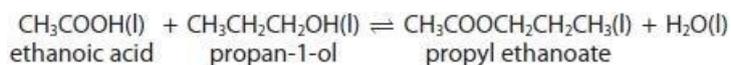




Questions

Q1.

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



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

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

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

(1)

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

(2)

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

(1)



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

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

(1)

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

(3)

Moles of propan-1-ol at equilibrium

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Moles of propyl ethanoate at equilibrium

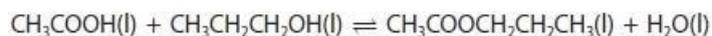
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Moles of water at equilibrium

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



(1)

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

(2)

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(iii) Calculate the value of K_c .

Give your answer to an appropriate number of significant figures.

(2)

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

Give a possible explanation for this observation.

(2)

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

(2)

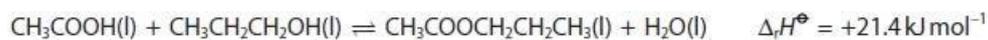
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(g) A student repeated the experiment, but left the mixture in a water bath at 40 °C until equilibrium was reached.



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

(2)

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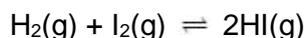
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(Total for question = 19 marks)



Q2.

The gas phase reaction between hydrogen and iodine is reversible.



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

(1)

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

(2)

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

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

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

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

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

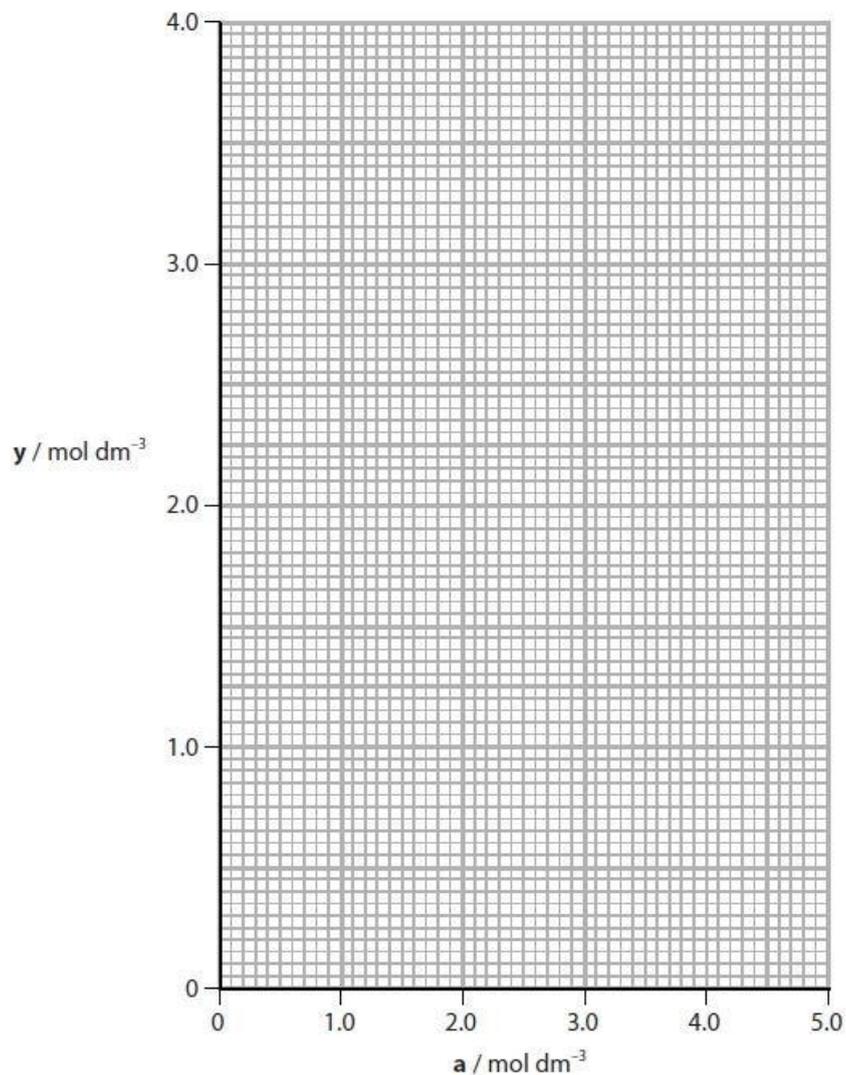
(1)

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



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

(2)



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

(2)



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

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

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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 cm³ flask instead of the 1 dm³ flask.

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

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



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

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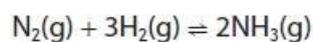
- (ii) On your graph in (b)(ii), draw and label the line you would expect if the experiment was carried out at 1000 K instead of 760 K. (1)

(Total for question = 16 marks)



Q3.

Ammonia is manufactured by the Haber Process.



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

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

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

Give your answer to an appropriate number of significant figures.

You must show your working.

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

(5)

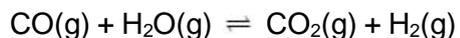
(Total for question = 5 marks)



Q4.

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

Carbon monoxide reacts with steam.



At 1100 K, $K_c = 1.00$

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

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

(3)

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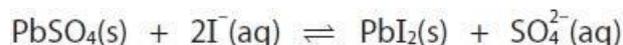
(Total for question = 3 marks)



Q5.

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

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



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

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

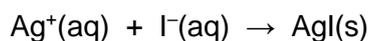
In an experiment, K_c may be determined by adding excess lead(II) sulfate to 25.0 cm³ of 0.100 mol dm⁻³ sodium iodide.

The volume remains constant at 25.0 cm³.

The mixture is left to reach equilibrium at room temperature.

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

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



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

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

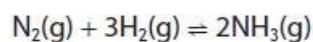
(7)

(Total for question = 7 marks)



Q6.

Ammonia is manufactured by the Haber Process.



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

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

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

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

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

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

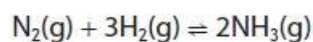
(4)

(Total for question = 4 marks)



Q7.

Ammonia is manufactured by the Haber Process.



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

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

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

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

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

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

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

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

(4)

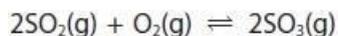
(Total for question = 4 marks)



Q8.

This question is about equilibrium systems.

Sulfur dioxide and oxygen form an equilibrium with sulfur trioxide.



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

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

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

Include units, if appropriate.

(5)

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

(1)

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

(2)

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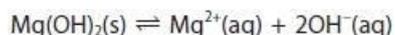
(Total for question = 8 marks)



Q9.

This question is about the solubility of metal hydroxides.

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



The equilibrium constant, K_c , for this reaction is

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

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

(1)

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(ii) Give the units for K_c .

(1)

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

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

(2)

**Q10.**

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

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



The expression for the equilibrium constant, K_p , is

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

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

(1)

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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)

(Total for question = 9 marks)



Q11.

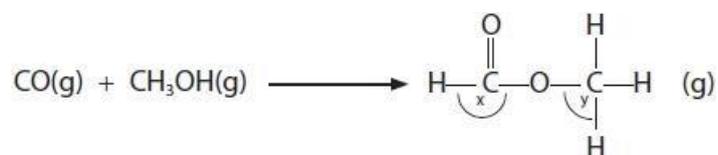
Answer the questions with a cross in the boxes you think are correct . If you change your mind about an answer, put a line through the box and then mark your new answer with a cross .

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



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

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



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

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

(1)

(ii) The reaction often forms an equilibrium mixture.

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

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

(1)

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

(2)

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(Total for question = 4 marks)



Q12.

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



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

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

(1)

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

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

(3)

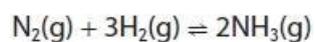
Amount of $\text{CH}_3\text{COOCH}_2\text{CH}_3$ =
Amount of H_2O =

(Total for question = 4 marks)



Q13.

Ammonia is manufactured by the Haber Process.



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

The pressure used in the Haber Process is 200 atm.

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

(2)

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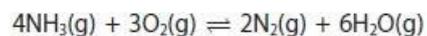
(Total for question = 2 marks)



Q14.

This question is about the oxidation of ammonia.

One equation for the oxidation of ammonia is



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

Expression

(2)

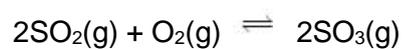
Units

(Total for question = 2 marks)



Q15.

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



(1)

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

(1)

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

(Total for question = 2 marks)