1. Complete the following table. (10 pts)

<table>
<thead>
<tr>
<th>[H⁺]</th>
<th>[OH⁻]</th>
<th>pH</th>
<th>pOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.35 x 10⁻¹²</td>
<td>7.42 x 10⁻³</td>
<td>11.87</td>
<td>2.13</td>
</tr>
<tr>
<td>9.77 x 10⁻⁹</td>
<td>1.02 x 10⁻⁶</td>
<td>8.01</td>
<td>5.99</td>
</tr>
<tr>
<td>3.81 x 10⁻¹¹</td>
<td>2.62 x 10⁻⁴</td>
<td>10.42</td>
<td>3.58</td>
</tr>
<tr>
<td>1.70 x 10⁻¹⁰</td>
<td>5.89 x 10⁻⁵</td>
<td>9.77</td>
<td>4.23</td>
</tr>
</tbody>
</table>

2. The $K_a$ for benzoic acid is $6.5 \times 10⁻⁵$. Calculate the pH of a 0.10 M benzoic acid solution. You may represent the weak acid as HA and the conjugate base as $A^−$. (10 pts)

$$ HA \rightleftharpoons A^− + H^+ $$

I 0.10 0 0
C -x +x +x
E 0.10-x x x

$$ x = 2.55 \times 10⁻³ \text{ M = } [H^+] $$

Check:

$$ pOH = -\log(2.55 \times 10⁻³) = 2.59 $$

$$ \frac{2.55 \times 10⁻³}{0.10} \times 100 = 2.6 \% \text{ approximation valid} $$

3. Sodium benzoate is the salt of the conjugate base of benzoic acid. Calculate the pH of a 0.25 M solution of sodium benzoate. (10 pts)

$$ NaA \rightleftharpoons Na^+ + A^− \text{ (strong electrolyte)} $$

$$ K_a = 6.5 \times 10⁻⁵ $$

$$ A^− + H_2O \rightleftharpoons HA + OH^- $$

I 0.25 0 0
C -x +x +x
E 0.25-x x x

$$ x = \frac{K_b}{K_a} = \frac{1 \times 10⁻¹⁴}{6.5 \times 10⁻⁵} = 1.5 \times 10⁻¹⁰ $$

$$ pOH = -\log(6.20 \times 10⁻⁶) $$

$$ pH = 14 - 5.21 = 8.79 $$

Chemistry 102 Exam 2
4. The pH of blood plasma is 7.40. Assuming the principle buffer system in blood is \( \text{HCO}_3^-/\text{H}_2\text{CO}_3 \), calculate the ratio \([A^-]/[HA]\). Is this buffer more effective against acid or base? (10 pts)

\[ K_a = 4.3 \times 10^{-7} \quad \text{pK}_a = 6.37 \]

**Henderson-Hasselbach**

\[
pH = pK_a + \log \left( \frac{[A^-]}{[HA]} \right)
\]

\[ 7.40 = 6.37 + \log \left( \frac{[A^-]}{[HA]} \right) \quad \text{or} \quad 1.02 = \log \left( \frac{[A^-]}{[HA]} \right) \]

\[
\frac{[A^-]}{[HA]} = 10.5
\]

Ratio for the buffer zone 0.1 to 10, therefore this buffer system is more effective against acid.

5. Predict if a precipitate forms when 175.0 mL of \( 5.5 \times 10^{-3} \) M KCl is added to 145.0 mL of \( 1.5 \times 10^{-3} \) M \( \text{AgNO}_3 \). *Hint: This is a double displacement reaction in which one of the products is a strong electrolyte.* (10 pts)

Total volume = 320 mL

\( K_{sp} \) for \( \text{AgCl} \) is \( 1.77 \times 10^{-10} \)

\[ \text{KCl}_{(aq)} + \text{AgNO}_3_{(aq)} \rightarrow \text{KNO}_3_{(aq)} + \text{AgCl}_{(s)} \]

\[ \left[ \text{Cl}^- \right] = \frac{0.175 \times 5.5 \times 10^{-3} \text{M}}{0.320 \text{L}} = 3.01 \times 10^{-3} \text{M} \]

\[ \left[ \text{Ag}^+ \right] = \frac{0.145 \times 1.5 \times 10^{-3} \text{M}}{0.320 \text{L}} = 6.80 \times 10^{-4} \text{M} \]

\[ \text{AgCl}_{(s)} \rightleftharpoons \text{Ag}^+_{(aq)} + \text{Cl}^-_{(aq)} \]

\[
\begin{array}{c|c|c}
\text{I} & - & 0 \\
\hline
\text{C} & +s & +s \\
\hline
\text{E} & s & s \\
\end{array}
\]

\[ Q_{sp} = [\text{Ag}^+][\text{Cl}^-] = 2.05 \times 10^{-6} \]

\[ Q_{sp} > K_{sp} \quad \text{The solution is super saturated, thus a precipitate would form.} \]

6. Calculate the solubility (g/L) of \( \text{Fe(OH)}_2 \) in a solution at pH = 8. (10 pts)

\( K_{sp} = 4.87 \times 10^{-17} \quad \text{MW} = 90 \text{ g/mol} \quad \text{pOH} = 14 - 8 = 6 \quad [\text{OH}^-] = 1 \times 10^{-6} \text{ M} \)

\[ \text{Fe(OH)}_2 \rightleftharpoons \text{Fe}^{2+} + 2\text{OH}^- \]

\[
\begin{array}{c|c|c}
\text{I} & - & 0 \\
\hline
\text{C} & +s & +2s \\
\hline
\text{E} & s & 2s \\
\end{array}
\]

\[ K_{sp} = 4.87 \times 10^{-17} = s(1 \times 10^{-6} + 2s)^2 = s(1 \times 10^{-6})^2 \]

\[ s = 4.87 \times 10^{-5} \text{ M} \]

\[ \text{Solubility} = 4.87 \times 10^{-5} \text{ M} \times 90 \text{ g/mol} = 4.38 \times 10^3 \text{ g/L} \]

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Chemistry 102 Exam 2
7. Calculate the pH 25.00 mL of a 0.10 M HClO weak acid solution upon titration with the following increments of a 0.10 M NaOH strong base solution. (15 pts)

\[ K_a = 2.9 \times 10^{-8} \]

0.025 L x 0.10 mol/L = 0.0025 mol acid

a) 0.00 mL of NaOH. (No base added)

\[
\text{HClO} \rightleftharpoons \text{ClO}^- + \text{H}^+ \\
\begin{array}{c|c|c|c}
\text{I} & 0.10 & 0 & 0 \\
\text{C} & -x & +x & +x \\
\text{E} & 0.10-x & x & x \\
\end{array}
\]

\[ K_a = 2.9 \times 10^{-8} = \frac{x^2}{0.10 - x} \approx \frac{x^2}{0.10} \]

\[ X = 5.39 \times 10^{-5} \text{ M} = [H^+] \]

\[ \text{pH} = -\log(5.39 \times 10^{-5}) = 4.27 \]

\[ \frac{5.39 \times 10^{-5}}{0.10} \times 100 = 0.054 \% \text{ valid} \]

b) 15.00 mL of NaOH. (Before equivalence point)

0.015 L x 0.10 mol/L = 0.0015 mol base

0.0025 mol acid – 0.0015 mol base = 0.0010 mol acid

\[ \text{pK}_a = -\log(2.9 \times 10^{-8}) = 7.54 \]

Henderson-Hasselbach

\[ \text{pH} = \text{pK}_a + \log \left( \frac{[A^-]}{[HA]} \right) = 7.54 + \log \left( \frac{0.0015}{0.0010} \right) = 7.54 + 0.18 = 7.72 \]

c) 25.00 mL of NaOH. (At equivalence point)

0.025 L x 0.10 mol/L = 0.0025 mol base \quad [\text{ClO}^-] = 0.0025 \text{ mol/L} / 0.050L = 0.05 \text{ M}

\[
\text{ClO}^- + \text{H}_2\text{O} \rightleftharpoons \text{HClO} + \text{OH}^- \\
\begin{array}{c|c|c|c}
\text{I} & 0.05 & 0 & 0 \\
\text{C} & -x & +x & +x \\
\text{E} & 0.05-x & x & x \\
\end{array}
\]

\[ K_b = \frac{K_w}{K_a} = \frac{1 \times 10^{-14}}{2.9 \times 10^{-8}} = 3.5 \times 10^{-7} \quad 3.5 \times 10^{-7} = \frac{x^2}{0.05 - x} \approx \frac{x^2}{0.05} \]

\[ X = 1.32 \times 10^{-4} = [\text{OH}^-] \]

\[ \text{pOH} = -\log(1.32 \times 10^{-4}) \]

\[ \text{pH} = 14 - 3.88 = 10.12 \]
8. Which of the following indicator(s) would be appropriate for a titration which has an equivalence point at pH = 8.4? (5 pts)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>$K_a$</th>
<th>$pK_a$</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$6.20 \times 10^{-8}$</td>
<td>7.27</td>
<td>8.10 – 10.10</td>
</tr>
<tr>
<td>B</td>
<td>$2.78 \times 10^{-6}$</td>
<td>5.56</td>
<td>C is appropriate</td>
</tr>
<tr>
<td>C</td>
<td>$7.94 \times 10^{-10}$</td>
<td>9.10</td>
<td></td>
</tr>
</tbody>
</table>

9. Predict whether a decrease in temperature is favorable or unfavorable for the following reactions. (10 pts) $\Delta G = \Delta H - T\Delta S$

a) $2\text{H}_2\text{O}(l) \rightarrow 2\text{H}_2\text{O}(g) + \text{O}_2(g)$ $+\Delta S$ decrease in $T$ is unfavorable

b) $2\text{Sb}(s) + 3\text{FeS}(s) \rightarrow \text{Sb}_2\text{S}_3(s) + 3\text{Fe}(s)$ $-\Delta S$ decrease in $T$ is favorable

c) $\text{H}_2\text{O}(s) \rightarrow \text{H}_2\text{O}(l)$ $+\Delta S$ decrease in $T$ is unfavorable

d) $\text{CO}_2(g) \rightarrow \text{CO}_2(s)$ $-\Delta S$ decrease in $T$ is favorable

10. Calculate the temperature in which the following reactions become spontaneous. (10 pts)

a) Reaction A: $\Delta H = 10.5 \text{ kJ/mol}$ ; $\Delta S = 30 \text{ J/mol K}$ Spontaneous = $\Delta G < 0$

$0 = \Delta H - T\Delta S$

$$T = \frac{\Delta H}{\Delta S} = \frac{10.5 \text{ kJ/mol}}{0.030 \text{ kJ/mol K}} = 350 \text{ K} \quad T > 350 \text{ K}$$

b) Reaction B: $\Delta H = 1.8 \text{ kJ/mol}$ ; $\Delta S = -113 \text{ J/mol K}$

$$T = \frac{\Delta H}{\Delta S} = \frac{1.8 \text{ kJ/mol}}{-0.113 \text{ kJ/mol K}} = -15.9 \text{ K} \quad T > -15.9 \text{ K}$$

* 0 Kelvin is absolute zero, thus it would be impossible for this reaction to be spontaneous.

11. (Extra Credit) A formic acid (HCHO$_2$) solution has a pH of 3.25. Which of the following substances will raise the pH of the solution upon addition? (5 pts)

a) HCl

b) NaBr

c) NaCHO$_2$

d) KCl

HCHO$_2$ $\rightleftharpoons$ CHO$_2^-$ + H$^+$

NaCHO$_2$ $\rightleftharpoons$ Na$^+$ + CHO$_2^-$

Common Ion Effect