Chapter 13

Equilibrium

Kc = constant for molar concentration

Kp = constant for partial pressure

Ksp = solubility product (no denominator because reactants are solids)

Ka= acid dissociation constant for a weak acid.

Kb = Base dissociation constant for weak base.

Kw = describes the ionization of water (Kw = 1x 10-14)

K_{eq} = equilibrium

Equilibrium Expression:

$$K = \frac{[HI]^2}{[H_2]\,[I_2]}$$

Equilibrium Constant:

$$K = \frac{(1.29)^2}{(0.106)\,(0.022)} = 7.1 \times 102$$

- The equilibrium constant K tells us the relative amount of product and reactant at equilibrium.

Q is different than K because K is the [react] and [prod] at equilibrium.

Q predicts the direction of the reaction.

K >> 1 Products Favored

K << 1 Reactants Favored

Relationship	Direction
Q > K	Shift to left
Q = K	Equilibrium
Q < K	Shift to right

$K_p = K_c(RT)^{\Delta n}$

[Concentration]

↑ [reactant] or [product]
The reaction will move in the direction that will use up the added substance

EX: A + B → C

If we add A rxn shifts forward (right) to use up A. If we add C rxn will reverse(left) to use up C

↓ [reactant] or [product]
The reaction will move in the direction that will produce that substance

VOLUME

↑ volume the rxn will move in the direction that will produce more moles of gas

↓ volume the rxn will move in the direction that will produce less moles of gas

If there is no gas in the rxn or if the reactant and product have the same number of moles a Δ volume will have no effect on the rxn.

Le Chatelier's Principle States:
If the system is disrupted by a change in one of the above, or [components], the system will shift in the direction to counteract the disruption

Temperature

↑ temperature the rxn moves in the endothermic direction (+ΔH)

ENDO → Right (K ↑)

↓ temperature the rxn moves in the exothermic direction (-ΔH)

EXO → Left (K ↓)

K only depends on temperature, catalysts have NO EFFECT on K

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16 • Chemical Equilibria

PROBLEM SET #1

For the following three reactions,

a) write the K_{eq} expression in terms of concentration, K_c.
b) given the equilibrium concentrations, state whether each equilibrium is product-favored, reactant-favored, or fairly even ([products] ≈ [reactants]).
c) calculate the value of K_c.

1. $N_2g) + 3\ H_2(g) \leftrightarrows 2\ NH_3(g)$

   At equilibrium: $[N_2] = 1.50$ M
   $[H_2] = 2.00$ M
   $[NH_3] = 0.01$ M

2. $HF(aq) \leftrightarrows H^+(aq) + F^-(aq)$

   At equilibrium: $[HF] = 0.55$ M
   $[H^+] = 0.001$ M
   $[F^-] = 0.001$ M

3. $Fe^{3+}(aq) + SCN^-(aq) \leftrightarrows FeSCN^{2+}(aq)$

   At equilibrium: $[Fe^{3+}] = 0.55$ M
   $[SCN^-] = 0.001$ M
   $[FeSCN^{2+}] = 0.001$ M

Summarize:
Fill in the blanks with product-favored, reactant-favored, and approximately equal

K_c	state of equilibrium
$K_c >> 1$	
$K_c << 1$	
$K_c \approx 1$	

4. Knowing that pure water has a density of 1g/1mL calculate the mass of 1.00 Liter of water.

   Calculate the number of moles in 1.00 L of H_2O.

   What is the concentration (M) of water in water?

   At this temperature, can you get more moles of water into this Liter of water?

   The $[H_2O]$ ________ (is / is not) constant.

> **Important Note:**
> Since the concentrations of solids and liquids are constant, they are incorporated into the equilibrium constant, K_{eq}. That means, just leave them out of the K_c or K_p expression. Only include (g) and (aq)!

5. Write equilibrium expressions for each of the following reactions:

   a) $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

   b) $Ni(s) + 4CO(g) \rightleftharpoons Ni(CO)_4(g)$

   c) $5CO(g) + I_2O_5(s) \rightleftharpoons I_2(g) + 5CO_2(g)$

   d) $Ca(HCO_3)_2(aq) \rightleftharpoons$
   $CaCO_3(s) + H_2O(l) + CO_2(g)$

   e) $AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq)$

6. Write the equilibrium expression in terms of partial pressures (K_p) for each of the following reactions.
Rate the reactions in order of their increasing tendency to proceed toward completion:

___ ___ ___ ___

(a) $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$
$K_p = 1 \times 10^{228}$ atm

(b) $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$
$K_p = 5 \times 10^{-31}$

(c) $2HF(g) \rightleftharpoons H_2(g) + F_2(g)$
$K_p = 1 \times 10^{-13}$

(d) $2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$
$K_p = 4.7 \times 10^{-4}$ atm

A Question That You Should Be Able To Answer:
Why don't the K_p's in (b) and (c) have units?

7. (a) Write the K_c expression for
$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$

Calculate the value of K_c:
At equilibrium: $[SO_2] = 1.50$ M
$[O_2] = 1.25$ M
$[SO_3] = 3.50$ M

(b) If we **reverse** the equation, it is:
$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$
Write the K_c expression for this equation and calculate the new value of K_c:

How does the expression and the value of K_c in 7(b) compare with those in 7(a)?

(c) If we now **multiply all of the coefficients by ½:**
$SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}\ O_2(g)$
Write the K_c expression for this equation and calculate the new value of K_c:

How do they compare with 7(b)?

(d) What would happen to the K_c expression and its value if we **doubled** the coefficients?

Summarize:

Equation	K_c expression & Value
doubled	
reversed	
halved	

8. Consider an equilibrium that occurs in two steps:
$H_2S(aq) \rightleftharpoons H^+(aq) + HS^-(aq)$
$HS^-(aq) \rightleftharpoons H^+(aq) + S^{2-}(aq)$

(a) Write the overall reaction.
(b) How do the K_c's for the two steps (K_{c1} & K_{c2}) relate to the K_c of the overall reaction (K_c)?

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16 • Chemical Equilibria

PROBLEM SET #2

1. Consider the equilibrium: $2\ SO_2(g) + O_2(g) \leftrightarrows 2\ SO_3(g)$ $K_c = 4.36\ \underline{M}^{-1}$
Calculate the value of "Q" for a situation in which the concentrations are $[SO_2] = 2.00\ \underline{M}$, $[O_2] = 1.50\ \underline{M}$, and $[SO_3] = 1.25\ \underline{M}$.

Does this mixture shift toward the reactants or products to reach equilibrium? ____________________

2. Study the discussion in your textbook about converting K_c and K_p. Write the K_p expression for the reaction in question 1 and calculate its value at 0°C. Remember, R = 0.0821 L·atm/mol·K.

3. Consider the equilibrium $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$.
How would the following changes affect the partial pressures of each gas at equilibrium? (↑, ↓, =)

	$PCl_3(g)$ +	$Cl_2(g)$ ⇌	$PCl_5(g)$
a) addition of PCl_3	___	___	___
b) removal of Cl_2	___	___	___
c) removal of PCl_5	___	___	___
d) decrease in the volume of the container	___	___	___
e) addition of He without change in volume	___	___	___

4. How will each of the changes in question 3 affect the K_{eq}? (↑=increase; ↓=decrease; — = unchanged)

a ___ b ___ c ___ d ___ e ___

5. Indicate how each of the following changes affects the amount of each gas in the system below, for which $\Delta H_{reaction} = +9.9$ kcal.

	$H_2(g)$ +	$CO_2(g)$ ⇌	$H_2O(g)$ +	$CO(g)$
a) addition of CO_2	___	___	___	___
b) addition of H_2O	___	___	___	___
c) addition of a catalyst	___	___	___	___
d) increase in temperature	___	___	___	___
e) decrease in the volume of the container	___	___	___	___

6. How will each of the changes in question 5 affect the equilibrium constant?

a ___ b ___ c ___ d ___ e ___

7. Consider the equilibrium: $2N_2O(g) + O_2(g) \rightleftharpoons 4NO(g)$
How will the amount of chemicals at equilibrium be affected by

	$2N_2O(g)$	$O_2(g)$	$4NO(g)$
a) adding N_2O	___	___	___
b) removing O_2	___	___	___
c) increasing the volume of the container	___	___	___
d) adding a catalyst	___	___	___

8. For the reaction, $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(l)$
How will the concentration of each chemical be affected by

	$4NH_3(g)$	$3O_2(g)$	$2N_2(g)$	$6H_2O(l)$
a) adding O_2 to the system	___	___	___	___
b) adding N_2 to the system	___	___	___	___
c) removing H_2O from the system	___	___	___	___
d) decreasing the volume of the container	___	___	___	___

9. Consider the equilibrium: $2N_2O(g) + O_2(g) \rightleftharpoons 4NO(g)$
3.00 moles of NO(g) are introduced into a 1.00-Liter evacuated flask. When the system comes to equilibrium, 1.00 mole of $N_2O(g)$ has formed. Determine the equilibrium concentrations of each substance. Calculate the K_c for the reaction based on these data.

	$2\ N_2O$	O_2	$4\ NO$
initial			
change			
equilibrium			

Remember: The "ice" box may be used with <u>*moles,*</u> <u>*molarity,*</u> *or* <u>*Liters*</u> *(for gaseous equilibria)... never* <u>*grams.*</u>

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16 • Chemical Equilibrium

PRACTICE TEST

1. Consider the reaction system,
$CoO(s) + H_2(g) \rightleftarrows Co(s) + H_2O(g)$.

The equilibrium constant expression is

a) $\frac{[CoO][H_2]}{[Co][H_2O]}$
b) $\frac{[Co][H_2O]}{[CoO][H_2]}$
c) $\frac{[Co][H_2O]}{[H_2]}$
d) $\frac{[H_2]}{[H_2O]}$
e) $\frac{[H_2O]}{[H_2]}$

2. Given the equilibrium,
$2SO_2(g) + O_2(g) \rightleftarrows 2SO_3(g)$, if this equilibrium is established by beginning with equal number of moles of SO_2 and O_2 in a 1.0 Liter bulb, then the following ***must*** be true at equilibrium:

a) $[SO_2] = [SO_3]$
b) $2[SO_2] = 2[SO_3]$
c) $[SO_2] = [O_2]$
d) $[SO_2] < [O_2]$
e) $[SO_2] > [O_2]$

Questions 3 & 4 refer to the following:

At a given temperature, 0.300 mole NO, 0.200 mol Cl_2 and 0.500 mol ClNO were placed in a 25.0 Liter container. The following equilibrium is established:
$2ClNO(g) \rightleftarrows 2NO(g) + Cl_2(g)$

3. At equilibrium, 0.600 mol of ClNO was present. The number of ***moles*** of Cl_2 present at equilibrium is

a) 0.050
b) 0.100
c) 0.150
d) 0.200
e) 0.250

4. The equilibrium constant, K_C, is:

a) 4.45×10^{-4}
b) 6.67×10^{-4}
c) 0.111
d) 0.167
e) 1500

5. At 985°C, the equilibrium constant for the reaction,
$H_2(g) + CO_2(g) \rightleftarrows H_2O(g) + CO(g)$
is 1.63. What is the equilibrium constant for the reverse reaction?

a) 1.63
b) 0.815
c) 2.66
d) 0.613
e) 1.00

6. What is the relationship between K_p and K_c for the reaction, $2ICl(g) \rightleftarrows I_2(g) + Cl_2(g)$?

a) $K_p = K_c(RT)^{-1}$
b) $K_p = K_c(RT)$
c) $K_p = K_c(RT)^2$
d) $K_p = K_c$
e) $K_p = K_c(2RT)$

7. For the reaction $2NO_2(g) \rightleftarrows N_2O_4(g)$, K_p at 25°C is 7.3, when all partial pressures are expressed in atmospheres. What is K_c for this reaction? [$R=0.0821\ L{\cdot}atm{\cdot}mol^{-1}{\cdot}K^{-1}$]

a) 4270
b) 0.0119
c) 0.291
d) 179
e) 2.06

8. 0.200 mol NO is placed in a one liter flask at 2273 K. After equilibrium is attained, 0.0863 mol N_2 and 0.0863 mol O_2 are present. What is K_c for this reaction?

$$2NO(g) \rightleftarrows N_2(g) + O_2(g)$$

a) 9.92
b) 3.15
c) 0.0372
d) 39.7
e) 0.576

9. $$N_2O_4(g) \rightleftarrows 2\ NO_2(g)$$

At 25°C, 0.11 mole of N_2O_4 reacts to form 0.10 mol of N_2O_4 and 0.02 mole of NO_2. At 90°C, 0.11 mole of N_2O_4 forms 0.050 mole of N_2O_4 and 0.12 mole of NO_2. From these data we can conclude

a) N_2O_4 molecules react by a second order rate law.
b) N_2O_4 molecules react by a first order rate law.
c) the reaction is exothermic.
d) N_2O_4 molecules react faster at 25°C than at 90°C.
e) the equilibrium constant for the reaction above increases with an increase in temperature.

10. For the equilibrium system

$$H_2O(g) + CO(g) \rightleftarrows H_2(g) + CO_2(g)$$

$$\Delta H = -42\ kJ/mol$$

K_c equals 0.62 at 1260 K. If 0.10 mole each of H_2O, CO, H_2 and CO_2 (each at 1260 K) were placed in a 1.0-Liter flask at 1260 K, when the system came to equilibrium...

	The temperature would	The mass of CO would
a)	decrease	increase
b)	decrease	decrease
c)	remain constant	increase
d)	increase	decrease
e)	increase	increase

11. For the reaction system,

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

the conditions that would favor maximum conversion of the reactants to products would be

a) high temperature and high pressure
b) high temperature, pressure unimportant
c) high temperature and low pressure
d) low temperature and high pressure
e) low temperature and low pressure

12. Solid HgO, liquid Hg, and gaseous O_2 are placed in a glass bulb and are allowed to reach equilibrium at a given temperature.

$$2HgO(s) \rightleftarrows 2Hg(l) + O_2(g) \quad \Delta H = +43.4\ kcal$$

The mass of HgO in the bulb could be increased by

a) adding more Hg.
b) removing some O_2.
c) reducing the volume of the bulb.
d) increasing the temperature.
e) removing some Hg.

Answers: (Please use ***CAPITAL*** letters)

1.		7.	
2.		8.	
3.		9.	
4.		10.	
5.		11.	
6.		12.	

Answers: 1E 2D 3C 4B 5D 6D 7D 8A 9E 10A 11D 12C

Name:____ **Date:**______________

Chapter 13 Review

1. write the equilibrium expression for each of the following
   a. $2NO\ (g) + O_2(g) \leftrightarrow 2NO_2\ (g)$

   b. $Ag^+ (aq) + I^-(aq) \leftrightarrow AgI\ (s)$

   c. $Fe^{3+} (aq) + 3OH^-(aq) \leftrightarrow Fe(OH)_3\ (S)$

2. Calculate the equilibrium constant K at 25°C for the reaction
   $$2NO\ (g) + O_2(g) \leftrightarrow 2NO_2\ (g)$$
   If the equilibrium concentrations are NO = $6.5e^{-5}$ atm $O_2 = 4.5e^{-5}$atm $NO_2 = 0.55$ atm

3. Of the equilibrium constant at 444°C for $2HI\ (g) \leftrightarrow H_2(g) + I_2(g)$ is 1.39×10^{-2}, find the equilibrium constant for the reverse reaction at 444°C.

4. For each value of K predict the effect on the reaction.
   $K = 1$ $K = 10^{10}$ $K = 10^{-10}$

(9)

5. The dissociation of acetic acid, CH_3COOH, has an equilibrium constant at 25°C of 1.8×10^{-5}. The reaction is

$$CH_3COOH\ (aq) \leftrightarrow CH_3COO^-\ (aq) + H^+\ (aq)$$

If the equilibrium concentration of CH_3COOH = 0.46 moles in 0.500 L of water and the concentration of CH_3COO^- is 8.1×10^{-3} moles in the same 0.500L calculate the concentration of H^+ for the reaction.

6. Indicate which has an effect on A. the speed of the reaction or B. the position of the equilibrium. (m)ark the appropriate lines(s)

1. Catalyst	2. Pressure	3. Temperature	4. Concentration
A______	A______	A______	A______
B______	B______	B______	B______

7. at 700K, the measured values of for the partial pressures of ammonia, hydrogen, and nitrogen are 0.400 atm , 7.20 atm, and 2.40 atm respectively. Calculate the K_p and K_c at 700K for the synthesis of ammonia:

$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3\ (g)$$

8. (Likely to see on AP) For the following process at700°C, what is the partial pressure of each gas at equilibrium if the total pressure is 0.750 atm? Hint: use X to solve

$$C\ (s) + CO_2\ (g) \leftrightarrow 2CO \qquad K_p = 1.50$$

(10)

9. Given the reaction of methane and water below

$$CH_4 + H_2O \leftrightarrow CO\ (l) + 3H_2\ (g) \qquad K = 5.67$$

predict what direction the system will shift in order to reach equilibrium given the following initial values of Q.

a. $Q = 11.85$

b. $Q = 3.8 \times 10^{-4}$

c. $Q = 5.67$

10. The reaction of carbon disulfide with chloride is as follows

$$CS_2(g) + 3Cl_2(g) \leftrightarrow CCl_4(g) + S_2Cl_2\ (g) \qquad \Delta H = -238\ kJ$$

Predict the effect of the following change to the system on the direction of the equilibrium.

a. The pressure on the system is doubled by halving the volume

b. CCl_4 is removed as it is generated

c. Heat is added to the system

11. Given the following reaction at equilibrium,

$$Cl_2\ (g) + 3F_2(g) \leftrightarrow 2ClF_3\ (g)$$

a. Predict the effect if the pressure were reduced at a constant temperature.

b. Predict the effect if the volume were reduced by increasing the pressure at a constant temperature.

(11)

CHAPTER 10 QUESTIONS

MULTIPLE-CHOICE QUESTIONS

Questions 1–4

(A) K_c
(B) K_p
(C) K_a
(D) K_w
(E) K_{sp}

1. This equilibrium constant uses partial pressures of gases as units.

2. This equilibrium constant always has a value of 1×10^{-14} at 25°C.

3. This equilibrium constant is used for the dissociation of an acid.

4. The equilibrium expression for this equilibrium constant does not contain a denominator.

5. For a particular salt, the solution process is endothermic. As the temperature at which the salt is dissolved increases, which of the following will occur?

   (A) K_{sp} will increase, and the salt will become more soluble.
   (B) K_{sp} will decrease, and the salt will become more soluble.
   (C) K_{sp} will increase, and the salt will become less soluble.
   (D) K_{sp} will decrease, and the salt will become less soluble.
   (E) K_{sp} will not change, and the salt will become more soluble.

6. $2\ HI(g) + Cl_2(g) \rightleftharpoons$

   $2\ HCl(g) + I_2(g) + \text{energy}$

   A gaseous reaction occurs and comes to equilibrium as shown above. Which of the following changes to the system will serve to increase the number of moles of I_2 present at equilibrium?

   (A) Increasing the volume at constant temperature
   (B) Decreasing the volume at constant temperature
   (C) Adding a mole of inert gas at constant volume
   (D) Increasing the temperature at constant volume
   (E) Decreasing the temperature at constant volume

(12)

7. A sealed isothermal container initially contained 2 moles of CO gas and 3 moles of H_2 gas. The following reversible reaction occurred:

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g)$$

At equilibrium, there was 1 mole of CH_3OH in the container. What was the total number of moles of gas present in the container at equilibrium?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

8. $4\,NH_3(g) + 3\,O_2(g) \rightleftharpoons 2\,N_2(g) + 6\,H_2O(g) + \text{energy}$

Which of the following changes to the system at equilibrium shown above would cause the concentration of H_2O to increase?

(A) The volume of the system was decreased at constant temperature.
(B) The temperature of the system was increased at constant volume.
(C) NH_3 was removed from the system.
(D) N_2 was removed from the system.
(E) O_2 was removed from the system.

9. A sample of solid potassium nitrate is placed in water. The solid potassium nitrate comes to equilibrium with its dissolved ions by the endothermic process shown below.

$$KNO_3(s) + \text{energy} \rightleftharpoons K^+(aq) + NO_3^-(aq)$$

Which of the following changes to the system would increase the concentration of K^+ ions at equilibrium?

(A) The volume of the solution is increased.
(B) The volume of the solution is decreased.
(C) Additional solid KNO_3 is added to the solution.
(D) The temperature of the solution is increased.
(E) The temperature of the solution is decreased.

10. Citric acid, $H_3C_6H_5O_7$, can give up 3 hydrogen ions in solution. The 3 dissociation reactions are as follows:

$$H_3C_6H_5O_7 \rightleftharpoons H^+ + H_2C_6H_5O_7^- \qquad K_1 = x$$

$$H_2C_6H_5O_7^- \rightleftharpoons H^+ + HC_6H_5O_7^{2-} \qquad K_2 = y$$

$$HC_6H_5O_7^{2-} \rightleftharpoons H^+ + C_6H_5O_7^{3-} \qquad K_3 = z$$

Which of the following expressions gives the equilibrium constant for the reaction shown below?

$$H_3C_6H_5O_7 \rightleftharpoons 3\,H^+ + C_6H_5O_7^{3-}$$

(A) xyz
(B) $\frac{xy}{z}$
(C) $\frac{x}{yz}$
(D) $\frac{z}{xy}$
(E) $\frac{1}{xyz}$

11. $$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$$

At 450°C, the equilibrium constant, K_c, for the reaction shown above has a value of 50. Which of the following is true of the reaction at equilibrium?

(A) The rate of the forward reaction is greater than the rate of the reverse reaction.
(B) The rate of the forward reaction is less than the rate of the reverse reaction.
(C) The rate of the forward reaction is equal to the rate of the reverse reaction.
(D) An increase in the volume of the system will cause an increase in the value of K_c.
(E) A decrease in the volume of the system will cause an increase in the value of K_c.

(13)

12. $2\,NOBr(g) \rightleftharpoons 2\,NO(g) + Br_2(g)$

The reaction above came to equilibrium at a temperature of 100°C. At equilibrium the partial pressure due to NOBr was 4 atmospheres, the partial pressure due to NO was 4 atmospheres, and the partial pressure due to Br_2 was 2 atmospheres. What is the equilibrium constant, K_p, for this reaction at 100°C?

(A) $\frac{1}{4}$

(B) $\frac{1}{2}$

(C) 1

(D) 2

(E) 4

13. $HCrO_4^- + Ca^{2+} \leftrightarrow H^+ + CaCrO_4$

If the acid dissociation constant for $HCrO_4^-$ is K_a and the solubility product for $CaCrO_4$ is K_{sp}, which of the following gives the equilibrium expression for the reaction above?

(A) K_aK_{sp}

(B) $\frac{K_a}{K_{sp}}$

(C) $\frac{K_{sp}}{K_a}$

(D) $\frac{1}{K_{sp}K_a}$

(E) $\frac{K_aK_{sp}}{2}$

14. $Br_2(g) + I_2(g) \leftrightarrow 2\,IBr(g)$

At 150°C, the equilibrium constant, K_c, for the reaction shown above has a value of 300. This reaction was allowed to reach equilibrium in a sealed container and the partial pressure due to IBr(*g*) was found to be 3 atm. Which of the following could be the partial pressures due to $Br_2(g)$ and $I_2(g)$ in the container?

	$Br_2(g)$	$I_2(g)$
(A)	0.1 atm	0.3 atm
(B)	0.3 atm	1 atm
(C)	1 atm	1 atm
(D)	1 atm	3 atm
(E)	3 atm	3 atm

15. $H_2(g) + CO_2(g) \leftrightarrow H_2O(g) + CO(g)$

Initially, a sealed vessel contained only $H_2(g)$ with a partial pressure of 6 atm and $CO_2(g)$ with a partial pressure of 4 atm. The reaction above was allowed to come to equilibrium at a temperature of 700 K. At equilibrium, the partial pressure due to CO(*g*) was found to be 2 atm. What is the value of the equilibrium constant K_p, for the reaction?

(A) $\frac{1}{24}$

(B) $\frac{1}{6}$

(C) $\frac{1}{4}$

(D) $\frac{1}{3}$

(E) $\frac{1}{2}$

14

PROBLEMS

1. $$BaF_2(s) \rightleftharpoons Ba^{2+}(aq) + 2\,F^-(aq)$$

The value of the solubility product, K_{sp}, for the reaction above is 1.0×10^{-6} at 25°C.

(a) Write the K_{sp} expression for BaF_2.

(b) What is the concentration of F^- ions in a saturated solution of BaF_2 at 25°C?

(c) 500 milliliters of a 0.0060-molar NaF solution is added to 400 ml of a 0.0060-molar $Ba(NO_3)_2$ solution. Will there be a precipitate?

(d) What is the value of $\Delta G°$ for the dissociation of BaF_2 at 25°C?

2. $$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad K_1 = 4.3 \times 10^{-7}$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-} \qquad K_2 = 5.6 \times 10^{-11}$$

The acid dissociation constants for the reactions above are given at 25°C.

(a) What is the pH of a 0.050-molar solution of H_2CO_3 at 25°C?

(b) What is the concentration of CO_3^{2-} ions in the solution in (a)?

(c) How would the addition of each of the following substances affect the pH of the solution in (a)?

(i) HCl

(ii) $NaHCO_3$

(iii) NaOH

(iv) NaCl

(d) What is the value of K_{eq} for the following reaction?

$$H_2CO_3 \rightleftharpoons 2\,H^+ + CO_3^{2-}$$

B