Assignment 15 A

1- Write the equilibrium constant for the heterogeneous reaction

\[ 2\text{NaHCO}_3(s) \rightleftharpoons \text{Na}_2\text{CO}_3(s) + \text{CO}_2(g) + \text{H}_2\text{O}(g). \]

a) \( P_{\text{CO}_2}P_{\text{H}_2\text{O}} \)
b) \( 1/[\text{CO}_2][\text{H}_2\text{O}] \)
c) \( [\text{Na}_2\text{CO}_3][\text{CO}_2][\text{H}_2\text{O}]/[\text{NaHCO}_3]^2 \)
d) \( [\text{Na}_2\text{CO}_3][\text{CO}_2][\text{H}_2\text{O}]/[\text{NaHCO}_3] \)
e) \( [\text{Na}_2\text{CO}_3][P_{\text{CO}_2}][\text{H}_2\text{O}] \)

(The concentrations \([\text{Na}_2\text{CO}_3(s)]\) and \([\text{NaHCO}_3(s)]\) are not included in the equilibrium constant expression.)

2- Gaseous hydrogen iodide is placed in a closed 1.0-L container at 425°C, where it partially decomposes to hydrogen and iodine: \( 2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g) \).

At equilibrium it is found that \( P_{\text{HI}} = 3.53 \times 10^{-3} \text{ atm} \); \( P_{\text{H}_2} = 4.79 \times 10^{-4} \text{ atm} \); and \( P_{\text{I}_2} = 4.79 \times 10^{-4} \text{ atm} \).

What is the value of \( K_p \) at this temperature?

a) \( 2.71 \times 10^{-1} \)
b) \( 5.43 \times 10^{0} \)
c) \( 1.54 \times 10^{4} \)
d) \( 6.50 \times 10^{-5} \)
e) \( 1.84 \times 10^{-2} \)

(You correctly substituted the partial pressures into the \( K_p \) expression.)

3- Consider the reaction \( \text{N}_2\text{O}_4(g) \rightleftharpoons 2\text{NO}_2(g) \). Determine the value of the equilibrium constant for this reaction if an initial partial pressure of \( \text{N}_2\text{O}_4(g) \) of 0.0400 atm is reduced to 0.0055 atm at equilibrium.

(There is no \( \text{NO}_2(g) \) present at the start of the reaction.)

a) \( 6.3 \)
b) \( 1.2 \)
c) \( 0.87 \)
d) \( 13 \)
e) \( 0.22 \)

(The \( P_{\text{NO}_2} \) is equal to twice the amount of \( P_{\text{N}_2\text{O}_4} \) that reacted.)

4- At 100°C the equilibrium constant for the reaction \( \text{COCl}_2(g) \rightleftharpoons \text{CO}(g) + \text{Cl}_2(g) \) has a value of \( K_p = 2.19 \times 10^{-10} \). Are the following mixtures of \( \text{COCl}_2 \), CO, and \( \text{Cl}_2 \) at equilibrium? If not, indicate the direction that the reaction must proceed to achieve equilibrium.

(i) \( P_{\text{COCl}_2} = 5.00 \times 10^{-2} \text{ atm}; P_{\text{CO}} = 3.31 \times 10^{-6} \text{ atm}; P_{\text{Cl}_2} = 3.31 \times 10^{-6} \text{ atm} \)
(ii) \( P_{\text{COCl}_2} = 3.50 \times 10^{-3} \text{ atm}; P_{\text{CO}} = 1.11 \times 10^{-5} \text{ atm}; P_{\text{Cl}_2} = 3.25 \times 10^{-6} \text{ atm} \)

a) (i) not at equilibrium, right to left, (ii) equilibrium
b) (i) equilibrium, (ii) not at equilibrium, left to right
c) (i) not at equilibrium, left to right, (ii) equilibrium
d) (i) equilibrium, (ii) equilibrium
e) (i) equilibrium, (ii) not at equilibrium, right to left

(For reaction (i), \( Q = K_p \). For reaction (ii), \( Q > K_p \); thus, more reactants will form until \( Q = K_p \).)

5- This question pertains to the equilibrium

\[ 2\text{POCl}_3(g) \rightleftharpoons 2\text{PCl}_3(g) + \text{O}_2(g) \] for which \( \Delta H_{\text{rxn}}^\circ = +508 \text{ kJ} \).

How will the equilibrium of the reaction shift if \( \text{POCl}_3 \) is added to the reaction vessel?

a) The equilibrium will not shift in either direction.
6- Both the forward and reverse reactions of the following equilibrium are believed to be elementary steps:

\[
\text{CO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{COCl}(g) + \text{Cl}(g)
\]

At 25°C the rate constants for the forward and reverse reactions are \(1.4 \times 10^{-28} \text{ M}^{-1} \text{ s}^{-1}\) and \(9.3 \times 10^{10} \text{ M}^{-1} \text{ s}^{-1}\), respectively. What is the value for the equilibrium constant at 25°C?

a) \(1.5 \times 10^{-39}\)
b) \(6.6 \times 10^{38}\)
c) \(1.3 \times 10^{-17}\)

(The equilibrium constant is the forward rate constant divided by the reverse rate constant.)

7- What is the expression for \(K_c\) for the reaction \(2\text{N}_2\text{O}(g) + \text{O}_2(g) \rightleftharpoons 4\text{NO}(g)\)?

a) \([\text{NO}]^2/[\text{N}_2\text{O}]^2[\text{O}_2]\)
b) \([\text{NO}]^2/[\text{N}_2\text{O}]^2\)
c) \([\text{NO}]/[\text{N}_2\text{O}][\text{O}_2]\)
d) \([\text{N}_2\text{O}]^2[\text{O}_2]/[\text{NO}]^4\)
e) \([\text{N}_2\text{O}]/[\text{O}_2]/[\text{NO}]\)

\(K_c = \text{[products]}^{\text{coefficients}} / \text{[reactants]}^{\text{coefficients}}\).

8- For the gas-phase reaction (all components are in the gas phase) \(\text{CO} + 3\text{H}_2 \rightleftharpoons \text{CH}_4 + \text{H}_2\text{O}\), which expression represents \(K_p\) correctly?

a) \(P_{\text{CH}_4}P_{\text{H}_2\text{O}}/P_{\text{CO}}P_{\text{H}_2}^3\)
b) \(P_{\text{CH}_4}P_{\text{H}_2\text{O}}/P_{\text{CO}}P_{\text{H}_2}^2\)
c) \(P_{\text{CO}}P_{\text{H}_2}^3/P_{\text{CH}_4}P_{\text{H}_2}\)
d) \(P_{\text{CO}}^2P_{\text{H}_2}/P_{\text{CH}_4}P_{\text{H}_2}\)
e) \(P_{\text{CH}_4}P_{\text{H}_2\text{O}}/P_{\text{CO}}P_{\text{H}_2}^3\)

(The partial pressure of the products is divided by the partial pressure of the reactants (with correct power terms).)

9- The proper expression for \(K_c\) for the reaction \(\text{NiCO}_3(s) + 2\text{H}^+(aq) \rightleftharpoons \text{Ni}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)\) is

a) \([\text{Ni}^{2+}]/[\text{H}^+]^2\).
b) \([\text{Ni}^{2+}]/[\text{CO}_2]/[\text{H}^+]^2\).
c) \([\text{CO}_2]\).
d) \([\text{Ni}^{2+}]/[\text{NiCO}_3]\).
e) \([\text{NiCO}_3]/[\text{Ni}^{2+}]\).

(The solid NiCO\(_3\) and the pure liquid H\(_2\)O are left out of the equilibrium constant expression.)

10- Calculate the equilibrium constant, \(K_p\), for the reaction below if a 3.25-L tank is found to contain 0.343 atm O\(_2\), 0.0212 atm SO\(_3\), and 0.00419 atm SO\(_2\) at equilibrium.

\(2\text{SO}_3(g) \rightleftharpoons 2\text{SO}_2(g) + \text{O}_2(g)\)

a) \(6.79 \times 10^{-3}\)
b) \(8.78\)
c) \(4.12 \times 10^{-3}\)
d) \(2.43 \times 10^2\)
e) \(1.34 \times 10^2\)

(The correct partial pressures were substituted into the \(K_p\) expression.)
11- A 2.21-L vessel was found to contain $4.18 \times 10^{-2}$ mol of CO$_2$, $2.81 \times 10^{-2}$ mol of CO, and $8.89 \times 10^{-3}$ mol of O$_2$ at 298 K. Is the system at equilibrium for the reaction $2\text{CO}_2 \rightleftharpoons \text{2CO} + \text{O}_2$? If not, which direction must the reaction proceed to achieve equilibrium? ($K_p = 1.2 \times 10^{-13}$)
   a) no, to the left
   b) no, to the right
   c) Yes
   \(Q > K_p\); thus, reaction will proceed to the left to reduce \(Q\).

12- At 500 K the equilibrium constant for the reaction $2\text{NO}(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{NOCl}(g)$ is $K_p = 52.0$. An equilibrium mixture of the three gases has partial pressures of 0.0950 atm and 0.171 atm for NO and Cl$_2$, respectively. What is the partial pressure of NOCl in the mixture?
   a) 0.845 atm
   b) 0.283 atm
   c) $8.02 \times 10^{-2}$ atm
   d) $5.45 \times 10^{-3}$ atm
   e) $2.97 \times 10^{-5}$ atm
   \(\text{You solved the } K_p \text{ expression for } P_{\text{NOCl}}\).

13- Which one of the following statements is incorrect?
   a) Adding reactants shifts the equilibrium to the right.
   b) Adding products shifts the equilibrium to the left.
   c) Removing a product shifts the equilibrium to the right.
   d) Exothermic reactions shift the equilibrium to the left with increasing temperature.
   e) Adding a catalyst shifts the equilibrium to the right.
   \(\text{It has no effect, since it changes the rates of the forward and reverse reactions equally.}\)

14- Of the following equilibria, which one will shift to the left in response to a decrease in volume?
   a) $2\text{SO}_3(g) \rightleftharpoons 2\text{SO}_2(g) + \text{O}_2(g)$
   b) $\text{H}_2(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{HCl}(g)$
   c) $4\text{Fe}(s) + 3\text{O}_2(g) \rightleftharpoons 2\text{Fe}_2\text{O}_3(s)$
   d) $\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g)$
   e) $\text{CO}_2(g) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{CO}_3(aq)$
   \(\text{There are more moles of gaseous product.}\)

15- How many of the following factors affect the numerical value of \(K\)?
   pressure, initial concentration, volume, temperature, chemical equation
   a) 2
   b) 4
   c) 3
   d) 1
   e) 0
   \(\text{Only temperature and the chemical equation affect the value of } K.\)

16- What is the relationship between the rate constants for the forward and reverse reactions and the equilibrium constant for a process involving just elementary reactions (very simple primary reactions)?
   a) $K = k_f + k_r$
   b) $K = k_f - k_r$
   c) $K = \frac{k_f}{k_r}$
   d) $K = k_f k_i$
   e) $K = k_f k_r$
(17) Suppose that the reactions $A \rightarrow B$ and $B \rightarrow A$ are both elementary processes with rate constants of $9.6 \times 10^2 \text{s}^{-1}$ and $3.8 \times 10^4 \text{s}^{-1}$, respectively.

(a) What is the value of the equilibrium constant for the equilibrium $A \rightleftharpoons B$?
(b) Which is greater at equilibrium, the concentration of $A$ or the concentration of $B$?

(a) $1.0$, $[A] > [B]$
(b) $4.0 \times 10^1$, $[A] > [B]$
(c) $2.5 \times 10^2$, $[B] > [A]$
(d) $2.5 \times 10^2$, $[A] > [B]$
(e) $4.0 \times 10^1$, $[B] > [A]$

(Use $K_c = \frac{k_f}{k_r}$. Since $K_c < 1$, there are more reactants present.)

(18) If $K_c = 0.0140$ at 100.0 °C for the reaction:

$$2\text{NOBr}(g) \rightleftharpoons 2\text{NO}(g) + \text{Br}_2(g)$$

what is $K_p$ at this same temperature for the reaction:

$$4\text{NO}(g) + 2\text{Br}_2(g) \rightleftharpoons 4\text{NOBr}(g)$$

(a) 8.53
(b) 71.4
(c) 2.33
(d) 5.44

(The change in the number of moles of gas is $-2$ for the new reaction; and you also remembered that the temperature was 373.15 K, not 298.15 K.)

(19) Consider the equilibrium system $\text{Fe}_3\text{O}_4(s) + \text{CO}(g) \rightleftharpoons \text{CO}_2(g) + 3\text{FeO}(s)$, a slightly endothermic reaction at room temperature. Which of the following changes is incorrect?

(a) Adding CO makes the equilibrium shift to the right.
(b) Removing some FeO does not change the equilibrium.
(c) Adding CO$_2$ makes the equilibrium shift to the left.
(d) Increasing the temperature above room temperature will drive the reaction to the left.
(e) Adding more FeO does not change the position of the equilibrium.

(Endothermic reactions produce more products with an increase in temperature.)

(20) Consider the following exothermic reaction:

$$\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g)$$

Which of the following changes would not increase the amount of NH$_3$ produced from given quantities of N$_2$ and H$_2$?

(a) increase in $P$
(b) decrease in $V$
(c) remove some NH$_3$ and reestablish equilibrium
(d) increase in $T$
(e) none of these

(This is an exothermic reaction. An increase in temperature will limit the yield of product. (Note: The system initially has no NH$_3$ present so at least some will be formed.)

(21) Consider the reaction at equilibrium as given below:

$$2\text{SO}_3(g) \rightleftharpoons 2\text{SO}_2(g) + \text{O}_2(g), \quad \Delta H^\circ = +198 \text{kJ}$$

All of the following changes would shift the equilibrium to the left except one. Which one would not cause the equilibrium to shift to the left?

(a) removing some SO$_3$
(b) decreasing the container volume
(c) decreasing the temperature
(d) adding some SO$_2$
22- Consider the reaction below:

\[ \text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}_2(g) + \text{H}_2(g) \quad \Delta H^\circ = -41 \text{ kJ} \]

All of the following changes would shift the equilibrium to the right except one. Which one would not cause the equilibrium to shift to the right?

a) adding some CO
b) removing some CO\(_2\)
c) decreasing the container volume
d) decreasing the temperature
e) increasing the partial pressure of H\(_2\)O

(This will increase the pressure. However, this will have no effect on the equilibrium since there is an equal number of gas molecules on both sides of the equation.)

23- To an equilibrium mixture of 2SO\(_2\)(g) + O\(_2\)(g) \rightleftharpoons 2SO\(_3\)(g), some helium, an inert gas, is added at constant volume. The addition of helium causes the total pressure to double. Which of the following is true?

a) The concentrations of all three gases are unchanged.
b) The number of moles of O\(_2\) increases.
c) [SO\(_3\)] increases.
d) The number of moles of SO\(_3\) increases.
e) [SO\(_2\)] increases.

(Since the He is not involved in the equilibrium, it has no effect on the equilibrium.)

24- A mixture is prepared with \( P_{\text{CO}} = 0.035 \text{ atm}, P_{\text{Cl}_2} = 0.015 \text{ atm}, \) and \( P_{\text{COCl}_2} = 0.95 \text{ atm}. \) It is known that \( K_p \) for the equilibrium \( \text{CO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{COCl}_2(g) \) is \( 1.2 \times 10^3 \) at 400°C. Predict what will happen.

a) The reaction proceeds in the reverse direction until equilibrium is established.
b) The reaction occurs in the forward direction.
c) The reaction is at equilibrium, so no net reaction occurs.
d) It is impossible to predict without more information.

\( Q > K_p. \) The production of reactants is favored.

25- At 300.0 K, \( K_p = 54.3 \) for the reaction \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g). \)

If 1.0 mole of H\(_2\) and 1.0 mole of I\(_2\) are placed in a 5.0-L container, what would be the equilibrium partial pressure of HI?

a) 0.79 atm
b) 0.88 atm
c) 3.9 atm
d) 7.7 atm
e) 1.6 atm

(The correct partial pressure terms were set up in terms of the variable \( x. \) The \( K_p \) expression was solved, and the appropriate \( P_{\text{HI}} \) was reported.)