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Email: [hello@contoureducation.com.au](mailto:hello@contoureducation.com.au)

VCE Chemistry  $\frac{3}{4}$   
Equilibrium [2.7]  
Homework Solutions

Admin Info & Homework Outline:



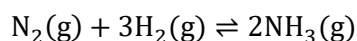
Student Name	
Questions You Need Help For	
Compulsory Questions	Pg 2 – Pg 16
Supplementary Questions	Pg 17 – Pg 32

## Section A: Compulsory Questions (55 Marks)

### Sub-Section [2.7.1]: Write Equilibrium Constant Expression & Find its Value (Including Units)

#### Question 1 (4 marks)

Christian is interested in the Haber process, for which the chemical equation has been shown below:



- a. In one experiment, at equilibrium there is 2.15 mol of nitrogen gas, 2.5 mol of hydrogen gas and 4.55 mol of ammonia gas in a 3.0 L beaker.

- i. Write the  $K_c$  expression. (1 mark)

$$K_c = \frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]}$$

- ii. Find the  $K_c$  value. (1 mark)

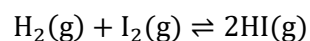
$$K_c = \frac{\left[\frac{4.55}{3}\right]^2}{\left[\frac{2.15}{3}\right] \left[\frac{2.5}{3}\right]^3} = 5.6 \text{ mol}^{-2}$$

- b. In another experiment, at equilibrium Christian finds 3.25 mol of nitrogen gas, 1.25 mol of hydrogen gas and 3.20 mol of ammonia gas in a 3.00 L beaker. Find the  $K_c$  value.

$$K_c = \frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]}$$

$$K_c = \frac{\left[\frac{3.2}{3}\right]^2}{\left[\frac{1.25}{3}\right]^3 \left[\frac{3.25}{3}\right]} = 14.5 \text{ mol}^{-2}$$

- c. Christian's friend, Umar, is experimenting with the equation shown below:



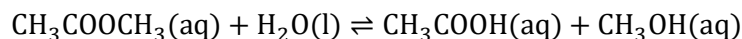
Umar finds that at equilibrium,  $1.05 \text{ mol}$  of hydrogen gas,  $2.10 \text{ mol}$  of iodine gas and  $1.50 \text{ mol}$  of hydrogen iodide remains in a  $2.00 \text{ L}$  beaker. Find the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} \\ &= \frac{\left(\frac{1.5}{2}\right)^2}{\left(\frac{1.05}{2}\right)\left(\frac{2.1}{2}\right)} \\ &= 1.02 \text{ (no units)} \end{aligned}$$

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**Question 2** (4 marks)

Ester hydrolysis is used commercially for methanol production to be used in fuels. One instance of this is the hydrolysis of methyl ethanoate in the presence of water to form ethanoic acid and methanol. The chemical equation has been provided below.



At equilibrium, Hamsini finds that 3.5 mol of  $\text{CH}_3\text{COOCH}_3$ , 3.25 mol of ethanoic acid and 1.05 mol of methanol remains all dissolved in 5.00 L of water.

- a. Calculate the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{CH}_3\text{OH}][\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COOCH}_3]} \\ &= \frac{\left[\frac{3.25}{5}\right]\left[\frac{1.05}{5}\right]}{\left[\frac{3.5}{5}\right]} \\ &= 0.20 \text{ M} \end{aligned}$$

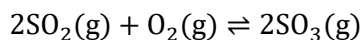
- b. At a different temperature, Hamsini finds that the equilibrium constant is 4.50 M. The 5.0 L vessel contains 1.5 mol of  $\text{CH}_3\text{COOCH}_3$ , 4.4 mol of water, 2.20 mol of  $\text{CH}_3\text{COOH}$  at equilibrium. Find the concentration of methanol, in M, in the vessel. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{CH}_3\text{OH}][\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COOCH}_3]} \\ [\text{CH}_3\text{OH}] &= \frac{4.5 \times \left(\frac{1.5}{5}\right)}{\left(\frac{2.2}{5}\right)} \\ &= 3.1 \text{ M} \end{aligned}$$

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**Question 3 (5 marks)**

- a. Estelle is investigating the following reaction:



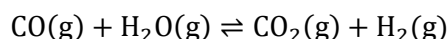
In a 3.0 L vessel at equilibrium, the  $K_c$  value is  $2.5 \text{ M}^{-1}$  and there remains 2.5 mol of  $2\text{SO}_2(\text{g})$  and 1.25 mol of  $\text{O}_2(\text{g})$  respectively. Find the concentration of sulphur trioxide ( $\text{SO}_3(\text{g})$ ). (2 marks)

$$K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$$

$$[\text{SO}_3] = \sqrt{2.5 \times \left[\frac{2.5}{3}\right]^2 \times \left[\frac{1.25}{3}\right]}$$

$$= 0.85 \text{ M}$$

- b. Estelle's friend, Eric, is interested in the following reaction:



In a 4.5 L vessel at equilibrium, the  $K_c$  value is 4.5 and there remains 1.5 mol of  $\text{CO}(\text{g})$ , 1.25 mol of  $\text{H}_2\text{O}(\text{g})$  and 2.125 mol of  $\text{H}_2(\text{g})$  respectively. Find the amount, in mol, of carbon dioxide ( $\text{CO}_2(\text{g})$ ). (3 marks)

$$K_c = \frac{[\text{H}_2][\text{CO}_2]}{[\text{CO}][\text{H}_2\text{O}]}$$

$$n(\text{H}_2) = \frac{4.5 \times \left(\frac{1.25}{4.5}\right) \times \left(\frac{1.5}{4.5}\right)}{\left(\frac{2.125}{4.5}\right)} \times 4.5$$

$$= 3.98 \text{ mol}$$

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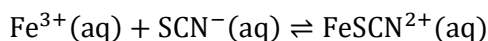


## Sub-Section [2.7.2]: Identify the Extent of Reaction

### Question 4 (3 marks)



Consider the following chemical reaction:



- a. If the  $K_c$  value is  $8.50 \times 10^{-5} \text{ M}^{-1}$ , state the extent of reaction. (1 mark)

Small extent of reaction.

- b. If the  $K_c$  value is  $7.50 \times 10^6 \text{ M}^{-1}$ , state the extent of reaction. (1 mark)

Large extent of reaction.

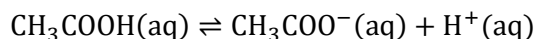
- c. If the  $K_c$  value is  $15.0 \text{ M}^{-1}$ , state the extent of reaction. (1 mark)

Medium extent of reaction.

### Question 5 (3 marks)



Theeran is experimenting with the following reaction.



At equilibrium in a 2.5 L container, he finds 1.5 mol of  $\text{CH}_3\text{COOH}$ , 1.25 mol of  $\text{CH}_3\text{COO}^{-}$  and 10.5 mol of  $\text{H}^{+}$  ions.

- a. Calculate the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{CH}_3\text{COO}^{-}][\text{H}^{+}]}{[\text{CH}_3\text{COOH}]} \\ &= \frac{\left(\frac{1.25}{2.5}\right) \times \left(\frac{10.5}{2.5}\right)}{\left(\frac{1.5}{2.5}\right)} \\ &= 3.5 \end{aligned}$$

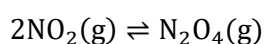
- b. Hence, determine the extent of reaction. (1 mark)

Medium extent of reaction. (1)

**Question 6** (2 marks)



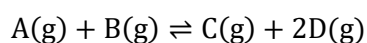
- a. When the following reaction reaches equilibrium, it is found that there is a low concentration of nitric dioxide ( $\text{NO}_2$ ) remaining.



Hence, predict the magnitude of the equilibrium constant. (1 mark)

The equilibrium constant is likely to be very high ( $> 10^4$ ) due to a high extent of reaction (1).

- b. In a system, the  $K_c$  value is given to be  $5.6 \times 10^5 \text{ M}$ . The equation for the reaction has been shown below:



Which of the following is correct regarding the system at equilibrium? (1 mark)

- A. A significant amount of reactants are present at equilibrium.
- B. A greater amount of  $D$  is present at equilibrium than  $C$ .
- C. Concentration of  $C$  is greater than the concentration of  $B$ .
- D. A significant amount of products are present at equilibrium.**

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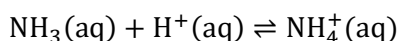
## Sub-Section [2.7.3]: Find Equilibrium Constant When Equation is Changed



### Question 7 (3 marks)



Vedika is investigating the following reaction. The equilibrium constant at 25.0°C is  $25.6 \text{ M}^{-1}$ .



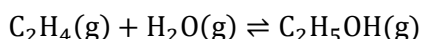
For the following reactions, state the equilibrium constant at 25.0°C.

Chemical Equation	$K_c$ value at 25°C
a. $2\text{NH}_3(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons 2\text{NH}_4^+(\text{aq})$	$655 \text{ M}^{-2}$
b. $\frac{1}{2}\text{NH}_3(\text{aq}) + \frac{1}{2}\text{H}^+(\text{aq}) \rightleftharpoons \frac{1}{2}\text{NH}_4^+(\text{aq})$	$5.06 \text{ M}^{-\frac{1}{2}}$
c. $\text{NH}_4^+(\text{aq}) \rightleftharpoons \text{NH}_3(\text{aq}) + \text{H}^+(\text{aq})$	$0.039 \text{ M}$

### Question 8 (3 marks)



Tabbita is investigating the following reaction. The equilibrium constant at 35.0°C is  $12.6 \text{ M}^{-1}$ .



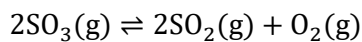
For the following reactions, state the equilibrium constant at 35.0°C.

Chemical Equation	$K_c$ value at 25°C
a. $\frac{1}{2}\text{C}_2\text{H}_5\text{OH}(\text{g}) \rightleftharpoons \frac{1}{2}\text{C}_2\text{H}_4(\text{g}) + \frac{1}{2}\text{H}_2\text{O}(\text{g})$	$0.28 \text{ M}^{\frac{1}{2}}$
b. $2\text{C}_2\text{H}_5\text{OH}(\text{g}) \rightleftharpoons 2\text{C}_2\text{H}_4(\text{g}) + 2\text{H}_2\text{O}(\text{g})$	$6.3 \times 10^{-3} \text{ M}^2$
c. $3\text{C}_2\text{H}_4(\text{g}) + 3\text{H}_2\text{O}(\text{g}) \rightleftharpoons 3\text{C}_2\text{H}_5\text{OH}(\text{g})$	$2000 \text{ M}^{-3}$




**Question 9** (5 marks)

Consider the equation shown below.



- a. State the equilibrium expression. (1 mark)

$$K_c = \left( \frac{[\text{O}_2(\text{g})][\text{SO}_2(\text{g})]^2}{[\text{SO}_3(\text{g})]^2} \right)$$

- b. It is known that at 200°C, this chemical equation has an equilibrium constant of 150 M. State the equilibrium constants for the following equations at the same temperature.

- i.  $\text{SO}_3(\text{g}) \rightleftharpoons \text{SO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g})$ . (1 mark)

$$12.25 \text{ M}^{\frac{1}{2}}$$

- ii.  $4\text{SO}_3(\text{g}) \rightleftharpoons 4\text{SO}_2(\text{g}) + 2\text{O}_2(\text{g})$ . (1 mark)

$$2.25 \times 10^4 \text{ M}^2$$

- iii.  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$ . (1 mark)

$$6.67 \times 10^{-3} \text{ M}^{-1}$$

- iv.  $\text{SO}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightleftharpoons \text{SO}_3(\text{g})$ . (1 mark)

$$0.082 \text{ M}^{-\frac{1}{2}}$$

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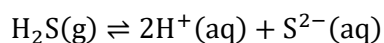


## Sub-Section [2.7.4]: Apply $Q_c$ to Find Direction of Equilibrium Shift

### Question 10 (3 marks)



Sun is investigating the following reaction. At 25°C, the system has an equilibrium constant of 25.0  $M^2$ .



Determine the direction of equilibrium shift when:

- a.  $Q_c = 10 M^2$ . (1 mark)

Forward shift

- b.  $Q_c = 25 M^2$ . (1 mark)

No shift

- c.  $Q_c = 35 M^2$ . (1 mark)

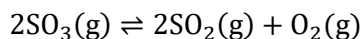
Backward shift

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### Question 11



Isabelle is interested in the following reaction occurring in a 2.5 L container. She knows that at equilibrium at 26°C,  $K_c = 4.0 M$ .



Isabelle adds 2.0 mol of oxygen gas, 1.5 mol of  $\text{SO}_2(\text{g})$  and 2.25 mol of  $\text{SO}_3(\text{g})$ . Calculate  $Q_c$  and hence, predict the direction of equilibrium shift.

$$Q_c = \frac{[\text{O}_2][\text{SO}_2]^2}{[\text{SO}_3]^2}$$

$$= \frac{\left(\frac{2}{2.5}\right) \times \left(\frac{1.5}{2.5}\right)^2}{\left(\frac{2.25}{2.5}\right)^2}$$

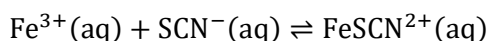
$$= 0.356 M$$

As  $Q_c < K_c$ ,  
System will shift forwards

### Question 12 (3 marks)



Jasmine is investigating the following equation occurring in a 5.0 L vessel:



Her laboratory technician tells her that at 24°C,  $K_c = 41.5 M$ . Jasmine adds 3.0 mol of  $\text{Fe}^{3+}$ , 10.1 mol of  $\text{FeSCN}^{2+}$  and an unknown amount of  $\text{SCN}^{-}$ . Given that the equilibrium shifts forward, calculate the  $\text{SCN}^{-}$  concentration, in M, which she must have been added.

$$Q_c = \frac{[\text{FeSCN}^{2+}]}{[\text{Fe}^{3+}][\text{SCN}^{-}]}$$

For equilibrium to shift forward,  
 $Q_c < K_c$

$$41.5 > \frac{\left(\frac{10.1}{5}\right)}{\left(\frac{3}{5}\right) \times [\text{SCN}^{-}]}$$

$$[\text{SCN}^{-}] > \frac{\left(\frac{10.1}{5}\right)}{\frac{3}{5} \times 41.5}$$

$$[\text{SCN}^{-}] > 0.08 M$$

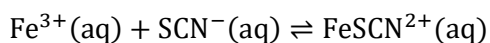


**Sub-Section [2.7.5]: Apply RICE Tables to Find  $K_c$**

**Question 13** (3 marks)



Mansi is running an experiment with the following reaction in a 1.0 L reaction vessel.



She adds 2.0 mol of  $\text{Fe}^{3+}$  and 1.55 mol of  $\text{SCN}^{-}$  into an empty reaction vessel. After the system reaches equilibrium, she notes that 0.55 mol of  $\text{FeSCN}^{2+}$  has been produced. Calculate the  $K_c$  value.

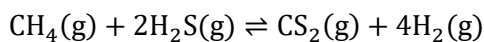
$\text{Fe}^{3+}(\text{aq}) + \text{SCN}^{-}(\text{aq}) \rightleftharpoons \text{FeSCN}^{2+}(\text{aq})$			
Ratio	1	1	1
Initial	2.0	1.55	0
change	-0.55	-0.55	+0.55
Equilibrium	1.45	1.0	0.55

$$\therefore K_c = \frac{0.55}{1.45} = 0.38 \text{ M}^{-1}$$

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**Question 14** (6 marks)

Ren is investigating the following reaction occurring in a 1.0 L vessel:



- a. In one trial, Ren adds 2.0 mol of  $\text{CH}_4$  and 1.70 mol of  $\text{H}_2\text{S}$  to an empty vessel. Ren notes that there is 1.55 mol of hydrogen gas at equilibrium. Calculate the  $K_c$  value. (3 marks)

$\text{CH}_4(\text{g}) + 2\text{H}_2\text{S}(\text{g}) \rightleftharpoons \text{CS}_2(\text{g}) + 4\text{H}_2(\text{g})$				
Ratio	1	2	1	4
Initial	2.0	1.70	0	0
change	$-\frac{1.55}{4}$ $= 0.3875$	$-\frac{1.55}{4} \times 2$ $= 0.775$	$+\frac{1.55}{4}$ $= 0.3875$	$+1.55$
Equilibrium	1.6125	0.925	0.3875	1.55

$$K_c = \frac{(1.55)^4 (0.3875)}{(0.925)^2 (1.6125)} = 1.6 \text{ M}^2$$

- b. In another trial, Ren adds 1.5 mol of  $\text{CH}_4$  and 1.60 mol of  $\text{H}_2\text{S}$  to an empty vessel. Ren notes that only 1.25 mol of  $\text{CH}_4$  remains at equilibrium. Calculate the  $K_c$  value. (3 marks)

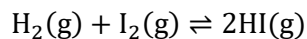
$\text{CH}_4(\text{g}) + 2\text{H}_2\text{S}(\text{g}) \rightleftharpoons \text{CS}_2(\text{g}) + 4\text{H}_2(\text{g})$				
Ratio	1	2	1	4
Initial	1.5	1.6	0	0
change	-0.25	$-0.25 \times 2$ $= -0.5$	+0.25	$0.25 \times 4$ $= +1$
Equilibrium	1.25	1.1	+0.25	1.0

$$K_c = \frac{1^4 \times 0.25}{1.1^2 \times 1.25} = 0.17 \text{ M}^2$$

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**Question 15** (4 marks)

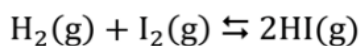
Amber decides to react hydrogen and iodine gas together, producing hydrogen iodide, in a 5.0 L vessel. The reaction is shown below.



- a. Write the equilibrium expression for this reaction. (1 mark)

$$K_c = \frac{[\text{HI}(\text{g})]^2}{[\text{H}_2(\text{g})][\text{I}_2(\text{g})]}$$

- b. Amber adds 5.00 g of hydrogen gas to 3.00 mol of iodine gas. Calculate the concentration of hydrogen iodide produced at this given temperature if it was found that 1.15 mol of hydrogen gas remains at equilibrium. (3 marks)



Molar Ratio	1	1	2
Initial $n$ (in mol)	$\frac{5}{2} = 2.5$	3.0	0
$\Delta n$ (in mol)	$\downarrow 1.35$	$\downarrow 1.35$	$\uparrow 2.70$
Equilibrium $n$ (in mol)	1.15	1.65	2.70

$$C(\text{HI}) = \frac{n(\text{HI})}{V} = \frac{2.7}{5} = 0.54 \text{ M}$$

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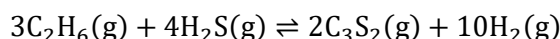
## Sub-Section: The 'Final Boss'

### Question 16 (4 marks)



Ethane and hydrogen sulfide react under high-temperature conditions in volcanic gas environments, leading to the formation of exotic carbon-sulphur compounds.

Radman is curious about this natural phenomenon, so is investigating the following chemical reaction at  $80^{\circ}\text{C}$  has a  $K_c$  value of  $10.5 \text{ M}^2$ . The reaction is occurring in a  $4.5 \text{ L}$  beaker.



- a. At a given moment,  $4.15 \text{ mol}$  of  $\text{C}_2\text{H}_6$ ,  $3.15 \text{ mol}$  of  $\text{H}_2\text{S}$ ,  $10.1 \text{ mol}$  of  $\text{C}_3\text{S}_2$  and  $1.55 \text{ mol}$  of hydrogen gas is present in the beaker.

- i. Determine the extent of the reaction. (1 mark)

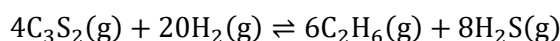
As  $K_c = 10.5 \text{ M}^2$ ,  $10^{-4} < K_c < 10^4$  medium extent of reaction.

- ii. Determine whether the system is at equilibrium. If so, justify your answer. If not, justify the direction it will shift to re-establish equilibrium. (2 marks)

$$\begin{aligned} Q_c &= \frac{[\text{C}_3\text{S}_2]^2}{[\text{C}_2\text{H}_6]^3 [\text{H}_2\text{S}]^4} \\ &= \frac{\left(\frac{10.1}{4.5}\right)^2 \left(\frac{1.55}{4.5}\right)^{10}}{\left(\frac{3.15}{4.5}\right)^4 \left(\frac{4.15}{4.5}\right)^3} \\ &= 6.29 \times 10^{-4} \text{ M}^5 \end{aligned}$$

'As  $Q_c < K_c$ , the system is not at equilibrium will shift forwards to re-establish equilibrium.'

- iii. The equation is altered as shown below:



Predict the new  $K_c$  value. (1 mark)

$$\begin{aligned} K_{c\text{new}} &= \frac{1}{10.5^2} \\ &= 9.07 \times 10^{-3} \text{ M}^{-10} \end{aligned}$$

- b. In another trial at 80°C, 2.2 mol of C<sub>2</sub>H<sub>6</sub>, 1.55 mol of H<sub>2</sub>S and 1.67 mol of H<sub>2</sub> is present in the beaker at equilibrium. Calculate the concentration of C<sub>3</sub>S<sub>2</sub> present.

$$K_c = 10.5$$

$$\therefore 10.5 = \frac{[C_3S_2]^2}{[H_2S]^4 [C_2H_6]^3}$$

$$[C_3S_2] = \sqrt{\frac{10.5 \times \left(\frac{1.55}{4.5}\right)^4 \times \left(\frac{2.2}{4.5}\right)^3}{\left(\frac{1.67}{4.5}\right)^{10}}}$$

$$[C_3S_2] = 18.7 \text{ M}$$

- c. Radman sets up another experiment at 65°C. He adds 5.1 mol of C<sub>2</sub>H<sub>6</sub>, 2.15 mol of H<sub>2</sub>S to the same, empty reaction vessel. After the system reaches equilibrium, he notes that only 1.05 mol of H<sub>2</sub>S remains in the vessel. Calculate the K<sub>c</sub> value for this system.

3C <sub>2</sub> H <sub>6</sub> (g) + 4H <sub>2</sub> S(g) ⇌ 2C <sub>3</sub> S <sub>2</sub> (g) + 10H <sub>2</sub> (g)				
Ratio	3	4	2	10
Initial	5.1	2.15	0	0
change	$-\frac{1.1}{4} \times 3$ = -0.825	-1.1	+0.55	+2.75
Equilibrium	4.275	1.05	0.55	2.75

$$\therefore K_c = \frac{\left(\frac{2.75}{4.5}\right)^{10} \left(\frac{0.55}{4.5}\right)^2}{\left(\frac{1.05}{4.5}\right)^4 \left(\frac{4.275}{4.5}\right)^3}$$

$$= 0.043 \text{ M}^5$$

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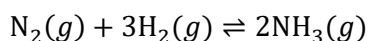


## Section B: Supplementary Questions (68 Marks)

### Sub-Section [2.7.1]: Write Equilibrium Constant Expression & Find its Value (Including Units)

#### Question 17 (4 marks)

Medha is interested in the Haber process, for which the chemical equation has been shown below:



- a. In one experiment, at equilibrium, there is 2.15 mol of nitrogen gas, 2.5 mol of hydrogen gas and 4.55 mol of ammonia gas in a 2.0 L beaker.

- i. Write the  $K_c$  expression. (1 mark)

$$K_c = \frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]}$$

- ii. Find the  $K_c$  value. (1 mark)

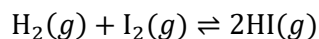
$$K_c = \frac{\left[\frac{4.55}{2}\right]^2}{\left[\frac{2.15}{2}\right] \left[\frac{2.5}{2}\right]^3} = 2.5 \text{ M}^{-2}$$

- b. In another experiment, at equilibrium, Medha finds 3.25 mol of nitrogen gas, 1.25 mol of hydrogen gas and 3.20 mol of ammonia gas in a 4.00 L beaker. Find the  $K_c$  value.

$$K_c = \frac{[\text{NH}_3]^2}{[\text{H}_2]^3 [\text{N}_2]}$$

$$K_c = \frac{\left[\frac{3.2}{4}\right]^2}{\left[\frac{1.25}{4}\right]^3 \left[\frac{3.25}{4}\right]} = 25.8 \text{ M}^{-2}$$

- c. Medha's friend, Nawid, is experimenting with the equation shown below:



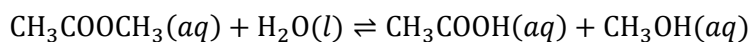
Nawid finds that at equilibrium,  $1.05 \text{ mol}$  of hydrogen gas,  $2.10 \text{ mol}$  of iodine gas and  $1.50 \text{ mol}$  of hydrogen iodide remain in a  $3.00 \text{ L}$  beaker. Find the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} \\ &= \frac{\left(\frac{1.5}{3}\right)^2}{\left(\frac{1.05}{3}\right)\left(\frac{2.1}{3}\right)} \\ &= 1.0 \quad (\text{no units}) \end{aligned}$$

Question 18 (4 marks)



Ester hydrolysis is used commercially for methanol production to be used in fuels. One instance of this is the hydrolysis of methyl ethanoate in the presence of water to form ethanoic acid and methanol. The chemical equation has been provided below.



At equilibrium, Hitani finds that  $3.5 \text{ mol}$  of methyl ethanoate,  $3.25 \text{ mol}$  of ethanoic acid and  $1.05 \text{ mol}$  of methanol remains all dissolved in  $4.00 \text{ L}$  of water.

- a. Calculate the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{CH}_3\text{OH}][\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COOCH}_3]} \\ &= \frac{\left[\frac{3.25}{4}\right]\left[\frac{1.05}{4}\right]}{\left[\frac{3.5}{4}\right]} \\ &= 0.24 \text{ M} \end{aligned}$$

- b. At a different temperature, Hinati finds that the equilibrium constant is  $5.50 \text{ M}$ . The  $3.125 \text{ L}$  vessel contains  $1.5 \text{ mol}$  of methyl ethanoate,  $4.4 \text{ mol}$  of water,  $2.20 \text{ mol}$  of ethanoic acid at equilibrium. Find the concentration of methanol, in  $\text{M}$ , in the vessel. (2 marks)

$$K_c = \frac{[\text{CH}_3\text{OH}][\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COOCH}_3]}$$

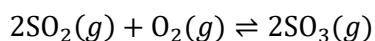
$$[\text{CH}_3\text{OH}] = \frac{5.5 \times \left(\frac{1.5}{3.125}\right)}{\left(\frac{2.2}{3.125}\right)}$$

$$= 3.75 \text{ M}$$

Question 19 (5 marks)



- a. Lachlan is investigating the following reaction:



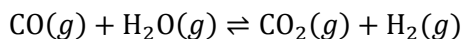
In a  $4.5 \text{ L}$  vessel at equilibrium, the  $K_c$  value is  $3.5 \text{ M}^{-1}$  and there remains  $2.5 \text{ mol}$  of  $\text{SO}_2(g)$  and  $1.25 \text{ mol}$  of  $\text{O}_2(g)$  respectively. Find the concentration of sulphur trioxide ( $\text{SO}_3(g)$ ). (2 marks)

$$K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2 [\text{O}_2]}$$

$$[\text{SO}_3] = \sqrt{3.5 \times \left[\frac{2.5}{4.5}\right]^2 \times \left[\frac{1.25}{4.5}\right]}$$

$$= 0.55 \text{ M}$$

- b. Lachlan's friend, Harsh, is interested in the following reaction:



In a 10.5 L vessel at equilibrium, the  $K_c$  value is 6.3 (no unit) and there remains 1.5 mol of  $\text{CO}(g)$ , 1.25 mol of  $\text{H}_2\text{O}(g)$  and 2.125 mol of  $\text{H}_2(g)$  respectively. Find the amount, in mol, of carbon dioxide ( $\text{CO}_2(g)$ ). (3 marks)

$$K_c = \frac{[\text{H}_2][\text{CO}_2]}{[\text{CO}][\text{H}_2\text{O}]}$$

$$n(\text{H}_2) = \frac{6.3 \times \left(\frac{1.25}{10.5}\right) \times \left(\frac{1.5}{10.5}\right)}{\left(\frac{2.125}{10.5}\right)} \times 4.5$$

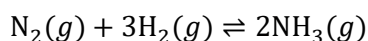
$$= 2.38 \text{ mol}$$

**Question 20** (6 marks)



Raph reacts nitrogen gas with hydrogen gas to form ammonia gas.

- a. Express the chemical reaction for this scenario. (1 mark)



- b. Provide the units of  $K_c$  for this reaction. (1 mark)

$$K_c = \frac{\text{M}^2}{[\text{M}^2][\text{M}]} = \text{M}^{-2}$$

- c. Write the equilibrium expression for this reaction. (1 mark)

$$K_c = \left( \frac{[\text{NH}_3(g)]^2}{[\text{H}_2(g)]^3 [\text{N}_2(g)]} \right) \text{M}^{-2}$$

- d. In an experiment, 1.20 mol of hydrogen gas, 3.64 mol nitrogen gas and 2.10 mol of ammonia gas was formed at equilibrium in a 2.0 L container at 120°C. Find the equilibrium constant. (3 marks)

$$[NH_3] = \frac{2.1}{2} = 1.05 \text{ M}$$

$$[H_2] = \frac{1.2}{2} = 0.6 \text{ M}$$

$$[N_2] = \frac{3.64}{2} = 1.82 \text{ M}$$

$$\therefore K_c = \left[ \frac{[1.05]^2}{[0.6]^3 [1.82]} \right] \text{ M}^{-2}$$

$$= 2.804$$

$$\approx 2.8 \text{ M}^{-2}$$

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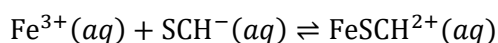


## Sub-Section [2.7.2]: Identify the Extent of Reaction

### Question 21 (3 marks)



Consider the following chemical reaction:



- a. If the  $K_c$  value is  $1.50 \times 10^6 \text{ M}^{-1}$ , state the extent of the reaction. (1 mark)

Large extent of reaction

- b. If the  $K_c$  value is  $9.50 \times 10^{-7} \text{ M}^{-1}$ , state the extent of the reaction. (1 mark)

Small extent of reaction

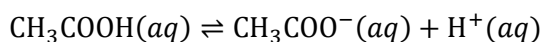
- c. If the  $K_c$  value is  $1.0 \text{ M}^{-1}$ , state the extent of the reaction. (1 mark)

Medium extent of reaction

### Question 22 (3 marks)



Brooke is experimenting with the following reaction.



At equilibrium in a 10.5 L container, he finds 1.5 mol of  $\text{CH}_3\text{COOH}$ , 1.25 mol of  $\text{CH}_3\text{COO}^{-}$  and 10.5 mol of  $\text{H}^{+}$  ions.

- a. Calculate the  $K_c$  value. (2 marks)

$$\begin{aligned} K_c &= \frac{[\text{CH}_3\text{COO}^{-}][\text{H}^{+}]}{[\text{CH}_3\text{COOH}]} \\ &= \frac{\left(\frac{1.25}{10.5}\right) \times \left(\frac{10.5}{10.5}\right)}{\left(\frac{1.5}{10.5}\right)} \\ &= 0.833 \end{aligned}$$

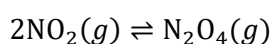
b. Hence, determine the extent of the reaction. (1 mark)

Medium extent of reaction (1)

**Question 23** (1 mark)



When the following reaction reaches equilibrium, it is found that there is a low concentration of nitric dioxide ( $\text{NO}_2$ ) remaining.



Hence, predict the magnitude of the equilibrium constant.

The equilibrium constant is likely to be very high ( $> 10^4$ ) due to a high extent of reaction (1).

**Question 24** (1 mark)



The value of the equilibrium constant,  $K_c$ , for a reaction is  $1.0 \times 10^{14}$ . Which statement about the extent of the reaction is correct?

- A. The reaction hardly proceeds.
- B. The reaction goes almost to completion.**
- C. The products have a lower concentration than the reactants.
- D. The concentrations of reactants and products are the same.

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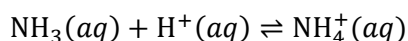
## Sub-Section [2.7.3]: Find Equilibrium Constant When Equation is Changed



### Question 25 (3 marks)



Dai is investigating the following reaction. The equilibrium constant at 25.0°C is  $10.6 \text{ M}^{-1}$ .



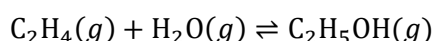
For the following reactions, state the equilibrium constant at 25.0°C.

Chemical Equation	$K_c$ value at 25°C
a. $2\text{NH}_3(\text{aq}) + 2\text{H}^+(\text{aq}) \rightleftharpoons 2\text{NH}_4^+(\text{aq})$	$112 \text{ M}^{-2}$
b. $\frac{1}{2}\text{NH}_3(\text{aq}) + \frac{1}{2}\text{H}^+(\text{aq}) \rightleftharpoons \frac{1}{2}\text{NH}_4^+(\text{aq})$	$3.26 \text{ M}^{-\frac{1}{2}}$
c. $\text{NH}_4^+(\text{aq}) \rightleftharpoons \text{NH}_3(\text{aq}) + \text{H}^+(\text{aq})$	$0.094 \text{ M}$

### Question 26 (3 marks)



Joanne is investigating the following reaction. The equilibrium constant at 35.0°C is  $11.6 \text{ M}^{-1}$ .



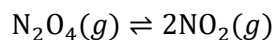
For the following reactions, state the equilibrium constant at 35.0°C.

Chemical Equation	$K_c$ value at 25°C
a. $\frac{1}{2}\text{C}_2\text{H}_5\text{OH}(\text{g}) \rightleftharpoons \frac{1}{2}\text{C}_2\text{H}_4(\text{g}) + \frac{1}{2}\text{H}_2\text{O}(\text{g})$	$0.294 \text{ M}^{\frac{1}{2}}$
b. $2\text{C}_2\text{H}_5\text{OH}(\text{g}) \rightleftharpoons 2\text{C}_2\text{H}_4(\text{g}) + 2\text{H}_2\text{O}(\text{g})$	$7.4 \times 10^{-3} \text{ M}^2$
c. $3\text{C}_2\text{H}_4(\text{g}) + 3\text{H}_2\text{O}(\text{g}) \rightleftharpoons 3\text{C}_2\text{H}_5\text{OH}(\text{g})$	$1561 \text{ M}^{-3}$




**Question 27** (4 marks)

Consider the following equilibrium reaction:



- a. Write the equilibrium expression for this reaction, including its unit. (1 mark)

$$K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$$

- b. Given that at a certain temperature, the equilibrium constant for this reaction is  $K_c = 50 \text{ M}$ , determine the equilibrium constants for the following modified reactions at the same temperature:

- i.  $\frac{1}{2}\text{N}_2\text{O}_4(g) \rightleftharpoons \text{NO}_2(g)$ . (1 mark)

$$\frac{1}{2}\text{N}_2\text{O}_4(g) \rightleftharpoons \text{NO}_2(g)$$

$$K_c = 50^{\frac{1}{2}} = 7.07 \text{ M}^{\frac{1}{2}}$$

- ii.  $2\text{N}_2\text{O}_4(g) \rightleftharpoons 4\text{NO}_2(g)$ . (1 mark)

$$2\text{N}_2\text{O}_4(g) \rightleftharpoons 4\text{NO}_2(g)$$

$$K_c = 50^2 = 2500 \text{ M}^2$$

- iii.  $2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$ . (1 mark)

$$2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)$$

$$K_c = \frac{1}{50} = 0.020 \text{ M}^{-1}$$

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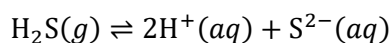


## Sub-Section [2.7.4]: Apply $Q_c$ To find the Direction of the Equilibrium Shift

### Question 28 (3 marks)



Naomi is investigating the following reaction. At 25°C, the system has an equilibrium constant of  $35.0 M^2$ .



Determine the direction of equilibrium shift when:

- a.  $Q_c = 34 M^2$ . (1 mark)

Forward shift

- b.  $Q_c = 105 M^2$ . (1 mark)

Backward shift

- c.  $Q_c = 35 M^2$ . (1 mark)

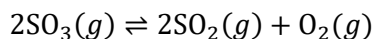
No shift

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### Question 29



Claire is interested in the following reaction occurring in a 3.5 L container. She knows that at equilibrium at 26°C,  $K_c = 0.1 M$ .



She adds 2.0 mol of oxygen gas, 1.5 mol of  $\text{SO}_2(g)$  and 2.25 mol of  $\text{SO}_3(g)$ . Calculate  $Q_c$  and hence predict the direction of the equilibrium shift.

$$Q_c = \frac{[\text{O}_2][\text{SO}_2]^2}{[\text{SO}_3]^2}$$

$$= \frac{\left(\frac{2}{3.5}\right) \times \left(\frac{1.5}{3.5}\right)^2}{\left(\frac{2.25}{3.5}\right)^2}$$

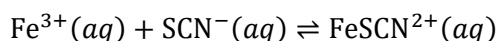
$$= 0.254$$

As  $Q_c > K_c$ ,  
system will shift Backwards

### Question 30 (3 marks)



Jasmine is investigating the following equation occurring in a 10.0 L vessel:



Her laboratory technician tells her that at 24°C,  $K_c = 30.5 M$ . Jasmine adds 2.0 mol of  $\text{Fe}^{3+}$ , 10.1 mol of  $\text{FeSCN}^{2+}$  and an unknown amount of  $\text{SCN}^-$ . Given that the equilibrium shifts backwards, calculate the  $\text{SCN}^-$  concentration, in M, which she must have been added.

$$Q_c = \frac{[\text{FeSCN}^{2+}]}{[\text{Fe}^{3+}][\text{SCN}^-]}$$

For Equilibrium to shift backward,  
 $Q_c > K_c$

$$30.5 < \frac{\left(\frac{10.1}{10}\right)}{\left(\frac{2}{10}\right) \times [\text{SCN}^-]}$$

$$[\text{SCN}^-] < \frac{\left(\frac{10.1}{10}\right)}{\frac{2}{10} \times 30.5}$$

$$[\text{SCN}^-] < 0.166 M$$

Less than 0.166 M of  $\text{SCN}^-$

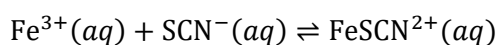


## Sub-Section [2.7.5]: Apply RICE Tables to Find $K_c$

### Question 31 (3 marks)



Hayley is running an experiment with the following reaction in a 1.0 L reaction vessel.



She adds 1.0 mol of  $\text{Fe}^{3+}$  and 1.355 mol of  $\text{SCN}^{-}$  into an empty reaction vessel. After the system reaches equilibrium, she notes that 0.125 mol of  $\text{FeSCN}^{2+}$  has been produced. Calculate the  $K_c$  value.

	$\text{Fe}^{3+}(\text{aq})$	$+$	$\text{SCN}^{-}(\text{aq})$	$\rightleftharpoons$	$\text{FeSCN}^{2+}(\text{aq})$
Ratio	1		1		1
Initial	1.0		1.355		0
Change	-0.125		-0.125		+0.125
Equilibrium	0.875		1.23		0.125

$$\therefore K_c = \frac{0.125}{1.23 \times 0.875} = 0.116 \text{ M}^{-1}$$

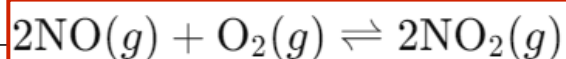
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**Question 32** (11 marks)

Clara adds  $0.30 \text{ mol}$  nitrogen monoxide to  $0.40 \text{ mol}$  oxygen gas, producing nitrogen dioxide in a  $3.0 \text{ L}$  vessel in an experiment at school.

- a. State the chemical equation for this reaction. (1 mark)



- b. Clara conducts the experiment and finds that at equilibrium,  $0.165 \text{ mol}$  of NO remains.

- i. Find the concentration of Nitrogen dioxide at equilibrium. (4 marks)

	$2\text{NO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}_2(g)$		
Ratio	2	1	2
Initial	0.3	0.4	0
Change	0.135	$\frac{0.135}{2} = 0.0675$	0.135
Equilibrium	0.165	0.3325	0.135

$n(\text{NO}_2) = 0.135$   
 $[\text{NO}_2] = \frac{0.135}{3} = 0.045$   
 $\approx 4.5 \times 10^{-2} \text{ M}$

- ii. Find the equilibrium constant at  $15^\circ\text{C}$ . (2 marks)

$$\begin{aligned}
 [\text{O}_2] &= \frac{0.3325}{3} = 0.1108 \\
 [\text{NO}] &= \frac{0.165}{3} = 0.055 \\
 K_c &= \frac{[0.045]^2}{[0.055]^2 [0.1108]} \\
 K_c &= 6.04 \text{ M}^{-1}
 \end{aligned}$$

- c. Another student in Clara's class is conducting the same experiment under the same conditions ( $15^{\circ}\text{C}$ ,  $3.0\text{ L}$  vessel). At one point during the chemical reaction, he notes that there is  $0.251\text{ mol}$  of  $\text{NO}$ ,  $0.754\text{ mol}$  of  $\text{O}_2$  and  $1.230\text{ mol}$  of  $\text{NO}_2$ .

- i. Find the reaction quotient. (2 marks)

$$Q_c = \frac{\left[\frac{1.23}{3}\right]^2}{\left[\frac{0.251}{3}\right]^2 \left[\frac{0.754}{3}\right]} = 95.5\text{ M}^{-1}$$

- ii. Comment on the relative rate of production/consumption of reactants and products. Explain how the system will return back to reaching the equilibrium constant. (2 marks)

As  $Q_c(95.5\text{ M}^{-1}) > K_c(6.04\text{ M}^{-1})$ , at this given point, there is too much products being produced and reactants being consumed (1).  
In order to reach the Equilibrium constant, the backwards reaction is favoured in order to produce more reactants and consume more products (2).

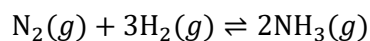
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**Question 33** (6 marks)

0.500 mol nitrogen gas and 0.400 mol hydrogen gas is added to a 4.0 L vessel, producing ammonia gas.

- a. Express the chemical equation for this reaction. (1 mark)



- b. If the equilibrium constant is known to be  $10.65 \text{ M}^{-2}$  at  $100^\circ\text{C}$ ,

- i. Express the equilibrium expression. (1 mark)

$$K_c = \frac{[\text{NH}_3(\text{g})]^2}{[\text{H}_2(\text{g})]^3[\text{N}_2(\text{g})]}$$

- ii. Find the equilibrium concentration of Ammonia gas. (4 marks)

Let change of  $\text{N}_2(\text{g})$  be represented by  $x$

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

Ratio	1	3	2
Initial	0.5	0.4	0
Change	$x$	$3x$	$2x$
Equilibrium	$0.5 - x$	$0.4 - 3x$	$2x$

$$K_c = \frac{[2x/4]^2}{\left[\frac{0.4-3x}{4}\right]^3 \left[\frac{0.5-x}{4}\right]} = 10.65$$

$$\therefore x = 0.075$$

$$[\text{NH}_3] = \frac{2 \times 0.075}{4} = 0.0375 \text{ M}$$

$$\approx 3.75 \times 10^{-2} \text{ M}$$

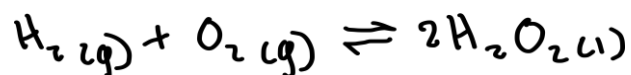
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**Question 34** (5 marks)

Hydrogen peroxide can be produced from the reversible reaction between hydrogen and oxygen:

- a. Write the equilibrium chemical equation. (1 mark)



- b. 0.85 mol of hydrogen and 0.4 mol of oxygen are added to an empty 1.00 L reactor. When equilibrium is reached, the amount of hydrogen peroxide present is 0.4 mol. Determine the value of  $K_c$ . (4 marks)

Initial:	0.85	0.4	0
Change:	-0.35	-0.1	+0.4
Equilibrium:	0.50	0.3	0.4

$$\begin{aligned}
 K_c &= \frac{[H_2O_2]^2}{[H_2][O_2]} \\
 &= \frac{[0.4]^2}{[0.3][0.5]} \\
 &= \frac{0.16}{0.15} \\
 &= 1.0667 \\
 &\approx 1.07 \text{ [NO UNITS]}
 \end{aligned}$$

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VCE Chemistry  $\frac{3}{4}$

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