

# Chapter 13

## Equilibrium



**K<sub>c</sub> = constant for molar concentration**

**Equilibrium Expression:**  
$$K = \frac{[HI]^2}{[H_2][I_2]}$$

**K<sub>p</sub> = constant for partial pressure**

**Equilibrium Constant:**  
$$K = \frac{(1.29)^2}{(0.106)(0.022)} = 7.1 \times 10^2$$

**K<sub>sp</sub> = solubility product (no denominator because reactants are solids)**

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

**K<sub>a</sub> = acid dissociation constant for a weak acid.**

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

**K<sub>b</sub> = Base dissociation constant for weak base.**

Q predicts the direction of the reaction.

**K<sub>w</sub> = describes the ionization of water (K<sub>w</sub> = 1 x 10<sup>-14</sup>)**

K >> 1 Products Favored  
K << 1 Reactants Favored

**K<sub>eq</sub> = equilibrium**

**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



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  $\Delta$  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 (+ $\Delta H$ )

ENDO  $\rightarrow$  Right ( K  $\uparrow$  )

↓ temperature the rxn moves in the exothermic direction (- $\Delta H$ )

EXO  $\rightarrow$  Left ( K  $\downarrow$  )

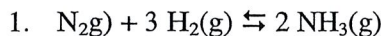
\*\*K only depends on temperature, catalysts have NO EFFECT on K\*\*

# 16 • Chemical Equilibria

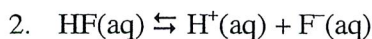
## PROBLEM SET # 1

For the following three reactions,

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



At equilibrium:  $[N_2] = 1.50 \text{ M}$   
 $[H_2] = 2.00 \text{ M}$   
 $[NH_3] = 0.01 \text{ M}$



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



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

### Summarize:

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

$K_c$	state of equilibrium
$K_c \gg 1$	
$K_c \ll 1$	
$K_c \approx 1$	

4. Knowing that pure water has a density of 1g/mL 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?

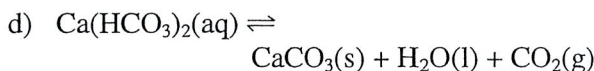
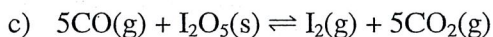
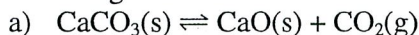
At this temperature, can you get more moles of water into this Liter of water?

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

### Important Note:

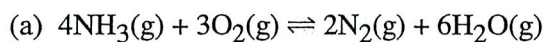
Since the concentrations of solids and liquids are constant, they are incorporated into the equilibrium constant,  $K_{eq}$ . That means, just leave them out of the  $K_c$  or  $K_p$  expression. Only include (g) and (aq)!

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

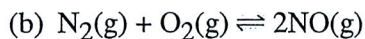


6. Write the equilibrium expression in terms of partial pressures ( $K_p$ ) for each of the following reactions.  
Rate the reactions in order of their increasing tendency to proceed toward completion:

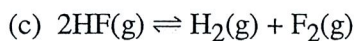
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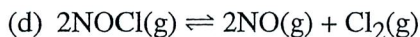
$$K_p = 1 \times 10^{228} \text{ atm}$$



$$K_p = 5 \times 10^{-31}$$

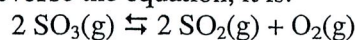


$$K_p = 1 \times 10^{-13}$$



$$K_p = 4.7 \times 10^{-4} \text{ atm}$$

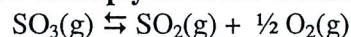
- (b) If we **reverse** the equation, it is:



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 1/2**:



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?

**A Question That You Should Be Able To Answer:**

Why don't the  $K_p$ 's in (b) and (c) have units?

**Summarize:**

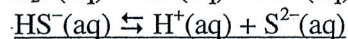
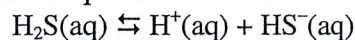
Equation	$K_c$ expression & Value
doubled	
reversed	
halved	

7. (a) Write the  $K_c$  expression for  
 $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g})$

Calculate the value of  $K_c$ :

At equilibrium:  $[\text{SO}_2] = 1.50 \text{ M}$   
 $[\text{O}_2] = 1.25 \text{ M}$   
 $[\text{SO}_3] = 3.50 \text{ M}$

8. Consider an equilibrium that occurs in two steps:



- (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 ( $K_c$ )?

# 16 • Chemical Equilibria

## PROBLEM SET # 2

1. Consider the equilibrium:  $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g})$   $K_c = 4.36 \text{ M}^{-1}$   
 Calculate the value of "Q" for a situation in which the concentrations are  $[\text{SO}_2] = 2.00 \text{ M}$ ,  $[\text{O}_2] = 1.50 \text{ M}$ , and  $[\text{SO}_3] = 1.25 \text{ M}$ .

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  $0^\circ\text{C}$ . Remember,  $R = 0.0821 \text{ L}\cdot\text{atm}/\text{mol}\cdot\text{K}$ .

3. Consider the equilibrium  $\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$ .

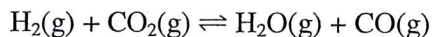
How would the following changes affect the partial pressures of each gas at equilibrium? ( $\uparrow, \downarrow, =$ )  
 $\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$

- |  |       |       |       |
|--|-------|-------|-------|
| a) addition of $\text{PCl}_3$              | _____ | _____ | _____ |
| b) removal of $\text{Cl}_2$                | _____ | _____ | _____ |
| c) removal of $\text{PCl}_5$               | _____ | _____ | _____ |
| 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  $K_{eq}$ ? ( $\uparrow$ =increase;  $\downarrow$ =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  $\Delta H_{\text{reaction}} = +9.9 \text{ kcal}$ .

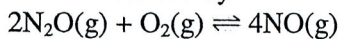


- |  |       |       |       |       |
|--|-------|-------|-------|-------|
| a) addition of $\text{CO}_2$               | _____ | _____ | _____ | _____ |
| b) addition of $\text{H}_2\text{O}$        | _____ | _____ | _____ | _____ |
| c) addition of a catalyst                  | _____ | _____ | _____ | _____ |
| 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?

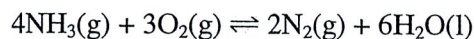
a \_\_\_\_\_ b \_\_\_\_\_ c \_\_\_\_\_ d \_\_\_\_\_ e \_\_\_\_\_

7. Consider the equilibrium:  $2\text{N}_2\text{O}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 4\text{NO}(\text{g})$   
 How will the amount of chemicals at equilibrium be affected by



- |   |     |     |     |
|---|-----|-----|-----|
| a) adding $\text{N}_2\text{O}$            | ___ | ___ | ___ |
| b) removing $\text{O}_2$                  | ___ | ___ | ___ |
| c) increasing the volume of the container | ___ | ___ | ___ |
| d) adding a catalyst                      | ___ | ___ | ___ |

8. For the reaction,  
 How will the concentration of each chemical be affected by



- |  |     |     |     |     |
|--|-----|-----|-----|-----|
| a) adding $\text{O}_2$ to the system             | ___ | ___ | ___ | ___ |
| b) adding $\text{N}_2$ to the system             | ___ | ___ | ___ | ___ |
| c) removing $\text{H}_2\text{O}$ from the system | ___ | ___ | ___ | ___ |
| d) decreasing the volume of the container        | ___ | ___ | ___ | ___ |

9. Consider the equilibrium:  $2\text{N}_2\text{O}(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 4\text{NO}(\text{g})$   
 3.00 moles of  $\text{NO}(\text{g})$  are introduced into a 1.00-Liter evacuated flask. When the system comes to equilibrium, 1.00 mole of  $\text{N}_2\text{O}(\text{g})$  has formed. Determine the equilibrium concentrations of each substance. Calculate the  $K_c$  for the reaction based on these data.

	2 $\text{N}_2\text{O}$	$\text{O}_2$	4 $\text{NO}$
initial			
change			
equilibrium			

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



**16 • Chemical Equilibrium****PRACTICE TEST**

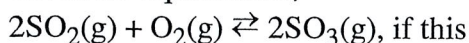
1. Consider the reaction system,



The equilibrium constant expression is

- a)  $\frac{[\text{CoO}][\text{H}_2]}{[\text{Co}][\text{H}_2\text{O}]}$       d)  $\frac{[\text{H}_2]}{[\text{H}_2\text{O}]}$   
 b)  $\frac{[\text{Co}][\text{H}_2\text{O}]}{[\text{CoO}][\text{H}_2]}$       e)  $\frac{[\text{H}_2\text{O}]}{[\text{H}_2]}$   
 c)  $\frac{[\text{Co}][\text{H}_2\text{O}]}{[\text{H}_2]}$

2. Given the equilibrium,

equilibrium is established by beginning with equal number of moles of  $\text{SO}_2$  and  $\text{O}_2$  in a1.0 Liter bulb, then the following *must* be true at equilibrium:

- a)  $[\text{SO}_2] = [\text{SO}_3]$       d)  $[\text{SO}_2] < [\text{O}_2]$   
 b)  $2[\text{SO}_2] = 2[\text{SO}_3]$       e)  $[\text{SO}_2] > [\text{O}_2]$   
 c)  $[\text{SO}_2] = [\text{O}_2]$

**Questions 3 & 4** refer to the following:At a given temperature, 0.300 mole  $\text{NO}$ , 0.200 mol  $\text{Cl}_2$  and 0.500 mol  $\text{ClNO}$  were

placed in a 25.0 Liter container. The

following equilibrium is established:

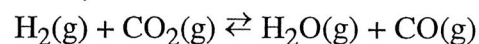


3. At equilibrium, 0.600 mol of  $\text{ClNO}$  was present. The number of *moles* of  $\text{Cl}_2$  present at equilibrium is
- a) 0.050                      d) 0.200  
 b) 0.100                      e) 0.250  
 c) 0.150

4. The equilibrium constant,
- $K_c$
- , is:

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

5. At
- $985^\circ\text{C}$
- , the equilibrium constant for the reaction,



is 1.63. What is the equilibrium constant for the reverse reaction?

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

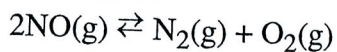
6. What is the relationship between
- $K_p$
- and
- $K_c$
- for the reaction,
- $2\text{ICl(g)} \rightleftharpoons \text{I}_2\text{(g)} + \text{Cl}_2\text{(g)}$
- ?

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

7. For the reaction
- $2\text{NO}_2\text{(g)} \rightleftharpoons \text{N}_2\text{O}_4\text{(g)}$
- ,
- $K_p$
- at
- $25^\circ\text{C}$
- is 7.3, when all partial pressures are expressed in atmospheres. What is
- $K_c$
- for this reaction? [
- $R=0.0821 \text{ L}\cdot\text{atm}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
- ]

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

8. 0.200 mol NO is placed in a one liter flask at 2273 K. After equilibrium is attained, 0.0863 mol N<sub>2</sub> and 0.0863 mol O<sub>2</sub> are present. What is K<sub>c</sub> for this reaction?



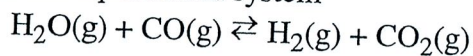
- a) 9.92                      d) 39.7  
b) 3.15                      e) 0.576  
c) 0.0372

9.  $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2 \text{NO}_2(\text{g})$

At 25°C, 0.11 mole of N<sub>2</sub>O<sub>4</sub> reacts to form 0.10 mol of N<sub>2</sub>O<sub>4</sub> and 0.02 mole of NO<sub>2</sub>. At 90°C, 0.11 mole of N<sub>2</sub>O<sub>4</sub> forms 0.050 mole of N<sub>2</sub>O<sub>4</sub> and 0.12 mole of NO<sub>2</sub>. From these data we can conclude

- a) N<sub>2</sub>O<sub>4</sub> molecules react by a second order rate law.  
b) N<sub>2</sub>O<sub>4</sub> molecules react by a first order rate law.  
c) the reaction is exothermic.  
d) N<sub>2</sub>O<sub>4</sub> 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

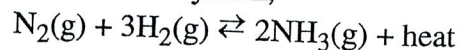


$$\Delta H = -42 \text{ kJ/mol}$$

K<sub>c</sub> equals 0.62 at 1260 K. If 0.10 mole each of H<sub>2</sub>O, CO, H<sub>2</sub> and CO<sub>2</sub> (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

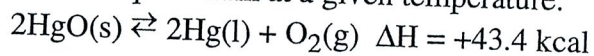
11. For the reaction system,



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<sub>2</sub> are placed in a glass bulb and are allowed to reach equilibrium at a given temperature.



The mass of HgO in the bulb could be increased by

- a) adding more Hg.  
b) removing some O<sub>2</sub>.  
c) reducing the volume of the bulb.  
d) increasing the temperature.  
e) removing some Hg.

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

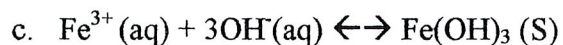
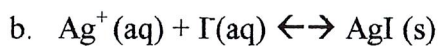
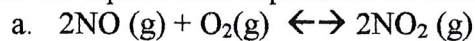
1.		7.	
2.		8.	
3.		9.	
4.		10.	
5.		11.	
6.		12.	

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

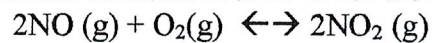
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**Chapter 13 Review**

1. write the equilibrium expression for each of the following



2. Calculate the equilibrium constant K at 25°C for the reaction



If the equilibrium concentrations are  $\text{NO} = 6.5 \times 10^{-5} \text{ atm}$   $\text{O}_2 = 4.5 \times 10^{-5} \text{ atm}$   $\text{NO}_2 = 0.55 \text{ atm}$

3. Of the equilibrium constant at 444°C for  $2\text{HI}(\text{g}) \leftrightarrow \text{H}_2(\text{g}) + \text{I}_2(\text{g})$  is  $1.39 \times 10^{-2}$ , find the equilibrium constant for the reverse reaction at 444°C.

4. For each value of K predict the effect on the reaction.

$$K = 1$$

$$K = 10^{10}$$

$$K = 10^{-10}$$

5. The dissociation of acetic acid,  $\text{CH}_3\text{COOH}$ , has an equilibrium constant at  $25^\circ\text{C}$  of  $1.8 \times 10^{-5}$ . The reaction is

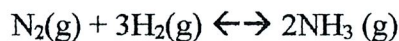


If the equilibrium concentration of  $\text{CH}_3\text{COOH} = 0.46$  moles in  $0.500$  L of water and the concentration of  $\text{CH}_3\text{COO}^-$  is  $8.1 \times 10^{-3}$  moles in the same  $0.500$  L calculate the concentration of  $\text{H}^+$  for the reaction.

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 _____

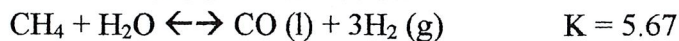
7. at  $700\text{K}$ , the measured values of for the partial pressures of ammonia, hydrogen, and nitrogen are  $0.400$  atm ,  $7.20$  atm, and  $2.40$  atm respectively. Calculate the  $K_p$  and  $K_c$  at  $700\text{K}$  for the synthesis of ammonia:



8. (Likely to see on AP) For the following process at  $700^\circ\text{C}$ , what is the partial pressure of each gas at equilibrium if the total pressure is  $0.750$  atm? Hint: use X to solve



9. Given the reaction of methane and water below



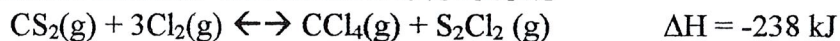
predict what direction the system will shift in order to reach equilibrium given the following initial values of Q.

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



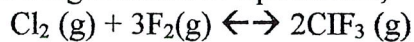
Predict the effect of the following change to the system on the direction of the equilibrium.

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

b.  $\text{CCl}_4$  is removed as it is generated

c. Heat is added to the system

11. Given the following reaction at equilibrium,



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.



# CHAPTER 10 QUESTIONS

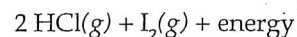
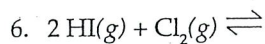
## MULTIPLE-CHOICE QUESTIONS

### 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  $1 \times 10^{-14}$  at  $25^\circ\text{C}$ .
  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?

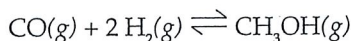
- (A)  $K_{sp}$  will increase, and the salt will become more soluble.  
(B)  $K_{sp}$  will decrease, and the salt will become more soluble.  
(C)  $K_{sp}$  will increase, and the salt will become less soluble.  
(D)  $K_{sp}$  will decrease, and the salt will become less soluble.  
(E)  $K_{sp}$ 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



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  $\text{I}_2$  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

7. A sealed isothermal container initially contained 2 moles of CO gas and 3 moles of H<sub>2</sub> gas. The following reversible reaction occurred:



At equilibrium, there was 1 mole of CH<sub>3</sub>OH in the container. What was the total number of moles of gas present in the container at equilibrium?

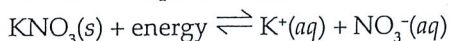
- (A) 1  
(B) 2  
(C) 3  
(D) 4  
(E) 5

8.  $4 \text{NH}_3(g) + 3 \text{O}_2(g) \rightleftharpoons 2 \text{N}_2(g) + 6 \text{H}_2\text{O}(g) + \text{energy}$

Which of the following changes to the system at equilibrium shown above would cause the concentration of H<sub>2</sub>O 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<sub>3</sub> was removed from the system.  
(D) N<sub>2</sub> was removed from the system.  
(E) O<sub>2</sub> was removed from the system.

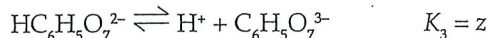
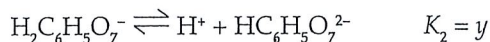
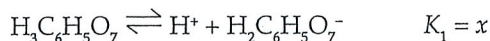
9. A sample of solid potassium nitrate is placed in water. The solid potassium nitrate comes to equilibrium with its dissolved ions by the endothermic process shown below.



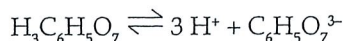
Which of the following changes to the system would increase the concentration of K<sup>+</sup> ions at equilibrium?

- (A) The volume of the solution is increased.  
(B) The volume of the solution is decreased.  
(C) Additional solid KNO<sub>3</sub> 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<sub>3</sub>C<sub>6</sub>H<sub>5</sub>O<sub>7</sub>, can give up 3 hydrogen ions in solution. The 3 dissociation reactions are as follows:



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



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

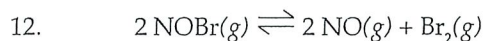
11.  $\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g)$

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  $K_c$ .

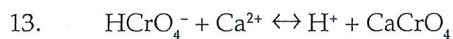
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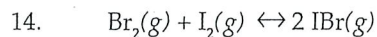
The reaction above came to equilibrium at a temperature of  $100^\circ\text{C}$ . At equilibrium the partial pressure due to  $\text{NOBr}$  was 4 atmospheres, the partial pressure due to  $\text{NO}$  was 4 atmospheres, and the partial pressure due to  $\text{Br}_2$  was 2 atmospheres. What is the equilibrium constant,  $K_p$ , for this reaction at  $100^\circ\text{C}$ ?

- (A)  $\frac{1}{4}$
- (B)  $\frac{1}{2}$
- (C) 1
- (D) 2
- (E) 4



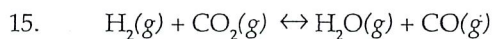
If the acid dissociation constant for  $\text{HCrO}_4^-$  is  $K_a$  and the solubility product for  $\text{CaCrO}_4$  is  $K_{sp}$ , which of the following gives the equilibrium expression for the reaction above?

- (A)  $K_a K_{sp}$
- (B)  $\frac{K_a}{K_{sp}}$
- (C)  $\frac{K_{sp}}{K_a}$
- (D)  $\frac{1}{K_{sp} K_a}$
- (E)  $\frac{K_a K_{sp}}{2}$



At  $150^\circ\text{C}$ , 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  $\text{IBr}(g)$  was found to be 3 atm. Which of the following could be the partial pressures due to  $\text{Br}_2(g)$  and  $\text{I}_2(g)$  in the container?

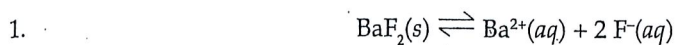
- |     | $\text{Br}_2(g)$ | $\text{I}_2(g)$ |
|-----|------------------|-----------------|
| (A) | 0.1 atm          | 0.3 atm         |
| (B) | 0.3 atm          | 1 atm           |
| (C) | 1 atm            | 1 atm           |
| (D) | 1 atm            | 3 atm           |
| (E) | 3 atm            | 3 atm           |



Initially, a sealed vessel contained only  $\text{H}_2(g)$  with a partial pressure of 6 atm and  $\text{CO}_2(g)$  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  $\text{CO}(g)$  was found to be 2 atm. What is the value of the equilibrium constant  $K_p$  for the reaction?

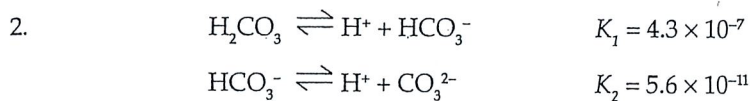
- (A)  $\frac{1}{24}$
- (B)  $\frac{1}{6}$
- (C)  $\frac{1}{4}$
- (D)  $\frac{1}{3}$
- (E)  $\frac{1}{2}$

## PROBLEMS



The value of the solubility product,  $K_{sp}$ , for the reaction above is  $1.0 \times 10^{-6}$  at  $25^\circ\text{C}$ .

- Write the  $K_{sp}$  expression for  $\text{BaF}_2$ .
- What is the concentration of  $\text{F}^{-}$  ions in a saturated solution of  $\text{BaF}_2$  at  $25^\circ\text{C}$ ?
- 500 milliliters of a 0.0060-molar  $\text{NaF}$  solution is added to 400 ml of a 0.0060-molar  $\text{Ba}(\text{NO}_3)_2$  solution. Will there be a precipitate?
- What is the value of  $\Delta G^\circ$  for the dissociation of  $\text{BaF}_2$  at  $25^\circ\text{C}$ ?



The acid dissociation constants for the reactions above are given at  $25^\circ\text{C}$ .

- What is the pH of a 0.050-molar solution of  $\text{H}_2\text{CO}_3$  at  $25^\circ\text{C}$ ?
- What is the concentration of  $\text{CO}_3^{2-}$  ions in the solution in (a)?
- How would the addition of each of the following substances affect the pH of the solution in (a)?
  - $\text{HCl}$
  - $\text{NaHCO}_3$
  - $\text{NaOH}$
  - $\text{NaCl}$
- What is the value of  $K_{eq}$  for the following reaction?

