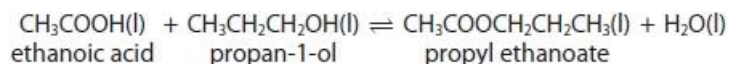


Questions

Q1.

This question is about an experiment to determine the equilibrium constant, K_c , for an esterification reaction producing propyl ethanoate. The equation for the reaction is



In an experiment to determine the equilibrium constant, K_c , the following steps were carried out.

- 6.0 cm³ of ethanoic acid (0.105 mol), 6.0 cm³ of propan-1-ol (0.080 mol) and 2.0 cm³ of dilute hydrochloric acid were mixed together in a sealed boiling tube. In this pre-equilibrium mixture, there is 0.111 mol of water
- The mixture was left for one week, at room temperature and pressure, to reach equilibrium
- The equilibrium mixture and washings were transferred to a volumetric flask and the solution made up to exactly 250.0 cm³ using distilled water
- 25.0 cm³ samples of the **diluted** equilibrium mixture were titrated with a solution of sodium hydroxide, concentration 0.200 mol dm⁻³, using phenolphthalein as the indicator
- The mean titre was 23.60 cm³ of 0.200 mol dm⁻³ sodium hydroxide solution.

(a) State the role of the hydrochloric acid in the esterification reaction.

(1)

.....

(b) (i) Calculate the total amount, in moles, of acid present in the **volumetric flask** in the equilibrium mixture.

(2)

(ii) The 2.0 cm³ of dilute hydrochloric acid contained 0.00400 mol of H⁺(aq) ions. Use this and your answer to part (b)(i) to calculate the amount, in moles, of ethanoic acid present in the equilibrium mixture.

(1)

(c) (i) The initial mixture in the boiling tube contained 0.105 mol of ethanoic acid.

Use your answer to (b)(ii) to calculate the amount, in moles, of ethanoic acid that reacted to form the ester in the equilibrium mixture.

(1)

(ii) Use information given in the method, and your answer to (c)(i), to calculate the amounts, in moles, of propan-1-ol, propyl ethanoate and water that are present in the equilibrium mixture.

(3)

Moles of propan-1-ol at equilibrium

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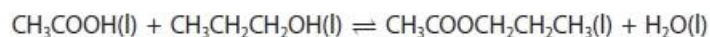
Moles of propyl ethanoate at equilibrium

.....

Moles of water at equilibrium

.....

(d) (i) Write the expression for the equilibrium constant, K_c , for this reaction.



(1)

(ii) Explain why it is possible, in this case, to calculate K_c using equilibrium amounts in moles, rather than equilibrium concentrations.

(2)

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(iii) Calculate the value of K_c .

Give your answer to an appropriate number of significant figures.

(2)

(e) The pink colour of the phenolphthalein fades after the end-point of the titration has been reached.

Give a possible explanation for this observation.

(2)

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(f) Explain what you could do to confirm that one week is sufficient time for the mixture to reach equilibrium.

(2)

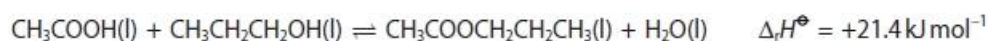
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(g) A student repeated the experiment, but left the mixture in a water bath at 40 °C until equilibrium was reached.



Deduce the effect, if any, on this student's value for K_c compared with that obtained in part (d)(iii).

(2)

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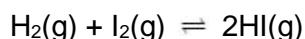
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(Total for question = 19 marks)

Q2.

The gas phase reaction between hydrogen and iodine is reversible.



(a) (i) Write the expression for the equilibrium constant, K_c , for this reaction.

(1)

(ii) If the starting concentration of both hydrogen and iodine was $a \text{ mol dm}^{-3}$ and it was found that $2y \text{ mol dm}^{-3}$ of hydrogen iodide had formed once equilibrium had been established, write the K_c expression in terms of a and y .

(2)

(b) The expression for the equilibrium constant in (a)(ii) can be rearranged as shown.

$$y = \frac{a\sqrt{K_c}}{2 + \sqrt{K_c}}$$

In an experiment, air was removed from a 1 dm^3 flask and amounts of hydrogen and iodine gases were mixed together such that their initial concentrations were both $a \text{ mol dm}^{-3}$. This mixture was allowed to reach equilibrium at 760 K . The equilibrium concentration of iodine was then measured.

The experiment was repeated for various initial concentrations, $a \text{ mol dm}^{-3}$, and the results recorded in the table.

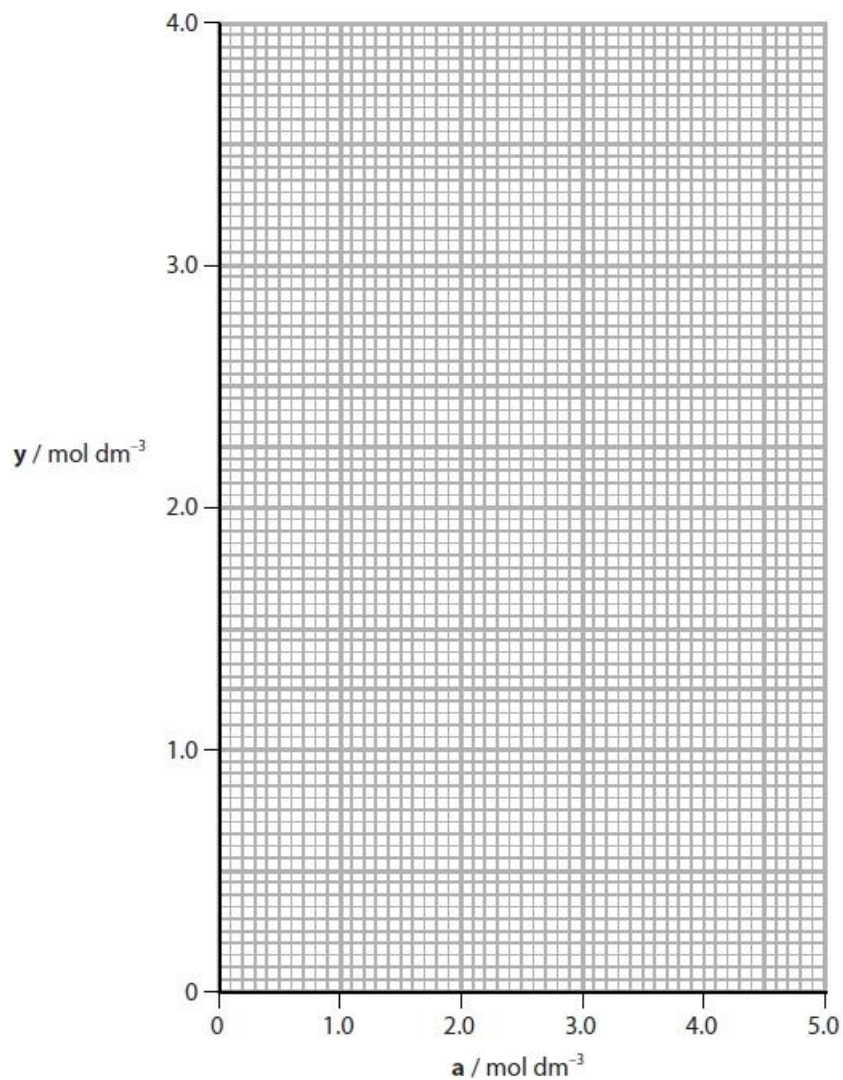
(i) Complete the table to give the two remaining values of $y \text{ mol dm}^{-3}$, to **two** decimal places.

(1)

$a / \text{mol dm}^{-3}$	$[\text{I}_2]_{\text{eq}} / \text{mol dm}^{-3}$	$y / \text{mol dm}^{-3}$
0.20	0.02	0.18
0.80	0.25	0.55
1.50	0.37	
2.10	0.57	1.53
2.80	0.65	2.15
3.80	0.87	
4.90	1.15	3.75

(ii) Plot a graph to show how $y \text{ mol dm}^{-3}$ varies with the initial concentrations of hydrogen and iodine, $a \text{ mol dm}^{-3}$.

(2)



(iii) Determine the gradient of your graph.
Show your working on the graph.

(2)

- (iv) Use your answer to (b)(iii) and the expression $y = \frac{a\sqrt{K_c}}{2 + \sqrt{K_c}}$ to calculate the value of K_c . (2)

- (c) Identify a safety issue associated with this experiment. (1)

.....
.....

- (d) One of the experiments in part (b) was repeated using the same molar quantities of hydrogen and iodine but in a 500 cm³ flask instead of the 1 dm³ flask.

Deduce the effect, if any, that this would have on the rate of reaction and on the value of K_c calculated. (2)

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- (e) The equation for the reaction between hydrogen and iodine is



- (i) Explain the effect, if any, on the value of K_c when the temperature is increased. (2)

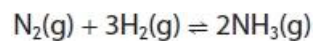
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- (ii) On your graph in (b)(ii), draw and label the line you would expect if the experiment was carried out at 1000 K instead of 760 K. (1)

(Total for question = 16 marks)

Q3.

Ammonia is manufactured by the Haber Process.



$$K_p = \frac{p(\text{NH}_3)^2}{p(\text{N}_2)p(\text{H}_2)^3}$$

A mixture of 1.0 mol of nitrogen and 3.0 mol of hydrogen is left to reach equilibrium at 700 K.

Calculate the total pressure, in atmospheres, needed to produce a yield of 0.30 mol of ammonia at 700 K.

Give your answer to an appropriate number of significant figures.

You must show your working.

[$K_p = 7.76 \times 10^{-5} \text{ atm}^{-2}$ at 700 K]

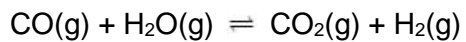
(5)

(Total for question = 5 marks)

Q4.

Hydrogen is produced on a large scale by several different processes.

Carbon monoxide reacts with steam.



At 1100 K, $K_c = 1.00$

In an experiment, 1 mol of carbon monoxide was mixed with 1 mol of steam, 2 mol of carbon dioxide and 2 mol of hydrogen.

Deduce, with reasons, the direction in which the reaction will shift to reach equilibrium.

(3)

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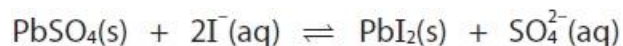
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(Total for question = 3 marks)

Q5.

This question is about electrode potentials, cells and equilibrium constants.

When solid lead(II) sulfate is added to aqueous sodium iodide, an equilibrium is established.



The expression for the equilibrium constant, K_c , for this reaction is

$$K_c = \frac{[\text{SO}_4^{2-}(\text{aq})]}{[\text{I}^-(\text{aq})]^2}$$

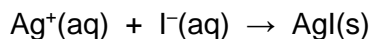
In an experiment, K_c may be determined by adding excess lead(II) sulfate to 25.0 cm³ of 0.100 mol dm⁻³ sodium iodide.

The volume remains constant at 25.0 cm³.

The mixture is left to reach equilibrium at room temperature.

Ice-cold water is added to freeze the position of equilibrium and the mixture is then titrated with standard silver nitrate solution.

The whole mixture requires 12.20 cm³ of 0.0500 mol dm⁻³ silver nitrate solution to react with the aqueous iodide ions at equilibrium.



Calculate the equilibrium concentrations of the sulfate ions and the iodide ions, and hence the value of K_c at room temperature.

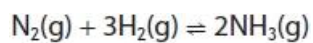
Give your answer to an appropriate number of significant figures and include units for K_c , if any.

(7)

(Total for question = 7 marks)

Q6.

Ammonia is manufactured by the Haber Process.



$$K_p = \frac{p(\text{NH}_3)^2}{p(\text{N}_2)p(\text{H}_2)^3}$$

The equilibrium constants for K_p and K_c are related by the equation

$$K_p = \frac{K_c}{(RT)^{\Delta n}}$$

where Δn is the number of moles of reactants minus the number of moles of products.

Calculate the value of K_c at 500 K when the value of $K_p = 3.55 \times 10^{-2} \text{ atm}^{-2}$.
Include the units for K_c .

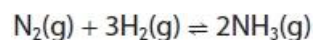
[Use the value of $R = 0.0821 \text{ dm}^3 \text{ atm K}^{-1} \text{ mol}^{-1}$]

(4)

(Total for question = 4 marks)

Q7.

Ammonia is manufactured by the Haber Process.



$$K_p = \frac{p(\text{NH}_3)^2}{p(\text{N}_2)p(\text{H}_2)^3}$$

The value of the equilibrium constant, K_p , varies with temperature.

The equation relating the values of the equilibrium constant at two temperatures is

$$\ln \left[\frac{K_2}{K_1} \right] = \frac{\Delta H}{R} \left[\frac{1}{T_1} - \frac{1}{T_2} \right]$$

The equilibrium constant, K_1 , for the formation of ammonia is $6.76 \times 10^5 \text{ atm}^{-2}$ when the temperature $T_1 = 298 \text{ K}$.

The enthalpy change $\Delta H = -92\,400 \text{ J mol}^{-1}$.

Calculate the value of the equilibrium constant for this reaction at 310 K.

[Use the value of $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$]

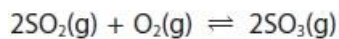
(4)

(Total for question = 4 marks)

Q8.

This question is about equilibrium systems.

Sulfur dioxide and oxygen form an equilibrium with sulfur trioxide.



The composition of an equilibrium mixture at 698 K and a total pressure of 2.40 atm is shown in the table.

Substance	SO ₂ (g)	O ₂ (g)	SO ₃ (g)
Number of moles /mol	0.0160	0.0120	0.772

(i) Calculate the value of K_p at this temperature.

Include units, if appropriate.

(5)

(ii) Calculate the number of sulfur dioxide molecules present in this equilibrium mixture.

(1)

(iii) Deduce, by referring to K_p , how the number of sulfur dioxide molecules will change if more oxygen is added to the equilibrium mixture.

(2)

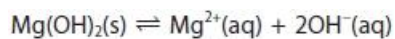
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(Total for question = 8 marks)

Q9.

This question is about the solubility of metal hydroxides.

When excess magnesium hydroxide is added to water and shaken, a saturated solution is formed and the mixture reaches equilibrium.



The equilibrium constant, K_c , for this reaction is

$$K_c = [\text{Mg}^{2+}(\text{aq})][\text{OH}^{-}(\text{aq})]^2$$

(i) Give a reason why the magnesium hydroxide is not included in the expression for K_c .

(1)

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(ii) Give the units for K_c .

(1)

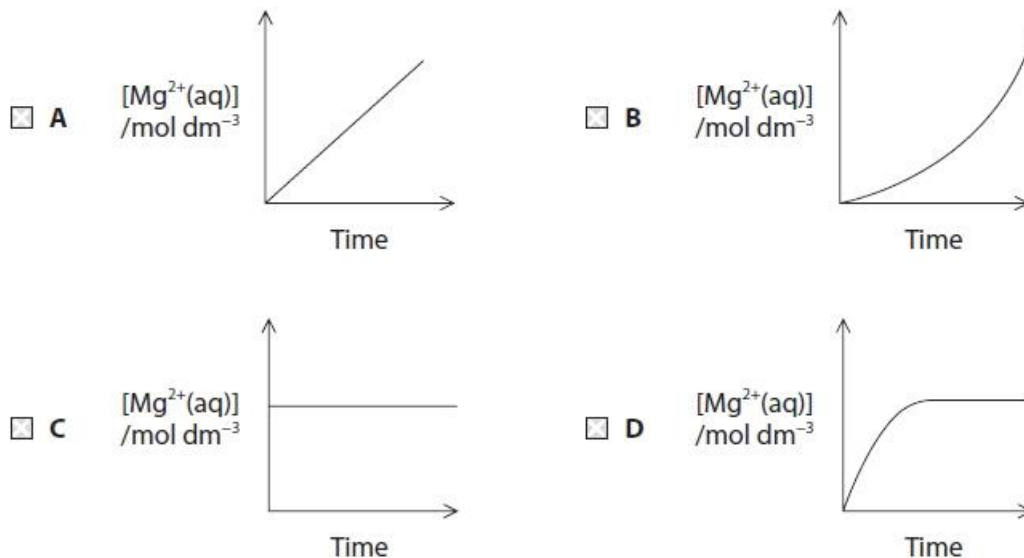
(iii) Calculate the enthalpy change of solution of magnesium hydroxide, using the following data.

Energy or enthalpy change	Value / kJ mol^{-1}
Lattice energy of $\text{Mg(OH)}_2(\text{s})$	-2842
$\Delta_{\text{hyd}}H (\text{Mg}^{2+}(\text{aq}))$	-1920
$\Delta_{\text{hyd}}H (\text{OH}^{-}(\text{aq}))$	-460

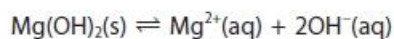
(2)

(iv) Which graph shows the change in the concentration of the $\text{Mg}^{2+}(\text{aq})$ ions when some solid magnesium hydroxide is shaken with water and left to reach equilibrium?

(1)



(v) Predict the effect, if any, of adding each of the following to a saturated solution of magnesium hydroxide in contact with solid magnesium hydroxide. Justify your answers in terms of the effect on the equilibrium.



(4)

Magnesium sulfate solution

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Dilute hydrochloric acid

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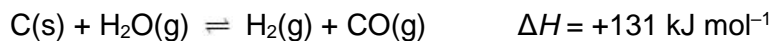
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(Total for question = 9 marks)

Q10.

Hydrogen is produced on a large scale by several different processes.

One process for producing hydrogen involves reacting white-hot carbon with steam.



The expression for the equilibrium constant, K_p , is

$$K_p = \frac{p(\text{H}_2) p(\text{CO})}{p(\text{H}_2\text{O})}$$

(i) Give a reason why the partial pressure of carbon is not included in the expression.

(1)

.....
.....

(ii) Explain the effect of an increase in pressure on the equilibrium position of this reaction.

(2)

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(iii) Explain, by reference to any change in the value of K_p , the effect of an increase in temperature on the equilibrium position of this reaction.

(2)

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(iv) At 1000 K and a total pressure of 2.0 atm, 1.00 mol of steam reacted with excess carbon.

At equilibrium, 0.81 mol of hydrogen was present.
Calculate the value of K_p at 1000 K, stating any units.

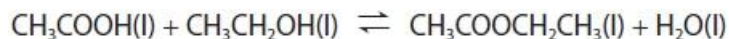
(4)

(Total for question = 9 marks)

Q11.

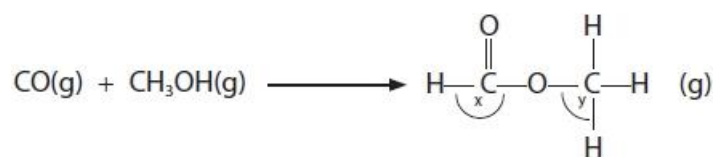
Answer the questions with a cross in the boxes you think are correct . If you change your mind about an answer, put a line through the box and then mark your new answer with a cross .

A mixture of ethanoic acid, ethanol and a catalyst was left for several days to reach equilibrium.



The equilibrium constant, K_c , **under these conditions**, was 0.28.

Another ester, methyl methanoate, can be formed by the reaction between methanol and carbon monoxide in the gaseous phase.



(i) The two O–C–H bond angles, x and y, in the ester are approximately

- A 180° and 90°
 B 120° and 90°
 C 120° and 109.5°
 D 109.5° and 109.5°

(1)

(ii) The reaction often forms an equilibrium mixture.

Which could be the units for the equilibrium constant, K_p ?

- A mol dm⁻³
 B dm³ mol⁻¹
 C atm
 D atm⁻¹

(1)

(iii) Describe what effect, if any, increasing the pressure would have on the equilibrium constant, K_p . Justify your answer.

(2)

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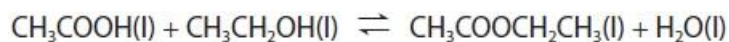
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(Total for question = 4 marks)

Q12.

A mixture of ethanoic acid, ethanol and a catalyst was left for several days to reach equilibrium.



The equilibrium constant, K_c , **under these conditions**, was 0.28.

(i) Write the expression for the equilibrium constant, K_c .

(1)

(ii) The initial amounts of ethanol and ethanoic acid used were 1.2 mol of each reactant.

Use this information, your expression for the equilibrium constant, K_c , and the value for K_c , to find the amounts of each product at equilibrium, in moles.

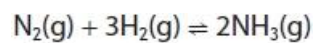
(3)

Amount of $\text{CH}_3\text{COOCH}_2\text{CH}_3$ =
Amount of H_2O =

(Total for question = 4 marks)

Q13.

Ammonia is manufactured by the Haber Process.



$$K_p = \frac{p(\text{NH}_3)^2}{p(\text{N}_2)p(\text{H}_2)^3}$$

The pressure used in the Haber Process is 200 atm.

Explain the effect, if any, of increasing the pressure on the equilibrium yield of ammonia.

(2)

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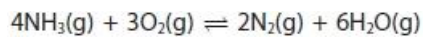
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(Total for question = 2 marks)

Q14.

This question is about the oxidation of ammonia.

One equation for the oxidation of ammonia is



Write the expression, including units, for the equilibrium constant K_c for this reaction.

Expression

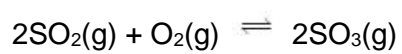
(2)

Units

(Total for question = 2 marks)

Q15.

(i) Write the expression for the equilibrium constant K_c for this reaction.



(1)

(ii) What are the units, if any, of the equilibrium constant, K_c ?

(1)

- A** mol dm⁻³
- B** dm³ mol⁻¹
- C** no units
- D** mol² dm⁻⁶

(Total for question = 2 marks)

Mark Scheme

Q1.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)	Any one from: Catalyst / speeds up reaction / increases rate / increases rate of attainment of equilibrium / lowers activation energy	Ignore any mention of protonation or mechanism for catalysis Do not award additional incorrect types of reaction	(1)
Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	<ul style="list-style-type: none"> calculation of moles of H⁺ in 25.0 cm³ (1) calculation of moles of H⁺ in 250 cm³ flask (1) 	Ignore SF throughout 8(b)(i) to 8(c)(ii) except 1 SF, which should be penalised once only <u>Example of calculation:</u> (moles NaOH = $0.200 \times \frac{23.60}{1000}$) = 0.00472 (mol) (= mol H ⁺ in 25.0 cm ³) (= 10×0.00472) = 0.0472 (mol) (in 250 cm ³) Allow TE for M2 on moles of NaOH Correct answer with or without working scores 2 marks	(2)
Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	<ul style="list-style-type: none"> subtracts moles of H⁺ in HCl from answer to (b)(i) 	<u>Example of calculation:</u> $0.0472 - 0.00400 = 0.0432$ (mol) Allow TE on answer to part (b)(i)	(1)
Question Number	Acceptable Answers	Additional Guidance	Mark
(c)(i)	<ul style="list-style-type: none"> calculation of moles of CH₃COOH that have reacted 	<u>Example of calculation:</u> $(0.105 - 0.0432) = 0.0618$ Allow TE on part (b)(ii) unless negative value	(1)
Question Number	Acceptable Answers	Additional Guidance	Mark
(c)(ii)	<ul style="list-style-type: none"> calculation of equilibrium moles of CH₃CH₂CH₂OH (1) calculation of equilibrium moles of CH₃COOCH₂CH₂CH₃ (1) calculation of equilibrium moles of H₂O (1) 	<u>Example of calculation:</u> $0.0800 - 0.0618 = 0.0182$ 0.0618 $0.111 + 0.0618 = 0.1728$ Allow TE on answer to part (c)(i) unless negative value	(3)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)(i)	$(K_c =)$ $\frac{[\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}]}$	IGNORE state symbols even if incorrect Do not award round brackets	(1)
(d)(ii)	An explanation that makes reference to the following points: <ul style="list-style-type: none"> Same number of moles/molecules on both sides of the equation (1) (so) volume / V cancels in K_c expression (1) 	2 marks could be scored by a correct mathematical expression showing V or dm^3 cancel Allow same number of terms on top and bottom of K_c expression Allow units cancel out Allow "all divided by the same volume"	(2)
(d)(iii)	<ul style="list-style-type: none"> calculates value of K_c (1) final value of K_c quoted to 2 or 3 SF (1) 	Example of calculation $K_c = \frac{(0.0618) \times (0.1728)}{(0.0432) \times (0.0182)} = 13.58241758$ $= 14 / 13.6 \text{ (no units)}$ Correct answer with no working gains full marks Ignore units No TE on wrong K_c expression	2
(e)	An explanation that makes reference to the following points: <ul style="list-style-type: none"> the equilibrium shifts to the left or the mixture absorbs carbon dioxide from the atmosphere (1) so the mixture is (becoming more) acidic / the acid reforms (1) 	Mark independently Allow no longer alkaline Do not award just "pH decreases"	(2)
(f)	An explanation that makes reference to the following points: <ul style="list-style-type: none"> carry out / repeat experiment and leave for longer than a week (1) the titre value / K_c value will remain unchanged (if equilibrium has been established) (1) 	Ignore pH probes / checking pH Allow repeat experiment and check titres within first week Allow moles / concentration are unchanged Ignore just "results unchanged"	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(g)	An answer that makes reference to the following points: <ul style="list-style-type: none"> K_c value will be greater than that calculated in (d)(iii) (1) because the (forward) reaction is endothermic or backward / reverse reaction is exothermic (1) 	M2 depends on M1 Ignore References to the equilibrium position shifting to the right (with increasing temperature)	(2)

Q2.

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(i)	$(K_c =) \frac{[\text{HI}(\text{g})]^2}{[\text{H}_2(\text{g})][\text{I}_2(\text{g})]}$	Ignore missing state symbols or units Do not award round brackets	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(a)(ii)	$(K_c =) \frac{4y^2}{(a-y)^2}$ <ul style="list-style-type: none"> Numerator term correct (1) Denominator term correct (1) 	Allow square brackets Allow $(2y)^2$ Allow $(a^2 - 2ay + y^2)$ or $(a-y)(a-y)$	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(i)	• both values correct to 2 DP	1.13 2.93	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(ii)	• All 7 points plotted correctly (1) • Appropriate straight line of best fit, drawn through the origin (1)	Allow TE for incorrect values from 9(b)(i) Do not allow all points above or below the line of best fit Allow line of best fit to intersect one square either side of the origin	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iii)	<ul style="list-style-type: none"> co-ordinates correctly read off the line on graph (1) <ul style="list-style-type: none"> gradient correctly calculated (1) 	<p>At least 1 line must be shown on the graph to indicate selection of co-ordinates</p> <p><u>Example of calculation</u> $\frac{3.40 - 0.00}{4.50 - 0.00}$ = gradient of graph Gradient = 0.76</p> <p>Ignore SF except 1SF Do not allow units for the gradient Allow a value from 0.71 to 0.81 inclusive</p>	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(b)(iv)	<ul style="list-style-type: none"> $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = \text{gradient} / \frac{y}{a}$ (1) re-arrangement of expression and calculation of K_c (1) 	<p><u>Example of calculation</u> $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = 0.76$ $K_c = 40.1 / 40$ (no units)</p> <p>Allow TE on gradient from part (iii) $K_c = [(2 \times \text{grad}) / (1 - \text{grad})]^2$</p> <p>Correct answer with no working scores (2)</p>	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(c)	<ul style="list-style-type: none"> hydrogen is flammable / explosive 	<p>Allow iodine vapour damages eyes /toxic</p> <p>Allow hydrogen iodide is corrosive / acidic / irritant (if qualified) / lachrymator</p> <p>Ignore references to high pressure</p> <p>Ignore references to safety precautions</p>	(1)

Question Number	Acceptable Answers	Additional Guidance	Mark
(d)	<ul style="list-style-type: none">Faster rate of reaction / increased rate (1)K_c unchanged (1)	Ignore references to shifting position of equilibrium	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(i)	An explanation that makes reference to the following points: <ul style="list-style-type: none">(K_c is) smaller / decreases / gets less (1)(forward) reaction is exothermic (1)	Allow reverse/backwards reaction is endothermic MP2 dependent on MP1	(2)

Question Number	Acceptable Answers	Additional Guidance	Mark
(e)(ii)	<ul style="list-style-type: none">straight line drawn on the graph with a less steep gradient (and goes through the origin)	Do not allow if lines cross	(1)

Q3.

Question Number	Answer	Additional Guidance	Mark																				
		<u>Example of calculation</u>	(5)																				
	<ul style="list-style-type: none"> calculation of eqm moles 	<table border="1"> <thead> <tr> <th></th> <th>N₂</th> <th>H₂</th> <th>NH₃</th> </tr> </thead> <tbody> <tr> <td>Initial mol</td> <td>1.0</td> <td>3.0</td> <td>-</td> </tr> <tr> <td>Eqm mol</td> <td>1.0 - 0.15 = 0.85</td> <td>3.0 - (3 x 0.15) = 2.55</td> <td>0.30</td> </tr> <tr> <td>Total mol at eqm</td> <td colspan="3">0.85 + 2.55 + 0.30 = 3.7</td> </tr> <tr> <td>Partial pressure</td> <td>$\frac{0.85 \times P}{3.7}$</td> <td>$\frac{2.55 \times P}{3.7}$</td> <td>$\frac{0.30 \times P}{3.7}$</td> </tr> </tbody> </table>		N ₂	H ₂	NH ₃	Initial mol	1.0	3.0	-	Eqm mol	1.0 - 0.15 = 0.85	3.0 - (3 x 0.15) = 2.55	0.30	Total mol at eqm	0.85 + 2.55 + 0.30 = 3.7			Partial pressure	$\frac{0.85 \times P}{3.7}$	$\frac{2.55 \times P}{3.7}$	$\frac{0.30 \times P}{3.7}$	
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	<ul style="list-style-type: none"> expressions for 3 partial pressures 																						
	<ul style="list-style-type: none"> substitution of values into K_p expression 	$K_p = 7.76 \times 10^{-5} = \frac{\left(\frac{0.30 \times P}{3.7}\right)^2}{\left(\frac{0.85 \times P}{3.7}\right)\left(\frac{2.55 \times P}{3.7}\right)^3}$																					
	<ul style="list-style-type: none"> rearrangement of K_p expression 	$7.76 \times 10^{-5} = \frac{0.087419}{P^2}$																					
	<ul style="list-style-type: none"> calculation of total pressure and answer to 1 / 2 SF 	$P^2 = 1126.5 \text{ (atm}^2\text{)}$ $P = 33.564$ $= 34 / 30 \text{ (atm)}$ <p>Allow any symbol for total pressure</p> <p>Allow TE throughout</p> <p>Correct answer to 1 or 2 SF with some working scores (5)</p> <p>Correct answer to 1 or 2 SF with no working scores (4)</p>																					

Q4.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> <li data-bbox="384 421 863 533">• the quotient / Q: $\frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]} = \frac{2 \times 2}{1 \times 1} = 4$, which is larger than K_c or (since $K_c = 1$) the concentrations of the products must be equal to the concentrations of the reactants at equilibrium (1) <li data-bbox="384 770 863 936">• the concentrations of CO_2 and H_2 / products need to decrease and those of CO and H_2O / reactants need to increase (1) <li data-bbox="384 994 751 1048">• so reaction shifts to the left (1) 	<p data-bbox="914 331 1243 421">Allow amounts / moles / (partial) pressures for concentrations</p> <p data-bbox="914 450 1243 533">Allow calculated K_c / the quotient / Q will be greater than 1</p> <p data-bbox="914 763 1243 824">Allow shift so that there is 1.5 mol of each substance</p> <p data-bbox="914 987 1198 1048">M3 conditional on some explanation</p>	(3)

Q5.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> calculation of initial mol I⁻ (1) calculation of eqm mol I⁻ (1) calculation of mol I⁻ reacted (1) calculation of eqm mol⁻¹ SO₄²⁻ (1) calculation of eqm [SO₄²⁻(aq)] and calculation of eqm [I⁻(aq)] (1) calculation of K_c and answer to 2 / 3 SF (1) units (1) 	<p><u>Example of calculation</u></p> <p>initial mol I⁻ = (25.0 x 0.100) ÷ 1000 = 2.5 x 10⁻³ / 0.0025 (mol)</p> <p>eqm mol I⁻ (= mol Ag⁺) = (12.20 x 0.0500) ÷ 1000 = 6.1 x 10⁻⁴ / 0.00061 (mol)</p> <p>mol I⁻ reacted = 2.5 x 10⁻³ - 6.1 x 10⁻⁴ = 1.89 x 10⁻³ / 0.00189 (mol)</p> <p>eqm mol SO₄²⁻ = mol I⁻ reacted / 2 = 1.89 x 10⁻³ ÷ 2 = 9.45 x 10⁻⁴ / 0.000945</p> <p>eqm [SO₄²⁻] = (9.45 x 10⁻⁴ x 1000) ÷ 25 = 0.0378 (mol dm⁻³)</p> <p>and</p> <p>eqm [I⁻] = (6.1 x 10⁻⁴ x 1000) ÷ 25.0 = 2.44 x 10⁻² / 0.0244 (mol dm⁻³)</p> <p>K_c = 0.0378 ÷ 0.0244² = (63.49) = 63 / 63.5</p> <p>Do not award unless their numbers are correct or are TE. Allow TE throughout. Correct answer with working gains 7 marks</p> <p>dm³ mol⁻¹ (standalone mark) Allow dm³ mol⁻¹ / mol⁻¹ dm³ / mol⁻¹ dm³</p>	(7)

Q6.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> rearrangement of formula (1) substitution of correct values (1) calculation of K_c (1) units (1) 	<p><u>Example of calculation</u></p> $K_c = K_p \times (RT)^{\Delta n}$ $K_c = 3.55 \times 10^{-2} \times (0.0821 \times 500)^2$ $K_c = 59.821$ <p>TE on Δn</p> <p>Stand alone mark $\text{dm}^6 \text{mol}^{-2}$ or $\text{mol}^{-2} \text{dm}^6$</p> <p>Correct value with units and no working scores (4)</p> <p>Ignore SF except 1 SF</p> <p>M1 and M2 can be in reverse order</p>	(4)

Q7.

Question Number	Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> substitution of numbers into expression (1) evaluation of $\Delta H/R$ and $1/T_1 - 1/T_2$ (1) rearrangement of expression (1) evaluation of expression (1) 	<p><u>Example of calculation</u></p> $\ln\left(\frac{K_2}{6.76 \times 10^5}\right) = \left(\frac{-92400}{8.31}\right)\left(\frac{1}{298} - \frac{1}{310}\right)$ $\ln\left(\frac{K_2}{6.76 \times 10^5}\right) = -11119.1 \times 1.299 \times 10^{-4}$ $= -1.4444$ $K_2 = 6.76 \times 10^5 \times e^{-1.4444}$ <p>TE on M2</p> $K_2 = 1.59467 \times 10^5 / 159467(\text{atm}^{-2})$ <p>TE on M3</p> <p>Allow answer from earlier correct rounding to 2 or more SF</p> <p>Ignore SF except 1 SF</p> <p>Correct answer with no / some working scores (4)</p>	(4)

Q8.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> • (M1) calculation of mole fractions (1) • (M2) calculation of partial pressures (1) • (M3) expression of K_p (1) • (M4) calculation of value of K_p (1) • (M5) units (1) 	<p>Example of calculation $X_{SO} = 0.0160 \div 0.8 = 0.02(0)$ ₂</p> <p>$X_O = 0.0120 \div 0.8 = 0.015$ ₂</p> <p>$X_{SO} = 0.772 \div 0.8 = 0.965$ ₃</p> <p>$P_{SO} = 0.02(0) \times 2.40 = 0.048$ ₂</p> <p>$P_O = 0.015 \times 2.40 = 0.036$ ₂</p> <p>$P_{SO} = 0.965 \times 2.40 = 2.316$ ₃</p> <p>$K_p = \frac{(P_{SO})^2}{(P_O)^2 \times P_O}$ ₃</p> <p>Do not award square brackets</p> <p>$K_p = \frac{2.316^2}{0.048^2 \times 0.036} =$</p> <p>$K_p = 64668.4\dots / 6.46684\dots \times 10^4$</p> <p>$K_p = 65000 / 6.5 \times 10^4 / 64700 / 6.47 \times 10^4$</p> <p>Ignore SF except 1</p> <p>atm⁻¹</p> <p>Correct final answer without working scores</p>	(5)

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> • calculation of the number of molecules 	<p>Example of calculation</p> <p>$N = (n \times L = 0.0160 \times 6.02 \times 10^{23})$</p> <p>$= 9.632 \times 10^{21}$</p> <p>Ignore SF except 1SF</p> <p>Do not award if any units are given</p>	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	<p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> to ensure that K_p stays the same/ quotient stays the same or only temperature changes the value of K_p (1) the number of (sulfur dioxide) molecules decreases Either because the equilibrium shifts to the right or because one of the denominators (oxygen) has increased so the other denominator (sulfur dioxide) has to decrease <p>(1)</p>	<p>Standalone marks</p> <p>Allow concentration changes have no effect on the value of K_p</p> <p>Allow 'moles' for molecules</p>	(2)

Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	<p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> the concentration of a solid / $Mg(OH)_2$ is constant / unchanged / changes very little 	<p>Allow magnesium hydroxide is in a different phase / state (from the aqueous ions)</p> <p>Ignore solids do not appear in K_c expressions / just 'it is solid'</p> <p>Ignore solid does not affect the concentration of the solution</p> <p>Ignore it is a heterogeneous equilibrium</p> <p>Ignore it is difficult to measure the concentration of a solid</p> <p>Do not award the solid does not have a concentration</p>	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
6(b)(ii)	<ul style="list-style-type: none"> $mol^3 dm^{-9}$ 	<p>Allow $dm^{-9} mol^3$</p> <p>mol^3/dm^9</p> <p>Ignore any working before the answer</p>	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(iii)	<ul style="list-style-type: none"> use of $\Delta_{\text{sol}}H = \Delta_{\text{hyd}}H[\text{Mg}^{2+}(\text{aq})] + 2\Delta_{\text{hyd}}H[\text{OH}^{-}(\text{aq})] - \Delta_{\text{latt}}H[\text{Mg}(\text{OH})_2(\text{s})]$ <p>(1)</p> <ul style="list-style-type: none"> calculation of $\Delta_{\text{sol}}H$ <p>(1)</p>	<p><u>Example of calculation</u> $\Delta_{\text{sol}}H = -1920 + 2(-460) - (-2842)$ Allow this shown on a Hess cycle</p> <p>$\Delta_{\text{sol}}H = (+)2 \text{ (kJ mol}^{-1}\text{) Allow}$ 2000 J mol⁻¹</p> <p>Correct answer with no working scores 2</p>	(2)

Question Number	Answer	Mark
(iv)	<p>The only correct answer is D</p> <p><i>A is not correct because it should not be linear and should level off</i></p> <p><i>B is not correct because it should not increase in that way and should level off</i></p> <p><i>C is not correct because it should not be horizontal</i></p>	(1)

Question Number	Acceptable Answer	Additional Guidance	Mark
(v)	<p>An answer that makes reference to the following points:</p> <p>Addition of magnesium sulfate solution:</p> <ul style="list-style-type: none"> equilibrium position shifts to the left / in the backwards direction (1) because increased concentration / amount of magnesium ions / $Mg^{2+}(aq)$ (1) <p>Addition of dilute hydrochloric acid:</p> <ul style="list-style-type: none"> equilibrium shifts to the right / in the forwards direction (1) because the hydrogen ions / $H^+(aq)$ react with / neutralise / removes the hydroxide ions / $OH^-(aq)$ (1) 	<p>Mark independently</p> <p>Allow more magnesium hydroxide precipitates / forms</p> <p>Allow more Mg^{2+} ions present</p> <p>Allow more magnesium hydroxide dissolves / dissociates</p> <p>Allow $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$</p> <p>Allow magnesium hydroxide reacts with / is neutralised by acid / equation to show this</p> <p>Allow acid / HCl reacts with / neutralises / removes hydroxide ions</p> <p>Penalise reference to K_c changing once only</p>	(4)

Q10.

Question Number	Answer	Additional Guidance	Mark
(i)	<p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> carbon / solid has no (vapour / partial) pressure or (partial) pressure of carbon / solid is constant or carbon does not contribute to the overall pressure (of the system) 	<p>Allow the reaction is heterogeneous and (partial) pressure of a pure solid is not included (in K_p expression)</p> <p>Do not allow just 'because carbon is a solid' or 'carbon is not a gas'</p>	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none">there are fewer moles / molecules / particles of gas on the left / reactant side (1)so equilibrium position/ it moves / shifts to the left / reactant side (1)	<p>Allow 2 moles / molecules of gas on right and 1 mole / molecule on left</p> <p>M2 is conditional on M1 or the idea of fewer particles on the left / decreasing the value of the quotient / Q</p> <p>Do not allow any indication of K_p changing</p>	(2)

Question Number	Answer	Additional Guidance	Mark
(iii)	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none">(forward) reaction is endothermic and so equilibrium constant / K_p increases as temperature increases (1)so equilibrium position / it moves / shifts to the right / product side (1)	<p>Ignore references to ΔG and ΔS</p> <p>M2 is conditional on M1 or endothermic or equilibrium constant increases</p>	(2)

Question Number	Answer	Additional Guidance	Mark																								
(iv)	<ul style="list-style-type: none"> calculation of moles of each substance at equilibrium (1) calculation of partial pressure of each substance (1) calculation of K_p (1) units (stand alone mark) (1) 	<p>Example of calculation:</p> <table border="1"> <thead> <tr> <th></th> <th>H₂O(g)</th> <th>H₂(g)</th> <th>CO(g)</th> </tr> </thead> <tbody> <tr> <td>Initial moles</td> <td>1.00</td> <td>0</td> <td>0</td> </tr> <tr> <td>Eqm moles</td> <td>1.00 - 0.81 = 0.19</td> <td>0.81</td> <td>0.81</td> </tr> <tr> <td colspan="4">Total moles = 0.19 + 0.81 + 0.81 = 1.81</td> </tr> <tr> <td>Mole fraction</td> <td>0.19/1.81 = 0.10497</td> <td>0.81/1.81 = 0.4475</td> <td>0.81/1.81 = 0.4475</td> </tr> <tr> <td>Partial pressure /atm</td> <td>0.10497 × 2.0 = 0.20994</td> <td>0.4475 × 2.0 = 0.895</td> <td>0.4475 × 2.0 = 0.895</td> </tr> </tbody> </table> $K_p = \frac{0.895 \times 0.895}{0.20994} = 3.815 / 3.82 / 3.8 \text{ atm}$ <p>3.8144 / 3.814 / 3.81 / 3.8 atm from 0.105 and 0.210</p> <p>Correct answer with units but no working scores (4)</p> <p>Allow TE for M2 and M3</p> <p>Ignore SF except 1 SF</p>		H ₂ O(g)	H ₂ (g)	CO(g)	Initial moles	1.00	0	0	Eqm moles	1.00 - 0.81 = 0.19	0.81	0.81	Total moles = 0.19 + 0.81 + 0.81 = 1.81				Mole fraction	0.19/1.81 = 0.10497	0.81/1.81 = 0.4475	0.81/1.81 = 0.4475	Partial pressure /atm	0.10497 × 2.0 = 0.20994	0.4475 × 2.0 = 0.895	0.4475 × 2.0 = 0.895	(4)
	H ₂ O(g)	H ₂ (g)	CO(g)																								
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Q11.

Question Number	Answer	Mark
(i)	<p>The only correct answer is C (120° and 109.5°)</p> <p><i>A is incorrect because both angles are incorrect</i></p> <p><i>B is incorrect because 90° is incorrect</i></p> <p><i>D is incorrect because 109.5° is incorrect for the left hand O-C-H angle</i></p>	(1)
(ii)	<p>The only correct answer is D (atm⁻¹)</p> <p><i>A is incorrect because it is the inverse of the units for K_c</i></p> <p><i>B is incorrect because it is the units for K_c</i></p> <p><i>C is incorrect because it is the inverse of the units for K_p</i></p>	(1)

Question Number	Answer	Additional Guidance	Mark
(iii)	<p>An explanation that makes reference to the following points</p> <ul style="list-style-type: none"> K_p will remain unchanged (1) equilibrium moves to right-hand side (to keep K_p constant) / only temperature affects K_p (1) 	<p>Allow answers in terms of quotient</p> <p>Do not award M2 if K_p is described as changing</p> <p>Ignore comments related to rate</p>	(2)

Q12.

Question Number	Answer	Additional Guidance	Mark
(i)	<ul style="list-style-type: none"> $K_c = \frac{[\text{CH}_3\text{COOCH}_2\text{CH}_3(\text{l})][\text{H}_2\text{O}(\text{l})]}{[\text{CH}_3\text{COOH}(\text{l})][\text{CH}_3\text{CH}_2\text{OH}(\text{l})]}$ 	<p>Ignore omission of state symbols</p> <p>Do not award round brackets</p>	(1)

Question Number	Answer	Additional Guidance	Mark
(ii)	<ul style="list-style-type: none"> expression for equilibrium amounts in terms of x (1) use equilibrium amounts in K_c expression and rearrangement to find amount of product / express as correct quadratic expression (1) calculation of amount of product (1) 	<p><u>Example of calculation</u></p> <p>Amounts $\text{CH}_3\text{CH}_2\text{OH} = 1.2 - x$; $\text{CH}_3\text{COOH} = 1.2 - x$; $\text{CH}_3\text{COOCH}_2\text{CH}_3 = x$; $\text{H}_2\text{O} = x$</p> $K_c = \frac{(x \div \text{vol})^2}{[(1.2-x) \div \text{vol}]^2}$ $K_c = (x^2 \div \text{vol}^2) \div ((1.2-x)^2 \div \text{vol}^2)$ $K_c = x^2 \div (1.2-x)^2 \text{ so } x^2 = K_c \times (1.2-x)^2$ $x = \sqrt{K_c \times (1.2-x)^2}$ <p>$x = 0.63498 \div 1.52915$; $x = 0.41525 = 0.42$</p> <p>(So amounts of each product = 0.42 (mol))</p> <p>Allow use of quadratic equation for M2</p> <p>Allow M2 for expression without inclusion of volume</p> <p>Correct answer with no working scores 3 marks</p> <p>Ignore SF except 1 SF</p> <p>Ignore negative amounts</p> <p>Allow alternative methods</p> <p>Allow TE throughout (a)(ii) for use of $x / (1.2-x)^2$ in K_c expression</p>	(3)

Q13.

Question Number	Answer	Additional Guidance	Mark
	<p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> there are fewer moles / molecules / particles of (gas) on the right (1) so (equilibrium) yield of ammonia increases (1) 	<p>Any reference to equilibrium constant changing scores (0) overall</p> <p>Allow 4 moles / molecules of gas on the left and 2 moles / molecules on right</p> <p>Allow 'equilibrium shifts to the right'</p> <p>M2 is conditional on M1 or the idea of fewer particles on the right / increasing the value of the quotient / Q</p> <p>Allow reverse argument</p>	(2)

Q14.

Question Number	Acceptable Answer	Additional Guidance	Mark
	<ul style="list-style-type: none"> K_c expression (1) units based on their K_c expression (1) 	<p>$(K_c =) \frac{[N_2(g)]^2 [H_2O(g)]^6}{[NH_3(g)]^4 [O_2(g)]^3}$</p> <p>ignore missing state symbols do not award round brackets</p> <p>mol dm⁻³ or mol/dm³</p>	(2)

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	$(K_c =) \frac{[SO_3]^2}{[O_2][SO_2]^2}$	<p>Do not award just K or K_p. must be square brackets</p> <p>do not accept partial pressures</p> <p>ignore units or lack of units</p> <p>ignore state symbols</p> <p>Allow x sign in the denominator but not +</p>	(1)

Question Number	Answer	Mark
(ii)	<p>The only correct answer is B</p> <p><i>A is not correct because it refers to the inverted expression for K_c</i></p> <p><i>C is not correct because units do not cancel for concentration²/concentration³</i></p> <p><i>D is not correct because it refers to concentration³/concentration or similar ratio of powers</i></p>	(1)