ELEMENTS OF CHEMICAL CHANGE II

8. ACIDS AND BASES

a. Classical Acid–Base Theory.

(1) Acids.

Arrhenius defined an acid as a compound that donates protons (H+) in solution.

Examples:

$$HCl \xrightarrow{HOH} H^+ + Cl^-$$

$$H_2SO_4 \xrightarrow{HOH} H^+ + HSO_4^-$$

NOTE: The HOH (H2O), which indicates that water is the solvent in these reactions.
Both HCl and H2SO4 contribute protons in solution.

(2) Bases.

Arrhenius defined a base as any compound that donates hydroxyl (OH–) ions in solution.

Examples:

$$NaOH \xrightarrow{HOH} Na^{+} + OH^{-}$$

$$KOH \xrightarrow{HOH} K^{+} + OH^{-}$$

(3) Discussion.

- These classical definitions are based on the dissociation of the compounds into ions in solution.
- This implies that all acids and bases must contain exchangeable hydrogen and hydroxyl ions, respectively, in their formulas.
- This theory did explain the majority of the compounds known at the time, but there were some exceptions.

(3) Discussion. (continued.)

- Chemists knew, for example, that metal oxides (MgO, CaO, etc.) dissolved in water exhibited base-like properties.
- Also, ammonia (NH_3) in solution exhibited the properties of a base.
- The attempts to explain these exceptions led to new definitions of acids and bases.

b. Modern Acid-Base Theory.

- In 1923, Bronsted and Lowry, two chemists in different countries, independently derived new definitions of acids and bases to explain the exceptions to the classical theory.
- The new theory they developed was named, appropriately, the Bronsted-Lowry theory.
- This theory differs from the classical theory in that the dissociation of water is considered as well as the dissociation of the compound.

(1) Dissociation of water.

- Even though we often think of water as merely being an inert solvent, it does dissociate into ions.

$$H_2O \rightleftharpoons H^+ + OH^-$$

- This is an equilibrium type reaction as indicated by the double arrow.
- Actually, very few ions exist at any time since they rapidly recombine to form molecular water.

(2) Bronsted-Lowry acid.

- By the Bronsted-Lowry theory, an acid is any compound (charged or uncharged) capable of donating a proton.
- This is essentially the same as the classical definition.

(3) Bronsted-Lowry base.

- The real value of the Bronsted-Lowry theory is in the definition of a base.
- A base is defined as a charged or uncharged substance capable of accepting a proton.
- Generally, the proton a base accepts comes from the dissociation of water.

(a) Consider, for example, ammonia dissolved in water:

$$NH_3 + H_2O \rightleftharpoons NH_3 + H^+ + OH^- \rightleftharpoons NH_4^+ + OH^-$$

- By accepting a proton from water, ammonia has effectively increased the concentration of hydroxyl ions in the solution.
- This would account for the properties like those of a classical base.

(b) A second example would be magnesium oxide dissolved in water.

$$MgO + H_2O \rightleftharpoons MgOH^+ + OH^-$$

- By accepting a proton from water, magnesium oxide has likewise increased the concentration of hydroxyl ions in the solution.

- The two theories explain all the properties of acids and bases that will be utilized in medicine.

c. Properties of Acids.

(1) Acids change blue litmus paper to red.
Litmus paper, which contains dyes sensitive to hydrogen ion concentration, turns red when there is a high concentration, blue when there is a low concentration.

(2) Acids have a sour taste.
This property is familiar to you if you have ever tasted a lemon. Lemons contain citric acid, which gives them their sour taste.

(3) Acids react with metals to release hydrogen gas. For example:

$$Zn + 2H^{+} \dashrightarrow Zn^{++} + H_2$$

(4) Acids react with carbonates and bicarbonates to form carbon dioxide. For example:

$$CaCO_3 + 2HCl \dashrightarrow CaCl_2 + H_2O + CO_2\uparrow$$

(5) Acids react with bases to form salts and water (neutralization reaction).
For example:

$$\underset{}{HCl} + NaOH \text{ -------> } \underset{\text{(salt)}}{NaCl} + H_2O$$

d. Properties of Bases. In the same manner that all acids had certain properties in common, all bases have related properties. The ones that are important to the medical personnel are as follows:

(1) Bases change red litmus paper to blue. This is just the opposite of the change which acids cause in litmus paper.

(2) Bases possess a bitter taste and feel soapy when in contact with the skin.

(3) Bases react with acids to form salts and water (neutralization reaction).

e. Classification of Acids and Bases.

(1) Some acids and bases dissociate more readily than others when placed in solution. Those that dissociate at a rate greater than 50 percent are considered to be strong acids or bases. Weak acids and bases dissociate at a rate that is less than 50 percent. Examples:

(a) When hydrochloric acid (HCl) is placed in solution, most of the molecules will dissociate to form free H^+ ions and Cl^- ions. Hydrochloric acid is therefore considered a strong acid.

(b) When carbonic acid (H2CO3) is placed in solution, less than 50% will ionize into free H+ ions and HCO3- ions. Most of the molecules will remain in molecular form.

$$H_2CO_3 \xrightarrow{HOH} H^+ + HCO_3 \longrightarrow H_2CO_3$$

(2) This means one mole (gram molecular weight) of HCl will produce more hydrogen ion in solution than will one mole of H2CO3 and will consequently exhibit acidic properties to a greater degree than will carbonic acid. A simpler way to say this is that HCL is a stronger acid than H2CO3.

(3) The same rationale holds for bases as well as acids. Therefore, we can divide or classify acids or bases into groups based on their dissociation--strong acids or bases (those that dissociate completely) and weak acids or bases (those that dissociate to a small degree).

f. Acids and Bases of Medicinal Importance.

- One may come in contact with a number of important acids and bases.
- You must be able to identify them as acids or bases and know their relative strengths.
- There is not an easy way to differentiate between strong and weak acids, but strong and weak bases can be differentiated based on valence.
- Strong bases have a positive valence of one; weak bases have a positive valence greater than one.

Relative strength of common acids and bases

STRONG ACIDS		WEAK ACIDS	
HCl	Hydrochloric acid	$HC_2H_3O_2$ (HAC)	Acetic acid
H_2SO_4	Sulfuric acid	H_2CO_3	Carbonic acid
H_3PO_4	Phosphoric acid	H_3BO_3	Boric acid

STRONG BASES		WEAK BASES	
KOH	Potassium hydroxide	$Fe(OH)_2$	Ferrous hydroxide
$NaOH$	Sodium hydroxide	$Al(OH)_3$	Aluminum hydroxide
		NH_3	Ammonia

* $Ca(OH)_2$	Calcium hydroxide
$Mg(OH)_2$	Magnesium hydroxide
MgO	Magnesium oxide

Relative strength of common acids and bases

g. Safety and Antidotes.

- Acids and bases should be handled with care to avoid spilling on skin.
- They should not be taken internally unless intended for that purpose.
- If the skin is exposed to these compounds or is ingested, the following antidotes are recommended for first aid treatment.

(1) Acids.

(a) External. Use large amounts of water to wash acids off the skin. Exception: If phenol (an organic acid) is spilled on the skin, wash off with alcohol.

(b) Internal. Give an antacid, other than a carbonate or bicarbonate, such as milk of magnesia or magnesium oxide. DO NOT give an emetic or induce vomiting.

(2) Bases.

(a) External. Wash the area with large amounts of water.

(b) Internal. Give a weak acid such as vinegar or fruit juice. Weak acids (or weak bases) are only effective if administered within 10–15 minutes of ingestion of strong base (or strong acid). DO NOT give an emetic or induce vomiting.

9. SALTS

- Salts are the third major classification of inorganic compounds (acids and bases being the first two).
- They are important in the physiology of the body and are often used as therapeutic agents.

a. Definition.

- Product of a reaction between an acid and a base.
- A more specific definition, however, would be an ionic compound formed by the replacement of part or all of the acid hydrogen of an acid by a metal or a radical acting like a metal.
- It is an ionic compound that contains a positive ion other than hydrogen and a negative ion other than hydroxyl (OH^-) or "O^{-2} ," as in MgO.

b. Types of Salts

There are four types of reactions possible between acids and bases as we classified them (strong or weak) earlier. These are as follows:

(1) Strong acid and strong base.

HCl+ NaOH ---> NaCl + H2O

(2) Weak acid and weak base.

$$2H_2CO_3 + Fe(OH)_2 \text{ ---> } Fe(HCO_3)_2 + 2H_2O$$

(3) Strong acid and weak base.

$$2HCl + Fe(OH)_2 \text{ -----> } FeCl_2 + 2H_2O$$

(4) Weak acid and strong base.

$$H_2CO_3 + NaOH \text{ -----> } NaHCO_3 + H_2O$$

c. Determination of Salt Type.

Example. $Al_2(SO_4)_3$.

(1) The first element, aluminum, comes from the base Al(OH)3. Since it has a valence of +3, it is a weak base.

(2) The sulfate radical comes from H2SO4, sulfuric acid, which is a strong acid.

(3) This compound is an acidic salt since it is the product of a reaction between a strong acid and a weak base.

Example. $FeBO_3$.

(1) The first element, iron, comes from the base Fe(OH)3, and since its valence is +3, it is a weak base.

(2) The borate radical comes from boric acid, which is a weak acid.

(3) Thus, this is a neutral salt, since it is the product of a reaction between a weak acid and a weak base.

d. Importance of Type of Salt.

- The type of salt is very important when a salt is used medicinally, since the body maintains a specific acidity in the tissues and fluids.
- The type of salt is also important in the prediction and understanding of incompatibilities.
- It is important for you to identify the type of salt from its formula.

REACTANTS---> ↓	WEAK ACID	STRONG ACID
WEAK BASE	Neutral Salt	Acidic Salt
STRONG BASE	Basic Salt	Neutral Salt

Salt types resulting from various acid-base combinations.

10. pH AND ACIDITY

- In discussing acids, bases, and salts, we often refer to a solution or compound being acidic, neutral, or basic in a qualitative manner.
- This concept is useful to us in a general sense, but would be of much greater value if we could speak in quantitative terms.
- It would be valuable if we could answer the question of how acidic one solution is in relation to another solution.

a. pH.

Acids donate protons (hydrogen ions, H +) in solution. Thus, the acidity of a solution must be related to this property.

(1) In fact, the acidity of a solution is the concentration of hydrogen ions in that solution. Since we can calculate the hydrogen ion concentration, we can now determine a numerical value of the acidity of a solution. The concentrations of hydrogen ions in both acidic and basic solutions are generally very small.

A strong solution of HCl, for example, may contain only 0.01 mole of hydrogen ions per liter of solution.

A solution of NaOH may have as little as 0.0000000001 mole of hydrogen ion per liter of solution.

(2) To simplify the expression of such terms, chemists have transformed the concentration values into numbers, called pH numbers, which are easier to utilize. This is done according to the following equation:

$$pH = -\log[H^+]$$

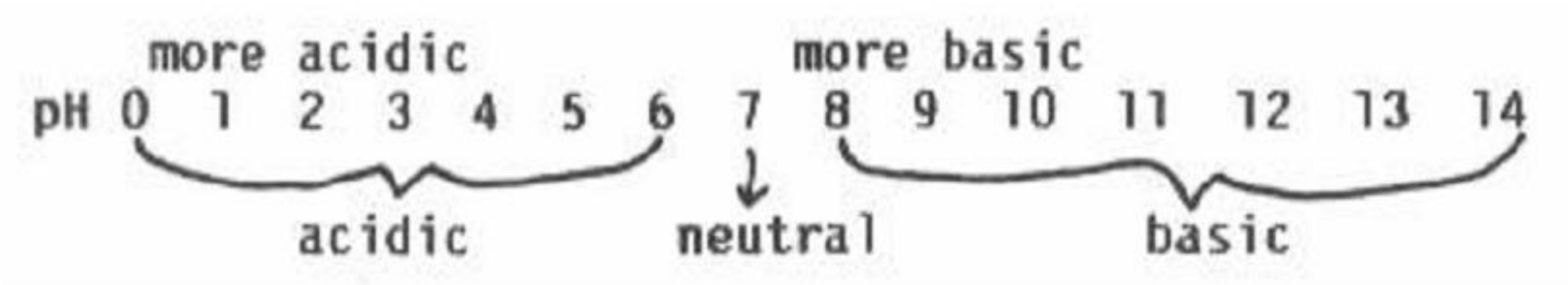
The abbreviation log stands for logarithm. (For example, log 1 = 0, log 0.1 = −1, log 0.01 = −2, log 0.001 = −3, log 0.0001 = −4.)
The expression [H+] here is the concentration of hydrogen ions in moles per liter.

b. pH Scale.

This transformation results in a range of pH numbers from 0 to 14, which is called the pH scale.

(1) The limits of the scale are related to the dissociation

(2) While you will not need to calculate a pH value, you will need to interpret what a pH value means at times. To learn this function, examine the following pH scale:



(3) A pH value less than 7.0 means the solution is acidic; the lower the number, the more acidic. A solution with a pH of 2.0 is more acidic than one with a pH of 4.0. Any pH value greater than 7.0 means the solution is basic with larger numbers indicating solutions that are more basic. The only value on the scale that indicates a neutral solution is 7.0.

The pH values for some common pharmaceutical products are given

PRODUCT	pH
Cherry Syrup	3.5 - 4
Benylin® Expectorant	5.0 - 5.5
Glycyrrhiza® Syrup	6.0 - 6.5
Iso-Alcoholic Elixir	5.0
Orange Syrup	2.5 - 3.0
Terpin Hydrate Elixir with Codeine	8.0

Thank you