INSTRUCTIONS:

- Code the answers to the True-False and Multiple-Choice questions on the scantron form. Mark A for true and B for false. There is only one correct answer for each multiple-choice question. There is no partial credit given for this section.

- Show all work on the problems section because partial credit is awarded for this section.

- Below your ID# above, answer the following question. If you could be a professional athlete, what sport would you choose? You will receive 1 bonus point.

- There are 90 points on this exam.

GOOD LUCK! ENJOY!!

PART I: True-false statements (3 points each)

1. If $K > 1$, then $\Delta G^\circ$ is positive. F

2. You prepare an CH$_3$COOH/NaCH$_3$COO buffer solution with a pH of 4.90. The solution will contain a greater concentration of CH$_3$COOH than NaCH$_3$COO. $[K_a(CH_3COOH) = 1.8 \times 10^{-5}]$ F

3. A 0.10 M NaH$_2$PO$_4$ and 0.10 M Na$_2$HPO$_4$ solution would function as a buffer solution. T

4. \[ \begin{array}{cccc} \text{F} & \text{B} & \text{F} \\ \text{F} & \end{array} \] fits the definition of a Lewis acid, but not that of a Brønsted acid. T

PART II: Multiple Choice (3 points each)

5. Which of the following has the lowest molar solubility?

<p>| | | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>[a] CaF$_2$</td>
<td>$K_{sp} = 4.0 \times 10^{-11}$</td>
<td></td>
</tr>
<tr>
<td>[b] Sr(IO$_3$)$_2$</td>
<td>$K_{sp} = 3.3 \times 10^{-7}$</td>
<td></td>
</tr>
<tr>
<td>[c] MgF$_2$</td>
<td>$K_{sp} = 6.5 \times 10^{-9}$</td>
<td></td>
</tr>
<tr>
<td>[d] PbCl$_2$</td>
<td>$K_{sp} = 1.6 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>[e] BaF$_2$</td>
<td>$K_{sp} = 1.7 \times 10^{-6}$</td>
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</tbody>
</table>

6. Which is the relationship between $K_{sp}$ and molar solubility, $x$, for Al(OH)$_3$ in water?

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<thead>
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<tbody>
<tr>
<td>[a] $K_{sp} = 3x^2$</td>
<td>[b] $K_{sp} = 3x^4$</td>
<td>[c] $K_{sp} = 9x^5$</td>
</tr>
<tr>
<td>[d] $K_{sp} = 27x^4$</td>
<td>[e] $K_{sp} = 9x^3$</td>
<td></td>
</tr>
</tbody>
</table>
7. What is the molar solubility of Pb(IO₃)₂ in water, at a temperature in which \( K_{sp} = 1.2 \times 10^{-13} \)?

[a] \( 1.2 \times 10^{-13} \) mol/L  
[b] \( 3.5 \times 10^{-7} \) mol/L  
[c] \( 5.0 \times 10^{-5} \) mol/L  
[d] \( 3.0 \times 10^{-14} \) mol/L  
[e] \( 3.1 \times 10^{-5} \) mol/L

8. What is the molar solubility of PbI₂ in a 0.10 \( M \) solution of NaI? \( [K_{sp}(PbI₂) = 7.1 \times 10^{-9}] \).

[a] \( 7.1 \times 10^{-8} \) mol/L  
[b] \( 7.1 \times 10^{-7} \) mol/L  
[c] \( 7.1 \times 10^{-9} \) mol/L  
[d] \( 3.6 \times 10^{-6} \) mol/L  
[e] \( 7.1 \times 10^{-10} \) mol/L

9. CdCO₃, a slightly soluble substance, will have the lowest solubility in which one of the following solvents or solutions?

[a] pure water  
[b] 0.20 \( M \) HCl  
[c] 0.20 \( M \) Na₂CO₃  
[d] 0.10 \( M \) Cd(NO₃)₂  
[e] 0.20 \( M \) KCl

10. Acid strength decreases in the series: HSO₄⁻ > CH₃COOH > H₂CO₃ > HCN. Which of the following is the weakest base?

[a] HCO₃⁻  
[b] CN⁻  
[c] CH₃COO⁻  
[d] SO₄²⁻  
[e] All will have the same strength.

11. Which of the following salts will produce a neutral solution when dissolved in water?

[a] LiBr  
[b] NaF  
[c] NH₄NO₃  
[d] KOH  
[e] NaCN

12. \( K_a \) for HX is \( 7.5 \times 10^{-10} \). What is the pH of a 0.15 \( M \) solution of NaX?

[a] 2.85  
[b] 4.97  
[c] 7.87  
[d] 9.03  
[e] 11.15

13. Which of the following statements are true?

I. HF is a stronger acid than HI.  
II. HClO₃ is a stronger acid than HClO.  
III. H₃PO₄ is a stronger acid than H₂SO₄.  
IV. HNO₂ is a weak acid.

[a] I and IV  
[b] II and IV  
[c] II, III, and IV  
[d] I and III  
[e] II only

14. In the reaction shown below, NH₃ is acting as a(n) _______ base.

\[\text{N}_3^\cdot + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^-\]

I. Arrhenius  
II. Brønsted-Lowry  
III. Lewis

[a] I and II  
[b] II and III  
[c] I and III  
[d] II only  
[e] I, II, and III
15. Which of the following buffers would be the best choice for preparing a pH = 4.5 buffer?

- [a] HCN/CN\(^-\), \([K_a(HCN)] = 5.0 \times 10^{-10}\)
- [b] HOCl/OCl\(^-\), \([K_a(HOCl)] = 3.5 \times 10^{-8}\)
- [c] H\(^2\)CO\(_3\)/HCO\(_3\)\(^-\) \([K_a(H\(^2\)CO\(_3\))] = 4.3 \times 10^{-7}\)
- [d] C\(_6\)H\(_5\)NH\(_2\)/C\(_6\)H\(_5\)NH\(_3\)\(^+\), \([K_b(C\(_6\)H\(_5\)NH\(_2\))] = 3.8 \times 10^{-10}\)
- [e] none of these could be used to prepare a pH = 4.5 buffer

16. Consider a solution prepared by dissolving 0.35 mol of solid CH\(_3\)NH\(_3\)\(^+\)Cl\(^-\) in 1.00 L of 1.1 M CH\(_3\)NH\(_2\) (methylamine). The \(K_b\) for methylamine is 4.4 \times 10^{-4}. If 0.01 mole of KOH is added to this buffer solution, the pH of the solution will increase slightly because the KOH reacts with CH\(_3\)NH\(_3\)\(^+\) present in solution.

- [a] decrease, CH\(_3\)NH\(_2\)
- [b] increase, CH\(_3\)NH\(_2\)
- [c] decrease, CH\(_3\)NH\(_3\)\(^+\)
- [d] increase, CH\(_3\)NH\(_3\)\(^+\)
- [e] This is a buffer solution, so the pH does not change.

17. Calculate the pH of a buffer solution prepared by dissolving 0.80 mole of cyanic acid (HCNO) and 0.20 mole of sodium cyanate (NaCNO) in enough water to make 2.0 L of solution. \([K_a(HCNO)] = 2.0 \times 10^{-4}\)

- [a] 2.85
- [b] 3.10
- [c] 3.70
- [d] 4.30
- [e] 9.70

18. Calculate the pH of the buffer in Problem 17 after 0.10 mole of KOH is added to the buffer. Assume no change in volume upon addition of the KOH.

- [a] 2.75
- [b] 3.22
- [c] 3.33
- [d] 4.07
- [e] 4.65

19. What ratio of [CH\(_3\)COOH]/[CH\(_3\)COO\(^-\)] is required to prepare a acetic acid/ sodium acetate buffer solution with a pH of 4.20? \([K_a(CH\(_3\)COOH)] = 1.8 \times 10^{-5}\)

- [a] 1.7
- [b] 0.29
- [c] 3.5
- [d] 0.58
- [e] none of these

20. How many milliliters of 1.00 M HCl will be needed to completely react with 5.00 mL of 2.00 M Ba(OH)\(_2\)?

- [a] 10.0 mL
- [b] 20.0 mL
- [c] 5.00 mL
- [d] 1.00 mL
- [e] none of these

21. Which one of the following would be the best choice as an indicator in the titration of a 0.100 M ammonia solution (NH\(_3\)) with a 0.100 M hydrochloric acid solution (HCl)?

- [a] thymol blue, \(K_a = 1.58 \times 10^{-9}\)
- [b] chlorophenol blue, \(K_a = 2.51 \times 10^{-6}\)
- [c] thymolphthalein, \(K_a = 1.26 \times 10^{-10}\)
- [d] cresol red, \(K_a = 1.26 \times 10^{-8}\)
- [e] All of these indicators would work equally well.

22. Consider the following reaction:

\[ AgBr(s) = Ag^+(aq) + Br^-(aq) \quad \Delta G^0 = +69.1 \text{ kJ} \]

Calculate \(\Delta G\) at 25°C for the reaction when \([Ag^+]\) = 1.0 \times 10^{-2} M and \([Br^-]\) = 1.0 \times 10^{-3} M. Is the reaction spontaneous or nonspontaneous at these concentrations?

- [a] \(\Delta G = 40.6 \text{ kJ}, \text{ nonspontaneous}\)
- [b] \(\Delta G = -69.1 \text{ kJ}, \text{ spontaneous}\)
- [c] \(\Delta G = 97.6 \text{ kJ}, \text{ nonspontaneous}\)
- [d] \(\Delta G = -40.6 \text{ kJ}, \text{ spontaneous}\)
- [e] \(\Delta G = -97.6 \text{ kJ}, \text{ spontaneous}\)
PART III: Problems

23. Consider the titration of 20.0 mL of 0.25 M HBr with 0.20 M KOH.

[a] What is the initial pH of the solution? (Before any KOH is added.) [2 pts]

\[ [\text{H}_3\text{O}^+] = 0.25 \, M \]
\[ \text{pH} = 0.60 \]

[b] What is the pH after the addition of 10.0 mL of KOH? [4 pts]

\[
\begin{array}{c c c}
\text{HBr} & + & \text{KOH} \rightarrow \text{H}_2\text{O} + \text{KBr} \\
\text{Initial (mol)}: & 0.0050 & 0.0020 \\
\text{Change (mol)}: & -0.0020 & -0.0020 \\
\text{Final (mol)}: & 0 & 0 \\
\end{array}
\]

\[ [\text{H}_3\text{O}^+] = \frac{0.0030 \, \text{mol}}{0.030 \, \text{L}} = 0.10 \, M \]
\[ \text{pH} = -\log(0.10) = 1.00 \]

[c] What is the pH after the addition of 25.0 mL of KOH? [2 pts]

\[
\begin{array}{c c c}
\text{HBr} & + & \text{KOH} \rightarrow \text{H}_2\text{O} + \text{KBr} \\
\text{Initial (mol)}: & 0.0050 & 0.0050 \\
\text{Change (mol)}: & -0.0050 & -0.0050 \\
\text{Final (mol)}: & 0 & 0 \\
\end{array}
\]
Equivalence point, \( \text{pH} = 7 \).

[d] What is the pH after the addition of 40.0 mL of KOH? [4 pts]

\[
\begin{array}{c c c}
\text{HBr} & + & \text{KOH} \rightarrow \text{H}_2\text{O} + \text{KBr} \\
\text{Initial (mol)}: & 0.0050 & 0.0080 \\
\text{Change (mol)}: & -0.0050 & -0.0060 \\
\text{Final (mol)}: & 0 & 0.0030 \\
\end{array}
\]
\[ [\text{OH}^-] = \frac{0.0030 \, \text{mol}}{0.060 \, \text{L}} = 0.050 \, M \]
\[ \text{pOH} = 1.30 \]
\[ \text{pH} = 12.70 \]
24. 8.26 g of a mixture containing an unknown monoprotic weak acid (HA) is titrated with 0.32 M NaOH. It takes 45.16 mL of NaOH to reach the equivalence point. Calculate the mass % of the unknown weak acid in the mixture. The molar mass of the unknown acid is 208 g. Assume that the other component of the mixture does not react with NaOH. [5 pts]

\[
\text{mass} \% \text{ acid} = \frac{\text{g acid}}{\text{g mixture}} \times 100
\]

\[
\frac{0.32 \text{ mol NaOH}}{1 \text{ L soln}} \times 0.04516 \text{ L} = 0.0145 \text{ mol NaOH}
\]

\[
0.0145 \text{ mol NaOH} \times \frac{1 \text{ mol HA}}{1 \text{ mol NaOH}} = 0.0145 \text{ mol HA}
\]

\[
0.0145 \text{ mol HA} \times \frac{208 \text{ g HA}}{1 \text{ mol HA}} = 3.006 \text{ g HA}
\]

\[
\text{mass} \% \text{ acid} = \frac{3.006 \text{ g}}{8.26 \text{ g}} \times 100 = 36.4\%
\]

25. 20.0 mL of \(1.1 \times 10^{-5} \text{ M} \) Ba(NO\(_3\))\(_2\) are added to 80.0 mL of \(8.4 \times 10^{-5} \text{ M} \) Na\(_2\)CO\(_3\)? Will a precipitate of BaCO\(_3\) form? \([K_{sp}(\text{BaCO}_3) = 8.1 \times 10^{-9}]\)

[a] Calculate the reaction quotient, \(Q\). [5 pts]

\[
\text{BaCO}_3 (s) \rightleftharpoons \text{Ba}^{2+} (aq) + \text{CO}_3^{2-} (aq)
\]

\[
Q_{sp} = [\text{Ba}^{2+}]_0[\text{CO}_3^{2-}]_0
\]

\[
[\text{Ba}^{2+}]_0: \quad M_1V_1 = M_2V_2 \\
(20.0 \text{ mL})(1.1 \times 10^{-5} \text{ M}) = (100.0 \text{ mL})M_2 \\
M_2 = 2.2 \times 10^{-6} \text{ M}
\]

\[
[\text{CO}_3^{2-}]_0: \quad M_1V_1 = M_2V_2 \\
(80.0 \text{ mL})(8.4 \times 10^{-5} \text{ M}) = (100.0 \text{ mL})M_2 \\
M_2 = 6.72 \times 10^{-5} \text{ M}
\]

\[
Q_{sp} = [\text{Ba}^{2+}]_0[\text{CO}_3^{2-}]_0 = (2.2 \times 10^{-6})(6.72 \times 10^{-5}) = 1.5 \times 10^{-10}
\]

[b] Based on your answer to part (a), will a precipitate of BaCO\(_3\) form? Yes or No. [2 pts]

\(Q < K\). The system will shift to the right to reach equilibrium. No precipitate of BaCO\(_3\) will form.
Potentially Useful Information

\[ R = 8.314 \text{ J/mol} \cdot \text{K} \]

\[ M = \frac{\text{mol solute}}{\text{L soln}} \]

\[ \text{molar mass} = \frac{\text{grams of substance}}{\text{moles of substance}} \]

A quadratic equation of the form \( ax^2 + bx + c = 0 \), has the solutions:

\[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

\[ K_c = \frac{[\text{products}]}{[\text{reactants}]} \]

\[ K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ \text{C} \]

\[ \text{pH} = -\log[\text{H}_3\text{O}^+] \]

\[ \text{pH + pOH = 14, at } 25^\circ \text{C} \]

\[ \text{pH} = \text{p}K_a + \log \left( \frac{[\text{base}]}{[\text{acid}]} \right) \]

\[ \Delta^\circ G = -RT\ln K \]

\[ \Delta^\circ G_{\text{rxn}} = \sum n\Delta^\circ G_i (\text{products}) - \sum n\Delta^\circ G_i (\text{reactants}) \]

\[ \Delta^\circ S_{\text{rxn}} = \sum n\Delta^\circ S_i (\text{products}) - \sum n\Delta^\circ S_i (\text{reactants}) \]

\[ \Delta G = \Delta G^\circ + RT\ln Q \]

\[ \Delta H_{\text{rxn}} = \sum n\Delta H_i^\circ (\text{products}) - \sum n\Delta H_i^\circ (\text{reactants}) \]

\[ \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \]

### SOLUBLE COMPOUNDS

<table>
<thead>
<tr>
<th>Compounds containing alkali metal ions (Li(^+), Na(^+), K(^+), Rb(^+), Cs(^+)) and the ammonium ion (NH(_4^+))</th>
<th>EXCEPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate (NO(_3^-)), bicarbonates (HCO(_3^-)), and chlorates (ClO(_3^-))</td>
<td>Halides of Ag(^+), Hg(_2^{2+}), and Pb(_2^{2+})</td>
</tr>
<tr>
<td>Halides (Cl(^-), Br(^-), I(^-))</td>
<td>Halides of Ag(^+), Hg(_2^{2+}), and Pb(_2^{2+})</td>
</tr>
<tr>
<td>Sulfates (SO(_4^{2-}))</td>
<td>Sulfates of Ag(^+), Ca(<em>{2+}), Sr(</em>{2+}), Ba(<em>{2+}), and Pb(</em>{2+})</td>
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</table>

### INSOLUBLE COMPOUNDS

<table>
<thead>
<tr>
<th>Carbonates (CO(_3^{2-})), phosphates (PO(_4^{3-})), chromates (CrO(_4^{2-})), and sulfides (S(_2^-))</th>
<th>EXCEPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroxides (OH(^-))</td>
<td>Compounds containing alkali metal ions and the Ba(_{2+}) ion</td>
</tr>
</tbody>
</table>