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VCE Chemistry ¾
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:

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

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)

$$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$$

ii. Find the K_c value. (1 mark)

$$K_c = \frac{\left[\frac{4.55}{3}\right]^2}{\left(\frac{2.15}{3}\right)\left(\frac{2.5}{3}\right)^3}$$

$$= 5.6\ M^{-2}$$

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.

$$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$$

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

$$= 14.5\ M^{-2}$$

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

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

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

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

$$= \frac{\left(\frac{1.5}{2}\right)^2}{\left(\frac{1.05}{2}\right)\left(\frac{2.1}{2}\right)}$$

$$= 1.02 \text{ (no units)}$$

Space for Personal Notes

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.

$$CH_3COOCH_3(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + CH_3OH(aq)$$

At equilibrium, Hamsini finds that 3.5 *mol* of CH_3COOCH_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)

$$K_c = \frac{[CH_3OH][CH_2COOH]}{[CH_3COOCH_3]}$$

$$= \frac{\left[\frac{3.25}{5}\right]\left[\frac{1.05}{5}\right]}{\left[\frac{3.5}{5}\right]}$$

$$= 0.20\ M$$

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 CH_3COOCH_3, 4.4 *mol* of water, 2.20 *mol* of CH_3COOH at equilibrium. Find the concentration of methanol, in M, in the vessel. (2 marks)

$$K_c = \frac{[CH_3OH][CH_2COOH]}{[CH_3COOCH_3]}$$

$$[CH_3OH] = \frac{4.5 \times \left(\frac{1.5}{5}\right)}{\left(\frac{2.2}{5}\right)}$$

$$= 3.1\ M$$

Space for Personal Notes

Question 3 (5 marks)

a. Estelle is investigating the following reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

In a 3.0 L vessel at equilibrium, the K_c value is 2.5 M^{-1} and there remains 2.5 mol of $2SO_2(g)$ and 1.25 mol of $O_2(g)$ respectively. Find the concentration of sulphur trioxide ($SO_3(g)$). (2 marks)

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

$$[SO_3] = \sqrt{2.5 \times \left[\frac{2.5}{3}\right]^2 \times \left[\frac{1.25}{3}\right]}$$

$$= 0.85\ M$$

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

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

In a 4.5 L vessel at equilibrium, the K_c value is 4.5 and there remains 1.5 mol of $CO(g)$, 1.25 mol of $H_2O(g)$ and 2.125 mol of $H_2(g)$ respectively. Find the amount, in mol, of carbon dioxide ($CO_2(g)$). (3 marks)

$$K_c = \frac{[H_2][CO_2]}{[CO][H_2O]}$$

$$n(H_2) = \frac{4.5 \times \left(\frac{1.25}{4.5}\right) \times \left(\frac{1.5}{4.5}\right)}{\left(\frac{2.125}{4.5}\right)} \times 4.5$$

$$= 3.98\ mol$$

Space for Personal Notes

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

Question 4 (3 marks)

Consider the following chemical reaction:

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

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

Small extent of reaction.

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

Large extent of reaction.

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

Medium extent of reaction.

Question 5 (3 marks)

Theeran is experimenting with the following reaction.

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^{-}(aq) + H^{+}(aq)$$

At equilibrium in a 2.5 L container, he finds 1.5 mol of CH_3COOH, 1.25 mol of CH_3COO^{-} and 10.5 mol of H^{+} ions.

a. Calculate the K_c value. (2 marks)

$$K_c = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$$

$$= \frac{\left(\frac{1.25}{2.5}\right) \times \left(\frac{10.5}{2.5}\right)}{\left(\frac{1.5}{2.5}\right)}$$

$$= 3.5\ M$$

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 (NO_2) remaining.

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

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 $5.6 \times 10^5\ M$. The equation for the reaction has been shown below:

$$A(g) + B(g) \rightleftharpoons C(g) + 2D(g)$$

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.

Space for Personal Notes

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 M^{-1}.

$$NH_3(aq) + H^+(aq) \rightleftharpoons NH_4^+(aq)$$

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

Chemical Equation	K_c value at 25°C
a. $2NH_3(aq) + 2H^+(aq) \rightleftharpoons 2NH_4^+(aq)$	655 M^{-2}
b. $\frac{1}{2}NH_3(aq) + \frac{1}{2}H^+(aq) \rightleftharpoons \frac{1}{2}NH_4^+(aq)$	5.06 $M^{-\frac{1}{2}}$
c. $NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$	0.039 M

Question 8 (3 marks)

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

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

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

Chemical Equation	K_c value at 25°C
a. $\frac{1}{2}C_2H_5OH(g) \rightleftharpoons \frac{1}{2}C_2H_4(g) + \frac{1}{2}H_2O(g)$	0.28 $M^{\frac{1}{2}}$
b. $2C_2H_5OH(g) \rightleftharpoons 2C_2H_4(g) + 2H_2O(g)$	6.3×10^{-3} M^2
c. $3C_2H_4(g) + 3H_2O(g) \rightleftharpoons 3C_2H_5OH(g)$	2000 M^{-3}

Question 9 (5 marks)

Consider the equation shown below.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

a. State the equilibrium expression. (1 mark)

$$K_c = \left(\frac{[O_{2(g)}][SO_{2(g)}]^2}{[SO_{3(g)}]^2}\right)$$

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. $SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$. (1 mark)

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

ii. $4SO_3(g) \rightleftharpoons 4SO_2(g) + 2O_2(g)$. (1 mark)

$2.25 \times 10^4\ M^2$

iii. $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$. (1 mark)

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

iv. $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$. (1 mark)

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

Space for Personal Notes

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.

$$H_2S(g) \rightleftharpoons 2H^+(aq) + S^{2-}(aq)$$

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

Space for Personal Notes

Question 11

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

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

Isabelle adds 2.0 mol of oxygen gas, 1.5 mol of $SO_2(g)$ and 2.25 mol of $SO_3(g)$. Calculate Q_c and hence, predict the direction of equilibrium shift.

$$Q_c = \frac{[O_2][SO_2]^2}{[SO_3]^2}$$

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

$$= 0.356\ M$$

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:

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

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

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

For Equilibrium to shift forward, $Q_c < K_c$

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

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

$[SCN^-] > 0.08\ M$

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.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

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

	$Fe^{3+}_{(aq)}$ +	$SCN^{-}_{(aq)}$ ⇌	$FeSCN^{2+}_{(aq)}$
Ratio	1	1	1
Initial	2.0	1.55	0
Change	−0.55	−0.55	+0.55
Equilibrium	1.45	1.0	0.55

$\therefore K_c = \frac{0.55}{1.45}$

$= 0.38\ M^{-1}$

Space for Personal Notes

Question 14 (6 marks)

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

$$CH_4(g) + 2H_2S(g) \rightleftharpoons CS_2(g) + 4H_2(g)$$

a. In one trial, Ren adds 2.0 mol of CH_4 and 1.70 mol of H_2S to an empty vessel. Ren notes that there is 1.55 mol of hydrogen gas at equilibrium. Calculate the K_c value. (3 marks)

$CH_{4(g)} + 2H_2S_{(g)} \rightleftharpoons CS_{2(g)} + 4H_{2(g)}$

	CH_4	H_2S	CS_2	H_2
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

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

$= 1.6\ m^2$

b. In another trial, Ren adds 1.5 mol of CH_4 and 1.60 mol of H_2S to an empty vessel. Ren notes that only 1.25 mol of CH_4 remains at equilibrium. Calculate the K_c value. (3 marks)

$CH_{4(g)} + 2H_2S_{(g)} \rightleftharpoons CS_{2(g)} + 4H_{2(g)}$

	CH_4	H_2S	CS_2	H_2
Ratio	1	2	1	4
Initial	1.5	1.6	0	0
Change	−0.25	−0.25 × 2 = −0.5	+0.25	0.25 × 4 = +1
Equilibrium	1.25	1.1	+0.25	1.0

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

Space for Personal Notes

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.

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

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

$$K_c = \left[\frac{[HI_{(g)}]^2}{[H_{2(g)}][I_{2(g)}]}\right]$$

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)

$$H_2(g) + I_2(g) \leftrightarrows 2HI(g)$$

Molar Ratio	1	1	2
Initial n (in mol)	$\frac{5}{2} = 2.5$	3.0	0
Δn (in mol)	↓ 1.35	↓ 1.35	↑ 2.70
Equilibirum n (in mol)	1.15	1.65	2.70

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

Space for Personal Notes

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°C has a K_c value of 10.5 M^2. The reaction is occurring in a 4.5 L beaker.

$$3C_2H_6(g) + 4H_2S(g) \rightleftharpoons 2C_3S_2(g) + 10H_2(g)$$

a. At a given moment, 4.15 mol of C_2H_6, 3.15 mol of H_2S, 10.1 mol of C_3S_2 and 1.55 mol of hydrogen gas is present in the beaker.

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

As $K_c = 10.5\ M^2$, $10^{-4} < K_c < 10^4$ 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)

$$Q_c = \frac{[H_2]^{10}[C_3S_2]^2}{[H_2S]^4[C_2H_6]^3} = \frac{\left(\frac{1.55}{4.5}\right)^{10}\left(\frac{10.1}{4.5}\right)^2}{\left(\frac{3.15}{4.5}\right)^4\left(\frac{4.15}{4.5}\right)^3} = 6.29\times10^{-4}\ M^5$$

'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:

$$4C_3S_2(g) + 20H_2(g) \rightleftharpoons 6C_2H_6(g) + 8H_2S(g)$$

Predict the new K_c value. (1 mark)

$$K_{c(new)} = \frac{1}{10.5^2} = 9.07\times10^{-3}\ M^{-10}$$

b. In another trial at 80°C, 2.2 *mol* of C_2H_6, 1.55 *mol* of H_2S and 1.67 *mol* of H_2 is present in the beaker at equilibrium. Calculate the concentration of C_3S_2 present.

$K_c = 10.5$

$$\therefore 10.5 = \frac{[H_2]^{10}[C_3S_2]^2}{[H_2S]^4[C_2H_6]^3}$$

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

$[C_3S_2] = 18.7$ M

c. Radman sets up another experiment at 65°C. He adds 5.1 *mol* of C_2H_6, 2.15 *mol* of H_2S to the same, empty reaction vessel. After the system reaches equilibrium, he notes that only 1.05 *mol* of H_2S remains in the vessel. Calculate the K_c value for this system.

$$3C_2H_6(g) + 4H_2S(g) \rightleftharpoons 2C_3S_2(g) + 10H_2(g)$$

	C_2H_6	H_2S	C_3S_2	H_2
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

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

$= 0.043$ M^5

Space for Personal N

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:

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

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)

$$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$$

ii. Find the K_c value. (1 mark)

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

$= 2.5\ M^{-2}$

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.

$$K_c = \frac{[NH_3]^2}{[H_2]^3[N_2]}$$

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

$= 25.8\ M^{-2}$

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

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

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

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

$$= \frac{\left(\frac{1.5}{3}\right)^2}{\left(\frac{1.05}{3}\right)\left(\frac{2.1}{3}\right)}$$

$$= 1.0 \text{ (no units)}$$

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.

$$CH_3COOCH_3(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + CH_3OH(aq)$$

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

a. Calculate the K_c value. (2 marks)

$$K_c = \frac{[CH_3OH][CH_3COOH]}{[CH_3COOCH_3]}$$

$$= \frac{\left[\frac{3.25}{4}\right]\left[\frac{1.05}{4}\right]}{\left[\frac{3.5}{4}\right]}$$

$$= 0.24 \text{ M}$$

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

$$K_c = \frac{[CH_3OH][CH_3COOH]}{[CH_3COOCH_3]}$$

$$[CH_3OH] = \frac{5.5 \times \left(\frac{1.5}{3.125}\right)}{\left(\frac{2.2}{3.125}\right)}$$

$$= 3.75\ M$$

Question 19 (5 marks)

a. Lachlan is investigating the following reaction:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

In a 4.5 L vessel at equilibrium, the Kc value is 3.5 M^{-1} and there remains 2.5 mol of $SO_2(g)$ and 1.25 mol of $O_2(g)$ respectively. Find the concentration of sulphur trioxide ($SO_3(g)$). (2 marks)

$$K_c = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$

$$[SO_3] = \sqrt{3.5 \times \left[\frac{2.5}{4.5}\right]^2 \times \left(\frac{1.25}{4.5}\right)}$$

$$= 0.55\ M$$

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

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

In a 10.5 L vessel at equilibrium, the Kc value is 6.3 (no unit) and there remains 1.5 mol of $CO(g)$, 1.25 mol of $H_2O(g)$ and 2.125 mol of $H_2(g)$ respectively. Find the amount, in mol, of carbon dioxide ($CO_2(g)$). (3 marks)

$$Kc = \frac{[H_2][CO_2]}{[CO][H_2O]}$$

$$n(H_2) = \frac{6.3 \times \left(\frac{1.25}{10.5}\right) \times \left(\frac{1.5}{10.5}\right)}{\left(\frac{2.125}{10.5}\right)} \times 4.5$$

$= 2.38$ 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)

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

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

$$K_c = \frac{M^2}{[M^3][M]} = M^{-2}$$

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

$$K_c = \left(\frac{[NH_{3(g)}]^2}{[H_{2(g)}]^3[N_{2(g)}]}\right) M^{-2}$$

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)

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

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

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

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

$= 2.804$

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

Space for Personal Notes

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

Question 21 (3 marks)

Consider the following chemical reaction:

$$Fe^{3+}(aq) + SCH^{-}(aq) \rightleftharpoons FeSCH^{2+}(aq)$$

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

Large extent of reaction

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

Small extent of reaction

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

Medium extent of reaction

Question 22 (3 marks)

Brooke is experimenting with the following reaction.

$$CH_3COOH(aq) \rightleftharpoons CH_3COO^{-}(aq) + H^{+}(aq)$$

At equilibrium in a 10.5 L container, he finds 1.5 mol of CH_3COOH, 1.25 mol of CH_3COO^{-} and 10.5 mol of H^{+} ions.

a. Calculate the K_c value. (2 marks)

$$K_c = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$$

$$= \frac{\left(\frac{1.25}{10.5}\right) \times \left(\frac{10.5}{10.5}\right)}{\left(\frac{1.5}{10.5}\right)}$$

$$= 0.83\ M$$

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 (NO_2) remaining.

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

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 1.0×10^{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 M^{-1}.

$$NH_3(aq) + H^+(aq) \rightleftharpoons NH_4^+(aq)$$

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

Chemical Equation	K_c value at 25°C
a. $2NH_3(aq) + 2H^+(aq) \rightleftharpoons 2NH_4^+(aq)$	112 M^{-2}
b. $\frac{1}{2}NH_3(aq) + \frac{1}{2}H^+(aq) \rightleftharpoons \frac{1}{2}NH_4^+(aq)$	3.26 $M^{-\frac{1}{2}}$
c. $NH_4^+(aq) \rightleftharpoons NH_3(aq) + H^+(aq)$	0.094 M

Question 26 (3 marks)

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

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

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

Chemical Equation	K_c value at 25°C
a. $\frac{1}{2}C_2H_5OH(g) \rightleftharpoons \frac{1}{2}C_2H_4(g) + \frac{1}{2}H_2O(g)$	0.294 $M^{\frac{1}{2}}$
b. $2C_2H_5OH(g) \rightleftharpoons 2C_2H_4(g) + 2H_2O(g)$	7.4×10^{-3} M^2
c. $3C_2H_4(g) + 3H_2O(g) \rightleftharpoons 3C_2H_5OH(g)$	1561 M^{-3}

Question 27 (4 marks)

Consider the following equilibrium reaction:

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

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

$$K_c = \frac{[NO_2]^2}{[N_2O_4]}$$

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

i. $\frac{1}{2}N_2O_4(g) \rightleftharpoons NO_2(g)$. (1 mark)

$$\frac{1}{2}N_2O_4(g) \rightleftharpoons NO_2(g)$$

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

ii. $2N_2O_4(g) \rightleftharpoons 4NO_2(g)$. (1 mark)

$$2N_2O_4(g) \rightleftharpoons 4NO_2(g)$$

$$K_c = 50^2 = 2500\ M^2$$

iii. $2NO_2(g) \rightleftharpoons N_2O_4(g)$. (1 mark)

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

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

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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.

$$H_2S(g) \rightleftharpoons 2H^+(aq) + S^{2-}(aq)$$

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, $K_c = 0.1\ M$.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

She adds 2.0 mol of oxygen gas, 1.5 mol of $SO_2(g)$ and 2.25 mol of $SO_3(g)$. Calculate Q_c and hence predict the direction of the equilibrium shift.

$$Q_c = \frac{[O_2][SO_2]^2}{[SO_3]^2}$$

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

$$= 0.254$$

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:

$$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

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

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

For equilibrium to shift backward, $Q_c > K_c$

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

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

$$[SCN^-] < 0.166\ M$$

Less than 0.166 M of 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.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

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

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

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

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Question 32 (11 marks)

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

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

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

b. Clara conducts the experiment and finds that at equilibrium, 0.165 mol of NO remains.

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

$2NO_{(g)} + O_{2(g)} \rightleftharpoons 2NO_{2(g)}$

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

$n(NO_2) = 0.135$

$[NO_2] = \frac{0.135}{3} = 0.045$

$\approx 4.5 \times 10^{-2}$ M

ii. Find the equilibrium constant at 15°C. (2 marks)

$[O_2] = \frac{0.3325}{3} = 0.1108$

$[NO] = \frac{0.165}{3} = 0.055$

$K_c = \frac{[0.045]^2}{[0.055]^2[0.1108]}$

$K_c = 6.04\ M^{-1}$

c. Another student in Clara's class is conducting the same experiment under the same conditions (15°C, 3.0 L vessel). At one point during the chemical reaction, he notes that there is 0.251 mol of NO, 0.754 mol of O_2 and 1.230 mol of NO_2.

i. Find the reaction quotient. (2 marks)

$$Q_c = \frac{\left[\frac{1.23}{3}\right]^2}{\left[\frac{0.251}{3}\right]^2\left[\frac{0.754}{3}\right]}$$

$$= 95.5\ M^{-1}$$

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 $Q_c(95.5M^{-1}) > K_c(6.04M^{-1})$, 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)

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

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

i. Express the equilibrium expression. (1 mark)

$$K_c = \frac{[NH_3(g)]^2}{[H_2(g)]^3[N_2(g)]}$$

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

Let change of $N_{2(g)}$ be represented by 'x'

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

	$N_{2(g)}$	$3H_{2(g)}$	$2NH_{3(g)}$
Ratio	1	3	2
Initial	0.5	0.4	0
Change	x	3x	2x
Equilibrium	0.5−x	0.4−3x	2x

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

$\therefore x = 0.075$

$$[NH_3] = \frac{2 \times 0.075}{4} = 0.0375\ M$$

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

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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)

$H_{2(g)} + O_{2(g)} \rightleftharpoons 2H_2O_{2(l)}$

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

$K_c = \frac{[H_2O_2]^2}{[H_2][O_2]}$

$= \frac{[0.4]^2}{[0.3][0.5]}$

$= \frac{0.16}{0.15}$

$= 1.0667$

≈ 1.07 [NO UNITS]

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