Equilibrium Test Topics!

(R = 0.0821 L-atm/mole-K will be given. OK to use a graphing calculator for this test)

1. What does it mean for a rxn to be at equilibrium? (What is "equal" at equlibrium?)

2. Interpreting K values:
   "Equilibrium lies to the left" = unfavorable = not spontaneous ; Keq < 1
   "Equilibrium lies to the right" = favorable = spontaneous ; Keq > 1

3. Writing Keq (Kc or Kp) expressions (do not include solid or liquid)

4. Keq: different versions: Kp, Kc, Ksp… what units do you use when plugging in?

5. Converting between Kp and Kc: $Kp = Kc(RT)^{\Delta n}$
Δn = moles product gas – moles reactant gas (in the balanced equation.)

6. What happens to the Keq if you reverse a rxn? Double it? Triple it? Halve it? Add two reactions together?

7. Q vs K : Will a rxn shift forward or backwards (right or left) to get to eqm?

8. Le Chatelier's Principle

9. How is Keq affected by temperature?
   Endothermic rxns
      ΔHrxn is positive
      Heat is absorbed by the rxn: Reactants + heat -----> products
      When temperature increases, Keq increases
      When temperature decreases, Keq decreases

   Exothermic rxns
      ΔHrxn is negative
      Heat is released by the rxn: Reactants -----> products + heat
      When temperature increases, Keq decreases
      When temperature decreases, Keq increases

   How are Ksp and solubility affected by temp if $\Delta H_{solution}$ is positive? If $\Delta H_{solution}$ is negative?

10. Calculating Keq if given initial concentrations (or pressures) and given 1 or more equilibrium concentration (or pressure), like problems A and B.

11. Calculating Kp if given the total equilibrium pressure of gases, like problem G.

12. Calculating final concentrations or pressures, based on a Keq value, like problems C-F

13. Ksp: Going from solubility in grams per liter to Ksp, or vice versa

14. Solubility of a compound into water, vs. into a salt solution (common ion effect)

15. Mixing Problems with Ksp

16. Ksp vs Qsp: will a ppt form?

Equilibrium Test Review:

1. The solubility of barium fluoride into water is 1.10(4) g/L. Find the Ksp of this compound.

2. At 25°C, CrF_3 has a Ksp of 6.6×10^{-11}.

a. Find the molar solubility of chromium (III) fluoride into water, and report the molarity of each ion in a saturated solution of chromium fluoride.

b. Find the molar solubility of chromium (III) fluoride, if it is dissolving into a solution of 0.80 M chromium (III) nitrate. Also report the concentration chromium and fluoride ions in this solution.

c. How many grams chromium fluoride can dissolve into 100. mL of 0.80 M chromium nitrate?

(#2, cont'd. CrF_3 has a Ksp of 6.6×10^{-11})

If 100. mL of 6.0 M Chromium (III) nitrate are mixed with 200. mL of 6.0 M NaF,

d. Verify that a precipitate will form. Show a calculation.

e. Find the mass of ppt that forms

f. Determine the concentrations of chromium (III) and fluoride ions after the reaction.

3. Based on the data shown below, determine the sign of $\Delta H_{solution}$ for calcium hydroxide and barium sulfate.

$Ca(OH)_2$ — Ksp = 0.000042 at 20°C; Ksp = 0.000017 at 60°C

$BaSO_4$ — Ksp = 1.1×10^{-10} at 20°C; Ksp = 1.5×10^{-10} at 30°C

4. $2HI_{(g)} \longleftrightarrow H_{2(g)} + I_{2(s)}$ ΔHrxn of -51.88 kJ/mole Kp = 2.86 at 25°C.

Which could be the Kp of this reaction at 50°C: 0.562, or 5.62? ____________

5. $C_{(s)} + CO_{2(g)} \longleftrightarrow 2\ CO_{(g)}$ ΔH rxn = + 172.5 kJ

Kc = 1.598 at 1000°C
Kc = 1×10^{-34} at ______°C.

a. fill in the missing temperature: is it 25°C or 2000 °C?

b. If the above reaction is at equilibrium, what will happen (which way will it "shift": left, right, or no change) if the following changes are made to the reaction mixture?

___________i. Add carbon dioxide gas

___________ii. Remove carbon monoxide gas

___________iii. Add CO

___________iv. Remove $C_{(s)}$ (assume this has a negligible effect on the available container volume)

___________v. Decrease the volume of the reaction container

___________vi. Add a catalyst

___________vii. Increase the temperature

___________viii. Decrease temperature

c. Find Kp of the above reaction at 1000 °C.

d. Find Kc of this reaction at 1000 °C: $CO_{(g)} \longleftrightarrow \frac{1}{2} C_{(s)} + \frac{1}{2} CO_{2(g)}$

6. In i-viii, above, for which stresses/letters does Keq stay the same, and for which letters does it change?

7. Given H_3PO_4 <-------> H^{+1} + $H_2PO_4^{-1}$ Keq = 0.0075

$H_2PO_4^{-1}$ <-------> 2 H^{+1} + PO_4^{-3} Keq = 2.6 x 10^{-20}

Find the Keq for this reaction: 3 H^{+1} + PO_4^{-3} <-------> H_3PO_4

8. The Haber Process: $N_{2(g)}$ + 3 $H_{2(g)}$ <-------> 2 $NH_{3(g)}$ ΔH rxn = - 92 kJ

Temp(°C)	Kc
25	69300
300	9.6
400	0.501
500	0.058

a. What does it mean for a reaction to be at equilibrium? Discuss this in the context of this reaction.

b. If 2.0 moles of each gas (nitrogen, hydrogen, and ammonia) are each placed into a 5.0 liter vessel at 300°C, which way will the reaction need to proceed in order to equilibrium?

c. Same question as (b), except change the temp to 400 °C

8. Continued: $N_{2(g)} + 3\ H_{2(g)}$ <-------> $2\ NH_{3(g)}$

d. Suppose that nitrogen, hydrogen, and ammonia are at equilibrium at 350 °C.
If some hydrogen gas is added (at 350°C) and equilibrium is reestablished, how will the new concentrations of N_2, H_2, and NH_3 compare to the concentrations before adding the extra hydrogen?

9. 25 grams of lead (II) iodide (molar mass 461.01 amu) are placed into a flask containing 200 mL of water and the mixture is shaken until equilibrium is established at 25°C. At this temperature, PbI_2 has a Ksp of 1.39×10^{-8}.

a. Verify (show math) that some solid lead iodide will remain undissolved in the flask.

b. How will the concentration of lead ion be affected (once equilibrium is reestablished) after the following changes are made? (increase, decrease, or no change)

__________ 5.00 grams of lead iodide powder are added to the mixture.

__________ Solid sodium iodide is added to the mixture.

__________ an additional 200 mL of water are added

__________ Solid silver nitrate is added to the mixture (The Ksp of AgI is 8.4×10^{-17} at 25°C)

__________ The solution is heated to 30°C. (Lead iodide has a positive heat of solution value)

__________ Solid lead nitrate is added to the mixture.

__________ Solid sodium sulfate is added to the mixture, and some lead sulfate precipitate forms.

10. $C_{(s)} + CO_{2(g)}$ <-----> $2\ CO_{(g)}$ $K_c = 1.598$ at 1000°C

Suppose that 2.00 moles of carbon dioxide are added to a flask containing carbon powder and heated to 1000°C. The available volume inside the flask is 9.80 liters.

a. What will be the equilibrium concentrations of carbon dioxide and carbon monoxide, at 1000°C?

b. What will be the total pressure in the flask at equilibrium, at 1000°C?

From 2000 AP Test.
Worth 10% of overall exam score
Time: about 18 minutes

$$2\,H_2S(g) \rightleftarrows 2\,H_2(g) + S_2(g)$$

11. ~~1.~~ When heated, hydrogen sulfide gas decomposes according to the equation above. A 3.40 g sample of $H_2S(g)$ is introduced into an evacuated rigid 1.25 L container. The sealed container is heated to 483 K, and 3.72×10^{-2} mol of $S_2(g)$ is present at equilibrium.

(a) Write the expression for the equilibrium constant, K_c, for the decomposition reaction represented above.

(b) Calculate the equilibrium concentration, in mol L^{-1}, of the following gases in the container at 483 K.

(i) $H_2(g)$

(ii) $H_2S(g)$

(c) Calculate the value of the equilibrium constant, K_c, for the decomposition reaction at 483 K.

(d) Calculate the partial pressure of $S_2(g)$ in the container at equilibrium at 483 K.

(e) For the reaction $H_2(g) + \frac{1}{2}\,S_2(g) \rightleftarrows H_2S(g)$ at 483 K, calculate the value of the equilibrium constant, K_c.

12. a. $C_5H_6O_{3\,(g)}$ <------> $C_2H_{6(g)}$ + $3\ CO_{(g)}$

5.63 grams of $C_5H_6O_3$ gas are placed into an evacuated 2.50 Liter flask and heated to 200. °C.

i. Calculate the initial pressure of $C_5H_6O_3$ in the container, before any reaction occurs.
ii. The total pressure in the container gradually rose to an equilibrium value of 1.63 atm.
Calculate Kp and Kc for the reaction at 200.°C.

b. The compound "arsine" (AsH_3) decomposes as follows $2\ AsH_{3(g)}$ <------> $2\ As_{(s)}$ + $3\ H_{2(g)}$
Some AsH_3 is added to an empty container so that it is present at 0.516 atm. After sitting for a couple of days, the reaction mixture reached a final equilibrium pressure of 0.642 atm. Calculate Kp for the reaction.

c. Some solid ferric oxide is placed into an evacuated flask at high temperature, and the following reaction is allowed to come to equilibrium. At equilibrium, the total gas pressure is 0.084 atm. Calculate Kp.

$2\ Fe_2O_{3\,(s)}$ <------> $4\ Fe_{(s)}$ + $3\ O_{2(g)}$

13. Ag_2CrO_4 has a Ksp of 1.2 x 10^{-12}
Ag_2CO_3 has a Ksp of 8.1 x 10^{-12}
AgCl has a Ksp of 1.8 x 10^{-10}

A dilute solution of silver nitrate is slowly added to a solution containing CrO_4^{-2} ion dissolved at 0.20 M, CO_3^{-2} dissolved at 0.10 M, and Cl^{-1} dissolved at 0.010 M.

a. For each silver compound, calculate the maximum concentration of Ag^{+1} ion that can be present in solution without a precipitate forming. (neglect volume changes; assume that adding the silver nitrate solution won't significantly affect the 3 given molarities.)

b. Which silver compound will precipitate first, as the $AgNO_3$ solution is added?

14. Consider a beaker containing a saturated solution of CaF_2 in equilibrium with undissolved CaF_2 (s).
If solid $CaCl_2$ is added to this solution,
a. will the amount of solid CaF_2 at the bottom of the beaker increase, decrease, or remain the same?
b. will the concentration of Ca^{+2} ions in solution increase or decrease?
c. will the concentration of F^{-1} ions in solution increase or decrease?
(For a, b, and c, assume that the mixture immediately reestablishes equilibrium.)

15. Consider a beaker containing a saturated solution of PbI_2 in equilibrium with undissolved PbI_2 (s).
If solid KI is added to this solution,
a. will the amount of solid PbI_2 at the bottom of the beaker increase, decrease, or remain the same?
b. will the concentration of Pb^{+2} ions in solution increase or decrease?
c. will the concentration of I^{-1} ions in solution increase or decrease?
(For a, b, and c, assume that the mixture immediately reestablishes equilibrium.)

16. Calcium Phosphate, $Ca_3(PO_4)_2$, has a Ksp of 2.0 x 10^{-29}.
a. Find the mass of precipitate that forms, and the concentration of $Ca^{+2}_{(aq)}$ and $PO_4^{-3}{}_{(aq)}$., if 100. mL of 0.80 M $CaCl_2$ are mixed with 150. mL of 0.20 M Na_3PO_4, and equilibrium is established. Assume that volumes are additive.

b. Find the concentration of $Ca^{+2}_{(aq)}$ and $PO_4^{-3}{}_{(aq)}$., if 100. mL of 0.30 M $CaCl_2$ are mixed with 200. mL of 0.10 M Na_3PO_4, and equilibrium is established. Assume that volumes are additive.

c. Find the concentration of $Ca^{+2}_{(aq)}$ and $PO_4^{-3}{}_{(aq)}$., if 200. mL of 0.40 M $CaCl_2$ are mixed with 350. mL of 0.20 M Na_3PO_4, and equilibrium is established. Assume that volumes are additive.

Equilibrium MC practice!

$$H_2(g) + Br_2(g) \rightleftarrows 2\ HBr(g)$$

42. At a certain temperature, the value of the equilibrium constant, K, for the reaction represented above is 2.0×10^5. What is the value of K for the reverse reaction at the same temperature?

(A) -2.0×10^{-5}
(B) 5.0×10^{-6}
(C) 2.0×10^{-5}
(D) 5.0×10^{-5}
(E) 5.0×10^{-4}

$$2\ SO_3(g) \rightleftarrows 2\ SO_2(g) + O_2(g)$$

41. After the equilibrium represented above is established, some pure $O_2(g)$ is injected into the reaction vessel at constant temperature. After equilibrium is reestablished, which of the following has a lower value compared to its value at the original equilibrium?

(A) K_{eq} for the reaction

(B) The total pressure in the reaction vessel

(C) The amount of $SO_3(g)$ in the reaction vessel

(D) The amount of $O_2(g)$ in the reaction vessel

(E) The amount of $SO_2(g)$ in the reaction vessel

67. What is the molar solubility in water of Ag_2CrO_4 ? (The K_{sp} for Ag_2CrO_4 is 8×10^{-12}.)

(A) $8 \times 10^{-12}\ M$

(B) $2 \times 10^{-12}\ M$

(C) $\sqrt{4 \times 10^{-12}}\ M$

(D) $\sqrt[3]{4 \times 10^{-12}}\ M$

(E) $\sqrt[3]{2 \times 10^{-12}}\ M$

75. In a saturated solution of $Zn(OH)_2$ at 25°C, the value of $[OH^-]$ is $2.0 \times 10^{-6}\ M$. What is the value of the solubility-product constant, K_{sp}, for $Zn(OH)_2$ at 25°C ?

(A) 4.0×10^{-18}

(B) 8.0×10^{-18}

(C) 1.6×10^{-17}

(D) 4.0×10^{-12}

(E) 2.0×10^{-6}

21. 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) $2\ Mg(s) + O_2(g) \rightleftarrows 2\ MgO(s)$

(B) $SF_4(g) + F_2(g) \rightleftarrows SF_6(g)$

(C) $H_2(g) + Br_2(g) \rightleftarrows 2\ HBr(g)$

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

(E) $SO_2Cl_2(g) \rightleftarrows SO_2(g) + Cl_2(g)$

36. Which of the following changes to a reaction system in equilibrium would affect the value of the equilibrium constant, K_{eq}, for the reaction? (Assume in each case that all other conditions are held constant.)

(A) Adding more of the reactants to the system
(B) Adding a catalyst for the reaction to the system
(C) Increasing the temperature of the system
(D) Increasing the pressure on the system
(E) Removing some of the reaction products from the system

Questions 29-33 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 below show the initial and equilibrium conditions of the system.

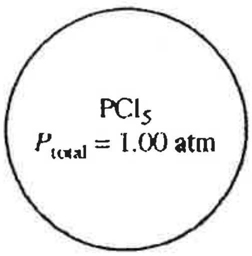


Figure 1: Initial

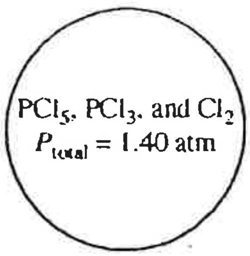


Figure 2: Equilibrium

29. Which of the following 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

30. 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

31. If the decomposition reaction were to go to completion, the total pressure in the container would be

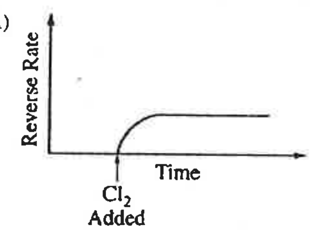
(A) 1.4 atm
(B) 2.0 atm
(C) 2.8 atm
(D) 3.0 atm

32. Which of the following statements about K_p, the equilibrium constant for the reaction, is correct?

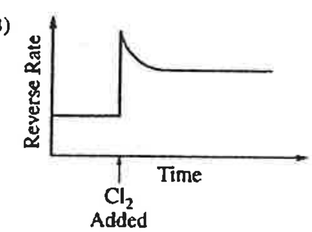
(A) $K_p > 1$
(B) $K_p < 1$
(C) $K_p = 1$
(D) It cannot be determined whether $K_p > 1$, $K_p < 1$, or $K_p = 1$ without additional information.

33. 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.)

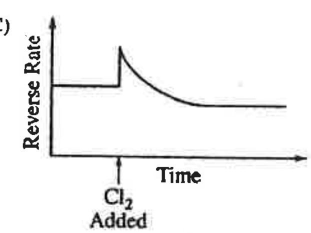
(A)



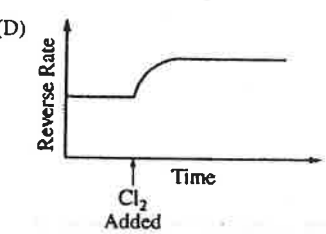
(B)

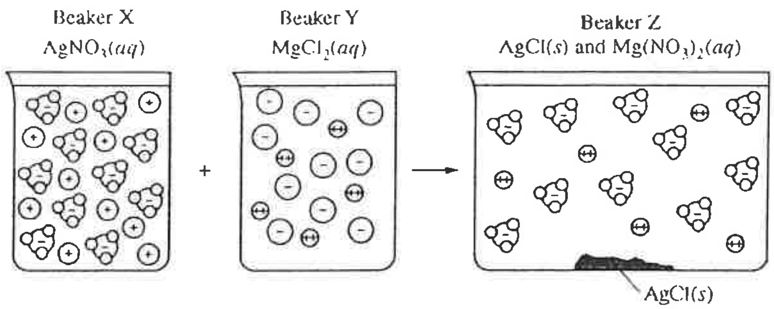


(C)



(D)





56. Beaker X and beaker Y each contain 1.0 L of solution, as shown above. A student combines the solutions by pouring them into a larger, previously empty beaker Z and observes the formation of a white precipitate. Assuming that volumes are additive, which of the following sets of solutions could be represented by the diagram above?

	Beaker X	Beaker Y	Beaker Z
(A)	2.0 *M* $AgNO_3$	2.0 *M* $MgCl_2$	4.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(B)	2.0 *M* $AgNO_3$	2.0 *M* $MgCl_2$	2.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(C)	2.0 *M* $AgNO_3$	1.0 *M* $MgCl_2$	1.0 *M* $Mg(NO_3)_2$ and $AgCl(s)$
(D)	2.0 *M* $AgNO_3$	1.0 *M* $MgCl_2$	0.50 *M* $Mg(NO_3)_2$ and $AgCl(s)$

$$COCl_2(g) \rightleftarrows CO(g) + Cl_2(g)$$

60. $COCl_2(g)$ decomposes according to the equation above. When pure $COCl_2(g)$ is injected into a rigid, previously evacuated flask at 690 K, the pressure in the flask is initially 1.0 atm. After the reaction reaches equilibrium at 690 K, the total pressure in the flask is 1.2 atm. What is the value of K_p for the reaction at 690 K?

(A) 0.040
(B) 0.050
(C) 0.80
(D) 1.0

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

7. 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.

Answers:

1. 9.99×10^{-7}

2. a. Molar solubility: 0.0013 M , $[Cr^{+3}] = 0.0013$ M, $[F^-] = 0.0038$ M
   b. Molar solubility = 0.00015 M, $[Cr^{+3}] = 0.80$ M, $[F^-] = 0.00044$ M
   c. 0.0016 g can dissolve.
   d. Qsp = 128. Since Qsp is larger than the Ksp (of 6.6×10^{-11}), a ppt will form.
   e. 44 g ppt, f. $[Cr^{+3}] = 0.67$ M, $[F^-] = 0.00046$ M

3. Calcium hydroxide has a negative ΔHsoln , Barium sulfate has a positive ΔHsoln
4. 0.562
5. a) 25˚C b) R, R, L, NC, L, NC, R, L c) Kp = 167.0, d) Kc = 0.7911
6. Keq stays the same in all except (vii) and (viii), which involved temperature changes.
7. Kc = 5.1×10^{21}

8. b. Q = 6.25, K = 9.6. Q > K so the reaction will proceed to the left.
   c. Q = 6.25, K = 0.501. Q < K so rxn will proceed to the right.
   d. Hydrogen and ammonia concentrations will increase. Nitrogen concentration will decrease.

9a. Based on the Ksp, the molar solubility is 0.00151 M, so 0.000303 moles can dissolve into 200 mL, so 0.140 grams can dissolve. 0.140 g << 25 grams, so lots o solid will remain.
OR..... if the 25 grams all dissolved into 200 mL, the molarity of dissolved lead iodide would be 0.271 M, so Qsp = (0.271)(0.542)^2 = 0.07974 . Qsp >> Ksp, so not all the solid can dissolve!

9b. NC, D, NC, I, I, I, D

10. [CO] = 0.297 M, $[CO_2] = 0.055$ M, $P_{total} = 36.9$ atm

11. a. $Kc = [H_2]^2[S_2] / [H_2S]^2$
    b. [H2] = .0595 M, [H2S] = 0.0203 M
    c. Kc = 0.257
    d. 1.18 atm
    e. 1.97

12. a. i. 0.766 atm   ii. Kp = 0.387   Kc = 6.61×10^{-6}
    b. Kp = 0.775
    c. Kp = 0.00059

13. a. $[Ag^{+1}]$max = 2.4×10^{-6} M for Ag_2CrO_4, 9.0×10^{-6} M for Ag_2CO_3, and 1.8×10^{-8} M for AgCl.
b. AgCl will be the first to form a precipitate.

14. a. increase, b. increase c. decrease

15. a. increase b. decrease c. increase

16. a. 4.7 grams ppt, $[Ca^{+2}] = 0.14$ M, $[PO_4^{-3}] = 8.5 \times 10^{-14}$ M
    b. $[Ca^{+2}] = 2.1 \times 10^{-6}$ M, $[PO_4^{-3}] = 1.4 \times 10^{-6}$ M
    c. $[Ca^{+2}] = 2.8 \times 10^{-9}$ M, $[PO_4^{-3}] = 0.030$ M

Multiple Choice:

41 E, 42 B, 67 E, 75 A, 21 E, 36 C, 29C, 30C, 31B, 32B, 33B, 56D, 60 B, 7 B