EQUILIBRIUM CONSTANT (K)

Name ____________________

rite the expression for the equilibrium constant K for the reactions below.

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

2. $2KClO_3(s) \leftrightarrow 2KCl(s) + 3O_2(g)$

3. $H_2O(l) \leftrightarrow H^+(aq) + OH^-(aq)$

4. $2CO(g) + O_2(g) \leftrightarrow 2CO_2(g)$

5. $Li_2CO_3(s) \rightarrow 2Li^+(aq) + CO_3^{-2}(aq)$

Name ____________________ Date __________ Class __________

16–2 Practice Problems

1. Write the equilibrium expression for the oxidation of hydrogen to form water vapor.
$2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$

2. Write the equilibrium expression for the formation of nitrosyl bromide.
$2NO(g) + Br_2(g) \rightleftharpoons 2NOBr(g)$

3. Write the equilibrium expression for the following reaction.
$NO(g) + O_3(g) \rightleftharpoons O_2(g) + NO_2(g)$

4. Write the equilibrium expression for the following reaction.
$CH_4(g) + Cl_2(g) \rightleftharpoons CH_3Cl(g) + HCl(g)$

5. Write the equilibrium expression for the following reaction.
$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$

6. Write the equilibrium expression for the following reaction.
$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

7. Write the equilibrium expression for the combustion of ethane at high temperature.
$2C_2H_6(g) + 7O_2(g) \rightleftharpoons 4CO_2(g) + 6H_2O(g)$

8. Write the equilibrium expression for the decomposition of ethane.
$C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$

9. Write the equilibrium expression for the following reaction.
$Hg(g) + I_2(g) \rightleftharpoons HgI_2(g)$

10. Write the equilibrium expression for the following reaction.
$SnO_2(s) + 2CO(g) \rightleftharpoons Sn(s) + 2CO_2(g)$

11. Write the equilibrium expression for the following reaction.
$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$

12. Write the equilibrium expression for the following reaction.
$FeO(s) + CO(g) \rightleftharpoons Fe(s) + CO_2(g)$

13. Write the equilibrium expression for the following reaction.
$KCl(l) + Na(l) \rightleftharpoons NaCl(l) + K(g)$

14. Write the equilibrium expression for the following reaction.
$NaCl(s) + H_2SO_4(l) \rightleftharpoons HCl(g) + NaHSO_4(s)$

15. Write the equilibrium expression for the following reaction.
$P_4(s) + 6NO(g) \rightleftharpoons P_4O_6(s) + 3N_2(g)$

16. Write the equilibrium expression for the following reaction.
$2NO(g) + 2H_2(g) \rightleftharpoons N_2(g) + 2H_2O(l)$

Name ________________________ Date __________ Class __________

16–2 Practice Problems *(continued)*

17. Write the equilibrium expression for the following reaction.
$H_2CO_3(s) \rightleftharpoons H_2O(l) + CO_2(g)$

18. Write the equilibrium expression for the following reaction.
$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(l)$

19. At 740°C, $K_{eq} = 0.0060$ for the decomposition of calcium carbonate ($CaCO_3$), which is described by the equation
$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
Find Q and predict how the reaction will proceed if $[CO_2] = 0.0004\ M$.

20. For the reaction
$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g)$
$K_{eq} = 5.10$ at 527°C. If $[CO] = 0.15\ M$, $[H_2O] = 0.25\ M$, $[H_2] = 0.42\ M$, and $[CO_2] = 0.37\ M$, calculate Q and determine how the reaction will proceed.

21. At 340°C, $K_{eq} = 0.064$ for the reaction
$Fe_2O_3(s) + 3H_2(g) \rightleftharpoons 2Fe(s) + 3H_2O(g)$
Given that $[H_2] = 0.45\ M$ and $[H_2O] = 0.37\ M$, find Q and predict how the reaction will proceed.

22. At 2130°C, $K_{eq} = 0.0025$ for the reaction
$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$
If $[N_2] = 0.81\ M$, $[O_2] = 0.75\ M$, and $[NO] = 0.030\ M$, find Q and determine the direction in which the reaction will proceed.

23. Ammonia is synthesized from nitrogen and hydrogen in the reaction
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
At 500°C, the equilibrium constant for this reaction is 0.080. Given that $[NH_3] = 0.0596\ M$, $[N_2] = 0.600\ M$, and $[H_2] = 0.420\ M$, find Q and predict how the reaction will proceed.

24. The decomposition of antimony pentachloride ($SbCl_5$) is described by the equation
$SbCl_5(g) \rightleftharpoons SbCl_3(g) + Cl_2(g)$
At 448°C, the equilibrium constant for this reaction is 0.0251. What is the value of Q if $[SbCl_5] = 0.095\ M$, $[SbCl_3] = 0.020\ M$, and $[Cl_2] = 0.050\ M$? How will this reaction proceed?

25. At 1000°C, $K_{eq} = 1.0 \times 10^{-13}$ for the decomposition of hydrofluoric acid (HF), as described in the reaction
$2HF(g) \rightleftharpoons H_2(g) + F_2(g)$
If $[HF] = 23.0\ M$, $[H_2] = 0.540\ M$, and $[F_2] = 0.380\ M$, determine the value of Q and predict how the reaction will proceed.

26. At 1227°C, K_{eq} for the following reaction is 0.15.
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
If $[SO_2] = 0.344\ M$, $[O_2] = 0.172\ M$, and $[SO_3] = 0.056\ M$, find Q and determine how the reaction will proceed.

LE CHATELIER'S PRINCIPLE

Name ____________________

Le Chatelier's Principle states that when a system at equilibrium is subjected to a stress, the system will shift its equilibrium point in order to relieve the stress.

Complete the following chart by writing left, right or none for equilibrium shift, and decreases, increases or remains the same for the concentrations of reactants and products, and for the value of K.

$$N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g) + 22.0 \text{ kcal}$$

Stress	Equilibrium Shift	$[N_2]$	$[H_2]$	$[NH_3]$	K
1. Add N_2	right	———	decreases	increases	remains the same
2. Add H_2			———		
3. Add NH_3				———	
4. Remove N_2		———			
5. Remove H_2			———		
6. Remove NH_3				———	
7. Increase Temperature					
8. Decrease Temperature					
9. Increase Pressure					
Decrease Pressure					

LE CHATELIER'S PRINCIPLE CONTINUED

Name ____________

$$12.6\ kcal + H_2(g) + I_2(g) \leftrightarrow 2HI(g)$$

Stress	Equilibrium Shift	$[H_2]$	$[I_2]$	$[HI]$	K
1. Add H_2	right	———	decreases	increases	remains the same
2. Add I_2			———		
3. Add HI				———	
4. Remove H_2		———			
5. Remove I_2			———		
6. Remove HI				———	
7. Increase Temperature					
8. Decrease Temperature					
9. Increase Pressure					
10. Decrease Pressure					

$$NaOH(s) \leftrightarrow Na^+(aq) + OH^-(aq) + 10.6\ kcal$$

(Remember that pure solids and liquids do not affect equilibrium values.)

Stress	Equilibrium Shift	Amount NaOH(s)	$[Na^+]$	$[OH^-]$	K
1. Add NaOH(s)		———			
2. Add NaCl (Adds Na^+)			———		
3. Add KOH (Adds OH^-)				———	
4. Add H^+ (Removes OH^-)				———	
5. Increase Temperature					
6. Decrease Temperature					
7. Increase Pressure					
8. Decrease Pressure					

mass action to the reaction? Explain. **(b)** Write the chemical reaction involved in the *Haber process*. Why is this reaction important to humanity? **(c)** Write the equilibrium expression for the reaction in part (b).

15.7 Write the expressions for K_c for the following reactions. In each case indicate whether the reaction is homogeneous or heterogeneous.
(a) $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$
(b) $N_2H_4(g) \rightleftharpoons N_2(g) + 2H_2(g)$
(c) $2C_2H_4(g) + 2H_2O(g) \rightleftharpoons 2C_2H_6(g) + O_2(g)$
(d) $FeO(s) + H_2(g) \rightleftharpoons Fe(s) + H_2O(g)$
(e) $Ti(s) + 2Cl_2(g) \rightleftharpoons TiCl_4(l)$

15.8 Write the expressions for K_c and K_p for the following reactions. In each case indicate whether the reaction is homogeneous or heterogeneous.
(a) $3NO(g) \rightleftharpoons N_2O(g) + NO_2(g)$
(b) $CH_4(g) + 2H_2S(g) \rightleftharpoons CS_2(g) + 4H_2(g)$
(c) $Ni(CO)_4(g) \rightleftharpoons Ni(s) + 4CO(g)$
(d) $Fe_2O_3(s) + 3H_2(g) \rightleftharpoons 2Fe(s) + 3H_2O(g)$
(e) $2N_2O_5(g) \rightleftharpoons 4NO_2(g) + O_2(g)$

15.9 The equilibrium constant for the reaction

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

is $K_c = 2.4 \times 10^3$ at 2000°C.
(a) Calculate K_c for $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$.
(b) At this temperature, does the equilibrium favor NO, or does it favor N_2 and O_2?

15.10 The equilibrium constant for the reaction

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

is $K_c = 2.4 \times 10^{-3}$ at 700°C.
(a) Calculate K_c for $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$.
(b) Does the equilibrium favor SO_2 and O_2, or does it favor SO_3 at this temperature?

15.11 Consider the equilibrium $Na_2SO_3(s) \rightleftharpoons Na_2O(s) + SO_2(g)$. **(a)** Write an expression for K_c that includes *all* of the reactants and products. **(b)** Explain why we normally exclude pure solids and liquids from equilibrium constant expressions. **(c)** Write an expression for K_c' that excludes the pure solids from the equilibrium expression, analogous to Equation 15.14.

15.12 Mercury(I) oxide decomposes into elemental mercury and elemental oxygen: $2Hg_2O(s) \rightleftharpoons 4Hg(l) + O_2(g)$. **(a)** Write an expression for K_c that includes *all* of the reactants and products. **(b)** Explain why we normally exclude pure solids and liquids from equilibrium expressions. **(c)** Write an expression for K_c' that excludes the pure solid and pure liquid from the equilibrium expression.

Calculating Equilibrium Constants

15.13 Gaseous hydrogen iodide is placed in a closed container at 425°C, where it partially decomposes to hydrogen and iodine: $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$. At equilibrium it is found that $[HI] = 3.53 \times 10^{-3}$ *M*; $[H_2] = 4.79 \times 10^{-4}$ *M*; and $[I_2] = 4.79 \times 10^{-4}$ *M*. What is the value of K_c at this temperature?

15.14 At temperatures near 800°C, steam passed over hot coke (a form of carbon obtained from coal) reacts to form CO and H_2:

$$C(s) + H_2O(g) \rightleftharpoons CO(g) + H_2(g)$$

The mixture of gases that results is an important industrial fuel called *water gas*. When equilibrium is achieved at 800°C, $[H_2] = 4.0 \times 10^{-2}$ *M*, $[CO] = 4.0 \times 10^{-2}$ *M*, and $[H_2O] = 1.0 \times 10^{-2}$ *M*. Calculate K_c at this temperature.

15.15 At 500 K, the equilibrium constant for the reaction $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ is $K_p = 52.0$. An equilibrium mixture of the three gases has partial pressures of 0.095 atm and 0.171 atm for NO and Cl_2, respectively. What is the partial pressure of NOCl in the mixture?

15.16 Phosphorus trichloride gas and chlorine gas react to form phosphorus pentachloride gas: $PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$. A gas vessel is charged with a mixture of $PCl_3(g)$ and $Cl_2(g)$, which is allowed to equilibrate at 450 K. At equilibrium the partial pressures of the three gases are $P_{PCl_3} = 0.124$ atm, $P_{Cl_2} = 0.157$ atm, and $P_{PCl_5} = 1.30$ atm. **(a)** What is the value of K_p at this temperature? **(b)** Does the equilibrium favor reactants or products?

15.17 A mixture of 0.100 mol of NO, 0.050 mol of H_2, and 0.10 mol of H_2O is placed in a 1.0-L vessel. The following equilibrium is established:

$$2NO(g) + 2H_2(g) \rightleftharpoons N_2(g) + 2H_2O(g)$$

At equilibrium $[NO] = 0.062$ *M*. **(a)** Calculate the equilibrium concentrations of H_2, N_2, and H_2O. **(b)** Calculate K_c.

15.18 A mixture of 1.374 g of H_2 and 70.31 g of Br_2 is heated in a 2.00-L vessel at 700 K. These substances react as follows:

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

At equilibrium the vessel is found to contain 0.566 g of H_2. **(a)** Calculate the equilibrium concentrations of H_2, Br_2, and HBr. **(b)** Calculate K_c.

15.19 At 700°C, $K_c = 20.4$ for the reaction

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$$

(a) What is the value of K_c for the reaction $SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$? **(b)** What is the value of K_c for the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$? **(c)** What is the value of K_p for the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$?

15.20 Consider the following equilibrium, for which $K_p = 0.0752$ at 480°C:

$$2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g)$$

(a) What is the value of K_p for the reaction $4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$? **(b)** What is the value of K_p for the reaction $Cl_2(g) + H_2O(g) \rightleftharpoons 2HCl(g) + \frac{1}{2}O_2(g)$? **(c)** What is the value of K_c for the reaction $2Cl_2(g) + 2H_2O(g) \rightleftharpoons 4HCl(g) + O_2(g)$?

15.21 A mixture of 0.1000 mol of CO_2, 0.05000 mol of H_2, and 0.1000 mol of H_2O is placed in a 1.000-L vessel. The following equilibrium is established:

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

At equilibrium $[CO_2] = 0.0954$ *M*. **(a)** Calculate the equilibrium concentrations of H_2, CO, and H_2O. **(b)** Calculate K_c for the reaction. **(c)** Is there sufficient information to calculate K_p for the reaction? Explain.

15.22 A flask is charged with 1.500 atm of $N_2O_4(g)$ and 1.000 atm of $NO_2(g)$ at 25°C. The equilibrium reaction is given in Equation 15.7. After equilibrium is reached, the partial pressure of NO_2 is 0.512 atm. **(a)** What is the equilibrium partial pressure of N_2O_4? **(b)** Calculate the value of K_p for the reaction. **(c)** Is there sufficient information to calculate K_c for the reaction? If so, evaluate K_c.

Applications of Equilibrium Constants

15.23 **(a)** How does a *reaction quotient* differ from an equilibrium constant? **(b)** If $Q < K$, in which direction will a reaction proceed in order to reach equilibrium? **(c)** What condition must be satisfied so that $Q = K$?

15.24 **(a)** How is a reaction quotient used to determine whether a system is at equilibrium? **(b)** If $Q > K$, how must the reaction proceed to reach equilibrium? **(c)** At the start of a certain reaction, only reactants are present; no products have been formed. What is the value of Q at this point in the reaction?

15.25 At 100°C the equilibrium constant for the reaction $COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$ has the value of $K_c = 2.19 \times 10^{-10}$. Are the following mixtures of $COCl_2$, CO, and Cl_2 at equilibrium? If not, indicate the direction that the reaction must proceed to achieve equilibrium. **(a)** $[COCl_2] = 5.00 \times 10^{-2}$ M, $[CO] = 3.31 \times 10^{-6}$ M, $[Cl_2] = 3.31 \times 10^{-6}$ M; **(b)** $[COCl_2] = 3.50 \times 10^{-3}$ M, $[CO] = 1.11 \times 10^{-5}$ M, $[Cl_2] = 3.25 \times 10^{-6}$ M; **(c)** $[COCl_2] = 1.45$ M, $[CO] = [Cl_2] = 1.56 \times 10^{-6}$ M.

15.26 As shown in Table 15.3, K_p for the equilibrium

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

is 4.51×10^{-5} at 450°C. For each of the mixtures listed here, indicate whether the mixture is at equilibrium at 450°C; if it is not at equilibrium, indicate the direction (toward product or toward reactants) in which the mixture must shift to achieve equilibrium: **(a)** 105 atm NH_3, 35 atm N_2, 495 atm H_2; **(b)** 35 atm NH_3, 595 atm H_2, no N_2; **(c)** 26 atm NH_3, 42 atm H_2, 202 atm N_2; **(d)** 105 atm NH_3, 55 atm H_2, 5.0 atm N_2.

15.27 At 100°C, $K_c = 0.078$ for the following reaction:

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

In an equilibrium mixture of the three gases the concentrations of SO_2Cl_2 and SO_2 are 0.136 M and 0.072 M, respectively. What is $[Cl_2]$ in the equilibrium mixture?

15.28 At 900 K the following reaction has $K_p = 0.345$:

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

In an equilibrium mixture the partial pressures of SO_2 and O_2 are 0.215 atm and 0.679 atm, respectively. What is the equilibrium partial pressure of SO_3 in the mixture?

15.29 At 1285°C the equilibrium constant for the reaction $Br_2(g) \rightleftharpoons 2Br(g)$ is $K_c = 1.04 \times 10^{-3}$. A 0.200-L vessel containing an equilibrium mixture of the gases has 0.245 g $Br_2(g)$ in it. What is the mass of $Br(g)$ in the vessel?

15.30 For the reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$, $K_p = 55.3$ at 700 K. In a 2.00-L flask containing an equilibrium mixture of the three gases, there are 0.056 g H_2 and 4.36 g I_2. What is the mass of HI in the flask?

15.31 At 2000°C the equilibrium constant for the reaction

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

is $K_c = 2.4 \times 10^3$. If the initial concentration of NO is 0.500 M, what are the equilibrium concentrations of NO, N_2, and O_2?

15.32 For the equilibrium

$$Br_2(g) + Cl_2(g) \rightleftharpoons 2BrCl(g)$$

at 400 K, $K_c = 7.0$. If 0.50 mol of Br_2 and 0.50 mol Cl_2 are introduced into a 1.0-L container at 400 K, what will be the equilibrium concentration of BrCl?

15.33 At 373 K, $K_p = 0.416$ for the equilibrium

$$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$$

If the pressures of $NOBr(g)$ and $NO(g)$ are equal, what is the equilibrium pressure of $Br_2(g)$?

15.34 At 21.8°C, $K_c = 1.2 \times 10^{-4}$ for the equilibrium

$$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$$

Calculate the equilibrium concentrations of NH_3 and H_2S if a sample of solid NH_4HS is placed in a closed vessel and decomposes until equilibrium is reached.

15.35 At 80°C, $K_c = 1.87 \times 10^{-3}$ for the following reaction:

$$PH_3BCl_3(s) \rightleftharpoons PH_3(g) + BCl_3(g)$$

(a) Calculate the equilibrium concentrations of PH_3 and BCl_3 if a solid sample of PH_3BCl_3 is placed in a closed vessel and decomposes until equilibrium is reached. **(b)** If the flask has a volume of 0.500 L, what is the minimum mass of $PH_3BCl_3(s)$ that must be added to the flask in order to achieve equilibrium?

15.36 Consider the following reaction:

$$NH_4SH(s) \rightleftharpoons NH_3(g) + H_2S(g)$$

At 22°C the equilibrium constant $K_p = 0.070$ for this reaction. **(a)** If $NH_4SH(s)$ is placed in a vessel and decomposes at 22°C, what are the equilibrium partial pressures of NH_3 and H_2S? **(b)** If the vessel has a volume of 15 L, what is the minimum mass of $NH_4SH(s)$ needed in order for equilibrium to be achieved?

15.37 At 250°C, the reaction

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

has an equilibrium constant $K_c = 1.80$. If 0.100 mol PCl_5 is added to a 5.00-L vessel, what are the concentrations of PCl_5, PCl_3, and Cl_2 at equilibrium at this temperature?

15.38 For the reaction $I_2(g) + Br_2(g) \rightleftharpoons 2IBr(g)$, $K_c = 280$ at 150°C. Suppose that 0.500 mol IBr in a 1.00-L flask is allowed to reach equilibrium at 150°C. What are the equilibrium concentrations of IBr, I_2, and Br_2?

Le Châtelier's Principle

15.39 Consider the following equilibrium, for which $\Delta H° < 0$:

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

How will each of the following affect an equilibrium mixture of the three gases? **(a)** $O_2(g)$ is added to the system; **(b)** the reaction mixture is heated; **(c)** the volume of the reaction vessel is doubled; **(d)** a catalyst is added to the mixture; **(e)** the total pressure of the system is increased by adding a noble gas; **(f)** $SO_3(g)$ is removed from the system.

15.40 For the following reaction, $\Delta H^\circ = 2816$ kJ

$$6CO_2(g) + 6H_2O(l) \rightleftharpoons C_6H_{12}O_6(s) + 6O_2(g)$$

How is the equilibrium yield of $C_6H_{12}O_6$ affected by **(a)** increasing P_{CO_2}; **(b)** increasing temperature; **(c)** removing CO_2; **(d)** increasing the total pressure; **(e)** removing part of the $C_6H_{12}O_6$; **(f)** adding a catalyst?

15.41 How do the following changes affect the value of the equilibrium constant for an exothermic reaction: **(a)** removal of a reactant or product; **(b)** decrease in the volume; **(c)** decrease in the temperature; **(d)** addition of a catalyst?

15.42 For a certain gas-phase reaction the fraction of products in an equilibrium mixture is increased by increasing the temperature and increasing the volume of the reaction vessel. **(a)** What can you conclude about the reaction from the influence of temperature on the equilibrium? **(b)** What can you conclude from the influence of increasing the volume?

15.43 Consider the following equilibrium between oxides of nitrogen:

$$3NO(g) \rightleftharpoons NO_2(g) + N_2O(g)$$

(a) Use data in Appendix C to calculate ΔH° for this reaction. **(b)** Will the equilibrium constant for the reaction increase or decrease with increasing temperature? Explain. **(c)** At constant temperature would a change in the volume of the container affect the fraction of products in the equilibrium mixture?

15.44 Methanol, CH_3OH, can be made by the reaction of CO with H_2:

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

(a) Use thermochemical data in Appendix C to calculate ΔH° for this reaction. **(b)** In order to maximize the equilibrium yield of methanol, would you use a high or low temperature? **(c)** Assuming equal pressures of CO and H_2, how would the conversion of the gas mixture to methanol vary with total pressure?

Additional Exercises

15.45 Both the forward and reverse reactions of the following equilibrium are believed to be elementary steps:

$$CO(g) + Cl_2(g) \rightleftharpoons COCl(g) + Cl(g)$$

At 25°C, the rate constants for the forward and reverse reactions are $1.4 \times 10^{-28}\ M^{-1}s^{-1}$ and $9.3 \times 10^{10}\ M^{-1}s^{-1}$, respectively. **(a)** What is the value for the equilibrium constant at 25°C? **(b)** Are reactants or products more plentiful at equilibrium?

15.46 A mixture of CH_4 and H_2O is passed over a nickel catalyst at 1000 K. The emerging gas is collected in a 5.00-L flask and is found to contain 8.62 g of CO, 2.60 g of H_2, 43.0 g of CH_4, and 48.4 g of H_2O. Assuming that equilibrium has been reached, calculate K_c for the reaction

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

15.47 A mixture of H_2, S, and H_2S is held in a 1.0-L vessel at 90°C until the following equilibrium is achieved:

$$H_2(g) + S(s) \rightleftharpoons H_2S(g)$$

At equilibrium, the mixture contains 0.46 g of H_2S and 0.40 g H_2. **(a)** Write the equilibrium expression for this reaction. **(b)** What is the value of K_c for the reaction at this temperature? **(c)** Why can we ignore the amount of S when doing the calculation in part (b)?

15.48 A sample of nitrosyl bromide, NOBr, decomposes according to the following equation:

$$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g)$$

An equilibrium mixture in a 5.00-L vessel at 100°C contains 3.22 g of NOBr, 3.08 g of NO, and 4.19 g of Br_2. **(a)** Calculate K_c. **(b)** Calculate K_p. **(c)** What is the total pressure exerted by the mixture of gases?

15.49 Consider the hypothetical reaction $A(g) \rightleftharpoons 2B(g)$. A flask is charged with 0.75 atm of pure A, after which it is allowed to reach equilibrium at 0°C. At equilibrium, the partial pressure of A is 0.50 atm. **(a)** What is the total pressure in the flask at equilibrium? **(b)** What is the value of K_p? **(c)** What is the value of K_c?

[15.50] As shown in Table 15.3, at 300°C the equilibrium constant for the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ is $K_p = 4.34 \times 10^{-3}$. Pure NH_3 is placed in a 1.00-L flask and allowed to reach equilibrium at this temperature. There is 0.753 g NH_3 in the equilibrium mixture. **(a)** What are the masses of N_2 and H_2 in the equilibrium mixture? **(b)** What was the initial mass of ammonia placed in the vessel? **(c)** What is the total pressure in the vessel?

15.51 For the equilibrium

$$2IBr(g) \rightleftharpoons I_2(g) + Br_2(g)$$

$K_c = 8.5 \times 10^{-3}$ at 150°C. If 0.040 mol of IBr is placed in a 1.0-L container, what is the concentration of this substance after equilibrium is reached?

15.52 For the equilibrium

$$PH_3BCl_3(s) \rightleftharpoons PH_3(g) + BCl_3(g)$$

$K_p = 0.052$ at 60°C. **(a)** Calculate K_c. **(b)** Some solid PH_3BCl_3 is added to a closed 0.500-L vessel at 60°C; the vessel is then charged with 0.0216 mol of $BCl_3(g)$. What is the equilibrium concentration of PH_3?

[15.53] Solid NH_4HS is introduced into an evacuated flask at 24°C. The following reaction takes place:

$$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g)$$

At equilibrium the total pressure (for NH_3 and H_2S taken together) was 0.614 atm. What is K_p for this equilibrium at 24°C?

[15.54] A 0.831-g sample of SO_3 is placed in a 1.00-L container and heated to 1100 K. The SO_3 decomposes to SO_2 and O_2:

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