Sample Exam Questions

1. Determine the formal charges for each of the unique atoms in
   a. $\text{SO}_3^{2-}$
   b. $\text{NH}_4^+$

   a. \[
   \begin{array}{c}
   \text{O} \quad \text{S} \quad \text{O} \\
   - \quad + \quad - \\
   \end{array}
   \]
   \[
   \begin{array}{c}
   \text{O} \quad \text{S} \quad \text{O} \\
   - \quad + \quad - \\
   \end{array}
   \]
   \[
   \begin{array}{c}
   \text{O} \quad \text{S} \quad \text{O} \\
   - \quad + \quad - \\
   \end{array}
   \]

   \[
   \begin{array}{c}
   \text{S} = 6 - 2 - 1/2(8) = 0 \\
   \text{O (double bond)} = 6 - 4 - 1/2(4) = 0 \\
   \text{O (single bond)} = 6 - 6 - 1/2(2) = -1
   \end{array}
   \]

   b. \[
   \begin{array}{c}
   \text{H} \\
   \text{N} \\
   \text{H}
   \end{array}
   \]

   \[
   \begin{array}{c}
   \text{H} \\
   \text{N} \\
   \text{H}
   \end{array}
   \]

   \[
   \begin{array}{c}
   \text{H} = 1 - 0 - 1/2(2) = 0 \\
   \text{N} = 5 - 0 - 1/2(8) = +1
   \end{array}
   \]

2. For the system $2 \text{HI}(g) \leftrightarrow \text{H}_2(g) + \text{I}_2(g)$, it is found that if one starts with pure HI at a concentration of 0.50 mol/L, its concentration at equilibrium is 0.10 mol/L. Calculate $K$ for the reaction.

   \[
   \begin{array}{c}
   \text{HI} \\
   \text{H}_2 \\
   \text{I}_2
   \end{array}
   \]

   \[
   \begin{array}{c}
   \begin{array}{c}
   \text{Initial} \\
   \text{Change} \\
   \text{Equilibrium}
   \end{array}
   \end{array}
   \]

   \[
   \begin{array}{c}
   0.50 \\
   -2x \\
   0.10
   \end{array}
   \]

   \[
   \begin{array}{c}
   0 \\
   +x \\
   x
   \end{array}
   \]

   \[
   \begin{array}{c}
   0 \\
   +x \\
   x
   \end{array}
   \]

   \[
   x = 0.20 \text{ M} \quad \therefore \quad [\text{H}_2] = [\text{I}_2] = 0.20 \text{ M}
   \]

   \[
   K = \frac{[\text{H}_2]RT [\text{I}_2]RT}{[\text{HI}]^2RT^2} = \frac{[\text{H}_2] [\text{I}_2]}{[\text{HI}]^2}
   \]

   \[
   = \frac{(0.20)^2}{(0.10)^2} = 4.0
   \]

3. Consider the equilibrium for the following exothermic reaction

   \[
   \begin{array}{c}
   \text{N}_2(g) + 3 \text{H}_2(g) \leftrightarrow 2 \text{NH}_3(g)
   \end{array}
   \]

   A mixture of these three substances reaches equilibrium at 200°C. Predict the direction in which the system will move (right or left) to re-establish equilibrium if

   a. 1 mole of $\text{H}_2$ is removed

   removing some reactant will make $Q$ larger than $K$. The reaction must shift to the left to re-establish equilibrium
b. the total pressure is increased by adding H₂ (volume remains constant)

adding some reactant will make Q smaller than K. The reaction must shift to the right to re-establish equilibrium.

c. the volume of the container is reduced

reducing the volume will cause the reaction to shift toward the smaller number of moles of gas -- to the right.

d. the temperature is raised to 300°C

the reaction is exothermic so raising the temperature is like adding some product -- the reaction with shift to the left.

4. Find the pH of solutions with the following:

a. \([H_3O^+] = 1.0 \times 10^{-2}\) M

\[\text{pH} = -\log (1.0 \times 10^{-2}\ M) = 2.00\]

b. \([\text{HCl}] = 7.4 \times 10^{-5}\) M

HCl is a strong acid and it reacts completely with water. The number of moles of HCl reacting will form the same number of moles of \(H_3O^+\). So the \([\text{HCl}] = [H_3O^+]\).

\[\text{pH} = -\log (7.4 \times 10^{-5}\ M) = 4.13\]

c. \([\text{OH}^-] = 4.0 \times 10^{-5}\) M

\[\text{pH} = 14.00 + \log (4.0 \times 10^{-5}\ M) = 9.60\]

d. \([\text{KOH}] = 6.2 \times 10^{-2}\) M

KOH is a strong base and it ionizes completely in water to form \(K^+\) and \(\text{OH}^-\). The number of moles of KOH equals the number of moles of \(\text{OH}^-\). So the \([\text{KOH}] = [\text{OH}^-]\).

\[\text{pH} = 14 + \log (6.2 \times 10^{-2}\ M) = 12.79\]

5. The following pictures represent aqueous solutions of three acids HA (A = X, Y, or Z); water molecules have been omitted for clarity:

(a) What is the conjugate base of each acid?
(b) Arrange the three acids in order of increasing acid strength.
(c) Which acid, if any, is a strong acid?
(d) Which acid has the smallest value of \(K_a\)?

a. \(\text{HX}: \ X^-; \ \text{HY}: \ Y^-; \ \text{HZ}: \ Z^-\)
b. $HX < HZ < HY$

c. HY is strong (completely dissociated)

d. HX

6. The freezing point of seawater is about $-1.85^\circ C$. If seawater is an aqueous solution of sodium chloride, calculate the molality of NaCl in seawater. The $K_f$ for water is $1.86^\circ C/m$.

$$\Delta T_f = -i K_f m$$

(here $m$ is the molality of the solution and $i$ is the # of particles)

$$-1.85 = -2 (1.86 \text{ kg K mol}^{-1}) m$$

$$m = 0.497 \text{ mol kg}^{-1}$$

7. What is the most important kind of intermolecular force present in chloroform, CHCl$_3$?

dipole-dipole forces

8. Water gas, a commercial fuel, is made by the reaction of hot coke with steam:

$$C(s) + H_2O(g) \leftrightarrow CO(g) + H_2(g)$$

When equilibrium is established at 800°C, the concentrations of CO, H$_2$, and H$_2$O are $4.0 \times 10^{-2}$ M, $4.0 \times 10^{-2}$ M, and $1.0 \times 10^{-2}$ M, respectively.

a. Calculate $K$.

$$K = \frac{[CO][H_2]}{[H_2O]} = \frac{(4.0 \times 10^{-2})^2}{(1.0 \times 10^{-2})} = 0.16$$

b. What will be the final concentrations of CO and H$_2$ if enough steam is added to raise its concentration temporarily to $4.0 \times 10^{-2}$ M?

\[
\begin{array}{cccc}
\text{C} & + & H_2O & \leftrightarrow & CO & + & H_2 \\
\text{Initial} & - & 4.0 \times 10^{-2} & 4.0 \times 10^{-2} & 4.0 \times 10^{-2} \\
\text{Change} & - & -x & +x & +x \\
\text{Equilibrium} & - & 4.0 \times 10^{-2} - x & 4.0 \times 10^{-2} + x & 4.0 \times 10^{-2} + x \\
\end{array}
\]

$$K = 0.16 = \frac{(4.0 \times 10^{-2} + x)^2}{4.0 \times 10^{-2} - x}$$

$$x = 0.0186 \quad \text{So} \ [CO] = [H_2] = 4.0 \times 10^{-2} + 0.0186 = 0.059 \text{ M}$$

9. Persons are medically considered to have lead poisoning if they have a concentration of greater than 10 micrograms of lead per deciliter of blood. What is this concentration in parts per billion? (Assume that blood has a density of 1.00 g / mL.)

\[
(10 \times 10^{-6} \text{ g} / 0.10 \text{ L})(1 \times 10^{-3} \text{ L} / 1.00 \text{ g}) = 1 \times 10^{-7} \text{ g Pb} / 1.00 \text{ g blood}
\]

\[
\text{ppb} = \frac{[1 \times 10^{-7} \text{ g} / (1 \times 10^{-7} \text{ g} + 1.00 \text{ g})]} {10^9} = 100 \text{ ppb}
\]

10. Consider the reaction $N_2(g) + 3 H_2(g) \leftrightarrow 2 NH_3(g)$ where the partial pressures of $N_2$, $H_2$, and $NH_3$ are 1.0, 4.2, and 6.3 atm, respectively, and the temperature is 400 K. For this reaction, $K = 41$ at 400 K. Is this reaction mixture likely to form reactants, products, or is it at equilibrium?

$$Q = \frac{P_{NH_3}^2}{P_{N_2} P_{H_2}^3} = \frac{(6.3)^2}{(1.0)(4.2)^3} = 0.54$$

This value of $Q$ is less than $K$, suggesting that the reaction mixture is likely to form products rather than go back to reactants at the given temperature.
11. What is the shape of the following molecules? Which are polar?
   a. SO₂  \hspace{1cm} \text{bent, polar}
   b. PH₃  \hspace{1cm} \text{trigonal pyramidal, polar}
   c. NO₃⁻  \hspace{1cm} \text{trigonal planar, nonpolar}
   d. CO₂  \hspace{1cm} \text{linear, nonpolar}

12. Consider the reaction \( \text{CO}_\text{(g)} + 2 \text{H}_\text{(g)} \leftrightarrow \text{CH}_\text{₃OH}_\text{(g)} \). At room temperature, \( K \) is approximately \( 2 \times 10^4 \) but at a higher temperature \( K \) is substantially smaller. Which of the following is true?
   a. At the higher temperature, more \( \text{CH}_\text{₃OH}_\text{(g)} \) is produced.
   b. The reaction is endothermic.
   c. The reaction is exothermic.

   If \( K \) is smaller at the higher temperature then at that temperature there are more reactants and less products. An exothermic reaction will shift toward reactants when \( T \) is increased.

13. The following pictures represent mixtures of A molecules (open circles) and B molecules (closed circles), which interconvert according to the equation \( A \leftrightarrow B \). If mixture (1) is in equilibrium, which of the other mixtures are also at equilibrium? Explain.

   For (1): \( K_c = \frac{2}{6} = \frac{1}{3} = 0.33 \)

   (2): \( Q = \frac{4}{4} = 1 \)  \hspace{1cm} \text{not at equilibrium}
   (3): \( Q = \frac{3}{9} = 0.33 \)  \hspace{1cm} \text{at equilibrium}
   (4): \( Q = \frac{9}{3} = 3 \)  \hspace{1cm} \text{not at equilibrium}