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. You prepare an CH₃COOH/NaCH₃COO buffer solution with a pH of 4.90. The solution will contain a greater concentration of CH₃COOH than NaCH₃COO. \( K_{a}(CH₃COOH) = 1.8 \times 10^{-5} \)  F

2. \( \text{F} \) fits the definition of a Lewis acid, but not that of a Brønsted acid. T

3. If \( K > 1 \), then \( \Delta G^\circ \) is positive. F

4. A 0.10 \( M \) NaH₂PO₄ and 0.10 \( M \) Na₂HPO₄ solution would function as a buffer solution. T

PART II: Multiple Choice (3 points each)

5. Acid strength decreases in the series: HSO₄⁻ > CH₃COOH > H₂CO₃ > HCN. Which of the following is the weakest base?
   \[ \text{[a]} \text{ HCO}_3^- \quad \text{[b]} \text{ CN}^- \quad \text{[c]} \text{ CH}_3\text{COO}^- \quad \text{[d]} \text{ SO}_4^{2-} \quad \text{[e]} \text{ All will have the same strength.} \]

6. Which of the following salts will produce a neutral solution when dissolved in water?
   \[ \text{[a]} \text{ LiBr} \quad \text{[b]} \text{ NaF} \quad \text{[c]} \text{ NH}_4\text{NO}_3 \quad \text{[d]} \text{ KOH} \quad \text{[e]} \text{ NaCN} \]

7. \( K_a \) for HX is 7.5 \( \times \) \( 10^{-10} \). What is the pH of a 0.15 \( M \) solution of NaX?
   \[ \text{[a]} \text{ 2.85} \quad \text{[b]} \text{ 4.97} \quad \text{[c]} \text{ 7.87} \quad \text{[d]} \text{ 9.03} \quad \text{[e]} \text{ 11.15} \]
8. Which of the following statements are true?
   I. HF is a stronger acid than HI.
   II. HClO\textsubscript{3} is a stronger acid than HClO.
   III. H\textsubscript{3}PO\textsubscript{4} is a stronger acid than H\textsubscript{2}SO\textsubscript{4}.
   IV. HNO\textsubscript{2} is a weak acid.
   [a] I and IV  [b] II and IV  [c] II, III, and IV  [d] I and III  [e] II only

9. In the reaction shown below, NH\textsubscript{3} is acting as a(n) _________ base.
   \[ \text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4^+ + \text{OH}^- \]
   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

10. Which of the following buffers would be the best choice for preparing a pH = 4.5 buffer?
    [a] HCN/CN\textsuperscript{-}, [K\textsubscript{a}(HCN) = 5.0 \times 10\textsuperscript{-10}]
    [b] HOCl/OCl\textsuperscript{-}, [K\textsubscript{a}(HOCl) = 3.5 \times 10\textsuperscript{-8}]
    [c] H\textsubscript{2}CO\textsubscript{3}/HCO\textsubscript{3}\textsuperscript{-}, [K\textsubscript{a}(H\textsubscript{2}CO\textsubscript{3}) = 4.3 \times 10\textsuperscript{-7}]
    [d] C\textsubscript{6}H\textsubscript{5}NH\textsubscript{2}/C\textsubscript{6}H\textsubscript{5}NH\textsubscript{3}\textsuperscript{+}, [K\textsubscript{b}(C\textsubscript{6}H\textsubscript{5}NH\textsubscript{2} = 3.8 \times 10\textsuperscript{-10}]
    [e] none of these could be used to prepare a pH = 4.5 buffer

11. Consider a solution prepared by dissolving 0.35 mol of solid CH\textsubscript{3}NH\textsubscript{3}\textsuperscript{+}Cl\textsuperscript{-} in 1.00 L of 1.1 M CH\textsubscript{3}NH\textsubscript{2} (methylamine). The K\textsubscript{b} for methylamine is 4.4 \times 10\textsuperscript{-4}. If 0.01 mole of KOH is added to this buffer solution, the pH of the solution will _____________ slightly because the KOH reacts with ___________ present in solution.
    [a] decrease, CH\textsubscript{3}NH\textsubscript{2}  [b] increase, CH\textsubscript{3}NH\textsubscript{2}  [c] decrease, CH\textsubscript{3}NH\textsubscript{3}\textsuperscript{+}
    [d] increase, CH\textsubscript{3}NH\textsubscript{3}\textsuperscript{+}  [e] This is a buffer solution, so the pH does not change.

12. 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\textsubscript{a}(HCNO) = 2.0 \times 10\textsuperscript{-4}]
    [a] 2.85  [b] 3.10  [c] 3.70  [d] 4.30  [e] 9.70

13. Calculate the pH of the buffer in Problem 12 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

14. What ratio of [CH\textsubscript{3}COOH]/[CH\textsubscript{3}COO\textsuperscript{-}] is required to prepare a acetic acid/ sodium acetate buffer solution with a pH of 4.20? [K\textsubscript{a}(CH\textsubscript{3}COOH) = 1.8 \times 10\textsuperscript{-5}]
    [a] 1.7  [b] 0.29  [c] 3.5  [d] 0.58  [e] none of these

15. How many milliliters of 1.00 M HCl will be needed to completely react with 5.00 mL of 2.00 M Ba(OH)\textsubscript{2}?
    [a] 10.0 mL  [b] 20.0 mL  [c] 5.00 mL  [d] 1.00 mL  [e] none of these
16. Which one of the following would be the best choice as an indicator in the titration of a 0.100 M ammonia solution (NH₃) 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.

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

<table>
<thead>
<tr>
<th></th>
<th>(K_{sp})</th>
</tr>
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<tbody>
<tr>
<td>[a] CaF₂</td>
<td>(4.0 \times 10^{-11})</td>
</tr>
<tr>
<td>[b] Sr(IO₃)₂</td>
<td>(3.3 \times 10^{-7})</td>
</tr>
<tr>
<td>[c] MgF₂</td>
<td>(6.5 \times 10^{-9})</td>
</tr>
<tr>
<td>[d] PbCl₂</td>
<td>(1.6 \times 10^{-5})</td>
</tr>
<tr>
<td>[e] BaF₂</td>
<td>(1.7 \times 10^{-6})</td>
</tr>
</tbody>
</table>

18. 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

19. Which is the relationship between \(K_{sp}\) and molar solubility, \(x\), for Al(OH)₃ in water?

- [a] \(K_{sp} = 3x^2\)
- [b] \(K_{sp} = 3x^4\)
- [c] \(K_{sp} = 9x^{10}\)
- [d] \(K_{sp} = 27x^4\)
- [e] \(K_{sp} = 9x^3\)

20. What is the molar solubility of Pb(IO₃)₂ in water, at a temperature in which \(K_{sp} = 1.2 \times 10^{-13}\)?

- [a] \(1.2 \times 10^{-12}\) 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

21. 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

22. Consider the following reaction:

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

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

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

23. 20.0 mL of \(1.1 \times 10^{-4} \text{ M} \) \(\text{Ba(NO}_3\text{)}_2\) are added to 80.0 mL of \(8.4 \times 10^{-4} \text{ M} \) \(\text{Na}_2\text{CO}_3\). Will a precipitate of \(\text{BaCO}_3\) form? \([K_{\text{sp}}(\text{BaCO}_3) = 8.1 \times 10^{-9}]\)

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

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

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

\[
[\text{Ba}^{2+}]_0: \quad M_1 V_1 = M_2 V_2 \\
(20.0 \text{ mL})(1.1 \times 10^{-4} \text{ M}) = (100.0 \text{ mL})M_2 \\
M_2 = 2.2 \times 10^{-5} \text{ M}
\]

\[
[\text{CO}_3^{2-}]_0: \quad M_1 V_1 = M_2 V_2 \\
(80.0 \text{ mL})(8.4 \times 10^{-4} \text{ M}) = (100.0 \text{ mL})M_2 \\
M_2 = 6.72 \times 10^{-4} \text{ M}
\]

\[
Q_{\text{sp}} = [\text{Ba}^{2+}]_0[\text{CO}_3^{2-}]_0 = (2.2 \times 10^{-5})(6.72 \times 10^{-4}) = 1.5 \times 10^{-8}
\]

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

\[Q > K. \text{ The system will shift to the left to reach equilibrium. Yes, a precipitate of } \text{BaCO}_3 \text{ will form.}\]

24. 8.26 g of a mixture containing an unknown monoprotic weak acid (HA) is titrated with 0.21 \(\text{ M} \) \(\text{NaOH}\). It takes 45.16 mL of \(\text{NaOH}\) 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 \(\text{NaOH}\). \([5 \text{ pts}]\)

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

\[
0.21 \text{ mol NaOH} \times \frac{1 \text{ L sol}}{1 \text{ L sol}} \times 0.04516 \text{ L} = 0.00948 \text{ mol NaOH}
\]

\[
0.00948 \text{ mol NaOH} \times \frac{1 \text{ mol HA}}{1 \text{ mol NaOH}} = 0.00948 \text{ mol HA}
\]

\[
0.00948 \text{ mol HA} \times \frac{208 \text{ g HA}}{1 \text{ mol HA}} = 1.97 \text{ g HA}
\]

\[
\text{mass % acid} = \frac{1.97 \text{ g}}{8.26 \text{ g}} \times 100 = 23.8\%
\]
25. Consider the titration of 40.0 mL of 0.25 M HBr with 0.40 M KOH.

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

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

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

\[
\begin{array}{c|c|c}
\text{Initial (mol):} & 0.010 & 0.0040 \\
\text{Change (mol):} & -0.0040 & -0.0040 \\
\text{Final (mol):} & 0.0060 & 0 \\
\end{array}
\]

\[ [\text{H}_3\text{O}^+] = \frac{0.0060 \text{ mol}}{0.050 \text{ L}} = 0.12 \text{ M} \]
\[ \text{pH} = -\log(0.12) = 0.92 \]

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

\[
\begin{array}{c|c|c}
\text{Initial (mol):} & 0.010 & 0.010 \\
\text{Change (mol):} & -0.010 & -0.010 \\
\text{Final (mol):} & 0 & 0 \\
\end{array}
\]

Equivalence point, \( \text{pH} = 7 \).

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

\[
\begin{array}{c|c|c}
\text{Initial (mol):} & 0.010 & 0.016 \\
\text{Change (mol):} & -0.010 & -0.010 \\
\text{Final (mol):} & 0 & 0.0060 \\
\end{array}
\]

\[ [\text{OH}^-] = \frac{0.0060 \text{ mol}}{0.080 \text{ L}} = 0.075 \text{ M} \]
\[ \text{pOH} = 1.12 \]
\[ \text{pH} = 12.88 \]
### Potentially Useful Information

- \( R = 8.314 \text{ J/mol} \cdot \text{K} \)
- \( K = ^\circ\text{C} + 273 \)
- \( M = \frac{\text{mol solute}}{\text{L soln}} \)
- 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:

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

- \( K_c = \frac{[\text{products}]^y}{[\text{reactants}]^x} \)
- \( K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\text{C} \)

\[
pH = -\log[\text{H}_3\text{O}^+] \quad \text{pH} + \text{pOH} = 14, \text{ at } 25^\circ\text{C} \quad K_w = K_a \times K_b
\]

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

- \( \Delta G^\circ = -RT\ln K \)
- \( \Delta G_{\text{rxn}}^\circ = \sum n\Delta G_i^\circ(\text{products}) - \sum n\Delta G_i^\circ(\text{reactants}) \)
- \( \Delta S_{\text{rxn}}^\circ = \sum nS^\circ(\text{products}) - \sum nS^\circ(\text{reactants}) \)

### SOLUBLE COMPOUNDS

| Compounds containing alkali metal ions (Li\(^+\), Na\(^+\), K\(^+\), Rb\(^+\), Cs\(^+\)) and the ammonium ion (NH\(_4^+\)) |
| Nitrites (NO\(_2^-\)), bicarbonates (HCO\(_3^-\)), and chlorates (ClO\(_3^-\)) |
| Halides (Cl\(^-\), Br\(^-\), I\(^-\)) |
| Sulfates (SO\(_4^{2-}\)) |

### INSOLUBLE COMPOUNDS

| Carbonates (CO\(_3^{2-}\)), phosphates (PO\(_4^{3-}\)), chromates (CrO\(_4^{2-}\)), and sulfides (S\(^2-\)) |
| Hydroxides (OH\(^-\)) |

### EXCEPTIONS

- Halides of Ag\(^+\), Hg\(_2^{2+}\), and Pb\(_2^{2+}\) for SO\(_4^{2-}\) and Cl\(^-\) for SO\(_4^{2-}\) and Cl\(^-\)
- Compounds containing alkali metal ions and the ammonium ion for SO\(_4^{2-}\), PO\(_4^{3-}\), CrO\(_4^{2-}\), S\(^2-\), and OH\(^-\)