1. At a certain temperature, an equilibrium mixture contains the following substances with the following concentrations:

[O2] = 4.2 x 10–3 *M*; [SO2] = 3.8 x 10–3 *M*, and [SO3] = 4.1 x 10–3 *M*.

Calculate the equilibrium constant *K*c for the following reactions:

(a) 2 SO2(g) + O2(g) ⇌ 2 SO3(g)

(b) SO3(g) ⇌ SO2(g) + ½ O2(g)

2. For the reaction: PCl5(g) ⇌ PCl3(g) + Cl2(g), *K*p = 23.6 at 500.K

(a) Calculate the equilibrium partial pressures of the reactant and products if the initial pressures were:

PPCl5 = 0.560 atm and PPCl3 = PCl2 = 0.0 atm

(b) If more chlorine gas is added after equilibrium is established, how will the concentration of PCl5 and PCl3 change?

3. The water-gas shift reaction is an important source of hydrogen gas.

CO(g) + H2O(g) ⇌ CO2(g) + H2(g); *K*c = 5.1 at 700 K

Calculate the equilibrium concentrations of the four gases at 700 K if the initial concentration of each of them is 0.050 *M*.

4. Ammonium carbamate, NH4(CO2NH2), is a salt of carbamic acid that is found in the blood and urine of mammals. It decomposes when heated and, in a closed container, the following equilibrium is established:

NH2CO2NH4(s) ⇌ 2 NH3(g) + CO2(g)

At 250.oC, the equilibrium constant for this reaction is *K*c = 1.58 x 10–5.(a) What is the value of *K*p for the reaction at 250 oC? (b) If 7.80 g of NH4(CO2NH2) is placed in a 5.00-L evacuated container, heated to 250 oC until equilibrium is established, what is the total pressure at equilibrium? (c) How many grams of NH2CO2NH4 have decomposed when equilibrium is established?

(R = 0.08206 L.atm/mol.K)

5. The reaction: CO(g) + H2O(g) ⇌ CO2(g) + H2(g), has *K*c = 2.7 at a certain temperature.

(a) Determine whether a mixture that contains 0.50 mol CO, 0.50 mol H2O, 0.50 mol CO2, and 0.50 mol H2 in a sealed 1.0-L flask, is at equilibrium. If not, predict in which direction the net reaction will occur to reach equilibrium. (b) Calculate the concentration of each component in the equilibrium mixture.

6. Patients suffering from carbon monoxide poisoning are treated with pure oxygen to remove CO from

the hemoglobin (Hb) in their blood. The two relevant equilibria are:

Hb + 4CO(g) ⇌ Hb(CO)4; *Kc*1

Hb + 4 O2(g) ⇌ Hb(O2)4; *K*c2

The value of *Kc*1 > *K*c2. Explain how does the treatment work?

7. Given the equilibrium constants, *K*c, for the following reactions at 1000 K:

(1) CO(g) + H2O(g) ⇌ CO2(g) + H2(g); *K*c1 = 1.4

(2) CH4(g) + H2O(g) ⇌ CO(g) + 3H2(g); *K*c2 = 5.3 x 10–3.

What is the value of *K*c for the following reaction at 1000 K?

CH4(g) + 2 H2O(g) ⇌ CO2(g) + 4H2(g)

8. Identify each of the following as strong acid or weak acid:

(a) HBr(aq) :\_\_\_\_\_\_\_\_\_\_\_\_ (b) HCl(aq):\_\_\_\_\_\_\_\_\_\_\_\_\_ (c) HF(aq) :\_\_\_\_\_\_\_\_\_\_\_\_\_

(d) HCOOH:\_\_\_\_\_\_\_\_\_\_\_\_ (e) CH3COOH:\_\_\_\_\_\_\_\_\_\_\_ (f) HNO3:\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(g) H2SO4:\_\_\_\_\_\_\_\_\_\_\_ (h) H3PO4:\_\_\_\_\_\_\_\_\_\_\_\_\_ (*i*) HOCl:\_\_\_\_\_\_\_\_\_\_\_\_\_

9. In each of the following pairs of acids, indicate the one with stronger conjugate bases:

(a) HNO2 and HNO3 (b) H3PO3 and H2SO3 (c) HOF and HOCl

(d) H2SO3 and HClO3 (e) CH3CO2H and CCl3CO2H (f) H2S and H2Se

10. Determine the pH and percent ionization of 0.20 M nitrous acid, HNO2 (*K*a = 4.0 x 10–4).

HNO2(aq) + H2O ⇌ H3O+(aq) + NO2–(aq)

11. Consider the following ionization of sulfurous acid:

H2SO3(aq) + H2O ⇌ H3O+(aq) + HSO3–(aq); *K*a1 = 1.2 x 10–2

HSO3–(aq) + H2O ⇌ H3O+(aq) + SO32–(aq); *K*a2 = 6.3 x 10–8

Calculate the equilibrium molar concentration, [H3O+], [HSO3-], and [SO32-], respectively, in 0.10 *M* H2SO3. Determine the equilibrium constant for the following equilibrium:

H2SO3(aq) + 2H2O ⇌ 2H3O+(aq) + SO32-(aq); *K*c = ?

12. A solution of 0.10 *M* HClO2 (chlorous acid) has the same pH as solution of 0.030 *M* HCl. Calculate the *K*a of HClO2. (b) What is the pH of 0.10 *M* HClO2? (c) What is the percent ionization of 0.10 *M* chlorous acid?

13. Predict whether each of the following solutions is neutral, acidic or basic? In each case, write the chemical equilibrium to support your reasoning.

(a) NaNO2 (d) Na2CO3

(b) KNO3 (e) KH2PO4 (*K*a of H2PO4– = 6.3 x 10–8)

(c) Fe(NO3)3

14. (a) Calculate the pH of 0.10 M NH3 solution (*K*b(NH3) = 1.8 x 10–5), which ionizes as follows:

NH3(aq) + H2O ⇌ NH4+(aq) + OH–(aq)

(b) What is the value of *K*a for NH4+ in the following equilibrium:

NH4+(aq) + H2O ⇌ NH3(aq) + H3O+(aq);

Calculate the pH of 0.10 M NH4Cl solution. (*K*w = 1.0 x 10–14)

15. (a) A 0.100 *M* lactic acid, HC3H5O3, has pH = 2.43. Write the dissociation equilibrium of lactic acid in aqueous solution and calculate the *K*a value for lactic acid.

(b) What is the *K*b of lactate ion (C3H5O3–) and the pH of 0.100 *M* sodium lactate, NaC3H5O3?

16. A 50.0-mL solution of 0.100 *M* HNO3 is titrated with 0.100 *M* of NaOH. Calculate the pH of the solution at various points of the titration:

(a) Before 0.100 *M* NaOH is added; (b) After 25.0 mL of NaOH is added; (c) After 50.0 mL of NaOH is added, and (d) After 75.0 mL of NaOH is added.

17. A 50.0-mL solution of 0.100 *M* potassium hydrogen phthalate (KHP; (HP– has *K*a ~ 4.0 x 10–6) is titrated with 0.100 *M* of NaOH. Calculate the pH of the solution at various points of the titration:

(a) Before 0.100 *M* NaOH is added; (b) After 25.0 mL of NaOH is added; (c) After 50.0 mL of NaOH is added, and (d) After 75.0 mL of NaOH is added.

18. A phosphate buffer solution is prepared by dissolving 15.0 g of KH2PO4 and 30.0 g of K2HPO4 in 500. mL of solution. (a) Calculate: (a) the molar concentrations of H2PO4- and HPO42-, respectively, in the solution. (b) What is the pH of the buffer? (c) Write equations for the buffering reaction (*i*) against strong acid; (*ii*) against strong base. (d) Calculate the pH of the solution after 0.025 mole of HCl is added to the solution. (Assume the volume remains constant) (H2PO4- has *K*a = 6.2 x 10-8)

**Answers:**

1. (a) *K*c = 280; (b) *K*c = 0.060

2. (a) PPCl5 = 0.013 atm; PPCl3 = PCl2 = 0.547 atm; (b) Equilibrium shifts left; PCl5 increases and PCl3 decreases

3. [CO] = [H2O] = 0.031 *M*; [CO2] = [H2] = 0.069 *M*)

4. (a) *K*p = 1.25; (b) Ptotal = 2.04 atm; (c) 4.91 g;

5. (a) *Q*c < *K*c 🡺 net forward reaction; (b) [CO] = [H2O] = 0.38 *M*; [CO2] = [H2O] = 0.62 *M*

7. *K*c = 7.4 x 10–3

8. (a) strong (b) strong (c) weak (d) weak (e) weak

(f) strong (g) strong (h) weak (*i*) weak

9. (a) HNO2 (b) H3PO3 (c) HOCl (d) H2SO3 (e) CH3CO2H (f) H2Se

10. pH = 2.05; % ionization = 4.5%

11. [H3O+] = 0.029 *M*; [HSO3–] = 0.029 *M*; [SO32–] = 4.3x 10–5 *M*; *K*c = 6.4 x 10–8;

12. (a) *K*a = 1.3 x 10–2; (b) pH = 1.52; (c) % ionization = 30.%

13. (a) Basic: NO2–(aq) + H2O ⇌ HNO2(aq) + OH– (aq)

(b) Neutral: NO3–(aq) + H2O ⇌ NR

(c) Acidic: Fe(H2O)63+(aq) + H2O ⇌ Fe(H2O)5(OH)2+(aq) + H3O+(aq)

(d) Basic: CO32–(aq) + H2O ⇌ HCO3–(aq) + OH–(aq)

(e) Acidic: H2PO4–(aq) + H2O ⇌ H3O+(aq) + HPO42–(aq)

14. (a) pH = 11.13; (b) *K*a = 5.6 x 10–10; pH = 5.13

15. (a) *K*a = 1.4 x 10–4; (b) *K*b = 7.1 x 10–11; pH = 8.43

16. (a) pH = 1.000; (b) pH = 1.477; (c) pH = 7.000; (d) pH = 12.30

17. (a) pH = 3.20; (b) pH = 5.40; (c) pH = 8.98; (d) pH = 12.30

18. (a) [H2PO4-] = 0.220 *M*; [HPO42-] = 0.344 *M*; (b) pH = 7.40;

(c) (*i*) H3O+(aq) + HPO42-(aq) → H2PO4-(aq) + H2O;

(*ii*) OH-(aq) + H2PO4-(aq) → HPO42-(aq) + H2O;

(d) pH = 7.25