

Problem Set #14  
CHEM101A: General College Chemistry

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## 12 Topic G Problem 12

1.00 g of  $\text{N}_2\text{O}_4$  is put into a 5.00 L container and heated to 50°C. At this temperature, the following reaction occurs and reaches equilibrium:



The concentration of  $\text{NO}_2$  in the equilibrium mixture is found to be equal to  $6.68 \times 10^{-4}$  M. Calculate  $K_c$  and  $K_p$  for this reaction at 50°C.

### 12.1 Solution

First convert grams to moles.

$$MM(\text{N}_2\text{O}_4) = 92.02 \text{ g/mol} \quad (1)$$

$$n(\text{N}_2\text{O}_4) = \frac{m}{MM} = \frac{1.00 \text{ g}}{92.02 \text{ g/mol}} = 0.0108672 \text{ mol} \quad (2)$$

$$M(\text{N}_2\text{O}_4) = \frac{n}{V} = \frac{0.0108672 \text{ mol}}{5.00 \text{ L}} = 0.00217344 \text{ M} \quad (3)$$

Now, I'll use an ICE table.

M	$\text{N}_2\text{O}_4$	$\rightleftharpoons$	$2\text{NO}_2$
I	0.00217344		0
C	$-3.34 \times 10^{-4}$		$6.68 \times 10^{-4}$
E	$18.3944 \times 10^{-4}$		$6.68 \times 10^{-4}$

Now we calculate  $K_c$ .

$$K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = \frac{(6.68 \times 10^{-4})^2}{18.3944 \times 10^{-4}} = \underline{242.5868 \times 10^{-6} \text{ M}} = \boxed{243 \times 10^{-6} \text{ M}} \quad (4)$$

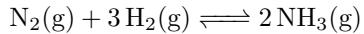
Next we use that to find  $K_p$ .

$$K_p = K_c(RT)^{\Delta n} = (\underline{242.5868 \times 10^{-6} \text{ M}})(0.08206 \times 323.15)^1 \quad (5)$$

$$= \underline{6.43284 \times 10^{-3} \text{ atm}} = \boxed{6.43 \times 10^{-3} \text{ atm}} \quad (6)$$

## 13 Topic G Problem 13

When 0.100 mol of gaseous N<sub>2</sub> and 0.100 mol of gaseous H<sub>2</sub> are put into a 5.00 L container at 300°C, the following reaction occurs and reaches equilibrium.



The partial pressure of ammonia in the equilibrium mixture is 0.0506 atm. Calculate K<sub>p</sub> and K<sub>c</sub> for this reaction at 300°C.

### 13.1 Solution

I'll use an ICE table.

M	N <sub>2</sub> (g)	+	3 H <sub>2</sub> (g)	$\rightleftharpoons$	2 NH <sub>3</sub> (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<sub>3</sub>.

$$PV = nRT \quad (7)$$

$$[\text{NH}_3] = \frac{n}{V} = \frac{P}{RT} = \frac{0.0506 \text{ atm}}{(0.08206 \frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}})(573.15 \text{ K})} \quad (8)$$

$$= 0.010688 \text{ M} \quad (9)$$

$$2x = [\text{NH}_3] \quad (10)$$

$$x = \frac{[\text{NH}_3]}{2} = \frac{0.010688 \text{ M}}{2} = 0.005344 \text{ M} \quad (11)$$

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

M	N <sub>2</sub> (g)	+	3 H <sub>2</sub> (g)	$\rightleftharpoons$	2 NH <sub>3</sub> (g)
E	0.01947		0.018397		0.010688

This can be used to find K<sub>c</sub>.

$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^2} = \frac{0.010688^2}{0.01947 \times 0.018397^2} = 9.42565 = \boxed{9.43} \quad (12)$$

Next convert it to pressure.

$$K_p = K_c(RT)^{\Delta n} = 9.42565 \left( 0.08206 \frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}} (573.15 \text{ K}) \right)^{-2} \quad (13)$$

$$= 0.004261 = \boxed{0.00426} \quad (14)$$

## 14 Topic G Problem 14

For the reaction below,  $K_c = 0.0168$  at  $250^\circ\text{C}$ :



- a) A flask contains 0.100 mol/L of  $\text{PCl}_5$ . 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  $\text{PCl}_5$ , 0.200 mol/L of  $\text{PCl}_3$ , and 0.300 mol/L of  $\text{Cl}_2$ . What will be the concentrations of all three gases when the above reaction reaches equilibrium?

### 14.1 Solution (a)

Use an ICE table.

M	$\text{PCl}_5(\text{g})$	$\rightleftharpoons$	$\text{PCl}_3(\text{g})$	+	$\text{Cl}_2(\text{g})$
I	0.100		0		0
C	$-x$		$+x$		$+x$
E	$0.100 - x$		$x$		$x$

Use  $K_c$  to find  $x$ .

$$K_c = 0.0168 = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{x^2}{0.100 - x} \quad (15)$$

$$x^2 = 0.00168 - 0.0168x \quad (16)$$

$$0 = x^2 + 0.0168x - 0.00168 \quad (17)$$

$$x = 0.0334397 \text{ or } -0.0502397 \quad (18)$$

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

M	$\text{PCl}_5(\text{g})$	$\rightleftharpoons$	$\text{PCl}_3(\text{g})$	+	$\text{Cl}_2(\text{g})$
E	0.0666		0.0334		0.0334

### 14.2 Solution (b)

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

$$Q = \frac{[\text{PCl}_3][\text{Cl}_2]}{[\text{PCl}_5]} = \frac{0.200 * 0.300}{0.100} = 0.6 \quad (19)$$

This is way bigger than  $K_c$ . This means it skews way towards  $\text{PCl}_5$  (left). From here, use an ICE table.

M	$\text{PCl}_5(\text{g})$	$\rightleftharpoons$	$\text{PCl}_3(\text{g})$	+	$\text{Cl}_2(\text{g})$
I	0.100		0.200		0.300
C	$+x$		$-x$		$-x$
E	$0.100 + x$		$0.200 - x$		$0.300 - x$

Find  $x$  using  $K_c$ .

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

$$0.00168 + 0.0168x = x^2 - 0.500x + 0.0600 \quad (21)$$

$$0 = x^2 - 0.5168x + 0.05832 \quad (22)$$

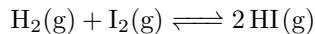
$$x = 0.350327 \text{ or } 0.166473 \quad (23)$$

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

M	$\text{PCl}_5(\text{g})$	$\rightleftharpoons$	$\text{PCl}_3(\text{g})$	+	$\text{Cl}_2(\text{g})$
E	0.266		0.0335		0.134

## 15 Topic G Problem 15

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



- 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  $x$ .

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

$$0.513x^2 = 0.0900 - 1.20x + 4x^2 \quad (25)$$

$$0 = 0.0900 - 1.20x + 3.487x^2 \quad (26)$$

$$x = 0.233689 \text{ or } 0.110447 \quad (27)$$

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.

$$Q = \frac{(0.0310)^2}{0.433 * 0.0471} = 0.047121 \quad (28)$$

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  $x$ .

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

$$0.513x^2 - 0.2462913x + 0.0104622759 = 0.000961 + 1.24x + 4x^2 \quad (30)$$

$$0 = 3.487x^2 + 0.3702913x - 0.0095012759 \quad (31)$$

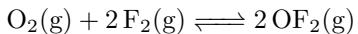
$$x = -0.1275537 \text{ or } 0.0213618 \quad (32)$$

Use the latter.

atm	H <sub>2</sub> (g)	+	I <sub>2</sub> (g)	↔	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:



- a) If you add some gaseous  $\text{F}_2$  to an equilibrium mixture of these three chemicals, which way will the reaction proceed?
- b) If you add some gaseous  $\text{O}_2$  to an equilibrium mixture of these three chemicals, what will happen to the partial pressure of  $\text{F}_2$  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  $\text{OF}_2$  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  $\text{OF}_2$  to be created to balance towards chemical equilibrium. This will inevitably lead to a lowering in the moles of  $\text{F}_2$  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  $\text{OF}_2$  will increase.
- e) The bond energy at 273K<sup>1</sup> 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.

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<sup>1</sup>See 10.9 of the textbook

## 18 Topic G Problem 18

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

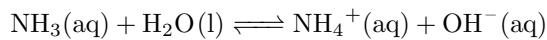


- a) If you add a little solid  $\text{NH}_4\text{Cl}$  to the mixture, what will happen to the mass of  $\text{NH}_3$ ?
- b) If you add a little gaseous  $\text{NH}_3$  to the mixture, what will happen to the mass of  $\text{HCl}$ ?
- c) If you add a little gaseous  $\text{HCl}$  to the mixture, what will happen to the mass of  $\text{NH}_4\text{Cl}$ ?

### 18.1 Solution

## 19 Topic G Problem 19

The reaction below is allowed to reach equilibrium:



- 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<sub>2</sub> 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<sub>4</sub>NO<sub>3</sub> 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

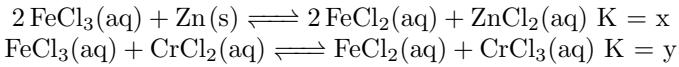
For the reaction  $4 \text{HBr}(\text{aq}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{Br}_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$ ,  $K_c = 6.7 \times 10^{10}$ . Use this information to calculate the equilibrium constant for each of the following reactions.

- a)  $2 \text{HBr}(\text{aq}) + \frac{1}{2} \text{O}_2(\text{g}) \rightleftharpoons \text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- b)  $4 \text{Br}_2(\text{aq}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 8 \text{HBr}(\text{aq}) + 2 \text{O}_2(\text{g})$

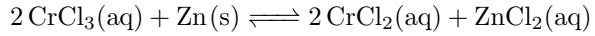
### 20.1 Solution

## 21 Topic G Problem 21

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



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



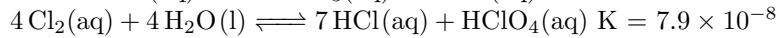
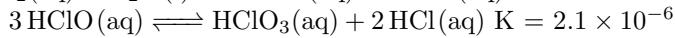
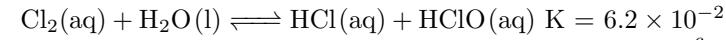
### 21.1 Solution

## 22 Topic G Problem 22

Calculate the equilibrium constant for the following reaction:



Use the following equilibrium constants.



### 22.1 Solution

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