Problem Set #14

CHEM101A: General College Chemistry

Donald Aingworth

November 21, 2025

12 Topic G Problem 12

1.00 g of N_2O_4 is put into a 5.00 L container and heated to 50°C. At this temperature, the following reaction occurs and reaches equilibrium:

$$N_2O_4(g) \rightleftharpoons 2\,NO_2(g)$$

The concentration of NO_2 in the equilibrium mixture is found to be equal to 6.68×10^{-4} M. Calculate K_c and K_p for this reaction at 50°C.

12.1 Solution

First convert grams to moles.

$$MM(N_2O_4) = 92.02\,\text{g/mol} \tag{1}$$

$$n(N_2O_4) = \frac{m}{MM} = \frac{1.00\,\text{g}}{92.02\,\text{g/mol}} = 0.0\underline{108}672\,\text{mol} \tag{2}$$

$$M(N_2O_4) = \frac{n}{V} = \frac{0.0\underline{217}344\,\text{mol}}{5.00\,\text{L}} = 0.00\underline{217}344\,\text{M} \tag{3}$$

Now, I'll use an ICE table.

M	N_2O_4	$\rightleftharpoons$	$2\,NO_2$
I	$0.00\underline{217}344$		0
C	-3.34×10^{-4}		6.68×10^{-4}
E	$\underline{18.3}944\times10^{-4}$		6.68×10^{-4}

Now we calculate K_c.

$$K_c = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(6.68\times10^{-4})^2}{\underline{18.3}944\times10^{-4}} = \underline{242}.5868\times10^{-6}\,\text{M} = \boxed{243\times10^{-6}\,\text{M}} \tag{4}$$

Next we use that to find K_p.

$$K_p = K_c(RT)^{\Delta n} = (\underline{242}.5868\times10^{-6}\,\text{M})(0.08206\times323.15)^1 \tag{5}$$

$$= \underline{6.43}284\times10^{-3}\,\text{atm} = \boxed{6.43\times10^{-3}\,\text{atm}} \tag{6}$$

13 Topic G Problem 13

When 0.100 mol of gaseous N_2 and 0.100 mol of gaseous H_2 are put into a 5.00 L container at 300°C, the following reaction occurs and reaches equilibrium.

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

The partial pressure of ammonia in the equilibrium mixture is 0.0506 atm. Calculate K_p and K_c for this reaction at 300°C.

13.1 Solution

I'll use an ICE table.

M	N_2 (g)	+	$3\,H_2$ (g)	$\rightleftharpoons$	$2\,NH_3$ (g)
I	0.0200		0.0200		0
C	$-x$		$-3x$		$2x$
E	$0.0200 - x$		$0.0200 - 3x$		$2x$

Now we solve for x, using the partial pressure of NH_3.

$$PV = nRT \tag{7}$$

$$[NH_3] = \frac{n}{V} = \frac{P}{RT} = \frac{0.0506\,\text{atm}}{\left(0.08206\,\frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}}\right)(573.15\,\text{K})} \tag{8}$$

$$= 0.0\underline{10}688\,\text{M} \tag{9}$$

$$2x = [NH_3] \tag{10}$$

$$x = \frac{[NH_3]}{2} = \frac{0.0\underline{10}688\,\text{M}}{2} = 0.00\underline{53}44\,\text{M} \tag{11}$$

This gives us the value of x, which we can use.

M	N_2 (g)	+	$3\,H_2$ (g)	$\rightleftharpoons$	$2\,NH_3$ (g)
E	$0.0\underline{19}47$		$0.0\underline{18}397$		$0.0\underline{10}688$

This can be used to find K_c.

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^2} = \frac{0.0\underline{10}688^2}{0.0\underline{19}47 \times 0.0\underline{18}397^3} = \underline{9.42}565 = \boxed{9.43} \tag{12}$$

Next convert it to pressure.

$$K_p = K_c(RT)^{\Delta n} = \underline{9.42}565(\left(0.08206\,\frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}}\right)(573.15\,\text{K}))^{-2} \tag{13}$$

$$= 0.00\underline{42}61 = \boxed{0.00426} \tag{14}$$

14 Topic G Problem 14

For the reaction below, $K_c = 0.0168$ at 250°C:

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

a) A flask contains 0.100 mol/L of PCl_5. What will be the concentrations of all three gases when the above reaction reaches equilibrium?

b) A different flask contains 0.100 mol/L of PCl_5, 0.200 mol/L of PCl_3, and 0.300 mol/L of Cl_2. What will be the concentrations of all three gases when the above reaction reaches equilibrium?

14.1 Solution (a)

Use an ICE table.

M	PCl_5 (g)	$\rightleftharpoons$	PCl_3 (g)	+	Cl_2 (g)
I	0.100		0		0
C	$-x$		$+x$		$+x$
E	$0.100 - x$		x		x

Use K_c to find x.

$$K_c = 0.0168 = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{x^2}{0.100 - x} \tag{15}$$

$$x^2 = 0.00168 - 0.0168x \tag{16}$$

$$0 = x^2 + 0.0168x - 0.00168 \tag{17}$$

$$x = 0.0\underline{33}4397 \text{ or } -0.0\underline{50}2397 \tag{18}$$

We use the postive one to complete the ICE table. That contains our answers.

M	PCl_5 (g)	$\rightleftharpoons$	PCl_3 (g)	+	Cl_2 (g)
E	0.0666		0.0334		0.0334

14.2 Solution (b)

First find Q. That tells us where it will skew.

$$Q = \frac{[PCl_3][Cl_2]}{[PCl_5]} = \frac{0.200 * 0.300}{0.100} = 0.6 \tag{19}$$

This is way bigger than K_c. This means it skews way towards PCl_5 (left). From here, use an ICE table.

M	PCl_5 (g)	$\rightleftharpoons$	PCl_3 (g)	+	Cl_2 (g)
I	0.100		0.200		0.300
C	$+x$		$-x$		$-x$
E	$0.100 + x$		$0.200 - x$		$0.300 - x$

Find x using K_c.

$$K_c = 0.0168 = \frac{(0.200 - x)(0.300 - x)}{0.100 + x} \tag{20}$$

$$0.00168 + 0.0168x = x^2 - 0.500x + 0.0600 \tag{21}$$

$$0 = x^2 - 0.5168x + 0.05832 \tag{22}$$

$$x = 0.\underline{350}327 \text{ or } 0.\underline{166}473 \tag{23}$$

The former is too big, so we use the latter.

M	PCl_5 (g)	$\rightleftharpoons$	PCl_3 (g)	+	Cl_2 (g)
E	0.266		0.0335		0.134

15 Topic G Problem 15

For the reaction below, $K_p = 0.513$ at a certain temperature.

$$H_2(g) + I_2(g) \rightleftharpoons 2\,HI(g)$$

a) A flask holds some gaseous HI at this temperature and a pressure of 3.00 atm. What will be the partial pressures of all three gases when the above reaction reaches equilibrium?

b) A second flask contains a mixture of the three gases with the following partial pressures: $H_2 = 0.433$ atm, $I_2 = 0.0471$ atm, HI = 0.0310 atm. What will be the partial pressures of all three gases when the above reaction reaches equilibrium?

15.1 Solution (a)

ICE table.

atm	H_2 (g)	+	I_2 (g)	$\rightleftharpoons$	2 HI (g)
I	0		0		3.00
C	$+x$		$+x$		$-2x$
E	x		x		$0.300 - 2x$

Find x.

$$K_p = 0.513 = \frac{(0.300 - 2x)^2}{x^2} \tag{24}$$

$$0.513x^2 = 0.0900 - 1.20x + 4x^2 \tag{25}$$

$$0 = 0.0900 - 1.20x + 3.487x^2 \tag{26}$$

$$x = 0.\underline{233}689 \text{ or } 0.\underline{110}447 \tag{27}$$

Use the latter.

atm	H_2 (g)	+	I_2 (g)	$\rightleftharpoons$	2 HI (g)
E	0.110		0.110		0.0791

15.2 Solution (b)

Find Q.

$$Q = \frac{(0.0310)^2}{0.433 * 0.0471} = 0.0\underline{471}21 \tag{28}$$

It skews hard to the right. ICE table.

atm	H_2 (g)	+	I_2 (g)	$\rightleftharpoons$	2 HI (g)
I	0.433		0.0471		0.0310
C	$-x$		$-x$		$+2x$
E	$0.433 - x$		$0.0471 - x$		$0.0310 + 2x$

Find x.

$$K_p = 0.513 = \frac{(0.0310 + 2x)^2}{(0.0471 - x)(0.433 - x)} \tag{29}$$

$$0.513x^2 - 0.2462913x + 0.0104622759 = 0.000961 + 1.24x + 4x^2 \tag{30}$$

$$0 = 3.487x^2 + 0.3702913x - 0.0095012759 \tag{31}$$

$$x = -0.\underline{127}5537 \text{ or } 0.0\underline{213}618 \tag{32}$$

Use the latter.

atm	H_2 (g)	+	I_2 (g)	$\rightleftharpoons$	2 HI (g)
E	0.412		0.0257		0.0737

16 Topic G Problem 16

Parts a through d of this problem relate to the reaction below:

$$O_2(g) + 2\,F_2(g) \rightleftharpoons 2\,OF_2(g)$$

a) If you add some gaseous F_2 to an equilibrium mixture of these three chemicals, which way will the reaction proceed?

b) If you add some gaseous O_2 to an equilibrium mixture of these three chemicals, what will happen to the partial pressure of F_2 in the mixture (i.e. will it go up, go down, or remain the same)?

c) If you increase the volume of the container, which way will the reaction proceed?

d) If you decrease the volume of the container, what will happen to the mass of OF_2 in the mixture?

e) If you increase the temperature, which way will the reaction proceed? You will need to look up the bond energy values to answer this question.

16.1 Solution

a) It will proceed forward (more than reverse) until it reaches equilibrium again.

b) The reaction will cause more OF_2 to be created to balance towards chemical equilibrium. This will inevitably lead to a lowering in the moles of F_2 and resultantly its partial pressure decreasing.

c) It will skew left (reverse reactions).

d) The reaction will skew right (forward reactions), so the mass of OF_2 will increase.

e) The bond energy at 273K[1] of F–F is 155 kJ/mol, O–O is 142 kJ/mol, and O–F is 190 kJ/mol. For this, one O–O and two F–F bonds are broken, so we would add those bond energies together and turn them negative. Meanwhile, four O–F bonds are formed, which we can keep positive. Adding all these together, we get 308 kJ/mol as the energy of the forward reaction. The increased temperature (added heat) would result in the reaction going forward more.

17 Topic G Problem 17

Will the value of the equilibrium constant K change in any of the parts of problem 16? If so, which parts?

17.1 Solution

Only part (e) will change the value of K.

[1] See 10.9 of the textbook

18 Topic G Problem 18

Consider an equilibrium mixture of ammonium chloride, ammonia, and hydrogen chloride:

$$\mathrm{NH_4Cl(s)} \rightleftharpoons \mathrm{NH_3(g) + HCl(g)}$$

a) If you add a little solid $\mathrm{NH_4Cl}$ to the mixture, what will happen to the mass of $\mathrm{NH_3}$?

b) If you add a little gaseous $\mathrm{NH_3}$ to the mixture, what will happen to the mass of HCl?

c) If you add a little gaseous HCl to the mixture, what will happen to the mass of $\mathrm{NH_4Cl}$?

18.1 Solution

19 Topic G Problem 19

The reaction below is allowed to reach equilibrium:

$$NH_3(aq) + H_2O(l) \rightleftharpoons {NH_4}^+(aq) + {OH}^-(aq)$$

a) If you add a little 1 M HCl to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

b) If you add a little 1 M $MgCl_2$ to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

c) If you add a little 1 M NH_4NO_3 to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.

19.1 Solution

20 Topic G Problem 20

For the reaction $4\,HBr\,(aq) + O_2(g) \rightleftharpoons 2\,Br_2(aq) + 2\,H_2O\,(l)$, $K_c = 6.7 \times 10^{10}$. Use this information to calculate the equilibrium constant for each of the following reactions.

a) $2\,HBr\,(aq) + \frac{1}{2}\,O_2\,(g) \rightleftharpoons Br_2(aq) + H_2O\,(l)$

b) $4\,Br_2(aq) + 4\,H_2O\,(l) \rightleftharpoons 8\,HBr\,(aq) + 2\,O_2(g)$

20.1 Solution

21 Topic G Problem 21

Consider the following reactions, where the equilibrium constants are represented by the variables x and y:

$$2\,FeCl_3(aq) + Zn(s) \rightleftharpoons 2\,FeCl_2(aq) + ZnCl_2(aq)\ K = x$$
$$FeCl_3(aq) + CrCl_2(aq) \rightleftharpoons FeCl_2(aq) + CrCl_3(aq)\ K = y$$

Write an expression for the equilibrium constant for the reaction below, in terms of x and y.

$$2\,CrCl_3(aq) + Zn(s) \rightleftharpoons 2\,CrCl_2(aq) + ZnCl_2(aq)$$

21.1 Solution

22 Topic G Problem 22

Calculate the equilibrium constant for the following reaction:

$$3\,HClO_3(aq) \rightleftharpoons 2\,HClO_4(aq) + HClO\,(aq)$$

Use the following equilibrium constants.

$$Cl_2(aq) + H_2O\,(l) \rightleftharpoons HCl\,(aq) + HClO\,(aq)\ K = 6.2 \times 10^{-2}$$
$$3\,HClO\,(aq) \rightleftharpoons HClO_3(aq) + 2\,HCl\,(aq)\ K = 2.1 \times 10^{-6}$$
$$4\,Cl_2(aq) + 4\,H_2O\,(l) \rightleftharpoons 7\,HCl\,(aq) + HClO_4(aq)\ K = 7.9 \times 10^{-8}$$

22.1 Solution

Contents