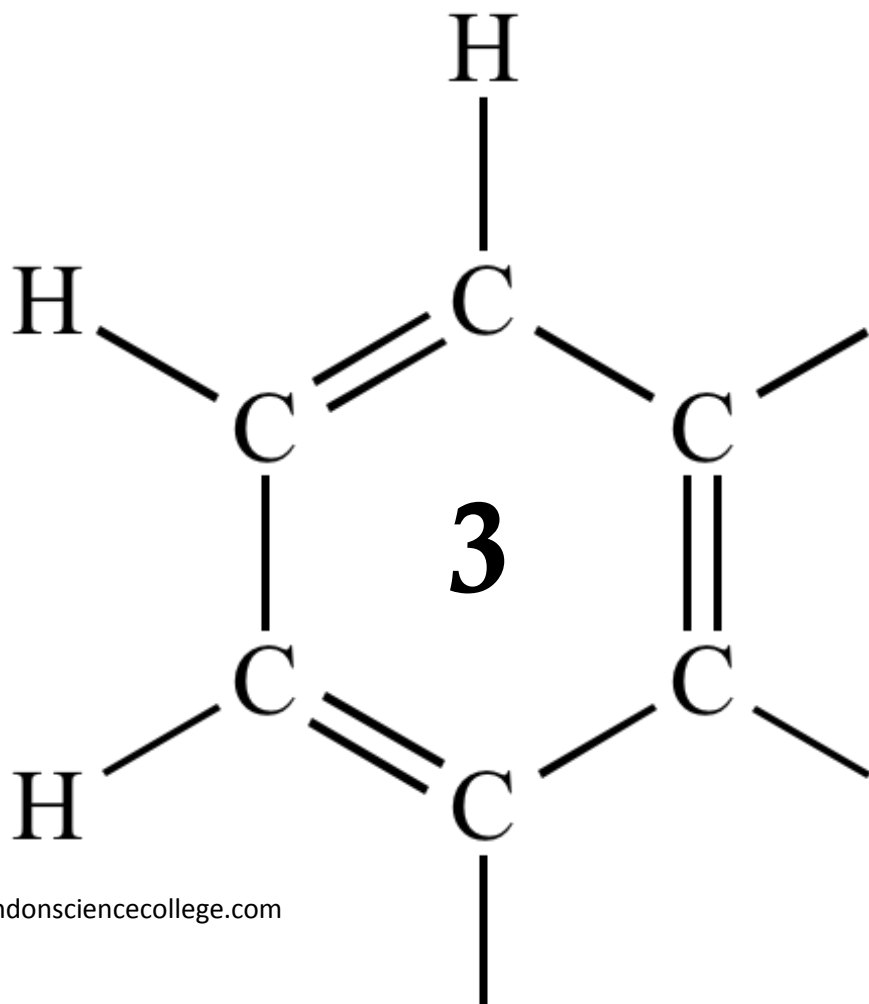


OCR AS CHEMISTRY

MODULE 3

EQUILIBRIUM - KC



1

A study of equilibrium is important for understanding chemical reactions.

(a) State le Chatelier's principle.

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(Extra space)
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(1)

(b) Catalysts play an important role in many reactions.

(i) State the meaning of the term *catalyst*.
Explain, in general terms, how catalysts work.

Meaning of the term *catalyst*
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How catalysts work
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(3)

(Extra space)
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(ii) State the effect, if any, of a catalyst on the time taken to reach equilibrium.

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(1)

(iii) State the effect, if any, of a catalyst on the position of an equilibrium.

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(1)

(c) Consider the following equilibrium reactions.

				$\Delta H^\ominus / \text{kJ mol}^{-1}$
P	$\text{H}_2(\text{g}) + \text{I}_2(\text{g})$	\rightleftharpoons	$2\text{HI}(\text{g})$	-10
Q	$\text{CO}_2(\text{g}) + 3\text{H}_2(\text{g})$	\rightleftharpoons	$\text{CH}_3\text{OH}(\text{g}) + \text{H}_2\text{O}(\text{g})$	-49
R	$\text{N}_2\text{O}_4(\text{g})$	\rightleftharpoons	$2\text{NO}_2(\text{g})$	+58
S	$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$	\rightleftharpoons	$2\text{NH}_3(\text{g})$	-92
T	$\text{C}_2\text{H}_4(\text{g}) + \text{H}_2\text{O}(\text{g})$	\rightleftharpoons	$\text{CH}_3\text{CH}_2\text{OH}(\text{g})$	-42

In each of parts (c)(i) to (c)(v), you should record in the box one of the letters, **P**, **Q**, **R**, **S** or **T**, that corresponds to the equilibrium that best fits the information provided. You may use each letter once, more than once or not at all.

- (i) A decrease in temperature at constant pressure shifts the position of this equilibrium from right to left.

(1)

- (ii) This equilibrium uses concentrated phosphoric acid as a catalyst in a hydration reaction.

(1)

- (iii) A decrease in pressure at constant temperature shifts the position of this equilibrium from left to right.

(1)

- (iv) There is no change in the position of this equilibrium when the pressure is increased at constant temperature.

(1)

- (v) An increase in the concentration of steam at constant temperature and constant pressure shifts the position of this equilibrium from right to left.

(1)

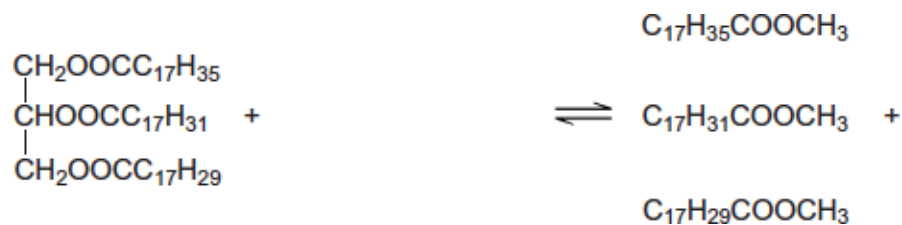
(Total 11 marks)

2

Esters are produced by the reaction of alcohols with other esters and by the reaction of alcohols with carboxylic acids.

(a) The esters which make up biodiesel are produced industrially from the esters in vegetable oils.

(i) Complete the equation for this formation of biodiesel.

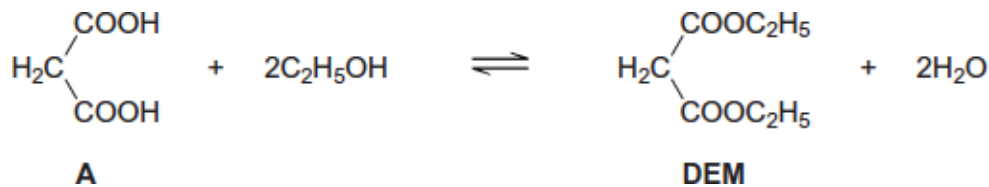


..... (2)

(ii) Write an equation for the complete combustion of $\text{C}_{17}\text{H}_{35}\text{COOCH}_3$.

..... (2)

(b) The ester commonly known as diethyl malonate (**DEM**) occurs in strawberries and grapes. It can be prepared from acid **A** according to the following equilibrium.



(i) A mixture of 2.50 mol of **A** and 10.0 mol of ethanol was left to reach equilibrium in an inert solvent in the presence of a small amount of concentrated sulfuric acid. The equilibrium mixture formed contained 1.80 mol of **DEM** in a total volume, $V \text{ dm}^3$, of solution.

Calculate the amount (in moles) of **A**, of ethanol and of water in this equilibrium mixture.

Moles of **A**

Moles of ethanol

Moles of water.....

(3)

- (ii) The total volume of the mixture in part (b)(i) was doubled by the addition of more of the inert solvent.

State and explain the effect of this addition on the equilibrium yield of **DEM**.

Effect

Explanation

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(2)

- (iii) Using **A** to represent the acid and **DEM** to represent the ester, write an expression for the equilibrium constant K_c for the reaction.

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(1)

- (iv) In a second experiment, the equilibrium mixture was found to contain 0.85 mol of **A**, 7.2 mol of ethanol, 2.1 mol of **DEM** and 3.4 mol of water.

Calculate a value of K_c for the reaction and deduce its units.

Calculation.....

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Units.....

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(3)

(Total 13 marks)

3

Methanol (CH₃OH) is an important fuel that can be synthesised from carbon dioxide.

(a) The table shows some standard enthalpies of formation.

	CO ₂ (g)	H ₂ (g)	CH ₃ OH(g)	H ₂ O(g)
$\Delta H_f^\ominus/\text{kJ mol}^{-1}$	- 394	0	- 201	- 242

(i) Use these standard enthalpies of formation to calculate a value for the standard enthalpy change of this synthesis.



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(Extra space)

(3)

(ii) State why the standard enthalpy of formation for hydrogen gas is zero.

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(1)

- (b) State and explain what happens to the yield of methanol when the total pressure is increased in this synthesis.



Effect on yield

Explanation

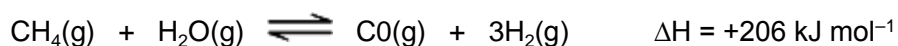
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(3)

- (c) The hydrogen required for this synthesis is formed from methane and steam in a reversible reaction. The equation for this reaction is shown below.



State and explain what happens to the yield of hydrogen in this reaction when the temperature is increased.

Effect on yield

Explanation

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(Extra space)

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(3)

(d) The methanol produced by this synthesis has been described as a carbon-neutral fuel.

(i) State the meaning of the term *carbon-neutral*.

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(Extra space)
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(1)

(ii) Write an equation for the complete combustion of methanol.

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(1)

(iii) The equation for the synthesis of methanol is shown below.



Use this equation and your answer to part (d)(ii) to deduce an equation to represent the overall chemical change that occurs when methanol behaves as a carbon-neutral fuel.

Equation

(1)

- (e) A student carried out an experiment to determine the enthalpy change when a sample of methanol was burned.

The student found that the temperature of 140 g of water increased by 7.5 °C when 0.011 mol of methanol was burned in air and the heat produced was used to warm the water.

Use the student's results to calculate a value, in kJ mol^{-1} , for the enthalpy change when one mole of methanol was burned.

(The specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$).

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(Extra space)

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(3)
(Total 16 marks)

4

A student investigated the chemistry of the halogens and the halide ions.

- (a) In the first two tests, the student made the following observations.

Test	Observation
1. Add chlorine water to aqueous potassium iodide solution.	The colourless solution turned a brown colour.
2. Add silver nitrate solution to aqueous potassium chloride solution.	The colourless solution produced a white precipitate.

- (i) Identify the species responsible for the brown colour in Test 1.

Write the **simplest ionic** equation for the reaction that has taken place in Test 1.

State the type of reaction that has taken place in Test 1.

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(Extra space)
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(3)

- (ii) Name the species responsible for the white precipitate in Test 2.

Write the **simplest ionic** equation for the reaction that has taken place in Test 2.

State what would be observed when an excess of dilute ammonia solution is added to the white precipitate obtained in Test 2.

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(Extra space)
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(3)

- (b) In two further tests, the student made the following observations.

Test	Observation
3. Add concentrated sulfuric acid to solid potassium chloride.	The white solid produced misty white fumes which turned blue litmus paper to red.
4. Add concentrated sulfuric acid to solid potassium iodide.	The white solid turned black. A gas was released that smelled of rotten eggs. A yellow solid was formed.

- (i) Write the **simplest ionic** equation for the reaction that has taken place in Test 3.

Identify the species responsible for the misty white fumes produced in Test 3.

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(Extra space)

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(2)

- (ii) The student had read in a textbook that the equation for one of the reactions in Test 4 is as follows.



Write the **two** half-equations for this reaction.

State the role of the sulfuric acid and identify the yellow solid that is also observed in Test 4.

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(Extra space)

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(4)

- (iii) The student knew that bromine can be used for killing microorganisms in swimming pool water.

The following equilibrium is established when bromine is added to cold water.



Use Le Chatelier's principle to explain why this equilibrium moves to the right when sodium hydroxide solution is added to a solution containing dissolved bromine.

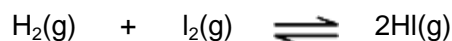
Deduce why bromine can be used for killing microorganisms in swimming pool water, even though bromine is toxic.

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(Extra space)
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(3)
(Total 15 marks)

5

- (a) A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume $V \text{ dm}^3$. The mixture was left to reach equilibrium as shown by the following equation.



At a given temperature, the equilibrium mixture contained 2.06 mol of hydrogen iodide.

- (i) Calculate the amounts, in moles, of hydrogen and of iodine in the equilibrium mixture.

Moles of hydrogen

Moles of iodine

(2)

- (ii) Write an expression for the equilibrium constant (K_c) for this equilibrium.

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(1)

- (iii) K_c for this equilibrium has no units.
State why the units cancel in the expression for K_c

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(1)

- (iv) A different mixture of hydrogen, iodine and hydrogen iodide was left to reach equilibrium at the same temperature in a container of the same volume. This second equilibrium mixture contained 0.38 mol of hydrogen, 0.19 mol of iodine and 1.94 mol of hydrogen iodide.

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

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(Extra space)

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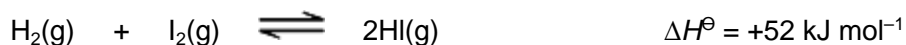
(2)

- (b) This question concerns changes made to the four equilibria shown in parts (b)(i) to (b)(iv). In each case, use the information in the table to help you choose from the letters **A** to **E** the best description of what happens as a result of the change described. Write your answer in the box.

Each letter may be used once, more than once or not at all.

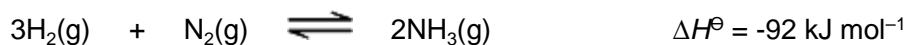
	Position of equilibrium	Value of equilibrium constant, K_c
A	remains the same	same
B	moves to the right	same
C	moves to the left	same
D	moves to the right	different
E	moves to the left	different

- (i) Change: increase the temperature of the equilibrium mixture at constant pressure.



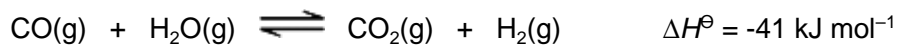
(1)

- (ii) Change: increase the total pressure of the equilibrium mixture at constant temperature.



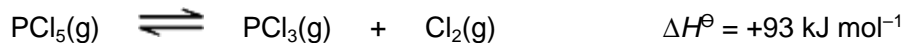
(1)

(iii) Change: add a catalyst to the equilibrium mixture at constant temperature.



(1)

(iv) Change: add chlorine to the equilibrium mixture at constant temperature.

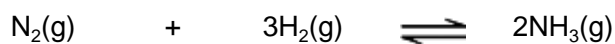


(1)

(Total 10 marks)

6

Ammonia is manufactured by the Haber process in which the following equilibrium is established.



(a) Give **two** features of a reaction at equilibrium.

Feature 1

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Feature 2

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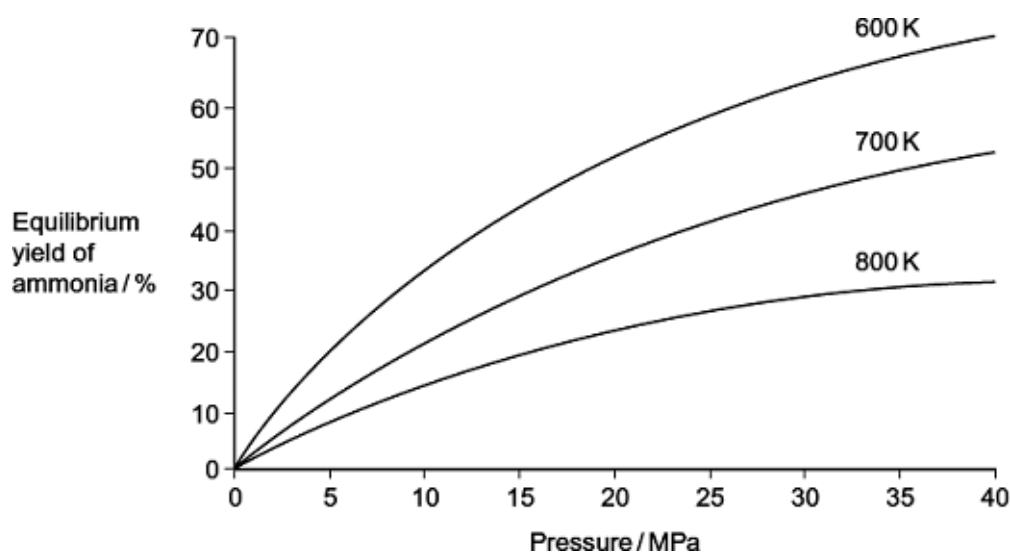
(2)

(b) Explain why a catalyst has no effect on the position of an equilibrium.

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(2)

(c) The diagram shows how the equilibrium yield of ammonia varies with changes in pressure and temperature.



(i) Use the diagram to state the effect of an **increase** in pressure at constant temperature on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield

Explanation

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(Extra space)
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(3)

- (ii) Use the diagram to state the effect of an **increase** in temperature at constant pressure on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield

Explanation

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(Extra space)

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(3)

- (d) At equilibrium, with a pressure of 35 MPa and a temperature of 600 K, the yield of ammonia is 65%.

- (i) State why industry uses a temperature higher than 600 K.

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(1)

- (ii) State why industry uses a pressure lower than 35 MPa.
 Do **not** include references to safety.

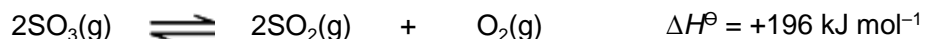
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(1)

(Total 12 marks)

7

At high temperatures and in the presence of a catalyst, sulfur trioxide decomposes according to the following equation.



- (a) In an experiment, 8.0 mol of sulfur trioxide were placed in a container of volume 12.0 dm³ and allowed to come to equilibrium.
 At temperature T_1 there were 1.4 mol of oxygen in the equilibrium mixture.

- (i) Calculate the amount, in moles, of sulfur trioxide and of sulfur dioxide in the equilibrium mixture.

Amount of sulfur trioxide

Amount of sulfur dioxide

(2)

(ii) Write an expression for the equilibrium constant, K_c , for this equilibrium.

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(1)

(iii) Deduce the units of K_c for this equilibrium.

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(1)

(iv) Calculate a value of K_c for this equilibrium at temperature T_1

(If you were unable to complete the calculations in part (a)(i) you should assume that the amount of sulfur trioxide in the equilibrium mixture was 5.8 mol and the amount of sulfur dioxide was 2.1 mol. These are **not** the correct values.)

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(Extra space)

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(3)

(b) The experiment was repeated at the same temperature using the same amount of sulfur trioxide but in a larger container.

State the effect, if any, of this change on:

(i) the amount, in moles, of oxygen in the new equilibrium mixture

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(1)

(ii) the value of K_c

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(1)

- (c) The experiment was repeated in the original container but at temperature T_2 . The value of K_c was smaller than the value at temperature T_1 . State which is the higher temperature, T_1 or T_2 . Explain your answer.

Higher temperature

Explanation

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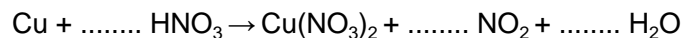
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(3)
(Total 12 marks)

8

A sample of nitrogen dioxide gas (NO_2) was prepared by the reaction of copper with concentrated nitric acid.

- (a) (i) Balance the equation for the reaction of copper with concentrated nitric acid.



(1)

- (ii) Give the oxidation state of nitrogen in each of the following compounds.

HNO_3

NO_2

(2)

- (iii) Deduce the half-equation for the conversion of HNO_3 into NO_2 in this reaction.

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(1)

- (b) The following equilibrium is established between colourless dinitrogen tetraoxide gas (N_2O_4) and dark brown nitrogen dioxide gas.



- (i) Give two features of a reaction at equilibrium.

Feature 1

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Feature 2

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(2)

- (ii) Use Le Chatelier's principle to explain why the mixture of gases becomes darker in colour when the mixture is heated at constant pressure.

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(2)

- (iii) Use Le Chatelier's principle to explain why the amount of NO₂ decreases when the pressure is increased at constant temperature.

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(2)
(Total 10 marks)

9

The following dynamic equilibrium was established at temperature T in a closed container.



The value of K_c for the reaction was 68.0 mol⁻¹ dm³ when the equilibrium mixture contained 3.82 mol of P and 5.24 mol of R.

- (a) Give the meaning of the term *dynamic equilibrium*.

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(Extra space)
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(2)

- (b) Write an expression for K_c for this reaction.

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(1)

- (c) The volume of the container was 10.0 dm³.

Calculate the concentration, in mol dm⁻³, of **Q** in the equilibrium mixture.

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(Extra space)

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(4)

- (d) State the effect, if any, on the equilibrium amount of **P** of increasing the temperature. All other factors are unchanged.

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(1)

- (e) State the effect, if any, on the equilibrium amount of **P** of using a container of larger volume. All other factors are unchanged.

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(1)

- (f) State the effect, if any, on the value of K_c of increasing the temperature. All other factors are unchanged.

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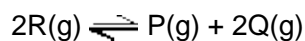
(1)

- (g) State the effect, if any, on the value of K_c of using a container of larger volume. All other factors are unchanged.

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(1)

- (h) Deduce the value of the equilibrium constant, at temperature T , for the reaction



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(1)
(Total 12 marks)

10

- (a) In an experiment, at a fixed temperature, an equilibrium mixture contained the following amounts, in moles, of each component.

$\text{CH}_3\text{CH}_2\text{COOH}$	$\text{CH}_3\text{CH}_2\text{OH}$	$\text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3$	H_2O
0.0424	0.0525	0.0745	0.0813

Use the data in the table above to calculate a value for the equilibrium constant, K_c , at this fixed temperature.

Record your answer to the appropriate precision.

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(2)

- (b) If the mixture is uncovered during the time it is left to reach equilibrium, some of the ester formed will evaporate.

Explain why a smaller volume of sodium hydroxide would then be required in the titration compared with the volume for the covered mixture.

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(2)

(Total 4 marks)