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. Consider the following reaction, $2\text{O}_3(g) \rightleftharpoons 3\text{O}_2(g)$, $K_P = 3.0 \times 10^{26}$. At equilibrium, the mixture will contain a very small amount of O$_2$ as compared to O$_3$. F

2. H$_2$PO$_4^-$ and HPO$_4^{2-}$ are a conjugate acid/base pair. T

3. A solution with a pH of 8 has a hydronium ion, H$_3$O$^+$, concentration that is 1000 times greater than that of a solution of pH 11. T

4. If the pH of an aqueous solution is greater than 7 at 25°C, then the $[\text{H}_3\text{O}^+] > 1.0 \times 10^{-7}$ M. F

PART II: Multiple Choice (3 points each)

5. In an acidic solution, pH is _____ and pOH is _____.
   [a] =7, = 7 [b] < 7, > 7 * [c] > 7, > 7 [d] > 7, < 7 [e] < 7, < 7

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

7. 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) *

8. Calculate the pH of 0.00756 M HNO$_3$.
   [a] 11.879 [b] 1.000 [c] **2.121** * [d] 12.879 [e] 1.121
9. What is the concentration of hydronium ions, $H_3O^+$, in a solution with a pOH = 3.64?

- [a] $4.37 \times 10^{-11} \text{ M}$
- [b] $2.29 \times 10^{-4} \text{ M}$
- [c] $10.36 \text{ M}$
- [d] $4.37 \times 10^{-3} \text{ M}$
- [e] $1.00 \times 10^{-7} \text{ M}$

10. 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 ($K_a = 4.9 \times 10^{-10}$)

11. Referring to the $K_a$ values in the previous problem, which of the following is the weakest base?

- [a] $F^-$
- [b] NO$_2^-$
- [c] CH$_3$COO$^-$
- [d] OCl$^-$
- [e] CN$^-$

12. 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.

13. An aqueous equilibrium mixture of CoCl$_4^{2-}$, CoBr$_4^{2-}$, 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 CoBr$_4^{2-}$ to the solution
- [d] Adding more CoCl$_4^{2-}$ to the solution
- [e] Putting the flask into an 80°C water bath

14. Which one of the following choices is the correct equilibrium constant expression for the reaction below?

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

- [a] $K_c = \frac{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3[\text{SO}_2]^3}{[\text{Al}_2(\text{SO}_3)_3][\text{HCl}]^6}$
- [b] $K_c = \frac{[\text{Al}_2(\text{SO}_3)_3][\text{HCl}]^6}{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3[\text{SO}_2]^3}$
- [c] $K_c = \frac{[\text{HCl}]^6}{[\text{SO}_2]^3}$
- [d] $K_c = \frac{[\text{SO}_2]^3}{[\text{HCl}]^6}$
- [e] $K_c = \frac{[\text{AlCl}_3]^2[\text{H}_2\text{O}]^3[\text{P}_{\text{SO}_2}]^3}{[\text{Al}_2(\text{SO}_3)_3][\text{P}_{\text{HCl}}]^6}$

15. Consider the following chemical reaction.

$\text{H}_2\text{(g)} + \text{I}_2\text{(g)} \rightarrow 2 \text{HI (g)}$

At equilibrium, the concentration of H$_2$, I$_2$, 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?

- [a] 0.0090
- [b] 0.016
- [c] 61
- [d] 111
- [e] none of these
16. 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) $2 \text{SO}_3 (g) \rightleftharpoons 2 \text{SO}_2 (g) + \text{O}_2 (g)$

[a] $K^2$  [b] $2K$  [c] $\frac{1}{2K}$  [d] $\frac{1}{K^2}$  [e] none of these

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

[a] products predominate.  [b] reactants predominate.  *[c] roughly equal molar amounts of products and reactants are present.  [d] only products exist.  [e] only reactants exist.

18. For which one of the following reactions is $K_c$ equal to $K_P$?

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

19. The value of $K_c$ for the following reaction is 1.6.

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

What is the **equilibrium concentration** of CO if the equilibrium concentration of CO$_2$ is 0.50 M?

[a] 0.80  [b] 0.75  [c] 0.89  *[d] 0.31  [e] none of these

20. Consider the following reaction:

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

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

21. For the **endothermic** reaction,

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

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).

22. 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] $1.1 \times 10^3$  *[e] $1.3 \times 10^2$
PART III: Problems

23. Consider a 0.20 M weak acid, HA. If the acid dissociates 2.5%, what is the $K_a$ value of this acid? [5 pts]

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

<table>
<thead>
<tr>
<th>Initial ($M$)</th>
<th>0.20</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>$0.20 - x$</td>
<td>$x$</td>
<td>$x$</td>
</tr>
</tbody>
</table>

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

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

\[
x = (0.025)(0.20) = 0.0050
\]

\[
K_a = \frac{(0.0050)^2}{0.20 - 0.0050}
\]

\[
K_a = 1.3 \times 10^{-4}
\]

24. 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) Mg(ClO$_4$)$_2$ is added as a drying agent to remove H$_2$O. **shift right**

b) UO$_2$(s) is added. **no change**

c) The volume of the container is increased. **shift left**

d) The temperature is increased **shift left**

e) 0.20 atm of argon gas is added. **no change**

f) HF(g) is added. **shift right**
25. Predict whether aqueous solutions of the following are acidic, basic, or neutral. [6 pts]

a) LiOH  basic
b) HBr  acidic
c) K₂CO₃  basic
d) NH₄Br  acidic
e) HCOOH  acidic
f) NaNO₃  neutral

26. The weak base trimethylamine, (CH₃)₃N, smells like rotten fish, so be very careful when dissolving 9.50 g of trimethylamine in enough water to make 100.0 mL of solution. Calculate the pH of this solution. [Kₐ (CH₃)₃N = 6.3 × 10⁻⁵] [7 pts]

\[ 9.50 \text{ g (CH}_3\text{)}_3\text{N} \times \frac{1 \text{ mol (CH}_3\text{)}_3\text{N}}{59.11 \text{ g (CH}_3\text{)}_3\text{N}} = 0.161 \text{ mol (CH}_3\text{)}_3\text{N} \]

\[ \frac{0.161 \text{ mol}}{0.100 \text{ L}} = 1.61 \text{ M} \]

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

\[ \begin{array}{ccc}
\text{Initial (M)}: & 1.61 & 0 & 0 \\
\text{Change (M)}: & -x & +x & +x \\
\text{Equilibrium (M)}: & 1.61 - x & x & x \\
\end{array} \]

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

\[ 6.3 \times 10^{-5} = \frac{x^2}{1.61 - x} \approx \frac{x^2}{1.61} \]

\[ x = [\text{OH}^-] = 0.0101 \text{ M} \]

\[ \text{pOH} = -\log(0.0101) = 2.00 \]

\[ \text{pH} = 14 - \text{pOH} = 14 - 2.00 = 12.00 \]
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:

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

\[ K_c = \frac{[\text{products}]^x}{[\text{reactants}]^y} \]

\[ K_p = K_c(0.0821 T)^{\Delta n} \]

\[ \text{pH} = -\log[H_3O^+] \]

\[ \text{pOH} = -\log[OH^-] \]

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

\[ K_w = [H_3O^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ C \]