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# at the top of this page, answer the following question. You will receive 1 bonus point. If you could travel to any place in the world over Spring Break, where would that be?

• There are 90 points on this exam.

GOOD LUCK! ENJOY!!

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

1. A solution with a pH of 8 has a hydronium ion, H₃O⁺, concentration that is 1000 times greater than that of a solution of pH 11.  
   [T]

2. If the pH of an aqueous solution is greater than 7 at 25°C, then the [H₃O⁺] > 1.0 × 10⁻⁷ M.  
   [F]

3. Consider the following reaction, 2O₃(g) ⇌ 3O₂(g), Kᵢ = 3.0 × 10²⁶. At equilibrium, the mixture will contain a very small amount of O₂ as compared to O₃.  
   [F]

4. H₂PO₄⁻ and HPO₄²⁻ are a conjugate acid/base pair.  
   [T]

PART II: Multiple Choice (3 points each)

5. At equilibrium, which of the following is true?
   [a] All chemical processes have ceased.
   [b] The rate of the forward reaction equals the rate of the reverse reaction.
   [c] The concentrations of reactants and products are no longer changing with time.
   [d] The concentrations of reactants and products are equal.
   [e] Both b and c are true.  
   [e] Both b and c are true. *

6. An aqueous equilibrium mixture of CoCl₄²⁻, CoBr₄²⁻, Cl⁻, and Br⁻ is present in a flask at 25°C. Which action below will change the value of the equilibrium constant, K.
   [a] Adding more Cl⁻ to the solution  
   [b] Adding more Br⁻ to the solution  
   [c] Adding more CoBr₄²⁻ to the solution  
   [d] Adding more CoCl₄²⁻ to the solution  
   [e] Putting the flask into an 80°C water bath  
   [e] Putting the flask into an 80°C water bath *
7. Which one of the following choices is the correct **equilibrium constant expression** for the reaction below?

\[ \text{Al}_2\text{(SO}_3\text{)}_3 (s) + 6 \text{HCl (g) } \rightleftharpoons 2 \text{AlCl}_3 (s) + 3 \text{H}_2\text{O (l) } + 3 \text{SO}_2 (g) \]

\[
\begin{align*}
[a] \quad & K_c = \frac{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3[\text{SO}_2]^3}{[\text{Al}_2\text{(SO}_3\text{)}_3][\text{HCl}]^6} \\
[b] \quad & K_c = \frac{[\text{Al}_2\text{(SO}_3\text{)}_3][\text{HCl}]^6}{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3[\text{SO}_2]^3} \\
[c] \quad & K_c = \frac{[\text{HCl}]^6}{[\text{SO}_2]^3} \\
[d] \quad & K_c = \frac{[\text{SO}_2]^3}{[\text{HCl}]^6} \\
[e] \quad & K_c = \frac{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3 (P_{\text{SO}_2})^3}{[\text{Al}_2\text{(SO}_3\text{)}_3](P_{\text{HCl}})^6}
\end{align*}
\]

8. Consider the following chemical reaction.

\[ \text{H}_2 (g) + \text{I}_2 (g) \rightleftharpoons 2 \text{HI (g) } \]

At *equilibrium*, the concentration of H2, I2, and HI were found to be 0.15 M, 0.033 M, and 0.55 M, respectively. What is the value of \( K_c \) for this reaction?

\[
\begin{align*}
[a] \quad & 0.0090 \\
[b] \quad & 0.016 \\
[c] \quad & 61 * \\
[d] \quad & 111 \\
[e] \quad & \text{none of these}
\end{align*}
\]

9. The equilibrium constant for reaction (1) is \( K \). What is the *equilibrium constant* for reaction (2)?

(1) \( \text{SO}_2 (g) + \frac{1}{2} \text{O}_2 (g) \rightleftharpoons \text{SO}_3 (g) \)

(2) \( 2 \text{SO}_3 (g) \rightleftharpoons 2 \text{SO}_2 (g) + \text{O}_2 (g) \)

\[
\begin{align*}
[a] \quad & K^2 \\
[b] \quad & 2K \\
[c] \quad & \frac{1}{2K} \\
[d] \quad & \frac{1}{K^2} * \\
[e] \quad & \text{none of these}
\end{align*}
\]

10. The balanced homogeneous vapor-phase reaction, \( A + B \rightleftharpoons X + Y \), has \( K_c = 1.1 \times 10^{-3} \) at 472 K. At equilibrium,

\[
\begin{align*}
[a] \quad & \text{products predominate.} \\
[b] \quad & \text{reactants predominate. } * \\
[c] \quad & \text{roughly equal molar amounts of products and reactants are present.} \\
[d] \quad & \text{only products exist.} \\
[e] \quad & \text{only reactants exist.}
\end{align*}
\]

11. For which one of the following reactions is \( K_c \) equal to \( K_P \)?

\[
\begin{align*}
[a] \quad & \text{H}_2(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{HCl(g) } * \\
[b] \quad & 2\text{SO}_3(g) \rightleftharpoons 2\text{SO}_2(g) + \text{O}_2(g) \\
[c] \quad & \text{N}_2\text{O}_4(g) \rightleftharpoons 2\text{NO}_2(g) \\
[d] \quad & \text{C(s) + CO}_2(g) \rightleftharpoons 2\text{CO(g) } \\
[e] \quad & K_c \text{ equals } K_P \text{ for all of these reactions.}
\end{align*}
\]

12. The value of \( K_c \) for the following reaction is 1.6.

\[ \text{C (s) + CO}_2 (g) \rightleftharpoons 2 \text{ CO (g) } \]

What is the *equilibrium concentration* of CO if the *equilibrium* concentration of CO2 is 0.50 M?

\[
\begin{align*}
[a] \quad & 0.80 \\
[b] \quad & 0.75 \\
[c] \quad & 0.89 * \\
[d] \quad & 0.31 \\
[e] \quad & \text{none of these}
\end{align*}
\]
13. Consider the following reaction:

\[ 2 \text{CO}_2 (g) \rightleftharpoons \text{CO} (g) + \text{O}_2 (g) \quad K_c = 1.2 \times 10^{-13} \]

A 2.21 L vessel was found to contain 0.0418 mole of CO\(_2\), 0.0281 mole of CO, and 0.00889 mole of O\(_2\). Is the system at equilibrium? If not, in which direction must the reaction proceed to achieve equilibrium?

[a] Yes  
[b] No, to the right  
[c] No, to the left *  
[d] impossible to determine without additional information

14. For the endothermic reaction,

\[ \text{CaCO}_3 (s) \rightleftharpoons \text{CaO (s) + CO}_2 (g) \]

which of the following actions would favor shifting the equilibrium position to form more CO\(_2\) gas?

[a] Increasing the system temperature *  
[b] Decreasing the system temperature  
[c] Increasing the system pressure  
[d] Both decreasing the system temperature and increasing the system pressure  
[e] none of these actions would form more CO\(_2\)(g).

15. 0.50 mole of I\(_2\) and 0.50 mole of Br\(_2\) are placed in a 1.00 L flask and allowed to reach equilibrium. At equilibrium, the flask contains 0.84 mole of IBr. What is the value of \(K_c\) for this reaction.

\[ \text{I}_2 (g) + \text{Br}_2 (g) \rightleftharpoons 2 \text{IBr (g)} \]

[a] 2.8  
[b] 3.4  
[c] 11  
[d] \(1.1 \times 10^2\) *  
[e] \(1.3 \times 10^2\)

16. In an acidic solution, pH is _____ and pOH is _____.

[a] =7, = 7  
[b] < 7, > 7 *  
[c] > 7, > 7  
[d] > 7, < 7  
[e] < 7, < 7

17. Which solution below has the greatest concentration of hydroxide ions?

[a] pH = 3.21  
[b] pH = 12.59 *  
[c] pH = 7.93  
[d] pH = 9.82  
[e] pH = −1.00

18. Of the following, ____________ is a weak acid.

[a] NaOH(aq)  
[b] NH\(_3\)(aq)  
[c] H\(_2\)SO\(_4\)(aq)  
[d] HNO\(_3\)(aq)  
[e] H\(_2\)S(aq) *

19. Calculate the pH of 0.00756 M HNO\(_3\).

[a] 11.879  
[b] 1.000  
[c] 2.121 *  
[d] 12.879  
[e] 1.121

20. What is the concentration of hydronium ions, H\(_3\)O\(^+\), in a solution with a pOH = 3.64?

[a] \(4.37 \times 10^{-11}\) M *  
[b] \(2.29 \times 10^{-4}\) M  
[c]  
[d] \(4.37 \times 10^{-3}\) M  
[e] \(1.00 \times 10^{-7}\) M

21. Consider 0.10 M solutions of each of the following. Which one would have the highest pH?

[a] HF \((K_a = 7.1 \times 10^{-4})\)  
[b] HNO\(_2\) \((K_a = 4.5 \times 10^{-4})\)  
[c] CH\(_3\)COOH \((K_a = 1.8 \times 10^{-5})\)  
[d] HOCl \((K_a = 3.0 \times 10^{-8})\)  
[e] HCN \((K_a = 4.9 \times 10^{-10})\) *

22. Referring to the \(K_a\) values in the previous problem, which of the following is the weakest base?
<p>| | | | | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>[a]</td>
<td>F(^{-}) *</td>
<td>[b]</td>
<td>NO(_2)(^{-})</td>
<td>[c]</td>
</tr>
</tbody>
</table>
PART III: Problems

23. The weak base trimethylamine, \((\text{CH}_3)_3\text{N}\), smells like rotten fish, so be very careful when dissolving 7.50 g of trimethylamine in enough water to make 100.0 mL of solution. Calculate the \(p\text{H}\) of this solution. 

\[K_b (\text{CH}_3)_3\text{N} = 6.3 \times 10^{-5}\] [7 pts]

\[
7.50 \text{ g (CH}_3)_3\text{N} \times \frac{1 \text{ mol (CH}_3)_3\text{N}}{59.11 \text{ g (CH}_3)_3\text{N}} = 0.127 \text{ mol (CH}_3)_3\text{N}
\]

\[
\frac{0.127 \text{ mol}}{0.100 \text{ L}} = 1.27 \text{ M}
\]

\[
(\text{CH}_3)_3\text{N} + \text{H}_2\text{O} \rightleftharpoons (\text{CH}_3)_3\text{NH}^+ + \text{OH}^-
\]

<table>
<thead>
<tr>
<th>Initial (M)</th>
<th>1.27</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change (M)</td>
<td>(-x)</td>
<td>(+x)</td>
<td>(+x)</td>
</tr>
<tr>
<td>Equilibrium (M)</td>
<td>1.27 (-x)</td>
<td>(x)</td>
<td>(x)</td>
</tr>
</tbody>
</table>

\[
K_b = \frac{[\text{CH}_3)_3\text{NH}^+][\text{OH}^-]}{[\text{(CH}_3)_3\text{N}]} = \frac{x^2}{1.27 - x} \approx \frac{x^2}{1.27}
\]

\[
x = [\text{OH}^-] = 8.94 \times 10^{-3} \text{ M}
\]

\[
p\text{OH} = -\log(8.94 \times 10^{-3}) = 2.05
\]

\[
p\text{H} = 14 - p\text{OH} = 14 - 2.05 = 11.95
\]

24. Predict whether aqueous solutions of the following are acidic, basic, or neutral. [6 pts]

a) \(\text{HCOOH}\) \textbf{acidic}

b) \(\text{NaNO}_3\) \textbf{neutral}

c) \(\text{HBr}\) \textbf{acidic}

d) \(\text{K}_2\text{CO}_3\) \textbf{basic}

e) \(\text{NH}_4\text{Br}\) \textbf{acidic}

f) \(\text{LiOH}\) \textbf{basic}
25. Consider the following reaction at equilibrium.

\[
\text{UO}_2 (s) + 4 \text{HF (g)} \rightleftharpoons \text{UF}_4 (g) + 2 \text{H}_2\text{O (g)} \quad \Delta H = -424.2 \text{ kJ/mol}
\]

How does the equilibrium position shift as a result of each of the following stresses. (Possible answers are: shift left, shift right, or no change.) [6 pts]

- a) 0.20 atm of argon gas is added. \textit{no change}

- b) HF(g) is added. \textit{shift right}

- c) Mg(ClO}_4)_2 is added as a drying agent to remove \text{H}_2\text{O}. \textit{shift right}

- d) UO}_2(s) is added. \textit{no change}

- e) The volume of the container is increased. \textit{shift left}

- f) The temperature is increased \textit{shift left}

26. Consider a 0.20 \textit{M} weak acid, \text{HA}. If the acid dissociates 1.5%, what is the \( K_a \) value of this acid? [5 pts]

\[
\text{HA} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{A}^-
\]

Initial (M): 0.20 0 0

<table>
<thead>
<tr>
<th>Change (M)</th>
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<th>+x</th>
<th>+x</th>
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</thead>
<tbody>
<tr>
<td>Equilibrium (M):</td>
<td>0.20 - x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

\[
K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}
\]

\[
K_a = \frac{x^2}{0.20 - x}
\]

\[
x = (0.015)(0.20) = 0.0030
\]

\[
K_a = \frac{(0.0030)^2}{0.20 - 0.0030}
\]

\[
K_a = 4.6 \times 10^{-5}
\]
**Potentially Useful Information**

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

\[ PV = nRT \]

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

\[ R = 0.0821 \text{ L-atm/mol-K} \]

\[ K = ^\circ C + 273 \]

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

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

\[ \begin{align*}
  K_c &= \frac{[\text{products}]^x}{[\text{reactants}]^y} \\
  K_p &= K_c(0.0821 \ T)^{\delta n} \\
  \text{pH} &= -\log[H_3O^+] \\
  \text{pOH} &= -\log[OH^-] \\
  \text{pH} + \text{pOH} &= 14, \text{ at } 25^\circ C \\
  K_w &= [H_3O^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ C
\end{align*} \]