Name ____________________________**Chem 163 Section**: ______ **Team Number:** ______

ALE 11. Acids, Bases, pOH and pH

(Reference: 18.1 – 18.3 Silberberg *5th edition*)

Why is baking soda basic?

The Model: Brønsted-Lowry Acids and Bases

Nitric acid satisfies the definition of an ***Arrhenius acid***, because when nitric acid dissolves in water the *concentration of aqueous hydrogen ions increases*.

$$HNO_3(l) \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$

Sodium hydroxide satisfies the definition of an ***Arrhenius base***, because when NaOH dissolves in water the *concentration of aqueous hydroxide ions increases*.

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

A more useful definition than the Arrhenius definition of an acid is the ***Brønsted-Lowry definition***, illustrated by the reversible reaction that occurs when aqueous molecules of acetic acid react with solvent molecules.

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

Acetic acid is the Brønsted-Lowry acid, and acetate is its ***conjugate base***. Water acts as a Brønsted-Lowry base, and the hydronium ion, H_3O^+, ($H_2O—H^+$ can be thought of as "solvated acidic protons" since protons are not "free" in aqueous solution) is its ***conjugate acid***. As a further illustration, consider what happens to ammonia in aqueous solution.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Here ammonia is the Brønsted-Lowry base, and the ammonium ion is its conjugate acid. Water acts as a Brønsted-Lowry acid, and hydroxide is its conjugate base.

Key Questions

1 a. Reproduced below are the reversible reactions that occur in aqueous solutions of acetic acid and ammonia, which were presented in the Model. *Circle* within each reaction all of the species that are classified as *Brønsted-Lowry acids* (according to the Model). And *underline* within each reaction all of the species that are classified as *Brønsted-Lowry bases* (according to the Model).

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

b. What do all of the Brønsted-Lowry acids have in common with each other? (*i.e.*, What defines a Brønsted-Lowry acid? *Hints*: What does each acid "do" to the second species on the same side of the reaction? How is an acid different from its conjugate base?)

A Brønsted-Lowry acid is ____

c. What do all of the Brønsted-Lowry bases have in common with each other? (*i.e.*, What defines a Brønsted-Lowry base? *Hint*: How is a base different from its conjugate acid?)

A Brønsted-Lowry base is ____

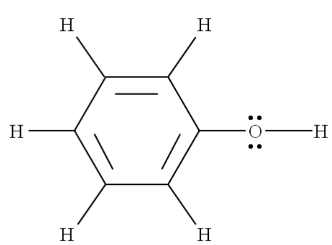
2. In addition to being a Brønsted-Lowry base, acetate is an Arrhenius base. When acetate is dissolved in water, the concentration of hydroxide is increased. Complete the following reversible reaction. *Then identify conjugate acid-base pairs*. Hint: think of water as HOH.

$$CH_3COO^-(aq) + H_2O(l) \rightleftharpoons$$

3. It is not difficult to see from the formula of acetic acid ($HC_2H_3O_2$) that it is an Arrhenius acid. And it is easy to see from the formula of sodium hydroxide (NaOH) that it is an Arrhenius base. But explain how the Brønsted-Lowry definition is superior to the Arrhenius definition in describing the acetate ion ($C_2H_3O_2^-$) as a base. (*Recall*: What is the Arrhenius definition of a base?)

4. Sodium carbonate (Na_2CO_3) is a base. Write the chemical equations that show how sodium carbonate is a (Brønsted-Lowry as well as an Arrhenius) base. (*Hints*: How can you show that the hydroxide ion concentration is increased when carbonate, CO_3^{2-}, is added to water? You will need to know that sodium is a spectator ion and that the bicarbonate ion, HCO_3^-, is a very weak acid.)

5. Phenol (C_6H_5OH) is a weak acid. Complete the reversible reaction that shows how phenol is a (Brønsted-Lowry as well as an Arrhenius) acid. *Then identify the conjugate acid-base pairs*. *Hint*: Which bond is more polar in phenol, the C—H or the O—H bond?



$+ H_2O(l) \rightleftharpoons$

6. From the reaction between acetic acid and water and the reaction between ammonia and water (question 1a), we can see that water is an **amphoteric** species. Based on how water reacts with both acetic acid and ammonia, explain what it means for a compound to be "amphoteric".

7. Through a collision, one molecule of water can donate a hydrogen cation to a neighboring water molecule:

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

$$K_w =$$

Finish the law of mass action for this reversible reaction. (The subscript "w" tells the reader that this is the **autoionization constant** for **w**ater. *Hint*: Don't forget what we learned previously about heterogeneous equilibria and the law of mass action!)

8. The value of $\boldsymbol{K_w}$ **is 1.00 × 10^{-14}** at 25 °C (the typical temperature that chemists are interested in).

   a. In pure water, the autoionization of water produces the same amount of hydronium as hydroxide ions. Use the K_w of water to calculate the $[H^+]$ in pure water at 25 °C. (NOTE: A solvated proton is actually "H_3O^+". But it is understood that water is the solvent and, therefore, the abbreviation of "H_3O^+" is "H^+".) *Circle your answer.*

   b. The **pH** of a solution is defined by the following equation: **pH = -log[H$^+$]**
   Calculate the pH of pure water at 25 °C. *Circle your answer.*

   c. The **pOH** of a solution is defined by the following equation: **pOH = -log[OH$^-$]**
   Calculate the pOH of pure water at 25 °C. *Circle your answer.*

   d. For pure water, what is the sum of the pH and pOH?

9. Consider a 0.1 *M* HCl(*aq*) solution.

   a. What is the $[H^+]$? (*Hint*: HCl is a strong acid—i.e. there is ~100% dissociation into H^+ and Cl^- ions in aqueous solution.) *Circle your answer.*

   b. What is the $[OH^-]$? (The law of mass action you discovered in Question 7 applies to all aqueous solutions at 25 °C.) *Circle your answer.*

   c. What are the pH and the pOH of a 0.1 *M* HCl(*aq*) solution? *Circle your answer.*

   d. For 0.1 *M* HCl(*aq*), what is the sum of the pH and the pOH?

   e. Compare your answer to Question 8d with your answer to Question 9d. Make an educated guess as to what the sum of pH and pOH would be for *any* aqueous solution of an acid or base.

10 a. What is the pH of a "neutral" solution (*i.e.*, one in which $[H^+] = [OH^-]$)?

   b. Relative to your answer to Question 10a, what is the pH of an "acidic" solution (*i.e.*, one in which $[H^+] > [OH^-]$)? (*Hint*: Look at your answers to Question 9, in which you were considering a hydrochloric acid solution.)

   c. If the pH range is from 0 to 14, what values of pH describes a "basic" solution (*i.e.*, one in which $[OH^-] > [H^+]$)?

11. We've seen that pH = $-\log[H^+]$. Given the pH, what formula can you use to calculate the $[H^+]$? *Hint*: What is an "antilog"? While it is not written, the logarithm is to the base 10.)

12. When the pH of a solution decreases from a pH of 11 to a pH of 8 the H_3O^+ concentration *increases* / *decreases* (circle you choice) by a factor of ______________, while the OH^- concentration *increases* / *decreases* (circle you choice) by a factor of ______________.

13. When the pH of a solution increases from a pH of 7 to a pH of 9 the H_3O^+ concentration *increases* / *decreases* (circle you choice) by a factor of ______________, while the OH^- concentration *increases* / *decreases* (circle you choice) by a factor of ______________.

Exercises

14. Complete the following table.

	Solution	$[H^+]$	$[OH^-]$	pH	pOH
a.	0.0125 *M* HNO_3				
b.	0.0037 *M* NaOH				
c.	0.70 *M* HCN (a weak acid)			4.73	
d.	0.016 *M* Aziridine, C_2H_5N (a cyclic amine—a weak base)				3.89

15. Identify (circle) the solution that has the ***higher pH***. <u>*Explain/justify your response*</u>.

a. A 0.1 *M* solution of weak acid or a 0.01 *M* solution of the same acid?

b. A 0.1 *M* solution of weak acid or a 0.1 *M* solution of a strong acid?

c. A 0.1 *M* solution of an acid or a 0.1 *M* solution of a base?

d. A solution with a pOH = 6.0 or one with a pOH = 8.0?

16. How many moles of H_3O^+ or OH^- must you add per liter of HA solution to adjust its pH from 9.33 to 9.07. Assume a negligible change in volume. Show your work.