Unit 6 Equilibrium Practice Test
AP Chemistry

Name Key

$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g)$$

1. At 450°C, 2.0 moles each of $H_2(g)$, $I_2(g)$, and $HI(g)$ are combined in a 1.0 L rigid container. The value of K_c at 450°C is 50. Which of the following will occur as the system moves toward equilibrium?
   (A) More $H_2(g)$ and $I_2(g)$ will form.
   (B) More $HI(g)$ will form.
   (C) The total pressure will decrease.
   (D) No net reaction will occur, because the number of molecules is the same on both sides of the equation.

$Q = \frac{2^2}{2 \times 2} = 1 < 50$ ∴ shift right

Questions 2 – 6 refer to the following.

$$PCl_5(g) \rightleftarrows PCl_3(g) + Cl_2(g)$$

$PCl_5(g)$ decomposes into $PCl_3(g)$ and $Cl_2(g)$ according to the equation above. A pure sample of $PCl_5(g)$ is placed in a rigid, evacuated 1.00 L container. The initial pressure of the $PCl_5(g)$ is 1.00 atm. The temperature is held constant until the $PCl_5(g)$ reaches equilibrium with its decomposition products. The figures show the initial and equilibrium conditions of the system.

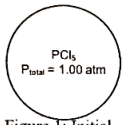


Figure 1: Initial

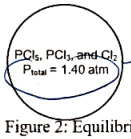


Figure 2: Equilibrium

2. Which is the most likely cause for the increase in pressure observed in the container as the reaction reaches equilibrium?
   (A) A decrease in the strength of intermolecular attractions among molecules in the flask
   (B) An increase in the strength of intermolecular attractions among molecules in the flask
   (C) An increase in the number of molecules, which increases the frequency of collisions with the walls of the container
   (D) An increase in the speed of the molecules that then collide with the walls of the container with greater force

3. As the reaction progresses toward equilibrium, the rate of the forward reaction
   (A) increases until it becomes the same as the reverse reaction rate at equilibrium
   (B) stays constant before and after equilibrium is reached
   (C) decreases to become a constant nonzero rate at equilibrium
   (D) decreases to become zero at equilibrium

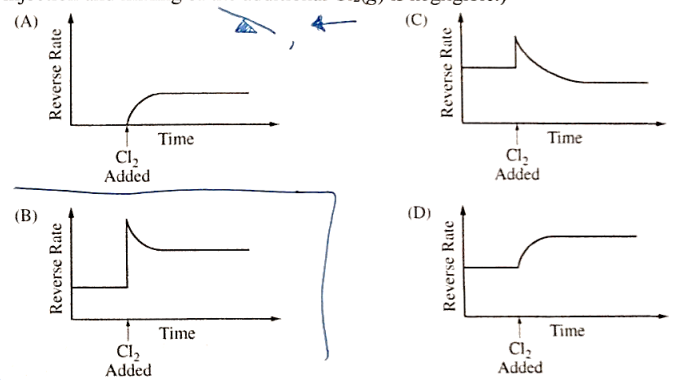
4. If the decomposition reaction were to go to completion, the total pressure in the container would be
   (A) 1.4 atm
   (B) 2.0 atm
   (C) 2.8 atm
   (D) 3.0 atm

$1 - x + x + x = 1.4$
$x = 0.4\,atm$ ∴ $K_p = \frac{(0.4)(0.4)}{(0.6)} < 1$

5. Which of the following statements about K_p, the equilibrium constant for the reaction, is correct?
   (A) $K_p > 1$
   (B) $K_p < 1$
   (C) $K_p = 1$
   (D) It cannot be determined whether $K_p > 1$, $K_p < 1$, or $K_p = 1$ without additional information.

	PCl_5	$\rightleftarrows PCl_3$	$+ Cl_2$
I	1	0	0
C	−x	+x	+x
E	1−x	x	x

6. Additional $Cl_2(g)$ is injected into the system at equilibrium. Which of the following graphs best shows the rate of the reverse reaction as a function of time? (Assume that the time for injection and mixing of the additional $Cl_2(g)$ is negligible.)



$$\text{Heat} + 2\,BaO_2(s) \rightleftarrows 2\,BaO(s) + O_2(g) \qquad \Delta H^\circ = 162\ kJ/mol_{rxn}$$

7. A sealed rigid vessel contains $BaO_2(s)$ in equilibrium with $BaO(s)$ and $O_2(g)$ as represented by the equation above. Which of the following changes will increase the amount of $BaO_2(s)$ in the vessel?
   (A) Removing a small amount of $O_2(g)$
   (B) Removing a small amount of $BaO(s)$
   (C) Adding He gas to the vessel
   (D) Lowering the temperature

8. Which of the systems in equilibrium represented below will exhibit a shift to the left (toward reactants) when the pressure on the system is increased by reducing the volume of the system? (Assume that temperature is constant.)
   (A) $SF_4(g) + F_2(g) \rightleftarrows SF_6(g)$
   (B) $H_2(g) + Br_2(g) \rightleftarrows 2\,HBr(g)$
   (C) $CaF_2(s) \rightleftarrows Ca^{2+}(aq) + 2\,F^-(aq)$
   (D) $SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g)$

Questions 9 – 11 refer to the following information.

$$CO(g) + 2\,H_2(g) \rightleftarrows CH_3OH(g) \qquad \Delta H < 0$$

+heat

The synthesis of $CH_3OH(g)$ from $CO(g)$ and $H_2(g)$ is represented by the equation above. The value of K_c for the reaction at 483 K is 14.5

9. Which of the following explains the effect on the equilibrium constant, K_c, when the temperature of the reaction system is increased to 650 K?
   (A) K_c will increase because the activation energy of the forward reaction increases more than that of the reverse reaction.
   (B) K_c will increase because there are more reactant molecules than product molecules.
   (C) K_c will decrease because the reaction is exothermic.
   (D) K_c is constant and will not change.

10. A 1.0 mol sample of $CO(g)$ and a 1.0 mol sample of $H_2(g)$ are pumped into a rigid, previously evacuated 2.0 L reaction vessel at 483 K. Which of the following is true at equilibrium?
   (A) $[H_2] = 2[CO]$
   (B) $[H_2] < [CO]$
   (C) $[CO] = [CH_3OH] < [H_2]$
   (D) $[CO] = [CH_3OH] = [H_2]$

	CO	+ 2H₂	⇌ CH₃OH
I	0.5	0.5	0
C	−x	−2x	+x
E	0.5−x	0.5−2x	x

11. A mixture of $CO(g)$ and $H_2(g)$ is pumped into a previously evacuated 2.0 L reaction vessel. The total pressure of the reaction system is 1.2 atm at equilibrium. What will be the total pressure of the system if the volume of the reaction vessel is reduced to 1.0 L at constant temperature?
   (A) Less than 1.2 atm
   (B) Greater than 1.2 atm but less than 2.4 atm
   (C) 2.4 atm
   (D) Greater than 2.4 atm

increase pressure → shift right

$$PCl_3(g) + Cl_2(g) \rightleftarrows PCl_5(g) \qquad K_c = 6.5$$

12. At a certain point in time, a 1.00 L rigid reaction vessel contains 1.5 mol of $PCl_3(g)$, 1.0 mol of $Cl_2(g)$, and 2.5 mol of $PCl_5(g)$. Which of the following describes how the measured pressure in the reaction vessel will change and why it will change that way as the reaction system approaches equilibrium at constant temperature?
   (A) The pressure will increase because $Q < K_c$.
   (B) The pressure will increase because $Q > K_c$.
   (C) The pressure will decrease because $Q < K_c$.
   (D) The pressure will decrease because $Q > K_c$.

$$Q = \frac{2.5}{1.5 \times 1} = \frac{5}{2} \times \frac{2}{3} = \frac{5}{3} < 6.5$$

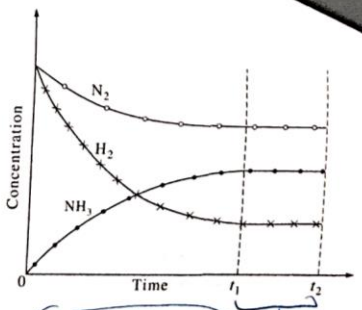
∴ shift right

Questions 13 – 14 refer to the following experiment:

H_2 gas and N_2 gas were placed in a rigid vessel and allowed to reach equilibrium in the presence of a catalyst according to the following equation.

$$3\,H_2(g) + N_2(g) \rightleftarrows 2\,NH_3(g)$$

The value of $\Delta H°$ for this reaction is equal to -92 kJ/mol$_{rxn}$. The diagram shows how the concentrations of H_2, N_2, and NH_3 in this system changed over time.



13. Which of the following was true for the system between time t_1 and time t_2?
   (A) The rates of the forward and reverse reactions were equal.
   (B) The temperature of the system decreased.
   (C) The number of effective collisions between H_2 and N_2 was zero.
   (D) The rate of formation of NH_3 molecules was equal to the rate of disappearance of H_2 molecules.

concentrations are constant ∴ @ equil.

14. More NH_3 gas is added to the system at time t_2. Which of the following will most likely occur as the approaches equilibrium at constant temperature?
   (A) $[N_2]$ will increase, and K_c will decrease.
   (B) $[N_2]$ will decrease, and K_c will increase.
   (C) $[N_2]$ will decrease, but K_c will remain constant.
   (D) $[N_2]$ will increase, but K_c will remain constant.

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftarrows Fe(SCN)^{2+}(aq)$$

15. For the reaction represented above, the value of the equilibrium constant, K_c, is 240 at 25°C. From this information, correct deductions about the reaction at 25°C include which of the following?
   I. The reaction is quite rapid.
   II. The product is favored over the reactants at equilibrium.
   III. The reaction is endothermic.

(A) I. only (B) II. only (C) I. and II. only (D) II. and III. only

$$Sr^{2+}(aq) + F^-(aq) \rightleftarrows SrF^+(aq)$$

16. At 25°C, the equilibrium constant for the reaction represented above has a value of 1.3. At 50°C, the value of the equilibrium constant is less than 1.3. Based on this information, which of the following must be correct?
   (A) $\Delta H°$ for the reaction is positive.
   (B) $\Delta H°$ for the reaction is negative.
   (C) The reaction rate decreases as the temperature is increased.
   (D) At 75°C, the value of the equilibrium constant will be greater than 1.3.

increased temp decreased K, meaning rxn shifted left (heat ←)

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g)$$

1. A 4.32 g sample of liquid SO_2Cl_2 is placed in a rigid, evacuated 1.50 L reaction vessel. As the container is heated to 400. K, the sample vaporizes completely and starts to decompose according to the equation above. The decomposition reaction is endothermic.

(a) If no decomposition occurred, what would be the pressure, in atm, of the $SO_2Cl_2(g)$ in the vessel at 400. K?

$$P = \frac{nRT}{V} = \frac{\left(4.32g \times \frac{1\,mol}{134.96g}\right)(.08206)(400K)}{1.50\,L} = \boxed{0.700\,atm}$$

(b) When the system has reached equilibrium at 400. K, the total pressure in the container is 1.26 atm. Calculate the partial pressures, in atm, of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ in the container at 400. K.

$$SO_2Cl_2 \rightleftharpoons SO_2 + Cl_2$$

0.7	0	0
−x	+x	+x
0.7−x	x	x

$0.7 - x + x + x = 1.26$ atm

$x = 0.56$ atm

$P_{SO_2Cl_2} = 0.14$ atm

$P_{SO_2} = P_{Cl_2} = 0.56$ atm

(c) For the decomposition reaction at 400. K,

(i) write the equilibrium-constant expression for K_p for the reaction

$$K_p = \frac{(P_{SO_2})(P_{Cl_2})}{P_{SO_2Cl_2}}$$

(ii) calculate the value of the equilibrium constant, K_p.

$$K_p = \frac{(0.56)(0.56)}{.14} = \boxed{2.24}$$

(iii) calculate the value of the equilibrium constant for the reverse reaction.

$$K_{rev} = \frac{1}{2.24} = \boxed{0.446}$$

(d) The temperature of the equilibrium mixture is increased to 425 K. Will the value of K_p increase, decrease, or remain the same? Justify your prediction. Since the reaction is endothermic, increasing temperature will cause a shift towards the products, increasing K_p.

(e) In another experiment, the original partial pressures of $SO_2Cl_2(g)$, $SO_2(g)$, and $Cl_2(g)$ are 1.0 atm each at 400. K. Predict whether the amount of $SO_2Cl_2(g)$ in the container will increase, decrease, or remain the same. Justify your prediction.

$$Q = \frac{1 \times 1}{1} = 1 < 2.24$$

∴ reaction will shift towards the right to achieve equilibrium, so the amount of SO_2Cl_2 will decrease.

$$MgF_2(s) \leftrightarrow Mg^{2+}(aq) + 2\,F^-(aq)$$

2. In a saturated solution of MgF_2 at 18°C, the concentration of Mg^{2+} is 1.21×10^{-3} molar. The equilibrium is represented by the equation above.

(a) Write the expression for the solubility-product constant, K_{sp}, and calculate its value at 18°C.

$$MgF_2(s) \rightleftharpoons Mg^{+2}(aq) + 2\,F^-(aq)$$

	0	0
	+x	+2x
	x	2x
	1.21×10^{-3}	2.42×10^{-3}

$$K_{sp} = [Mg^{+2}][F^-]^2 = 7.09 \times 10^{-9}$$

(b) Calculate the equilibrium concentration of Mg^{2+} in 1.000 liter of saturated MgF_2 solution at 18°C to which 0.100 mole of solid KF has been added (the value for Ksp is the same as in the previous part). The KF dissolves completely. Assume the volume change is negligible.

$$MgF_2(s) \rightleftharpoons Mg^{+2}(aq) + 2\,F^-$$

	0	.100
	+x	+2x
	x	.1+2x

$7.09 \times 10^{-9} = x(.1 + 2x)^2$

$7.09 \times 10^{-9} \approx x(.1)^2$

$x = [Mg^{+2}] = 7.09 \times 10^{-7}$ M

(c) Predict whether a precipitate of MgF_2 will form when 100.0 milliliters of a 3.00×10^{-3}-molar $Mg(NO_3)_2$ solution is mixed with 200.0 milliliters of a 2.00×10^{-3}-molar NaF solution at 18°C. Calculations to support your prediction must be shown.

$M_1V_1 = M_2V_2$

$$[Mg^{+2}] = \frac{(3 \times 10^{-3})(100)}{300} = .001$$

$$[F^-] = \frac{(2 \times 10^{-3})(200)}{300} = 0.00\overline{13}$$

$$Q = (.001)(.00\overline{133})^2 = 1.7\overline{7} \times 10^{-9} < 7.09 \times 10^{-9}$$

∴ NO a precipitate will NOT form

(d) At 27°C the concentration of Mg^{2+} in a saturated solution of MgF_2 is 1.17×10^{-3} molar. Is the dissolving of MgF_2 in water an endothermic or an exothermic process? Give an explanation to support your conclusion.

K_{sp} @ 18°C $= 7.09 \times 10^{-9}$

K_{sp} @ 27°C $= (1.17 \times 10^{-3})(2 \times 1.17 \times 10^{-3})^2 = 6.41 \times 10^{-9}$

Ksp is smaller at a higher temperature therefore dissolving MgF_2 in water must be an exothermic process