CH40S **Chemical Equilibrium Unit Review**

Part A: Multiple Choice

1. Consider the following equilibrium:

$$H_2O_{(g)} + CO_{(g)} \leftrightarrow H_{2(g)} + CO_{2(g)}$$

At high temperature, H_2O and CO are placed in a closed container. As the system approaches equilibrium, the

A) rate of the forward and reverse reactions both increase.
B) rate of the forward and reverse reactions both decrease.
C) rate of the forward reaction decreases and the rate of the reverse reaction increases.
D) rate of the forward reaction increases and the rate of the reverse reaction decreases.

2. Which of the following **BEST** explains why solids and liquids are not included in equilibrium expressions?

A) Concentrations of solids and liquids cancel in the equilibrium expression.
B) Concentrations of solids and liquids = 1 *M*.
C) Concentrations of solids and liquids = 0 in equilibrium expressions.
D) Concentrations of solids and liquids are constants.

3. Which of the following is the correct equilibrium expression for the reaction

$$CH_{4(g)} + 2H_2O_{(g)} \leftrightarrow CO_{2(g)} + 4H_{2(g)}?$$

A) $K_c = \frac{[CH_4][H_2O]}{[CO_2][H_2]}$

B) $K_c = \frac{[CO_2][H_2]}{[CH_4][H_2O]}$

C) $K_c = \frac{[CO_2][H_2]^4}{[CH_4][H_2O]^2}$

D) $K_c = \frac{[CH_4][H_2O]^2}{[CO_2][H_2]^4}$

4. Consider the following equilibrium:

$$2NOCl_{(g)} \leftrightarrow 2NO_{(g)} + Cl_{2(g)}$$

In a 1.0 L container at equilibrium there are 1.0 mol NOCl, 0.70 mol NO and 0.40 mol Cl_2. At constant temperature and volume, 0.10 mol NOCl is added. The concentrations in the "new"equilibrium in comparison to the concentrations in the "old" equilibrium are

	[NOCl]	[NO]	[Cl_2]
A)	new = old	new = old	new = old
B)	new > old	new > old	new > old
C)	new < old	new < old	new > old
D)	new < old	new > old	new > old

5. An equilibrium system shifts reverse when the temperature is increased. The forward reaction is

   A) exothermic and ΔH is positive.
   B) exothermic and ΔH is negative.
   C) endothermic and ΔH is positive.
   D) endothermic and ΔH is negative.

6. What is the value of K_{eq} for the reaction $\boldsymbol{CO_{(g)} + 2H_{2(g)} \leftrightarrow CH_3OH_{(g)}}$, if the equilibrium concentrations are [CO] = 2.0 *M*, [H_2] = 5.3 *M*, and [CH_3OH] = 4.0 *M*?

   A) 5.3
   B) 0.072
   C) 2.6
   D) 14

7. Consider the following equilibrium:

   $$2O_{3(g)} \cdots\cdots \leftrightarrow 3O_{2\cdot(g)} \cdots\cdots \quad K_c = \cdot 55$$

   If 0.060 mol of O_3 and 0.70 mol of O_2 are introduced into a 1.0 L vessel, the equilibrium shifts

   A) reverse and the [O_2] increases.
   B) forward and the [O_2] increases.
   C) reverse and the [O_2] decreases.
   D) forward and the [O_2] decreases.

8. Which of the following statements is correct concerning the relationship of the equilibrium constant to temperature?

   A) If the heat of reaction is negative for a given reaction, then the equilibrium constant for that reaction will increase with increasing temperature.
   B) If the heat of reaction is positive for a given reaction, then the equilibrium constant for that reaction will decrease with increasing temperature.
   C) The equilibrium constant for an exothermic reaction decreases as the temperature increases.
   D) The equilibrium constant for a reaction is independent of temperature.

9. A closed flask is set up in which only substance C is present with an initial concentration of 0.80 *M*. When a state of equilibrium is reached in the reaction

   $$\boldsymbol{C \leftrightarrow D + 2E}$$

   the equilibrium concentration of C is 0.20 *M*. What are the equilibrium concentrations of D and E?

   A) [D] = 0.60 *M* and [E] = 0.30 *M*
   B) [D] = 0.20 *M* and [E] = 0.10 *M*
   C) [D] = 0.60 *M* and [E] = 0.60 *M*
   D) [D] = 0.60 *M* and [E] = 1.2 *M*

10. Which of the following **incorrectly** matches the concentration stress with the direction of the net reaction for the equilibrium reaction

$$Fe_2O_{3(s)} + 3CO_{(g)} \leftrightarrow 2Fe_{(s)} + 3CO_{2(g)}?$$

A) adding CO_2 : shifts reaction reverse
B) adding CO : shifts reaction forward
C) removing CO : shifts reaction forward
D) adding Fe : no shift

Part B: Long Answer

1. At a high temperature the following system reaches equilibrium:

$$\boldsymbol{N_{2\,(g)} + O_{2(g)} \leftrightarrow 2\,NO_{(g)}}$$

An analysis of the mixture in a one litre container gives the following results: nitrogen = 0.50 moles, oxygen = 0.50 moles, nitrogen monoxide = 0.020 mol.

a) Calculate K_c for this system. **(1.6×10^{-3})**

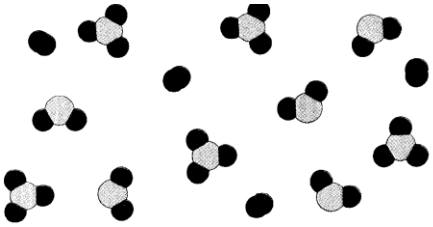
b) At the same temperature, a new system is made with 0.70 moles of each of the reactants. Find the concentration of the NO after equilibrium is reached. **(0.0027M)**

2. One of the steps in the synthesis of sulfuric acid is the combustion of sulfur dioxide:

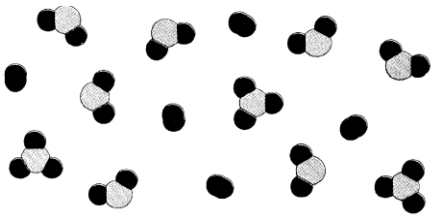
$$\boldsymbol{2\,SO_{2(g)} + O_{2(g)} \leftrightarrow 2\,SO_{3(g)}}$$

The diagrams below represent various equilibrium mixtures for this reaction.

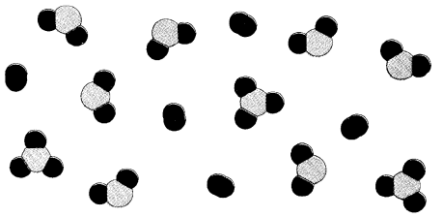
Equilibrium mixture at 1100°C, at 1 atmosphere pressure.



a) Equilibrium mixture at 1100 °C and different pressure. Has pressure increased or decreased? Explain.



b) Equilibrium mixture at 1300 °C, with 1 atmosphere pressure. Is reaction exo- or endothermic? Explain.



3. The reaction $N_2O_4(g) \longleftrightarrow 2\ NO_2(g)$ has a ΔH = +56.9 kJ/mol. How will the amount of NO_2 at equilibrium be affected by
   a) lowering the pressure?
   b) raising the temperature?

4. Write the Mass-action expression of the Law of Chemical Equilibrium for the following reversible reactions.
   a) $C_3H_7OH_{(l)} + CH_3COOH_{(l)} \leftrightarrow CH_3COOC_3H_{7(l)} + H_2O_{(l)}$
   b) $2H_{2(g)} + O_{2(g)} \leftrightarrow 2H_2O_{(g)}$
   c) $NH_4Cl_{(s)} \leftrightarrow NH_{3\ (g)} + HCl_{(g)}$

5. At 25 °C, Kc =0.0146 for the following reaction: $PCl_5 \leftrightarrow PCl_3 + Cl_2$
   If, at equilibrium, the molar concentrations for PCl_5 and PCl_3 are 0.500 M and 0.200 M respectfully, calculate the concentration of chlorine gas. **(0.0365M)**

6. Consider the reaction: $CO + 2H_2 \leftrightarrow CH_3OH$. All substances are in the gaseous state and the change in enthalpy is -92 kJ, whether the reactants (left side) or the products (right side) will be favored by the following changes (consider each change independently):

   a) increased pressure
   b) increased temperature
   c) addition of hydrogen
   d) removal of the product, CH_3OH

7. A mixture of ethyl propionate (an ester) and water is prepared in which the initial ester concentration is 6.0 M and the initial water concentration is 10.0 M. (You may assume that the initial concentration of each product is zero.) After equilibrium is established, the concentration of propionic acid is 3.0 M. The reaction is:

   $$C_3H_7COOC_2H_{5(aq)} + H_2O_{(g)} \leftrightarrow C_3H_7COOH_{(aq)} + C_2H_5OH_{(aq)}$$

   Calculate Kc for the reaction. **(0.43)**

8. Consider the reaction: 2A <=======> B + C. Suppose the equilibrium constant for the reaction at 25 °C is 4.0 X 10^{-6} If you allow 500 ml of a 2.00 M solution of A to come into equilibrium, how many moles of A, B, and C are present at equilibrium?
([A]=1.992M, [B]=[c]=.004M)

9. A mixture at equilibrium at 827°C contains 0.552 mol CO_2, 0.552 mol H_2, 0.448 mole CO and 0.448 mol H_2O. Calculate the Kc. **(0.66)**

$$CO_{2(g)} + H_{2(g)} \leftrightarrow CO_{(g)} + H_2O_{(g)}$$

10. For the reaction, $2SO_{2(g)} + O_{2(g)} \leftrightarrow 2SO_{3(g)}$, the concentrations of sulfur oxides are [SO2] = 4.0M and [SO3] = 12.0M. What is the concentration of the oxygen if the Kc is 75.0? **(0.12M)**

11. At a specific temperature, 0.08 mole of each reactant is placed in to a 1L container. At equilibrium, the [CO] is 0.03M. What is the value of the Kc? **(0.36)**

$$CO_{2(g)} + H_{2(g)} \leftrightarrow CO_{(g)} + H_2O_{(g)}$$

12. A substance decomposes according to the reaction $CD_{(g)} \leftrightarrow C_{(g)} + D_{(g)}$. At the temperature of the experiment, 25% of CD is decomposed when equilibrium is established.
    a) If the initial concentration of CD is 0.25M, what are the equilibrium concentrations of CD, C and D? **([CD]=0.1875M, [C]=[D]=0.083M)**
    b) What is the Kc for the reaction at this temperature? **(0.02)**

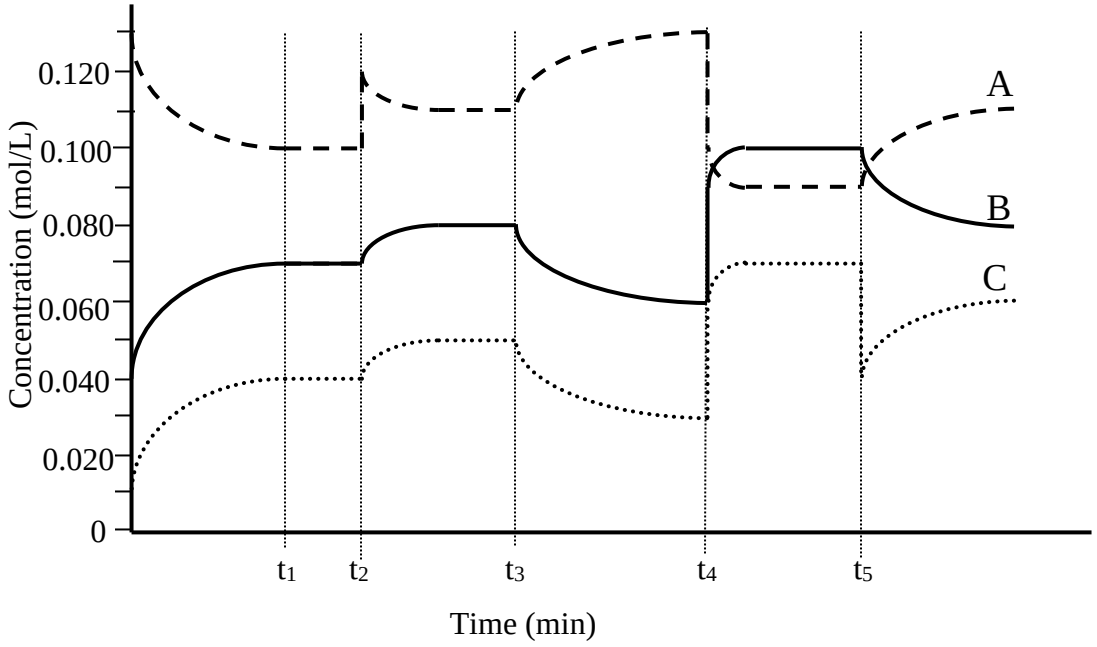
13. Given the reaction $N_{2(g)} + 3Cl_{2(g)} \leftrightarrow 2NCl_{3(g)}$ if 1.0 mole of N_2, Cl_2, are placed in a 2L container and allowed to reach equilibrium. What is the concentration of NCl_3 and N_2 if 0.75 mole of Cl_3 remains? Kc?
([NCl_3]=0.083M, [N_2]=0.459M, Kc=0.28)

14. Can a pressure change be used to shift the position of equilibrium in every reversible reaction? Explain. **(notes)**

16. How do the rates of the forward and reverse reactions compare in a state of dynamic chemical equilibrium? Use a labeled diagram along with your answer.

17. Give two examples of physical equilibrium and explain the conditions required to maintain it. **(notes)**

18. Use the graph below represents the reaction A ←→ B + C ΔH = 22 kJ/mol



a) Calculate K_c at t_1.

b) Describe all the changes that may have occurred at
   i) t_2
   ii) t_3
   iii) t_4
   iv) t_5

Multiple Choice Answers:

1. C
2. D
3. C
4. B
5. B
6. B
7. C
8. C
9. D
10. C

CH40S **Ksp Unit Review**

Part A: Multiple Choice

1. Gold chloride, AuCl, has a K_{sp} of 2.0×10^{-13}. How many grams of gold chloride are found in 500 mL of a saturated aqueous solution of AuCl?

   A) 1.0×10^{-13} g
   B) 4.5×10^{-7} g
   C) 2.2×10^{-7} g
   D) 5.2×10^{-5} g

2. The mineral fluorite is composed of CaF_2. The molar solubility of calcium fluoride in water is 2.1×10^{-4} mol/L. What is the K_{sp} of CaF_2?

   A) 3.7×10^{-11}
   B) 2.14×10^{-4}
   C) 4.6×10^{-8}
   D) $.8 \times 10^{-12}$

3. Which of the following solids is *incorrectly* matched with its solubility product expression?

   A) $PbBr_2 : K_{sp} = [Pb^{2+}][Br^-]^2$
   B) $Ag_2S : K_{sp} = [Ag^+]^2[S^{2-}]$
   C) $Ni(OH)_2 : K_{sp} = [Ni^{2+}][OH^-]^2$
   D) $Ag_2CO_3 : K_{sp} = [Ag^+]^2[CO_3^{2-}]^3$

4. A 1.000 L solution is prepared in which Au^+, Ag^+, and Cu^+ ions are present in solution as nitrates, all at a concentration of 0.0010 mol/L. A solution of sodium chloride is slowly added. Which compound will begin to precipitate **first**? The K_{sp} of AuCl = 2.0×10^{-13}; AgCl = 1.8×10^{-10}; CuCl = 1.9×10^{-7}.

   A) CuCl
   B) AgCl
   C) AuCl
   D) $NaNO_3$

5. Which of the following compounds does **not** have an effect on the solubility of calcium phosphate when added to a saturated solution of calcium phosphate in pure water?

   A) $Mg_3(PO_4)_2$
   B) $CaCl_2$
   C) $MgSO_4$
   D) Na_3PO_4

6. Which of the following ions could be added to an aqueous mixture containing Pb^{2+} and Ba^{2+} to separate the ions by precipitating one of them?

   A) I^-
   B) NO_3^-
   C) PO_4^{3-}
   D) SO_4^{2-}

7. What is the concentration of a saturated solution of $BaCO_3$? (K_{sp} = 5.1 x 10^{-9})

A) 1.4 x 10^{-4} *M* B) 5.1 x 10^{-9} *M*
C) 7.1 x 10^{-5} *M* D) 1.0 x 10^{-8} *M*

8. The solubility of TlCl is 2.9 g in 1000 mL. What is the K_{sp}?

A) 1.5 x 10^{-4} B) 1.5 x 10^{-6}
C) 1.2 x 10^{-8} D) 1.2 x 10^{-7}

9. Which of the following when dissolved in water has the highest concentration of strontium ion?

A) $SrCO_3$; K_{sp} = 1.1 x 10^{-10} B) SrF_2; K_{sp} = 2.5 x 10^{-9}
C) $SrSO_4$; K_{sp} = 3.2 x 10^{-7} D) SrI_2; K_{sp} = 7.9 x 10^{-12}

10. The K_{sp} values for $CaSO_4$, $BaSO_4$, and Ag_2SO_4 are 2.0 x 10^{-4}, 1.5 x 10^{-9}, and 1.5x10^{-5} respectively. If 0.010 *M* Na_2SO_4 is slowly added to a solution that contains Ca^{2+}, Ba^{2+}, and Ag^{+} (each 0.10 *M*), which solid will precipitate last?

A) $CaSO_4$ B) Ag_2SO_4
C) $BaSO_4$ D) More information is required

Part B: Long Answer

11. The solubility of silver chromate, Ag_2CrO_4, in water is 0.011 g per 250. mL. Calculate the Ksp for Ag_2CrO_4. (**Ksp=9.41x10^{-12}**)

12. Calculate the solubility of strontium fluoride, SrF_2, in grams per 250. mL of water. (Ksp SrF_2 = 2.8 x 10^{-9}) **(2.79x10^{-2} g/250mL)**

13. Calculate the solubility in mol/L of SrF_2 in a solution of 0.010 mol/L NaF. **(2.8x10^{-5} mol/L)**

14. Which would dissolve more AgCl(*s*), 1.0 L of pure water or 1.0 L of tap water (remember that tap water has Cl^-)? Explain **(pure water)**

15. Calculate the solubility of $CaSO_4$ in mol/L and g/L if its Ksp is 6.1×10^{-5}.
(7.8×10^{-3} mol/L, 1.1 g/L)

16. Write the complete set of equations for the mixing of the following solutions:
    a) silver nitrate + potassium iodide
    b) copper sulfate + sodium sulfide

17. What **mass** of precipitate is formed when 100.0 mL of $AgNO_3$ is added to 20.0 mL of 1.00 mol/L NaBr? **(2.82 g)**

18. Calculate the mass of $PbSO_4$ formed when 1.25 L of 0.0500 mol/L $Pb(NO_3)_2$ and 2.00 L of 0.0250 mol/L Na_2SO_4 are mixed. **(15.2 g)**

19. Calculate the Ksp for bismuth sulfide (Bi_2S_3), which has a solubility of 5.1×10^{-13} g/L. **(1.0×10^{-73})**

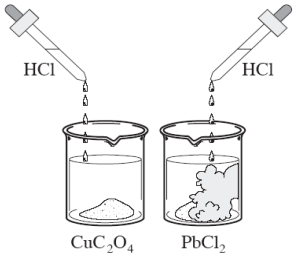
20. 100 mL of 0.100 mol/L $CaCl_2$ and 100. mL of 0.0400 mol/L Na_2SO_4 are mixed. Does a precipitate form? (Ksp = 3.6×10^{-5}) **(Q = 1.00×10^{-3})**

21. Tap water has a chloride concentration of 2.8×10^{-8} mol/L. What is the maximum concentration of Ag^+ that can be dissolved in 500.0 mL of this water such that a precipitate does **not** form. $K_{sp} = 1.7 \times 10^{-10}$ **(0.003 mol/500mL)**

22. What is the only factor that will affect the value of Ksp? Explain why, in terms of the amount of ions dissolved. **(notes)**

23. What is the molar solubility of magnesium carbonate, $MgCO_3$ ($K_{sp} = 8.5 \times 10^{-8}$), in 1.0 L of a 0.020 mol/L solution of $CaCO_3$ solution? **($4.25.5 \times 10^{-6}$M)**

24. As shown in the figure below, when HCl is added to a saturated solution of the sparingly soluble salt CuC_2O_4, some more of the undissolved CuC_2O_4 dissolves. However, when HCl is added to a saturated solution of $PbCl_2$, additional precipitate forms. Explain these observations. Support your explanation with chemical equations. **(Common Ion Theory)**



25. Calculate the K_{sp} for MgF_2 if the solubility of MgF_2 is 2.7×10^{-3} mol/L. **($ksp=7.9x10^{-8}$)**

26. Consider the slightly soluble salt $PbSO_4$ with $K_{sp} = 1.8 \times 10^{-8}$
How many grams of $PbSO_4$ dissolve in 1 L of solution? **(0.04g/1L)**

27. The solubility of PbI_2 is 0.63 g/L. What is the solubility product constant for PbI_2? **($Ksp=1.02x10^{-8}$)**

28. What is the molar solubility of AgCl ($K_{sp} = 1.8 \times 10^{-10}$) in 1.0 L of a solution with $[Cl^-] = 0.20$ mol/L? **($9.0x10^{-10}$mol/L)**

29. In an experiment, a student transfers a sample of saturated $MgBr_2$ solution into a beaker and evaporates the sample to dryness. She recorded the following data:

Volume of saturated $MgBr_2$	*25.00 mL*
Mass of beaker	*89.05 g*
Mass of beaker and residue	*93.47 g*

Calculate the solubility of $MgBr_2$ in moles per litre. **(0.96mol/L)**

30. A container is filled with 1.0 L of 0.050 M NaI. Calculate the maximum mass of solid $Pb(NO_3)_2$ that can be dissolved without forming a precipitate, given that K_{sp} $PbI_2 = 8.5x10^{-9}$ **(0.0016g)**

<u>Multiple Choice Key:</u>
1. D, 2. A, 3. D, 4. C, 5. C, 6. A, 7. C, 8. A, 9. C, 10. A