General Equilibrium Problems

1983

Sulfuryl chloride, SO_2Cl_2, is a highly reactive gaseous compound. When heated, it decomposes as follows:

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

This decomposition is endothermic. A sample of 3.509 grams of SO_2Cl_2 is placed in an evacuated 1.00 liter bulb and the temperature is raised to 375 K.

(a) What would be the pressure in atmospheres in the bulb if no dissociation of the $SO_2Cl_2(g)$ occurred?
(b) When the system has come to equilibrium at 375 K, the total pressure in the bulb is found to be 1.43 atmospheres. Calculate the partial pressures of SO_2, Cl_2, and SO_2Cl_2 at equilibrium at 375 K.
(c) Give the expression for the equilibrium constant (either K_p or K_c) for the decomposition of $SO_2Cl_2(g)$ at 375 K. Calculate the value of the equilibrium constant you have given, and specify its units.
(d) If the temperature were raised to 500 K, what effect would this have on the equilibrium constant? Explain briefly.

1988

At elevated temperatures, $SbCl_5$ gas decomposes into $SbCl_3$ gas and Cl_2 gas as shown by the following equation:

$$SbCl_5(g) \leftrightarrows SbCl_3(g) + Cl_2(g)$$

(a) An 89.7 gram sample of $SbCl_5$ (molecular weight 299.0) is placed in an evacuated 15.0 liter container at 182°C.

1. What is the concentration in moles per liter of $SbCl_5$ in the container before any decomposition occurs?
2. What is the pressure in atmospheres of $SbCl_5$ in the container before any decomposition occurs?

(b) If the $SbCl_5$ is 29.2 percent decomposed when equilibrium is established at 182°C, calculate the value for either equilibrium constant K_p or K_c, for this decomposition reaction. Indicated whether you are calculating K_p or K_c.

(c) In order to produce some $SbCl_5$, a 1.00 mole sample of $SbCl_3$ is first placed in an empty 2.00 liter container maintained at a temperature different from 182°C. At this temperature, K_c, equals 0.117. How many moles of Cl_2 must be added to this container to reduce the number of moles of $SbCl_3$ to 0.700 mole at equilibrium?

1992

$$2\ NaHCO_3(s) \leftrightarrows Na_2CO_3(s) + H_2O(g) + CO_2(g)$$

Solid sodium hydrogen carbonate, $NaHCO_3$, decomposes on heating according to the equation above.

(a) A sample of 100. grams of solid $NaHCO_3$ was placed in a previously evacuated rigid 5.00-liter container and heated to 160°C. Some of the original solid remained and the total pressure in the container was 7.76 atmospheres when equilibrium was reached. Calculate the number of moles of $H_2O(g)$ present at equilibrium.

(b) How many grams of the original solid remain in the container under the conditions described in (a)?

(c) Write the equilibrium expression for the equilibrium constant, K_p, and calculate its value for the reaction under the conditions in (a).

(d) If 110. grams of solid $NaHCO_3$ had been placed in the 5.00-liter container and heated to 160°C, what would the total pressure have been at equilibrium? Explain.

1995

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

When $H_2(g)$ is mixed with $CO_2(g)$ at 2,000 K, equilibrium is achieved according to the equation above. In one experiment, the following equilibrium concentrations were measured.

$[H_2]$ = 0.20 mol/L
$[CO_2]$ = 0.30 mol/L
$[H_2O] = [CO]$ = 0.55 mol/L

(a) What is the mole fraction of $CO(g)$ in the equilibrium mixture?

(b) Using the equilibrium concentrations given above, calculate the value of K_c, the equilibrium constant for the reaction.

(c) Determine K_p in terms of K_c for this system.

(d) When the system is cooled from 2,000 K to a lower temperature, 30.0 percent of the $CO(g)$ is converted back to $CO_2(g)$. Calculate the value of K_c at this lower temperature.

(e) In a different experiment, 0.50 mole of $H_2(g)$ is mixed with 0.50 mole of $CO_2(g)$ in a 3.0-liter reaction vessel at 2,000 K. Calculate the equilibrium concentration, in moles per liter, of $CO(g)$ at this temperature.

2008B

Answer the following questions regarding the decomposition of arsenic pentafluoride, $AsF_5(g)$.

(a) A 55.8 g sample of $AsF_5(g)$ is introduced into an evacuated 10.5 L container at 105°C.

(i) What is the initial molar concentration of $AsF_5(g)$ in the container?

(ii) What is the initial pressure, in atmospheres, of the $AsF_5(g)$ in the container?

At 105°C, $AsF_5(g)$ decomposes into $AsF_3(g)$ and $F_2(g)$ according to the following chemical equation.

$$AsF_5(g) \rightleftharpoons AsF_3(g) + F_2(g)$$

(b) In terms of molar concentrations, write the equilibrium-constant expression for the decomposition of $AsF_5(g)$.

(c) When equilibrium is established, 27.7 percent of the original number of moles of $AsF_5(g)$ has decomposed.

(i) Calculate the molar concentration of $AsF_5(g)$ at equilibrium.

(ii) Using molar concentrations, calculate the value of the equilibrium constant, K_{eq}, at 105°C.

(d) Calculate the mole fraction of $F_2(g)$ in the container at equilibrium.

2010B

The compound butane, C_4H_{10}, occurs in two isomeric forms, *n*-butane and isobutane (2-methyl propane). Both compounds exist as gases at 25°C and 1.0 atm.

(a) Draw the structural formula of each of the isomers (include all atoms). Clearly label each structure.

(b) On the basis of molecular structure, identify the isomer that has the higher boiling point. Justify your answer.

The two isomers exist in equilibrium as represented by the equation below.

$$n\text{-butane}(g) \rightleftarrows \text{isobutane}(g) \qquad K_c = 2.5 \text{ at } 25°\text{C}$$

Suppose that a 0.010 mol sample of pure *n*-butane is placed in an evacuated 1.0 L rigid container at 25°C.

(c) Write the expression for the equilibrium constant, K_c, for the reaction.

(d) Calculate the initial pressure in the container when the n-butane is first introduced (before the reaction starts).

(e) The *n*-butane reacts until equilibrium has been established at 25°C.

(i) Calculate the total pressure in the container at equilibrium. Justify your answer.

(ii) Calculate the molar concentration of each species at equilibrium.

(iii) If the volume of the system is reduced to half of its original volume, what will be the new concentration of n-butane after equilibrium has been reestablished at 25°C? Justify your answer.

Suppose that in another experiment a 0.010 mol sample of pure isobutane is placed in an evacuated 1.0 L rigid container and allowed to come to equilibrium at 25°C.

(f) Calculate the molar concentration of each species after equilibrium has been established.

General Equilibrium Essay Questions

1988

$$NH_4HS(s) \leftrightarrows NH_3(g) + H_2S(g) \qquad \Delta H° = +93 \text{ kilojoules}$$

The equilibrium above is established by placing solid NH_4HS in an evacuated container at 25°C. At equilibrium, some solid NH_4HS remains in the container. Predict and explain each of the following.

(a) The effect on the equilibrium partial pressure of NH_3 gas when additional solid NH_4HS is introduced into the container.
(b) The effect on the equilibrium partial pressure of NH_3 gas when additional H_2S gas is introduced into the container.
(c) The effect on the mass of solid NH_4HS present when the volume of the container is decreased.
(d) The effect on the mass of solid NH_4HS present when the temperature is increased.

1997

For the gaseous equilibrium represented below, it is observed that greater amounts of PCl_3 and Cl_2 are produced as the temperature is increased.

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

(a) What is the sign of $\Delta S°$ for the reaction? Explain.

(b) What change, if any, will occur in $\Delta G°$ for the reaction as the temperature is increased. Explain your reasoning in terms of thermodynamic principles.

(c) If He gas is added to the original reaction mixture at constant volume and temperature, what will happen to the partial pressure of Cl_2? Explain.

(d) If the volume of the original reaction is decreased at constant temperature to half the original volume, what will happen to the number of moles of Cl_2 in the reaction vessel? Explain.

1998

$$C(s) + H_2O(g) \leftrightarrows CO(g) + H_2(g) \qquad \Delta H° = +131 \text{ kJ}$$

A rigid container holds a mixture of graphite pellets (C(*s*)), $H_2O(g)$, $CO(g)$, and $H_2(g)$ at equilibrium. State whether the number of moles of CO(*g*) in the container will increase, decrease, or remain the same after each of the following disturbances is applied to the original mixture. For each case, assume that all other variables remain constant except for the given disturbance. Explain each answer with a short statement.

(a) Additional $H_2(g)$ is added to the equilibrium mixture at constant volume.

(b) The temperature of the equilibrium mixture is increased at constant volume.

(c) The volume of the container is decreased at constant temperature.

(d) The graphite pellets are pulverized.