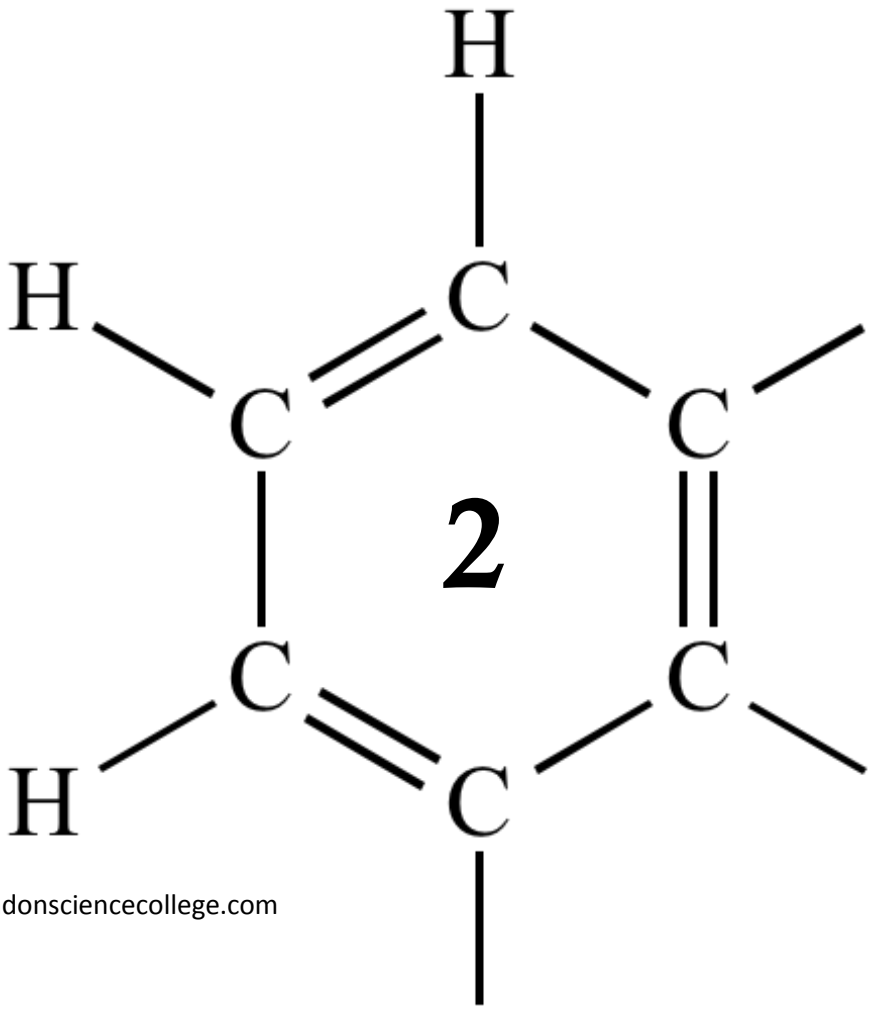
LONDON SCIENCE COLLEGE

OCR AS CHEMISTRY

MODULE 3

EQUILIBRIUM - KC



1 Hydrogen is produced in industry from methane and steam in a two-stage process.

(a) In the first stage, carbon monoxide and hydrogen are formed.
The equation for this reaction is

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

(i) Use Le Chatelier's principle to state whether a high or low temperature should be used to obtain the highest possible equilibrium yield of hydrogen from this first stage.
Explain your answer.

Temperature .....

Explanation .....

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(3)

(ii) Le Chatelier's principle suggests that a high pressure will produce a low yield of hydrogen in this first stage.

Explain, in terms of the behaviour of particles, why a high operating pressure is used in industry.

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(2)

(iii) A nickel catalyst is used in the first stage.

Explain why the catalyst is more effective when coated onto an unreactive honeycomb.

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(2)

(b) The second stage is carried out in a separate reactor. Carbon monoxide is converted into carbon dioxide and more hydrogen is formed.

The equation for this reaction is

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -41$ kJ mol^{-1}

Use Le Chatelier's principle to state the effect, if any, of a **decrease** in the total pressure on the yield of hydrogen in this second stage. Explain your answer.

Effect .....

Explanation .....

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(2)
(Total 9 marks)

2 Sulfur dioxide reacts with oxygen to form sulfur trioxide according to the equation

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(a) Write an expression for the equilibrium constant, K_c, for this reaction and deduce its units.

K_c .....

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Units .....

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(2)

(b) Samples of sulfur dioxide, oxygen and sulfur trioxide were added to a flask of volume 1.40 dm^3 and allowed to reach equilibrium at a given temperature.
The flask contained 0.0550 mol of sulfur dioxide and 0.0720 mol of sulfur trioxide at equilibrium.
K_c has the numerical value of 27.9 under these conditions.

Calculate the amount, in moles, of oxygen gas in this equilibrium mixture.

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(3)

(c) The experiment in (b) was repeated with the same amounts of sulfur dioxide, oxygen and sulfur trioxide at the same temperature but in a smaller flask.
The mixture was allowed to reach equilibrium.

(i) State the effect, if any, of using a smaller flask on the value of K_c

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(1)

(ii) State the effect, if any, of using a smaller flask on the amount of sulfur trioxide at equilibrium.
Explain your answer.

Effect .....

Explanation .....

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(3)
(Total 9 marks)

3 For many years, swimming pool water has been treated with chlorine gas. The chlorine is added to kill any harmful bacteria unintentionally introduced by swimmers. Pool managers are required to check that the chlorine concentration is high enough to kill the bacteria without being a health hazard to the swimmers.

When chlorine reacts with water in the absence of sunlight, the chlorine is both oxidised and reduced and an equilibrium is established.

(a) Write an equation for this equilibrium.

For each chlorine-containing species in the equation, write the oxidation state of chlorine below the species.

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(2)

(b) The pool manager maintains the water at a pH slightly greater than 7.0

Explain how this affects the equilibrium established when chlorine is added to water.

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(2)

(c) Explain why chlorine is used to kill bacteria in swimming pools, even though chlorine is toxic.

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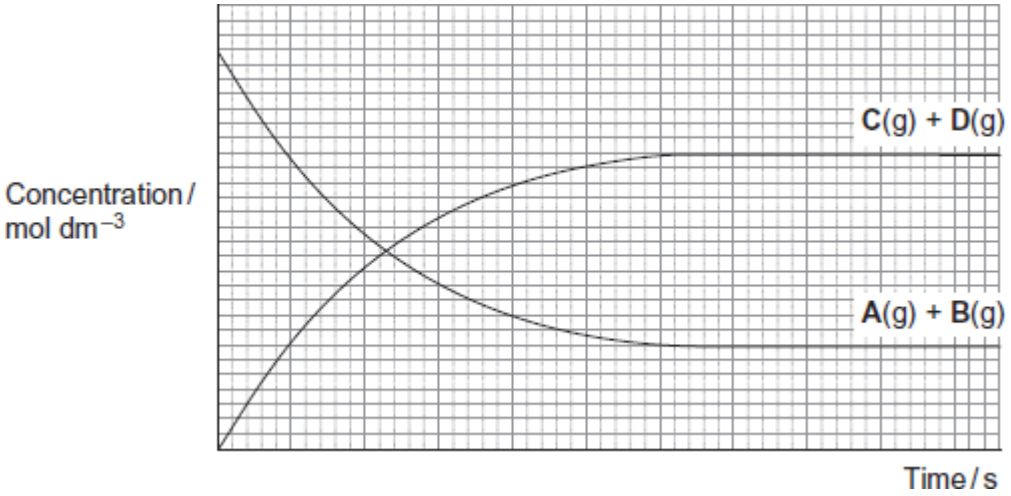
(2)

(Total 6 marks)

4 A dynamic equilibrium is established when gas **A** is mixed with gas **B** at a given temperature.

$$\mathbf{A}(g) + \mathbf{B}(g) \rightleftharpoons \mathbf{C}(g) + \mathbf{D}(g)$$

The figure below shows how the concentrations of reactants and products change with time.



(a) (i) On the appropriate axis of the figure, place an **X** to show the time when equilibrium is first established.

(1)

(ii) State how the rate of the forward reaction and the rate of the reverse reaction are related to each other at equilibrium.

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(1)

(b) Give the meaning of the term **dynamic** in the context of a dynamic equilibrium.

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(1)

(c) The total pressure on the system is increased at constant temperature.

(i) State and explain the effect, if any, of this change on the position of this equilibrium.

Effect .....

Explanation .....

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(2)

(ii) State and explain the effect, if any, of this change on the time taken to reach this equilibrium.

Effect .....

Explanation .....

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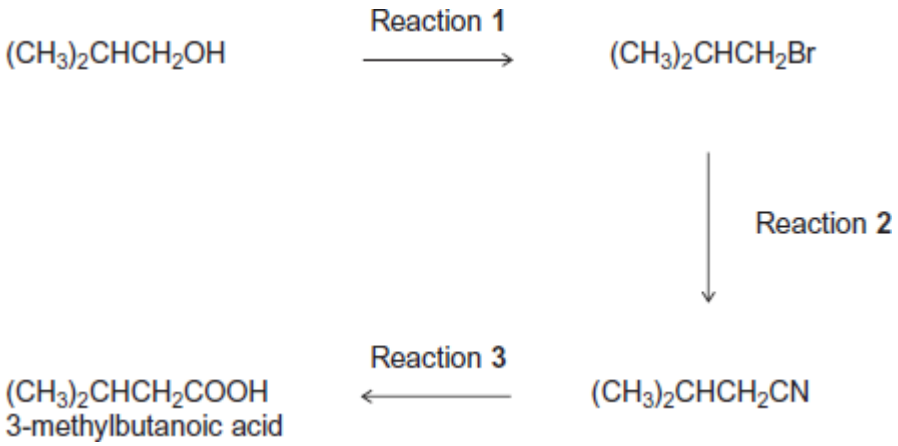
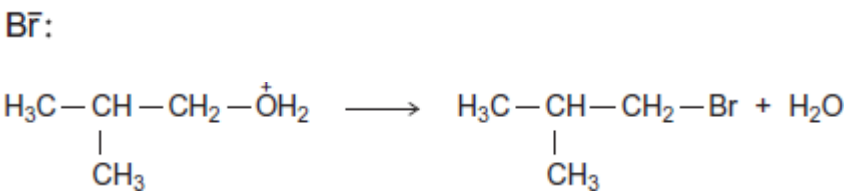
(3)
(Total 8 marks)

5 The carboxylic acid 3-methylbutanoic acid is used to make esters for perfumes.
The following scheme shows some of the reactions in the manufacture of this carboxylic acid.



(a) One of the steps in the mechanism for Reaction **1** involves the replacement of the functional group by bromine.

(i) Use your knowledge of organic reaction mechanisms to complete the mechanism for this step by drawing **two** curly arrows on the following equation.



(2)

(ii) Deduce the name of the mechanism in part (i).

Give the IUPAC name of $(CH_3)_2CHCH_2Br$

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(2)

(b) Reaction **3** is an acid-catalysed reaction in which water is used to break chemical bonds when the CN functional group is converted into the COOH functional group.
Infrared spectroscopy can be used to distinguish between the compounds in this reaction.

Deduce the name of the type of reaction that occurs in Reaction **3**.

Identify **one** bond in $(CH_3)_2CHCH_2CN$ and a **different** bond in $(CH_3)_2CHCH_2COOH$ that can be used with infrared spectroscopy to distinguish between each compound.
For each of these bonds, give the range of wavenumbers at which the bond absorbs.
Use **Table A** on the Data Sheet when answering this question.

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(3)

(c) When 3-methylbutanoic acid reacts with ethanol in the presence of an acid catalyst, an equilibrium is established. The organic product is a pleasant-smelling ester.

$$(CH_3)_2CHCH_2COOH + CH_3CH_2OH \rightleftharpoons \underset{\text{an ester}}{(CH_3)_2CHCH_2COOCH_2CH_3} + H_2O$$

The carboxylic acid is very expensive and ethanol is inexpensive. In the manufacture of this ester, the mole ratio of carboxylic acid to ethanol used is 1 to 10 rather than 1 to 1.

(i) Use Le Chatelier's principle to explain why a 1 to 10 mole ratio is used. In your explanation, you should **not** refer to cost.

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(Extra space) .....

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(3)

(ii) Explain how a catalyst increases the rate of a reaction.

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(Extra space) .....

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(2)

(Total 12 marks)

6 This question is about the gaseous equilibrium between compounds **E**, **F** and **G** as shown in the equation.

$$\mathbf{E}\,(g) + 2\mathbf{F}(g) \rightleftharpoons 2\mathbf{G}(g) \qquad \Delta H = -50\ \text{kJ mol}^{-1}$$

(a) A 2.0 mol sample of **E** was heated in a sealed container with a 1.0 mol sample of **F**. Equilibrium was established at a given temperature and the equilibrium mixture formed contained 0.80 mol of **G**.

Calculate the amount, in moles, of **E** and of **F** in this equilibrium mixture.

Moles of **E** .....

Moles of **F** .....

(2)

(b) Write an expression for the equilibrium constant K_c for this equilibrium.
State the units of K_c

Expression .....

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Units .....

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(2)

(c) A different mixture of **E** and **F** reached equilibrium at temperature T_1 in a container ofvolume 1.50 dm^3. This equilibrium mixture contained 2.50 mol of **E**, 1.20 mol of **F** and 0.85 mol of **G**.

Calculate a value of K_c for the equilibrium at temperature T_1

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(2)

(d) The mixture in part (c) was allowed to reach equilibrium at temperature T_1 in a different container of volume 3.00 dm^3.

State whether the amount of **G** in the equilibrium mixture will increase, decrease or stay the same. Explain your answer.

Effect on the amount of **G** .....

Explanation .....

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(3)

(e) The mixture in part (c) was allowed to reach equilibrium at temperature T_2 in the original container of volume 1.50 dm^3.

The value of K_c for the equilibrium was found to have increased.

State and explain which of T_1 or T_2 is the higher temperature.

Higher temperature .....

Explanation .....

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(3)
(Total 12 marks)

7 Ethanol is an important industrial compound.

(a) Ethanol can be produced by the hydration of ethene.
The equation for the equilibrium that is established is

$$H_2C{=}CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g) \qquad \Delta H = -42 \text{ kJ mol}^{-1}$$

The operating conditions for the process are a temperature of 300 °C and a pressure of 7 MPa.
Under these conditions, the conversion of ethene into ethanol is 5%.

(i) Identify the catalyst used in this process.
Deduce how an overall yield of 95% is achieved in this process without changing the operating conditions.

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(2)

(ii) Use your knowledge of equilibrium reactions to explain why a manufacturer might consider using an excess of steam in this process, under the same operating conditions.

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(3)

(iii) At pressures higher than 7 MPa, some of the ethene reacts to form a solid with a relative molecular mass greater than 5000.

Deduce the identity of this solid.

Give **one** other reason for **not** operating this process at pressures higher than 7 MPa.
Do **not** include safety reasons.

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(2)

(b) Write an equation for the reaction that has an enthalpy change that is the standard enthalpy of formation of ethanol.

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(2)

(c) When ethanol is used as a fuel, it undergoes combustion.

(i) Define the term *standard enthalpy of combustion*.

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(3)

(ii) Consider these bond enthalpy data.

	C–H	C–C	C–O	O=O	C=O	O–H
Bond enthalpy / kJ mol^{-1}	412	348	360	496	805	463

Use these data and the equation to calculate a value for the enthalpy of combustion of gaseous ethanol.

$$CH_3CH_2OH(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(g)$$

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(3)

(d) Gaseous ethanol can be used to convert hot copper(II) oxide into copper.

(i) Deduce the role of ethanol in this reaction.

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(1)

(ii) Draw the structure of the organic compound with M_r = 60 that is produced in this reaction.

(1)

(Total 17 marks)

8 When heated above 100 °C, nitrosyl chloride (NOCl) partly decomposes to form nitrogen monoxide and chlorine as shown in the equation.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$$

(a) A 2.50 mol sample of NOCl was heated in a sealed container and equilibrium was established at a given temperature. The equilibrium mixture formed contained 0.80 mol of NO.

Calculate the amount, in moles, of Cl_2 and of NOCl in this equilibrium mixture.

Moles of Cl_2 .....

Moles of NOCl .....

(2)

(b) A different mixture of NOCl, NO and Cl_2 reached equilibrium in a sealed container of volume 15.0 dm^3. The equilibrium mixture formed contained 1.90 mol of NOCl and 0.86 mol of NO at temperature *T*.

The value of K_c for the equilibrium at temperature *T* was 7.4×10^{-3} mol dm^{-3}.

(i) Write an expression for the equilibrium constant K_c

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(1)

(ii) Calculate the amount, in moles, of Cl_2 in this equilibrium mixture.

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(Extra space) .....

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(4)

(iii) Consider this alternative equation for the equilibrium at temperature *T*.

$$NOCl(g) \rightleftharpoons NO(g) + \frac{1}{2}Cl_2(g)$$

Calculate a value for the different equilibrium constant K_c for the equilibrium as shown in this alternative equation. Deduce the units of this K_c

Calculation .....

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Units .....

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(2)
(Total 9 marks)