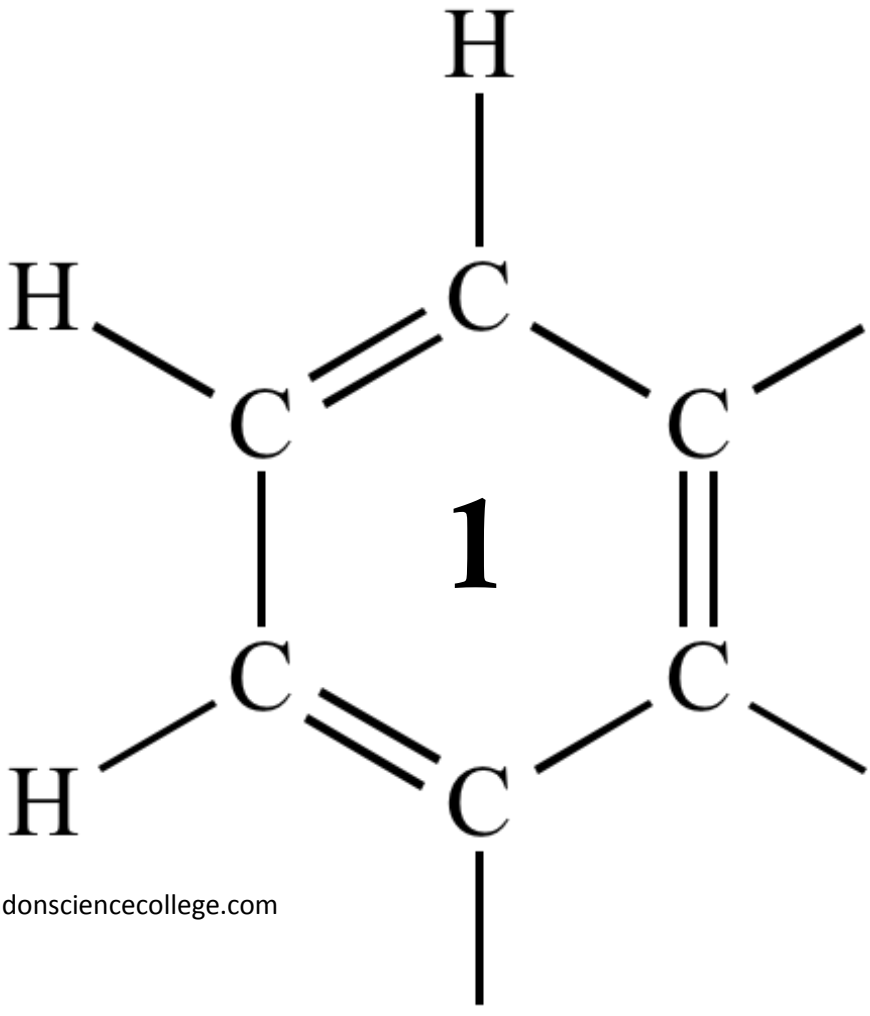
LONDON SCIENCE COLLEGE

OCR AS CHEMISTRY

MODULE 3

EQUILIBRIUM - KC



1 A pale brown mixture of NO_2 and N_2O_4 is allowed to reach equilibrium in a sealed gas syringe according to the following equation.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

When the plunger is pushed further into the syringe the pressure increases and the mixture becomes paler in colour.

When the syringe is placed in a hot oven the mixture becomes darker in colour.

Which of the following statements is correct?

A NO_2 is brown and the forward reaction is exothermic. ⬭

B NO_2 is brown and the forward reaction is endothermic. ⬭

C NO_2 is colourless and the forward reaction is exothermic. ⬭

D NO_2 is colourless and the forward reaction is endothermic. ⬭

(Total 1 mark)

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

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

(a) Write an expression for the equilibrium constant K_c for this equilibrium.
Deduce the units of K_c.

Expression .....

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Units .....

(2)

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

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

Give your answer to an appropriate number of significant figures.

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(2)
(Total 4 marks)

3 **A** and **B** react together in this reversible reaction.

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

A mixture of 10 mol of **A** and 10 mol of **B** were left to reach equilibrium. The equilibrium mixture contained 4 mol of **B**.

What is the total amount, in moles, of substances in the equilibrium mixture?

A 14 ⬭

B 16 ⬭

C 18 ⬭

D 20 ⬭

(Total 1 mark)

4 Hydrogen is produced by the reaction of methane with steam. The reaction mixture reaches a state of dynamic equilibrium.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

Which of the following shows how the equilibrium yield of hydrogen and the value of the equilibrium constant are affected by the changes shown?

	Change	Effect on equilibrium yield of $H_2(g)$	Effect on value of K_c	
A	Increase pressure	decrease	decrease	⬭
B	Add a catalyst	increase	no effect	⬭
C	Increase temperature	increase	increase	⬭
D	Remove CO(g) as formed	increase	increase	⬭

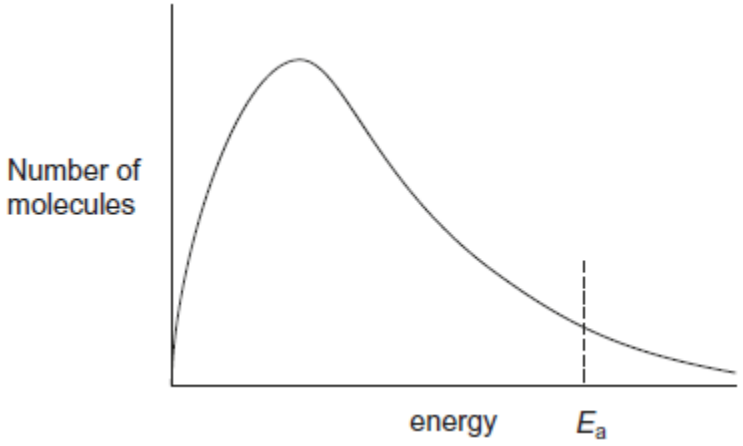
(Total 1 mark)

5 Methanol, for use as a fuel, can be produced by the reaction of carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -90 \text{ kJ mol}^{-1}$$

The reaction is typically carried out at 300 °C and 3×10^7 Pa, in the presence of a catalyst.

(a) The graph shows the Maxwell–Boltzmann distribution for a mixture of carbon monoxide and hydrogen at 300 °C.



(i) Sketch a second curve on the graph to show the distribution of molecular energies in this mixture at a higher temperature.

(1)

(ii) Explain with reference to both curves on the graph how a small change in temperature leads to a large change in the rate of reaction.

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(2)

(b) Both the rate of production and equilibrium yield of methanol are considered when choosing the most appropriate conditions for the operation of this process on an industrial scale.

(i) State and explain the effect of a higher pressure on the equilibrium yield of methanol.

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(3)

(ii) By considering both rate and yield, state why the reaction is carried out at a temperature of 300 °C rather than at a higher temperature.

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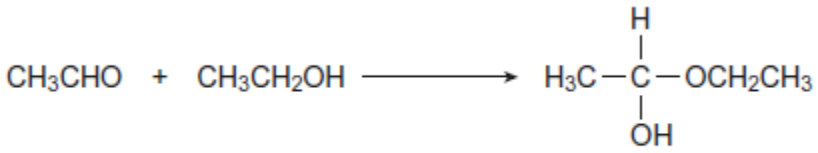
(2)
(Total 8 marks)

6 Hemiacetals and acetals are compounds formed by the reaction of aldehydes with alcohols, such as the reaction of ethanal with ethanol.



a hemiacetal

(a) (i) Use your knowledge of carbonyl mechanisms to suggest the name of the mechanism of this reaction.

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(1)

(ii) Outline how an ethanol molecule reacts with an ethanal molecule in the first step of this mechanism. Include two curly arrows to show the movement of electron pairs.

(2)

(b) The reaction produces a racemic mixture of chiral molecules.

(i) Explain the meaning of the term racemic mixture.

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(1)

(ii) State the relationship between two chiral molecules with the same structural formula.

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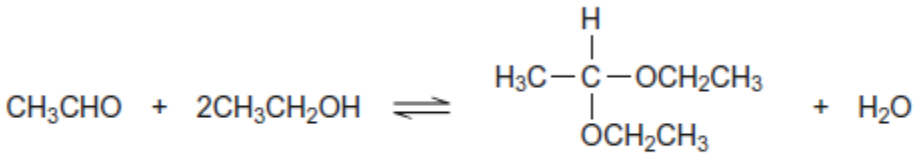
(1)

(c) In the presence of an acid catalyst such as dry hydrogen chloride, ethanal reacts with an excess of ethanol to form an acetal.

The overall reaction of ethanal with an excess of ethanol forms an equilibrium mixture as shown. All reactants and products are liquids.



an acetal

A mixture of 0.75 mol of ethanal and 5.00 mol of ethanol was left to reach equilibrium in the presence of dry hydrogen chloride at a given temperature. The equilibrium mixture contained 0.42 mol of the acetal.

(i) Calculate the amount, in moles, of ethanal and of ethanol in this equilibrium mixture.

Amount of ethanal ..... mol

Amount of ethanol ..... mol

Space for working .....

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(2)

(ii) In a different experiment using the same reaction as in part **(c)**, an equilibrium mixture was established at a given temperature.
This mixture contained 0.58 mol of ethanal, 3.76 mol of ethanol, 0.37 mol of the acetal and 0.65 mol of water in a total volume of 310 cm^3.

Write an expression for the equilibrium constant K_c for this reaction.
Calculate a value for K_c at this temperature. Give units with your answer.

K_c.....

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Calculation .....

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(4)

(d) Draw the structure of the acetal ($C_4H_8O_2$) formed by the reaction of ethanal with ethane-1,2-diol.

(1)
(Total 12 marks)

7 This question is about magnesium chloride.

(a) Write the equation, including state symbols, for the process corresponding to the enthalpy of solution of magnesium chloride.

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(1)

(b) Use these data to calculate the standard enthalpy of solution of magnesium chloride.

Enthalpy of lattice dissociation of $MgCl_2$	= +2493 kJ mol^{-1}
Enthalpy of hydration of magnesium ions	= –1920 kJ mol^{-1}
Enthalpy of hydration of chloride ions	= –364 kJ mol^{-1}

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(2)

(c) Solubility is the measure of how much of a substance can be dissolved in water to make a saturated solution. A salt solution is saturated when an undissolved solid is in equilibrium with its aqueous ions.

Use your answer to part **(b)** to deduce how the solubility of $MgCl_2$ changes as the temperature is increased.
Explain your answer.

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(3)
(Total 6 marks)

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

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

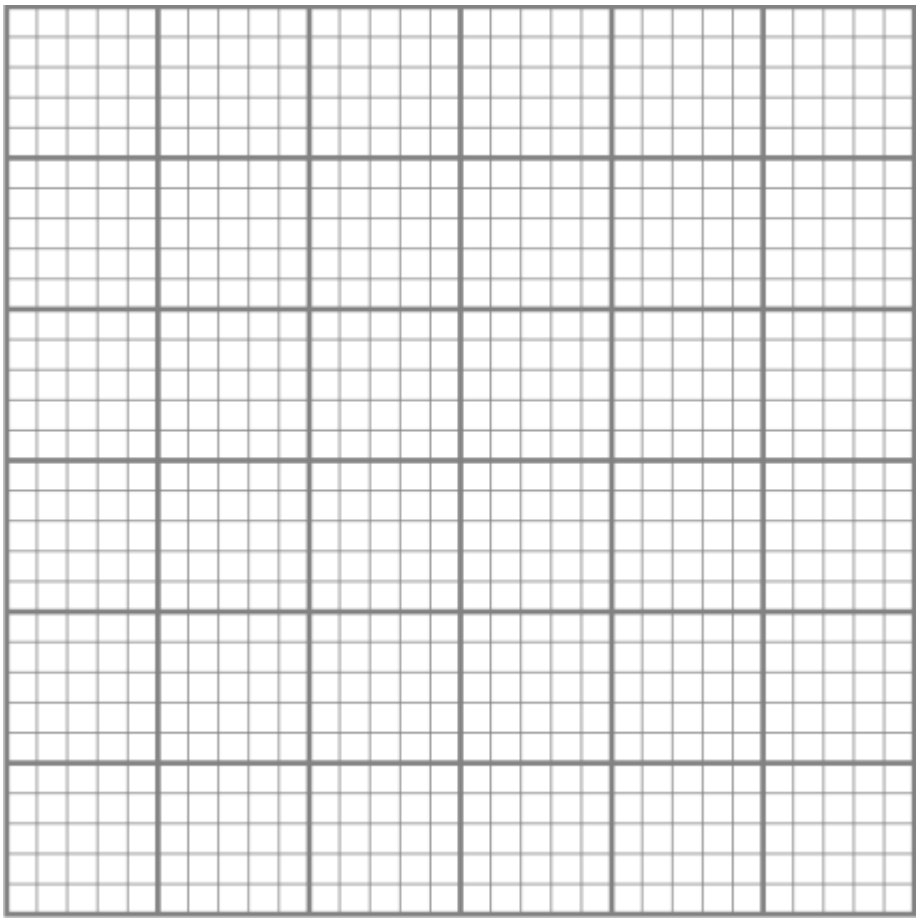
A student added a solution containing 0.50 mol of **X**(aq) to a solution containing 0.50 mol of **Y**(aq) and shook the mixture.
After 30 seconds, there was no further change in colour.
The amount of **Z**(aq) at equilibrium was 0.20 mol.

(a) Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

Amount of **X**(aq) = ... mol Amount of **Y**(aq) = ... mol

(2)

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



(3)

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

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

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

(3)

(d) The student added a few drops of **Y**(aq) to the equilibrium mixture of **X**(aq), **Y**(aq) and **Z**(aq) in part (c).

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

Colour change .....

Reason .....

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(3)

(e) The student warmed the equilibrium mixture from part (c).

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

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(1)
(Total 12 marks)

9 Dodecane ($C_{12}H_{26}$) is a hydrocarbon found in the naphtha fraction of crude oil. Dodecane can be used as a starting material to produce a wide variety of useful products. The scheme below shows how one such product, polymer **Y**, can be produced from dodecane.

Reaction **1**

$$C_{12}H_{26} \longrightarrow C_2H_4 + C_4H_8 + \mathbf{X}$$

Reaction **2**

$$nC_4H_8 \rightleftharpoons \left(\begin{array}{cc} H & CH_3 \\ | & | \\ C & C \\ | & | \\ CH_3 & H \end{array} \right)_n$$

Polymer **Y**

(a) Name the homologous series that both C_2H_4 and C_4H_8 belong to.
Draw a functional group isomer of C_4H_8 that does **not** belong to this homologous series.

Name .....

Functional group isomer

(2)

(b) Identify compound **X**.

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(1)

(c) Name polymer **Y**.

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(1)

(d) Reaction **1** is an example of thermal cracking and is carried out at a temperature of 750 °C.

State **one other** reaction condition needed.

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(1)

(e) Reaction **2** is exothermic. A typical compromise temperature of 200 °C is used industrially for this reaction.

Explain the effect of a change of temperature on both the position of equilibrium and the rate of reaction, and justify why a compromise temperature is used industrially.

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(6)

(Total 11 marks)

10 Many chemical processes release waste products into the atmosphere. Scientists are developing new solid catalysts to convert more efficiently these emissions into useful products, such as fuels. One example is a catalyst to convert these emissions into methanol. The catalyst is thought to work by breaking a H–H bond.

An equation for this formation of methanol is given below.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H = -49 \text{ kJ mol}^{-1}$$

Some mean bond enthalpies are shown in the following table.

Bond	C=O	C–H	C–O	O–H
Mean bond enthalpy / kJ mol^{-1}	743	412	360	463

(a) Use the enthalpy change for the reaction and data from the table to calculate a value for the H–H bond enthalpy.

H–H bond enthalpy = ... kJ mol^{-1}

(3)

(b) A data book value for the H–H bond enthalpy is 436 kJ mol^{-1}.

Suggest **one** reason why this value is different from your answer to part (a).

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(1)

(c) Suggest **one** environmental advantage of manufacturing methanol fuel by this reaction.

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(1)

(d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

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(3)

(e) Suggest why the catalyst used in this process may become less efficient if the carbon dioxide and hydrogen contain impurities.

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(1)

(f) In a laboratory experiment to investigate the reaction shown in the equation below, 1.0 mol of carbon dioxide and 3.0 mol of hydrogen were sealed into a container. After the mixture had reached equilibrium, at a pressure of 500 kPa, the yield of methanol was 0.86 mol.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

Calculate a value for K_p
Give your answer to the appropriate number of significant figures.
Give units with your answer.

K_p = ... Units = ...

(7)
(Total 16 marks)

11 Ethanol and ethanoic acid react reversibly to form ethyl ethanoate and water according to the equation:

$$CH_3COOH + CH_3CH_2OH \rightleftharpoons CH_3COOCH_2CH_3 + H_2O$$

A mixture of 8.00×10^{-2} mol of ethanoic acid and 1.20×10^{-1} mol of ethanol is allowed to reach equilibrium at 20 °C.

- The equilibrium mixture is placed in a graduated flask and the volume made up to 250 cm^3 with distilled water.
- A 10.0 cm^3 sample of this equilibrium mixture is titrated with sodium hydroxide added from a burette.
- The ethanoic acid in this sample reacts with 3.20 cm^3 of 2.00×10^{-1} mol dm^{-3} sodium hydroxide solution.

(a) Calculate the value for K_c for the reaction of ethanoic acid and ethanol at 20 °C.
Give your answer to the appropriate number of significant figures.

K_c .....

(6)

(b) A student obtained the titration results given in **Table 1**.

Table 1

	Rough	**1**	**2**	**3**
Final burette reading / cm^3	4.60	8.65	12.85	16.80
Initial burette reading / cm^3	0.10	4.65	8.65	12.85
Titre / cm^3				

Complete **Table 1**.

(1)

(c) Calculate the mean titre and justify your choice of titres.

Calculation

Mean titre = ...cm^3

Justification .....

.....

(2)

(d) The pH ranges of three indicators are shown in **Table 2**.

Table 2

Indicator	**pH range**
Bromocresol green	3.8–5.4
Bromothymol blue	6.0–7.6
Thymol blue	8.0–9.6

Select from **Table 2** a suitable indicator for the titration of ethanoic acid with sodium hydroxide.

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(1)

(e) The uncertainty in the mean titre for this experiment is ±0.15 cm^3.

Calculate the percentage uncertainty in this mean titre.

Percentage uncertainty = ... %

(1)

(f) Suggest how, using the same mass of ethanoic acid, the experiment could be improved to reduce the percentage uncertainty.

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(2)

(Total 13 marks)

12 When one mole of ammonia is heated to a given temperature, 50% of the compound dissociates and the following equilibrium is established.

$$NH_3(g) \rightleftharpoons \tfrac{1}{2}N_2(g) + \tfrac{3}{2}H_2(g)$$

What is the total number of moles of gas present in this equilibrium mixture?

A 1.5 ⬭

B 2.0 ⬭

C 2.5 ⬭

D 3.0 ⬭

(Total 1 mark)