Ch. 7 – Reactions in Aqueous Solutions

Precipitation Reaction: A reaction where a solid is formed upon the mixing of two aqueous solutions.

Precipitate: The solid that is formed in a precipitation reaction.

Dissolving of Ionic Compounds in Water: The polar characteristics of water molecules are sufficiently strong enough to dissociate (pull apart) many ionic compounds by the process of hydration. The negative end of the water molecule is attracted to the positively charged cation while the positive end of the water molecule is attracted to the negatively charged anion. The numerous water-to-ion attraction forces eventually overcome the strong cation-to-anion attraction forces. As the ions separate, more water molecules cluster around and encircle the ions forming a hydration shell. The ions move about in solution surrounded by this hydration shell of water molecules.

Strong Electrolyte: An ionic compound that completely dissociates into its constituent ions when dissolved in water.

Salt: An ionic compound.

Solubility: The degrees to which a solid dissolves in water.

Soluble Solid: A solid which readily dissolves in water. Almost all the solid dissolves. To the naked eye, the solid seems to completely disappear.

Insoluble Solid (Slightly Soluble Solid): A solid which barely dissolves in water. The amount of solid that dissolves in so negligible that it is undetectable to the naked eye.

Acid (Arrhenius Acid): A substance that produces hydrogen ions (H^+) when it dissolves and dissociates in water.

e.g., $HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$

Base (Arrhenius Base): A substance that produces hydroxide ions (OH^-) when it dissolves and dissociates in water.

e.g., $NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$

Strong Acid: An acid which almost completely dissociates in water.

Strong Base: A base which almost completely dissociates in water.

Acid-Base Reaction (Neutralization Reaction): A reaction where an Arrhenius acid reacts with and neutralizes an Arrhenius base, vice versa. The hydrogen ion (H^+) from the acid combines with the hydroxide ion (OH^-) from the base to form a water molecule.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

e.g., $HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$

General Rules for the Solubility of Ionic Compounds in Water

Note: In the event of a conflict, Rule 1 usually overrides all other rules.

1. Most salts containing the alkali metals (Li^+, Na^+, Cs^+, and Rb^+) and ammonium (NH_4^+) are soluble.

2. Most nitrate (NO_3^-), acetate ($C_2H_3O_2^-$), chlorate (ClO_3^-), and perchlorate (ClO_4^-) salts are soluble.

3. Most chloride (Cl^-), bromide (Br^-), and iodide (I^-) salts are soluble. Notable exceptions are salts containing the ions Ag^+, Cu^+, Pb^{2+}, and Hg_2^{2+}.

4. Most sulfate (SO_4^{2-}) salts are soluble. Notable exceptions are salts containing the ions Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}, and Hg_2^{2+}.

5. Most hydroxide (OH^-) salts are only slightly soluble. Notable exceptions are salts containing the ions Ca^{2+}, Sr^{2+}, and Ba^{2+}.

6. Most carbonate (CO_3^{2-}), phosphate (PO_4^{3-}), sulfite (SO_3^{2-}), chromate (CrO_4^{2-}), arsenite (AsO_3^{3-}), and arsenate (AsO_4^{3-}) salts are only slightly soluble.

7. Most sulfide (S^{2-}) salts are only slightly soluble. Notable exceptions are those salts containing alkaline earth metals (Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, and Ba^{2+}).

Steps for Predicting and Writing Reactions in Aqueous Solutions:

1. List the constituent ions in the reactants. All ionic compounds, acids, and bases existent as an aqueous solutions dissociate into their constituent cations and anions.

2. Predict and write the chemical formulas for the possible products that could form from the constituent ions in the reagent solutions.

(a) The possible products must have cations combining with anions and form different compounds than the original reactants. The net charge of the possible products must be zero.

(b) Hydrogen ions (H^+) and hydroxide ions (OH^-) will always combine to form water.

3. Use the solubility rules to predict whether the possible products other than water are soluble or insoluble. The insoluble products are precipitates.

4. Write a complete chemical equation with products indicating all physical states. If none of the possible products is a precipitate or water, then ***no reaction*** has occurred.

Note: If no reaction occurs, do no write a complete chemical equation with products. Write "No Reaction" or "No Rxn".

(a) The insoluble products (precipitates) are solids.

(b) The soluble products are aqueous solutions.

(c) Water is a liquid.

6. Balance and write the final chemical equation.

Ex 7.1: Complete and balance the following reactions. If no reactions occurs, write "No Rxn".

(a) $AgNO_3(aq) + Na_2S(aq) \rightarrow$

(b) $Ba(OH)_2(aq) + HBr(aq) \rightarrow$

(c) $KCl(aq) + Pb(NO_3)_2(aq) \rightarrow$

(d) $HC_2H_3O_2(aq) + Ag_2SO_4(aq) \rightarrow$

(e) $Ca(OH)_2(aq) + H_3AsO_4(aq) \rightarrow$

Molecular Equation: A chemical equation which shows the molecular formulas and physical states of all the reactants and products.

e.g., $Pb(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow PbSO_4(s) + 2NaNO_3(aq)$

Complete Ionic Equation: A chemical equation which shows the constituent ions of all soluble ionic compounds in a chemical reaction as distinct reactants and products.

e.g., $Pb^{2+}(aq) + 2NO_3^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2Na^+(aq) + 2NO_3^-(aq)$

Spectator Ions: Ions in chemical reaction which do not directly undergo chemical change. In a complete ionic equation, these ions are present as both a distinct reactant and a distinct product.

e.g., Na^+, NO_3^-

Net Ionic Equation: A chemical equation which shows only those ions which undergo chemical change. The spectator ions are not included.

e.g., $Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(aq)$

Ex 7.2: Write the balanced molecular, complete ionic, and net ionic equations, and list all spectator ions for the following reactions.

(a) $Mg(OH)_2(aq) + H_2S(aq) \rightarrow$

(b) $H_2SO_4(aq) + Ca(OH)_2(aq) \rightarrow$

Oxidation-Reduction (Redox) Reactions: Chemical reactions involving the transfer of electrons between reactant atoms. An atom of one reactant donates electrons to an atom of a different reactant.

Note: Any reaction which is not an acid-base or precipitation reaction is an oxidation-reduction reaction.

Predicting Simple Oxidation-Reduction Reactions:

Combustion:

A vigorous exothermic oxidation-reduction reaction that takes place when certain substances react with oxygen gas (assumed excess unless otherwise indicated). For all reactants containing the following elements, each element will react with oxygen generating the corresponding gaseous product.

Element	Product
C	$CO_2(g)$
H	$H_2O(g)$
N	$NO_2(g)$
S	$SO_2(g)$
O	None

Ex 7.3: Complete and balance the following reactions.

(a) $S_8(s) + O_2(g) \rightarrow$

(b) $C_8H_{10}N_2O_4(l) + O_2(g) \rightarrow$

Metals and Nonmetals:

An oxidation-reduction reaction where a metal element reacts with a nonmetal element. The metal element loses electrons forming a cation while the nonmetal element gains electrons forming an anion. The cation and anion then combine to form a solid ionic compound.

e.g., $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$

Note; Each calcium atom loses 2 electrons to form the ion Ca^{2+} while each oxygen atom gains 2 electrons to form the ion O^{2-}. To balance the equation, 2 calcium atoms must react with 1 oxygen molecule. This requires that a total of 4 electrons be transferred from calcium atoms to oxygen atoms. The reaction mechanism showing the individual reaction steps is as follows.

e.g., $2Ca(s) \rightarrow 2Ca^{2+}(s) + 4e^-$ donating electrons
$O_2(g) + 4e^- \rightarrow 2O^{2-}$ accepting electrons
$2Ca^{2+}(s) + 2O^{2-}(g) \rightarrow 2CaO(s)$ ionic bonding

$2Ca(s) + O_2(g) \rightarrow 2CaO(s)$

Ex 7.4: Complete and balance the following reactions.

(a) $Mg(s) + F_2(g) \rightarrow$

(b) $K(s) + N_2(g) \rightarrow$

Classifying Chemical Reactions: All chemical reactions can be classified as one or more different reaction types. Every reaction will be at least one of the following types: precipitation, acid-base, or oxidation-reduction.

Other Types of Chemical Reactions:

Combustion Reaction: An oxidation-reduction reaction where oxygen is a elemental reactant.

e.g., $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$

e.g., $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

Synthesis (Combination) Reaction: A reaction where a complex compound is formed from elements and/or simpler compounds (*many → one*).

e.g., $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$

e.g., $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

e.g., $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

Decomposition Reaction: A reaction where a complex compound is broken down into elements and/or simpler compounds (*one → many*).

e.g., $2CaO(s) \rightarrow 2Ca(s) + O_2(g)$

e.g., $2NO_2(g) \rightarrow 2NO(g) + O_2(g)$

e.g., $NH_4Cl(s) \rightarrow NH_3(g) + HCl(g)$

Single-Displacement Reaction: A reaction where an atom from an element displaces an ion in a compound. The products will always be an ionic compound and an element.

General Form: **A + BX → AX + B**

Some Common Single-Displacement Reactions:

(1) A metal displaces hydrogen from either water or an acid.

e.g., $2Al(s) + 6H_2O(g) \rightarrow 2Al(OH)_3(s) + H_2(g)$

e.g., $Ba(s) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2(g)$

(2) A metal displaces a metal cation in an ionic compound.

e.g., $Ca(s) + Mg(OH)_2(aq) \rightarrow Ca(OH)_2(aq) + Mg(s)$

(3) A halogen displaces a halide anion in an ionic compound.

e.g., $2KBr(aq) + Cl_2(aq) \rightarrow Br_2(aq) + 2KCl(aq)$

Double-Displacement (Double-Decomposition, Metathesis, or Methathetical) Reaction: A reaction where an atom or ion from one compound displaces an ion from another compound. At least one of the reactants and one of the products must be an ionic compound, acid, or water.

General Form: **AX + BY → AY +BX**

Some Common Double-Displacement Reactions:

(1) Two aqueous ionic compounds react producing a precipitate.

e.g., $KBr(aq) + AgNO_3(aq) \rightarrow AgBr(s) + KNO_3(aq)$

(2) An ionic compound reacts with acid producing a precipitate.

e.g., $NaF(s) + H_2SO_4(aq) \rightarrow NaHSO_4(s) + HF(aq)$

(3) An acid neutralizes a base producing water.

e.g., $3HCl(aq) + Al(OH)_3(aq) \rightarrow 3H_2O(l) + AlCl_3(aq)$

(4) A covalent compound reacts with water producing an acid.

e.g., $SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq)$

(5) An ionic compound reacts with a covalent compound producing another ionic compound and covalent compound.

e.g., $3AgF(s) + PCl_3(l) \rightarrow 3AgCl(s) + PF_3(g)$

(6) A carbonate or sulfite compound reacts with an acid producing water and either carbon dioxide or sulfur dioxide gas.

e.g., $MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + O_2(g)$

e.g., $Na_2SO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + SO_2(g)$

Note: The carbonate and sulfite reactions have three different products which does not fit the general form of a double-displacement reaction (AX + BY → AY +BX). These reactions generate H_2CO_3 and H_2SO_3 as intermediate products which are chemically unstable and immediately decompose into water and carbon dioxide or water and sulfur dioxide. The reaction mechanisms with the intermediate products are as follows.

e.g.,

$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2CO_3(aq)$
$H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$

$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$

e.g.,

$Na_2SO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2SO_3(aq)$
$H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$

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