# Reactions in Solution

Ions in Aqueous Solution. (theory developed by Arrhenius)

Ionic solids (some, not all) dissolve in water creating freely floating ions in solution. The ions can move under an applied electric current. The positive ions move towards the negative electrode and the negative ions move towards the positive electrode. Substances that dissolve in water to give an electrically conductive solution are called *electrolytes*. Ionic substances that dissolve in water are, in general, electrolytes.

Not all electrolytes are ionic substances. Acids are electrolytes and are, when they are not dissolved in water, molecular substances.

*Non-electrolytes* are substances that do not form electrically conducting solutions when dissolved in water. Most molecular substances are non-electrolytes.

Electrolytes:

Strong vs. Weak

An electrolyte is *strong* if it dissociates completely into ions in an aqueous solution.

An electrolyte is *weak* if it does not dissociate completely into ions in an aqueous solution.

Strong Electrolytes

$NaCl$, $HCl$, $HNO_3$,

Weak Electrolytes

$NH_3$, $HC_2H_3O_2$

Molecular and Ionic Equations.

Molecular Equations: A chemical equation in which all species are written as if they are molecular substances.

Complete Ionic Equation: A chemical equation where:

a. molecular substances are written as molecules
b. strong electrolytes are written as separated ions
c. weak electrolytes are written as molecular substances.

Net Ionic Equations: An ionic equation in which spectator ions have been canceled.

*Spectator ions*: An ion that does not take part in the reaction.

Types of Chemical Reactions:

1. Precipitation reactions. Two solutions form a solid
2. Acid-base reactions. Involve the transfer of a proton.
3. Oxidation-reduction reactions. Involve the transfer of electrons.

Precipitation Reactions: In order to know what, if anything, will precipitate, we need to know which substances are soluble and which are not.

Solubility Rules:

1. All ionic compounds of Group IA metals, Ammonium, acetate, and Nitrate are soluble.
2. All Halide compounds ($Cl^-$, $Br^-$, $I^-$) are soluble unless combined with $Ag^+$, $Pb^{2+}$, $Hg_2^{\ 2+}$.
3. Most sulfate compounds are soluble except when combined with $Ca^{2+}$, $Sr^{2+}$, $Ba^{2+}$, $Ag^+$, $Pb^{2+}$, $Hg_2^{\ 2+}$.
4. Most carbonates, phosphates, and sulfides are INSOLUBLE, except Rule 1.
5. Most hydroxides are insoluble except Group IA, $Ca^{2+}$, $Sr^{2+}$, $Ba^{2+}$.

*Precipitate*: an insoluble compound formed during a chemical reaction in solution.

Precipitation reactions are known as double displacement reactions, Metathesis reactions, or exchange reactions. In this type of reaction the cations and anions switch partners.

Acid-Base reactions:

Properties

Acids: Taste sour, turn litmus red
Bases: Taste bitter, turn litmus blue.

*Litmus* is a type of chemical known as an indicator. Indicators are dyes which change color under acidic or basic environments.

Definitions (Arrhenius):

Acid: A substance that produces $H^+$ when dissolved in water.
Base: A substance that produces $OH^-$ when dissolved in water.

Bronsted-Lowry

Acid: a substance that acts as a proton donor.
Base: a substance that acts as a proton acceptor.

Strong and weak acids and bases:

Acids:

Strong: dissociates completely when dissolved in water.
Weak: doesn't

Strong acids:

$HClO_4$,$HClO_3$, $H_2SO_4$, HI, HBr, HCl, $HNO_3$

Weak acids:

anything that isn't strong.

Bases:

Strong: present entirely as ion, one of which is $OH^-$.
Weak: only partially ionized in water.

Strong bases:

LiOH, NaOH, KOH, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

Weak bases:

$NH_3$

Neutralization reactions: Reaction between an acid and a base that results in an ionic compound and possible water. The ionic compound produced is known as a *salt*.

Acid-Base reactions with gas formation.

Certain substances, when they react with acids, produce gases. Compounds of carbonates, sulfites and sulfides all do this.

Carbonates react with acids to produce carbon dioxide.

$$2\ HCl\ (aq) + Na_2CO_3\ (aq) \rightarrow 2\ NaCl\ (aq) + H_2O\ (l) + CO_2\ (g)$$

Sulfites react with acids to produce sulfur dioxide

$$2\ HCl\ (aq) + Na_2SO_3\ (aq) \rightarrow 2\ NaCl\ (aq) + H_2O\ (l) + SO_2\ (g)$$

Sulfides react with acids to produce hydrogen sulfide.

$$2\ HCl\ (aq) + Na_2S\ (aq) \rightarrow 2\ NaCl\ (aq) + H_2S\ (g)$$

Oxidation-Reduction reactions (REDOX) :

Oxidation-reduction reactions occur when an electron is transferred from one species to another.

*Oxidation Numbers* are a means of keeping track of where the electrons are going.

Rules for assigning oxidation numbers.

1. The oxidation number of an atom in an element is zero.

2. The oxidation number of an atom in an ionic compound is equal to its charge.

3. The oxidation number of oxygen is -2. Exceptions: In peroxides it is -1 and in compounds with fluorine it is +1.

4. The oxidation number of hydrogen is +1 unless it is combined with at metal then it is -1.

5. The oxidation number of fluorine in its compounds is -1. The oxidation number of other halogens is -1 unless it is combined with oxygen or fluorine.

6. The sum of the oxidation numbers in a compound must equal zero. In polyatomic ions it must equal the charge on the ion.

Terminology of oxidation-reduction reactions.

Half-reaction: one of the two parts of an oxidation-reduction reaction. One half-reaction involves a loss of electrons. The other involves the gain of electrons.

Oxidation: loss of electrons (increase in oxidation number)

Reduction: gain of electrons (decrease in oxidation number)
Oxidizing agent: the species that is reduced.

Reducing agent: the species that is oxidized.

Types of oxidation-reduction reactions:

- Combination
- Decomposition
- Displacement
- Combustion

Combination reactions: two or more substances react to form one substance

$A + B \rightarrow C$ ($2\ Na + Cl_2 \rightarrow 2\ NaCl$)

Decomposition reactions: One substance reacts to produce two or more substances.

$A \rightarrow B + C$ ($KClO_3 \rightarrow KCl + O_2$)

Displacement reactions: An atom takes the place of another atom in a substance.

$A + BC \rightarrow AC + B$ ($Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$)

Combustion: A substance reacts with oxygen.

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Balancing redox reactions:

1. Write the skeletal equation. This is an unbalanced equation that shows the species being oxidized and reduced and whether the solution is acidic or basic. Writing the skeletal equation involves identifying any spectator ions present and removing them.

2. Assign oxidation number to all atoms to determine what is being oxidized and what is being reduced.

3. Split the skeletal equation into two half-reactions. One half-reaction shows what is being oxidized and one half-reaction that shows what is being reduced.

4. Complete and balance each half-reaction.
   a. Balance all atoms except O and H.

   b. Balance O by adding water.

   c. Balance H.

      i. In acid by adding $H^+$.
      ii. In base:
         a. Count the number of H needed.
         b. Add that number of waters to the side needing H
         c. Add the same number of $OH^-$ to the opposite side.

5. Combine the two half-reactions into a single balanced equation.

   a. Multiply each half-reaction by the number of electrons in the other half-reaction.

   b. Simplify the balanced equation by canceling species that appear on both sides of the equation and reduce coefficients to smallest whole numbers.

6. To get complete chemical equation, add the spectator ions back in. Double check to make sure that the equation is balanced.

Solutions.

*Solvent* is the substance that does the dissolving. Usually present in the larger amount.

*Solute* is the substance that is dissolved. Usually present in the smaller amount.

In solutions involving water, water is usually the solvent, even if it is present in the smaller amount.

*Concentrated* means having a large amount of solute in the solution.

*Dilute* means having a small amount of solute in the solution.

Both terms are relative to the substance being discussed. A substance with a large solubility will require a larger amount of solute to be concentrated. A substance with a small solubility will require a smaller amount of solute to be concentrated.

*Solubility* is the maximum amount of solute that will dissolve in a given volume of solvent.

Commercially, a solution is termed concentrated when the solution is at the solubility limit.

We can quantify all of this by using concentration units. The unit used most in chemistry is called *molarity* or the *molar concentration*. The symbol for molarity is M and is defined as the number of moles of solute in one liter of solution.

$$\text{Molarity (M)} = \frac{\text{moles of solute}}{\text{liters of solution}}$$

This concentration unit is just a conversion factor that allows us to convert between the volume of a solution and the number of moles of solute present in that solution or vice versa. Giving the volume of a solution and the concentration of that solution will allow you to calculate the moles of reactant for use in stoichiometry problems.

**Dilution of solutions**

"the solution to pollution is dilution" Not exactly true. Some pollutants are dangerous in the environment even in very small amounts.

When solutions are diluted the number of moles of solute remains the same. Only the volume of the solution changed (by adding water). Because the moles of solute remain the same we can start with:

initial moles of solute = final moles of solute

This can be rewritten as:

initial molarity $\times$ initial volume = final molarity $\times$ final volume.

Three of these values will always be given.

**Quantitative analysis**

Gravimetric. (measure mass) In gravimetric analysis reacting the solute with another substance and weighing the solid product that is produced determines a solution's concentration. The reaction is carried out such that the solute that is being sought is the limiting reactant.

Example:

A 50.00 mL sample of water is analyzed for its Lead(II) ion content. The sample of water is treated with an excess of Sodium Chloride solution. The solid precipitate has a mass of 153.8 mg when dried. What is the molar concentration of Lead(II) ions in the solution?

Answer:

We first need to have a balanced chemical equation.

$$Pb^{2+}\,(aq) + 2\,NaCl\,(aq) \rightarrow PbCl_2\,(s) + 2\,Na^{+}\,(aq)$$

We can now do the math:

$$\frac{153.8\text{ mg }PbCl_2}{50.00\text{ mL sol'n}} \times \frac{1\text{ mol }PbCl_2}{278.10\text{ g }PbCl_2} \times \frac{1\text{ mol }Pb^{2+}}{1\text{ mol }PbCl_2} = 0.01106\text{ M }Pb^{2+}$$

Volumetric. (measure volume) In volumetric analysis a solutions concentration is determined by reacting the solution with another solution and an indication that shows when the reaction is complete. Knowing the volume of the original solution and the volume and concentration of the reacting solution allows you to calculate the concentration of the original solution. This process is called a titration. This method is used to determine the concentration of acid and base solutions.

Example:

What is the molar concentration of a solution of nitric acid if 25.00 mL of the acid required 35.22 mL of 0.1376 M Calcium Hydroxide solution for complete neutralization?

Answer:

$$2\,HNO_3\,(aq) + Ca(OH)_2\,(aq) \rightarrow Ca(NO_3)_2\,(aq) + 2\,H_2O\,(l)$$

$$\frac{35.22\text{ mL }Ca(OH)_2}{25.00\text{ mL }HNO_3} \times \frac{0.1376\text{ mol }Ca(OH)_2}{1\text{ L }Ca(OH)_2} \times \frac{2\text{ mol }HNO_3}{1\text{ mol }Ca(OH)_2} = 0.3877\text{ M }HNO_3$$