Problem Set #14

CHEM101A: General College Chemistry

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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	$\underline{18.3}944 \times 10^{-4}$		6.68×10^{-4}

Now we calculate K_c.

$$K_c = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(6.68 \times 10^{-4})^2}{\underline{18.3}944 \times 10^{-4}} = \underline{242}.5868 \times 10^{-6}\,\text{M} = \boxed{243 \times 10^{-6}\,\text{M}} \tag{4}$$

Next we use that to find K_p.

$$K_p = K_c(RT)^{\Delta n} = (\underline{242}.5868 \times 10^{-6}\,\text{M})(0.08206 \times 323.15)^1 \tag{5}$$
$$= \underline{6.43}284 \times 10^{-3}\,\text{atm} = \boxed{6.43 \times 10^{-3}\,\text{atm}} \tag{6}$$

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.

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

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

$$= 0.0\underline{106}88\,\text{M} \tag{9}$$

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

$$x = \frac{[NH_3]}{2} = \frac{0.0\underline{106}88\,\text{M}}{2} = 0.00\underline{534}4\,\text{M} \tag{11}$$

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	$0.0\underline{194}7$		$0.0\underline{183}97$		$0.0\underline{106}88$

This can be used to find K_c.

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^2} = \frac{0.0\underline{106}88^2}{0.0\underline{194}7 \times 0.0\underline{183}97^3} = \underline{9.42}565 = \boxed{9.43} \tag{12}$$

Next convert it to pressure.

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

$$= 0.00\underline{426}1 = \boxed{0.00426} \tag{14}$$

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.

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

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

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

$$x = 0.0\underline{334}397 \text{ or } -0.0\underline{502}397 \tag{18}$$

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:

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

a) If you add a little solid NH_4Cl to the mixture, what will happen to the mass of NH_3?
b) If you add a little gaseous 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 NH_4Cl?

18.1 Solution

a/ It will not change.
b/ It will reduce.
c/ It will increase.

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

a) The hydrogen in the HCl will bond with the OH^-, which will reduce the amount of products. This will in turn cause the reaction to go <u>forward</u>.
b) The Mg^{2+} of the $MgCl_2$ will bond with the OH^- and form a precipitate, reducing the amount of OH^- and causing the reaction to go <u>forward</u>.
c) The $NO_3{}^-$ will not bond wth anything. The $NH_4{}^+$ will cause an imbalance, which will result in a <u>reverse</u> reaction as a counterbalance.

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 (a)

Take the square root of K_c.

$$\sqrt{K_c} = \sqrt{6.7 \times 10^{10}} = \boxed{2.6 \times 10^5} \tag{33}$$

20.2 Solution (b)

Square the reciprocal.

$$\left(\frac{1}{K_c}\right)^2 = \frac{1}{(6.7 \times 10^{10})^2} = \boxed{1.2 \times 10^{-22}} \tag{34}$$

21 Topic G Problem 21

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

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

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

Let's make this simple. Start by reversing the second equation (reciprocal for K).

$$FeCl_2(aq) + CrCl_3(aq) \rightleftharpoons FeCl_3(aq) + CrCl_2(aq) \qquad K = \frac{1}{y} \tag{35}$$

Double that (square K).

$$2\,FeCl_2(aq) + 2\,CrCl_3(aq) \rightleftharpoons 2\,FeCl_3(aq) + 2\,CrCl_2(aq) \qquad K = \frac{1}{y^2} \tag{36}$$

Next add the first and new second together (multiply K-values).

$$\begin{array}{c} \cancel{2\,FeCl_3(aq)} + Zn(s) \\ + \cancel{2\,FeCl_2(aq)} + 2\,CrCl_3(aq) \end{array} \rightleftharpoons \begin{array}{c} \cancel{2\,FeCl_2(aq)} + ZnCl_2(aq) \\ + \cancel{2\,FeCl_3(aq)} + 2\,CrCl_2(aq) \end{array} \qquad K = \frac{x}{y^2} \tag{37}$$

$$2\,CrCl_3(aq) + Zn(s) \rightleftharpoons 2\,CrCl_2(aq) + ZnCl_2(aq) \qquad K = \boxed{\frac{x}{y^2}} \tag{38}$$

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.

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

22.1 Solution

Start by reversing the equations necessary so chemicals in the equations are in the same side as they are in the final equation. Take the reciprocal of the K-values. Also invert the first one, since that would be the only way to counter the bottom equation.

$$HCl\,(aq) + HClO\,(aq) \rightleftharpoons Cl_2(aq) + H_2O\,(l); K = 1.6 \times 10^{1} \tag{39}$$
$$HClO_3(aq) + 2\,HCl\,(aq) \rightleftharpoons 3\,HClO\,(aq); K = 4.8 \times 10^{5} \tag{40}$$
$$4\,Cl_2(aq) + 4\,H_2O\,(l) \rightleftharpoons 7\,HCl\,(aq) + HClO_4(aq); K = 7.9 \times 10^{-8} \tag{41}$$

Multiply these by coefficients that are found in the final equation. Raise the K-values to the coefficient's power.

$$8\,HCl\,(aq) + 8\,HClO\,(aq) \rightleftharpoons 8\,Cl_2(aq) + 8\,H_2O\,(l); K = 4.6 \times 10^{9} \tag{42}$$
$$3\,HClO_3(aq) + 6\,HCl\,(aq) \rightleftharpoons 9\,HClO\,(aq); K = 1.1 \times 10^{17} \tag{43}$$
$$8\,Cl_2(aq) + 8\,H_2O\,(l) \rightleftharpoons 14\,HCl\,(aq) + 2\,HClO_4(aq); K = 6.2 \times 10^{-15} \tag{44}$$

Add the first and the last. This is mostly a formality, since the next step can be combined with this one. Multiply K-values together.

$$8\,HClO\,(aq) \rightleftharpoons 6\,HCl\,(aq) + 2\,HClO_4(aq); K = 2.9 \times 10^{-5} \tag{45}$$
$$3\,HClO_3(aq) + 6\,HCl\,(aq) \rightleftharpoons 9\,HClO\,(aq); K = 1.1 \times 10^{17} \tag{46}$$

Do the same thing with the (new) first and the second.

$$3\,HClO_3(aq) \rightleftharpoons 2\,HClO_4(aq) + HClO\,(aq); K = \boxed{3.1 \times 10^{17}} \tag{47}$$

That will be all.

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