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A' Level Chemistry

Year 2

Unit 12: Equilibrium & Kp

Summer Examination Revision Pack

The questions in this pack should be attempted **AFTER** completing all other revision.

Grade Accelerator

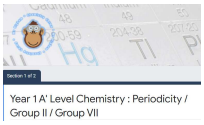
Recall Definitions
Drawing Diagrams
Using Equations
Drawing Graphs

Quizlet Classes

Flashcard Based
Games
Tests & Quizzes
Keyword Spell Checker

Condensed Notes

Keywords & Definitions
Key Concepts
Application
Key Skills



Online Forms

Take Time to Answer
Use Paper & Calculator
Work It Out
Review Missed Marks

Use the 3 Wave Process when completing these revision packs.

1. Complete the questions without assistance
(Can't answer a question? Leave it and move on)
2. Use your notes to fill any gaps after step 1
3. Use the mark scheme to fill in any remaining gaps.

1. Having gaps after step 1 is normal, that's why we are doing revision!
2. If your notes don't help during step 2, they are not good enough!
(Change your note taking method and try to understand the problem)
3. If you don't understand why the mark scheme answer is correct, **see Andy.**

If you struggle with the questions in the pack, **STOP!** and complete some more revision.

If you come to a complete dead-end, **STOP!** and speak to **Andy** asap.

0 9 There are several stages in the industrial production of methanol from methane.

0 9 . 1 The first stage involves a gaseous equilibrium between the reactants (methane and steam), and some gaseous products. **Figures 1** and **2** show the percentage conversion of methane into the gaseous products under different conditions at equilibrium.

Figure 1

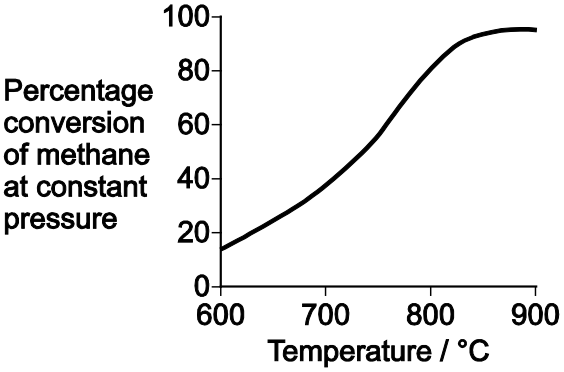
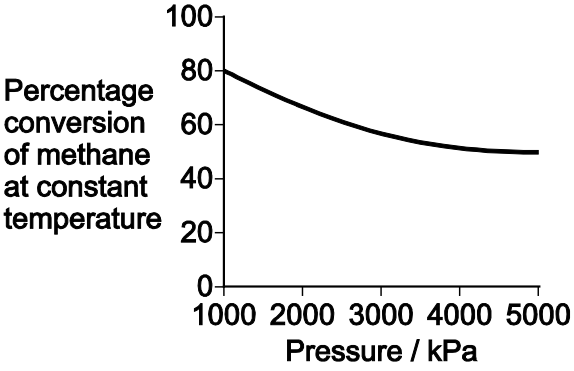


Figure 2



Deduce the optimum conditions for the industrial conversion of methane and steam into the gaseous products.

Explain your deductions.

[6 marks]

0 9 . 2 The equation shows the final stage in the production of methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

20.1 mol of carbon monoxide and 24.2 mol of hydrogen were placed in a sealed container. An equilibrium was established at 600 K. The equilibrium mixture contained 2.16 mol of methanol.

Calculate the amount, in moles, of carbon monoxide and of hydrogen in the equilibrium mixture.

[2 marks]

Amount of carbon monoxide _____ mol

Amount of hydrogen _____ mol

Question 9 continues on the next page

0 9 . 3 A different mixture of carbon monoxide and hydrogen was allowed to reach equilibrium at 600 K

At equilibrium, the mixture contained 2.76 mol of carbon monoxide, 4.51 mol of hydrogen and 0.360 mol of methanol. The total pressure was 630 kPa

Calculate a value for the equilibrium constant, K_p, for this reaction at 600 K and state its units.

[6 marks]

Value of K_p _____ Units _____

14

Question	Answers		Mark	Additional Comments/Guidance
09.1	This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.		6	**Indicative Chemistry content** **Stage 1: Deductions from graph** 1a Yield increases as temperature increases (or converse) 1b After a certain temperature yield no longer increases 1c Yield decreases as pressure increases (or converse) **Stage 2: Optimum temperature and explanation** 2a High temperature results in high energy costs/expensive 2b (After a certain temperature) yield no longer increases therefore there is no gain in using a higher temperature 2c Optimum temperature is between 780-880^{o}C **Stage 3: Optimum pressure and explanation** 3a Low pressure may be too slow 3b So compromise pressure required 3c Optimum pressure is 1000-2000kPa or moderate pressure used
	Level 3 5–6 marks	All stages are covered and the explanation of each stage is generally correct and virtually complete. To access Level 3, statement 3a must be considered. Answer is communicated coherently and shows a logical progression from stage 1 (including 1b) to stage 2 and stage 3		
	Level 2 3–4 marks	All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete. Answer is mainly coherent and shows progression from stage 1 to stage 2 and/or stage 3.		
	Level 1 1–2 marks	Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete. Answer includes isolated statements but these are presented in a logical order, with sensible reasoning.		

	Level 0 0 marks	Insufficient correct chemistry to gain a mark.		

Question	Answers	Mark	Additional Comments/Guidance
09.2	Moles of carbon monoxide 17.9 Moles of hydrogen 19.9	1 1	Allow 17.94 Allow 19.88
09.3	$K_p = \frac{pp(CH^3OH)}{pp(CO)\times pp(H_2)2}$ ignore brackets Total moles of gas = (2.76 + 4.51 + 0.36) = 7.63 $pp(CO) = \frac{2.76}{7.63}$ x 630 (kPa) (= 228 (kPa)) $pp(H_2) = \frac{4.51}{7.63}$ x 630 (kPa) (= 372 (kPa)) $pp(CH_3OH) = \frac{0.36}{7.63}$ x 630 (kPa) (= 29.7 (kPa)) $K_p = \frac{29.7}{228x(372)2}$ = 9.4(1) x 10^{-7} or 9.4(1) x 10^{-13} if *pp* in Pa can also score M1 from this expression $\underline{kPa^{-2}}$ or $\underline{Pa^{-2}}$ (if converted to 630 000)	1 1 2 1 1	If K_p expression incorrect can only score M2 & M3 & M4 If CE in M2 allow ecf for M3, M4 and M6 If no total moles calculated then can only score M1 and M6 All 3 pp of CO, H_2 and CH_3OH = 2 marks 2 pp correct = 1 mark Allow 9.39 to 9.50 x 10^{-7} (kPa^{-2}) If no marks awarded allow M6 only for $\underline{kPa^{-2}}$ or $\underline{Pa^{-2}}$
Total		**14**	

0 2 Nitrogen and hydrogen were mixed in a 1:3 mole ratio and left to reach equilibrium in a flask at a temperature of 550 K. The equation for the reaction between nitrogen and hydrogen is shown.

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

0 2 . 1 When equilibrium was reached, the total pressure in the flask was 150 kPa and the mole fraction of $NH_3(g)$ in the mixture was 0.80

Calculate the partial pressure of each gas in this equilibrium mixture.

[3 marks]

Partial pressure of nitrogen _____ kPa

Partial pressure of hydrogen _____ kPa

Partial pressure of ammonia _____ kPa

0 2 . 2 Give an expression for the equilibrium constant (K_p) for this reaction.

[1 mark]

K_p

0 2 . 3 In a different equilibrium mixture, under different conditions, the partial pressures of the gases are shown in **Table 2**.

Table 2

Gas	Partial pressure / kPa
N_2	1.20×10^2
H_2	1.50×10^2
NH_3	1.10×10^3

Calculate the value of the equilibrium constant (K_p) for this reaction and give its units.

[2 marks]

K_p _____ Units _____

0 2 . 4 The enthalpy change for the reaction is –92 kJ mol^{-1}

State the effect, if any, of an increase in temperature on the value of K_p for this reaction.
Justify your answer.

[3 marks]

Effect on K_p _____

Justification _____

_____

_____

_____

_____

9

Question	Answers	Additional Comments/Guidance	Mark
02.1	pp nitrogen = 0.25 x 30 = 7.5 kPa pp hydrogen = 0.75 x 30 = 22.5 or 23 kPa pp of ammonia = 0.8 x 150 = 120 kPa	(pp hydrogen + nitrogen = 150-120 = 30 kPa) Alternative method pp hydrogen = 0.15 x 150 = 22.5 or 23 kPa pp nitrogen = 0.05 x 150 = 7.5 kPa	1 1 1
02.2	$K_p = \frac{(ppNH_3)^2}{(ppN_2) \times (ppH_2)^3}$	Penalise [ ]	1
02.3	$K_p = \frac{(1.10 \times 10^3)^2}{(1.50 \times 10^2)^3 \times 1.20 \times 10^2}$ $= 0.0029$ to $0.003(0)$ or 2.9×10^{-3} to $3(.0) \times 10^{-3}$ kPa^{-2}	No mark for this expression If expression inverted in 02.2 allow 1 mark for kPa^2 Allow 2.9 to $3(.0) \times 10^{-9}$ Pa^{-2}	1 1
02.4	decreases/smaller/lower (Reaction/equilibrium) shifts/moves/goes in the endothermic direction (which is to the left) to reduce the temperature OR oppose the increase in temperature	If increase or no change, 0 marks If blank, mark on Allow reaction is exothermic so equilibrium moves to the left side	1 1 1
Total			9

Do not write outside the box

0 7 Sulfur trioxide decomposes on heating to form an equilibrium mixture containing sulfur dioxide and oxygen.

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

0 7 . 1 A sample of sulfur trioxide was heated and allowed to reach equilibrium at a given temperature.
The equilibrium mixture contained 6.08 g of sulfur dioxide.

Calculate the mass, in g, of oxygen gas in the equilibrium mixture.

[2 marks]

Mass _____ g

Question 7 continues on the next page

Do not write outside the box

0 7 . 2 A different mass of sulfur trioxide was heated and allowed to reach equilibrium at 1050 K

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

The amounts of each substance in the equilibrium mixture are shown in **Table 4**.

Table 4

Substance	**Amount at equilibrium / mol**
sulfur trioxide	0.320
sulfur dioxide	1.20
oxygen	0.600

For this reaction at 1050 K the equilibrium constant, $K_p = 7.62 \times 10^5$ Pa

Calculate the mole fraction of each substance at equilibrium.
Give the expression for the equilibrium constant, K_p
Calculate the total pressure, in Pa, of this equilibrium mixture.

[4 marks]

Mole fraction SO_3 _____

Mole fraction SO_2 _____

Mole fraction O_2 _____

K_p

Total pressure _____ Pa

Do not write outside the box

0 7 . 3 For this reaction at 1050 K the equilibrium constant, K_p = 7.62 x 10^5 Pa
For this reaction at 500 K the equilibrium constant, K_p = 3.94 x 10^4 Pa

Explain how this information can be used to deduce that the forward reaction is endothermic.

[2 marks]

0 7 . 4 Use data from Question **07.3** to calculate the value of K_p, at 500 K, for the equilibrium represented by this equation.
Deduce the units of K_p

$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g)$$

[2 marks]

K_p _____

Units _____

10

Turn over for the next question

Question	Answers	Additional Comments/Guidelines	Mark
07.1	Moles SO_2 eqbm (=6.08/64.1 = 0.0949) so moles O_2 eqbm = 0.0474 Mass of oxygen (= 0.0474 x 32(.0)) = 1.52 g	Allow 0.0475 Allow M1 x 32	1 1
07.2	M1: Mole fraction SO_3 = 0.15 Mole fraction SO_2 = 0.57 Mole fraction O_2 = 0.28 M2: $K_p = \frac{(pSO_2)^2 \times (pO_2)}{(pSO_3)^2}$ (= $\frac{(\lambda SO_2)^2 P^2 \times (\lambda O_2) P}{(\lambda SO_3)^2 P^2}$) M3: $P = \frac{K_p \times (\lambda SO_3)^2}{(\lambda SO_2)^2 \times (\lambda O_2)}$ or $\frac{K_p \times (0.15)^2}{(0.57)^2 \times (0.28)}$ M4 P = 1.91 x 10^5 (Pa) Allow range 1.88 x 10^5 to 1.94 x 10^5	Accept fractions for M1 Do not accept [ ] λ = mole fraction M3 is for rearrangement with or without numbers If incorrect rearrangement allow correct M1 and M2 only	1 1 1 1
07.3	M1 Kp is higher at higher temperature or converse M2 At higher temperature more dissociation occurs / more products are formed / equilibrium shifts to the right/forward direction	 M2: Allow converse arguments M2 dependent on M1.	1 1
07.4	($\sqrt{}$3.94 x 10^4 Pa) = 198.5 $Pa^{1/2}$ or $Pa^{0.5}$	Allow 198 – 198.5 (answer is 198.49) If $\sqrt{}$7.62 x 10^5 = 873 then lose M1 but allow M2	1 1

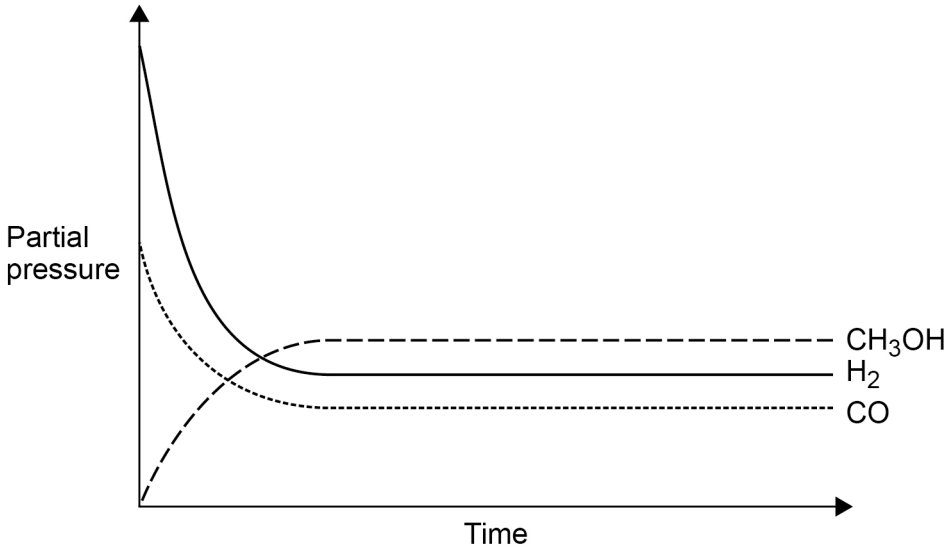
Do not write outside the box

0 6 Methanol can be manufactured in a reversible reaction as shown.

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$$

Figure 3 shows how the partial pressures change with time at a constant temperature.

Figure 3



0 6 . 1 Draw a cross (x) on the appropriate axis of **Figure 3** when the mixture reaches equilibrium.

[1 mark]

0 6 . 2 A 0.230 mol sample of carbon monoxide is mixed with hydrogen in a 1:2 mol ratio and allowed to reach equilibrium in a sealed flask at temperature *T*.
At equilibrium the mixture contains 0.120 mol of carbon monoxide.
The total pressure of this mixture is 1.04×10^4 kPa

Calculate the partial pressure, in kPa, of hydrogen in the equilibrium mixture.

[4 marks]

Partial pressure of hydrogen _____ kPa

Do not write outside the box

0 6 . 3 Give an expression for the equilibrium constant (K_p) for this reaction.

State the units.

[2 marks]

K_p

Units _____

0 6 . 4 Some more carbon monoxide is added to the mixture in Question **06.2**. The new mixture is allowed to reach equilibrium at temperature *T*.

State the effect, if any, on the partial pressure of methanol and on the value of K_p

[2 marks]

Effect on partial pressure of methanol _____

Effect on value of K_p _____

0 6 . 5 State the effect, if any, of the addition of a catalyst on the value of K_p for this equilibrium.
Explain your answer.

[2 marks]

Effect on value of K_p _____

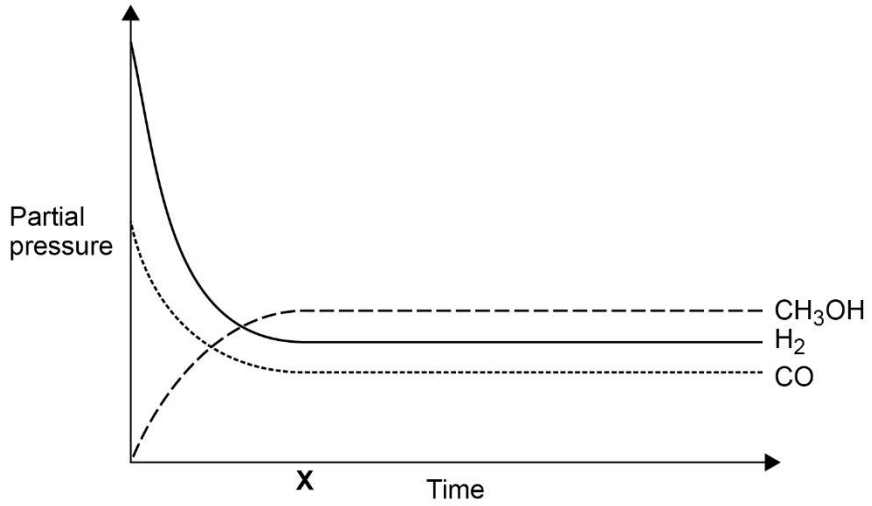
Explanation _____

_____

_____

11

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark
06.1		X must be on or just below line of x axis	1
06.2	M1 Equilibrium $n(H_2) = \underline{0.24}$ M2 Total number of moles = $\underline{0.47}$ M3 Mole fraction of H_2 = 0.51(1) or $\frac{\underline{0.24}}{0.47}$ M4 Partial pressure of hydrogen = 5310 or 5.31×10^3 kPa	M3 Allow mole fraction of $H_2 = \frac{\underline{M1}}{M2}$ M4 Allow Partial pressure of hydrogen = M3 $\underline{\times 1.04 \times 10^4}$	1 1 1 1

06.3	M1 K_p = $\frac{ppCH_3OH}{ppH_2^2 \times ppCO}$ OR $\frac{pCH_3OH}{pH_2^2 \times pCO}$ Pa^{-2} or kPa^{-2}	Do not allow square brackets Allow any pressure to power of $^{-2}$	1 1
06.4	M1 Increases M2 No effect		1 1
06.5	M1 No effect M2 Increases <u>rate</u> of forward and backward reaction equally/by the same amount OR catalyst does not affect position of equilibrium	M2 Allow Catalyst does not appear in the K_p expression M2 Allow Only temperature affects Kp Ignore Catalysts increase the rate of reaction or rate at which equilibrium is reached	1 1

0 5 Ethanoic acid and ethane-1,2-diol react together to form the diester ($C_6H_{10}O_4$) as shown.

$$2CH_3COOH(l) + HOCH_2CH_2OH(l) \rightleftharpoons C_6H_{10}O_4(l) + 2H_2O(l)$$

0 5 . 1 Draw a structural formula for the diester $C_6H_{10}O_4$

[1 mark]

0 5 . 2 A small amount of catalyst was added to a mixture of 0.470 mol of ethanoic acid and 0.205 mol of ethane-1,2-diol.

The mixture was left to reach equilibrium at a constant temperature.

Complete **Table 1**.

Table 1

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At the start	0.470	0.205	0	0
At equilibrium	0.180			

[3 marks]

Space for working

0 5 . 3 Write an expression for the equilibrium constant, K_c, for the reaction.

The total volume of the mixture does not need to be measured to allow a correct value for K_c to be calculated.

Justify this statement.

[2 marks]

Expression

Justification _____

0 5 . 4 A different mixture of ethanoic acid, ethane-1,2-diol and water was prepared and left to reach equilibrium at a different temperature from the experiment in Question **5.2**

The amounts present in the new equilibrium mixture are shown in **Table 2**.

Table 2

Amount in the mixture / mol				
	CH_3COOH	$HOCH_2CH_2OH$	$C_6H_{10}O_4$	H_2O
At new equilibrium	To be calculated	0.264	0.802	1.15

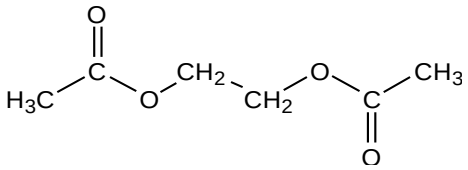
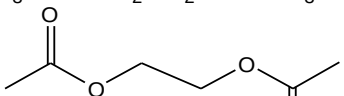
The value of K_c was 6.45 at this different temperature.

Use this value and the data in **Table 2** to calculate the amount, in mol, of ethanoic acid present in the new equilibrium mixture.
Give your answer to the appropriate number of significant figures.

[3 marks]

Amount of ethanoic acid _____ mol

9

Question	Answers	Mark	Additional Comments/Guidance
05.1		1	Allow $CH_3COOCH_2CH_2OOCCH_3$ OR $CH_3COOCH_2CH_2OCOCH_3$  OR
05.2	Mol $HOCH_2CH_2OH$ = 6.00×10^{-2} OR 0.06(00) Mol $C_6H_{10}O_4$ = 1.45×10^{-1} OR 0.145 Mol H_2O = 2.90×10^{-1} OR 0.29(0)	1 1 1	

05.3	$(K_c =)\ \dfrac{[\text{ester}]\times[H_2O]^2}{[CH_3COOH]^2\times[HOCH_2CH_2OH]}$ The volume cancels out (Penalise a contradictory justification from expression if the volumes do not cancel out) OR there are <u>equal no of moles on each side of the equation</u> OR there are <u>equal no of molecules on each side of the equation</u>	1 1	Allow words for acid and alcohol

05.4	(Mol $CH_3COOH/V)^2$ = $\dfrac{(8.02\times10^{-1}/V)(1.15/V)^2}{6.45\times(2.64\times10^{-1}/V)}$ Mol CH_3COOH = $\sqrt{\dfrac{(8.02\times10^{-1})\times(1.15)^2}{6.45\times(2.64\times10^{-1})}}$ = $\sqrt{0.623}$ Mol CH_3COOH = 0.789 (<u>must be 3 sfs</u>) Allow 0.788 – 0.790	M1 M2 M3	0.789 scores 3 Allow without V : $(nCH_3COOH)^2$ = $\dfrac{(8.02\times10^{-1})(1.15)^2}{6.45\times(2.64\times10^{-1})}$ If $(nCH_3COOH)^2$ =0.623 then award M1 and M2 If Kc is correct in 05.3 but incorrect rearrangement, then CE=0 except if upside down rearrangement then M3 only awarded for 1.27 If Kc is incorrect in 05.3 then only M1 can be awarded for correct rearrangement.

Total		**9**	

0 4 Compounds **A** and **B** react together to form an equilibrium mixture containing compounds **C** and **D** according to the equation

$$2\mathbf{A} + \mathbf{B} \rightleftharpoons 3\mathbf{C} + \mathbf{D}$$

0 4 . 1 A beaker contained 40 cm^3 of a 0.16 mol dm^{-3} aqueous solution of **A**.
9.5×10^{-3} mol of **B** and 2.8×10^{-2} mol of **C** were added to the beaker and the mixture was left to reach equilibrium.
The equilibrium mixture formed contained 3.9×10^{-3} mol of **A**.

Calculate the amounts, in moles, of **B**, **C** and **D** in the equilibrium mixture.

[5 marks]

Amount of **B** _____ mol

Amount of **C** _____ mol

Amount of **D** _____ mol

0 4 . 2 Give the expression for the equilibrium constant (K_c) for this equilibrium **and** its units.

[2 marks]

K_c

Units _____

0 4 . 3 A different equilibrium mixture of these four compounds, at a different temperature, contained 0.21 mol of **B**, 1.05 mol of **C** and 0.076 mol of **D** in a total volume of 5.00×10^2 cm^3 of solution.
At this temperature the numerical value of K_c was 116

Calculate the concentration of **A**, in mol dm^{-3}, in this equilibrium mixture.
Give your answer to the appropriate number of significant figures.

[3 marks]

Concentration of **A** _____ mol dm^{-3}

0 4 . 4 Justify the statement that adding more water to the equilibrium mixture in Question **04.3** will lower the amount of **A** in the mixture.

[3 marks]

_____

_____

_____

_____

_____

_____

_____

13

Turn over ►

Question	Answers	Mark	Additional Comments/Guidance
04.1	Initial amount of A = 6.4×10^{-3} Equ A = $6.4 \times 10^{-3} - 2x$ ∴ $x = 1.25 \times 10^{-3}$ B = $9.5 \times 10^{-3} - x = 8.25 \times 10^{-3}$ C = $2.8 \times 10^{-2} + 3x = 0.0318$ D = $x = 1.25 \times 10^{-3}$	M1 M2 M3 M4 M5	If M1 wrong can score max 3 If incorrect x can score max 3 Allow 2 or more sig figs
04.2	$K_c = \frac{[C]^3[D]}{[A]^2[B]}$ Units = mol dm^{-3}	1 1	Penalise ( ) but mark on in 4.2 & 4.3 If K_c wrong no mark for units
04.3 Can see 4.2	M1 for correct rearrangement $[A]^2 = \frac{[C]^3[D]}{K_c[B]}$ or $[A] = \sqrt{\frac{[C]^3[D]}{K_c[B]}}$ M2 for division of mol of B, C and D by correct volume $[A]^2 = \frac{[1.05/0.5]^3[0.076/0.5]}{116 \times [0.21/0.5]}$ or 0.0289 or 0.0290 M3 for final answer: [A] = <u>0.17</u> (must be 2 sfs)	M1 M2 M3	If K_c wrong in 4.2 can score 1 for dividing by correct volume If K_c correct but incorrect rearrangement can score 1 for dividing by correct volume
04.4	(All) conc fall: (ignore dilution) Equm moves to side with more moles To oppose the decrease in conc	1 1 1	OR K_c = mole ratio × 1/V If vol increases, mole ratio must increase To keep K_c constant If only conc of A falls CE=0 If pressure falls CE=0
Total		13	

Do not write outside the box

0 9 **A** and **B** react together to form an equilibrium mixture.

$$A(aq) + 2B(aq) \rightleftharpoons C(aq)$$

An aqueous solution containing 0.25 mol of **A** is added to an aqueous solution containing 0.25 mol of **B**.

When equilibrium is reached, the mixture contains 0.015 mol of **C**.

0 9 . 1 Calculate the amount of **A** and the amount of **B**, in moles, in the equilibrium mixture.

[2 marks]

Amount of **A** _____ mol

Amount of **B** _____ mol

0 9 . 2 At a different temperature, another equilibrium mixture contains 0.30 mol of **A**, 0.25 mol of **B** and 0.020 mol of **C** in 350 cm^3 of solution.

Calculate the value of the equilibrium constant K_c

Deduce the units of K_c

[4 marks]

K_c _____

Units _____

Turn over ►

Do not write outside the box

When an excess of water is added to chloroethanal, an equilibrium mixture is formed.

$$ClCH_2CHO(aq) + H_2O(l) \rightleftharpoons ClCH_2CH(OH)_2(aq)$$

An expression for an equilibrium constant (K) for the reaction under these conditions is

$$K = \frac{[ClCH_2CH(OH)_2]}{[ClCH_2CHO]}$$

0 9 . 3 Suggest why an expression for K can be written without the concentration of water.

[1 mark]

0 9 . 4 Distilled water is added to 4.71 g of chloroethanal (M_r = 78.5) to make 50.0 cm^3 of solution. The mixture is allowed to reach equilibrium.

The value of the equilibrium constant (K) is 37.0

Calculate the equilibrium concentration, in mol dm^{-3}, of $ClCH_2CH(OH)_2$

[5 marks]

Concentration _____ mol dm^{-3}

Question	Answers	Additional comments/Guidelines	Mark
09.1	**M1** EQM amount A = 0.25 – 0.015 = 0.235 mol **M2** EQM amount B = 0.25 – (2 x 0.015) = 0.22 mol	Allow 0.24 mol for M1	1 1
09.2	**M1** $K_c = \frac{[C]}{[A][B]^2}$		1
	M2 $\frac{\frac{0.02}{0.35}}{\frac{0.30}{0.35} \times \left(\frac{0.25}{0.35}\right)^2}$	Correct insertion of numbers and use of volume Allow ecf from their K_c Scores M1 here (even if volume not used)	1
	M3 = 0.13 **M4** Units $mol^{-2}\ dm^6$	Kc = 1.067 if vol not used Max 3 Kc = 7.63 if expression upside down Max 3 Allow answers using cm^3 and then the corresponding units i.e. $1.31 \times 10^5\ mol^{-2}\ cm^6$ Allow conseq units to wrong K_c	1 1
09.3	$[H_2O]$ / conc of water is (effectively) constant (because it it so much larger than the other concentrations)		1

09.4	**M1** Initial amount $ClCH_2CHO = {}^{4.71}/_{78.5} = 0.06$ mol **M2** EQM amount $ClCH_2CHO = (0.06 - x)$ mol EQM amount $ClCH_2CH(OH)_2 = x$ mol	Calculates initial mol Sets up algebraic expressions for EQM mol of both If no M2 can only score M3 and M5 conseq leads to 44.4 mol dm^{-3} via $[ClCH_2CHO] = \frac{0.06}{0.05}$	1 1
	M3 $37 = \frac{\frac{x}{V}}{\frac{(0.06-x)}{V}}$	Inserts into *K* Does not need to show V as it cancels but allow expressions that do show V and subsequent calculations	1
	M4 $37(0.06 - x) = x$ $2.22 = 38x$ $x = 0.058421$ **M5** $[ClCH_2CH(OH)_2] = \frac{0.058421}{0.05} = 1.17$ mol dm^{-3}	Solve for x Calculate concentration	1 1

Do not write outside the box

0 5 This question is about the equilibrium

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

0 5 . 1 State and explain the effect, if any, of a decrease in overall pressure on the equilibrium yield of SO_3

[3 marks]

Effect _____

Explanation _____

_____

_____

0 5 . 2 A 0.460 mol sample of SO_2 is mixed with a 0.250 mol sample of O_2 in a sealed container at a constant temperature.
When equilibrium is reached at a pressure of 215 kPa, the mixture contains 0.180 mol of SO_3

Calculate the partial pressure, in kPa, of SO_2 in this equilibrium mixture.

[4 marks]

Partial pressure of SO_2 _____ kPa

Do not write outside the box

Question 5 continues on the next page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

0 5 . 3 A different mixture of SO_2 and O_2 reaches equilibrium at a different temperature.

Table 4 shows the partial pressures of the gases at equilibrium.

Table 4

Gas	Partial pressure / kPa
SO_2	1.67×10^2
O_2	1.02×10^2
SO_3	1.85×10^2

Give an expression for the equilibrium constant (K_p) for this reaction.

Calculate the value of the equilibrium constant for this reaction and give its units.

[3 marks]

K_p

K_p _____

Units _____

Do not write outside the box

0 5 . 4 What is the effect on the value of K_p if the pressure of this equilibrium mixture is increased at a constant temperature?

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

[1 mark]

Tick (✓) **one** box.

The value of K_p

increases. ☐

stays the same. ☐

decreases. ☐

11

Turn over for the next question

Question	Answers	Additional comments/Guidelines	Mark
05.1	M1 decreases yield M2 So equilibrium shifts to side with more moles/molecules or more moles/molecules on LHS M3 So equilibrium shifts (to left side) to oppose decrease in pressure **OR** to increase pressure	 Allow M2 independent of M1 Must refer to equilibrium shifting to gain maximum marks	1 1 1

Question	Answers	Additional comments/Guidelines	Mark
05.2	M1 amount SO_2 (= 0.46 – 0.18) = 0.28 mol M2 amount O_2 (= 0.25 – 0.09) = 0.16 mol M3 total amount (= 0.28 + 0.16 + 0.18) = 0.62 mol M4 partial pressure of SO_2 = $\frac{0.28}{0.62}$ x 215 = 97(.1) (kPa)	 M4 = $\frac{M1}{M3}$ x 215	1 1 1 1

Question	Answers	Additional comments/Guidelines	Mark
05.3	M1 K_p = $\frac{(pp\ SO_3)^2}{(pp\ SO_2)^2 \times pp\ O_2}$ M2 = $1.2(0) \times 10^{-2}$ M3 = kPa^{-1}	Penalise square brackets in M1	1 1 1

Question	Answers	Additional comments/Guidelines	Mark
05.4	Stays the same		1

Answer **all** questions in the spaces provided.

Do not write outside the box

0 1 This question is about equilibria.

0 1 . 1 Give **two** features of a reaction in dynamic equilibrium.

[2 marks]

Feature 1 _____

_____

Feature 2 _____

_____

0 1 . 2 A gas-phase reaction is at equilibrium.
When the pressure is increased the yield of product decreases.

State what can be deduced about the chemical equation for this equilibrium.

[1 mark]

_____

_____

Question 1 continues on the next page

Do not write outside the box

0 1 . 3 Carbon monoxide and hydrogen react to form methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

0.430 mol of carbon monoxide is mixed with 0.860 mol of hydrogen.
At equilibrium, the total pressure in the flask is 250 kPa and the mixture contains 0.110 mol of methanol.

Calculate the amount, in moles, of carbon monoxide present at equilibrium.

Calculate the partial pressure, in kPa, of carbon monoxide in this equilibrium mixture.

[3 marks]

Amount of carbon monoxide _____ mol

Partial pressure _____ kPa

0 1 . 4 Give an expression for the equilibrium constant (K_p) for this reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

[1 mark]

K_p

Do not write outside the box

0 1 . 5 A different mixture of carbon monoxide and hydrogen is left to reach equilibrium at a temperature *T*.

Some data for this equilibrium are shown in **Table 1**.

Table 1

Partial pressure of CO	125 kPa
Partial pressure of CH_3OH	5.45 kPa
K_p	1.15×10^{-6} kPa^{-2}

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Calculate the partial pressure, in kPa, of hydrogen in this equilibrium mixture.

[3 marks]

Partial pressure _____ kPa

0 1 . 6 Use the K_p value from **Table 1** to calculate a value for K_p for the following reaction at temperature *T*.

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

Give the units for K_p

[2 marks]

K_p _____

Units _____

12

Turn over ►

Question	Answers	Additional Comments/Guidelines	Mark
01.1	forward and reverse reactions proceed at equal <u>rates</u>	allow answers in either order	1
	concentrations (of reactants and products) remain constant **or** concentrations (of reactants and products) stay the same	do **not** accept equal concentrations do **not** accept concentrations are the same ignore closed system	1 AO1

Question	Answers	Additional Comments/Guidelines	Mark
01.2	more moles of (gaseous) products (than (gaseous) reactants) **or** more moles on the RHS (than LHS)	allow molecules do **not** accept atoms	1 AO3

Question	Answers	Additional Comments/Guidelines	Mark
01.3	M1 (at equilibrium) n(CO) = 0.32 (mol) M2 total number of moles (at equilibrium) = 1.07 (mol) **or** mole fraction (CO) = 0.299 M3 p(CO) $\left(= \frac{0.320 \times 250}{1.07} \right)$ = 74.8 (kPa)	M3 = $\frac{M1 \times 250}{M2}$ allow 75 (kPa) an answer of 67.8 (kPa) = **2** marks max	1 1 1 AO2

Question	Answers	Additional Comments/Guidelines	Mark
01.4	$K_p = \frac{p(CH_3OH)}{p(H_2)^2\, p(CO)}$	do **not** accept square brackets	1 AO1

Question	Answers	Additional Comments/Guidelines	Mark
01.5	M1 $p(H_2)^2 = \frac{p(CH_3OH)}{K_p \times p(CO)}$ **or** $\frac{5.45}{1.15 \times 10^{-6} \times 125}$	rearrangement with or without numbers	1
	M2 $p(H_2) = \sqrt{37\,913}$ **or** $p(H_2)^2 = 37\,913$		1
	M3 $p(H_2) = 194.7$ (kPa)	M3 = $\sqrt{M2}$ allow 195 (kPa) if rearrangement incorrect in M1 allow M3 only if $p(H_2)$ is not squared in Question **01.4** allow $p(H_2) = \frac{p(CH_3OH)}{K_p \times p(CO)}$ for M1 and 37 913 for M2 (max **2**)	1 AO2

Question	Answers	Additional Comments/Guidelines	Mark
01.6	$= \left(\frac{1}{1.15 \times 10^{-6}} \right) = 8.7(0) \times 10^5$	allow 869 565	1
	kPa^2		1 AO2

Do not write outside the box

0 5 This question is about equilibrium.

0 5 . 1 1 mol of a diester with molecular formula $C_7H_{12}O_4$ is added to 1 mol of water in the presence of a small amount of catalyst.
The mixture is left to reach equilibrium at a constant temperature.

$$C_7H_{12}O_4(l) + 2\,H_2O(l) \rightleftharpoons 2\,CH_3COOH(l) + HO(CH_2)_3OH(l)$$

At equilibrium, x mol of ethanoic acid are present in the mixture.

Complete **Table 2** by deducing the amounts, in terms of x, of the diester, water and diol present in the equilibrium mixture.

[3 marks]

Table 2

	Amount in the mixture / mol			
	Diester	**Water**	**Acid**	**Diol**
At the start	1	1	0	0
At equilibrium			x	

0 5 . 2 Deduce the structure of the diester in Question **05.1**

[1 mark]

Question 5 continues on the next page

Turn over ►

Do not write outside the box

0 5 . 3 A new equilibrium mixture of the substances from Question **05.1** is prepared at a different temperature.

$$C_7H_{12}O_4(l) + 2\,H_2O(l) \rightleftharpoons 2\,CH_3COOH(l) + HO(CH_2)_3OH(l)$$

Table 3 shows the amount of each substance in this new equilibrium mixture.

Table 3

Amount in the mixture / mol				
	Diester	**Water**	**Acid**	**Diol**
At equilibrium	0.971	To be calculated	0.452	0.273

The value of the equilibrium constant, K_c is 0.161 at this temperature.

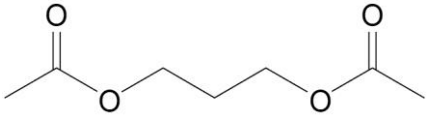
Calculate the amount of water, in mol, in this new equilibrium mixture.
Show your working.

[3 marks]

Amount of water _____ mol

7

Question	Answers	Additional Comments/Guidelines	Mark
05.1	Amount Diester = 1 - $\frac{x}{2}$ Amount Water = 1- x Amount Diol = $\frac{x}{2}$		M1 M2 M3

Question	Answers	Additional Comments/Guidelines	Mark
05.2		Allow other versions of the structure (abbreviated or displayed)	1

Question	Answers	Additional Comments/Guidelines	Mark
05.3	K_c = $\frac{0.452^2 \times 0.273}{0.971 \times (\text{amount } H_2O)^2}$ or $\frac{[\text{acid}]^2 \times [\text{diol}]}{[\text{diester}] \times [H_2O]^2}$ (Amount $H_2O)^2$ = $\frac{0.452^2 \times 0.273}{0.161 \times 0.971}$ or $\frac{[\text{acid}]^2 \times [\text{diol}]}{[\text{diester}] \times K_c}$ = (0.357) Amount H_2O = $\sqrt{0.357}$ = 0.597 mol	**OR** $K_c = \frac{\left(\frac{0.452}{V}\right)^2 \times \left(\frac{0.273}{V}\right)}{\left(\frac{0.971}{V}\right)\left(\frac{amount\ H2O}{V}\right)^2}$	M1 M2 M3

Do not write outside the box

0 2 Tetrafluoroethene is made from chlorodifluoromethane in this reversible reaction.

$$2\,CHClF_2(g) \rightleftharpoons C_2F_4(g) + 2\,HCl(g) \qquad \Delta H = +128\ kJ\ mol^{-1}$$

A 2.00 mol sample of $CHClF_2$ is placed in a container of volume 23.2 dm^3 and heated. When equilibrium is reached, the mixture contains 0.270 mol of $CHClF_2$

0 2 . 1 Calculate the amount, in moles, of C_2F_4 and of HCl in the equilibrium mixture.

[2 marks]

Amount of C_2F_4 _____ mol

Amount of HCl _____ mol

0 2 . 2 Give an expression for K_c for this equilibrium.

[1 mark]

K_c

Do not write outside the box

0 2 . 3 Calculate a value for K_c

Give its units.

[3 marks]

K_c _____ Units _____

0 2 . 4 State and explain the effect of using a higher temperature on the equilibrium yield of tetrafluoroethene.

[3 marks]

Effect on yield _____

Explanation _____

_____

_____

_____

_____

Question 2 continues on the next page

Do not write outside the box

0 2 . 5 Chemists provided evidence that was used to support a ban on the use of chlorodifluoromethane as a refrigerant.

Many refrigerators now use pentane as a refrigerant.

State the environmental problem that chlorodifluoromethane can cause.

Give **one** reason why pentane does not cause this problem.

[2 marks]

Environmental problem _____

_____

Reason why pentane does not cause this problem _____

_____

_____

_____

11

Question	Answers	Additional Comments/Guidelines	Mark
02.1	C_2F_4 = 0.865 mol HCl = 1.73 mol	Award 1 mark if HCl = 2 × C_2F_4	M1 M2 (2 x AO2)

Question	Answers	Additional Comments/Guidelines	Mark
02.2	$K_c = \frac{[C_2F_4]\,[HCl]^2}{[CHClF_2]^2}$	Penalise round brackets	1 (AO2)

Question	Answers	Additional Comments/Guidelines	Mark
02.3	$K_c = \frac{[0.865/23.2][1.73/23.2]^2}{[0.27/23.2]^2}$	Allow ecf for use of their answer(s) to Q2.1 and Q2.2 M1 for dividing by volume	M1
	K_c = 1.5(3) must be at least 2sf Allow 1.53-1.54 Units = mol dm^{-3}	If no use of volume allow M2 for 35.5 If upside down can allow all 3 marks as ECF to Q2.2 Leads to an answer of 0.65(3) $mol^{-1}dm^3$	M2 M3 (3 x AO2)

Question	Answers	Additional Comments/Guidelines	Mark
02.4	Yield would increase Equilibrium opposes temperature increase Moves in the endothermic direction	 Shifts /moves to reduce temperature Ignore favours	M1 M2 M3 (3 x AO2)

Question	Answers	Additional Comments/Guidelines	Mark
02.5	Causes ozone depletion/decomposition/damage Pentane does not have C-Cl bonds	Accept hole in the ozone layer Accept does not produce Cl radicals Accept does not contain chlorine	M1 M2 (2 x AO1)