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EDEXCEL A LEVEL CHEMISTRY: QUESTIONS BY TOPIC

## Equilibrium II (11)

### A Level Chemistry Topic 11

10 questions · 117 marks · Mark schemes included

*Pearson Edexcel A Level Chemistry (9CH0), June 2017 - June 2025*

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**HOW TO USE THIS BOOKLET**

Questions are grouped by specification sub-topic; within each sub-topic they run from the lowest mark tariff to the highest.

Click any sub-topic heading or question row below to jump straight to it.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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# QUESTIONS

10 questions · 117 marks · grouped by sub-topic



SUB-TOPIC 11(a)

# KC AND KP CALCULATIONS

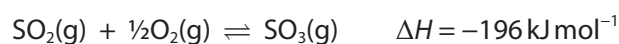
10 questions in this sub-topic · 117 marks · lowest tariff first



7 This question is about vanadium.

The contact process is used in the manufacture of sulfuric acid. In the second stage, sulfur dioxide is converted into sulfur trioxide by passing sulfur dioxide and air over a solid  $V_2O_5$  catalyst.

The equation for the second stage is shown.



(a) (i) What are the expression and the units for the equilibrium constant ( $K_p$ ) for this reaction?

(1)

|                            | Expression                            | Units               |
|----------------------------|---------------------------------------|---------------------|
| <input type="checkbox"/> A | $\frac{p(SO_3)}{p(SO_2)p(O_2)^{1/2}}$ | $\text{atm}^2$      |
| <input type="checkbox"/> B | $\frac{p(SO_2)p(O_2)^{1/2}}{p(SO_3)}$ | $\text{atm}^{1/2}$  |
| <input type="checkbox"/> C | $\frac{p(SO_2)p(O_2)^{1/2}}{p(SO_3)}$ | $\text{atm}^{-1/2}$ |
| <input type="checkbox"/> D | $\frac{p(SO_3)}{p(SO_2)p(O_2)^{1/2}}$ | $\text{atm}^{-1/2}$ |

(ii) Which variable affects the value of  $K_p$ ?

(1)

- ☐ A pressure
- ☐ B temperature
- ☐ C surface area of the catalyst
- ☐ D concentration of  $O_2(g)$



- (b) Write **two** equations that show the conversion of  $\text{SO}_2$  and  $\text{O}_2$  into  $\text{SO}_3$  by using  $\text{V}_2\text{O}_5$  as the catalyst.  
State symbols are not required.

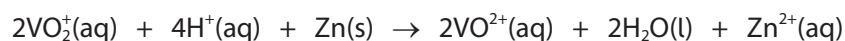
(2)

- (c) Which row of the table shows the correct colour of the solution and oxidation number of vanadium in the aqueous ions shown?

(1)

|                                   | Aqueous ion      | Colour of solution | Oxidation number of vanadium |
|-----------------------------------|------------------|--------------------|------------------------------|
| <input type="checkbox"/> <b>A</b> | $\text{VO}_2^+$  | yellow             | +3                           |
| <input type="checkbox"/> <b>B</b> | $\text{VO}^{2+}$ | green              | +4                           |
| <input type="checkbox"/> <b>C</b> | $\text{VO}_2^+$  | yellow             | +5                           |
| <input type="checkbox"/> <b>D</b> | $\text{VO}^{2+}$ | blue               | +5                           |

- (d) What is the value of the cell potential for the reaction of Zn and  $\text{VO}_2^+$ ?  
Use your Data Booklet.



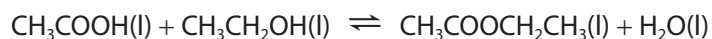
(1)

- ☐ **A** +1.76V  
☐ **B** +0.24V  
☐ **C** -0.24V  
☐ **D** -1.76V

(Total for Question 7 = 6 marks)



- 7 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.

- (a) (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.

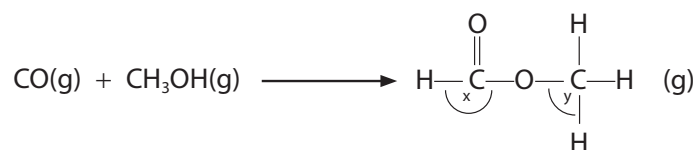
(3)

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

Amount of  $\text{H}_2\text{O}$  = .....



- (b) 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

(1)

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

- (ii) The reaction often forms an equilibrium mixture.

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

(1)

- ☐ **A** mol dm<sup>-3</sup>
- ☐ **B** dm<sup>3</sup> mol<sup>-1</sup>
- ☐ **C** atm
- ☐ **D** atm<sup>-1</sup>

- (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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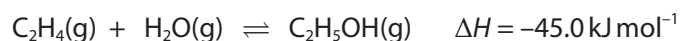
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(Total for Question 7 = 8 marks)



- 4 Ethanol is made industrially by the reaction of ethene and steam.  
The equation is shown.



The catalyst used is phosphoric acid,  $\text{H}_3\text{PO}_4$ , which is bound to a solid silicon dioxide support.

90.0 mol of ethene and 54.0 mol of steam are mixed in a sealed reactor at 500 K.  
At equilibrium, the total pressure is 60.0 atm and 5% of the ethene has been converted into ethanol.

- (a) Calculate the value of  $K_p$  at this temperature.  
Include the expression for  $K_p$  and units as appropriate.

(5)



(b) (i) It is proposed to increase the pressure in the reactor to 70.0 atm.

Explain the effect this change would have on the yield of ethanol by referring to the equilibrium.

(2)

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(ii) Which of these factors would change the value of  $K_p$ ?

(1)

- ☐ A using a different catalyst
- ☐ B increasing the pressure
- ☐ C decreasing the temperature
- ☐ D increasing the volume of the reaction vessel

**(Total for Question 4 = 8 marks)**



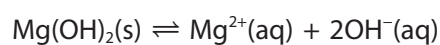
6 This question is about the solubility of metal hydroxides.

(a) Which of these metal hydroxides is the most soluble in water?

(1)

- ☐ A barium hydroxide
- ☐ B calcium hydroxide
- ☐ C magnesium hydroxide
- ☐ D potassium hydroxide

(b) 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)



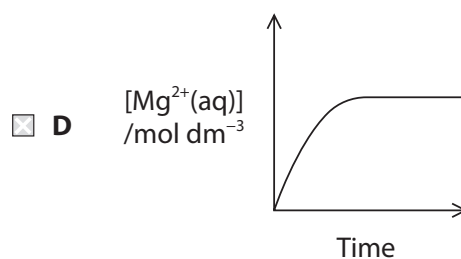
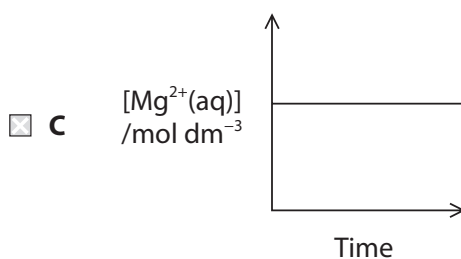
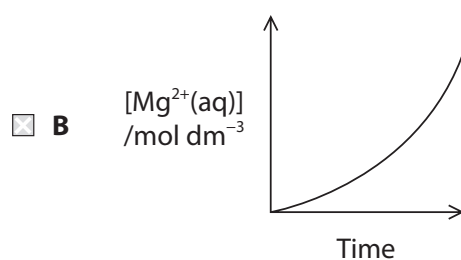
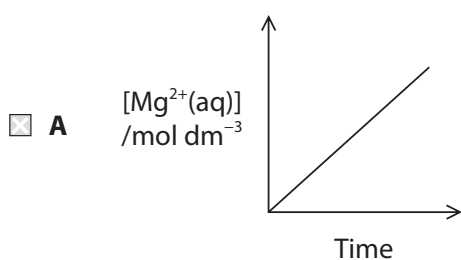
(iii) Calculate the enthalpy change of solution of magnesium hydroxide, using the following data.

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

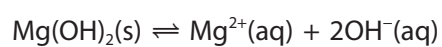
(2)

(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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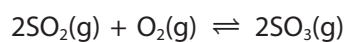
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(Total for Question 6 = 10 marks)



**10** This question is about equilibrium systems.

(a) 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 <sub>2</sub> (g) | O <sub>2</sub> (g) | SO <sub>3</sub> (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)

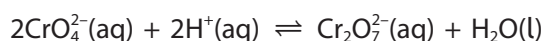
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(b) An equilibrium exists in aqueous solution between the chromate(VI) ions and the dichromate(VI) ions.



Explain any change in the position of equilibrium if a few drops of sodium hydroxide solution are added to this equilibrium system.

(2)

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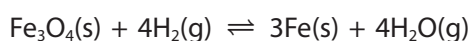
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(c) The equilibrium for the reaction between hydrogen gas and an oxide of iron is



The  $K_c$  expression for this equilibrium is

(1)

☐ A  $K_c = \frac{[\text{Fe}] \times [\text{H}_2\text{O}]}{[\text{Fe}_3\text{O}_4] \times [\text{H}_2]}$

☐ B  $K_c = \frac{[\text{Fe}]^3 \times [\text{H}_2\text{O}]^4}{[\text{Fe}_3\text{O}_4] \times [\text{H}_2]^4}$

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

☐ D  $K_c = \frac{[\text{H}_2\text{O}]^4}{[\text{H}_2]^4}$

(Total for Question 10 = 11 marks)



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

- (a) 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)

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- (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.

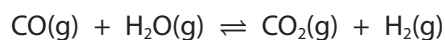
At equilibrium, 0.81 mol of hydrogen was present.

Calculate the value of  $K_p$  at 1000 K, stating any units.

(4)



(b) 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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**(Total for Question 10 = 12 marks)**



5 This question is about cobalt complexes.

- (a) A sample of cobalt(II) chloride was dissolved in aqueous ammonia,  $\text{NH}_3(\text{aq})$ . During the process, a stream of oxygen was gently bubbled through the solution to oxidise the cobalt(II) ion.

A coloured solid, **R**, was extracted from the solution. A pure sample of this solid was found to contain the masses of the elements shown and had a molar mass of  $233.4 \text{ g mol}^{-1}$ .

| Element | Mass / g |
|---------|----------|
| Co      | 1.26     |
| N       | 1.20     |
| H       | 0.257    |
| Cl      | 2.28     |

- (i) Show that the empirical formula **and** the molecular formula of **R** is  $\text{CoN}_4\text{H}_{12}\text{Cl}_3$ . You must show your working.

(2)



- (ii) 1.00 g of **R** was dissolved in water forming a coloured solution of the complex ion, **Q**.

The solution was reacted with excess silver nitrate solution, forming 0.614 g of silver chloride, AgCl(s).

Calculate the number of moles of chloride ions released when 1 mol of **R** dissolves.

(2)

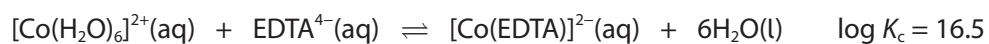
- (iii) Draw the three-dimensional shape of the complex ion, **Q**, using your answer to (a)(ii) to help deduce the formula and overall charge.

(3)



(b) An aqueous solution of cobalt(II) chloride contains the complex ion  $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ .

The dynamic equilibria shown occur when  $\text{NH}_3(\text{aq})$  and  $\text{EDTA}^{4-}(\text{aq})$  are each added to separate solutions of this complex ion.



(i) State what is meant by the term 'dynamic equilibrium'.

(2)

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(ii) Explain, in terms of equilibria and entropy, which of the three complex ions is the most stable.

(3)

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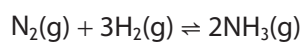
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**(Total for Question 5 = 12 marks)**



- 9 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) 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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- (b) The equilibrium constants for  $K_p$  and  $K_c$  are related by the equation

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

where  $\Delta n$  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)



- (c) 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.

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

(5)



- (d) 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  $\Delta H = -92400 \text{ J mol}^{-1}$ .

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

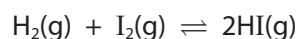
[Use the value of  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ ]

(4)

(Total for Question 9 = 15 marks)



- 9 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  $1 \text{ dm}^3$  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.

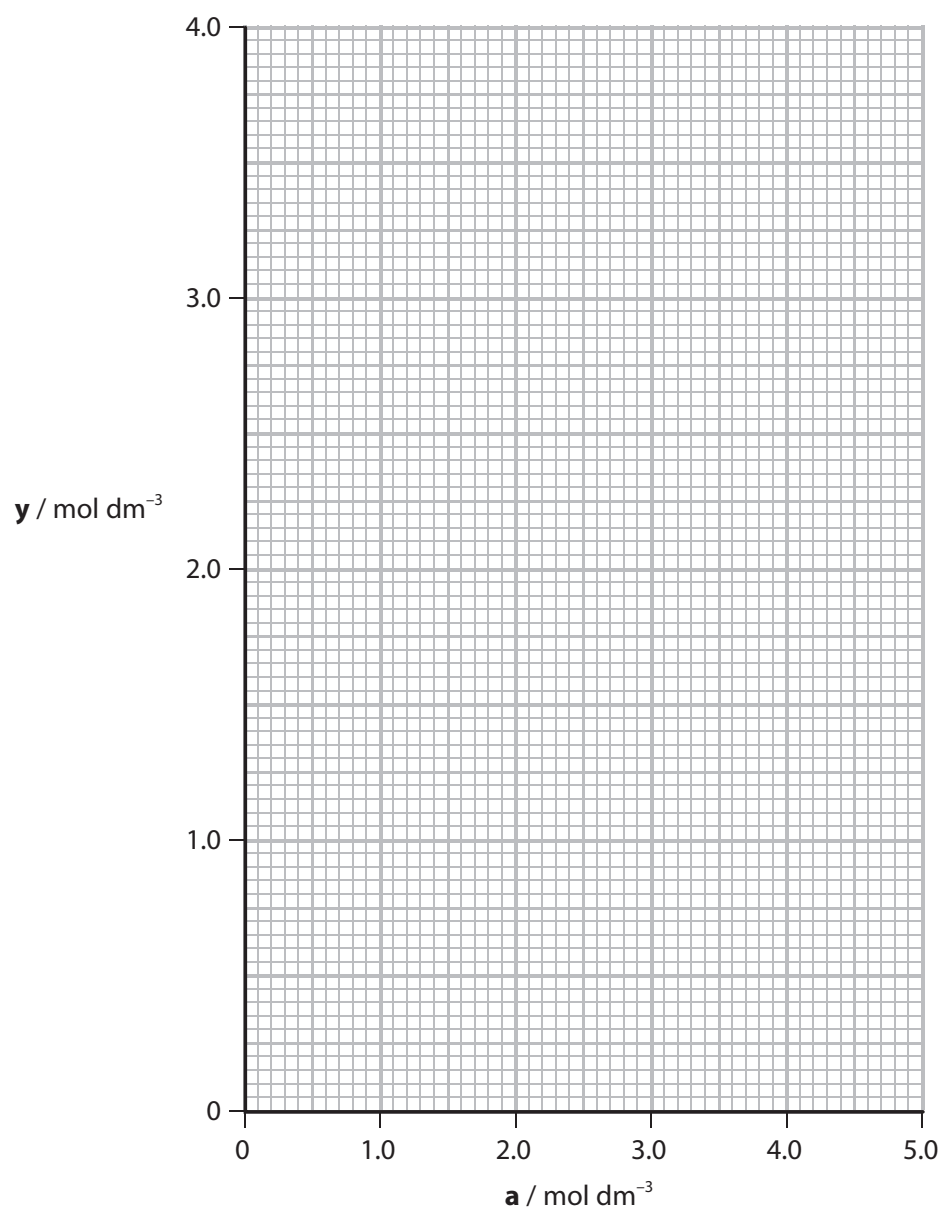
- (i) Complete the table to give the two remaining values of  $y \text{ mol dm}^{-3}$ , to **two** decimal places.

(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)

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- (d) One of the experiments in part (b) was repeated using the same molar quantities of hydrogen and iodine but in a 500 cm<sup>3</sup> flask instead of the 1 dm<sup>3</sup> 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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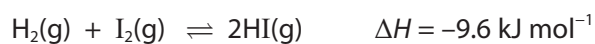
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(e) The equation for the reaction between hydrogen and iodine is



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

(2)

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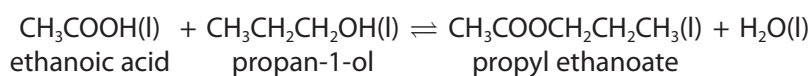
(ii) On your graph in (b)(ii), draw and label the line you would expect if the experiment was carried out at 1000 K instead of 760 K.

(1)

**(Total for Question 9 = 16 marks)**



- 8 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.

- $6.0\text{ cm}^3$  of ethanoic acid (0.105 mol),  $6.0\text{ cm}^3$  of propan-1-ol (0.080 mol) and  $2.0\text{ cm}^3$  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  $250.0\text{ cm}^3$  using distilled water
- $25.0\text{ cm}^3$  samples of the **diluted** equilibrium mixture were titrated with a solution of sodium hydroxide, concentration  $0.200\text{ mol dm}^{-3}$ , using phenolphthalein as the indicator
- The mean titre was  $23.60\text{ cm}^3$  of  $0.200\text{ mol dm}^{-3}$  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  $2.0\text{ cm}^3$  of dilute hydrochloric acid contained  $0.00400\text{ mol}$  of  $\text{H}^+(\text{aq})$  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  $0.105\text{ mol}$  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)

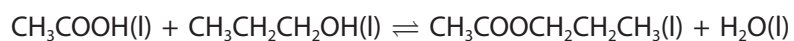
Moles of propan-1-ol at equilibrium.....

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)

.....

.....

.....

.....

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

(2)

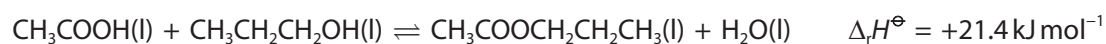
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- (g) A student repeated the experiment, but left the mixture in a water bath at 40 °C until equilibrium was reached.



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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**(Total for Question 8 = 19 marks)**



# MARK SCHEMES

official Pearson Edexcel mark schemes



| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                       | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(a)(i)         | <p><b>The only correct answer is D</b> (<math>\frac{p(\text{SO}_3)}{p(\text{SO}_2) p(\text{O}_2)^{1/2}}</math>, <math>\text{atm}^{-1/2}</math>)</p> <p><i>A is not correct because the expression is correct but the units are incorrect</i></p> <p><i>B is not correct because both the expression and the units are incorrect</i></p> <p><i>C is not correct because the expression is not correct</i></p> | (1)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                               | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(a)(ii)        | <p><b>The only correct answer is B</b> (temperature)</p> <p><i>A is not correct because this would affect the rate of the reaction but not the value of <math>K_p</math></i></p> <p><i>C is not correct because this would affect the rate of the reaction but not the value of <math>K_p</math></i></p> <p><i>D is not correct because this would affect the rate of the forward reaction temporarily but not the value of <math>K_p</math></i></p> | (1)  |



| Question Number | Acceptable Answer                                                                                                                                                                                                                                                                                                        | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(b)            | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• <math>\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow \text{SO}_3 + \text{V}_2\text{O}_4</math></li> <li>• <math>\text{V}_2\text{O}_4 + \frac{1}{2} \text{O}_2 \rightarrow \text{V}_2\text{O}_5</math></li> </ul> | <p>(1)</p> <p>(1) Allow multiples<br/>Allow reversible arrows<br/>Ignore state symbols even if incorrect<br/>Do not award equations with electrons</p> <p>Allow for 2 marks any balanced equations showing formation of a lower oxidation state oxide by reaction with <math>\text{SO}_2</math> and a higher oxidation state by reaction with <math>\text{O}_2</math><br/>Example<br/><math>2\text{SO}_2 + \text{V}_2\text{O}_5 \rightarrow 2\text{SO}_3 + \text{V}_2\text{O}_3</math><br/><math>\text{V}_2\text{O}_3 + \text{O}_2 \rightarrow \text{V}_2\text{O}_5</math></p> <p>Allow use of <math>2\text{VO}_2</math> instead of <math>\text{V}_2\text{O}_4</math> in both equations</p> | (2)  |



| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(c)            | <p><b>The only correct answer is C</b> (<math>\text{VO}_2^+</math> yellow +5 )</p> <p><i>A is not correct as although the colour is correct for <math>\text{VO}_2^+</math> the oxidation number is incorrect</i></p> <p><i>B is not correct as although the oxidation number of vanadium is correct, <math>\text{VO}^{2+}</math> is blue</i></p> <p><i>D is not correct as <math>\text{VO}^{2+}</math> as although the colour of the solution is blue, the oxidation number of vanadium in <math>\text{VO}^{2+}</math> is +4</i></p> | (1)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                     | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(d)            | <p><b>The only correct answer is A</b> (+1.76 V)</p> <p><i>B is not correct because the <math>E^\circ</math> values have been added</i></p> <p><i>C is not correct because the <math>E^\circ</math> values have been added and the sign reversed</i></p> <p><i>D is not correct because this is the value for the reverse reaction</i></p> | (1)  |

(Total for Question 7 = 6 marks)



| Question Number | Answer                                                                                                                                                                                                                                    | Additional Guidance                                             | Mark |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|------|
| 7(a)(i)         | <ul style="list-style-type: none"> <li><math>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})]}</math></li> </ul> | Ignore omission of state symbols<br>Do not award round brackets | (1)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                         | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Mark |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(a)(ii)        | <ul style="list-style-type: none"> <li>expression for equilibrium amounts in terms of x (1)</li> <li>use equilibrium amounts in <math>K_c</math> expression and rearrangement to find amount of product / express as correct quadratic expression (1)</li> <li>calculation of amount of product (1)</li> </ul> | <p><u>Example of calculation</u></p> <p>Amounts<br/> <math>\text{CH}_3\text{CH}_2\text{OH} = 1.2 - x</math>; <math>\text{CH}_3\text{COOH} = 1.2 - x</math>;<br/> <math>\text{CH}_3\text{COOCH}_2\text{CH}_3 = x</math>; <math>\text{H}_2\text{O} = x</math></p> $K_c = \frac{(x\text{Ovol})^2}{[(1.2-x)\text{Ovol}]^2}$ $K_c = (x^2\text{Ovol}^2) \div ((1.2-x)^2 \text{Ovol}^2)$ $K_c = x^2 \div (1.2-x)^2 \text{ so } x^2 = K_c \times (1.2-x)^2$ $x = \sqrt{K_c \times (1.2-x)}$ <p><math>x=0.6349801.52915</math>; <math>x=0.41525=0.42</math><br/>         (So amounts of each product = 0.42 (mol) )<br/>         Allow use of quadratic equation for M2<br/>         Allow M2 for expression without inclusion of volume<br/>         Correct answer with no working scores 3 marks<br/>         Ignore SF except 1 SF<br/>         Ignore negative amounts<br/>         Allow alternative methods<br/>         Allow TE throughout (a)(ii) for use of <math>x / (1.2-x)^2</math> in <math>K_c</math> expression</p> | (3)  |



| Question Number | Answer                                                                                                                                                                                                                                                                   | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(b)(i)         | <p><b>The only correct answer is C (120° and 109.5°)</b></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)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                           | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(b)(ii)        | <p><b>The only correct answer is D (atm<sup>-1</sup>)</b></p> <p><i>A is incorrect because it is the inverse of the units for K<sub>C</sub></i></p> <p><i>B is incorrect because it is the units for K<sub>C</sub></i></p> <p><i>C is incorrect because it is the inverse of the units for K<sub>p</sub></i></p> | (1)  |

(Total Question 7 = 8 marks)

| Question Number | Answer                                                                                                                                                                                                                                                                                         | Additional Guidance                                                                                                                               | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 7(b)(iii)       | <p>An explanation that makes reference to the following points</p> <ul style="list-style-type: none"> <li><i>K<sub>p</sub> will remain unchanged</i></li> <li><i>equilibrium moves to right-hand side (to keep K<sub>p</sub> constant) / only temperature affects K<sub>p</sub></i></li> </ul> | <p>Allow answers in terms of quotient</p> <p>Do not award M2 if K<sub>p</sub> is described as changing</p> <p>Ignore comments related to rate</p> | (2)  |



| Question Number   | Answer                                                                                                                                                                                                                                                              | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Mark                                |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-----------------------------------|---------------------|-------------------------------------|---------------|------|------|-----|-----------------|------|------|------|-------------------|------|------|-----|---------------|-------------------------------|-------------------------------|------------------------------|------------------|-------------------------------|-------------------------------|------------------------------|-----|
| 4(a)              | <ul style="list-style-type: none"> <li>calculation of moles at equilibrium</li> <li>calculation of mole fractions</li> <li>calculation of partial pressures</li> <li>expression for <math>K_p</math></li> <li>value of <math>K_p</math> <b>and</b> units</li> </ul> | <p><u>Example of calculation</u></p> <table border="1"> <thead> <tr> <th></th><th>C<sub>2</sub>H<sub>4</sub>(g)</th><th>H<sub>2</sub>O(g)</th><th>C<sub>2</sub>H<sub>5</sub>OH(g)</th></tr> </thead> <tbody> <tr> <td>Initial moles</td><td>90.0</td><td>54.0</td><td>0.0</td></tr> <tr> <td>Change in moles</td><td>−4.5</td><td>−4.5</td><td>+4.5</td></tr> <tr> <td>Equilibrium moles</td><td>85.5</td><td>49.5</td><td>4.5</td></tr> <tr> <td>Mole fraction</td><td><math>85.5 \div 139.5</math><br/>= 0.6129</td><td><math>49.5 \div 139.5</math><br/>= 0.3548</td><td><math>4.5 \div 139.5</math><br/>= 0.0323</td></tr> <tr> <td>Partial pressure</td><td><math>0.6129 \times 60</math><br/>= 36.77</td><td><math>0.3548 \times 60</math><br/>= 21.29</td><td><math>0.0323 \times 60</math><br/>= 1.94</td></tr> </tbody> </table> <p>(1) <math>K_p = \frac{p(\text{C}_2\text{H}_5\text{OH})}{p(\text{C}_2\text{H}_4) p(\text{H}_2\text{O})}</math><br/> Allow <math>p</math> inside bracket<br/> Allow <math>pp</math><br/> Allow without brackets<br/> Do not award square brackets</p> <p>(1) <math>K_p = \frac{1.94}{(36.77 \times 21.29)}</math><br/> = <math>0.00248 / 2.48 \times 10^{-3} / 0.0025 / 2.5 \times 10^{-3} \text{ atm}^{-1}</math><br/> Allow TE throughout<br/> Ignore SF except for 1 SF<br/> Correct answer with no working scores M1 to M3 and M5<br/> <math>K_p</math> with no early rounding = <math>0.00247 / 2.47 \times 10^{-3}</math></p> |                                     | C <sub>2</sub> H <sub>4</sub> (g) | H <sub>2</sub> O(g) | C <sub>2</sub> H <sub>5</sub> OH(g) | Initial moles | 90.0 | 54.0 | 0.0 | Change in moles | −4.5 | −4.5 | +4.5 | Equilibrium moles | 85.5 | 49.5 | 4.5 | Mole fraction | $85.5 \div 139.5$<br>= 0.6129 | $49.5 \div 139.5$<br>= 0.3548 | $4.5 \div 139.5$<br>= 0.0323 | Partial pressure | $0.6129 \times 60$<br>= 36.77 | $0.3548 \times 60$<br>= 21.29 | $0.0323 \times 60$<br>= 1.94 | (5) |
|                   | C <sub>2</sub> H <sub>4</sub> (g)                                                                                                                                                                                                                                   | H <sub>2</sub> O(g)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | C <sub>2</sub> H <sub>5</sub> OH(g) |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
| Initial moles     | 90.0                                                                                                                                                                                                                                                                | 54.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 0.0                                 |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
| Change in moles   | −4.5                                                                                                                                                                                                                                                                | −4.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | +4.5                                |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
| Equilibrium moles | 85.5                                                                                                                                                                                                                                                                | 49.5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 4.5                                 |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
| Mole fraction     | $85.5 \div 139.5$<br>= 0.6129                                                                                                                                                                                                                                       | $49.5 \div 139.5$<br>= 0.3548                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $4.5 \div 139.5$<br>= 0.0323        |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |
| Partial pressure  | $0.6129 \times 60$<br>= 36.77                                                                                                                                                                                                                                       | $0.3548 \times 60$<br>= 21.29                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | $0.0323 \times 60$<br>= 1.94        |                                   |                     |                                     |               |      |      |     |                 |      |      |      |                   |      |      |     |               |                               |                               |                              |                  |                               |                               |                              |     |



| Question Number | Answer                                                                                                                                                                                                                                                                                                                    | Additional Guidance                                                                                                                                                                                             | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 4(b)(i)         | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>(so increased pressure) will increase the yield of ethanol (1)</li> <li>because the position of equilibrium will move to the RHS as there are less moles / molecules / particles (of gas) on the RHS (1)</li> </ul> | <p>Mark points independently</p> <p>Allow because the position of equilibrium will move to the products side as there are less moles / molecules (of gas) on the RHS</p> <p>Allow forward direction for RHS</p> | (2)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Mark |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 4(b)(ii)        | <p><b>The only correct answer is C</b> (decreasing the temperature)</p> <p><i>A is not correct as changing the catalyst might affect the rate at which equilibrium was established, but would have no effect on the value of <math>K_p</math></i></p> <p><i>B is not correct because although increasing the pressure would allow equilibrium to be established faster, this would not affect the value of <math>K_p</math></i></p> <p><i>D is not correct because increasing the volume would mean that equilibrium would be established more slowly, but this would not affect the value of <math>K_p</math>.</i></p> | (1)  |

(Total for Question 4 = 8 marks)



| Question Number | Answer                                                                                                                                                                                                                                                              | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 6(a)            | <p><b>The only correct answer is D</b></p> <p><i>A is not correct because it is the 2<sup>nd</sup> most soluble</i></p> <p><i>B is not correct because it is the 3<sup>rd</sup> most soluble</i></p> <p><i>C is not correct because it is the least soluble</i></p> | (1)  |

| Question Number | Acceptable Answer                                                                                                                                                                                               | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                   | Mark |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 6(b)(i)         | <p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> <li>the concentration of a solid / Mg(OH)<sub>2</sub> is constant / unchanged / changes very little</li> </ul> | <p>Allow magnesium hydroxide is in a different phase / state (from the aqueous ions)</p> <p>Ignore solids do not appear in K<sub>c</sub> 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"> <li><math>\text{mol}^3 \text{ dm}^{-9}</math></li> </ul> | Allow<br>$\text{dm}^{-9} \text{ mol}^3$<br>$\text{mol}^3/\text{dm}^9$<br>Ignore any working before the answer | (1)  |

| Question Number | Acceptable Answer                                                                                                                                                                                                                                                                                                          | Additional Guidance                                                                                                                                                                                                                                              | Mark |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 6(b)(iii)       | <ul style="list-style-type: none"> <li>use of <math>\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})]</math> (1)</li> <li>calculation of <math>\Delta_{\text{sol}}H</math> (1)</li> </ul> | Example of calculation<br>$\Delta_{\text{sol}}H = -1920 + 2(-460) - (-2842)$<br>Allow this shown on a Hess cycle<br><br>$\Delta_{\text{sol}}H = (+)2 \text{ (kJ mol}^{-1}\text{)}$<br>Allow $2000 \text{ J mol}^{-1}$<br>Correct answer with no working scores 2 | (2)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                    | Mark |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 6(b)(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 |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 6(b)(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"> <li>equilibrium position shifts to the left / in the backwards direction (1)</li> <li>because increased concentration / amount of magnesium ions / <math>\text{Mg}^{2+}(\text{aq})</math> (1)</li> </ul> <p>Addition of dilute hydrochloric acid:</p> <ul style="list-style-type: none"> <li>equilibrium shifts to the right / in the forwards direction (1)</li> <li>because the hydrogen ions / <math>\text{H}^+(\text{aq})</math> react with / neutralise / removes the hydroxide ions / <math>\text{OH}^-(\text{aq})</math> (1)</li> </ul> | <p>Mark independently</p> <p>Allow more magnesium hydroxide precipitates / forms</p> <p>Allow more <math>\text{Mg}^{2+}</math> ions present</p> <p>Allow more magnesium hydroxide dissolves / dissociates</p> <p>Allow <math>\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})</math></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 <math>K_c</math> changing once only</p> | (4)  |

**(Total for Question 6 = 10 marks)**

| Question Number | Answer                                                                                                                                                                                                                                                                          | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(a)(i)        | <ul style="list-style-type: none"> <li>(M1) calculation of mole fractions (1)</li> <li>(M2) calculation of partial pressures (1)</li> <li>(M3) expression of <math>K_p</math> (1)</li> <li>(M4) calculation of value of <math>K_p</math> (1)</li> <li>(M5) units (1)</li> </ul> | <p>Example of calculation</p> $X_{\text{SO}_2} = 0.0160 \div 0.8 = 0.02(0)$ $X_{\text{O}_2} = 0.0120 \div 0.8 = 0.015$ $X_{\text{SO}_3} = 0.772 \div 0.8 = 0.965$<br>$P_{\text{SO}_2} = 0.02(0) \times 2.40 = 0.048$ $P_{\text{O}_2} = 0.015 \times 2.40 = 0.036$ $P_{\text{SO}_3} = 0.965 \times 2.40 = 2.316$<br>$K_p = \frac{(P_{\text{SO}_3})^2}{(P_{\text{SO}_2})^2 \times P_{\text{O}_2}}$ <p>Do not award square brackets</p> $K_p = \frac{2.316^2}{0.048^2 \times 0.036} =$<br>$K_p = 64668.4 \dots / 6.46684 \dots \times 10^4$ $K_p = 65000 / 6.5 \times 10^4 / 64700 / 6.47 \times 10^4$ <p>Ignore SF except 1</p><br>$\text{atm}^{-1}$<br><p>Correct final answer without working scores<br/>(5)</p> | (5)  |

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

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Additional Guidance                                                                                                                           | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(a)(iii)      | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>to ensure that <math>K_p</math> stays the same/ quotient stays the same<br/> <b>or</b><br/>               only temperature changes the value of <math>K_p</math> (1)</li> <li>the number of (sulfur dioxide) molecules decreases<br/> <b>Either</b><br/>               because the equilibrium shifts to the right<br/>               or<br/>               because one of the denominators (oxygen) has increased so the other denominator (sulfur dioxide) has to decrease (1)</li> </ul> | <p>Standalone marks</p> <p>Allow concentration changes have no effect on the value of <math>K_p</math></p> <p>Allow 'moles' for molecules</p> | (2)  |



| Question Number | Answer                                                                                                                                                                                                                                                                                         | Additional Guidance                                                                                                                                                                                                                                                     | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(b)           | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>equilibrium position shifts to the left (1)</li> <li>(because) the hydroxide ions combine with/neutralise the H<sup>+</sup> ions to remove them from the equilibrium (1)</li> </ul> | <p>'Equilibrium moves to the right' scores (0)</p> <p>Allow<br/>Hydroxide ions react with H<sup>+</sup> ions to make water/<br/>hydroxide ions react with H<sup>+</sup> ions to reduce their number/concentration</p> <p>Ignore reference to 'more products formed'</p> | (2)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Mark |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(c)           | <p><b>The only correct answer is D</b> <math>K_c = \frac{[\text{H}_2\text{O}]^4}{[\text{H}_2]^4}</math></p> <p><b>A</b> is not correct because the solids should not be included in the expression and the powers of the remaining substituents have been omitted</p> <p><b>B</b> is not correct because the solids should not be included in the expression</p> <p><b>C</b> is not correct because the powers of the substituents have been omitted</p> | (1)  |

(Total Question 10 = 11 marks)



| Question Number | Answer                                                                                                                                                                                                                                                                                                                    | Additional Guidance                                                                                                                                                                                                  | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(a)(i)        | <p>An answer that makes reference to the following point:</p> <ul style="list-style-type: none"> <li>carbon / solid has no (vapour / partial) pressure<br/><b>or</b><br/>(partial) pressure of carbon / solid is constant<br/><b>or</b><br/>carbon does not contribute to the overall pressure (of the system)</li> </ul> | <p>Allow the reaction is heterogeneous <b>and</b> (partial) pressure of a pure solid is not included (in K<sub>p</sub> 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 |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 10(a)(ii)       | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>there are fewer moles / molecules / particles of <b>gas</b> on the left / reactant side (1)</li> <li>so equilibrium position/ it moves / shifts to the left / reactant side (1)</li> </ul> | <p>Allow 2 moles / molecules of <b>gas</b> on right and 1 mole / molecule on left</p> <p>M2 is conditional on M1 <b>or</b> the idea of fewer particles on the left / decreasing the value of the quotient / Q</p> <p>Do not allow any indication of K<sub>p</sub> changing</p> | (2)  |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                         | Additional Guidance                                                                                                          | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|------|
| 10(a)(iii)      | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>(forward) reaction is endothermic<br/><b>and</b><br/>so equilibrium constant / K<sub>p</sub> increases as temperature increases (1)</li> <li>so equilibrium position / it moves / shifts to the right / product side (1)</li> </ul> | <p>Ignore references to ΔG and ΔS</p> <p>M2 is conditional on M1 <b>or</b> endothermic or equilibrium constant increases</p> | (2)  |



| Question Number                         | Answer                                                                                                                                                                                                                                                        | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Mark                 |                     |                    |       |               |      |   |   |           |                    |      |      |                                         |  |  |  |               |                     |                    |                    |                       |                         |                      |                      |     |
|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------|--------------------|-------|---------------|------|---|---|-----------|--------------------|------|------|-----------------------------------------|--|--|--|---------------|---------------------|--------------------|--------------------|-----------------------|-------------------------|----------------------|----------------------|-----|
| 10(a)(iv)                               | <ul style="list-style-type: none"> <li>calculation of moles of each substance at equilibrium (1)</li> <li>calculation of partial pressure of each substance (1)</li> <li>calculation of <math>K_p</math> (1)</li> <li>units (stand alone mark) (1)</li> </ul> | <p>Example of calculation:</p> <table border="1"> <thead> <tr> <th></th><th>H<sub>2</sub>O(g)</th><th>H<sub>2</sub>(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 x 2.0 = 0.20994</td><td>0.4475 x 2.0 = 0.895</td><td>0.4475 x 2.0 = 0.895</td></tr> </tbody> </table> <p> <math>K_p = \frac{0.895 \times 0.895}{0.20994}</math><br/>           = 3.815 / 3.82 / 3.8 atm         </p> <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 <sub>2</sub> O(g) | H <sub>2</sub> (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 x 2.0 = 0.20994 | 0.4475 x 2.0 = 0.895 | 0.4475 x 2.0 = 0.895 | (4) |
|                                         | H <sub>2</sub> O(g)                                                                                                                                                                                                                                           | H <sub>2</sub> (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 x 2.0 = 0.20994                                                                                                                                                                                                                                       | 0.4475 x 2.0 = 0.895                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.4475 x 2.0 = 0.895 |                     |                    |       |               |      |   |   |           |                    |      |      |                                         |  |  |  |               |                     |                    |                    |                       |                         |                      |                      |     |



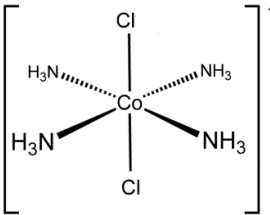
| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Additional Guidance                                                                                                                                                                                                                                           | Mark       |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 10(b)           | <ul style="list-style-type: none"> <li>the quotient / Q:<br/> <math display="block">\frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]} = \frac{2 \times 2}{1 \times 1} = 4</math>, which is larger than K<sub>c</sub><br/> <b>or</b><br/>           (since K<sub>c</sub> = 1) the concentrations of the products must be equal to the concentrations of the reactants at equilibrium <b>(1)</b> </li> <li>the concentrations of CO<sub>2</sub> and H<sub>2</sub> / products need to decrease<br/> <b>and</b><br/>           those of CO and H<sub>2</sub>O / reactants need to increase <b>(1)</b> </li> <li>so reaction shifts to the left <b>(1)</b></li> </ul> | <p>Allow amounts / moles / (partial) pressures for concentrations</p> <p>Allow calculated K<sub>c</sub> / the quotient / Q will be greater than 1</p> <p>Allow shift so that there is 1.5 mol of each substance</p> <p>M3 conditional on some explanation</p> | <b>(3)</b> |

**(Total for Question 10 = 12 marks)**

| Question Number | Answer                                                                                                                                                                                                                                                                             | Additional Guidance |  |                                                                                                                                                                                                                                                                                                 |                           |                           | Mark                     |                           |     |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|---------------------------|--------------------------|---------------------------|-----|
| 5(a)(i)         | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"><li>calculate moles of each element</li><li>show ratio by division by smallest number <b>and</b> show RFM of <math>\text{CoN}_4\text{H}_{12}\text{Cl}_3</math> is 233.4</li></ul> | (1)                 |  | mol                                                                                                                                                                                                                                                                                             | Co                        | N                         | H                        | Cl                        | (2) |
|                 |                                                                                                                                                                                                                                                                                    |                     |  |                                                                                                                                                                                                                                                                                                 | $1.26 \div 58.9 = 0.0214$ | $1.20 \div 14.0 = 0.0857$ | $0.257 \div 1.0 = 0.257$ | $2.28 \div 35.5 = 0.0642$ |     |
|                 |                                                                                                                                                                                                                                                                                    |                     |  |                                                                                                                                                                                                                                                                                                 | ratio                     | $0.0214 / 0.0214 = 1$     | $0.0857 / 0.0214 = 4$    | $0.257 / 0.0214 = 12$     |     |
|                 |                                                                                                                                                                                                                                                                                    |                     |  | <p><math>(58.9 + (4 \times 14) + 12 + (3 \times 35.5)) = 233.4</math> (so molecular formula = <math>\text{CoN}_4\text{H}_{12}\text{Cl}_3</math>)</p> <p>M1 % of each element by mass in sample of 4.997 g<br/>M2 % of each element by comparing <math>\Sigma A_r</math> to <math>M_r</math></p> |                           |                           |                          |                           |     |

| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 5(a)(ii)        | <p>EITHER</p> <ul style="list-style-type: none"> <li>calculation of moles of AgCl / Cl<sup>-</sup> (1)</li> <li>calculation of moles of R (1)<br/><b>and</b><br/>show ratio is 1:1 (so one mole of R releases 1 mol of chloride ions)</li> </ul> <p><b>OR</b></p> <ul style="list-style-type: none"> <li>calculation of moles of R (1)</li> <li>calculation of moles of AgCl / Cl<sup>-</sup> (1)<br/><b>and</b><br/>show ratio is 1:1 (so one mole of R releases 1 mol of chloride ions)</li> </ul> | <p><u>Example of calculation</u></p> <p>moles of AgCl = <math>0.614 \div 143.4 = 4.2817 \times 10^{-3}</math> mol</p> <p>moles of R = <math>1.00 \div 233.4 = 4.2845 \times 10^{-3}</math> mol</p> <p><math>4.2845 \times 10^{-3}</math> mol : <math>4.2817 \times 10^{-3}</math> mol <math>\approx</math> 1:1, (so 1 mol of R releases 1 mol of chloride ions)</p> <p>Do not award 3Cl<sup>-</sup> ions</p> <p>moles of R = <math>1.00 \div 233.4 = 4.2845 \times 10^{-3}</math> mol</p> <p>moles of AgCl = <math>0.614 \div 143.4 = 4.2817 \times 10^{-3}</math> mol</p> <p><math>4.2845 \times 10^{-3}</math> mol : <math>4.2817 \times 10^{-3}</math> mol <math>\approx</math> 1:1, (so 1 mol of R releases 1 mol of chloride ions)</p> <p>Do not award 3Cl<sup>-</sup> ions</p> <p>Ignore SF except 1 SF</p> | (2)  |



| Question Number | Answer                                                                                                                                                                                                                                                | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Mark |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 5(a)(iii)       | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>octahedral shape (around cobalt) using wedges (1)</li> <li>correct number and type of ligand (1)</li> <li>correct overall charge (1)</li> </ul> |  <p>Allow dashed line for dashed wedges<br/>         Allow '+' on cobalt<br/>         Allow correct calculation of charge from incorrect ligands<br/>         Ignore position of Cl ligands relative to NH<sub>3</sub> ligands<br/>         Ignore connectivity<br/>         Ignore omission of square brackets<br/>         Ignore additional chloride ion (to form R)<br/>         Arrows if drawn must be pointing towards the cobalt</p> | (3)  |

| Question Number | Answer                                                                                                                                                                                                                                                              | Additional Guidance                                                                                                                    | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|------|
| 5(b)(i)         | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>forward and backward reactions proceed at the same rate (1)</li> <li>concentration of reactants and products remain constant / remain the same (1)</li> </ul> | <p>Do not award rates of forward and backward reactions are constant</p> <p>Accept resulting in no observable change in the system</p> | (2)  |



| Question Number | Answer                                                                                                                                                                                                                                                                                                                                                                                                                           | Additional Guidance                                                                                                                                                                                                                                            | Mark |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 5(b)(ii)        | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• (The most stable is) [Co(EDTA)]<sup>2-</sup>(aq) as it has the larger (log) K<sub>c</sub> / eqm lies furthest to RHS (1)</li> <li>• 2 moles (of ions) forms 7 moles (of product in EDTA equation) (1)</li> <li>• (greater) increase in entropy (change of the system) / ΔS<sub>sys</sub> is positive (1)</li> </ul> | <p>Ignore calculated K<sub>c</sub> values</p> <p>Allow more moles of product than reactant<br/>Allow species<br/>Do not award 'molecules'</p> <p>Do not award increase in entropy if clear that it is referring to the EDTA (complex) and not the reaction</p> | (3)  |

(Total for Question 5 = 12 marks)



| Question Number | Answer                                                                                                                                                                                                                                                 | Additional Guidance                                                                                                                                                                                                                                                                                                                                                  | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(a)            | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>there are fewer moles / molecules / particles of (gas) on the right (1)</li> <li>so (equilibrium) yield of ammonia increases (1)</li> </ul> | <p>Any reference to equilibrium constant changing scores (0) overall</p> <p>Allow 4 moles / molecules of gas on the left <b>and</b> 2 moles / molecules on right</p> <p>Allow 'equilibrium shifts to the right'<br/>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)  |

| Question Number | Answer                                                                                                                                                                                     | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                 | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(b)            | <ul style="list-style-type: none"> <li>rearrangement of formula (1)</li> <li>substitution of correct values (1)</li> <li>calculation of <math>K_c</math> (1)</li> <li>units (1)</li> </ul> | <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 <math>\Delta n</math></p> <p>Stand alone mark<br/><math>\text{dm}^6 \text{mol}^{-2}</math> or <math>\text{mol}^{-2} \text{dm}^6</math></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)  |



| Question Number  | Answer                                                                                                                                                                                                                                                                                                                                  | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Mark                        |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|----------------|----------------|-----------------|-------------|-----|-----|---|---------|----------------------|----------------------------|------|------------------|--------------------------|--|--|------------------|-----------------------------|-----------------------------|-----------------------------|-----|
| 9(c)             | <ul style="list-style-type: none"> <li>calculation of eqm moles (1)</li> <li>expressions for 3 partial pressures (1)</li> <li>substitution of values into <math>K_p</math> expression (1)</li> <li>rearrangement of <math>K_p</math> expression (1)</li> <li>calculation of total pressure <b>and</b> answer to 1 / 2 SF (1)</li> </ul> | <p><u>Example of calculation</u></p> <table border="1"> <tr> <td></td><td>N<sub>2</sub></td><td>H<sub>2</sub></td><td>NH<sub>3</sub></td></tr> <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<br/>= 0.85</td><td>3.0 - (3 x 0.15)<br/>= 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><math>\frac{0.85}{3.7} \times P</math></td><td><math>\frac{2.55}{3.7} \times P</math></td><td><math>\frac{0.30}{3.7} \times P</math></td></tr> </table> $K_p = 7.76 \times 10^{-5} = \frac{\left(\frac{0.30 \times P}{3.7}\right)^2}{\left(\frac{0.85 \times P}{3.7}\right)\left(\frac{2.55 \times P}{3.7}\right)^3}$ $7.76 \times 10^{-5} = \frac{0.087419}{P^2}$ $P^2 = 1126.5 \text{ (atm}^2\text{)}$ $P = 33.564$ $= 34 / 30 \text{ (atm)}$ <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> |                             | N <sub>2</sub> | H <sub>2</sub> | NH <sub>3</sub> | Initial mol | 1.0 | 3.0 | - | Eqm mol | 1.0 - 0.15<br>= 0.85 | 3.0 - (3 x 0.15)<br>= 2.55 | 0.30 | Total mol at eqm | 0.85 + 2.55 + 0.30 = 3.7 |  |  | Partial pressure | $\frac{0.85}{3.7} \times P$ | $\frac{2.55}{3.7} \times P$ | $\frac{0.30}{3.7} \times P$ | (5) |
|                  | N <sub>2</sub>                                                                                                                                                                                                                                                                                                                          | H <sub>2</sub>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | NH <sub>3</sub>             |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |
| Initial mol      | 1.0                                                                                                                                                                                                                                                                                                                                     | 3.0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | -                           |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |
| Eqm mol          | 1.0 - 0.15<br>= 0.85                                                                                                                                                                                                                                                                                                                    | 3.0 - (3 x 0.15)<br>= 2.55                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 0.30                        |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |
| Total mol at eqm | 0.85 + 2.55 + 0.30 = 3.7                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                             |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |
| Partial pressure | $\frac{0.85}{3.7} \times P$                                                                                                                                                                                                                                                                                                             | $\frac{2.55}{3.7} \times P$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | $\frac{0.30}{3.7} \times P$ |                |                |                 |             |     |     |   |         |                      |                            |      |                  |                          |  |  |                  |                             |                             |                             |     |



| Question Number | Answer                                                                                                                                                                                                                                         | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(d)            | <ul style="list-style-type: none"> <li>substitution of numbers into expression</li> <li>evaluation of <math>\Delta H/R</math> and <math>1/T_1 - 1/T_2</math></li> <li>rearrangement of expression</li> <li>evaluation of expression</li> </ul> | <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)  |

(Total for Question 9 = 15 marks)

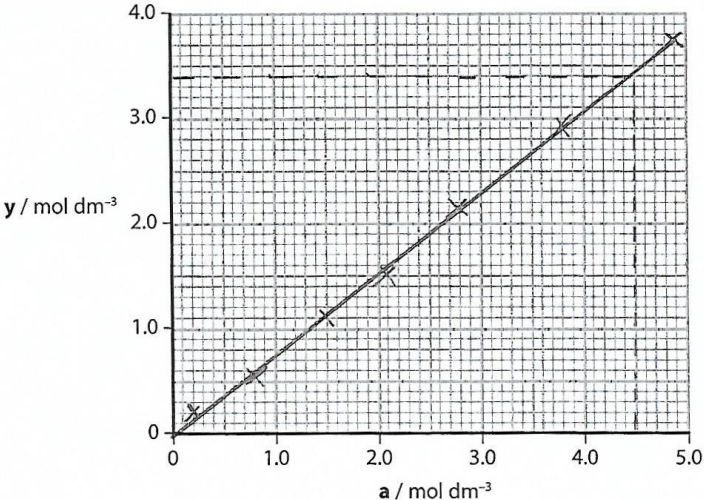


|                |                                                                                        |                                                                      |            |
|----------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------|------------|
| <b>9(a)(i)</b> | $(K_c =) \frac{[\text{HI}(\text{g})]^2}{[\text{H}_2(\text{g})][\text{I}_2(\text{g})]}$ | Ignore missing state symbols or units<br>Do not award round brackets | <b>(1)</b> |
|----------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------|------------|

| Question Number | Acceptable Answers                                                                                                                           | Additional Guidance                                                                  | Mark       |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|------------|
| <b>9(a)(ii)</b> | $(K_c =) \frac{4y^2}{(a-y)^2}$<br><ul style="list-style-type: none"> <li>Numerator term correct</li> <li>Denominator term correct</li> </ul> | Allow square brackets<br>Allow $(2y)^2$<br>Allow $(a^2 - 2ay + y^2)$ or $(a-y)(a-y)$ | <b>(2)</b> |

| Question Number | Acceptable Answers                                                            | Additional Guidance | Mark       |
|-----------------|-------------------------------------------------------------------------------|---------------------|------------|
| <b>9(b)(i)</b>  | <ul style="list-style-type: none"> <li>both values correct to 2 DP</li> </ul> | 1.13<br>2.93        | <b>(1)</b> |

| Question Number | Acceptable Answers                                                                                                                                        | Additional Guidance                                                                                                                                                                   | Mark       |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>9(b)(ii)</b> | <ul style="list-style-type: none"> <li>All 7 points plotted correctly</li> <li>Appropriate straight line of best fit, drawn through the origin</li> </ul> | Allow TE for incorrect values from 9(b)(i)<br>Do not allow all points above or below the line of best fit<br>Allow line of best fit to intersect one square either side of the origin | <b>(2)</b> |

| Question Number | Acceptable Answers                                                                                                                                                                                                                                                             | Additional Guidance                                                                                                                                                                                                                                                                                                                | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(b)(iii)       | <ul style="list-style-type: none"> <li>co-ordinates correctly read off the line on graph (1)</li> </ul>  <ul style="list-style-type: none"> <li>gradient correctly calculated (1)</li> </ul> | <p>At least 1 line must be shown on the graph to indicate selection of co-ordinates</p> <p><u>Example of calculation</u></p> $\frac{3.40 - 0.00}{4.50 - 0.00} = \text{gradient of graph}$ <p>Gradient = 0.76</p> <p>Ignore SF except 1SF<br/>Do not allow units for the gradient<br/>Allow a value from 0.71 to 0.81 inclusive</p> | (2)  |

| Question Number | Acceptable Answers                                                                                                                                                                                              | Additional Guidance                                                                                                                                                                                                                                                         | Mark |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(b)(iv)        | <ul style="list-style-type: none"> <li><math>\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = \text{gradient} / \frac{y}{a}</math> (1)</li> <li>re-arrangement of expression and calculation of K<sub>c</sub> (1)</li> </ul> | <p>Example of calculation</p> $\frac{\sqrt{K_c}}{2 + \sqrt{K_c}} = 0.76$ <p>K<sub>c</sub> = 40.1 / 40 (no units)</p> <p>Allow TE on gradient from part (b)(iii)</p> $K_c = [(2 \times \text{grad}) / (1 - \text{grad})]^2$ <p>Correct answer with no working scores (2)</p> | (2)  |

| Question Number | Acceptable Answers                                                                  | Additional Guidance                                                                                                                                                                                                                | Mark |
|-----------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 9(c)            | <ul style="list-style-type: none"> <li>hydrogen is flammable / explosive</li> </ul> | <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 |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|------|
| 9(d)            | <ul style="list-style-type: none"> <li>Faster rate of reaction / increased rate (1)</li> <li>K<sub>c</sub> unchanged (1)</li> </ul> | <p>Ignore references to shifting position of equilibrium</p> | (2)  |

| Question Number | Acceptable Answers                                                                                                                                                                                                                              | Additional Guidance                                                                | Mark       |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|------------|
| <b>9(e)(i)</b>  | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>• (<math>K_c</math> is) smaller / decreases / gets less <b>(1)</b></li> <li>• (forward) reaction is exothermic <b>(1)</b></li> </ul> | <p>Allow reverse/backwards reaction is endothermic</p> <p>MP2 dependent on MP1</p> | <b>(2)</b> |

| Question Number | Acceptable Answers                                                                                                                            | Additional Guidance         | Mark       |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------|
| <b>9(e)(ii)</b> | <ul style="list-style-type: none"> <li>• straight line drawn on the graph with a less steep gradient (and goes through the origin)</li> </ul> | Do not allow if lines cross | <b>(1)</b> |

**(Total for Question 9 = 16 marks)**

| Question Number | Acceptable Answers                                                                                                                           | Additional Guidance                                                                                                 | Mark       |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------|
| <b>8(a)</b>     | Any one from:<br><br>Catalyst / speeds up reaction / increases rate / increases rate of attainment of equilibrium / lowers activation energy | Ignore any mention of protonation or mechanism for catalysis<br>Do not award additional incorrect types of reaction | <b>(1)</b> |

| Question Number | Acceptable Answers                                                                                                                                                                                                                                        | Additional Guidance                                                                                                                                                                                                                                                                                                                                                                                                                                       | Mark       |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>8(b)(i)</b>  | <ul style="list-style-type: none"> <li>calculation of moles of <math>\text{H}^+</math> in <math>25.0 \text{ cm}^3</math> <b>(1)</b></li> <li>calculation of moles of <math>\text{H}^+</math> in <math>250 \text{ cm}^3</math> flask <b>(1)</b></li> </ul> | Ignore SF throughout 8(b)(i) to 8(c)(ii) except 1 SF, which should be penalised once only<br><br><u>Example of calculation:</u><br><br>(moles NaOH = $0.200 \times \frac{23.60}{1000}$ )<br>= $0.00472 \text{ (mol)}$ (= mol $\text{H}^+$ in $25.0 \text{ cm}^3$ )<br><br>(= $10 \times 0.00472$ ) = $0.0472 \text{ (mol)}$ (in $250 \text{ cm}^3$ )<br><br>Allow TE for M2 on moles of NaOH<br><br>Correct answer with or without working scores 2 marks | <b>(2)</b> |

| Question Number | Acceptable Answers                                                                                                        | Additional Guidance                                                                                                      | Mark       |
|-----------------|---------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|------------|
| <b>8(b)(ii)</b> | <ul style="list-style-type: none"> <li>subtracts moles of <math>\text{H}^+</math> in HCl from answer to (b)(i)</li> </ul> | <u>Example of calculation:</u><br><br>$0.0472 - 0.00400 = 0.0432 \text{ (mol)}$<br><br>Allow TE on answer to part (b)(i) | <b>(1)</b> |



| Question Number | Acceptable Answers                                                                                             | Additional Guidance                                                                                              | Mark |
|-----------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|------|
| 8(c)(i)         | <ul style="list-style-type: none"> <li>calculation of moles of CH<sub>3</sub>COOH that have reacted</li> </ul> | <p>Example of calculation:</p> $(0.105 - 0.0432) = 0.0618$ <p>Allow TE on part (b)(ii) unless negative value</p> | (1)  |

| Question Number | Acceptable Answers                                                                                                                                                                                                                                                                                                  | Additional Guidance                                                                                                                                         | Mark |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 8(c)(ii)        | <ul style="list-style-type: none"> <li>calculation of equilibrium moles of CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>OH (1)</li> <li>calculation of equilibrium moles of CH<sub>3</sub>COOCH<sub>2</sub>CH<sub>2</sub>CH<sub>3</sub> (1)</li> <li>calculation of equilibrium moles of H<sub>2</sub>O (1)</li> </ul> | <p>Example of calculation:</p> $0.0800 - 0.0618 = 0.0182$ $0.0618$ $0.111 + 0.0618 = 0.1728$ <p>Allow TE on answer to part (c)(i) unless negative value</p> | (3)  |

| Question Number | Acceptable Answers                                                                                                                                           | Additional Guidance                                                              | Mark |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------|
| 8(d)(i)         | $(K_c =) \frac{[\text{CH}_3\text{COOCH}_2\text{CH}_2\text{CH}_3][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}]}$ | <p>IGNORE state symbols even if incorrect</p> <p>Do not award round brackets</p> | (1)  |



| Question Number | Acceptable Answers                                                                                                                                                                                                                                         | Additional Guidance                                                                                                                                                                                                                                                             | Mark |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 8(d)(ii)        | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>Same number of moles/molecules on both sides of the equation (1)</li> <li>(so) volume / V cancels in <math>K_c</math> expression (1)</li> </ul> | <p>2 marks could be scored by a correct mathematical expression showing V or <math>\text{dm}^3</math> cancel</p> <p>Allow same number of terms on top and bottom of <math>K_c</math> expression</p> <p>Allow units cancel out</p> <p>Allow "all divided by the same volume"</p> | (2)  |

| Question Number | Acceptable Answers                                                                                                                                          | Additional Guidance                                                                                                                                                                                                                                                                | Mark |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 8(d)(iii)       | <ul style="list-style-type: none"> <li>calculates value of <math>K_c</math> (1)</li> <li>final value of <math>K_c</math> quoted to 2 or 3 SF (1)</li> </ul> | <p><u>Example of calculation</u></p> $K_c = \frac{(0.0618) \times (0.1728)}{(0.0432) \times (0.0182)} = 13.58241758$ $= 14 / 13.6 \text{ (no units)}$ <p>Correct answer with no working gains full marks</p> <p>Ignore units</p> <p>No TE on wrong <math>K_c</math> expression</p> | 2    |



| Question Number | Acceptable Answers                                                                                                                                                                                                                                                                                             | Additional Guidance                                                                            | Mark       |
|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|------------|
| <b>8(e)</b>     | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>the equilibrium shifts to the left<br/><b>or</b><br/>the mixture absorbs carbon dioxide from the atmosphere (1)</li> <li>so the mixture is (becoming more) acidic / the acid reforms (1)</li> </ul> | <p>Mark independently</p> <p>Allow no longer alkaline<br/>Do not award just "pH decreases"</p> | <b>(2)</b> |

| Question Number | Acceptable Answers                                                                                                                                                                                                                                                                                                | Additional Guidance                                                                                                                                                                                 | Mark       |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>8(f)</b>     | <p>An explanation that makes reference to the following points:</p> <ul style="list-style-type: none"> <li>carry out / repeat experiment <b>and</b> leave for longer than a week (1)</li> <li>the titre value / <math>K_c</math> value will remain unchanged (if equilibrium has been established) (1)</li> </ul> | <p>Ignore pH probes / checking pH</p> <p>Allow repeat experiment <b>and</b> check titres within first week</p> <p>Allow moles / concentration are unchanged<br/>Ignore just "results unchanged"</p> | <b>(2)</b> |

| Question Number | Acceptable Answers                                                                                                                                                                                                                                                                                                  | Additional Guidance                                                                                                                  | Mark       |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>8(g)</b>     | <p>An answer that makes reference to the following points:</p> <ul style="list-style-type: none"> <li><math>K_c</math> value will be greater than that calculated in (d)(iii) (1)</li> <li>because the (forward) reaction is endothermic<br/><b>or</b><br/>backward / reverse reaction is exothermic (1)</li> </ul> | <p>M2 depends on M1</p> <p>Ignore<br/>References to the equilibrium position shifting to the right (with increasing temperature)</p> | <b>(2)</b> |

**(Total for Question 8 = 19 marks)****TOTAL FOR PAPER = 120 MARKS**