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 \( K_w = 1.00 \times 10^{-14} \) at 25 °C

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. \( \text{HCO}_2\text{H(aq)} + \text{H}_2\text{O(ℓ)} \rightleftharpoons \text{HCO}_2^-\text{(aq)} + \text{H}_3\text{O}^+(aq) \)
   b. \( \text{NH}_3\text{(aq)} + \text{H}_2\text{S(aq)} \rightleftharpoons \text{NH}_4^+(aq) + \text{HS}^-\text{(aq)} \)
   c. \( \text{HSO}_4^-\text{(aq)} + \text{OH}^-\text{(aq)} \rightleftharpoons \text{SO}_4^{2-}\text{(aq)} + \text{H}_2\text{O(ℓ)} \)

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. \( \text{HClO}_4 + \text{H}_2\text{O} \rightarrow \)
   b. \( \text{NH}_4^+ + \text{H}_2\text{O} \rightarrow \)

3. Write balanced equations showing how the \( \text{HPO}_4^{2-} \) ion of sodium hydrogen phosphate, \( \text{Na}_2\text{HPO}_4 \), can be a Brønsted acid or a Brønsted base.

4. Several acids are listed here with their respective equilibrium constants:
   \[
   \text{HF(aq)} + \text{H}_2\text{O(ℓ)} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{F}^-\text{(aq)}
   \]
   \[
   K_a = 7.2 \times 10^{-4}
   \]
   \[
   \text{HPO}_4^{2-}(aq) + \text{H}_2\text{O(ℓ)} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{PO}_4^{3-}(aq)
   \]
   \[
   K_a = 3.6 \times 10^{-13}
   \]
   \[
   \text{CH}_3\text{CO}_2\text{H(aq)} + \text{H}_2\text{O(ℓ)} \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{CH}_3\text{CO}_2^-\text{(aq)}
   \]
   \[
   K_a = 1.8 \times 10^{-5}
   \]
   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. \( \text{H}_2\text{S(aq)} + \text{CO}_3^{2-}(aq) \rightleftharpoons \text{HS}^-\text{(aq)} + \text{HCO}_3^-\text{(aq)} \)
   b. \( \text{HCN(aq)} + \text{SO}_4^{2-}(aq) \rightleftharpoons \text{CN}^-\text{(aq)} + \text{HSO}_4^-\text{(aq)} \)
   c. \( \text{SO}_4^{2-}(aq) + \text{CH}_3\text{CO}_2\text{H(aq)} \rightleftharpoons \text{HSO}_4^-\text{(aq)} + \text{CH}_3\text{CO}_2^-\text{(aq)} \)

6. A saturated solution of milk of magnesia, \( \text{Mg(OH)}_2 \), 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?

*Problem Set #2 continues on the next page*
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 p$K_a$ = 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 $4.0 \times 10^{-9}$. Calculate the equilibrium concentrations of H$_3$O$^+$, A$^{-1}$ and HA in a 0.040 M solution of the acid.

11. The weak base methylamine, CH$_3$NH$_2$, 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$_2$NNH$_2$, hydrazine (Hint: draw the electron dot structure)
   c. The reactants in the reaction:
      \[ \text{Fe}(s) + 5 \text{CO}(g) \rightleftharpoons \text{Fe(CO)}_5(g) \]
### Table of Acids and Bases for CH 223

<table>
<thead>
<tr>
<th>Acid Name</th>
<th>Acid</th>
<th>$K_a$</th>
<th>Base Name</th>
<th>$K_b$</th>
<th>Base Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitric acid</td>
<td>HNO₃</td>
<td>large</td>
<td>ClO₄⁻</td>
<td>very small</td>
<td>perchlorate ion</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>HCl</td>
<td>large</td>
<td>Cl⁻</td>
<td>very small</td>
<td>chloride ion</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>H₂SO₄</td>
<td>large</td>
<td>HSO₄⁻</td>
<td>very small</td>
<td>sulfite ion</td>
</tr>
<tr>
<td>Sulfurous acid</td>
<td>H₂SO₃</td>
<td>1.2 × 10⁻⁷</td>
<td>HSO₄⁻</td>
<td>8.3 × 10⁻¹³</td>
<td>hydrogen sulfite ion</td>
</tr>
<tr>
<td>Hydrogen sulfate ion</td>
<td>HSO₄⁻</td>
<td>1.2 × 10⁻²</td>
<td>SO₄²⁻</td>
<td>8.3 × 10⁻¹³</td>
<td>sulfate ion</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>H₃PO₄</td>
<td>7.5 × 10⁻³</td>
<td>H₃PO₄³⁻</td>
<td>1.3 × 10⁻¹²</td>
<td>dihydrogen phosphate ion</td>
</tr>
<tr>
<td>Hexaaquairon(II) ion</td>
<td>[Fe(H₂O)₆]²⁺</td>
<td>6.3 × 10⁻³</td>
<td>[Fe(H₂O)₆(OH)]²⁺</td>
<td>6.3 × 10⁻⁸</td>
<td>pentaaquahydroxoiron(II) ion</td>
</tr>
<tr>
<td>Hydroflouric acid</td>
<td>HF</td>
<td>7.2 × 10⁻⁴</td>
<td>F⁻</td>
<td>1.4 × 10⁻¹¹</td>
<td>fluoride ion</td>
</tr>
<tr>
<td>Nitrous acid</td>
<td>HNO₂</td>
<td>4.5 × 10⁻⁴</td>
<td>NO₂⁻</td>
<td>2.2 × 10⁻¹¹</td>
<td>nitrite ion</td>
</tr>
<tr>
<td>Formic acid</td>
<td>HCO₂H</td>
<td>1.8 × 10⁻⁴</td>
<td>HCO₂⁻</td>
<td>5.6 × 10⁻¹¹</td>
<td>formate ion</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>CH₃CO₂H</td>
<td>1.8 × 10⁻⁵</td>
<td>CH₃CO₂⁻</td>
<td>5.6 × 10⁻¹⁰</td>
<td>acetate ion</td>
</tr>
<tr>
<td>Propanoic acid</td>
<td>CH₃CH₂CO₂H</td>
<td>1.3 × 10⁻⁵</td>
<td>CH₃CH₂CO₂⁻</td>
<td>7.7 × 10⁻¹⁰</td>
<td>propanoate ion</td>
</tr>
<tr>
<td>Hexaquaaluminum ion</td>
<td>[Al(H₂O)₆]³⁺</td>
<td>7.9 × 10⁻⁶</td>
<td>[Al(H₂O)₆(OH)]³⁺</td>
<td>1.3 × 10⁻⁹</td>
<td>pentaaqahydroaluminum ion</td>
</tr>
<tr>
<td>Boric acid</td>
<td>B(OH)₃</td>
<td>7.3 × 10⁻¹⁰</td>
<td>B(OH)₄⁻</td>
<td>1.4 × 10⁻⁵</td>
<td>tetrahydroxoborate ion</td>
</tr>
<tr>
<td>Ammonium ion</td>
<td>NH₃⁺</td>
<td>5.6 × 10⁻⁵</td>
<td>NH₄⁺</td>
<td>1.8 × 10⁻⁵</td>
<td>ammonia</td>
</tr>
<tr>
<td>Hydrocyanic acid</td>
<td>HCN</td>
<td>4.0 × 10⁻¹⁰</td>
<td>CN⁻</td>
<td>2.5 × 10⁻⁵</td>
<td>cyanide ion</td>
</tr>
<tr>
<td>Hydroxiquiron(II)</td>
<td>[Fe(H₂O)₆]³⁺</td>
<td>3.2 × 10⁻¹⁰</td>
<td>[Fe(H₂O)₆(OH)]³⁺</td>
<td>3.1 × 10⁻⁵</td>
<td>pentaaquahydroxoiron(II) ion</td>
</tr>
<tr>
<td>Hydrogen carbonate ion</td>
<td>HCO₃⁻</td>
<td>4.8 × 10⁻¹¹</td>
<td>CO₃²⁻</td>
<td>2.1 × 10⁻⁴</td>
<td>carbonate ion</td>
</tr>
<tr>
<td>Hydroxanickel(II) ion</td>
<td>[Ni(H₂O)₆]²⁺</td>
<td>2.5 × 10⁻¹¹</td>
<td>[Ni(H₂O)₆(OH)]²⁻</td>
<td>4.0 × 10⁻⁴</td>
<td>pentaaquahydroxanickel(II) ion</td>
</tr>
<tr>
<td>Hydrogen phosphate ion</td>
<td>PHO₄³⁻</td>
<td>3.6 × 10⁻¹³</td>
<td>PO₄³⁻</td>
<td>2.8 × 10⁻¹²</td>
<td>phosphate ion</td>
</tr>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>1.0 × 10⁻¹⁴</td>
<td>OH⁻</td>
<td>1.0</td>
<td>hydroxide ion</td>
</tr>
<tr>
<td>Hydrogen sulfide ion*</td>
<td>HS⁻</td>
<td>1 × 10⁻¹³</td>
<td>S²⁻</td>
<td>1 × 10⁻⁰⁵</td>
<td>sulfide ion</td>
</tr>
<tr>
<td>Ethanol</td>
<td>C₂H₅OH</td>
<td>very small</td>
<td>C₂H₅O⁻</td>
<td>large</td>
<td>ethoxide ion</td>
</tr>
<tr>
<td>Ammonia</td>
<td>NH₃</td>
<td>very small</td>
<td>NH₂⁻</td>
<td>large</td>
<td>amide ion</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>very small</td>
<td>H⁺</td>
<td>large</td>
<td>hydride ion</td>
</tr>
</tbody>
</table>

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