CH 223 Spring 2024:

Problem Set #2

Instructions

Step One (all sections):

- **Learn the material** for Problem Set #2 by **reading Chapter 14 (up to 14.5) and Chapter 15 (15.2)** of the textbook and/or by watching the videos found on our website (https://mhchem.org/223)
- **Try the problems** for Problem Set #2 found on the next pages on your own first. Use separate paper and write out your answers, showing all of your work. If you write the answers on the problem set itself, you will receive fewer points. Include your name on your problem set!

Step Two:

Section 01 and H1: We will go over Problem Set #2 during recitation. ***Self correct all problems*** of your problem set before turning it in at the end of recitation.

- *Section 01:* due **Monday, April 15 at 1:10 PM**
- *Section H1:* due **Wednesday, April 17 at 1:10 PM**

Section W1: **Watch the recitation video** for Problem Set #2:

http://mhchem.org/v/n.htm

- **Self correct *all* of the problems** while viewing the video. Mark correct problems with a star (or other similar mark), and correct all incorrect problems (show the correct answer and the steps required to achieve it.)
- **Submit Problem Set #2 via email (mike.russell@mhcc.edu) as a single PDF file** (use CamScanner (https://camscanner.com), CombinePDF (https://combinepdf.com), etc.) **by 11:59 PM Wednesday, April 17.**

If you have any questions regarding this assignment, please email (mike.russell@mhcc.edu) the instructor! Good luck on this assignment!

CH 223 Problem Set #2

** Complete problem set on separate pieces of paper showing all work, circling final answers, etc.*
** Self correct your work before turning it in to the instructor.*

Covering: **Chapter Fourteen Part I** *and* **Chapter Guide Two**
Important Tables and/or Constants: The **Table of Acids and Bases for CH 223** *which follows this problem set, and* **K_w = 1.00 x 10^{-14}** at 25 °C

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1. In each of the following acid-base reactions, identify the Brønsted acid and base on the left and their conjugate partners on the right.
   a. $HCO_2H(aq) + H_2O(\ell) \rightleftharpoons HCO_2^{-1}(aq) + H_3O^{+}(aq)$
   b. $NH_3(aq) + H_2S(aq) \rightleftharpoons NH_4^{+}(aq) + HS^{-1}(aq)$
   c. $HSO_4^{-1}(aq) + OH^{-1}(aq) \rightleftharpoons SO_4^{2-}(aq) + H_2O(\ell)$
2. What are the products of each of the following acid-base reactions? Indicate the acid and its conjugate base, and the base and its conjugate acid.
   a. $HClO_4 + H_2O \rightarrow$
   b. $NH_4^{+} + H_2O \rightarrow$
3. Write balanced equations showing how the HPO_4^{2-} ion of sodium hydrogen phosphate, Na_2HPO_4, can be a Brønsted acid or a Brønsted base.
4. Several acids are listed here with their respective equilibrium constants:

$$HF(aq) + H_2O(\ell) \rightleftharpoons H_3O^{+}(aq) + F^{-1}(aq)$$

$$K_a = 7.2 \times 10^{-4}$$

$$HPO_4^{-2}(aq) + H_2O(\ell) \rightleftharpoons H_3O^{+}(aq) + PO_4^{-3}(aq)$$

$$K_a = 3.6 \times 10^{-13}$$

$$CH_3CO_2H(aq) + H_2O(\ell) \rightleftharpoons H_3O^{+}(aq) + CH_3CO_2^{-1}(aq)$$

$$K_a = 1.8 \times 10^{-5}$$

   a. Which is the strongest acid? Which is the weakest acid?
   b. What is the conjugate base of the acid HF?
   c. Which acid has the weakest conjugate base?
   d. Which acid has the strongest conjugate base?
5. For each of the following reactions, predict whether the equilibrium lies predominantly to the left or to the right. Explain your prediction briefly. *Use a table of acids and bases to answer this question.*
   a. $H_2S(aq) + CO_3^{2-}(aq) \rightleftharpoons HS^{-1}(aq) + HCO_3^{-1}(aq)$
   b. $HCN(aq) + SO_4^{2-}(aq) \rightleftharpoons CN^{-1}(aq) + HSO_4^{-1}(aq)$
   c. $SO_4^{2-}(aq) + CH_3CO_2H(aq) \rightleftharpoons HSO_4^{-1}(aq) + CH_3CO_2^{-1}(aq)$
6. A saturated solution of milk of magnesia, $Mg(OH)_2$, has a pH of 10.52. What is the hydronium ion concentration of the solution? What is the hydroxide ion concentration? Is the solution acidic or basic?

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7. The pH of a solution of $Ba(OH)_2$ is 10.66 at 25 °C. What is the hydroxide ion concentration in the solution? If the solution volume is 125 mL, how many grams of $Ba(OH)_2$ must have been dissolved?
8. An organic acid has $pK_a = 8.95$. What is its K_a value?
9. A weak base has $K_b = 1.5 \times 10^{-9}$. What is the value of K_a for the conjugate acid?
10. The ionization constant of a very weak acid, HA, is 4.0×10^{-9}. Calculate the equilibrium concentrations of H_3O^+, A^{-1} and HA in a 0.040 M solution of the acid.
11. The weak base methylamine, CH_3NH_2, has $K_b = 4.2 \times 10^{-4}$. Calculate the equilibrium hydroxide ion concentration in a 0.25 M solution of the base. What are the pH and pOH of the solution?
12. Calculate the hydronium ion concentration and pH for a 0.015 M solution of sodium formate, $NaHCO_2$. *Use a table of acids and bases to answer this question.*
13. Decide whether each of the following substances should be classified as a Lewis acid or a Lewis base.
    a. BCl_3 (Hint: draw the electron dot structure)
    b. H_2NNH_2, hydrazine (Hint: draw the electron dot structure)
    c. The reactants in the reaction:

$$Fe(s) + 5\ CO(g) \rightleftharpoons Fe(CO)_5(g)$$

Table of Acids and Bases for CH 223

Increasing Acid Strength ↑

Acid Name	Acid	K_a	Base	K_b	Base Name
Perchloric acid	$HClO_4$	large	ClO_4^-	very small	perchlorate ion
Sulfuric acid	H_2SO_4	large	HSO_4^-	very small	hydrogen sulfate ion
Hydrochloric acid	HCl	large	Cl^-	very small	chloride ion
Nitric acid	HNO_3	large	NO_3^-	very small	nitrate ion
Hydronium ion	H_3O^+	1.0	H_2O	1.0×10^{-14}	water
Sulfurous acid	H_2SO_3	1.2×10^{-2}	HSO_3^-	8.3×10^{-13}	hydrogen sulfite ion
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}	SO_4^{2-}	8.3×10^{-13}	sulfate ion
Phosphoric acid	H_3PO_4	7.5×10^{-3}	$H_2PO_4^-$	1.3×10^{-12}	dihydrogen phosphate ion
Hexaaquairon(III) ion	$[Fe(H_2O)_6]^{3+}$	6.3×10^{-3}	$[Fe(H_2O)_5OH]^{2+}$	1.6×10^{-12}	pentaaquahydroxoiron(III) ion
Hydrofluoric acid	HF	7.2×10^{-4}	F^-	1.4×10^{-11}	fluoride ion
Nitrous acid	HNO_2	4.5×10^{-4}	NO_2^-	2.2×10^{-11}	nitrite ion
Formic acid	HCO_2H	1.8×10^{-4}	HCO_2^-	5.6×10^{-11}	formate ion
Benzoic acid	$C_6H_5CO_2H$	6.3×10^{-5}	$C_6H_5CO_2^-$	1.6×10^{-10}	benzoate ion
Acetic acid	CH_3CO_2H	1.8×10^{-5}	$CH_3CO_2^-$	5.6×10^{-10}	acetate ion
Propanoic acid	$CH_3CH_2CO_2H$	1.3×10^{-5}	$CH_3CH_2CO_2^-$	7.7×10^{-10}	propanoate ion
Hexaaquaaluminum ion	$[Al(H_2O)_6]^{3+}$	7.9×10^{-6}	$[Al(H_2O)_5OH]^{2+}$	1.3×10^{-9}	pentaaquahydroxoaluminum ion
Carbonic acid	H_2CO_3	4.2×10^{-7}	HCO_3^-	2.4×10^{-8}	hydrogen carbonate ion
Hexaaquacopper(II) ion	$[Cu(H_2O)_6]^{2+}$	1.6×10^{-7}	$[Cu(H_2O)_5OH]^+$	6.3×10^{-8}	pentaaquahydroxocopper(II) ion
Hydrogen sulfide	H_2S	1×10^{-7}	HS^-	1×10^{-7}	hydrogen sulfide ion
Dihydrogen phosphate ion	$H_2PO_4^-$	6.2×10^{-8}	HPO_4^{2-}	1.6×10^{-7}	hydrogen phosphate ion
Hydrogen sulfite ion	HSO_3^-	6.2×10^{-8}	SO_3^{2-}	1.6×10^{-7}	sulfite ion
Hypochlorous acid	$HClO$	3.5×10^{-8}	ClO^-	2.9×10^{-7}	hypochlorite ion
Hexaaqualead(II) ion	$[Pb(H_2O)_6]^{2+}$	1.5×10^{-8}	$[Pb(H_2O)_5OH]^+$	6.7×10^{-7}	pentaaquahydroxolead(II) ion
Hexaaquacobalt(II) ion	$[Co(H_2O)_6]^{2+}$	1.3×10^{-9}	$[Co(H_2O)_5OH]^+$	7.7×10^{-6}	pentaaquahydroxocobalt(II) ion
Boric acid	$B(OH)_3(H_2O)$	7.3×10^{-10}	$B(OH)_4^-$	1.4×10^{-5}	tetrahydroxoborate ion
Ammonium ion	NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}	ammonia
Hydrocyanic acid	HCN	4.0×10^{-10}	CN^-	2.5×10^{-5}	cyanide ion
Hexaaquairon(II) ion	$[Fe(H_2O)_6]^{2+}$	3.2×10^{-10}	$[Fe(H_2O)_5OH]^+$	3.1×10^{-5}	pentaaquahydroxoiron(II) ion
Hydrogen carbonate ion	HCO_3^-	4.8×10^{-11}	CO_3^{2-}	2.1×10^{-4}	carbonate ion
Hexaaquanickel(II) ion	$[Ni(H_2O)_6]^{2+}$	2.5×10^{-11}	$[Ni(H_2O)_5OH]^+$	4.0×10^{-4}	pentaaquahydroxonickel(II) ion
Hydrogen phosphate ion	HPO_4^{2-}	3.6×10^{-13}	PO_4^{3-}	2.8×10^{-2}	phosphate ion
Water	H_2O	1.0×10^{-14}	OH^-	1.0	hydroxide ion
Hydrogen sulfide ion*	HS^-	1×10^{-19}	S^{2-}	1×10^5	sulfide ion
Ethanol	C_2H_5OH	very small	$C_2H_5O^-$	large	ethoxide ion
Ammonia	NH_3	very small	NH_2^-	large	amide ion
Hydrogen	H_2	very small	H^-	large	hydride ion

Increasing Base Strength ↓

*The values of K_a for HS^- and K_b for S^{2-} are estimates.