4 Colourless solutions of **X**(aq) and **Y**(aq) react to form an orange solution of **Z**(aq) according to the following equation.

$$\mathbf{X}(aq) + 2\mathbf{Y}(aq) \rightleftharpoons \mathbf{Z}(aq) \qquad \Delta H = -20 \text{ kJ mol}^{-1}$$

A student added a solution containing 0.50 mol of **X**(aq) to a solution containing 0.50 mol of **Y**(aq) and shook the mixture.
After 30 seconds, there was no further change in colour.
The amount of **Z**(aq) at equilibrium was 0.20 mol.

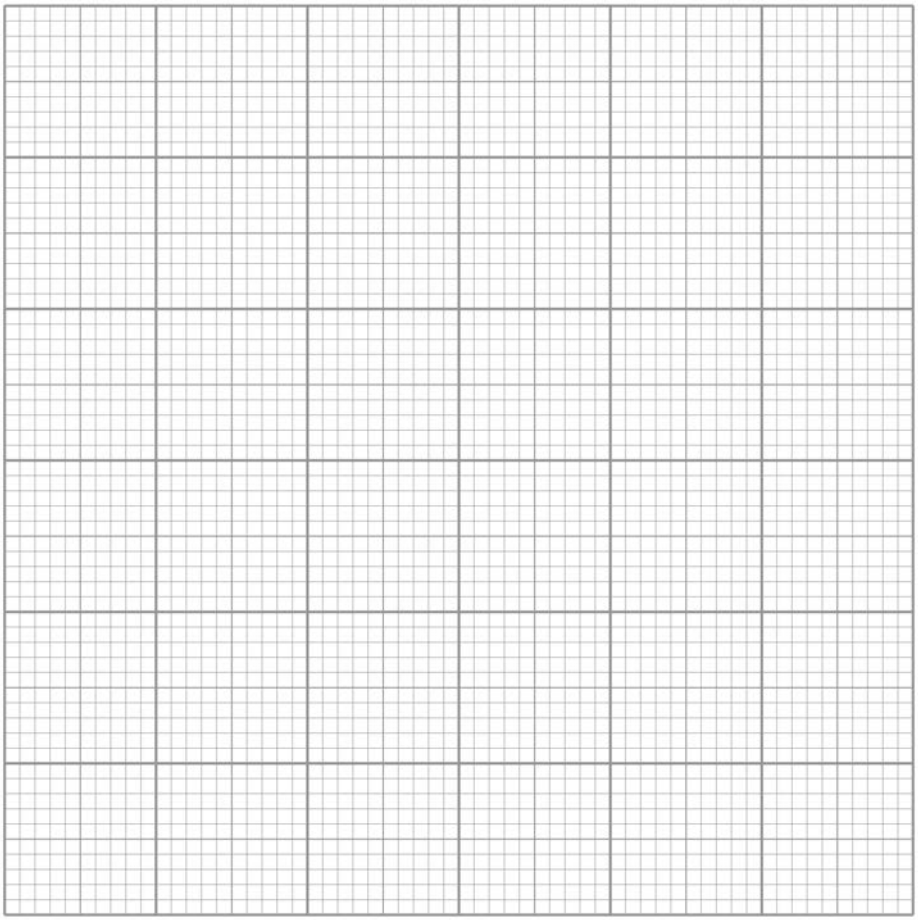
0 4 . 1 Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

[2 marks]

Amount of **X**(aq) =_____mol Amount of **Y**(aq) =_____mol

0 4 . 2 On the grid below, draw a graph to show how the amount of **Z**(aq) changed from the time of initial mixing until 60 seconds had elapsed.

[3 marks]



0 4 . 3 The student prepared another equilibrium mixture in which the equilibrium concentrations of **X** and **Z** were:
X(aq) = 0.40 mol dm^{-3} and **Z**(aq) = 0.35 mol dm^{-3}.

For this reaction, the equilibrium constant K_c = 2.9 mol^{-2} dm^6.
Calculate a value for the concentration of **Y** at equilibrium.
Give your answer to the appropriate number of significant figures.

[3 marks]

[**Y**] = _____ mol dm^{-3}

0 4 . 4 The student added a few drops of **Y**(aq) to the equilibrium mixture of **X**(aq), **Y**(aq) and **Z**(aq) in Question **4.3**.

Suggest how the colour of the mixture changed. Give a reason for your answer.

[3 marks]

Colour change _____

Reason _____

_____

_____

_____

0 4 . 5 The student warmed the equilibrium mixture from Question **4.3**.

Predict the colour change, if any, when the equilibrium mixture was warmed.

[1 mark]

_____

_____

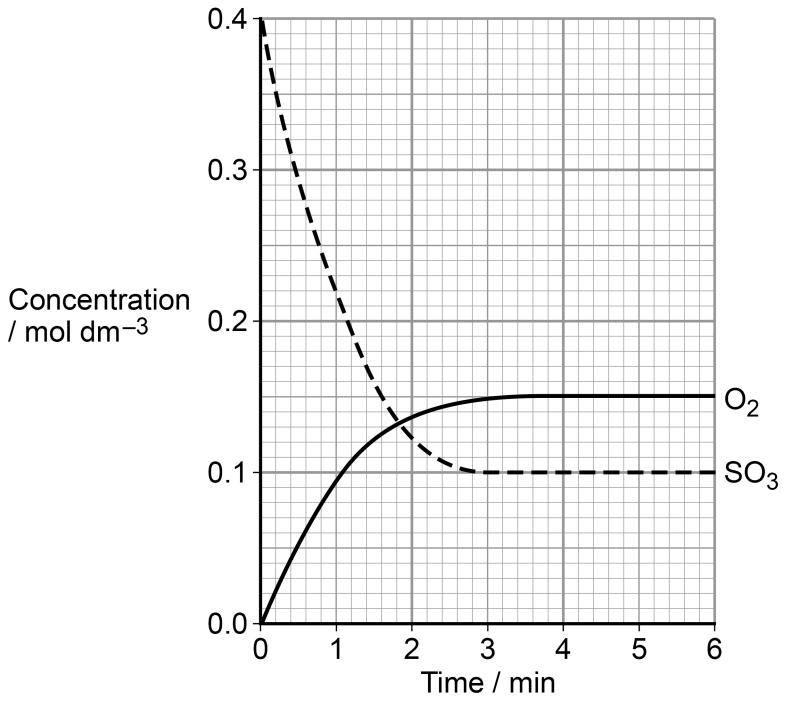
0 5 This question is about equilibrium.

Sulfur trioxide decomposes to form sulfur dioxide and oxygen at temperature T_1 according to the equilibrium shown.

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g) \qquad \Delta H = +196 \text{ kJ mol}^{-1}$$

The graph in **Figure 4** shows the concentrations of sulfur trioxide and of oxygen over a period of 6 minutes at temperature T_1

Figure 4



0 5 . 1 State the time, to the nearest minute, when equilibrium is first established.
Explain your answer.

[2 marks]

Time _____ minutes

Explanation _____

_____

_____

_____

_____

0 5 . 2 Sketch on the graph in **Figure 4** how the concentration of sulfur dioxide changes over these 6 minutes at temperature T_1

[2 marks]

0 5 . 3 The temperature of the mixture was changed to T_2 and the mixture left to establish a new equilibrium.
In the new equilibrium mixture the concentration of sulfur trioxide was found to be 0.07 mol dm^{-3}

Deduce which of T_1 and T_2 is the higher temperature.
Explain your deduction.

[2 marks]

Higher temperature _____

Explanation _____

_____

_____

_____

_____

6

Turn over for the next question

0 8 Methanol can be manufactured in a reversible reaction as shown by the equation.

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

0 8 . 1 State and explain the effect of using a catalyst on the yield of methanol in this equilibrium.

[2 marks]

0 8 . 2 Give an expression for the equilibrium constant (K_c) for this reaction.

[1 mark]

0 8 . 3 A mixture of carbon monoxide and hydrogen was allowed to reach equilibrium in a container of volume 250 cm^3 at temperature *T*.
At equilibrium, the mixture contained 0.340 mol of carbon monoxide, 0.190 mol of hydrogen and 0.0610 mol of methanol.

Calculate the value of the equilibrium constant (K_c) for this reaction at temperature *T*.

[3 marks]

K_c _____ mol^{-2} dm^6

0 8 . 4 Methanol decomposes on heating in a reaction that is the reverse of that used in its manufacture.

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

Use your answer from Question **08.3** to determine the value of K_c for this equilibrium at temperature *T*.
State the units for this value of K_c

(If you were unable to complete the calculation in Question **08.3**, assume a value of $K_c = 0.825$ mol^{-2} dm^6. This is **not** the correct value.)

[2 marks]

Value of K_c _____

Units of K_c _____

8

Section A

Answer **all** questions in this section.

1 Ethene reacts with steam in the presence of an acid catalyst to form ethanol.

$$CH_2{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$$

0 1 . 1 Write an expression for the equilibrium constant K_c for this equilibrium. Deduce the units of K_c.

[2 marks]

Expression _____

_____

_____

Units _____

0 1 . 2 An equilibrium mixture was found to contain 0.700 mol of ethene, 1.20 mol of steam and 4.40 mol of ethanol at a temperature ***T***. The volume of the container was 2.00 dm^3.

Calculate a value of K_c for this equilibrium at this temperature.

Give your answer to an appropriate number of significant figures.

[2 marks]

_____

_____

_____

_____

_____

_____

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

Question	Marking guidance	Mark	AO	Comments
04.1	amount of X = 0.50 – 0.20 = 0.30 (mol) amount of Y = 0.50 – 2 × 0.20 = 0.10 (mol)	1 1	AO2h AO2h	
04.2	Axes labelled with values, units and scales that use over half of each axis Curve starts at origin Then flattens at 30 seconds at 0.20 mol	1 1 1	AO2h AO2h AO2h	All three of values, units and scales are required for the mark
04.3	Expression = $K_c = \frac{[Z]}{[X][Y]^2}$ $[Y]^2 = \frac{[Z]}{[X]\,K_c}$ $[Y] = (0.35 / 0.40 \times 2.9)^{0.5} = 0.5493 = 0.55$ (mol dm^{-3})	1 1 1	AO1a AO2b AO1b	Answer must be to 2 significant figures
04.4	Darkened / went more orange The equilibrium moved to the right To oppose the increased concentration of Y	1 1 1	AO2g AO2g AO2g	
04.5	The orange colour would fade	1	AO3 1a	

Qu	Marking Guidance	Additional Comments	Mark
5.1	3 minutes	M2 dependent on M1 or near miss	1
	(At equilibrium, $rate_{fwd}$ = $rate_{back}$ so) concentrations (of O_2 and SO_3) remain constant	Not concentrations are the same/equal Allow (after this point) gradient is zero / curve flattens out	1
5.2	Sketch begins at origin <u>and</u> goes up until 3 mins		1
	Levels off at 0.3 mol dm^{-3}	Mark Independently	1
5.3	T_2 (Not worth a mark alone)	T_1, CE=0	
	Equilibrium has <u>moved / shifted</u> to <u>RHS/forward</u> in <u>endothermic</u> direction	Both RHS / forward and endothermic needed	1
	Equilibrium has opposed the increase in T / Equilibrium moves to decrease the T	Not just to oppose the change	1

Question	Marking Guidance	Mark	Comments
8.1	**M1** no effect (on yield) **M2** increases rate / speed of both / forward and reverse reactions <u>equally / by the same amount</u>	1 1	CE = 0 if yield changes If no reference to effect on yield, could still score **M2** Ignore reference to no change in position of equilibrium, and reference to lowering activation energies **M2** allow changes rate of both / forward and reverse reactions <u>equally / by the same amount</u>
8.2	$(K_c =) \frac{[CH_3OH]}{[CO][H_2]^2}$	1	Must be square brackets Ignore state symbols Ignore units
8.3	**M1** divides moles by volume (0.250 or $\frac{250}{1000}$) **M2** $K_c = \frac{\frac{0.0610}{0.250}}{\left[\frac{0.340}{0.250}\right]\left[\frac{0.190}{0.250}\right]^2} \left(= \frac{0.244}{1.36 \times 0.76^2}\right)$ **M3** 0.311	1 1 1	Correct answer scores 3; **M3** to at least 2sf (0.3106159 …); ignore units Allow ECF from **M1** to **M2** if an attempt to calculate concentration has been made by dividing by some factor of 250 cm^3 Allow ECF from **M2** to **M3** for use of an expression containing each reagent in a correctly substituted K_c expression If volume not used, then allow **M3** only for 4.97 (4.96985 … to at least 2sf)

8.4	**M1** $\frac{1}{Answer\ to\ 8.3}$ = 3.22 **M2** $mol^2\ dm^{-6}$	1 1	**M1** to at least 2sf (0.31 gives 3.2(258)) **M1** = 1.21 if alternative answer to 8.3 used If an error was made in 8.3, but the candidate produced an answer in 8.4 that did fit the inverted calculation from 8.3, then candidate could score **M1** (if volumes are not used, then candidate would get 0.20(12.)

Question	Marking Guidance	Mark	Comments
01.1	M1 $(K_c =) \frac{[CH_3CH_2OH]}{[CH_2{=}CH_2][H_2O]}$ M2 $mol^{-1}\ dm^3$	1 1	M1 penalise missing brackets or use of (); allow correct molecular formulae in correct expression (and allow CH_2CH_2); ignore powers shown as 1 M2 units must be in simplest form on one line (or $dm^3\ mol^{-1}$) M2 units are consequential on expression in M1 ($mol^{-1}\ dm^3$ only scores if it is the units for the expression in M1)
01.2	M1 $\frac{[\frac{4.40}{2.00}]}{[\frac{0.70}{2.00}]\times[\frac{1.20}{2.00}]}$ or $\frac{2.20}{0.35 \times 0.60}$ or $\frac{4.40}{0.70 \times 1.20} \times 2.00$ M2 10.5 (must be 3sf)	1 1	10.5 (3sf) scores both marks; correct value to 2sf (10) or 4sf or more (10.476…) scores 1 mark Volume not used is CE=0 If use incorrect expression for K_c in 1.2 then no marks in 1.2 If a value from the question is copied incorrectly into the expression, could still score M2 if then used correctly in calculation (AE -1) Ignore units

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	