arrow is treated like an equal sign.
  - Equation as a whole is similar to an algebraic equation.

    (1) Coefficients indicate relative, not absolute, amounts of reactants and products.
    - Shows the smallest number of atoms/molecules needed to satisfy the law of conservation if mass
    - Consider: $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$
      - 1 molecule of hydrogen reacts with 1 molecule of chlorine to form 2 molecules of hydrogen chloride
      - Giving the following molecular ratio of reactants and products
        - 1 molecule H_2:1 molecule Cl_2:2 molecules HCl
        - To obtain larger relative amounts, we simply multiply ALL of the coefficients by the same number, say 20
          - 20 molecule H_2:20 molecule Cl_2:40 molecules HCl
      - Reaction can also be considered in terms of amounts of moles
        - 1mol H_2:1 mol Cl_2:2 mol HCl

    (2) The relative masses of the reactants and products can be determined from coefficients.
    - Multiply coefficient by the MM of each compound that follows coefficient.

    reactants:

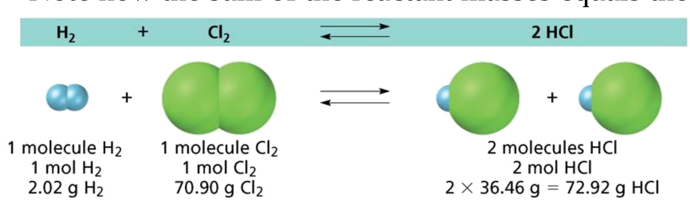
    $$1\ \text{mol}\ H_2 \times \frac{2.02\text{g}}{\text{mol}\ H_2} = 2.02\text{g}\ H_2$$

    $$1\ \text{mol}\ Cl_2 \times \frac{70.90\text{g}}{\text{mol}\ Cl_2} = 70.90\text{g}\ Cl_2$$

    product:

    $$2\ \text{mol HCl} \times \frac{36.46\text{g}}{\text{mol HCl}} = 72.92\ \text{g HCl}$$

    *Note how the sum of the reactant masses equals the mass of the products.



    (3) The reverse reaction has the same relative amounts of substances as the forward reaction.
    - Like an algebraic equation, a chemical equation can be read in either direction.
  - Items NOT in a chemical equation
    - Whether the reaction will occur or not.
    - No indication as to the speed the reaction progresses
- Balancing Chemical Equations

  (1) Identify the names of the reactants and products, and write a word equation.

(2) Write a formula equation.
(3) Balance the formula equation according to the law of conservation of mass
- Balance the different types of atoms one at a time
- First balance atoms of elements that are combined and occur only once on each side of the equation.
- Balance any polyatomic ions that appear on both sides of the equation as single units.
- Balance H and O atoms after all other elements have been balanced.

(4) Count atoms to be sure that the equation is balanced.

- **Sample Problem 9.4** – Balancing Equations
  Aluminum (III) sulfate and calcium hydroxide are used in a water-purification process. When added to water, they dissolve and react to produce two insoluble products, aluminum hydroxide and calcium sulfate. These products settle out, taking suspended impurities with them. Write a balanced equation for this reaction.
- **Sample Problem 9.5** – Balancing Equations
  The reaction of zinc with aqueous hydrochloric acid produces a solution of zinc (II) chloride and hydrogen gas. Write a balanced equation for the reaction.

TYPES OF CHEMICAL REACTIONS SECTION #2

- Intro
  - 5 basic types of general reactions
  - Synthesis (composition), decomposition, single-replacement (single displacement), double-replacement (double-displacement), and combustion
  - Not all encompassing
    - Not all reactions can fit neatly into these five categories
- Synthesis
  - Two or more substances combine to form a new substance
    - $A + X \rightarrow AX$
      - A is a metal
      - X is a nonmetal
        - $2Na + Cl_2 \rightarrow 2NaCl$
    - $X + Y \rightarrow XY$
      - Both X and Y are nonmetals
        - $S_8 + 8O_2 \rightarrow 8SO_2$
    - $C + C \rightarrow BC$
      - C is a compound
      - BC bigger compound
        - $H_2O + CO_2 \rightarrow H_2CO_3$
    - $A + B \rightarrow$ no reaction
      - Both A and B are metals
      - Two metals can never form a bond to form and make a compound.
- Decomposition
  - A single compound undergoes a reaction that produces two smaller substances: 2 elements; 1 element and 1 compound; or 2 simpler compounds

- Binary compounds
  - Only two elements make up compound
    - AX → A + X
      - A is a metal
      - X is a nonmetal
        - $2NaCl \rightarrow 2Na + Cl_2$
    - XY → X + Y
      - Both X and Y are nonmetals
        - $8SO_2 \rightarrow S_8 + 8O_2$
    - BC → C + C
      - C is a compound (or element)
      - BC is a bigger compound
        - $NaClO_3 \rightarrow NaCl + O_2$
        - $H_2CO_3 \rightarrow H_2O + CO_3$

- Single-Replacement Reactions (Single-Displacement)
  - One element replaces a similar element in a compound
    - A + BX → AX + B -or- Y + BX → BY + X
      - A and B are metallic elements while X, and Y are nonmetallic elements
      - BX, AX, and BY are ionic compounds
        - A and B are 1st parts of the ionic compound formula
          - Metals or ammonium
          - Cationic single-replacement; SR(c)
            - $3Na + FeCl_3 \rightarrow 3NaCl + Fe$
        - X and Y are 2nd parts of the ionic compound formula
          - Nonmetals or polyatomic anion
          - Anionic single-replacement; SR(a)
            - $F_2 + 2NaCl \rightarrow 2NaF + Cl_2$
      - Metals always replace the 1st part
      - Nonmetals always replace the 2nd part

- Double-replacement reactions
  - Ions of two compounds exchange places in an aqueous solution forming two new compounds
  - AX + BY → AY + BX
    - A and B represent cations (metals or ammonium)
      - 1st part of compound
    - X and Y represent anions (nonmetals or polyatomic ions)
      - 2nd part of compound
    - 1st part can only switch positions w/ another 1st part
    - 2nd part can only switch positions with another 2nd part
      - $Na_3PO_4 + CaCl_2 \rightarrow NaCl + Ca_3(PO_4)_2$

- Combustion
  - $C_xH_y + O_2 \rightarrow xCO_2 + (\frac{1}{2}y)H_2O$
  - A substance combines with oxygen, releasing a large amount of heat and light
    - Oxygen combines with every element in compound

- $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

- **Sample Problems 9.6** – Classifying Chemical Equation

  Classify and balance the following equations.

  (1) _____ __$N_2(g)$ + __$H_2(g) \rightarrow$ __$NH_3(g)$

  (2) _____ __$Li(s)$ + __$H_2O(l) \rightarrow$ __$LiOH(aq)$ + __$H_2(g)$

  (3) _____ __$NaNO_3(s) \rightarrow$ __$NaNO_2(s)$ + __$O_2(g)$

  (4) _____ __$C_4H_{14}(l)$ + __$O_2(g) \rightarrow$ __$CO_2(g)$ + __$H_2O(g)$

  (5) _____ __$NH_4Cl(s) \rightarrow$ __$NH_3(g)$ + __$HCl(g)$

ACTIVITY SERIES OF THE ELEMENTS SECTION #3

- Intro
  - The ability for an element to react is called its *activity*.
    - The more readily it reacts the greater its activity.
  - Activity Series
    - A list of elements arranged by the activity
      - Metals
        - Greater ease of losing electrons
      - Nonmetals
        - Greater ease at gaining electrons

Metals				
Metal Activity Series				
Li>Rb>K>Ba>Sr>Ca>Na	>Mg>Al>Mn>Zn>Cr>Fe>Cd	>Co>Ni>Sn>Pb	$>H_2$>Sb>Bi>Cu>Hg	>Ag>Pt>Au
cold H_2O, acids, oxygen	steam, acids, oxygen	acids, oxygen	oxygen	unreactive

Nonmetals
Nonmetal Activity Series
$F_2>Cl_2>Br_2>I_2$

- Using activity series.
  - Find metal/nonmetal in compound on series
    - If the free element is to the left of the metal/nonmetal in compound then reaction occurs.
- **Sample Problems 9.7** – Activity Series

  Using the activity series, predict whether a reaction occurs. If a reaction occurs, then predict the products and balance the equation. If no reaction occurs, the write NR.

  1. Y/N __$Mn(s)$ + __$H_2O(l) \rightarrow$ __ ____________ + __ ____________
  2. Y/N __$Sn(s)$ + __$BiCl_3(aq) \rightarrow$ __ ____________ + __ ____________
  3. Y/N __$Ag(s)$ + __$NaCl(aq) \rightarrow$ __ ____________ + __ ____________
  4. Y/N __$Zn(s)$ + __$Ni(NO_3)_2(aq) \rightarrow$ __ ____________ + __ ____________
  5. Y/N __$Fe(s)$ + __$H_2O(l) \xrightarrow{\Delta}$ __ ____________ + __ ____________
  6. Y/N __$Cl_2(g)$ + __$NaI(aq) \rightarrow$ __ ____________ + __ ____________
  7. Y/N __$Cl_2(g)$ + __$NaF(aq) \rightarrow$ __ ____________ + __ ____________

8. Identify the element that replaces hydrogen from acids but cannot replace tin from its compounds. ___________
9. According to the activity series above, what is the most active transition metal? ___________

PREDICTING PRODUCTS OF REACTIONS SECTION #4

- Synthesis
  - metal + nonmetal → cation-anion
  - A + X → AX
    - Reactions with oxygen, sulfur, and halogens
      - Oxygen
        - $2Rb(s) + O_2(g) \rightarrow Rb_2O(s)$
        - $Mg(s) + O_2(g) \rightarrow MgO(s)$
        - $Fe(s) + O_2(g) \rightarrow FeO(s)$ (iron becomes Fe^{2+})
        - $4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3$ (iron becomes Fe^{3+})
      - Sulfur
        - $16Rb(s) + S_8(s) \rightarrow 8Rb_2S(s)$
        - $8Ba(s) + S_8(s) \rightarrow 8BaS(s)$
      - Halogens
        - $2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$
        - $2K(s) + I_2(s) \rightarrow 2KI(s)$
        - $Mg(s) + F_2(g) \rightarrow MgF_2(s)$
        - $Sr(s) + Br_2(l) \rightarrow SrBr_2(s)$
        - $2Na(s) + F_2(g) \rightarrow 2NaF(s)$
        - $2Co(s) + 3F_2(g) \rightarrow 2CoF_3(s)$ (cobalt becomes Co^{3+})
        - $U(s) + 3F_2(g) \rightarrow UF_6(s)$ (uranium becomes U^{6+})
  - nonmetal + nonmetal → nonmetal-nonmetal (molecular compound)
    - Use Lewis structures to predict synthesized compound
      - $S_8(s) + 12O_2(g) \rightarrow 8SO_3(g)$ (excess oxygen)
      - $C(s) + O_2(g) \rightarrow CO_2(g)$ (excess oxygen)
      - $2C(s) + O_2(g) \rightarrow 2CO(g)$ (limited oxygen)
      - $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$ (excess oxygen)
    - Oxides
      - $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$*
      - $SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$
      - $2H_2SO_3(aq) + O_2(g) \rightarrow 2H_2SO_4(aq)$
      - $CaO(s) + SO_2(g) \rightarrow CaSO_4(s)$
- Decomposition Reactions
  - Binary
    - cation-anion → metal + nonmetal
    - AX → A + X
      - $2NaCl(l) \xrightarrow{\text{electicity}} 2Na(l) + Cl_2(g)$
        - Decomposition of a substance with an electric current is called electrolysis

            - $2HgO(s) \xrightarrow{\Delta} 2Hg(l) + O_2(g)$
        - $XY \rightarrow X + Y$
            - X and Y are nonmetals
                - $8SO_2(g) \rightarrow S_8(s) + 8O_2(g)$
                - $2H_2O(l) \xrightarrow{\text{electricity}} 2H_2(g) + O_2(g)$
    - Ternary Compounds
        - Three or more elements make up compound
            - $BC \rightarrow C + C$ or $BC \rightarrow C$ + element
                - Metal carbonates (breakdown into a metal oxide and carbon dioxide)
                    - $\_\_CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$
                - Metal hydroxides (breakdown into water and a base anhydride (metal oxide)
                    - $\_\_Ca(OH)_2(s) \xrightarrow{\Delta} CaO(s) + H_2O(g)$
                - Metal chlorates (breakdown into a metal chloride and oxygen gas)
                    - $2KClO_3(s) \xrightarrow{\Delta MnO2} 2KCl(s) + 3O_2(g)$
                - Acids (breakdown into water and an acid anhydride (a nonmetal oxide))
                    - $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$
                    - $H_2SO_4(aq) \xrightarrow{\Delta} H_2O(l) + SO_3(g)$
                    - $H_2SO_3(aq) \xrightarrow{\Delta} H_2O(l) + SO_2(g)$
- Single-Replacement Reactions (Single-Displacement)
    - Cationic single-replacement; SR(c)
        - $A + BX \rightarrow AX + B$
            - A and B are metallic elements and 1st parts of the compound's formula
                - Metals or ammonium
            - X is either a nonmetal or a polyatomic ion
            - BX and AX are ionic compounds
        - Metal replacing metal (cation)
            - $\_\_Al(s) + \_\_Pb(NO_3)_2(aq) \rightarrow Al(NO_3)_3(aq) + Pb(s)$
        - Metal replacing H in water (H acts like a metal in this type of reaction)
            - $2Na(s) + 2H_2O(HOH)(l) \rightarrow 2NaOH(aq) + H_2(g)$
            - $Mg(s) + 2H_2O(HOH)(g) \xrightarrow{\Delta} Mg(OH)_2(s) + H_2(g)$
                - $H_2O(g)$ is steam (Heat water until it is a gas)
        - Metal replacing H in an acid (H acts like a metal in this type of reaction)
            - $2Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
    - Anionic single-replacement; SR(a)
        - $Y + BX \rightarrow BY + X$
            - Y and X are nonmetals and 2nd parts of the compound's formula
            - BX and BY are ionic compounds
                - Halogens replacing anions
                - $Cl_2(g) + 2KBr(aq) \rightarrow 2KCl(s) + Br_2(l)$
                - $F_2(g) + 2NaCl(aq) \rightarrow 2NaF(s) + Cl_2(g)$
                - $Br_2(l) + 2KCl(aq) \rightarrow 2KBr(s) + Cl_2(g)$

- Double Replacement Reactions (Double-Displacement)
  - AX + BY → AY + BX
    - Formation of a precipitate (ppt)
      - $2KI(aq) + Pb(NO_3)_2(aq) \rightarrow 2KNO_3(aq) + PbI_2(s)$
    - Formation of a gas
      - $FeS(s) + 2HCl(aq) \rightarrow H_2S(g) + FeCl_2(aq)$
    - Formation of water
      - $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + HOH(l)$
- Combustion reactions
  - A substance combines with oxygen, releasing a large amount of heat and light
    - Oxygen combines with every element in compound
    - $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$
      - When the compound reacting with oxygen contains ONLY carbon and hydrogen (hydrocarbon), the products are always CO_2 and H_2O.
        - If any other element is present in the compound then oxygen combine in a 2:1 ratio with the other element
          - $S \rightarrow SO_2$ and $N \rightarrow NO_2$
  - **Sample Problems 9.9** – Predicting Reactants/Products

    Identify the type (S, D, SR(c), SR(a), DR, or C) of reaction then write the name of the product(s). After the correct name of the product(s) are written write the balance formula equation.

    (1) Type: ____: potassium + fluorine → ____________________

    Balanced equation: __ _________ + __ _________ → __ _________

    (2) Type: ____: zinc (II) carbonate $\xrightarrow{\Delta}$ ____________________ + ____________________

    Balanced equation: __ _________ $\xrightarrow{\Delta}$ __ _________ + __ _________

    (3) Type: ____: sodium bromide + silver (I) nitrate → ________________ + ________________

    Balanced equation: __ _________ + __ _________ $\xrightarrow{\Delta}$ __ _________ + __ _________

    (4) Type: ____: strontium + lead (II) chlorate → ________________ + ________________

    Balanced equation: __ _________ + __ _________ $\xrightarrow{\Delta}$ __ _________ + __ _________

    (5) Type: ____: fluorine + iron (III) bromide → ________________ + ________________

    Balanced equation: __ _________ + __ _________ $\xrightarrow{\Delta}$ __ _________ + __ _________

    (6) Type: ____: nonane (C_9H_{10}) + oxygen gas → ________________ + ________________

    Balanced equation: __ _________ + __ _________ $\xrightarrow{\Delta}$ __ _________ + __ _________

Home