1. (2 points) Acids that do not ionize extensively in solution are referred to as
   a) non-dissociators.
   b) weak acids.
   c) Arrhenius acids.
   d) Brønsted-Lowry acids.
   e) strong electrolytes.

2. (2 points) An acid with a large $K_a$
   a) slightly increases the $\text{H}_2\text{O}^+$ concentration in an aqueous solution.
   b) is an electron pair-donor.
   c) is a proton acceptor.
   d) is a strong electrolyte.
   e) none of the above.

3. (3 points) For a reversible reaction at the equilibrium
   a) The concentration of reactants equals the concentration of products.
   b) The forward and reverse reactions still occur.
   c) The rates of the forward and reverse reactions are equal to zero.
   d) The value of $Q = K$ only for reactions in the gas phase.
   e) None of the above.

4. (2 points) In the following reaction
   \[ \text{HCO}_3^- (\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+ (\text{aq}) \]
   a) $\text{HCO}_3^-$ is an acid and $\text{H}_2\text{O}$ is its conjugate base.
   b) $\text{HCO}_3^-$ is an acid and $\text{CO}_3^{2-}$ is its conjugate base.
   c) $\text{H}_3\text{O}^+$ is an acid and $\text{HCO}_3^-$ is its conjugate base.
   d) $\text{H}_2\text{O}$ is an acid and $\text{CO}_3^{2-}$ is its conjugate base.
   e) $\text{H}_3\text{O}^+$ is an acid and $\text{CO}_3^{2-}$ is its conjugate base.

5. (3 points) The conjugate acid of $\text{HSO}_4^-$ is ________.
   a) $\text{OH}^-$
   b) $\text{SO}_4^{2-}$
   c) $\text{H}_2\text{SO}_4$
   d) $\text{H}_2\text{O}$
   e) $\text{H}_3\text{O}^+$

6. (4 points) What variables give you a linear plot that will tell you the activation energy of a reaction?
   a. rate constant $k$ vs temperature
   b. rate constant $k$ vs $1/\text{temperature}$
   c. $\ln$ (rate constant $k$) vs temperature
   d. $\ln$ (rate constant $k$) vs $1/\text{temperature}$
   e. None of the above

7. (3 points) If we dissolve $\text{NH}_4\text{Cl}$ ($\text{NH}_4^+ K_a = 5.6 \times 10^{-10}$) in water, the pH of the solution is:
   a) higher than 7  b) equal to 7  c) lower than 7  d) 9.25  e) cannot tell

\[ \text{NH}_4^+ + \text{H}_2\text{O} \rightleftharpoons \text{NH}_3 + \text{H}_3\text{O}^+ \Rightarrow \text{will generate } \text{H}_3\text{O}^+ \]
\[ \Rightarrow [\text{H}_3\text{O}^+] > [\text{OH}^-] \Rightarrow \text{lower than } 7 \]
8. (2 points) If \( Q < K \) for the following reaction \( 2A + B \rightleftharpoons 3C \), in order to reach the equilibrium

a) more reactants are produced

b) more C is produced
c) the concentration of C decreases by \( 1/3 \)
d) the concentration of A increases two fold
e) none of the above

9. (3 points) If the following reaction \( N_2(g) + 3H_2(g) \rightleftharpoons NH_3(g) \) is at equilibrium in a 2 L container, an increase in pressure at constant temperature will

a) increase the \( NH_3 \) concentration.
b) increase the \( N_2 \) concentration.
c) not affect the equilibrium.
d) increase the concentration of the three compounds.
e) none of the above.

10. (4 points) At 50 °C, the water ionization constant, \( K_w \), is \( 5.5 \times 10^{-14} \). What is the \( H_3O^+ \) concentration in neutral water at this temperature?

a) \( 5.5 \times 10^{-28} \) M  b) \( 8.5 \times 10^{-7} \) M  c) \( 4.3 \times 10^{-8} \) M  d) \( 2.3 \times 10^{-7} \) M  e) \( 5.5 \) M

\[
K_w = [H_3O^+][OH^-] \quad \text{in neutral H}_2\text{O} \Rightarrow \frac{[H_3O^+]}{[OH^-]} = \sqrt{K_w} = \sqrt{5.5 \times 10^{-14}} = 2.3 \times 10^{-7}
\]

11. (4 points) At 25 °C, what is the \( H_3O^+ \) concentration in 0.044 M NaOH(aq)? \( (K_w = 1.0 \times 10^{-14}) \)

a) \( 4.4 \times 10^{-16} \) M  b) \( 2.3 \times 10^{-13} \) M  c) \( 4.4 \times 10^{-7} \) M  d) \( 1.36 \) M  e) \( 2.6 \) M

\[
\text{in 0.044 M NaOH} \Rightarrow [OH^-] = 0.044 \text{ M}
\]

\[
\text{At 25°C, } \frac{[H_3O^+]}{[OH^-]} = \frac{K_w}{[OH^-]} = \frac{1 \times 10^{-14}}{0.044} = 2.3 \times 10^{-13}
\]

12. (3 points) What is the \( H_3O^+ \) concentration of an aqueous solution with a pH of 12.17?

a) \( 8.1 \times 10^{-13} \) M  b) \( 1.9 \times 10^{-9} \) M  c) \( 5.2 \times 10^{-6} \) M  d) \( 1.5 \times 10^{-2} \) M  e) \( 1.1 \) M

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

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

\[
[H_3O^+] = 10^{-12.17} = 6.8 \times 10^{-13}
\]

\[
10^{-\text{pH}} = [H_3O^+]
\]
13. (3 points) Which of the following chemical equations corresponds to the acid ionization constant, $K_a$, for formic acid ($\text{HCO}_2\text{H}$)?
   a) $\text{HCO}_2\text{H}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCO}_2^-(aq) + \text{H}_3\text{O}^+(aq)$
   b) $\text{HCO}_2\text{H}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCO}_2\text{H}^+(aq) + \text{H}_2\text{O}(l)$
   c) $\text{HCO}_2^- + \text{H}_2\text{O}(aq) \rightleftharpoons \text{HCO}_2\text{H}(aq) + \text{OH}^-(aq)$
   d) $\text{HCO}_2^- + \text{H}_2\text{O}(aq) \rightleftharpoons \text{HCO}_2\text{H}(aq) + \text{H}_2\text{O}(l)$
   e) $\text{HCO}_2\text{H}(aq) + \text{OH}^-(aq) \rightleftharpoons \text{HCO}_2^- + \text{H}_2\text{O}(l)$

14. (4 points) Which of the following solutions is NOT a buffer?
   a) 0.10 M NaF + 0.05 M HF
   b) 0.10 M NH$_3$ + 0.05 M NH$_4$Cl
   c) 0.10 M KCH$_3$CO$_2$ + 0.05 M CH$_3$CO$_2$H
   d) 0.10 M NaCl + 0.05 M HCl
   e) all the above are buffers

15. (4 points) Assuming equal initial concentrations of the given species, which of the following is the weakest acid in an aqueous solution?
   a) hydrogen phosphate ion, $K_a = 3.6 \times 10^{-13}$
   b) formic acid, $K_a = 1.8 \times 10^{-4}$
   c) benzoic acid, $K_a = 6.3 \times 10^{-5}$
   d) hydrogen sulfite ion, $K_a = 6.2 \times 10^{-8}$
   e) nitrous acid, $K_a = 4.5 \times 10^{-4}$

16. (4 points) Propanoic acid (CH$_3$CH$_2$CO$_2$H) has a pK$_a$ value of 4.89. What is the value of $K_b$ for sodium propanoate (Na CH$_3$CH$_2$CO$_2$)?
   a) $1.3 \times 10^{-5}$
   b) $7.8 \times 10^{-10}$
   c) $1.3 \times 10^{-19}$
   d) -9.11
   e) 9.11

\[
14 = pK_a + pK_b \\
pK_b = 14 - pK_a = 14 - 4.89 = 9.11 \\
K_b = 10^{-pK_b} = 10^{-9.11} = 7.8 \times 10^{-10}
\]

17. (4 points) Which salt forms a 0.10 M aqueous solution with the lowest pH?
   a) MgCO$_3$
   b) NaCl
   c) NaF
   d) NH$_4$Cl
   e) K$_3$PO$_4$

   a) $\text{CO}_3^{2-} + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{OH}^- \Rightarrow \text{increase pH}$
   b) NaCl neutral salt $\Rightarrow$ pH remains constant
   c) $\text{F}^- + \text{H}_2\text{O} \rightleftharpoons \text{FH}^- + \text{OH}^- \Rightarrow \text{same as a)}$
   d) $\text{NH}_4^+ + \text{H}_2\text{O} \rightleftharpoons \text{NH}_3 + \text{H}_3\text{O}^+ \Rightarrow \text{increase (H}_3\text{O}^+) \Rightarrow \text{decrease pH}$
   c) $\text{PO}_4^{3-} + \text{H}_2\text{O} \rightleftharpoons \text{HPO}_4^{2-} + \text{OH}^- \Rightarrow \text{same as a}$
18. (6 points) What is the $\text{H}_3\text{O}^+$ concentration in 0.45 M HCN(aq)? ($K_a$ of HCN = $4.0 \times 10^{-10}$)
   a) $4.0 \times 10^{-10}$ M  
   b) $1.8 \times 10^{-10}$ M  
   c) $3.0 \times 10^{-5}$ M  
   d) $2.0 \times 10^{-5}$ M  
   e) 0.45 M

   $K_a = \frac{x \cdot x}{0.45 - x}$
   
   $C_a = 0.45\, \text{M} \gg 1000.$
   
   $K_a = 4.0 \times 10^{-10}$
   
   $x = \sqrt{K_a \cdot 0.45} = \sqrt{4.0 \times 10^{-10} \cdot 0.45} = 1.3 \times 10^{-5}$

19. (6 points) The pH of aqueous 0.050 M trimethylamine ($\text{(CH}_3\text{)}_3\text{N}$) is 11.24. What is the $K_b$ of this base?
   a) $6.6 \times 10^{-22}$  
   b) $5.8 \times 10^{-12}$  
   c) $6.3 \times 10^{-5}$  
   d) $1.7 \times 10^{-3}$  
   e) 2.76

   $\text{Base} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{OH}^-$
   
   0.050  
   
   $p\text{OH} = 14 - pH = 2.76$
   
   $[\text{OH}^-] = 10^{-p\text{OH}} = 10^{-2.76} = 1.3 \times 10^{-3}$

20. (5 points) Given a solution of 0.10 M NH$_3$(aq), what is the effect of adding NH$_4$Cl(s) to this solution?
   1. The pH will decrease.  
   2. The concentration of NH$_3$ will increase.  
   3. The concentration of H$_3$O$^+$ will increase.
   a) 1, only  
   b) 2 only  
   c) 3 only  
   d) 1 and 3  
   e) 1, 2, and 3

21. (3 points) Which of the following statements are CORRECT?
   1. For gas phase equilibria, the partial pressures of reactants and products are equal.
   2. For a chemical system at equilibrium, the forward and reverse rates of reaction are equal.
   3. For an aqueous chemical system at equilibrium, the concentrations of products divided by the concentrations of reactants equals one.
   a) 1 only  
   b) 1 and 2  
   c) 2 only  
   d) 3 only  
   e) 1, 2, and 3
22. (4 points) Write a balanced chemical equation which corresponds to the following equilibrium constant expression.

\[ K = [\text{Fe}^{3+}] [\text{OH}^-]^3 \]

a) \( \text{FeOH}^2^+(s) \rightleftharpoons \text{Fe}^{3+}(aq) + \text{OH}^-(aq) \)
b) \( 3 \text{ Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \rightleftharpoons 3 \text{ Fe(OH)}_3(aq) \)
c) \( \text{Fe(OH)}_3(aq) \rightleftharpoons \text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \)
d) \( \text{Fe(OH)}_3(s) \rightleftharpoons \text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \)
e) \( \text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \rightleftharpoons 3 \text{ Fe(OH)}_3(s) \)

solids are not included in equilibrium expressions.

23. (4 points) What is the relationship between \( K_p \) and \( K_c \) for the reaction below?

\[ \text{CS}_2(g) + 3 \text{ Cl}_2(g) \rightleftharpoons \text{S}_2\text{Cl}_2(g) + \text{CCl}_4(g) \]

a) \( K_c = \frac{K_p}{(RT)^2} \)
b) \( K_c = \frac{(RT)^2}{K_p} \)
c) \( K_c = (RT)^2 K_p \)
d) \( K_c = \left( \frac{RT}{K_p} \right)^2 \)
e) \( K_c = \left( \frac{K_p}{RT} \right)^2 \)

24. (6 points) A 4.00 L flask is filled with 0.75 mol \( \text{SO}_3 \), 2.50 mol \( \text{SO}_2 \), and 1.30 mol \( \text{O}_2 \). Predict the effect on the concentrations of \( \text{SO}_3 \) as equilibrium is achieved by using \( Q \), the reaction quotient. Assume the temperature of the mixture is chosen so that \( K_c = 12 \).

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

a) \( [\text{SO}_3] \) will decrease because \( Q > K \).
b) \( [\text{SO}_3] \) will decrease because \( Q < K \).
c) \( [\text{SO}_3] \) will increase because \( Q < K \).
d) \( [\text{SO}_3] \) will increase because \( Q > K \).
e) \( [\text{SO}_3] \) will remain the same because \( Q = K \).

\[ \left[ \text{SO}_3 \right] = \frac{0.75 \text{ mol}}{4.00 \text{ L}} = 0.187 \text{ M} \]

\[ \left[ \text{SO}_2 \right] = \frac{2.50 \text{ mol}}{4.00 \text{ L}} = 0.625 \text{ M} \]

\[ \left[ \text{O}_2 \right] = \frac{1.30 \text{ mol}}{4.00 \text{ L}} = 0.325 \text{ M} \]

\[ Q = \frac{[\text{SO}_2]^2 [\text{O}_2]}{[\text{SO}_3]^2} = \frac{(0.625)^2 \cdot 0.325}{(0.187)^2} = 3.632 < K_c = 12 \]

\( Q < K \Rightarrow [\text{SO}_3] \) will decrease.

\( 2\text{SO}_3 \rightleftharpoons 2\text{SO}_2 + \text{O}_2 \)
25. (6 points) The equilibrium constant, $K_c$, for the following reaction is $1.0 \times 10^{-5}$ at 1500 K.

$$
N_2(g) + O_2(g) \rightleftharpoons 2 \text{NO(g)}
$$

If 0.750 M $N_2$ and 0.750 M $O_2$ are allowed to equilibrate at 1500 K, what is the final concentration of NO?

a) $6.7 \times 10^{-4}$ M  
 b) $1.2 \times 10^{-3}$ M  
 c) $2.4 \times 10^{-3}$ M  
 d) $2.7 \times 10^{-3}$ M  
 e) $5.5 \times 10^{-3}$ M

$$
\begin{align*}
K_c &= \frac{(2x)^2}{(0.750-x)^2} \\
C &= 0.750 > 100. \\
k_c &= 1.0 \times 10^{-5} \\
k_c = \frac{4x^2}{(0.750)^2} \quad \Rightarrow \quad k_c(0.750)^2 = x^2 \\
x &= \sqrt{\frac{1.0 \times 10^{-5} \times (0.750)^2}{4}} = 1.2 \times 10^{-3} \\
\left[ \text{NO} \right] &= 2x = 2.12 \times 10^{-3} = 2.4 \times 10^{-3}
\end{align*}
$$

26. (6 points) If the rate constant $k$ for a reaction goes from 10/sec to 30/sec when a reaction goes from 300K to 310K, what is the activation energy of the reaction?

a) $9.82 \times 10^{-7}$ kJ/mole  
 b) $84.9$ kJ/mole  
 c) $232$ kJ/mole  
 d) $8.49 \times 10^4$ kJ/mole  
 e) None of the above

$$
\ln \frac{k_2}{k_1} = -\frac{E_a}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)
$$

$$
-\frac{R \ln(k_2/k_1)}{\frac{1}{T_2} - \frac{1}{T_1}} = E_a
$$

$$
E_a = \frac{-8.31 \times 10^{-3} \text{ kJ/mol} \cdot \ln \left( \frac{30}{300} \right)}{\frac{1}{310K} - \frac{1}{300K}} = 84.9 \text{ kJ/mol}
$$
27. (6 points) Given the following acid dissociation constants,

\[ K_a (HF) = 7.2 \times 10^{-4} \]
\[ K_a \left( \text{NH}_4^+ \right) = 5.6 \times 10^{-10} \]

determine the equilibrium constant for the reaction below at 25 °C.

\[
\text{HF(aq) + NH}_3\text{(aq)} \rightleftharpoons \text{NH}_4^+(aq) + F^-(aq)
\]

\[ a) \ 4.0 \times 10^{-13} \quad b) \ 1.3 \times 10^{6} \quad c) \ 7.8 \times 10^{-7} \quad d) \ 1.3 \times 10^{-8} \quad e) \ 2.5 \times 10^{12} \]

\[
\begin{align*}
K_a \left( \text{HF} + \text{H}_2\text{O} \right) &= \text{F}^- + \text{H}_3\text{O}^+ \\
K_a \left( \text{NH}_4^+ + \text{H}_2\text{O} \right) &= \text{NH}_3 + \text{H}_3\text{O}^+ \\
\frac{1}{K_a \left( \text{NH}_4^+ + \text{H}_2\text{O} \right)} &= \frac{1}{K_{a_2}} \Rightarrow \\
\frac{1}{K_{a_2}} &= \frac{K_a \left( \text{HF} + \text{H}_2\text{O} \right)}{K_a \left( \text{NH}_4^+ + \text{H}_2\text{O} \right)} \\
K &= K_a \left( \text{HF} + \text{H}_2\text{O} \right) \frac{1}{K_{a_2}} = \frac{7.2 \times 10^{-4}}{5.6 \times 10^{-10}} = 1.3 \times 10^6
\end{align*}
\]

28. (4 points) The thermochemical equation for the formation of ammonia from elemental nitrogen and hydrogen is as follows.

\[
\text{N}_2\text{(g)} + 3 \text{H}_2\text{(g)} \rightleftharpoons 2 \text{NH}_3\text{(g)} \quad \Delta H = -92.2 \text{ kJ}
\]

Which of the following will drive the equilibrium system to the right?

a) adding \( \text{NH}_3\text{(g)} \)
b) removing \( \text{N}_2\text{(g)} \)
c) increasing the volume of the reaction vessel
d) increasing the temperature
e) adding \( \text{H}_2\text{(g)} \)

b) adding \( \text{NH}_3 \) will drive the equil to the left

c) increasing the V \( \Rightarrow \) increase num of molecules \( \Rightarrow \) to the left

d) increasing T for exothermic reaction will drive the eq. to the left

e) adding \( \text{H}_2 \) will drive the eq. to the right

Please sign the following statement at the completion of the exam:

I did not cheat on this exam. ____________________________ (name)

__________________________ (signature)