Reactions in Aqueous Solution
Chapter 7 Notes

Section 7.1 and Section 7.2

Reactions most vital to our existence occur in water—AQUEOUS SOLUTION

Chapter Seven focuses on these types of reactions.

Section 7.1—Predicting if a Reaction will Occur

Why does a reaction occur?
What causes reactants to "want" to form products?

Several tendencies indicate a reaction will progress from reactants to products.

These tendencies are:

1. Formation of a Solid
2. Formation of Water
3. Formation of a Gas
4. Transfer of Electrons

These are considered "driving forces" behind why chemical reactions occur.
The reason for these "driving forces" is the achievement of lower energy. This is an area that can be studied for months itself, for now; just know that the driving forces are creating more stable compounds- those with less energy.

Section 7.2—Reactions in Which a Solid Forms

The formation of a solid is known as PRECIPITATION.

The solid formed is known as the PRECIPITATE.

Reactions in which a solid is formed are known as PRECIPITATION REACTIONS.

First we have to know what is occurring in the solution.

- When ionic compounds are added to water (aqueous solution) the ions are free to move around separate from each other. For example. $Ba(NO_3)_2$ (aq) is really Ba^{2+} (aq) and 2 NO_3^{1-} (aq). When an ionic compound behaves in this manner it is known as a STRONG ELECTROLYTE.
- When two aqueous solutions are mixed together all the ions present come into contact with each other.
- New compounds can be formed.

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To determine if a new compound will be formed, several areas must be looked at:

Determining Possible Products--

- Cations cannot create compounds with other Cations!
- Anions cannot create compounds with other Anions!
- The only possible way for new compounds to be made is an exchange. For Example: Compound A is made of Cation A and Anion A, Compound B is made of Cation B and Anion B. If Compound A and Compound B are put together in aqueous solution the only possible products are the compound made from Cation A and Anion B and Cation B with Anion A.

Determining the properties of the New products—

- If new products are also ionic compounds that act as strong electrolytes, that is they completely dissolve in water, leaving separate ions, **then no reaction occurs**.
- If one or more of the products formed is not soluble in water, it will precipitate out of solution as a solid, **a reaction obviously has occurred**.
- SOLUBILITY RULES allow you to predict if a reaction will occur.

    - Nitrate (NO_3^{1-}) containing compounds are soluble.
    - Sodium (Na^{1+}), potassium (K^{1+}), ammonium (NH_4^{1+}) containing compounds are soluble.
    - Chloride (Cl^{1-}) containing compounds are soluble, EXCEPT: AgCl, $PbCl_2$ and Hg_2Cl_2.
    - Sulfate (SO_4^{2-}) containing compounds are soluble, EXCEPT: $BaSO_4$, $PbSO_4$, $CaSO_4$.
    - Hydroxide (OH^{1-}) containing compounds are NOT soluble, EXCEPT: NaOH and KOH, $Ba(OH)_2$ and $Ca(OH)_2$ are moderately soluble.
    - Sulfide (S^{2-}), carbonate (CO_3^{2-}), and phosphate (PO_4^{3-}) are NOT soluble.

Overall Steps to Predict Precipitates when Two Ionic Compound Solutions are Mixed.

1. Write the reactants as they occur in aqueous solution (show separate ions).
2. Predict possible products (exchange anions). Remember ZERO NET CHARGE
3. Use SOLUBILITY RULES to determine if any precipitates form.
4. You can then write and balance an overall equation for the reaction.

Example: Aqueous silver nitrate is mixed with aqueous potassium chloride, determine if a reaction occurs and if so, write the correct formulas (including state of matter) and balance the overall equation for the reaction.

1. $Ag^+ + NO_3^- + K^+ + Cl^-$
2. Possible products: AgCl and KNO_3
3. Solubility rules tell that KNO_3 is soluble, but AgCl is NOT Soluble.
4. Overall reaction is $AgNO_3 (aq) + KCl (aq) \rightarrow AgCl (s) + KNO_3 (aq)$

Types of Equations for Describing Precipitation Reactions

Section 7.3 in the textbook focuses on the three ways to describe Precipitation Reactions. These descriptions take the form of three different types of chemical equations. You are currently familiar with only one way to write chemical equations.

1. **Molecular Equation**: shows the complete formulas for all reactants and all products. This type of equation does not give a clear picture of what is actually happening in the reaction. This is the type of equation that you have been taught so far.

   Example: $AgNO_3$ (aq) + KCl (aq) → AgCl (s) + KNO_3 (aq)

2. **Complete Ionic Equation**: all substances that are strong electrolytes (those that dissolve in water) are represented as ions, not as complete molecules. This more accurately represents what is occurring on the molecular level in the reaction.

Example: Ag^+(aq)+ NO_3^-(aq) + K^+(aq)+ Cl^-(aq)→ AgCl (s) + K^+ (aq)+ NO_3^- (aq)

3. **Net Ionic Equation**: only the substances directly involved with the reaction are listed in the equation. This type of equation focuses on the actual chemical change taking place and does not include those chemical present but not taking place in the reaction. This type of equation is most often used by chemists.

   Example: Ag^+(aq) + Cl^-(aq)→ AgCl (s)

- **Spectator Ions**: These are the ions that are present during a precipitation reaction, but do not take place in the reaction. In the above example, NO_3^- and K^+ ions are present both on the reactant side and the product side (look at the complete ionic equation for the reaction). This means that those two ions do NOT undergo any chemical change! Therefore there was not a chemical reaction involving these two ions. They can be left out of the reaction and the important information about the reaction can still be obtained.

Example/Practice Problems:

A solution of Lead nitrate is added to a solution of Sodium sulfate, predict if a precipitation reaction occurs, and then write and balance the molecular equation, complete ionic equation and net ionic equations for the reaction.

Do the same for the following combinations of chemicals:

- a solution of Barium nitrate combined with a solution of sodium chloride
- Sodium sulfide solution mixed with copper (II) nitrate solution
- Ammonium chloride solution added to a solution of lead (II) nitrate

Reactions in Aqueous Solution that form Water

Section 7.4 in the textbook outlines the key points of reactions that involve strong acids and strong bases.

Some Definitions First

ACIDS:

- first associated with sour taste of citrus fruits
- a substance that produces H^+ ions when it is dissolved in water
- STRONG ACIDS are those acids that completely dissolve in water leaving no intact acid molecules. For example HCl is a strong acid, if 100 molecules of HCl are dissolved in water, 100 H^+ ions are present and 100 Cl^- ions are present.

BASES:

- associated with a bitter taste and slippery (soapy) feel
- sometimes called alkalis
- a substance that produces OH^- ions when it is dissolved in water
- STRONG BASES are those bases that completely dissolve in water leaving no intact base molecules. For example NaOH is a strong base, if 100 molecules of NaOH are dissolved in water, 100 Na^+ ions are present and 100 OH^- ions are present.

A man named Arrhenius, in the late 1800's, described the essential nature of acids and bases (the donation of either H^+ ions or OH^- ions from acids and bases respectively).

Arrhenius Acid- donates H^+ ions

Arrhenius Base- donates OH^- ions

Reacting Strong Acids and Strong Bases

When a strong acid react with a strong base, the driving force for the reaction is the formation of water. Water is a very stable chemical and therefore the creation of water will cause a reaction to happen (driving force/ natural tendency).

HCl (aq) + NaOH (aq) $\rightarrow$ HOH (l) + NaCl (aq)

HOH is the same as H_2O, you may write it either way. Writing it as HOH may help you to see what is happening in the reaction a bit better than H_2O.

The H^+ ions have a strong affinity for the OH^- ions because their combination forms water and the formation of water is a driving force or natural tendency that will cause a reaction to occur.

The other product in the reaction of a strong acid and a strong base is an ionic salt. This salt may stay dissolved in solution (as NaCl does in the example) or may precipitate out of solution.

The behavior of the salt is determined using the solubility rules that were learned earlier in this chapter.

These types of reactions can be describe in the same three ways a precipitation reaction can be described, Molecular Equations, Complete Ionic Equations and Net Ionic Equations.

Net ionic equations for all reactions between a strong acid and a strong base will be the same. H^+ (aq) + OH^- (aq) → HOH or H_2O (l)

The following are strong acids and bases- learn them!

Strong Acids

HCl, HBr, HI, H_2SO_4, HNO_3

Strong Bases

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

Reactions in Aqueous Solution that Result from the Transfer of Electrons

Section 7.5 in the textbook outlines the key points of reactions that involve the transfer of electrons.

OXIDATION-REDUCTION REATION- A reaction that involves the transfer of electrons

At the most basic this type of reaction involves metals reacting with nonmetals.

EXAMPLE:

$2Na + Cl_2 \rightarrow 2NaCl$

Actually sodium is losing one electron to become the Na^+ ion and chlorine is gaining an electron to become the Cl^- ion. The opposite charges attract and cause the strong bond between the two atoms.

The exchange of electrons is the driving force for the reaction.

Reactant(s) are uncharged atoms, the product(s) contain ions.

The reactants do not have to be only elements:

EXAMPLE:

$2Al + Fe_2O_3 \rightarrow 2Fe + Al_2O_3$

Aluminum initially has no charge, iron has a charge
As products, aluminum has a charge and iron does not
Therefore, electrons have been exchanged; Aluminum lost 3 electrons, iron gained 3 electrons.

Electron transfer can also occur between two nonmetals

This type of reaction is not discussed in detail at this time, maybe later in the year if we get to it, or definitely if you take Chemistry II.

For now know that the presence of O_2 (g) as either a reactant or a product is an indication of an oxidation-reduction reaction, as these reactions will result in the transfer of electrons.

EXAMPLES:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ or $SO_2 + O_2 \rightarrow SO_3$

It should be noted that when two nonmetals react in an oxidation-reduction reaction the product is not an ionic compound.

Oxidation-Reduction Reactions are also known as REDOX Reactions.

Lots of Ways to Classify Reactions

Sections 7.6 and 7.7 in the textbook focus on multiple ways to classify reactions.

We have already discussed ways to describe three types of reactions:

1. Reactions driven by the formation of a solid = precipitation reactions
2. Reactions driven by the formation of water = acid-base or neutralization reactions
3. Reactions driven by the transfer of electrons = oxidation-reduction or redox reactions

The fourth driving force we mentioned at the beginning of chapter seven was the formation of gas. This force is often not alone in causing a reaction to happen.

Consider the following example taken from the text:

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

This reaction is driven by the formation of a gas --- Carbon dioxide and is also driven by the formation of water. Because this reaction has H^+ ions that form water this reaction can be classified as an acid-base reaction.

It is this type of reaction that allows Calcium carbonate or calcium bicarbonate to neutralize the acid in your stomach. Consider this reaction:

$2HCl\ (aq) + CaCO_3\ (aq) \rightarrow CO_2\ (g) + H_2O\ (l) + CaCl_2\ (aq)$

In this reaction, the stomach acid is neutralized into water, calcium chloride and carbon dioxide. Can you think of a possible side effect of taking an antacid that contains calcium carbonate as the neutralizing agent as compared to magnesium hydroxide?

Answer: the reaction utilizing calcium carbonate produces gas as a byproduct, the magnesium hydroxide does not. You will burp with the calcium carbonate remedy, you will probably not burp with the magnesium hydroxide version.

Another reaction that results in the formation of a gas is given by the example:

$Zn\ (s) + 2\ HCl\ (aq) \rightarrow H_2\ (g) + ZnCl_2\ (aq)$

Hydrogen gas formation is one driving force for the reaction; however a closer examination provides a second driving force also. The second driving force for the reaction of zinc with hydrochloric acid is the transfer of electrons, aka a redox reaction.

There are also additional ways to classify reactions. A worksheet handout in class will show the breakdown and explain each one in detail also.

1. **Combustion reactions** are a specialized version of an oxidation-reduction reaction. This special form of redox reaction always involves the reaction of a carbon containing compound with oxygen gas to form carbon dioxide and water. A combustion reaction can also be described as any reaction that involves oxygen as one of the reactants that yields water and often a flame due to the rapid release of energy. These reactions also usually involve the exchange of electrons and therefore are also redox reactions.

2. **Synthesis (or Combination) reactions** are any reaction where elements are combined into compounds. That is to say that simple components are put together to make more complex species. Many of these reactions involve oxygen as a reactant and could be classified as combustion reactions because of this fact. Most of these reactions can also be classified as redox reactions as the combination of elements to compounds usually results in the transfer of electrons.

3. **Decomposition reactions** are those reactions that break down compounds into their component elements. These reactions often require energy for the reaction to occur. They can be considered to be the opposite of synthesis reactions. Many are again also classified as redox reactions.

4. **Single displacement reactions** are those reactions that can be summarized by the generic equation $A + BC \rightarrow B + AC$. These reactions are also often redox reactions as they involve elements becoming ions and ions becoming elements.

5. **Double displacement reactions** are those reactions that can be summarized by the generic equation $AB + CD \rightarrow CB + AD$. Often precipitation reactions and acid-base reactions can also be classified as double displacement reactions.