CHEM 115
Intro to Redox Rxns and Solution Concentrations

Lecture 11
Prof. Sevian

The new set of assignments was posted on the website Tuesday, and will also be handed out in class today

Agenda

- Predicting products of acid-base reactions
- Oxidation-reduction (redox) reactions
  - How to recognize these reactions
  - Determining oxidation numbers of elements within a compound
  - Comparative reactivity (activity)
- Solution concentration

- (What comes next: Titration as a way to do stoichiometry)

Grouping Reactions

- Exchange rxns: no oxidation number change
  - Precipitation rxns
  - Acid-base rxns
    - Acid + Base → Salt + Water
    - Gas-forming rxns
- Redox rxns: oxidation numbers change
  - Single replacement (*e.g.*, many electrochemistry reactions)
  - Formation of compound from elements (*e.g.*, synthesis of sulfuric acid anhydride)
  - Decomposition of compound into elements (*e.g.*, producing pure metals from metal ores)
  - Combustion
- Other rxns that are neither exchange nor redox, but oxidation numbers do not change
  - Acid anhydride rxns with water
    - $SO_3\ (g) + H_2O\ (l) \rightarrow H_2SO_4\ (aq)$
  - Some decomposition rxns
    - $MgCO_3\ (s) \rightarrow MgO\ (s) + CO_2\ (g)$

The trouble with mixing up classifying rxns based on patterns (e.g., exchange, synthesis, decomposition) or based on an underlying theoretical model (e.g., redox)

What you need to know about pH

- You need to be able to calculate pH if given H^+ concentration (symbol for this is $[H^+]$)
- You need to know the general regions of the pH scale (strong acid, weak acid, neutral, weak base, strong base)
- You need to know how to predict products of an acid-base reaction, and how to write net ionic equations for reactions (to do this, you need to know the difference between strong and weak acids – this is what we practiced with last week's group problem)

Clicker question #1

What is the pH of a 0.0010 M solution of HCl?

(A) 1.0

(B) 1.00

(C) 3.0

(D) 3.00

(E) 0.0010

Clicker question #2

What is the pH of a 1.6 × 10^{-5} M solution of HCl?

(A) 1.6

(B) 3.80

(C) 4.8

(D) 4.79

(E) 4.80

Practice predicting products of acid-base reactions

What reaction occurs when these solutions are mixed? Write the net ionic equation for each.

1. Aqueous nitric acid is mixed with aqueous sodium hydroxide (assume equal molar quantities)
2. Aqueous acetic acid is mixed with aqueous potassium hydroxide (assume equal molar quantities)
3. Aqueous oxalic acid is mixed with aqueous sodium hydroxide in a 1:1 molar ratio

To solve redox reactions you first need to know: What are oxidation numbers?

- A charge (sometimes real, sometimes fake) that can be assigned to each atom in a compound
  - In charged particles (ions within ionic solid, ions dissolved in water), the charge is real
  - In molecules (which are neutral), atoms don't have real charges
- Measures electron density that resides on the individual atom
  - Caveat: if the atom is in a molecule, and there is more than one of a particular kind of atom, in reality each one doesn't have the same electron density
- A model that provides an accounting method for explaining electron transfer in redox reactions
- The oxidation number model is one of several models we will learn about in freshman chemistry that attempts to explain chemical behavior and molecular structure in terms of how electrons are distributed (other models will include electronegativity, formal charge, Lewis dot structures)

How to assign oxidation numbers

- Oxidation numbers sum to zero if compound is neutral, and total charge on ion if not neutral
- Atoms in free, neutral elements have oxidation number zero (0)

  Zn (*s*), **Ar** (*g*), **O_2** (*g*), **S_8** (*s*), **Ag** (*s*), **N_2** (*g*)

- Charged ions have oxidation number equal to their charges

  $FeCl_3$ (*s*), **$FeCl_2$** (*s*), **Na^+** (*aq*), **Al^{3+}** (*aq*), **$AlBr_3$** (*s*)

- Oxygen, when in a compound or ion, nearly always has oxidation number -2 (exception: peroxides)

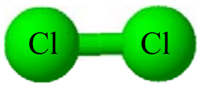
  Al_2O_3 (*s*), **MgO** (*s*), **SO_4^{2-}** (*aq*), **NO_3^-** (*aq*); Exceptions: **H_2O_2** (*l*), **Na_2O_2** (*s*)

- Hydrogen, when in a compound or ion, nearly always has oxidation number +1 (exception: hydrides)

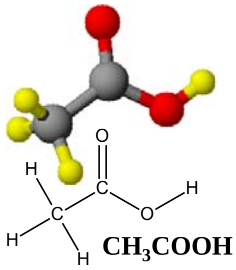
  HCl (*l*), **H_2SO_3** (*aq*), **CH_3COO^-** (*aq*); Exceptions: **CaH_2** (*s*), **NaH** (*s*)

Practice with oxidation numbers

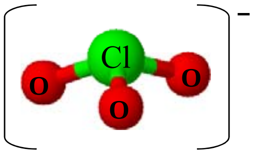
Identify oxidation numbers for each atom



Cl_2 (*g*)



CH_3COOH (*aq*)



ClO_3^- (*aq*)

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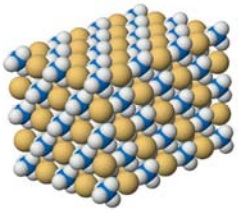
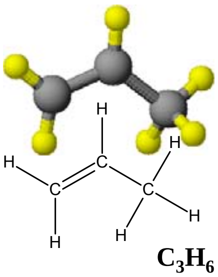
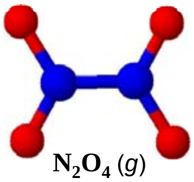


NH_4Cl (*s*)



C_3H_6 (*g*)



N_2O_4 (*g*)

Clicker question #3

What is the oxidation number of S in H_2SO_3?

(A) -2

(B) 0

(C) +1

(D) +4

(E) +5

Redox Reactions

Macroscopic View

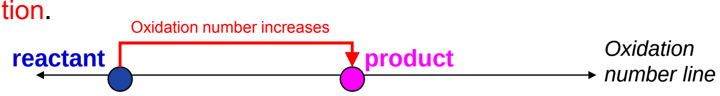
- Two distinct changes occur (*e.g.*, a new solid forms and a new ionic species appears in solution)
- Two half-reactions can be separated in such a way as to produce electrical current
- Some examples
  - Iron (III) oxide + aluminum (thermite reaction) http://www.jce.divched.org/JCESoft/CCA/samples/cca7thermite.html
  - Sodium + chlorine http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA0/Movies/NACL1.html
  - Magnesium + carbon dioxide http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA0/MOVIES/MAGCO2.html

Redox Reactions

Particle Level

- Process involved in a redox reaction is electron transfer
- Electron is transferred from a "donor" to an "acceptor"
- Electrons are negatively charged
- When the "acceptor" receives the electron, its oxidation number decreases (because electrons are negative). This part of the process is called reduction.

- When the "donor" loses the electron, its oxidation number increases (because electrons are negative). This part of the process is called oxidation.



- The two parts of the process can only happen simultaneously, but they can be separated so that the electrons must travel through a wire.

Redox Reactions

Symbolic Representation

Thermite reaction: Iron (III) oxide + aluminum

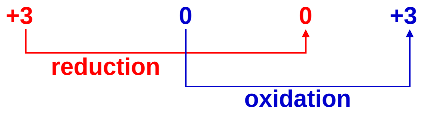
http://www.jce.divched.org/JCESoft/CCA/samples/cca7thermite.html

$$\mathbf{Fe_2O_3}\ (s) + \mathbf{Al}\ (s) \rightarrow ?$$

+3 -2 0

What are the products?

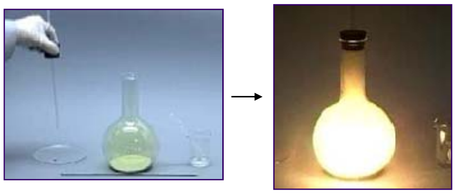
$$\mathbf{Fe_2O_3}\ (s) + \mathbf{Al}\ (s) \rightarrow \mathbf{Fe}\ (s) + \mathbf{Al_2O_3}\ (s)$$



- Fe_2O_3 gets reduced to Fe metal. It gets reduced by Al. Therefore, Al is the reducing agent.
- Al metal gets oxidized to Al_2O_3. It gets oxidized by Fe_2O_3. Therefore, Fe_2O_3 is the oxidizing agent.

Redox Reactions

Symbolic Representation



http://jchemed.chem.wisc.edu/JCESoft/CCA/CCA0/Movies/NACL1.html

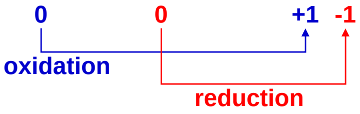
Sodium + chlorine

$\mathbf{Na}\ (s) + \mathbf{Cl_2}\ (g) \rightarrow ?$

0 0

What are the products?

$2\ \mathbf{Na}\ (s) + \mathbf{Cl_2}\ (g) \rightarrow 2\ \mathbf{NaCl}\ (s)$



- Cl_2 gas gets reduced to Cl^- ions in NaCl crystals. It gets reduced by Na metal. Therefore, Na metal is the reducing agent.
- Na metal gets oxidized to Na^+ ions in NaCl crystals. It gets oxidized by Cl_2 gas. Therefore, Cl_2 gas is the oxidizing agent.

Ranking reactivity of metals with other metal cations in aqueous solution

- Called the activity series
- Metals that are higher are more reactive, *i.e.*, will react more readily than those below them
- Example: which reaction will occur?

  $Mg\ (s) + Ni^{2+}\ (aq)$

  or

  $Ni\ (s) + Mg^{2+}\ (aq)$

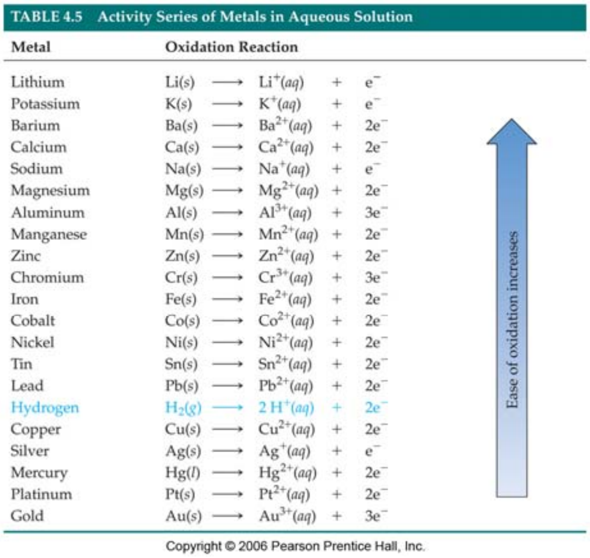


TABLE 4.5 Activity Series of Metals in Aqueous Solution

Metal	Oxidation Reaction
Lithium	$Li(s) \longrightarrow Li^+(aq) + e^-$
Potassium	$K(s) \longrightarrow K^+(aq) + e^-$
Barium	$Ba(s) \longrightarrow Ba^{2+}(aq) + 2e^-$
Calcium	$Ca(s) \longrightarrow Ca^{2+}(aq) + 2e^-$
Sodium	$Na(s) \longrightarrow Na^+(aq) + e^-$
Magnesium	$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^-$
Aluminum	$Al(s) \longrightarrow Al^{3+}(aq) + 3e^-$
Manganese	$Mn(s) \longrightarrow Mn^{2+}(aq) + 2e^-$
Zinc	$Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^-$
Chromium	$Cr(s) \longrightarrow Cr^{3+}(aq) + 3e^-$
Iron	$Fe(s) \longrightarrow Fe^{2+}(aq) + 2e^-$
Cobalt	$Co(s) \longrightarrow Co^{2+}(aq) + 2e^-$
Nickel	$Ni(s) \longrightarrow Ni^{2+}(aq) + 2e^-$
Tin	$Sn(s) \longrightarrow Sn^{2+}(aq) + 2e^-$
Lead	$Pb(s) \longrightarrow Pb^{2+}(aq) + 2e^-$
Hydrogen	$H_2(g) \longrightarrow 2\,H^+(aq) + 2e^-$
Copper	$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$
Silver	$Ag(s) \longrightarrow Ag^+(aq) + e^-$
Mercury	$Hg(l) \longrightarrow Hg^{2+}(aq) + 2e^-$
Platinum	$Pt(s) \longrightarrow Pt^{2+}(aq) + 2e^-$
Gold	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^-$

Another example: silver and copper

Which reaction will occur, based on the metal activity series?

$Ag\ (s) + Cu^{2+}\ (aq)$ or $Ag^{+}\ (aq) + Cu\ (s)$

http://media.pearsoncmg.com/ph/esm/esm_brown_chemistry_10/irc/Chapter_04/Present/eMedia_Library/Movies/Chapter_04/Present/eMedia_Library/FormationofSilverCrystals/FormationofSilverCrystals.html

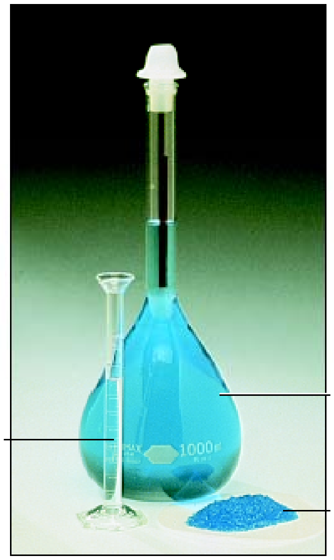
$Ag^{+}\ (aq) + Cu\ (s) \rightarrow Cu^{2+}\ (aq) + Ag\ (s)$ [note: not balanced]

Solution Concentration

- Many reactions of interest occur in aqueous solution
- To be able to quantify how much of a chemical reacts, and how much product is made, it is necessary to know quantities in moles
- In pure materials, the concentration of particles can be presented as density
- In mixtures that are aqueous solutions, the concentration of the particles of interest (solute) is usually presented as molarity
- Concentration just means how many particles (of interest, i.e., solute) are present in a given amount of space (in this case volume of solution)
- Since Molarity = moles solute / Liter of solution, if you know the molarity and the volume of solution, you can find the moles of solute

How to Calculate Concentration of a Solution

Copper (II) sulfate solution has 25.0 g of $CuSO_4 \bullet 5H_2O$ (FW 250. g/mol) included in a total of 1.00 L of solution



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Need to know:

- Amount of solute (in mol)
- Amount of solution (in L)

$$\text{Molarity} = \frac{mol \text{ of solute}}{L \text{ of solution}}$$

$$= \frac{\left(25.0\ g \times \frac{1\ mol}{250.\ g}\right)}{1.00\ L}$$

$$= 0.100 \frac{mol}{L} = 0.100\ M$$

Variations on the Theme

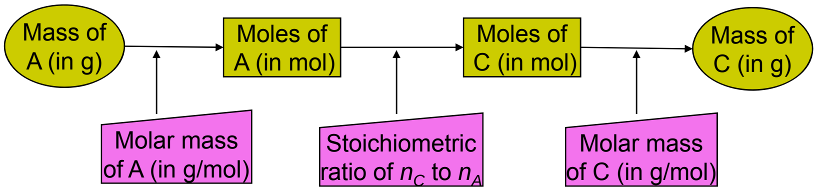
- Three variables:
  - Concentration of solution (molarity)
  - Amount of solute (moles or grams)
  - Volume of solution (liters)
- Given any two, you can always calculate the third. Examples of how problems might be phrased:
  - What is the concentration *(M?)* of a solution made by mixing ... *(solute amount)* into water to make a *(certain number of liters)* of solution?
  - How much solute *(grams?)* would be required to make *(certain number of liters)* of a *(specific concentration)* molar solution?
  - What volume *(L or mL?)* of a *(specific concentration)* molar solution must be used to obtain *(solute amount)*?

Reminder: Stoichiometry

$$n_A\,\mathrm{A} + n_B\,\mathrm{B} \rightarrow n_C\,\mathrm{C} + n_D\,\mathrm{D}$$

A typical scenario

Given mass of chemical A, find mass that could be produced of chemical C.



Mass of A (in g) → Moles of A (in mol) → Moles of C (in mol) → Mass of C (in g)

Molar mass of A (in g/mol)

Stoichiometric ratio of n_C to n_A

Molar mass of C (in g/mol)

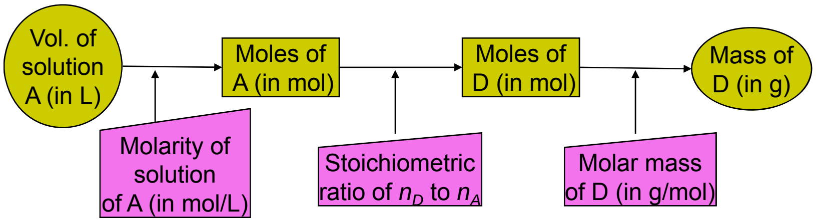
$$\text{mass of A (in } g) \times \frac{1\,mol\ \text{A}}{\text{molar mass of A}\,(g)} \times \frac{n_C\ mol\ \text{C}}{n_A\ mol\ \text{A}} \times \frac{\text{molar mass of C}\,(g)}{1\,mol\ \text{C}} = \text{mass of C (in } g)$$

Same Idea for Solution Stoichiometry

$$n_A\,\mathrm{A}\,(aq) + n_B\,\mathrm{B}\,(aq) \rightarrow n_C\,\mathrm{C}\,(aq) + n_D\,\mathrm{D}\,(s)$$

A typical scenario

Given volume of a certain molar solution of chemical A, find mass that could be produced of chemical D.



Vol. of solution A (in L) → Moles of A (in mol) → Moles of D (in mol) → Mass of D (in g)

Molarity of solution of A (in mol/L)

Stoichiometric ratio of n_D to n_A

Molar mass of D (in g/mol)

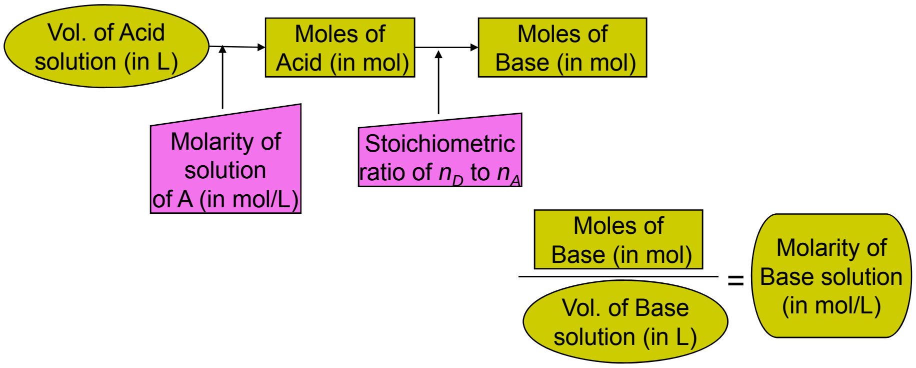
$$\text{volume of solution of A (in } L) \times \frac{\text{molarity of solution A}\,(mol)}{1\,L} \times \frac{n_D\ mol\ \text{D}}{n_A\ mol\ \text{A}} \times \frac{\text{molar mass of D}\,(g)}{1\,mol\ \text{D}} = \text{mass of D (in } g)$$

Acid-Base Titration

n_A Acid (aq) + n_B Base $(aq) \rightarrow n_S$ Salt (aq) + n_W H_2O (l)

A typical scenario

Given volume of a certain molar solution of Acid, find concentration of the Base solution if certain volume of Base used.



Vol. of Acid solution (in L)

Moles of Acid (in mol)

Moles of Base (in mol)

Molarity of solution of A (in mol/L)

Stoichiometric ratio of n_D to n_A

Moles of Base (in mol) / Vol. of Base solution (in L) = Molarity of Base solution (in mol/L)

What we've learned today

1. How to assign oxidation numbers to each element in a chemical reaction
2. Exchange reactions have no oxidation number changes, redox reactions do
3. Reduction is a change where the oxidation number of an element decreases in going from reactant to product
4. Oxidation is a change where the oxidation number of an element increases in going from reactant to product
5. Some metals are more reactive (active) than others
6. Metals can be ordered according to their relative reactivity
7. The metal activity ordering/ranking can be used to predict whether a given metal and a different metal cation will react together or not
8. Molarity of a solution = (moles of solute) / (liters of solution)
9. If you know any two of these quantities, you can calculate the third
10. You can also use molarity in stoichiometry calculations for reactions that occur in aqueous solutions

Two example problems

We will begin with these at the next lecture. I include them here so that you can read them and give them a try over the weekend

a) The following chemical reaction takes place in solution:

$$2\ AgNO_3\ (aq)\ +\ Cu\ (s)\ \rightarrow\ Cu(NO_3)_2\ (aq)\ +\ 2\ Ag\ (s)$$

If you used 34.2 mL of 0.100 M $AgNO_3$ solution, how many grams of copper metal would react?

Example problem (b)

Solid sodium hydroxide absorbs moisture from the air, so it is difficult to weigh accurately to make a solution of known concentration. Potassium hydrogen phthalate, or KHP (m.w. 204.23), is monoprotic, can be weighed accurately, and is often used to standardize solutions of bases. 0.05182 grams of KHP are placed in a flask beneath a buret filled with NaOH solution of unknown concentration. If 23.4 mL of NaOH solution are required to exactly neutralize the KHP solution, what is the concentration of the NaOH solution?