ROUND 6

Formation of a Molecular Species *(Weak or Nonelectrolytes)*

Metathesis reactions that produce primarily molecules in the form of partially dissociated or ionized molecules (weak electrolytes) or molecules that do not ionize or dissociate at all (nonelectrolytes) serve as the driving force in some aqueous reactions. Forming molecular products in double replacement reactions results in the removal of ions from solution. Such reactions tend to go to completion (shift to the right) and form primarily products.

Simplified list of rules:

A. The common strong acids and thus strong electrolytes are $HClO_4$, $HClO_3$, HCl, HBr, HI, HNO_3, and H_2SO_4. (Memorize these seven strong acids!) All other common acids are weak acids and thus weak electrolytes (CH_3COOH, H_3PO_4, HF, and HNO_2 are examples of weak acids. (*Note:* All organic acids (R–COOH) are weak electrolytes.) All strong acids in their pure form (as opposed to dilute aqueous form) are nonelectrolytes (molecular). When water is added, the action of the solvent water with a strong acid produces a hydrated proton (hydronium ion) and a negatively charged anion. The process of making ions from molecular species is known as ionization. Strong acids ionize 100% in water. An example of a strong electrolyte undergoing ionization is as follows:

$$HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$$

This reaction may be abbreviated as:

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

B. The common strong bases are the soluble hydroxides (those of Group IA elements and Ba^{2+}) and the slightly soluble hydroxides (those of Ca^{2+} and Sr^{2+}). Strong bases, like strong acids, are strong electrolytes. Memorize the strong bases! NH_4OH is a soluble weak electrolyte which normally decomposes into $NH_3(g)$ and HOH(l). Technically speaking, the pure compound ammonium hydroxide has never been isolated and the substance is more correctly known as aqueous ammonia. Most other hydroxides are insoluble. Pure *liquid* hydroxides are strong electrolytes because they already contain ions. The action of the solvent water releasing the ions of a base into solution is known as dissociation. Acids ionize in water; bases dissociate!

C. Most common (soluble) salts are strong electrolytes and thus dissociate into ions when placed in water.

D. Water is a weak electrolyte which is typically produced in acid–base neutralization reactions.

Some Examples of Weak Electrolytes Forming as Products (shown in bold):

$$Ca(CH_3COO)_2(aq) + 2HCl(aq) \longrightarrow CaCl_2(aq) + \mathbf{2CH_3COOH(aq)}$$

$$2Na_3PO_4(aq) + 3H_2SO_4(aq) \longrightarrow 3Na_2SO_4(aq) + \mathbf{2H_3PO_4(aq)}$$

$$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + \mathbf{HOH(l)}$$

Acid–Base Neutralization Reactions

Acids react with bases to produce salts and water. One mole of hydrogen ions will react with one mole of hydroxide ions to produce one mole of water. Learn which acids are strong acids (written in ionic form) and which are weak acids (written in molecular form). Check the solubility rules for the solubility of the salt produced. If it is soluble, it is written in ionic form; if it is insoluble it is written in molecular form. This will be covered further in Chapter 10.

$$\textbf{Acid} + \textbf{Base} \longrightarrow \textbf{Salt} + \textbf{Water}$$

(A salt consists of a cation from a base and an anion from an acid. e.g., the salt sodium sulfate contains sodium ions from sodium hydroxide and sulfate ions from sulfuric acid.)

Example 1: Hydrogen sulfide gas is bubbled through excess potassium hydroxide solution.

$$H_2S(g) + 2KOH(aq) \longrightarrow K_2S(aq) + 2HOH(l)$$

Polyprotic acids can be tricky when it comes to predicting neutralization reactions. Sulfuric acid and phosphoric acid are classic examples frequently encountered on AP Examinations. If the base is in excess, all hydrogen ions will react with strong base to produce water.

Example 2: Dilute sulfuric acid is reacted with excess sodium hydroxide.

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2HOH(l)$$

If, however, the reaction in Example 2 stated that equal numbers of moles of sulfuric acid and sodium hydroxide react, then the coefficients for both reactants must be one and the salt that forms is sodium hydrogen sulfate.

Example 3: Equal number of moles of sulfuric acid and sodium hydroxide react.

$$H_2SO_4(aq) + NaOH(aq) \longrightarrow NaHSO_4(aq) + HOH(l)$$

Take into account information dealing with the quantity of each reactant.

Example 4: Equal volumes of 0.1 M phosphoric acid and 0.2 M sodium hydroxide are reacted together.

$$H_3PO_4(aq) + 2NaOH(l) \longrightarrow Na_2HPO_4(aq) + 2HOH(l)$$

Watch for substances that react with water before reacting with an acid or a base. The acid and basic anhydrides covered in Chapter 7 behave in such a manner. These are really two-step reactions.

Example 5: Excess sulfur dioxide gas is bubbled into a saturated solution of calcium hydroxide.

$$SO_2(g) + Ca(OH)_2(aq) \longrightarrow CaSO_3(s) + HOH(l)$$

(Remember, $SO_2(g)$ is an acid anhydride)

If an acid + base yields a salt + water, then an **acid anhydride + basic anhydride will yield a salt.**

Example 6: Sulfur dioxide gas and solid calcium oxide are reacted together.

$$SO_2(g) + CaO(s) \longrightarrow CaSO_3(s)$$

(*Note:* $SO_2(g)$ is the acid anhydride for sulfurous acid and CaO(s) is the basic anhydride for calcium hydroxide.)

Exercise 9–3: Predict and balance the following reactions. Use the abbreviations (s), (l), (g), and (aq) for the reactants and products. All reactants are aqueous unless otherwise stated.

1. carbon dioxide gas is bubbled through a solution of lithium hydroxide

2. sodium nitrite is reacted with hydrochloric acid

3. ammonium bromide + sodium hydroxide

4. carbon dioxide gas is reacted with solid potassium oxide

5. solid magnesium oxide is reacted with hydrochloric acid

6. equal numbers of moles of potassium hydroxide and phosphoric acid react

7. sodium fluoride reacts with dilute nitric acid

8. ammonium carbonate + potassium bromide

9. oxalic acid (0.1 M) reacts with an equal volume of cesium hydroxide (0.1 M)

10. silver nitrate + sodium chromate