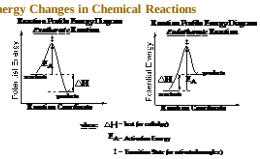
TYPES OF CHEMICAL REACTIONS

Energy Changes in Chemical Reactions



Note: It is IMPERATIVE that you learn to look at a particular set of reactants and identify the TYPE of chemical reaction that is occurring. This takes LOTS OF PRACTICE!!!

COMBUSTION

A reaction which generally involves the presence of oxygen and releases energy (exothermic).

- **Hydrocarbons and other organic compounds combine with excess oxygen to form carbon dioxide and water.**
  Propanol ($CH_3CH_2CH_2OH$) is burned completely in air.
- **Metals combine with oxygen to form metallic oxides.**
  Calcium metal is heated strongly in the presence of oxygen.

COMBUSTION

- **Nonmetallic hydrides combine with oxygen to form water and nonmetal oxides.**
  Gaseous diborane, B_2H_6, is burned in excess oxygen.
- **Nonmetallic sulfides combine with oxygen to form sulfur dioxide and nonmetal oxides.**
  Carbon disulfide vapor is burned in excess oxygen.
- **If sulfur is present, SO_2 is formed; if nitrogen is present, NO_2 is formed.**
  Excess oxygen is mixed with ammonia(NH_3) in the presence of platinum.

Workshop Rx1 on Combustion Reactions:

Write the formulas to show the reactants and products for the following laboratory situations described below. Assume that solutions are aqueous unless otherwise indicated.

1. **A piece of solid bismuth is heated strongly in oxygen.**
2. **Butanol ($CH_3CH_2CH_2CH_2OH$) is burned in air.**
3. **Solid copper(II) sulfide is heated strongly in oxygen gas.**
4. **Hexane is burned in excess oxygen.**
5. **Sodium metal is burned in excess oxygen gas.**
6. **Gaseous silane, SiH_4, is burned in oxygen.**
7. **Solid zinc sulfide is heated in an excess of oxygen.**

SYNTHESIS or COMBINATION REACTIONS

- **A metal combines with a nonmetal to form a binary salt.**
  A piece of lithium metal is dropped into a container of nitrogen gas.
- **Nonmetallic oxides and water form acids. The nonmetal retains its oxidation number.**
  Dinitrogen pentoxide is bubbled into water.
- **Metallic oxides and nonmetallic oxides form salts.**
  Solid calcium oxide is added to sulfur trioxide.

DECOMPOSITION REACTIONS

- **Metallic carbonates decompose into metallic oxides and carbon dioxide.**
  A sample of magnesium carbonate is heated.
- **Metallic chlorates decompose into metallic chlorides and oxygen.**
  A sample of magnesium chlorate is heated.
- **Ammonium carbonate decomposes into ammonia, water, and carbon dioxide.**

DECOMPOSITION

Some common reactions should be memorized.

- **Sulfurous acid (H_2SO_3) decomposes into sulfur dioxide and water.**
- **Carbonic acid (H_2CO_3) decomposes into carbon dioxide and water.**
- **Hydrogen peroxide decomposes into water and oxygen.**
- **Ammonium hydroxide decomposes into ammonia and water.**

Workshop Rx2 on Synthesis and Decomposition Reactions:

Write the formulas to show the reactants and products for the following laboratory situations described below. Assume that solutions are aqueous unless otherwise indicated.

1. **A sample of calcium carbonate is heated.**
2. **Sulfur dioxide gas is bubbled through water.**
3. **Solid potassium oxide is added to a container of carbon dioxide gas.**
4. **Liquid hydrogen peroxide is warmed.**
5. **A pea-sized piece of sodium is added to a container of iodine vapor.**
6. **A sample of carbonic acid is heated.**
7. **A sample of potassium chlorate is heated.**
8. **Solid magnesium oxide is added to sulfur trioxide gas.**

SINGLE REPLACEMENT/DISPLACEMENT

Use a standard reduction potential table or the Activity Series

For metal displacements, the metal with the more POSITIVE reduction potential (i.e. *less* active) will be replaced; for halogens, the displacement order follows the periodic table, fluorine being the *most* reactive. Consider the following example:

Magnesium metal is added to an aqueous solution of nickel sulfate.

In the previous single replacement reaction example, we have written the molecular equation for the reaction. Although this equation shows the reactants and products of the reaction, it does not give a very clear picture of what truly occurs in solution. In fact, such an aqueous solution actually contains individual IONS, not molecules, in solution. By looking at the aforementioned reaction, we can see that certain ions are present in solution both before and after the reaction. Ions such as these that do NOT participate directly in the reaction are called spectator ions. The ions that DO participate in the reaction combine to form the precipitate (or solid, which is termed "insoluble"). This is represented with the following balanced net ionic equation:

Net Ionic equations include only those solution components directly involved in the reaction. Chemists usually write the net ionic equation for a reaction in solution because it gives the actual forms of the reactants and products and only includes the species that undergo a change. Write the following as net ionic equations.

- **Active metals replace less active metals from their compounds in aqueous solution.**
  Magnesium turnings are added to a solution of iron(III) chloride.
- **Active metals replace hydrogen in water.**
  Sodium is added to water.
- **Active metals replace hydrogen in acids.**
  Lithium is added to hydrochloric acid (HCl).
- **Active nonmetals replace less active nonmetals from their compounds in aqueous solution.**
  Chlorine gas is bubbled into a solution of potassium iodide.

ACTIVITY SERIES OF SOME SELECTED METALS

A brief activity series of selected metals, hydrogen and halogens are shown below. The series are listed in descending order of chemical reactivity, with the most active metals and halogens at the top (the elements most likely to undergo oxidation). Any metal on the list will replace the ions of those metals (to undergo reduction) that appear anywhere underneath it on the list.

METALS	HALOGENS
K (most oxidized	F_2
Ca	Cl_2
Na	Br_2
Mg	I_2
Al	
Zn	
Fe	
Ni	
Sn	
Pb	
H	
Cu	
Ag	
Hg	
Au(least oxidized)	

Oxidation refers to the loss of electrons and reduction refers to the gain of electrons

Workshop Rx3 on Single Replacement/Displacement Reactions:
Write the formulas to show the reactants and products for the following laboratory situations described below. Assume that solutions are aqueous unless otherwise indicated. Write NR if no reaction occurs.

1. **Liquid bromine is added to sodium iodide crystals.**
2. **An aluminum strip is immersed in a solution of silver nitrate.**
3. **Zinc pellets are added to sulfuric acid (H_2SO_4).**
4. **Fluorine gas is bubbled into a solution of aluminum chloride.**
5. **Calcium metal is added to nitrous acid (HNO_2).**
6. **A pea-sized piece of lithium is added to water.**
7. **Magnesium turnings are added to a solution of lead(II) acetate.**
8. **Liquid bromine is reacted with a solution of calcium chloride.**

DOUBLE REPLACEMENT (or metathesis)
All double replacement reactions must have a driving force to allow for it to go to completion. This driving force is the removal of at least one pair of ions from solution, which can occur in one of two ways:

1. **formation of a precipitate***
2. **formation of a gas**

*** formation of a precipitate – apply the solubility rules**

Solubility Rules*: Please note that "soluble" refers to the ability to dissolve in a solvent, while "insoluble" refers to a solid or precipitate. The Solubility Rules are summarized on the next slide.*

NEGATIVE ION	*POSITIVE ION*	*SOLUBILITY*
Chloride (Cl^-), Bromide (Br^-), Iodide (I^-)	Ag^+, Pb^{2+}, Hg_2^{2+}, Cu^+	Insoluble
Phosphate (PO_4^{3-}) Carbonate (CO_3^{2-}), Sulfite (SO_3^{2-}), Hydroxide (OH^-),	All positive ions EXCEPT alkali ions and NH_4^+	Insoluble
Sulfate (SO_4^{2-})	Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}, Ag^+, Pb^{2+}	Insoluble
Sulfide (S^{2-})	All positive ions EXCEPT alkali ions, alkaline earth ions, NH_4^+	Insoluble

*** All nitrates, perchlorates, and acetates are soluble.***

Example: A solution of potassium chloride is mixed with a solution of silver nitrate.

Workshop Rx5 on Double Displacement Reactions:
Write the formulas to show the reactants and products for the following laboratory situations described below. Assume that solutions are aqueous unless otherwise indicated. Write NR if no reaction occurs.

1. **Silver nitrate combines with potassium chromate.**
2. **Ammonium chloride combines with cobalt(II) sulfate.**
3. **Lithium hydroxide reacts with sodium chromate.**
4. **Zinc acetate is mixed with cesium hydroxide.**
5. **Ammonium sulfide reacts with lead(II) nitrate.**
6. **Iron(III) sulfate combines with barium iodide.**
7. **Chromium(III) bromide reacts with sodium nitrate.**
8. **Rubidium phosphate mixes with titanium(IV) nitrate.**
9. **Ammonium carbonate combines with nickel(II) chloride.**
10. **Tin(IV) nitrate reacts with potassium sulfite.**

Formation of a Gas
Common gases formed in metathesis reaction are listed below:

H_2S **Any sulfide (salt of S^{2-}) plus any acid form H_2S(g) and a salt.**
Solid iron(II) sulfide is mixed with hydrochloric acid.

CO_2 **Any carbonate (salt of CO_3^{2-}) plus any acid form CO_2(g), H_2O, and a salt.**
Potassium carbonate is reacted with nitric acid.

SO_2 **Any sulfite (salt of SO_3^{2-}) plus any acid form SO_2(g), H_2O, and a salt.**
Sodium sulfite is combined with hydrochloric acid.

NH_3 **Any ammonium salt (salt of NH_4^+) plus any soluble strong hydroxide react upon heating to form NH_3(g), H_2O, and a salt.**
Ammonium chloride is mixed with sodium hydroxide.

Workshop Rx6 on Gas Formation Reactions:
Write the formulas to show the reactants and products for the following laboratory situations described below. Assume that solutions are aqueous unless otherwise indicated. Write NR if no reaction occurs.

1. **Ammonium sulfate & potassium hydroxide are mixed.**
2. **Ammonium sulfide reacts with hydrochloric acid.**
3. **Cobalt(II) chloride combines with silver nitrate.**
4. **Solid calcium carbonate reacts with sulfuric acid.**
5. **Potassium sulfite reacts with hydrobromic acid.**
6. **Potassium sulfide reacts with nitric acid.**
7. **Ammonium iodide mixes with magnesium sulfate.**
8. **Solid titanium(IV) carbonate reacts with hydrochloric acid.**
9. **Solid calcium sulfite is mixed with acetic acid.**
10. **Strontium hydroxide combines with ammonium sulfide.**

ACID/BASE REACTIONS:

Acid + Base → Salt + Water

One mole of hydrogen ions will react with one mole of hydroxide ions to produce one mole of water. Diprotic (acids with two ionizable hydrogens) and triprotic (acids with three ionizable hydrogens) acids will only be encountered selectively in this course!

A. Arrhenius Acid – a compound that releases H^+ (protons)/ H_3O^+ (hydronium ions) in water.
An aqueous nitric acid solution.

B. Arrhenius Base – a compound that produces OH^- in water.
Potassium hydroxide pellets are dissolved in water.

C. Brønsted-Lowry Acid – proton donor.
Nitric acid reacts with potassium hydroxide.

ACID/BASE REACTIONS:

Acid + Base → Salt + Water

D. Brønsted-Lowry Base – proton acceptor
Sulfuric acid reacts with barium hydroxide.

E. Strong Acid – fully dissociates in solution, releasing H^+ ion(s)
Hydrobromic acid reacts with calcium hydroxide.

F. Weak Acid – does NOT fully dissociate in solution
Acetic acid reacts with potassium hydroxide.

G. Strong Base – completely protonated in solution
Hydrochloric acid reacts with sodium hydroxide.

H. Weak Base – NOT completely protonated in solution
Nitric acid reacts with ammonium hydroxide.

ACID/BASE REACTIONS:

STRONG	vs	WEAK
_ completely ionized		_ partially ionized
_ strong electrolyte		_ weak electrolyte
_ ionic/very polar bonds		_ some covalent bonds

Strong Acids:
- $HClO_4$
- H_2SO_4
- HI
- HBr
- HCl
- HNO_3

Strong Bases:
- LiOH
- NaOH
- KOH
- $Ca(OH)_2$
- $Sr(OH)_2$
- $Ba(OH)_2$

Workshop Rx7 on Acid-Base Reactions:

Predict and balance each of the acid/base reactions given below:

1. Hydrogen sulfide gas is bubbled through excess potassium hydroxide solution.
2. Aqueous barium hydroxide is reacted with excess hydrochloric acid.
3. Dilute sulfuric acid is reacted with excess sodium hydroxide.
4. Solid silver hydroxide is reacted with hydrobromic acid.
5. Perchloric acid ($HClO_4$) is reacted with solid iron(III) hydroxide.
6. Aqueous sulfuric acid is reacted with solid lithium oxide.

OXIDATION/REDUCTION

(commonly abbreviated REDOX)

The last set of reactions that we will cover involve the transfer of electrons between reactants. Such reactions are called oxidation-reduction reactions, or REDOX.

When an atom, ion, or molecule has become more positively charged, we say that is has been oxidized. Loss of electrons by a substance is called oxidation. For example, when solid calcium loses two electrons, it is oxidized to Ca^{+2} in solution. This can be represented by the following half-reaction:

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

OXIDATION/REDUCTION

In contrast, when an atom, ion, or molecule has become more negatively charged, we say that it is reduced. Gain of electrons by a substance is called reduction. For example, when fluorine gains electrons, it is converted to the fluoride ion as shown in the following half-reaction:

$$F_2 + 2e^- \rightarrow 2F^-$$

Overall, when one reactant loses electrons, another reactant must gain them. As such, the oxidation of one substance is ALWAYS accompanied by the reduction of another as electrons are transferred between them.

Rules for Balancing Oxidation/Reduction Reactions Half Reaction Method

1. Write the corresponding half reactions.
2. Balance all atoms except O and H.
3. Balance O; add H_2O as needed.
4. Balance H as acidic (H^+).
5. Add electrons to both half reactions and balance.
6. Add the half reactions; cross out "like" terms.
7. If basic or alkaline, add the equivalent number of hydroxides (OH^-) to counterbalance the H^+ (remember to add to both sides of the equation). Recall that $H^+ + OH^- \rightarrow H_2O$.

Workshop Rx8 on Balancing Redox Reactions:

Consider the following problems below. Balance each of the following oxidation/reduction reactions utilizing the half reaction method:

1. $Br_{2\,(aq)} + OH^-_{(aq)} \rightarrow Br^-_{(aq)} + BrO_3^-{}_{(aq)} + H_2O_{(l)}$ in acidic solution
2. $MnO_4^-{}_{(aq)} + C_2O_4^{-2}{}_{(aq)} \rightarrow CO_{2(g)} + Mn^{+2}{}_{(aq)}$ in basic solution
3. $MnO_4^- + H_2O_2 \rightarrow O_2 + Mn^{2+}$ in acidic solution
4. $CrO_4^{2-}{}_{(aq)} + CN^-_{(aq)} \rightarrow CNO^-_{(aq)} + Cr(OH)_4^-{}_{(aq)}$ in basic solution
5. $Cr_2O_7^{2-}{}_{(aq)} + Cl^-_{(aq)} \rightarrow Cr^{3+}{}_{(aq)} + Cl_{2\,(g)}$ in acidic solution
6. $Fe(OH)_{2\,(s)} + CrO_4^{2-}{}_{(aq)} \rightarrow Fe_2O_{3\,(s)} + Cr(OH)_4^-{}_{(aq)}$ in basic solution

CHEMICAL EQUILIBRIA

$$H_2CO_3 \Leftrightarrow CO_2 + H_2O$$

$$CaCO_3 \Leftrightarrow CaO + CO_2$$

$$CH_3COOH \Leftrightarrow H^+ + CH_3COO^-$$

$$NH_3 + H_2O \Leftrightarrow NH_4OH$$

Workshop Rx9 on Writing General Chemical Equations:

Identify the reaction type, predict the products, and write balanced (net ionic where applicable) chemical equations for each of the following. Write NR if No Reaction occurs.

1. Liquid ethanol (C_2H_5OH) is combusted.
2. Solid calcium reacts with oxygen gas.
3. Solutions of aluminum chloride & sodium carbonate are mixed.
4. Liquid magnesium bromide is decomposed at high temperature.
5. Solid nickel is reacted with aqueous magnesium sulfate.
6. Chlorine gas is reacted with aqueous potassium bromide.
7. Solid magnesium is reacted with aqueous aluminum chloride.
8. Solid potassium is reacted with chlorine gas.
9. Equal volumes of 0.1 M sulfuric acid and 0.1 M potassium hydroxide are mixed.
10. Gold metal will not dissolve in either concentrated nitric acid or concentrated hydrochloric acid. It will dissolve, however, in *aqua regia*, a mixture of the two concentrated acids. The products of the reaction are the $AuCl_4^-$ ion and gaseous NO. Write a balanced equation for the dissolution of gold in aqua regia.

Additional Practice Problems

Predict and balance (include net ionic if applicable) the following reactions, making sure to include the phases of all reactants and products where possible. Write NR if No Reaction occurs.

1. Sodium metal is added to a container of iodine vapor.

2. Aluminum wire is immersed in aqueous silver nitrate.

3. Cobalt(II) chloride is combined with silver nitrate.

4. Potassium sulfide is reacted with nitric acid (HNO_3).

5. Iodine crystals are added to a solution of sodium chloride.

6. Zinc acetate and cesium hydroxide are mixed.

7. Butanol (C_4H_9OH) is burned completely in air.

8. A solution of iron(III) chloride is poured over a piece of platinum wire.

9. Magnesium turnings are added to a solution of lead(II) acetate.

10. Iron(III) sulfate and barium iodide are mixed.

11. Excess potassium hydroxide solution is added to a solution of potassium dihydrogen phosphate.

12. Balance the following REDOX reactions, which occur in acidic solution.

A. $Pb(s) + PbO_2(s) + SO_4^{-2}(aq) \rightarrow PbSO_4(s)$
B. $AsO_4^{-3}(aq) + Zn(s) \rightarrow AsH_3(g) + Zn^{+2}(aq)$
C. $As_2O_3(s) + NO_3^-(aq) \rightarrow AsO_4^{-3}(aq) + NO(g)$
D. $CH_3OH(aq) + Cr_2O_7^{-2}(aq) \rightarrow CH_2O(aq) + Cr^{+3}(aq)$

13. Balance the following REDOX reactions, which occur in basic solution.

A. $Cl_2(g) \rightarrow Cl^-(aq) + ClO^-(aq)$
B. $MnO_4^-(aq) + S^{-2}(aq) \rightarrow MnS(s) + S(s)$
C. $CN^-(aq) + MnO_4^-(aq) \rightarrow CNO^-(aq) + MnO_2(s)$
D. $Fe(OH)_2(s) + H_2O_2(aq) \rightarrow Fe(OH)_3(s)$