

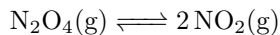
Problem Set #14  
CHEM101A: General College Chemistry

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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  $50^\circ\text{C}$ . 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  $50^\circ\text{C}$ .

### 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  $K_c$ .

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

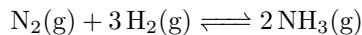
Next we use that to find  $K_p$ .

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

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

## 13 Topic G Problem 13

When 0.100 mol of gaseous  $\text{N}_2$  and 0.100 mol of gaseous  $\text{H}_2$  are put into a 5.00 L container at  $300^\circ\text{C}$ , the following reaction occurs and reaches equilibrium.



The partial pressure of ammonia in the equilibrium mixture is 0.0506 atm. Calculate  $K_p$  and  $K_c$  for this reaction at  $300^\circ\text{C}$ .

### 13.1 Solution

I'll use an ICE table.

M	$\text{N}_2(\text{g})$	+	$3 \text{H}_2(\text{g})$	$\rightleftharpoons$	$2 \text{NH}_3(\text{g})$
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  $\text{NH}_3$ .

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

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

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

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

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

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

M	$\text{N}_2(\text{g})$	+	$3 \text{H}_2(\text{g})$	$\rightleftharpoons$	$2 \text{NH}_3(\text{g})$
E	0.01947		0.018397		0.010688

This can be used to find  $K_c$ .

$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} = \frac{0.010688^2}{0.01947 \times 0.018397^3} = 9.42565 = \boxed{9.43} \quad (12)$$

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 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?
- 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  $K_c$ .

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

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

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

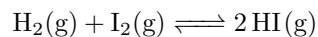
$$x = 0.\underline{350}327 \text{ or } 0.\underline{166}473 \quad (23)$$

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:  $\text{H}_2 = 0.433$  atm,  $\text{I}_2 = 0.0471$  atm,  $\text{HI} = 0.0310$  atm. What will be the partial pressures of all three gases when the above reaction reaches equilibrium?

### 15.1 Solution (a)

ICE table.

atm	$\text{H}_2(\text{g})$	+	$\text{I}_2(\text{g})$	$\rightleftharpoons$	$2 \text{HI}(\text{g})$
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	$\text{H}_2(\text{g})$	+	$\text{I}_2(\text{g})$	$\rightleftharpoons$	$2 \text{HI}(\text{g})$
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	$\text{H}_2(\text{g})$	+	$\text{I}_2(\text{g})$	$\rightleftharpoons$	$2 \text{HI}(\text{g})$
I	0.433		0.0471		0.0310
C	$-x$		$-x$		$+2x$
E	$0.433 - x$		$0.0471 - x$		$0.0310 + 2x$

Find  $x$ .

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

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

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

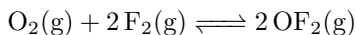
$$x = -0.\underline{1275537} \text{ or } 0.0\underline{213618} \quad (32)$$

Use the latter.

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



- 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  $273\text{K}^1$  of  $\text{F}-\text{F}$  is  $155\text{ kJ/mol}$ ,  $\text{O}-\text{O}$  is  $142\text{ kJ/mol}$ , and  $\text{O}-\text{F}$  is  $190\text{ kJ/mol}$ . For this, one  $\text{O}-\text{O}$  and two  $\text{F}-\text{F}$  bonds are broken, so we would add those bond energies together and turn them negative. Meanwhile, four  $\text{O}-\text{F}$  bonds are formed, which we can keep positive. Adding all these together, we get  $308\text{ kJ/mol}$  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:

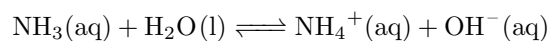


- a) If you add a little solid  $\text{NH}_4\text{Cl}$  to the mixture, what will happen to the mass of  $\text{NH}_3$ ?
- b) If you add a little gaseous  $\text{NH}_3$  to the mixture, what will happen to the mass of  $\text{HCl}$ ?
- c) If you add a little gaseous  $\text{HCl}$  to the mixture, what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

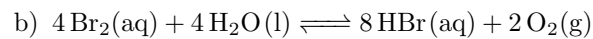
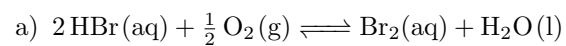


- a) If you add a little 1 M HCl to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.
- b) If you add a little 1 M MgCl<sub>2</sub> to the mixture, which way will the reaction proceed? Or will it be unaffected? Explain your answer.
- c) If you add a little 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

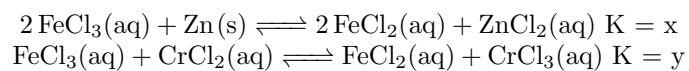
For the reaction  $4\text{HBr}(\text{aq}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{Br}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ ,  $K_c = 6.7 \times 10^{10}$ . Use this information to calculate the equilibrium constant for each of the following reactions.



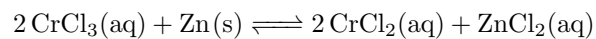
### 20.1 Solution

## 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  $y$ .



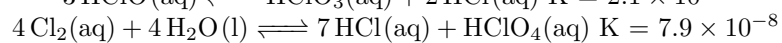
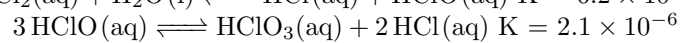
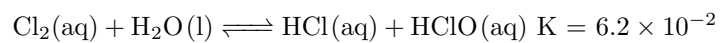
### 21.1 Solution

## 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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