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

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

(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 .....

.....

Units .....

.....

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

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

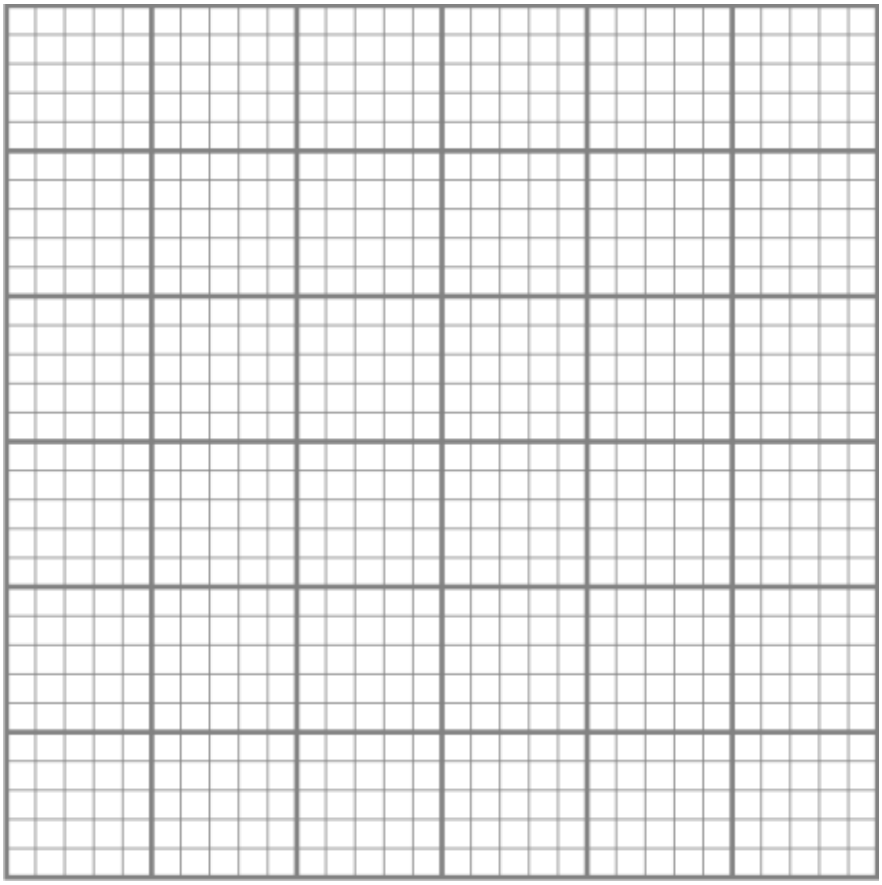
A student added a solution containing 0.50 mol of **X**(aq) to a solution containing 0.50 mol of **Y**(aq) and shook the mixture.
After 30 seconds, there was no further change in colour.
The amount of **Z**(aq) at equilibrium was 0.20 mol.

(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)

5 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**.

.....

(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)

6 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)

7 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 / cm³	4.60	8.65	12.85	16.80
Initial burette reading / cm³	0.10	4.65	8.65	12.85
Titre / cm³				

Complete **Table 1**.

(1)

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

Calculation

Mean titre = ...cm³

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)

8 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 ⬭

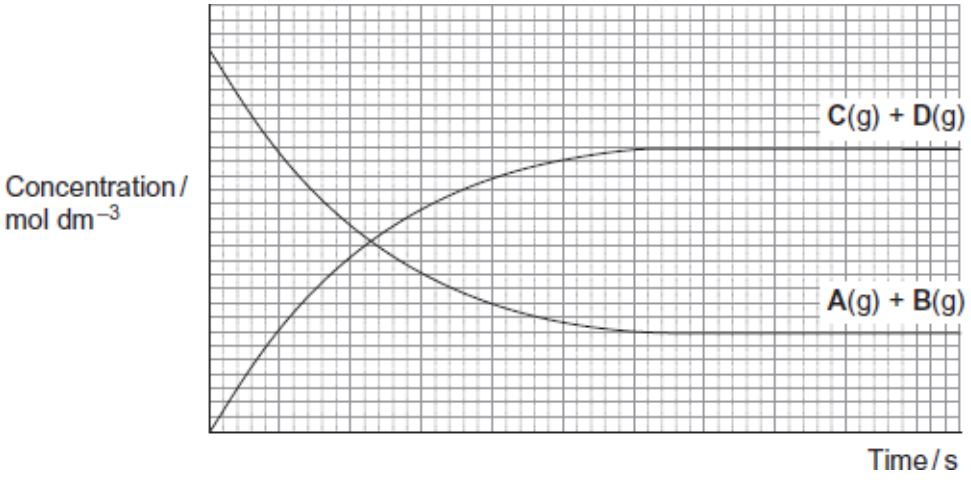
D 3.0 ⬭

(Total 1 mark)

9 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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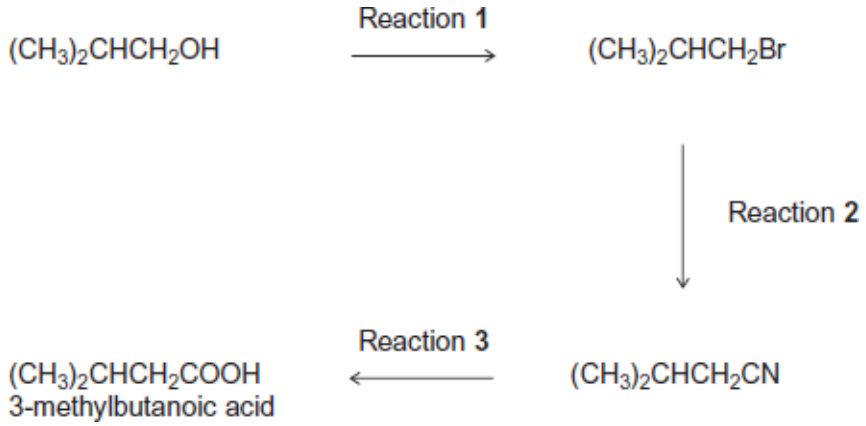
(3)

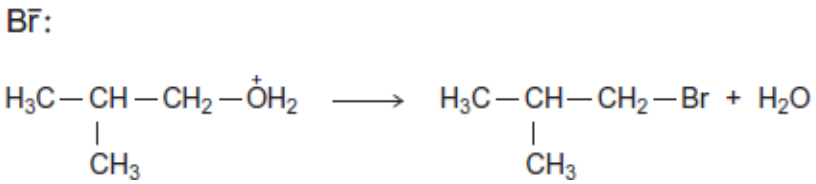
(Total 8 marks)

10 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)

11 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)

12 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)

13 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)

14 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.

				$\Delta H^{\ominus}$ / kJ mol^{-1}
P	$H_2(g) + I_2(g)$	$\rightleftharpoons$	$2HI(g)$	−10
Q	$CO_2(g) + 3H_2(g)$	$\rightleftharpoons$	$CH_3OH(g) + H_2O(g)$	−49
R	$N_2O_4(g)$	$\rightleftharpoons$	$2NO_2(g)$	+58
S	$N_2(g) + 3H_2(g)$	$\rightleftharpoons$	$2NH_3(g)$	−92
T	$C_2H_4(g) + H_2O(g)$	$\rightleftharpoons$	$CH_3CH_2OH(g)$	−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)

15 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.

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(2)

(ii) Write an equation for the complete combustion of $C_{17}H_{35}COOCH_3$.

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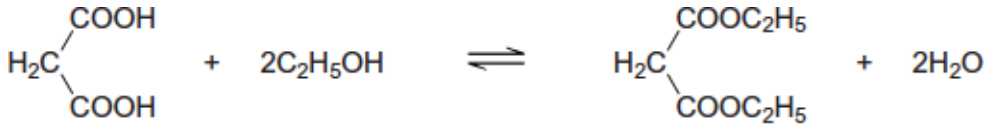
(2)

(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.



A **DEM**

(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 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)

16 Methanol (CH_3OH) is an important fuel that can be synthesised from carbon dioxide.

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

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/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.

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

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(Extra space) .....

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(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.

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

Effect on yield .....

Explanation .....

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(Extra space) .....

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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.

$$CH_4(g) + H_2O(g) \rightleftharpoons C0(g) + 3H_2(g) \qquad \Delta H = +206 \text{ kJ mol}^{-1}$$

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.

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

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 J K^{-1} g^{-1}).

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(Extra space) .....

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(3)

(Total 16 marks)

17 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.

$$8H^+ + 8I^- + H_2SO_4 \longrightarrow 4I_2 + H_2S + 4H_2O$$

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.

$$Br_2(l) + H_2O(l) \rightleftharpoons HBrO(aq) + H^+(aq) + Br^-(aq)$$

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)

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

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

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.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\quad \Delta H^{\ominus} = +52 \text{ kJ mol}^{-1}$ [ ]

(1)

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

$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$ $\quad \Delta H^{\ominus} = -92 \text{ kJ mol}^{-1}$ [ ]

(1)

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

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

(1)

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

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ $\Delta H^{\ominus} = +93 \text{ kJ mol}^{-1}$

(1)

(Total 10 marks)

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

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

(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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(Extra space) .....

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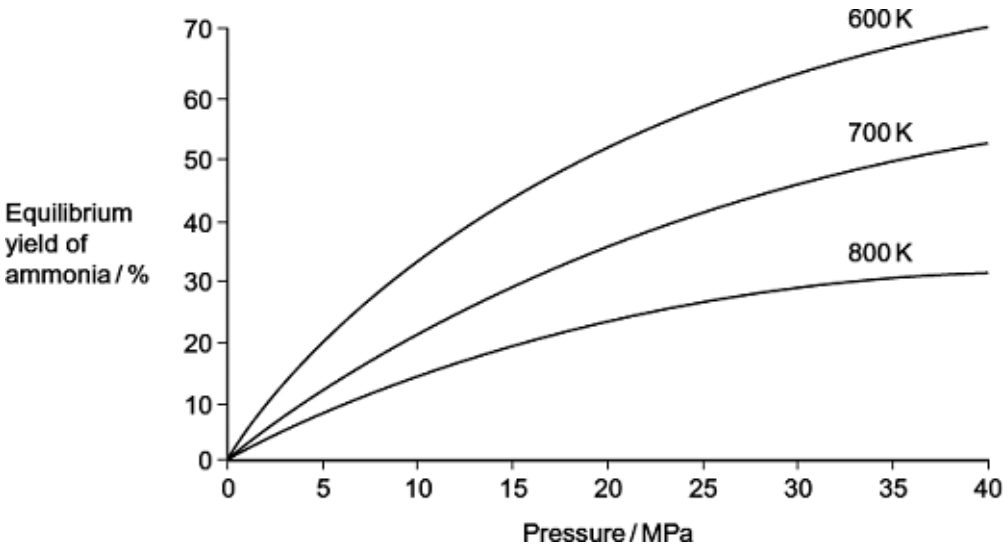
(2)

(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)

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

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g) \qquad \Delta H^{\ominus} = +196 \text{ kJ mol}^{-1}$$

(a) In an experiment, 8.0mol of sulfur trioxide were placed in a container of volume 12.0 dm^3 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

.....

(1)

(ii) the value of K_c

.....

(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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(Extra space) .....

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(3)
(Total 12 marks)

21 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.

$$Cu + \ldots\ldots HNO_3 \rightarrow Cu(NO_3)_2 + \ldots\ldots NO_2 + \ldots\ldots H_2O$$

(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.

.....

(1)

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

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = 58 \text{ kJ mol}^{-1}$$

(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 NO_2 decreases when the pressure is increased at constant temperature.

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(2)
(Total 10 marks)

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

$$P(g) + 2Q(g) \rightleftharpoons 2R(g) \qquad \Delta H^{\ominus} = -50 \text{ kJ mol}^{-1}$$

The value of K_c for the reaction was 68.0 mol^{-1} dm^3 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 dm^3.

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.

.....

(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.

.....

(1)

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

$$2R(g) \rightleftharpoons P(g) + 2Q(g)$$

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(1)
(Total 12 marks)

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

CH_3CH_2COOH	CH_3CH_2OH	$CH_3CH_2COOCH_2CH_3$	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)

24 (a) State why it is necessary to maintain a constant temperature in an experiment to measure an equilibrium constant.

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(1)

(b) Suggest **one** method for maintaining a constant temperature in an experiment.

.....

(1)
(Total 2 marks)

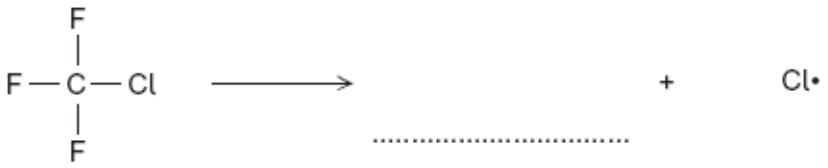
25 Oxygen and ozone (O_3) both occur as gases in the upper atmosphere.
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF_3Cl

(a) (i) Give the IUPAC name of CF_3Cl

.....

(1)

(ii) Complete the following equation that shows the formation of a chlorine atom from a molecule of CF_3Cl



(1)

(iii) State what the • represents in Cl•

.....

(1)

(b) Write two equations that show how chlorine atoms catalyse the decomposition of ozone into oxygen.

Equation 1 .....

Equation 2 .....

(2)

(c) An equilibrium is established between oxygen and ozone molecules as shown below.

$3O_2(g) \rightleftharpoons 2O_3(g)$ $\Delta H = +284$ kJ mol^{-1}

(i) State Le Chatelier's principle.

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(1)

(ii) Use Le Chatelier's principle to explain how an increase in temperature causes an increase in the equilibrium yield of ozone.

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(2)

(d) Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants.
With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

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(1)
(Total 9 marks)

26 Synthesis gas is a mixture of carbon monoxide and hydrogen. Methanol can be manufactured from synthesis gas in a reversible reaction as shown by the following equation.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$$

(a) A sample of synthesis gas containing 0.240 mol of carbon monoxide and 0.380 mol of hydrogen was sealed together with a catalyst in a container of volume 1.50 dm^3.
When equilibrium was established at temperature T_1 the equilibrium mixture contained 0.170 mol of carbon monoxide.

Calculate the amount, in moles, of methanol and the amount, in moles, of hydrogen in the equilibrium mixture.

Methanol .....

Hydrogen .....

(2)

(b) A different sample of synthesis gas was allowed to reach equilibrium in a similar container of volume 1.50 dm^3 at temperature T_1

At equilibrium, the mixture contained 0.210 mol of carbon monoxide, 0.275 mol of hydrogen and 0.0820 mol of methanol.

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

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(1)

(ii) Calculate a value for K_c for the reaction at temperature T_1 and state its units.

Calculation ….....

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.....

Units .....

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(4)

(iii) State the effect, if any, on the value of K_c of adding more hydrogen to the equilibrium mixture.

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(1)

(c) The temperature of the mixture in part (b) was changed to T_2 and the mixture was left to reach a new equilibrium position. At this new temperature the equilibrium concentration of methanol had increased.

Deduce which of T_1 or T_2 is the higher temperature and explain your answer.

Higher temperature .....

Explanation .....

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(3)

(d) The following reaction has been suggested as an alternative method for the production of methanol.

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

The hydrogen used in this method is obtained from the electrolysis of water.

Suggest **one** possible environmental disadvantage of the production of hydrogen by electrolysis.

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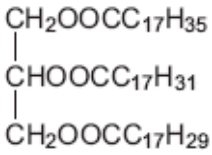
(1)

(e) One industrial use of methanol is in the production of biodiesel from vegetable oils such as



Give the formula of **one** compound in biodiesel that is formed by the reaction of methanol with the vegetable oil shown above.

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(1)

(Total 13 marks)

27 Sulfuric acid is made from SO_3 which can be manufactured in a series of stages from iron(II) disulfide (FeS_2), found in the mineral iron pyrites.

(a) In the first stage, FeS_2 is roasted in air to form iron(III) oxide and sulfur dioxide.

(i) Balance the following equation for this reaction.

.....FeS_2 + ...O_2 → .....Fe_2O_3 + ...SO_2

(1)

(ii) Deduce the oxidation state of sulfur in each of the following compounds.

SO_2 .....

FeS_2.....

(2)

(b) In the second stage of the manufacture of sulfuric acid, sulfur dioxide reacts with oxygen. The equation for the equilibrium that is established is shown below.

$$SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \qquad \Delta H = -98 \text{ kJ mol}^{-1}$$

State and explain the effect of an increase in temperature on the equilibrium yield of SO_3

Effect of increase in temperature on yield .....

Explanation ….....

.....

.....

(3)

(c) In the extraction of iron, carbon monoxide reacts with iron(III) oxide. Write an equation for this reaction and state the role of the carbon monoxide.

Equation .....

Role of the carbon monoxide .....

(2)
(Total 8 marks)

28 The method of extraction of zinc has changed as different ores containing the element have been discovered and as technology has improved.

Extraction process 1
In the earliest process, calamine (impure zinc carbonate) was heated with charcoal in earthenware pots. This two-stage process gave a low yield of zinc.

$$ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$$

$$ZnO(s) + C(s) \rightarrow Zn(s) + CO(g)$$

Extraction process 2
Deposits of calamine were being used up and a new two-stage process was developed using zinc sulfide ores. All of the waste gases from this process were released into the atmosphere.

$$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$$

$$ZnO(s) + C(s) \rightarrow Zn(s) + CO(g)$$

Extraction process 3

The modern process uses the electrolysis of aqueous solutions of very pure zinc sulfate. The first step in this process is the same as the first step in Extraction process **2**. The second step uses sulfuric acid made from the SO_2 collected in the first step. The third step involves the electrolysis of zinc sulfate solution to form pure zinc.

$$2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)$$

$$ZnO(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l)$$

$$ZnSO_4(aq) \xrightarrow{\text{electrolysis}} Zn(s)$$

(a) In the first stage of Extraction process **1** the following equilibrium is established when zinc carbonate is heated in a closed container.

$$ZnCO_3(s) \rightleftharpoons ZnO(s) + CO_2(g)$$

Use Le Chatelier's principle to suggest and explain the effect on the yield of zinc oxide of allowing the carbon dioxide to escape from the container.

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(3)

(b) State and explain **one** environmental reason why Extraction process **3** is an improvement over Extraction process **2**.

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(3)

(c) Give **one** reason why Extraction process **3** is an expensive method of making zinc but one which is justified in terms of the product formed.

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(2)

(d) Deduce the half-equation for the formation of zinc from zinc ions during the electrolysis of zinc sulfate solution and identify the electrode at which this reaction occurs.

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(2)

(e) Identify **one** reaction from the three extraction processes that is **not** a redox reaction and state the type of reaction that it is. In terms of redox, state what happens to the carbon in Extraction process **2**.

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(3)

(f) Zinc and magnesium both react with steam in a similar way. Write an equation for the reaction of zinc with steam and name the products of this reaction.

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(2)
(Total 15 marks)

29 The reaction of methane with steam produces hydrogen for use in many industrial processes. Under certain conditions the following reaction occurs.

$CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$ $\Delta H^{\ominus} = +165 \text{ kJ mol}^{-1}$

(a) Initially, 1.0 mol of methane and 2.0 mol of steam were placed in a flask and heated with a catalyst until equilibrium was established. The equilibrium mixture contained 0.25 mol of carbon dioxide.

(i) Calculate the amounts, in moles, of methane, steam and hydrogen in the equilibrium mixture.

Moles of methane .....

Moles of steam .....

Moles of hydrogen .....

(3)

(ii) The volume of the flask was 5.0 dm^3. Calculate the concentration, in mol dm^{-3}, of methane in the equilibrium mixture.

.....

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(1)

(b) The table below shows the equilibrium concentration of each gas in a different equilibrium mixture in the same flask and at temperature *T*.

gas	$CH_4(g)$	$H_2O(g)$	$CO_2(g)$	$H_2(g)$
concentration / mol dm^{-3}	0.10	0.48	0.15	0.25

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

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(1)

(ii) Calculate a value for K_c at temperature *T* and give its units.

Calculation .....

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.....

.....

Units of K_c .....

(3)

(c) The mixture in part (b) was placed in a flask of volume greater than 5.0 dm^3 and allowed to reach equilibrium at temperature *T*.
State and explain the effect on the amount of hydrogen.

Effect on amount of hydrogen .....

Explanation .....

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(3)

(d) Explain why the amount of hydrogen decreases when the mixture in part (b) reaches equilibrium at a lower temperature.

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(2)
(Total 13 marks)

30 Hydrogen gas is used in the chemical industry.

(a) Tungsten is extracted by passing hydrogen over heated tungsten oxide (WO_3).

(i) State the role of the hydrogen in this reaction.

.....

(1)

(ii) Write an equation for this reaction.

.....

(1)

(iii) State **one** risk of using hydrogen gas in metal extractions.

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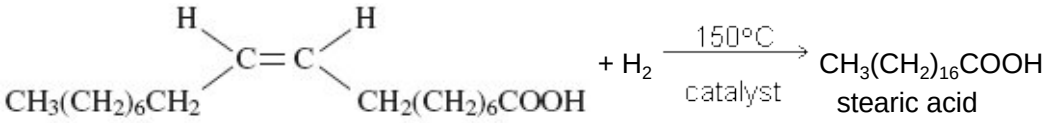
(1)

(b) Hydrogen is used to convert oleic acid into stearic acid as shown by the following equation.



(i) Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

.....

(1)

(ii) State the type of stereoisomerism shown by oleic acid.

.....

(1)

(c) Hydrogen reacts with nitrogen in the Haber Process. The equation for the equilibrium that is established is shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(i) State Le Chatelier's principle.

.....

.....

(1)

(ii) Use Le Chatelier's principle to explain why an increase in the total pressure of this equilibrium results in an increase in the equilibrium yield of ammonia.

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(2)

(d) Hydrogen reacts with oxygen in an exothermic reaction as shown by the following equation.

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g) \qquad \Delta H = -242 \text{ kJ mol}^{-1}$$

Use the information in the equation and the data in the following table to calculate a value for the bond enthalpy of the H–H bond.

	O–H	O=O
Mean bond enthalpy / kJ mol^{-1}	+ 463	+ 496

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(3)

(Total 11 marks)

31 A mixture was prepared using 1.00 mol of propanoic acid, 2.00 mol of ethanol and 5.00 mol of water. At a given temperature, the mixture was left to reach equilibrium according to the following equation.

$$CH_3CH_2COOH + CH_3CH_2OH \rightleftharpoons CH_3CH_2COOCH_2CH_3 + H_2O \qquad \Delta H^{\ominus} = -22 \text{ kJ mol}^{-1}$$

The equilibrium mixture contained 0.54 mol of the ester ethyl propanoate.

(a) (i) Calculate the amounts, in moles, of propanoic acid, of ethanol and of water in this equilibrium mixture.

Moles of propanoic acid .....

Moles of ethanol .....

Moles of water .....

(3)

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

.....

.....

(1)

(iii) Calculate a value for K_c for this equilibrium at this temperature. Explain why this K_c value has no units.

Calculation .....

.....

.....

.....

Explanation .....

.....

(3)

(b) For this equilibrium, predict the effect of an increase in temperature on each of the following.

(i) the amount, in moles, of ester at equilibrium

.....

(1)

(ii) the time taken to reach equilibrium

.....

(1)

(iii) the value of K_c

.....

(1)

(Total 10 marks)

32 Carbon monoxide and hydrogen are used in the manufacture of methanol. An equilibrium is established according to the following equation.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -9l \text{ kJ mol}^{-1}$$

(Cu catalyst)

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

Feature 1 .....

.....

Feature 2 .....

.....

(2)

(b) Explain why an increase in temperature causes a decrease in the equilibrium yield of methanol.

.....

.....

.....

(2)

(c) (i) State what is meant by the term *catalyst*.

.....

.....

(1)

(ii) State the effect, if any, of the copper catalyst on the position of this equilibrium at a fixed temperature.

.....

(1)

(d) Two methods are used to produce carbon monoxide from natural gas. Equations for these two methods are shown below.

Method 1 $CH_4 + H_2O \rightarrow 2CO + 3H_2$

Method 2 $CH_4 + CO_2 \rightarrow 2CO + 2H_2$

The manufacture of methanol from these sources of carbon monoxide has been described as carbon neutral.

(i) .....

.....

.....

.....

(1)

(ii) Show how combining the equations from these two methods can lead to the 1:2 mol ratio of carbon monoxide to hydrogen required for this synthesis of methanol.

.....

.....

.....

(1)

(Total 8 marks)

33 In the past 150 years, three different processes have been used to extract bromine from potassium bromide. These processes are illustrated below.

Extraction Process **1**

$2KBr + MnO_2 + 2H_2SO_4 \rightarrow MnSO_4 + K_2SO_4 + 2H_2O + Br_2$

Extraction Process **2**

The reaction of solid potassium bromide with concentrated sulfuric acid.

Extraction Process **3**

The reaction of aqueous potassium bromide with chlorine gas.

(a) Write a half-equation for the conversion of MnO_2 in acid solution into Mn^{2+} ions and water. In terms of electrons, state what is meant by the term *oxidising agent* and identify the oxidising agent in the overall reaction.

.....

.....

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.....

.....

(3)

(b) Write an equation for Extraction Process **2** and an equation for Extraction Process **3**. Calculate the percentage atom economy for the extraction of bromine from potassium bromide by Extraction Process **3**. Suggest why Extraction Process **3** is the method in large-scale use today.

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(5)

(c) Bromine has been used for more than 70 years to treat the water in swimming pools. The following equilibrium is established when bromine is added to water.

$$Br_2 + H_2O \rightleftharpoons HBrO + HBr$$

Give the oxidation state of bromine in HBr and in HBrO

Deduce what will happen to this equilibrium as the HBrO reacts with micro-organisms in the swimming pool water. Explain your answer.

.....

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.....

(4)
(Total 12 marks)

34 Methanol is a useful liquid fuel that can be produced by direct combination of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$$

(a) Explain why a low temperature and a high pressure favour a high yield of methanol in this reaction.

Low temperature .....

.....

.....

High pressure .....

.....

.....

(4)

(b) The industrial manufacture of methanol using this reaction is carried out at a compromise temperature of 400 °C under a pressure of 20 MPa in the presence of a Cr_2O_3/ZnO catalyst.

(i) Justify the use of a compromise temperature.

.....

.....

(ii) What effect, other than on the yield, does the use of high pressure have on the reaction?

.....

(3)
(Total 7 marks)

35 The study of equilibrium constants enables chemists to calculate the composition of equilibrium mixtures.

(a) The expression for an equilibrium constant, K_c, for a homogeneous equilibrium is given below.

$$K_c = \frac{[C]^2[D]}{[E][F]^3}$$

(i) Write an equation for the forward reaction.

.....

(ii) Deduce the units of K_c

.....

.....

(iii) State what can be deduced from the fact that the value of K_c is larger when the equilibrium is established at a lower temperature.

.....

(3)

(b) When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm^3, the following equilibrium was established at 700 K.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

The equilibrium mixture was found to contain 0.023 mol of hydrogen.

(i) Calculate the number of moles of iodine and the number of moles of hydrogen iodide in the equilibrium mixture.

Number of moles of iodine .....

Number of moles of hydrogen iodide .....

.....

(ii) Write an expression for K_c for the equilibrium.

.....

.....

(iii) State why the volume of the flask need not be known when calculating a value for K_c.

.....

.....

(iv) Calculate the value of K_c at 700 K.

.....

.....

.....

.....

(v) Calculate the value of K_c at 700 K for the equilibrium

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

.....

.....

(7)
(Total 10 marks)

36 A method of synthesising ammonia directly from nitrogen and hydrogen was developed by Fritz Haber. On an industrial scale, this synthesis requires a high temperature, a high pressure and a catalyst and is very expensive to operate.

(a) Use the data given below to calculate a value for the enthalpy of formation of ammonia

Bond	N ≡N	H – H	N – H
Mean bond enthalpy/kJ mol^{-1}	945	436	391

(3)

(b) A manager in charge of ammonia production wished to increase the daily production of ammonia and reduce the production costs. How would a chemist explain the factors that would influence the commercial efficiency of this production process?

(8)

(Total 11 marks)

37 In the Haber Process for the manufacture of ammonia, nitrogen and hydrogen react as shown in the equation.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H^{\ominus} = -92 \text{ kJ mol}^{-1}$$

The table shows the percentage yield of ammonia, under different conditions of pressure and temperature, when the reaction has reached dynamic equilibrium.

Temperature / K	600	800	1000
% yield of ammonia at 10 MPa	50	10	2
% yield of ammonia at 20 MPa	60	16	4
% yield of ammonia at 50 MPa	75	25	7

(a) Explain the meaning of the term *dynamic equilibrium*.

.....

.....

(2)

(b) Use Le Chatelier's principle to explain why, at a given temperature, the percentage yield of ammonia increases with an increase in overall pressure.

.....

.....

.....

(3)

(c) Give a reason why a high pressure of 50 MPa is not normally used in the Haber Process.

.....

(1)

(d) Many industrial ammonia plants operate at a compromise temperature of about 800 K.

(i) State and explain, by using Le Chatelier's principle, one advantage, other than cost, of using a temperature lower than 800 K.

Advantage .....

Explanation .....

.....

(ii) State the major advantage of using a temperature higher than 800 K.

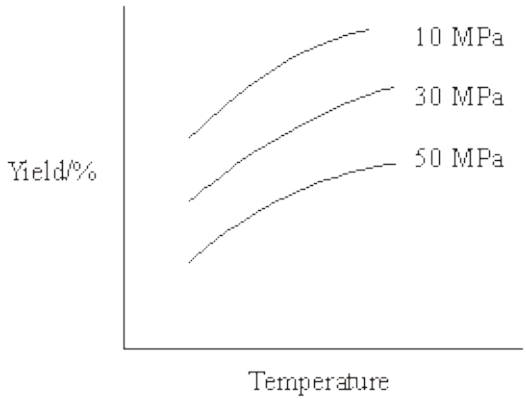
.....

(iii) Hence explain why 800 K is referred to as a *compromise temperature*.

.....

(5)
(Total 11 marks)

38 (a) The diagram below shows the effect of temperature and pressure on the equilibrium yield of the product in a gaseous equilibrium.



(i) Use the diagram to deduce whether the forward reaction involves an increase or a decrease in the number of moles of gas. Explain your answer.

Change in number of moles .....

Explanation .....

.....

.....

(ii) Use the diagram to deduce whether the forward reaction is exothermic or endothermic.
Explain your answer.

The forward reaction is .....

Explanation .....

.....

.....

(6)

(b) When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm^3, the following equilibrium was established at 700 K.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

The equilibrium mixture was found to contain 0.023 mol of hydrogen.

(i) Calculate the number of moles of iodine and the number of moles of hydrogen iodide in the equilibrium mixture.

Number of moles of iodine.....

Number of moles of hydrogen iodide ….....

.....

(ii) Write an expression for K_c for the equilibrium.

.....

.....

(iii) State why the volume of the flask need not be known when calculating a value for K_c.

.....

.....

(iv) Calculate the value of K_c at 700 K.

.....

.....

.....

(v) Calculate the value of K_c at 700 K for the equilibrium

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

.....

.....

(7)
(Total 13 marks)

39 The standard enthalpy of formation, ΔH_f for $O_3(g)$ is + 142 kJ mol^{-1}. In which one of the following would both the changes shown increase the amount of O_2 gas in an equilibrium mixture containing only $O_2(g)$ and $O_3(g)$?

A increasing the temperature and increasing the pressure

B increasing the temperature and decreasing the pressure

C decreasing the temperature and increasing the pressure

D decreasing the temperature and decreasing the pressure

(Total 1 mark)

40 At high temperatures, nitrogen is oxidised by oxygen to form nitrogen monoxide in a reversible reaction as shown in the equation below.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H^{\ominus} = +180 \text{ kJ mol}^{-1}$$

(a) In terms of electrons, give the meaning of the term *oxidation*.

.....

(1)

(b) State and explain the effect of an increase in pressure, and the effect of an increase in temperature, on the yield of nitrogen monoxide in the above equilibrium.

Effect of an increase in pressure on the yield .....

Explanation .....

.....

.....

.....

.....

Effect of an increase in temperature on the yield .....

Explanation .....

.....

.....

(6)

(c) Nitrogen monoxide, NO, is formed when silver metal reduces nitrate ions, NO_3^- in acid solution.

(i) Deduce the oxidation state of nitrogen in NO and in NO_3^-

NO.....

NO_3^- .....

(ii) Write a half-equation for the reduction of NO_3^- ions in acid solution to form nitrogen monoxide and water.

.....

(iii) Write a half-equation for the oxidation of silver metal to $Ag^+(aq)$ ions.

.....

(iv) Hence, deduce an overall equation for the reaction between silver metal and nitrate ions in acid solution.

.....

(5)
(Total 12 marks)

41 (a) The expression for an equilibrium constant, K_c, for a homogeneous equilibrium reaction is given below.

$$K_c = \frac{[A]^2[B]}{[C][D]^3}$$

(i) Write an equation for the forward reaction.

.....

(ii) Deduce the units of K_c

.....

(iii) State what can be deduced from the fact that the value of K_c is larger when the equilibrium is established at a lower temperature.

.....

(3)

(b) A 36.8 g sample of N_2O_4 was heated in a closed flask of volume 16.0 dm^3. An equilibrium was established at a constant temperature according to the following equation.

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

The equilibrium mixture was found to contain 0.180 mol of N_2O_4

(i) Calculate the number of moles of N_2O_4 in the 36.8 g sample.

.....

.....

(ii) Calculate the number of moles of NO_2 in the equilibrium mixture.

.....

.....

(iii) Write an expression for K_c and calculate its value under these conditions.

Expression for K_c .....

.....

Calculation .....

.....

.....

.....

(iv) Another 36.8 g sample of N_2O_4 was heated to the same temperature as in the original experiment, but in a larger flask. State the effect, if any, of this change on the position of equilibrium and on the value of K_c compared with the original experiment.

Effect on the position of equilibrium .....

Effect on the value of K_c .....

(9)

(Total 12 marks)

42 The following information concerns the equilibrium gas-phase synthesis of methanol.

$$CO(g) + 2H_2(g) \rightleftharpoons CH3OH(g)$$

At equilibrium, when the temperature is 68 °C, the total pressure is 1.70 MPa.
The number of moles of CO, H_2 and CH_3OH present are 0.160, 0.320 and 0.180, respectively.

Thermodynamic data are given below.

Substance	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
CO(g)	−110	198
H_2(g)	0	131
CH_3OH(g)	−201	240

Which one of the following statements applies to this equilibrium?

A The value of K_p increases if the temperature is raised.

B The value of K_p increases if the pressure is raised.

C The yield of methanol decreases if the temperature is lowered.

D The yield of methanol decreases if the pressure is lowered.

(Total 1 mark)

43 (a) Hydrogen used in the Haber Process is produced in the following dynamic equilibrium reaction.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

(i) In terms of rates and of concentrations, what does the term *dynamic equilibrium* mean?

Rates .....

Concentrations .....

(ii) State how an increase in pressure will affect the equilibrium yield of hydrogen. Explain your answer.

Equilibrium yield .....

Explanation .....

(iii) The equilibrium yield of hydrogen is reduced when the reaction is carried out at a lower temperature. What can be deduced about the enthalpy change in this reaction?

.....

(iv) Explain why the equilibrium yield is unchanged when a catalyst is introduced.

.....

.....

(8)

(b) Ammonia is produced in the Haber Process according to the following equation.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H_f^{\ominus} = -92 \text{ kJ mol}^{-1}$

Typical operating conditions are 450 °C and 20 MPa (200 bar).

(i) Explain why 450 °C is a compromise temperature.

.....

.....

.....

.....

(ii) Explain why 20 MPa is a compromise pressure.

.....

.....

.....

.....

(6)
(Total 14 marks)

44 When one mole of ammonia is heated to a high temperature, 50% dissociates according to the following equilibrium.

$$2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$$

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

A 1.5

B 2.0

C 2.5

D 3.0

(Total 1 mark)

45 Methanol is synthesised from carbon monoxide and hydrogen according to the equation below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H^{\ominus} = -91 \text{ kJ mol}^{-1}$$

Which one of the following changes would **not** affect the value of the equilibrium constant and would **not** increase the yield of methanol?

A increase in temperature

B decrease in temperature

C increase in pressure

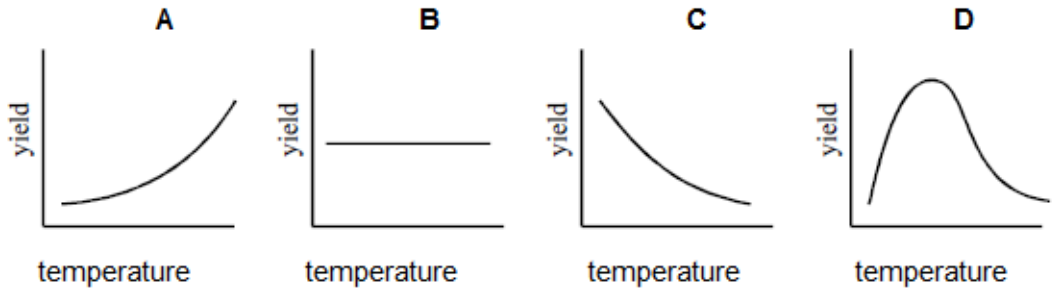
D decrease in pressure

(Total 1 mark)

46 Normal water and heavy water react together to form isotopically mixed water according to the equation

$$H_2O(l) + D_2O(l) \rightleftharpoons 2HDO(l)$$

The standard enthalpy of formation of $H_2O(l)$ is -286 kJ mol^{-1}, that of $D_2O(l)$ is -294 kJ mol^{-1}, and that of HDO(l) is -290 kJ mol^{-1}. Which one of the following best represents the variation with temperature of the yield of HDO at equilibrium?



(Total 1 mark)

47 The equilibrium constant, K_c, for a reaction which leads to ozone (O_3) formation is

$$K_c = \frac{[N_2][O_3]^2}{[NO]^2[O_2]^2}$$

More ozone is formed as the temperature rises. Which one of the following is true at equilibrium?

A When ozone molecules collide with nitrogen they may form nitrogen monoxide.

B The enthalpy change for the reaction has a negative sign.

C Less ozone is formed at high pressure.

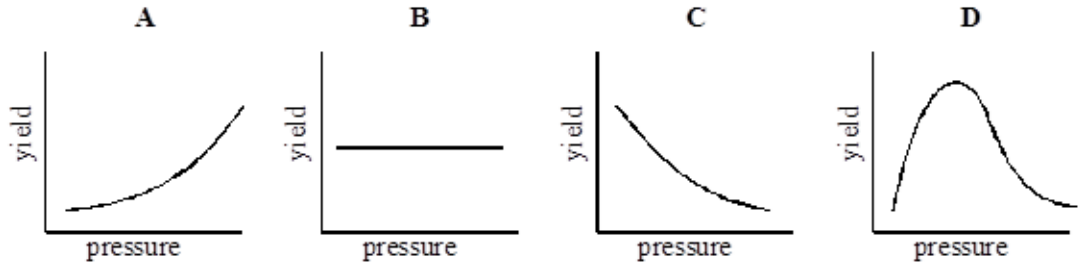
D At a fixed temperature, the magnitude of K_c increases as the concentration of NO decreases.

(Total 1 mark)

48 Phosphorus(V) chloride decomposes at high temperatures into phosphorus(III) chloride and chlorine according to the equation.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

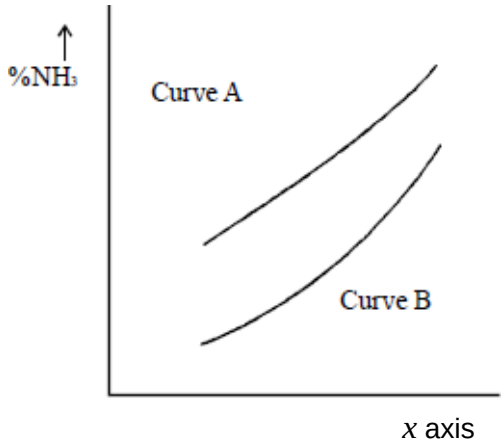
Which one of the graphs best represents the variation with pressure of the yield of chlorine at equilibrium?



(Total 1 mark)

49 The graph shows the equilibrium percentage of ammonia present during the formation of ammonia by the Haber process:

$N_2 + 3H_2 \rightleftharpoons 2NH_3$ $\Delta H = -92$ kJ mol^{-1}



Which one of the following are correct labels for the graph?

	x axis	*Curve A*	*Curve B*
A	temperature	high pressure	low pressure
B	temperature	low pressure	high pressure
C	pressure	high temperature	low temperature
D	pressure	low temperature	high temperature

(Total 1 mark)

50 A weak acid HA dissociates in aqueous solution as shown below

$HA(aq) \rightleftharpoons H^+(aq) + A^-(aq)$ $\Delta H = +20$ kJ mol^{-1}

Which one of the following changes will result in a decrease in the pH of an aqueous solution of the acid?

A addition of a little aqueous sodium hydroxide solution

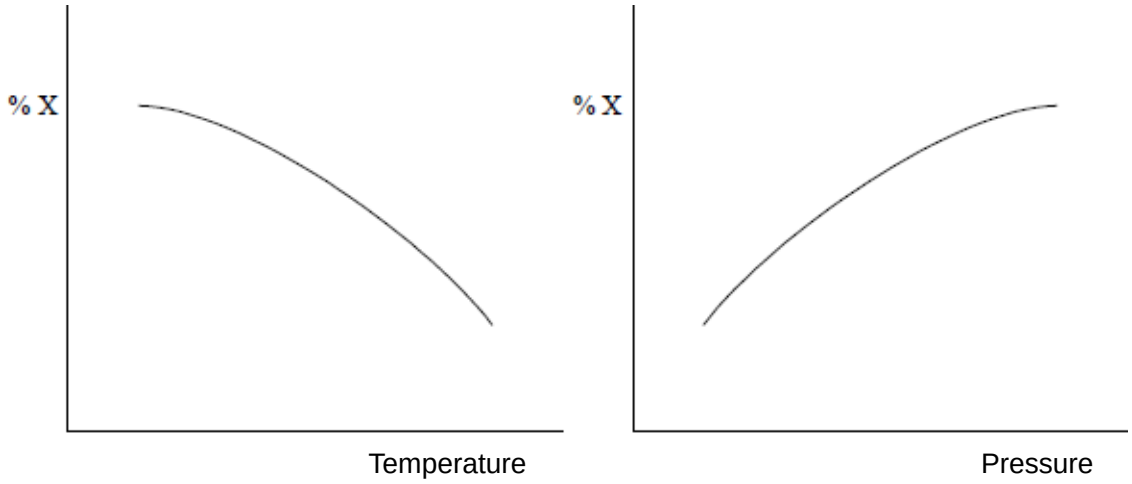
B raising the temperature of the solution

C dissolving a little of the sodium salt, NaA, in the solution

D adding a platinum catalyst to the solution

(Total 1 mark)

51 A compound **X** is formed during a gas phase reaction. The graphs below show how the percentage of a compound **X** present at equilibrium varies with temperature and pressure.



Which one of the following statements concerning the formation of **X** is correct?

A The reaction is exothermic and involves a decrease in the number of moles of gas.

B The reaction is exothermic and involves no change in the number of moles of gas.

C The reaction is exothermic and involves an increase in the number of moles of gas.

D The reaction is endothermic and involves a decrease in the number of moles of gas.

(Total 1 mark)

52 A sample of chlorine gas was sealed in a tube, heated and an equilibrium was established.

$Cl_2(g) \rightleftharpoons 2Cl(g)$

Which one of the following is **not** true?

A The concentration of chlorine atoms remains the same when a catalyst is added to the tube.

B Increase in temperature causes an increase in the concentration of chlorine atoms.

C Increase in pressure causes an increase in the concentration of chlorine atoms relative to chlorine molecules.

D Addition of more chlorine gas to the tube causes an increase in the concentration of chlorine atoms.

(Total 1 mark)

53 When one mole of ammonia is heated to a given temperature, 50 per cent 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 mixture?

A 1.5

B 2.0

C 2.5

D 3.0

(Total 1 mark)

54 The ester methyl ethanoate is hydrolysed as shown in the following equation.

$$CH_3COOCH_3(l) + H_2O(l) \rightleftharpoons CH_3COOH(l) + CH_3OH(l) \quad \Delta H^{\ominus} = +3 \text{ kJ mol}^{-1}$$

A 3 mol sample of methyl ethanoate was mixed with 3 mol of water and left to reach equilibrium at 298 K. The equilibrium yield of ethanoic acid was 2 mol. The value of K_c for this reaction at 298 K is

A $\frac{2}{3}$

B $\frac{4}{9}$

C 2

D 4

(Total 1 mark)

55 Methanol can be synthesised from carbon monoxide by the reversible reaction shown below.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

The process operates at a pressure of 5 MPa and a temperature of 700 K in the presence of a copper-containing catalyst. This reaction can reach dynamic equilibrium.

(a) By reference to rates and concentrations, explain the meaning of the term *dynamic equilibrium.*

.....

.....

(2)

(b) Explain why a high yield of methanol is favoured by high pressure.

.....

.....

(2)

(c) Suggest **two** reasons why the operation of this process at a pressure much higher than 5 MPa would be very expensive.

Reason 1.....

Reason 2.....

.....

(2)

(d) State the effect of an increase in temperature on the equilibrium yield of methanol and explain your answer.

Effect.....

Explanation.....

.....

.....

(3)

(e) If a catalyst were not used in this process, the operating temperature would have to be greater than 700 K. Suggest why an increased temperature would be required.

.....

(1)
(Total 10 marks)

56 Nitrogen dioxide dissociates according to the following equation.

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

When 21.3 g of nitrogen dioxide were heated to a constant temperature, *T*, in a flask of volume 11.5 dm^3, an equilibrium mixture was formed which contained 7.04 g of oxygen.

(a) (i) Calculate the number of moles of oxygen present in this equilibrium mixture and deduce the number of moles of nitrogen monoxide also present in this equilibrium mixture.

Number of moles Of O_2 at equilibrium .....

.....

Number of moles of NO at equilibrium .....

(ii) Calculate the number of moles in the original 21.3 g of nitrogen dioxide and hence calculate the number of moles of nitrogen dioxide present in this equilibrium mixture.

Original number of moles of NO_2 .....

.....

Number of moles of NO_2 at equilibrium .....

.....

(4)

(b) Write an expression for the equilibrium constant, K_c, for this reaction. Calculate the value of this constant at temperature T and give its units.

Expression for K_c .....

.....

Calculation .....

.....

.....

.....

.....

(4)

(c) The total number of moles of gas in the flask is 0.683. Use the ideal gas equation to determine the temperature *T* at which the total pressure in the flask is 3.30×10^5 Pa. (The gas constant $R = 8.31$ J $K^{-1}mol^{-1}$)

.....

.....

.....

.....

.....

(3)

(d) State the effect on the equilibrium yield of oxygen and on the value of K_c when the same mass of nitrogen dioxide is heated to the same temperature *T*, but in a different flask of greater volume.

Yield of oxygen .....

Value of K_c .....

(2)

(Total 13 marks)

57 Hydrogen is produced by the reaction between steam and methane when the following dynamic equilibrium is established.

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

(a) Use Le Chatelier's principle to predict the separate effects of an increase in temperature and of an increase in pressure on the yield of hydrogen obtained in the above reaction. In each case, explain your answer.

(6)

(b) State how, and explain why, the use of a catalyst might or might not change the equilibrium yield of hydrogen, and also the amount of hydrogen produced, in a given time.

(4)

(Total 10 marks)

1 (a) (i) **M1**

High (temperature) OR Increase (the temperature)

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2

The (forward) reaction / to the right is endothermic or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives out / releases heat

M3 depends on correct M2 and must refer to temperature / heat

M3** depends on a correct statement for **M2

At high temperature, the (position of) equilibrium shifts / moves left to right to oppose the increase in temperature

*For **M3**, the position of equilibrium shifts / moves*

to absorb heat OR

to lower the temperature OR

to cool down the reaction

3

(ii) **M1**

The reaction gets to equilibrium faster / in less time

OR

Produces a small yield faster / in less time

OR

Increases the rate (of reaction / of attainment of equilibrium)

Mark independently

M2

High pressure leads to **one** of the following

- more particles / molecules in a given volume
- particles / they are closer together
- higher concentration of particles / molecules

AND

- more collisions in a given time / increased collision frequency

*Penalise **M2** for reference to increased energy of the particles*

2

(iii) **M1** Increase in / more / large(r) / big(ger) surface area / surface sites

Mark independently

*For **M1** accept "an increase in surface"*

M2 increase in / more successful / productive / effective collisions (in a given time) (on the surface of the catalyst / with the nickel)

*For **M2** not simply "more collisions"*

Ignore "the chance or likelihood" of collisions

2

(b) **M1**

No effect / None

*If **M1** is incorrect **CE = 0** for the clip*

*If **M1** is blank, mark on and seek to **credit the correct information in the text***

M2 requires a correct M1

Equal / same number / amount of moles / molecules / particles on either side of the equation

OR

2 moles / molecules / particles on the left and 2 moles / molecules / particles on the right

M2** depends on a correct statement for **M1

*In **M2 not** "atoms"*

2

[9]

2

(a) $K_c = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$

Penalise ( ) in this part but can score units; mark on in (b)

If K_c expression wrong no marks in this part but can score M1 & M3 in (b)

1

units = $mol^{-1}\ dm^3$

1

(b) $[O_2] = \dfrac{[SO_3]^2}{[SO_2]^2 K_c}$ or $\dfrac{(0.072/1.4)^2}{(0.055/1.4)^2 \times 27.9}$ or $\dfrac{(0.072)^2}{(0.055)^2 \times 27.9}$

Correct answer scores three marks

Ignore ( ) in this part

Penalise contradiction in M1

M1

1

0.061(4)

If K_c expression wrong in (a) can score M1 here for rearrangement of their K_c & M3 for multiplication by 1.4

M2

mol O_2 = 0.0614 × 1.4 = 0.086 (allow 0.085−0.087)

If K_c or rearrangement wrong here score only M3 for multiplication by 1.4

1

M3 = correct answer of (M2 × 1.4)

M3

1

(c) (i) No effect **OR** none **OR** no change **OR** stays the same

1

(ii) Effect: Increase or more SO_3

Increase or more SO_3

If wrong effect, no further marks, but M2 and M3 are independent of each other

M1

1

Fewer mole(cule)s on RHS
or 3 moles to 2 moles
or (eqm shifts) to side with fewer moles
(V^3 or) residual V decreases in numerator of K_c expression

M2

1

Equilibrium moves / shifts to reduce the pressure / oppose the increase in pressure

to keep K_c constant,

ratio $\frac{(\text{mol } SO_3)^2}{(\text{mol } SO_2)^2(\text{mol } O_2)}$
must increase

Allow to oppose the change only if increase pressure mentioned

M3

1

[9]

3

(a) $Cl_2 + H_2O \rightleftharpoons HOCl + HCl$

Allow the products shown as ions.

1

$Cl_2 = 0$, HOCl = +1 and HCl = −1

1 mark for all three oxidation states correct. Allow a reaction arrow in this equation.

Oxidation states must match the species

1

(b) Hydroxide / alkali ions react with the acids

Mark independently

1

Equilibrium moves to the right

1

(c) Only used in small amounts

1

The health benefits outweigh the risks

1

[6]

4

(a) amount of X = 0.50 – 0.20 = 0.30 (mol)

1

amount of Y = 0.50 – 2 × 0.20 = 0.10 (mol)

1

(b) Axes labelled with values, units and scales that use over half of each axis

All three of values, units and scales are required for the mark

1

Curve starts at origin

1

Then flattens at 30 seconds at 0.20 mol

1

(c) Expression = $K_c = \frac{[Z]}{[X][Y]^2}$

1

$[Y]^2 = \frac{[Z]}{[X]\,K_c}$

1

$[Y] = (0.35 / 0.40 \times 2.9)^{0.5} = 0.5493 = 0.55$ (mol dm^{-3})

Answer must be to 2 significant figures

1

(d) Darkened / went more orange

1

The equilibrium moved to the right

1

To oppose the increased concentration of Y

1

(e) The orange colour would fade

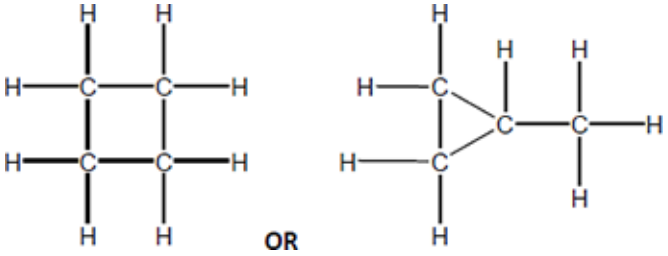
1

[12]

5

(a) Alkenes

1



OR

Correctly drawn molecule of cyclobutane or methyl cyclopropane, need not be displayed formula

1

(b) C_6H_{14} (or correct alkane structure with 6 carbons)

Allow hexane or any other correctly named alkane with 6 carbons

1

(c) Poly(but-2-ene)

1

(d) High pressure

Allow pressure ≥ MPa

Mention of catalyst loses the mark

1

(e) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

Level 3

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer communicates the whole process coherently and shows a logical progression from stage 1 and stage 2 (in either order) to stage 3.

5–6 marks

Level 2

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression. Some steps in each stage may be out of order and incomplete.

3–4 marks

Level 1

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete.

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

1–2 marks

Level 0

Insufficient correct chemistry to gain a mark.

0 marks

Indicative chemistry content

Stage 1*: consider effect of higher temperature on yield*

(Or vice versa for lower temperature)

- *Le Chatelier's principle predicts that equilibrium shifts to oppose any increase in temperature*
- *Exothermic reaction, so equilibrium shifts in endothermic direction / to the left*
- *So a Higher T will reduce yield*

Stage 2*: consider effect of higher temperature on rate*

(Or vice versa for lower temperature)

- *At higher temperature, more high energy molecules*
- *more collisions have E>Ea*
- *So rate of reaction increases / time to reach equilibrium decreases*

Stage 3*: conclusion*

Industrial conditions chosen to achieve (cost-effective) balance of suitable yield at reasonable rate

[11]

6 (a) Bonds broken = 2(C=O) + 3(H–H) = 2 × 743 + 3 × H–H

Bonds formed = 3(C–H) +(C–O) + 3(O–H) = 3 × 412 + 360 + 3 × 463

Both required

1

–49 = [2 × 743 + 3 × (H–H)] – [3 × 412 + 360 + 3 × 463]

3(H–H) = –49 – 2 × 743 + [3 × 412 + 360 + 3 × 463] = 1450

Both required

1

H–H = 483 (kJ mol^{-1})

Allow 483.3(3)

1

(b) Mean bond enthalpies are not the same as the actual bond enthalpies in CO_2 (and / or methanol and / or water)

1

(c) The carbon dioxide (produced on burning methanol) is used up in this reaction

1

(d) 4 mol of gas form 2 mol

1

At high pressure the position of equilibrium moves to the right to lower the pressure / oppose the high pressure

1

This increases the yield of methanol

1

(e) Impurities (or sulfur compounds) block the active sites

Allow catalyst poisoned

1

(f) Stage 1: moles of components in the equilibrium mixture

Extended response question

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

Initial moles	1.0	3.0	0	0
Eqm moles	(1–0.86) = 0.14	(3–3×0.86) = 0.42	0.86	0.86

1

Stage 2: Partial pressure calculations

Total moles of gas = 2.28

Partial pressures = mol fraction × p_{total}

1

p_{CO2} = mol fraction × p_{total} = 0.14 × 500 / 2.28 = 30.7 kPa

p_{H2} = mol fraction × p_{total} = 0.42 × 500 / 2.28 = 92.1 kPa

M3 is for partial pressures of both reactants

Alternative M3 =

pp_{CO2} = 0.0614 × 500

pp_{H2} = 0.1842 × 500

1

p_{CH3OH} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

p_{H2O} = mol fraction × p_{total} = 0.86 × 500 / 2.28 = 188.6 kPa

M4 is for partial pressures of both products

Alternative M4 =

pp_{CH3OH} = 0.3772 × 500

pp_{H2O} = 0.3772 × 500

1

Stage 3: Equilibrium constant calculation

$K_p = p_{CH3OH} \times p_{H2O} / p_{CO2} \times (p_{H2})^3$

1

Hence $K_p = 188.6 \times 188.6 / 30.7 \times (92.1)^3 = 1.483 \times 10^{-3} = 1.5 \times 10^{-3}$

Answer must be to 2 significant figures

1

Units = $\underline{kPa}^{-2}$

1

[16]

7 (a) Stage 1: Moles of acid at equilibrium

Moles of sodium hydroxide in each titration
= $(3.20 \times 2.00 \times 10^{-1}) / 1000 = 6.40 \times 10^{-4}$

Extended response

1

Sample = 10 cm^3 so moles of acid in 250 cm^3 of equilibrium mixture
= $25 \times 6.40 \times 10^{-4} = 1.60 \times 10^{-2}$

M2 can only be scored if = answer to M1 × 25

1

Stage 2: Moles of ester and water formed

Moles of acid reacted = $8.00 \times 10^{-2} - 1.60 \times 10^{-2} = 6.40 \times 10^{-2}$

= moles ester and water formed

M3 is 8.00×10^{-2} – M2

1

Stage 3: Moles of ethanol at equilibrium

Moles of ethanol remaining = $1.20 \times 10^{-1} - 6.40 \times 10^{-2} = 5.60 \times 10^{-2}$

M4 is 1.20×10^{-1} – M3

1

Stage 4: Calculation of equilibrium constant

$K_c = [CH_3COOCH_2CH_3]\,[H_2O] / [CH_3COOH]\,[CH_3CH_2OH]$

1

$= (6.40 \times 10^{-2})^2 / (1.60 \times 10^{-2})(5.60 \times 10^{-2})$

$= 4.5714 = 4.57$

M6 is $M3^2$ / M2 × M4

Answer must be given to 3 significant figures

1

(b)

	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	4.50	4.00	4.20	3.95

1

(c) Mean = 4.00 + 3.95 / 2 = 3.98 (cm^3)

Allow 3.975 (cm^3)

1

Titres 1 and 3 are concordant

Allow titre 2 is not concordant

1

(d) Thymol blue

1

(e) Percentage uncertainty: 0.15 / 3.98 × 100 = 3.77%

Allow consequential marking on mean titre from 2.3

1

(f) Use a lower concentration of NaOH

1

So that a larger titre is required (reduces percentage uncertainty in titre)

1

[13]

8 A

[1]

9 (a) (i) Award mark for **X on the time axis** at the point where the lines just become **horizontal**

*Allow this mark if **X** is above the letters "sh" in the word "show" in part(ii) - in the range of lines 31 to 33.*

1

(ii) They are equal / the same

OR

Forward (rate) = Reverse / backward (rate)

Allow the word 'speed' in this context.

Ignore reference to concentration.

1

(b) Both **OR** forward and reverse reactions occur at the same time

OR both are occurring at once

OR both occur all of the time

OR both are ongoing

OR both never stop

Ignore 'at equal rates'.

Ignore reference to concentration or equilibrium.

The idea that both reactions occur simultaneously is essential.

The simple idea of 'both reactions occurring' is insufficient for the mark.

1

(c) (i) **M1** No effect / no change / none / stays the same

M2 requires correct **M1**

*In **M2**, ignore reference to particles or atoms.*

M2 Equal (number of) moles / molecules on both sides

2

(ii) **M1** Less time or it decreases or (equilibrium) reached faster (ie **M1** is a reference to time taken)

*If **M1** is 'more time / it increases' or 'no effect', then **CE=0** for the clip.*

*Reference to faster / increased rate / increased speed alone penalises **M1**, but mark on **M2** and **M3**.*

M2 More particles / molecules in a given volume / space

OR the particles / molecules are closer together

*If **M1** is blank, then look for all three marks in the text.*

M3 More successful / productive collisions in a given time

OR more collisions with $E>E_{Act}$ in a given time

OR more frequent successful / productive collisions

OR increased / greater successful / productive collision frequency / rate

Ignore reference to reactants / products.

*Penalise **M3** if an increase / decrease in the value of E_{Act} is stated.*

3

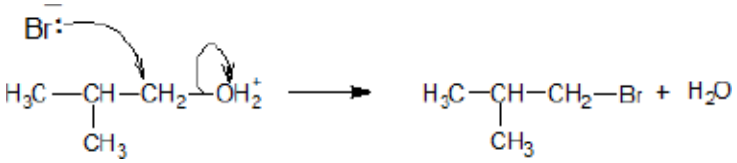
[8]

10 (a) (i) **M1** double-headed curly arrow from the lone pair of the bromide ion to the C atom of the CH_2

Penalise additional arrows.

M2 double-headed arrow from the bond to the O atom

As follows



2

(ii) **M1** nucleophilic substitution

***M1** both words needed (allow phonetic spelling).*

M2 1-bromo(-2-)methylpropane

***M2** Require correct spelling in the name but ignore any hyphens or commas.*

2

(b) **M1** hydrolysis

*For **M1** give credit for 'hydration' on this occasion only.*

M2 C≡N with absorption range 2220–2260 (cm^{-1})

*Credit 1 mark from **M2** and **M3** for identifying C≡N **and** either O–H(acids) **or** C=O **or** C–O without reference to wavenumbers or with incorrect wavenumbers.*

M3 O–H(acids) with absorption range 2500–3000 (cm^{-1})

OR

C=O with absorption range 1680–1750 (cm^{-1})

OR

C–O with absorption range 1000–1300 (cm^{-1})

*Apply the list principle to **M3***

3

(c) (i) **M1** Yield / product **OR** ester increases / goes up / gets more

M2 (By Le Chatelier's principle) the position of equilibrium is driven / shifts / moves to the right / L to R / in the forward direction / to the product(s)

M3 – requires a correct statement in M2

(The position of equilibrium moves)

to oppose the increased concentration of ethanol

to oppose the increased moles of ethanol

to lower the concentration of ethanol

to oppose the change and decrease the ethanol

*If no reference to **M1**, marks **M2** and **M3** can still score BUT if **M1** is incorrect CE=0*

*If there is reference to 'pressure' award **M1** ONLY.*

3

(ii) **M1**

Catalysts provide an alternative route / pathway / mechanism

OR

surface adsorption / surface reaction occurs

*For **M1**, not simply 'provides a surface' as the only statement.*

***M1** may be scored by reference to a specific example.*

M2

that has a lower / reduced activation energy

OR

lowers / reduces the activation energy

*Penalise **M2** for reference to an increase in the energy of the molecules.*

*For **M2**, the student may use a definition of activation energy without referring to the term.*

*Reference to an increase in successful collisions in unit time alone is not sufficient for **M2** since it does not explain why this has occurred.*

2

[12]

11 (a) Mol of **E** 1.6(00)

Ignore extra zeros.

1

Mol of **F** 0.2(00)

1

(b) $K_c = \dfrac{[G]^2}{[E][F]^2}$

Penalise expression containing V.

Penalise missing brackets or ( ).

1

$mol^{-1}\ dm^3$

If K_c wrong, allow units consequential to their K_c, but no marks in (c) unless correct K_c used in (c).

1

(c) $K_c = \dfrac{(0.85/1.5)^2}{(2.50/1.5)(1.20/1.5)^2}$

Vol missed or used wrongly – no marks.

If K_c correct in (b) but squared term missed here, no further marks.

1

= 0.3(01) Allow 0.299−0.304

Ignore units.

1

(d) M1 Decrease

If M1 is incorrect CE=0 for the clip.

If M1 is blank, mark on and seek to credit the correct information in the explanation.

1

M2 More moles on LHS / reactants or fewer / less moles on RHS / products (allow correct ratio 3:2)

M2 not just a generic statement 'shifts to more moles'.

1

M3 (Equilibrium) shifts / moves either to oppose reduction in pressure / or to increase the pressure

M3 depends on a correct statement for M2.

Not 'favours'.

Allow 'to oppose change' only if reduction in pressure noted.

1

(e) M1 T_1

If M1 is incorrect, CE=0 for the clip.

If M1 is blank, mark on and seek to credit the correct information in the explanation.

1

M2 (Forward*) reaction is exothermic

OR Backward reaction is endothermic

**Assume answer refers to forward reaction unless otherwise stated.*

1

M3 (at T_2 or lower temperature)

(Equilibrium) shifted / moved to oppose reduction in temp

OR

at T_1 or higher temp, (Equilibrium) shifted / moved to oppose (increase in temp)

M3 depends on a correct statement for M2

Allow "to oppose change" only if change in temperature is stated.

Not 'favours'.

1

[12]

12 (a) (i) M1 c(oncentrated) phosphoric acid / c(onc.) H_3PO_4
OR c(oncentrated) sulfuric acid / c(onc.) H_2SO_4

*In **M1**, the acid must be concentrated.*
Ignore an incorrect attempt at the correct formula that is written in addition to the correct name.

M2 Re-circulate / re-cycle the (unreacted) ethene (and steam) / the reactants
OR pass the gases over the catalyst several / many times

*In **M2**, ignore "remove the ethanol".*
Credit "re-use".

2

(ii) M1
(By Le Chatelier's principle) the equilibrium is driven / shifts / moves to the right / L to R / forwards / in the forward direction

M2 depends on a correct statement of M1
The equilibrium moves / shifts to

- oppose the addition of / increased concentration of / increased moles / increased amount of water / steam
- to decrease the amount of steam / water

Mark M3 independently
M3 Yield of product / conversion increase ***OR*** ethanol increases / goes up / gets more

3

(iii) M1 Poly(ethene) / polyethene / polythene / HDPE / LDPE

M2 At higher pressures
More / higher cost of electrical energy to pump / pumping cost
OR
Cost of higher pressure equipment / valves / gaskets / piping etc.
OR expensive equipment

*Credit all converse arguments for **M2***

2

(b) M1 for balanced equation

M2 for state symbols in a correctly balanced equation

$2C(s / graphite) + 3H_2(g) + ½O_2(g) \longrightarrow CH_3CH_2OH(l)$ (C_2H_5OH)

Not multiples but credit correct state symbols in a correctly balanced equation.

Penalise C_2H_6O but credit correct state symbols in a correctly balanced equation.

2

(c) (i) M1 The enthalpy change / heat change at constant pressure when 1 mol of a compound / substance / element

*If standard enthalpy of formation **CE=0***

M2 is burned / combusts / reacts completely in oxygen
OR burned / combusted / reacted in excess oxygen

M3 with (all) reactants and products / (all) substances in standard / specified states
OR (all) reactants and products / (all) substances in normal states under standard conditions / 100 kPa / 1 bar and specified T / 298 K

*For **M3***
Ignore reference to 1 atmosphere

3

(ii) M1

Correct answer gains full marks

ΣB(**reactants**) − ΣB(**products**) = *ΔH*

Credit 1 mark for (+) 1279 (kJ mol^{-1})

OR
Sum of bonds broken − Sum of bonds formed = ΔH
OR
B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) (LHS)
− 4B(C=O) − 6B(O−H) (RHS) = *ΔH*

M2 (also scores **M1**)
348+360+463+5(412)+3(496) [LHS = **4719**]
(2060) (1488)
− 4(805) − 6(463) [RHS = − **5998**] = *ΔH*
(3220) (2778)
OR using only bonds broken and formed (**4256 − 5535**)

For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either a correct cycle with 2C and 6H and 7O OR a clear statement of **M1** which could be in words and scores **only M1***

M3
ΔH= **− 1279** (kJ mol^{-1})

*Allow a maximum of one mark if the only scoring point is LHS = 4719 **OR** RHS = 5998*

Award 1 mark for +1279

Candidates may use a cycle and gain full marks

3

(d) (i) Reducing agent ***OR*** reductant ***OR*** electron donor
OR to reduce the copper oxide

Not "reduction".

Not "oxidation".

Not "electron pair donor".

1

(ii) CH_3COOH

1

[17]

13 (a) Cl_2 0.4

1

NOCl 1.7

1

(b) (i) $K_c = \frac{[NO]^2[Cl_2]}{[NOCl]^2}$

Penalise expression containing V
Allow ( ) here, but must have all brackets.
If K_c expression wrong, max 2 in (b)(ii) for
M1 for correct rearrangement of their K_c and
M4 for multiplying by 15

1

(ii) M1 $[Cl_2] = K_c \times \frac{[NOCl]^2}{[NO]^2}$

Mark is for rearrangement of correct K_c expression.
If K_c rearrangement wrong, can only score max 2 for:
M3 and M4

1

M2

$[Cl_2] = \frac{(7.4 \times 10^{-3}) \times (1.90/15)^2}{(0.86/15)^2} \left(= \frac{(7.4 \times 10^{-3}) \times (0.127)^2}{(0.0573)^2}\right)$

Rounding 1.90 / 15 wrongly to 0.126 is AE

1

M3 $[Cl_2]$ = 0.0361 to 0.0365 (min 2 sfs)

Mark for correct calculation of $[Cl_2]$

1

M4 mol Cl_2 = 0.54 to 0.55

Correct answer scores 4 ignore working

Mark is for <u>answer</u> of (M3 × 15)

1

(iii) ($\sqrt{}$?(7.4×10^{-3}) =) 0.086

Allow 0.085 to 0.086)

*Mark for answer **OR** conseq on their Cl_2*

$K_c = \sqrt{\frac{M4}{15}} \times \frac{0.86}{1.90} = \sqrt{M4} \times 0.117$

Or $\sqrt{M3} \times 0.453$

1

mol ½ dm$^{-3/2}$ ***OR*** mol $^{0.5}$ dm $^{-1.5}$

NOT $\sqrt{\text{mol dm}^{-3}}$ nor $(\text{mol dm}^{-3})^{1/2}$

1

[9]

14 (a) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift / move so as to oppose / counteract the change.

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase

OR

(When a system / reaction in equilibrium is disturbed), the (position of) equilibrium shifts / moves in a direction which tends to reduce the disturbance

An alternative to shift / move would be the idea of changing / altering the position of equilibrium

1

(b) (i) M1

A substance that speeds up the reaction / alters the rate but is chemically unchanged at the end / not used up

*Both ideas needed for **M1***

*Credit can score for **M1**, **M2** and **M3** from anywhere within the answer*

M2

Catalysts provide an alternative route / alternative pathway / different mechanism

M3

that has a lower activation energy / E_a

OR

lowers the activation energy / E_a

3

(ii) (Time is) less / shorter / decreases / reduces

Credit "faster", "speeds up", "quicker" or words to this effect

1

(iii) None

1

(c) (i) R

1

(ii) T

1

(iii) R

1

(iv) P

1

(v) Q

1

[11]

15 (a) (i) $\underline{3}CH_3OH$

Not molecular formula

1

$HOCH_2CH(OH)CH_2OH$

1

(ii) $\rightarrow \quad 19CO_2 \quad + \quad 19H_2O$

Or doubled

1

$C_{17}H_{35}COOCH_3$ + 27½ or 55/2 O_2

Consequential on correct right-hand side

1

(b) (i) A 0.7

1

Ethanol 6.4

1

Water 3.6

1

(ii) No effect

If wrong, CE= 0

1

Equal moles on each side of equation ***OR*** V cancels

Ignore moles of gas

1

(iii) M1 $K_c = \dfrac{[DEM][H_2O]^2}{[A][C_2H_5OH]^2}$

Must have all brackets but allow ( )

1

(iv) M2 $\dfrac{2.1 \times (3.4)^2}{0.85 \times (7.2)^2}$

If K_c wrong can only score M4 for units consequential to their K_c working in (b)(iv)

1

M3 0.55 (min 2dp)

1

M4 No units

1

[13]

16 (a) (i) **M1** **(could be scored by a correct mathematical expression which must have all ΔH symbols and the $\sum$ or SUM)**

M1 ΔH_r **=** $\Sigma\Delta H_f$ **(products)** - $\Sigma\Delta H_f$ **(reactants)**

OR a correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$

M2 $\Delta H_r = -201 + (-242) - (-394)$
$\Delta H_r = -201 - 242 + 394$
$\Delta H_r = -443 + 394$
(This also scores M1)

M3 = – **49** (kJ mol^{-1})
(Award 1 mark ONLY for + 49)
Correct answer gains full marks
Credit 1 mark ONLY for + 49 (kJ mol^{-1})
For other incorrect or incomplete answers, proceed as follows

- *check for an arithmetic error (AE), which is either a transposition error or an incorrect multiplication; this would score 2 marks (**M1** and **M2**)*
- *If no AE, check for a correct method; this requires either correct cycle of balanced equations with 1C, $3H_2$ and $1O_2$*
  *OR a clear statement of **M1** which could be in words and scores only **M1***

3

(ii) It is an element / elemental
Ignore reference to "standard state"

OR

By definition

1

(b) **M1** (The yield) increases / goes up / gets more

*If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank M1*

M2 There are more moles / molecules (of gas) on the left / of reactants
OR fewer moles / molecules (of gas) on the right / products
OR there are 4 moles /molecules (of gas) on the left and 2 moles / molecules on the right.
OR (equilibrium) shifts / moves to the side with less moles / molecules

*Ignore "volumes", "particles" "atoms" and "species" for **M2***

M3: Can only score M3 if M2 is correct

The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in pressure

*For **M3**, not simply "to oppose the change"*

*For **M3** credit the equilibrium shifts / moves (to right) to lower / decrease the pressure*

(There must be a specific reference to the change that is opposed)

3

(c) **M1** Yield increases goes up

M2 The (forward) reaction / to the right is endothermic OR takes in/ absorbs heat

OR

The reverse reaction / to the left is exothermic OR gives out / releases heat

*If M1 is given as "decrease" / "no effect" / "no change" then CE= 0 for clip, but mark on only **M2** and **M3** from a blank **M1***

Can only score M3 if M2 is correct

M3 The (position of) equilibrium shifts / moves (from left to right) to oppose the increase in temperature **(QoL)**

*For **M3**, not simply "to oppose the change"*

*For **M3**, credit the (position of) equilibrium shifts / moves **(QoL)***

*to absorb the heat **OR***

*to cool the reaction **OR***

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount / level of carbon dioxide /CO_2 carbon /greenhouse gas present in the atmosphere.

The idea that the carbon /CO_2 given out equals the carbon /CO_2 that was taken in from the atmosphere

1

(ii) $CH_3OH + \mathbf{1}½\ O_2 \longrightarrow CO_2 + \mathbf{2}H_2O$

Ignore state symbols

Accept multiples

1

(iii) $\mathbf{3}H_2 + \mathbf{1}½\ O_2 \longrightarrow \mathbf{3}H_2O$

Ignore state symbols

OR

Accept multiples

$\mathbf{2}H_2 + O_2 \longrightarrow \mathbf{2}H_2O$

Extra species must be crossed through

1

(e) **M1** $q = m\ c\ \Delta T$

Award full marks for correct answer

Ignore the case for each letter

OR $q = 140 \times 4.18 \times 7.5$

M2 = 4389 (J) OR 4.389 (kJ) OR 4.39 (kJ) OR 4.4 (kJ)(also scores M1)

M3 Using 0.0110 mol

therefore ΔH = **– 399** ($kJmol^{-1}$)

OR **– 400**

*Penalise **M3** ONLY if correct numerical answer but sign is incorrect; +399 **gains 2 marks***

*Penalise **M2** for arithmetic error and mark on*

*In **M1**, do not penalise incorrect cases in the formula*

If ΔT = 280.5; score $q = m\ c\ \Delta T$ only

*If c = 4.81 (leads to 5050.5) penalise **M2** ONLY and mark on for **M3** = – 459*

+399 or +400 gains 2 marks

Ignore incorrect units

3

[16]

17 (a) (i) **M1** iodine ***OR*** I_2 OR I_3^-

Ignore state symbols

*Credit **M1** for "iodine solution"*

M2 $Cl_2 + 2I^- \longrightarrow 2Cl^- + I_2$

OR

$\frac{1}{2} Cl_2 + I^- \longrightarrow Cl^- + \frac{1}{2} I_2$

Penalise multiples in M2 except those shown

***M2** accept correct use of I_3^-*

M3 redox or reduction-oxidation or displacement

3

(ii) **M1** (the white precipitate is) <u>silver chloride</u>

***M1** <u>must be named</u> and for <u>this mark</u> ignore incorrect formula*

M2 $Ag^+ + Cl^- \longrightarrow AgCl$

*For **M2** ignore state symbols*

Penalise multiples

M3 (white) precipitate / <u>it dissolves</u>

OR <u>colourless solution</u>

Ignore references to "clear" alone

3

(b) (i) **M1** $H_2SO_4 + 2Cl^- \longrightarrow 2HCl + SO_4^{2-}$

*For **M1** ignore state symbols*

OR $H_2SO_4 + Cl^- \longrightarrow HCl + HSO_4^-$

Penalise multiples for equations and apply the list principle

OR $H^+ + Cl^- \longrightarrow HCl$

M2 hydrogen chloride ***OR*** HCl ***OR*** hydrochloric acid

2

(ii) **M1 and M2 in either order**

*For **M1** and **M2**, ignore state symbols and credit multiples*

M1 $\mathbf{2}I^- \longrightarrow \mathbf{I_2} + \mathbf{2}e^-$

OR

$\mathbf{8}I^- \longrightarrow \mathbf{4}I_2 + \mathbf{8}e -$

Do not penalise absence of charge on the electron

Credit electrons shown correctly on the other side of each equation

M2 $H_2SO_4 + \mathbf{8}H^+ + \mathbf{8}e^- \longrightarrow H_2S + \mathbf{4}H_2O$

OR

$SO_4^{2-} + \mathbf{10}H+ + \mathbf{8}e^- \longrightarrow H_2S + \mathbf{4}H_2O$

Additional equations should not contradict

M3 <u>oxidising agent</u> / <u>oxidises the iodide</u> (ions)

OR

<u>electron acceptor</u>

M4 sulfur ***OR*** S ***OR*** S_2 ***OR*** S_8 ***OR*** sulphur

4

(iii) **M1** The NaOH / OH^- / (sodium) hydroxide reacts with / neutralises the H^+ / acid / HBr (lowering its concentration)

OR a correct neutralisation equation for H^+ or HBr with NaOH or with hydroxide ion

Ignore reference to NaOH reacting with bromide ions

Ignore reference to NaOH reacting with HBrO alone

M2 Requires a correct statement for M1

The (position of) equilibrium moves / shifts(from L to R)

- to replace the H^+ / acid / HBr that has been removed / lost
- ***OR*** to increase the H^+ / acid / HBr concentration
- ***OR*** to make more H^+ / acid / HBr / product(s)
- ***OR*** to oppose the loss of H^+ / loss of product(s)
- ***OR*** to oppose the decrease in concentration of product(s)

*In **M2**, answers must refer to the (position of) equilibrium shifts / moves and is not enough to state simply that it / the system / the reaction shifts to oppose the change.*

M3 The (health) benefit outweighs the risk or wtte

OR

a clear statement that once it has done its job, little of it remains

OR

used in (very) dilute concentrations / small amounts / low doses

3

[15]

18 (a) (i) mol H_2 = 0.47

1

mol I_2 = 0.17

If answers reversed, ie

mol H_2 = 0.17

mol I_2 = 0.47

then allow one mark (for second answer).

1

(ii) $\frac{[HI]^2}{[H_2][I_2]}$

Penalise expression containing V
But mark on in (a)(iv)

Penalise missing square brackets *in this part (and not elsewhere in paper) but mark on in (a)(iv)*

1

(iii) equal number of <u>moles</u> (on each side of equation)

OR

equal <u>moles</u> (top and bottom of *K*c expression)

1

(iv) $\frac{[1.94]^2}{[0.38][0,19]}$

Ignore V

If Kc wrong in (a)(ii) (wrong powers or upside down etc) no marks here

1

= 52(.1)

1

(b) (i) **D**

1

(ii) **B**

1

(iii) **A**

1

(iv) **C**

1

[10]

19 (a) **In either order**

For M1 accept [ ] for concentration

M1 Concentrations (of reactants and products) remain or stay constant / the same

NOT "equal concentrations" and NOT "concentration(s) is / are the same"

M2 Forward rate = Reverse / backward rate

NOT "amount"

Ignore "dynamic" and ignore "speed"

Ignore "closed system"

It is possible to score both marks under the heading of a single feature

2

(b) **M1** Catalysts increase rate of / speed up both forward and reverse / backward reactions

If M1 is given as "no effect" / "no change" then CE= 0 for clip

M2 increase in rate / affect on rate / speed is equal / the same

Ignore references to "decrease in rate"

2

(c) (i) **M1** (The yield) increases / goes up / gets more

If M1 is given as "decreases" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank.

M2 There are more moles / molecules (of gas) on the left / of reactants

Ignore "volumes", "articles" "atoms" and "species" for M2

OR fewer moles / molecules (of gas) on the right / products

OR there are 4 moles / molecules (of gas) on the left and 2 moles / molecules on the right.

OR (equilibrium) shifts / moves to the side with less moles / molecules

M3 Can only score M3 if M2 is correct

The equilibrium shifts / moves (from left to right) to oppose the increase in pressure

For M3, not simply "to oppose the change"

For M3 credit the equilibrium shifts / moves to lower / decrease the pressure

(There must be a specific reference to the change that is opposed)

3

(ii) **M1** The yield decreases / goes down / gets less

If M1 is given as "increase" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank.

M2 (Forward) reaction is exothermic ***OR*** gives out / releases heat

OR

reverse reaction is endothermic ***OR*** takes in / absorbs heat

Can only score M3 if M2 is correct

The equilibrium shifts / moves (from right to left) to oppose the increase in temperature

For M3, not simply "to oppose the change"

For M3 credit the equilibrium shifts / moves

to absorb the heat OR

to cool the reaction OR

to lower the temperature

(There must be a specific reference to the change that is opposed)

3

(d) (i) Must be comparative

Credit correct reference to rate being too (s)low / (s)lower at temperatures less than 600 K

Higher rate of reaction

OR increase / speed up the rate (of reaction)

Ignore statements about the "yield of ammonia"

OR Gets to equilibrium faster/ quicker

OR faster or quicker rate / speed of attainment of equilibrium

1

(ii) Less electrical pumping cost

Not just "less expensive" alone

OR

Not just "less energy or saves energy" alone

Use lower pressure equipment / valves / gaskets / piping etc.

Credit correct qualified references to higher pressures

OR

Uses less expensive equipment

Ignore references to safety

1

[12]

20 (a) (i) Mol SO_3 = 5.2

1

Mol SO_2 = 2.8

1

(ii) $$\frac{[SO_2]^2[O_2]}{[SO_3]^2}$$

Penalise expression containing numbers or V

Allow ( ) but must have all brackets. If brackets missing but otherwise correct, penalise here but mark on

Ignore subsequent correct working

If Kc wrong (wrong powers or upside down etc) can only score M1 in (a)(iv)

1

(iii) mol dm^{-3}

Allow conseq to their wrong Kc

1

(iv) *If Kc wrong in (a)(iv) (wrong powers or upside down etc) can only score M1*

Values from (a)(i)

$$\frac{[2.8/12]^2[1.4/12]}{[5.2/12]^2} \text{ or } \frac{[0.233]^2[0.117]}{[0.433]^2}$$

Alternative values

$$\frac{[2.1/12]^2[1.4/12]}{[5.8/12]^2}$$

1

M1 *For dividing all three by volume – if volume missed or used wrongly, lose M1 & M2 but can score M3 conseq*

M2 *insertion of values (allow conseq use of their wrong values from (a)(i))*

AE (–1) for copying numbers wrongly or swapping two numbers

1

Values from (a)(i)

M3 = 0.0338 or 0.034
(allow 0.03376 to 0.035)
Min 2 sfs
Ignore units in (a)(iv)

If vol missed score only M3

Values from (a)(i)

0.406 - allow values between 0.40 (if correctly rounded) and 0.41

Alternative values

M3 0.0153 or 0.015
(allow 0.015 to 0.017)
Min 2 sfs
Ignore units in (a)(iv)

from alternative values allow 0.18 to 0.184

1

(b) (i) Increase or more moles (of oxygen) or higher

1

(ii) No change or no effect or none or (remains) same

1

(c) **M1** T_1

If T_2 CE = 0

1

M2 (At Temp,T2, when Kc is lower) Equm/reaction moves to left or towards reagent or towards SO_3 OR moles SO_3 increases

1

M3 This reverse reaction is exothermic,

OR

M3 (forward) reaction is endothermic

M2 if Temp is increased Equm/reaction moves to right or towards product or towards SO_2 OR moles SO_2 increases

OR

M3 (forward) reaction is endothermic

M2 if Temp is decreased Equm/reaction moves to left or towards reagent or towards SO_3 OR moles SO_3 increases

1

[12]

21 (a) (i) $Cu + \mathbf{4}HNO_3 \longrightarrow Cu(NO_3)_2 + \mathbf{2}NO_2 + \mathbf{2}H_2O$

Or multiples

Ignore state symbols

1

(ii) **M1** HNO_3 (+) **5**

M2 NO_2 (+) **4**

Ignore working out

M1 Credit (V)

M2 Credit (IV)

2

(iii) $HNO_3 + H^+ + e^- \longrightarrow NO_2 + H_2O$

OR

$NO_3^- + 2H^+ + e^- \longrightarrow NO_2 + H_2O$

Or multiples

Ignore state symbols

Ignore charge on the electron unless incorrect and accept loss of electron on the RHS

1

(b) (i) **In either order**

M1 Concentration(s) (of reactants and products) remain(s) constant / stay(s) the same / remain(s) the same / do(es) not change

M2 Forward rate = Reverse / backward rate

For M1 accept [ ] for concentration

NOT "equal concentrations" and NOT "concentration(s) is/are the same"

NOT "amount"

Ignore "dynamic" and ignore "speed"

Ignore "closed system"

It is possible to score both marks under the heading of a single feature

2

(ii) **M1**

The (forward) reaction / to the right is endothermic
or takes in / absorbs heat

OR

The reverse reaction / to the left is exothermic or gives
out / releases heat

M2 depends on correct M1 and must refer to temperature/heat

The equilibrium shifts / moves left to right to oppose the increase in temperature

M2 depends on a correct statement for M1

For M2, the equilibrium shifts/moves

to absorb the heat OR

to lower the temperature OR

to cool the reaction

2

(iii) **M1 refers to number of moles**

There are fewer moles (of gas) on the left OR more
moles (of gas) on the right.
OR there is one mole (of gas) on the left and 2 moles
on the right.

M2 depends on correct M1 and must refer to pressure
The equilibrium shifts / moves right to left to oppose the
increase in pressure

M2 depends on a correct statement for M1

For M2, the equilibrium shifts/moves to lower the pressure.

2

[10]

22 (a) Forward and backward reactions proceeding at equal rate

1

Amount (Conc or moles or proportion) of reactants and
products remain constant

Not "reactants and products have equal conc"

1

(b) **M1** $\frac{[R]^2}{[P][Q]^2}$

Allow ( ) but must have all brackets

*If Kc wrong can only score **M3** (process mark)*

for dividing both R and P by volume)

1

(c) **M2** $[Q]^2 = \frac{[R]^2}{k_c[P]}$

Rearrangement of correct Kc expression

*If wrong Kc used can only score **M3** for correct use of vol*

*If wrong rearrangement can only score max 2 for **M3** and **M5** for correct √*

1

M3 $[Q]^2 = \frac{(5.24/10)^2}{68.0 \times (3.82/10)}$

Process mark for dividing both R and P by volume even in incorrect expression

*If vol missed can only score max 2 for **M2** and M5 for correct √*

*If vol used but then wrong maths can score **M2 M3** and **M5** for correct √*

If moles used wrongly, eg (2 × 5.24) or (5.24 × 10/10^3)

*can only score **M2** and **M5***

1

M4 $[Q]^2 = 0.0106$

Correct calculation of Q^2

1

M5 [Q] = 0.10(3)

Correct taking of √

1

(c) cont.

Wrong rearrangement and no use of volume

0

Wrong rearrangement

*For Correct use of volume **M3** and Correct taking of square root **M5***

2 max

No use of volume

2 max

answer = 0.325

Ignore subsequent multiplying or dividing by 10.

***0.0325 or 3.25** still score max 2*

*For Correct rearrangement **M2** and*

*Correct taking of square root **M5***

2 max

Use of volume but maths error e.g. using $(5.24)^2/10$
when should be $(5.24/10)^2$

Scores 3

also giving answer 0.325

*for **M2**, **M3** and **M5***

3

Use of volume but Q/10 also used
or Q multiplied by 10 at end
(i.e.muddling moles with concentration)

Gives answer 1.03

*For Correct rearrangement **M2** and*
*Correct taking of square root **M5***

2 max

Wrong use of moles, e.g (5.24×2) or $(5.24 \times 10/10^3)$

*For Correct rearrangement **M2** and*
*Correct taking of square root **M5***

2 max

Wrong Kc used, e.g. missing powers

*For Correct use of volume **M3***

1 max

(d) Increase or more or larger

Allow moves to left

1

(e) Increase or more or larger

Allow moves to left

1

(f) Decrease or less or smaller

NOT allow moves left

1

(g) No effect or unchanged or none

1

(h) 0.0147 or 0.0148 or 1.47×10^{-2} or 1.48×10^{-2}

Allow 0.015 or 1.5×10^{-2}

If not 0.0147, look at (c) for conseq correct use
of their [Q] in new $Kc = 1.39 \times [Q]^2$

Not allow just 1/68.0

ignore units

1

[24]

23 (a) = (0.0745) × (0.0813) / (0.0424) × (0.0525)
= 2.72

Allow answer only without working if correct.

Lose this mark if the wrong K_c expression is used.

1

Answer, whether or not correct, given to three significant figs

Do not expect conversion from moles to concentration but allow if shown.

1

(b) Less acid is present (so less NaOH needed)

1

Equilibrium would shift to right (side with more ester / less acid)

1

[4]

24 (a) K_c / K_a / equilibrium constant / constant is temperature dependent

Do not allow 'affects or shifts equilibrium'.

1

(b) Thermostat / water bath

1

[2]

25 (a) (i) chlorotrifluoromethane

Spelling must be correct but do not penalise "flouro"

Ignore use of 1–

1

(ii) CF_3•

May be drawn out with dot on C

OR if as shown dot may be anywhere

1

(iii) An unpaired/non-bonded/unbonded/free/a single/one/lone electron

NOT "bonded electron" and NOT "paired electron"

NOT "pair of electrons"

NOT "electron s"

Ignore "(free) radical"

1

(b) **M1** $Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$

M2 $ClO\bullet + O_3 \rightarrow \mathbf{2}O_2 + Cl\bullet$

Mark independently

Equations could gain credit in either position

The dot can be anywhere on either radical

Penalise the absence of a dot on the first occasion that it is seen and then mark on. Do not make the same penalty in the next equation, but penalise the absence of a dot on the other radical.

Apply the list principle for additional equations

2

(c) (i) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift/move so as to oppose the change.

OR

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

Must refer to equilibrium

Ignore reference to "system" alone

A variety of wording will be seen here and the key part is the last phrase.

An alternative to shift/move would be the idea of changing/altering the position of equilibrium

1

(ii) **M1** The (forward) reaction/to the right is endothermic or takes in heat

OR The reverse reaction/to the left is exothermic or gives out heat

M2 The equilibrium moves/shifts to oppose the increase in temperature

M2 depends on a correct statement for M1

For M2 accept

The equilibrium moves/shifts

- *to take in heat/lower the temperature*
- *to promote the endothermic reaction and take in heat/ lower the temperature*
- *to oppose the change and take in heat/lower the temperature*

(leading to the formation of more ozone)

2

(d) Any one of

- Pentane does not contain chlorine OR C–Cl (bond)
- Pentane is chlorine-free
- Pentane does not release chlorine (atoms/radicals)

Ignore reference to F OR C–F OR halogen
Ignore "Pentane is not a CFC"
Ignore "Pentane is a hydrocarbon"
Ignore "Pentane only contains C and H"
Ignore "Pentane is C_5H_{12}"

1

[9]

26 (a) mol CH_3OH = 0.07(0)

1

mol H_2 = 0.24(0)

1

(b) (i) $\frac{[CH_3OH]}{[CO][H_2]^2}$ or $\frac{(0.082/1.5)}{(0.210/1.5)(0.275/1.5)^2}$

allow ( ) but expression using formulae must have brackets
alternative expression using numbers must include volumes

1

(ii) **M1** divides by vol

Mark independently from (b)(i)
any AE is –1
if volume missed, can score only M3 and M4

1

M2 $\frac{(0.082/1.5)}{(0.210/1.5)(0.275/1.5)^2}$ $\left(= \frac{(0.05467)}{(0.14)(0.1833)^2}\right)$

mark is for correct insertion of correct numbers in correct Kc expression in b(ii)
If Kc expression wrong, can only score M1 & M4
If numbers rounded, allow M2 but check range for M3

1

M3 11.6 or 11.7

mark for answer
above 11.7 up to 12.2 scores 2 for M1 and M2
if vol missed, can score M3 for 5.16 (allow range 4.88 to 5.21)

1

M4 $mol^{-2}\ dm^6$

Units conseq to their Kc in (b)(ii)

1

(iii) no effect or no change or none

1

(c) **M1** T_1

if wrong - no further marks

1

M2 (forward) reaction is exothermic **OR** gives out heat

backward reaction is endothermic

only award M3 if M2 is correct

1

M3 shifts to RHS to replace lost heat

OR to increase the temperature

OR to oppose fall in temp

backward reaction takes in heat

OR to lower the temperature

not just to oppose the change

1

(d) fossil fuels used
OR
CO_2 H_2O produced/given off/formed which are greenhouse gases
OR
SO_2 produced/given off/formed which causes acid rain
OR
Carbon produced/given off/formed causes global dimming

not allow electricity is expensive
ignore just global warming
ignore energy or hazard discussion

1

(e) $C_{17}H_{35}COOCH_3$ **or** $C_{17}H_{31}COOCH_3$ or $C_{17}H_{29}COOCH_3$

OR

$CH_3OOCC_{17}H_{35}$ or $CH_3OOCC_{17}H_{31}$ or $CH_3OOCC_{17}H_{29}$

1

[13]

27 (a) (i) $\mathbf{4}FeS_2 + \mathbf{11}O_2 \longrightarrow \mathbf{2}Fe_2O_3 + \mathbf{8}SO_2$

2 **5½** **(1)** **4**

Or multiples of this equation

1

(ii) **M1** **(+) 4**

M2 **– 1**

Ignore working

M1, credit (+) IV

M2, credit – I

2

(b) **M1** Lower/smaller/decreases/reduced yield
OR equilibrium shifts (right) to left

M2 (Forward) reaction is exothermic OR reverse reaction is endothermic

M3 (By Le Chatelier's principle) equilibrium responds/shifts/moves
(R to L)
to lower the temperature
OR to absorb the heat
OR to cool the reaction

If M1 is blank, mark on and credit M1 in the text.

If M1 is incorrect, only credit correct M2

Mark M2 independently – it may be above the arrow in the equation

For M3, not simply "to oppose the change/temperature"

3

(c) **M1** $Fe_2O_3 + 3CO \longrightarrow \mathbf{2}Fe + \mathbf{3}CO_2$

Or multiples

Ignore state symbols

M2 Reducing agent
OR Reduce(s) (Fe_2O_3/iron(III) oxide)
OR Electron donor
OR to remove the oxygen (from iron(III) oxide to form CO_2)
OR reductant

For M2, credit "reduction"

2

[8]

28 (a) **M1** The yield of zinc oxide <u>increases/greater</u>

If M1 is given as "decrease" OR "no effect" then CE= 0

M2 Removal of the carbon dioxide results in the **<u>equilibrium</u>**
Either
Shifting/moving/goes to the right
shifting/moving/goes L to R
favours the forward reaction/towards the products

M3 (By Le Chatelier's principle) the reaction/equilibrium will respond so as <u>to replace the CO_2/lost product</u>
OR <u>to make more CO_2</u>
OR <u>to increase concentration of CO_2</u>

For M3, not simply "to oppose the change/to oppose the loss of CO_2/to oppose the removal of carbon dioxide."

3

(b) **M1** Process 2 produces/releases SO_2
OR Process 2 produces/releases CO

M2 It/Process 3 avoids the release of SO_2 OR CO
OR It/Process 3 (captures and) converts SO_2 to H_2SO_4

M3 SO_2 causes acid rain OR is toxic/poisonous
OR CO is toxic/poisonous

3

Ignore "global warming" and "greenhouse gases" and "the ozone layer"

If both CO and SO_2 claimed to form acid rain, treat as contradiction

(c) **M1** Process 3 (is expensive because it) uses <u>electrolysis</u>
OR due to high <u>electricity/electrical</u> consumption

M2 this is justified because the product/zinc is pure

Ignore "energy"

Penalise "pur<u>er</u>"

2

(d) **M1** $Zn^{2+} + 2e^- \longrightarrow Zn$

Ignore state symbols

M2 the negative electrode OR the cathode

Ignore absence of negative charge on electron

Accept electrons subtracted from RHS

2

(e) **M1** The reaction of ZnO with sulfuric acid
OR the second reaction in Extraction process 3

M2 neutralisation or acid-base

OR alternatively

M1 The reaction of zinc carbonate in Extraction process 1

M1 could be the equation written out in both cases

M2 (thermal) decomposition

M2 depends on correct M1

M3 It/carbon is <u>oxidised/gains oxygen/changes oxidation state/number from 0 to +2/increase in oxidation state/number</u> in Process 2

Do not forget to award this mark

Ignore reference to electron loss but penalise electron gain

Ignore "carbon is a reducing agent"

3

(f) **M1** $Zn + H_2O \longrightarrow ZnO + H_2$

M2 Zinc oxide and hydrogen

OR as an alternative

M1 $Zn + 2H_2O \longrightarrow Zn(OH)_2 + H_2$

M2 Zinc hydroxide and hydrogen

Mark independently

If ZnO_2 is given for zinc oxide in the equation, penalise M1 and mark on

If ZnOH is given for zinc hydroxide in the equation, penalise M1 and mark on

Ignore state symbols

Credit multiples of the equation

If M1 is blank, either of the M2 answers could score

To gain both marks, the names must match the correct equation given.

2

[15]

29 (a) (i) mol $CH_4 = 0.75$

1

mol $H_2O = 1.5$

1

mol $H_2 = 1(.0)$

1

(ii) 0.15 (mol dm^{-3})

conseq = (mol CH_4)/5

1

(b) (i) $\frac{[CO_2][H_2]^4}{[CH_4][H_2O]^2}$

not just numbers

do not penalise ( )

If wrong Kc no marks for calc but allow units conseq to their Kc

1

(ii) $\frac{(0.15)(0.25)^4}{(0.10)(0.48)^2}$

No marks for calc if concs used wrongly or wrong values inserted

1

0.025(4)

1

$mol^2\ dm^{-6}$

allow 1 here for correct units from wrong Kc

1

(c) increase

if wrong, no further marks in (c)

1

M1 lower P

1

M2 eqm shifts to side with more moles (Le Chatelier)

not "greater volume" for M1 but allow "moves to form a greater volume" for M2

1

(d) (forward reaction is) endothermic or <u>backward</u> reaction is exothermic

1

eqm shifts in exothermic direction or to oppose reduction of or change in temp

This mark must have reference to temp change or exothermic reaction

1

[13]

30 (a) (i) Reducing agent

OR

Reduce(s) (WO_3/tungsten oxide)

OR

electron donor

OR

to remove <u>oxygen</u> (from WO_3/tungsten oxide or to form water);

1

(ii) $WO_3 + \mathbf{3}H_2 \rightarrow W + \mathbf{3}H_2O$

Or multiples

1

(iii) *One from*

H_2 is

- explosive
- flammable or inflammable
- easily ignited

Ignore reference to pressure or temperature

1

(b) (i) Addition

Ignore "electrophilic"

Penalise "nucleophilic addition"

OR

(catalytic) hydrogenation

OR

Reduction

1

(ii) Geometric(al)

OR

cis/trans OR E Z OR E/Z

1

(c) (i) (If any factor is changed which affects an equilibrium), the position of equilibrium will shift/move/change/respond/act so as to oppose the change.

OR

(When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance

A variety of wording will be seen here and the key part is the last phrase and must refer to movement of the equilibrium.

QoL

1

(ii) **M1 – Statement of number of moles/molecules**
There are <u>more moles/molecules</u> (of gas) on the left/of reactants

OR

<u>fewer moles/molecules</u> (of gas) on the right./products

OR

there are <u>4 moles/molecules</u> (of gas) on the left <u>and 2 moles/ molecules</u> on the right.

Ignore "volumes" for M1

Mark independently

M2 – Explanation of response/movement in <u>terms of pressure</u>
<u>Increase in pressure is opposed</u> (or words to that effect)

OR

<u>pressure is lowered</u> by a shift in the equilibrium (from left) <u>to right</u>/favours forward reaction.

2

(d) ΣB(reactants) – ΣB(products) = Δ*H* (**M1**)

OR

<u>Sum</u> of bonds broken – <u>Sum</u> of bonds formed = ΔH (**M1**)

B(H–H) + ½B(O=O) – 2B(O–H) = – 242 (**M1**)

B(H–H) = – 242 – ½(+496) + 2(+463) (this scores **M1** and **M2**)

B(H–H) = (+)<u>436</u> (kJ mol^{-1}) (**M3**)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

M1 could stand alone

<u>Award full marks for correct answer.</u>

Ignore units.

Two marks can score with an arithmetic error in the working.

3

[11]

31 (a) (i) acid 0.46

1

alcohol 1.46

1

water 5.54

1

(ii) $K_c = \frac{CH_3CH_2COOCH_2CH_3][H_2O]}{[CH_3CH_2COOH][CH_3CH_2OH]} = \frac{[ester][water]}{[acid][alcohol]}$

penalise ( )
allow molecular formulae or minor slip in formulae

1

(iii) $\frac{(0.54/V)(5.54/V)}{(0.46/V)(1.46/V)}$

Allow without V

Conseq on values in (a)(i)
If values used wrongly
or wrong values inserted
or wrong K_c no marks for calc

1

4.45 or 4.5

Part (a)(iii) for info 0.46 × 1.46 = 0.6716

1

<u>cancel</u> (as equal no of moles on each side of equation)

1

Possible wrong answers

acid	*0.46*	✓	*gives*
alcohol	*1.46*	✓	*K_c = 3.59*
water	*4.46*	✗	✓✓

acid	*0.46*	✓	*gives*
alcohol	*1.46*	✓	*K_c = 0.434*
water	*0.54*	✗	✓✓

(b) (i) decrease or be reduced or fewer

1

(ii) decrease or be reduced or less time or faster or quicker

1

(iii) decrease or be reduced

1

[10]

32 (a) **M1** Concentrations of reactants and products remain constant

For M1
NOT "equal concentrations"
NOT "amount"

1

M2 Forward rate = Reverse / backward rate

Credit the use of [ ] for concentration
Ignore dynamic, ignore closed system

1

(b) **M1** The (forward) reaction / to the right is exothermic or releases heat OR converse for reverse reaction.

1

M2 The equilibrium responds by absorbing heat / lowering temperature
OR
Promotes the endothermic reaction by absorbing heat / lowering temperature
OR
Temperature increase is opposed (by shift to the left)
OR
Change is opposed by absorbing heat / lowering temperature.

1

(c) (i) A substance that speeds up / alters the rate but is unchanged at the end / not used up.

Both ideas needed
Ignore references to activation energy and alternative route.

1

(ii) None OR no change OR no effect OR nothing OR Does not affect it / the position (of equilibrium) OR (The position is) the same or unchanged.

1

(d) (i) An activity which has no net / overall (annual) carbon emissions to the atmosphere

OR

An activity which has no net / overall (annual) greenhouse gas emissions to the atmosphere.

OR

There is no change in the total amount of carbon dioxide / carbon /greenhouse gas present in the atmosphere.

The idea that the carbon / CO_2 given out equals the carbon / CO_2 that was taken in

Ignore carbon monoxide

1

(ii) A method which shows (see below) OR states in words that two times the first equation + the second equation gives the correct ratio.

$$2\,(CH_4 + H_2O \rightarrow CO + 3H_2)$$
$$CH_4 + CO_2 \rightarrow 2CO + 2H_2$$
$$3CH_4 + 2H_2O + CO_2 \rightarrow 4CO + 8H_2$$

Ratio = 1 : 2

1

[8]

33 (a) **M1** $MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$

1

OR multiples

M2 An oxidising agent is an electron acceptor OR receives / accepts / gains electrons

Ignore state symbols

M2 NOT an "electron pair acceptor"

1

M3 MnO_2 is the oxidising agent

Ignore "takes electrons" or "takes away electrons"

1

(b) **M1** Formation of SO_2 and Br_2 (could be in an equation)

1

M2 Balanced equation

Several possible equations

2KBr + **3**H_2SO_4 → **2**$KHSO_4$ + Br_2 + SO_2 + **2**H_2O

OR

2KBr + 2H_2SO_4 → K_2SO_4 + Br_2 + SO_2 + **2**H_2O

1

M3 **2**KBr + Cl_2 → **2**KCl + Br_2

M2 Could be ionic equation with or without K^+

2Br^- + ***6***H^+ + ***3***SO_4^{2-} → Br_2 + ***2***HSO_4^- + SO_2 + ***2***H_2O

*(**3**H_2SO_4)*

2Br^- + ***4***H^+ + SO_4^{2-} → Br_2 + SO_2 + ***2***H_2O

*(**2**HBr + H_2SO_4)*

Accept HBr and H_2SO_4 in these equations as shown or mixed variants that balance.

Ignore equations for KBr reacting to produce HBr

M3 Could be ionic equation with or without K^+

2Br^- + Cl_2 → ***2***Cl^- + Br_2

1

M4 % atom economy of bromine

$$= \frac{Br_2}{2KBr + Cl_2} \times 100 = \frac{(2 \times 79.9)}{238 + 71} \times 100 = \frac{159.8}{309} \times 100$$

= **51.7%** OR **52%**

M4 Ignore greater number of significant figures

1

M5 One from:

- High atom economy
- Less waste products
- Cl_2 is available on a large-scale
- No SO_2 produced
- Does not use concentrated H_2SO_4
- (Aqueous) KBr or bromide (ion) in seawater.
- Process 3 is simple(st) or easiest to carry out

M5 Ignore reference to cost

Ignore reference to yield

1

(c) **M1** HBr **–1**

1

M2 HBrO **(+)1**

1

M3 Equilibrium will shift to the right
OR
L to R
OR
Favours forward reaction
OR
Produces more HBrO

1

M4 **Consequential on correct M3**
OR
to oppose the loss of HBrO
OR
replaces (or implied) the HBrO (that has been used up)

1

[12]

34 (a) Low temperature
Reaction is exothermic

1

Low T reduces effect of heat evolved
or heat evolved opposes the change in temperature

1

High pressure
3 mol gas → 1 mol gas

1

High p favours fewer moles by lowering p
or forward reaction reduces volume and lowers p

1

(b) High T gives a low yield

1

but Low T gives a low rate ∴ compromise

1

increases reaction rate/catalyst surface contact

1

[7]

35 (a) (i) $C + 3D \rightarrow 2A + B$

1

(ii) mol dm^{-3}

1

(iii) (forward reaction is) exothermic or more products formed

1

(b) (i) Moles of iodine = 0.023

1

Moles of HI = 0.172

1

(ii) $K_c = \frac{[H_2][I_2]}{[HI]^2}$

1

(iii) V cancels in K_c expression

1

(iv) $K_c = \frac{(0.023)^2}{(0.172)^2}$

1

$= 0.0179$ or 1.79×10^{-2}

1

(v) $K_c = 55.9$ or 56

Conseq i.e. (answer to (iv))$^{-1}$

1

[10]

36 (a) Equation $1/2N_2 + 3/2H_2 \rightarrow NH_3$

1

$\Delta Hf = [(945 \times 0.5) + (426 \times 1.5)] - (391 \times 3)$

1

$= -46.5$ kJ mol^{-1}

1

Mark Range	The marking scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC). There are no discrete marks for the assessment of QWC but the candidates' QWC in this answer will be one of the criteria used to assign a level and award the marks for this part of the question **Descriptor** an answer will be expected to meet most of the criteria in the level descriptor
4-5	– claims supported by an appropriate range of evidence – good use of information or ideas about chemistry, going beyond those given in the question – argument well structured with minimal repetition or irrelevant points – accurate and clear expression of ideas with only minor errors of grammar, punctuation and spelling
2-3	– claims partially supported by evidence – good use of information or ideas about chemistry given in the question but limited beyond this – the argument shows some attempt at structure – the ideas are expressed with reasonable clarity but with a few errors of grammar, punctuation and spelling
0-1	– valid points but not clearly linked to an argument structure – limited use of information or ideas about chemistry – unstructured – errors in spelling, punctuation and grammar or lack of fluency

(b) The higher the temperature the faster the reaction QWC

1

but, since the reaction is exothermic

1

the equilibrium yield is lower QWC

1

The higher the pressure the greater the equilibrium yield QWC

1

because there is a reduction in the number of moles of gas in the reaction

1

but higher pressure is expensive to produce or plant is more expensive to build QWC

1

A better catalyst would lessen the time to reach equilibrium

1

and allow more ammonia to be produced in a given time QWC

1

[11]

37 (a) Rate forward reaction = rate backward reaction (1)

Concentrations of reactants and products are constant (1)

2

(b) System opposes change (1)

Moves to the side with fewer moles (1)

In this case NH_3 (2 moles) on right side < N_2 + H_2 together (4 moles) on left side of equation (1)

3

(c) Too expensive to generate etc (1)

1

(d) (i) Yield of ammonia increases (1)

Exothermic reaction favoured (1)

System moves to raise temp / or oppose decrease in temp (1)

3

(ii) Faster reaction (1)

1

(iii) Balance between rate and yield (1)

1

[11]

38 (a) (i) Increase (if wrong no further marks in part (i)

1

higher *P* gives lower yield or moves to left

1

Eqm shifts to reduce *P* or eqm favours side with fewer moles

1

(ii) Endothermic if wrong no further marks in part (ii)

1

increase *T* increases yield or moves to right

1

Eqm shifts to reduce *T* or eqm favours endothermic direction

1

(b) (i) Moles of iodine = 0.023

If wrong no marks in (i)

1

Moles of HI = 0.172

1

If × 2 missed, max 1 in part (iv)

(ii) $K_c = \frac{[H_2][I_2]}{[HI]^2}$

must be square brackets (penalise once in paper)
– if round, penalise but mark on in (iv)
if K_c wrong, no marks in (iv) either but mark on from a minor slip in formula

1

(iii) V cancels in K_c expression

or no moles same on top and bottom of expression
or total moles reactants = moles products,
i.e. total no of moles does not change

1

(iv) $K_c = \frac{(0.023)^2}{(0.172)^2}$

Conseq on (i)

1

= 0.0179 or 1.79×10^{-2}

Allow 0.018 or 1.8×10^{-2}

1

(v) K_c = 55.9 or 56

Conseq i.e. (answer to (iv))$^{-1}$

1

[13]

39 D

[1]

40 (a) removal/loss of electrons

1

(b) no change

1

equal number of gaseous moles on either side

1

both sides affected equally

1

increases

1

equilibrium moves to lower the temperature/oppose the change

1

endothermic reaction favoured /forward reaction is endothermic

1

(c) (i) +2

1

+5

1

(ii) $NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$

1

(iii) $Ag \rightarrow Ag^+ + e^-$

1

(iv) $NO_3^- + 4H^+ + 3Ag \rightarrow NO + 2H_2O + 3Ag^+$

1

[12]

41 (a) (i) $C + 3D \longrightarrow 2A + B$

1

(ii) mol dm^{-3}

1

(iii) (forward reaction is) exothermic or more products formed

1

(b) (i) for N_2O_4 $M_r = 92.0$

1

$$\text{Mol} = \frac{36.8}{92.0} = 0.400$$

1

(ii) mol N_2O_4 reacted = 0.400 – 0.180 = 0.220

1

mol NO_2 formed = 0.440

1

(iii) $K_c = \frac{(NO_2)^2}{(N_2O_4)}$

1

$= \frac{(0.44/16)^2}{(0.18/16)}$

1

$= 0.067$

1

(iv) move to NO_2/ to right / forwards

1

none

1

[12]

42 D

[1]

43 (a) (i) *Rates:* Rates are equal, forward and backward **(1)**
Concentrations: Concentrations are constant **(1)**

Q of L mark

(ii) *Equilibrium yield:* Decreases **(1)**

if wrong allow max 1 for a correct moles statement

Explanation: More moles / molecules of product (or 2 → 4) **(1)**
Reaction / equilibrium moves to left / reduce constraint **(1)**

NOT "volume" answers

Allow one for "Reaction favours fewer molecules"

(iii) Enthalpy of reaction is positive / endothermic **(1)**

(iv) Both forward and backward rates changed / increased **(1)**
by equal amount (same proportion) **(1)**

allow one for "Ea of forward and backward reactions reduced by an equal amount"

8

(b) (i) The reaction is exothermic **(1)**
High temperature gives a low equilibrium yield **(1)**
Rate of reaction higher at higher temperature **(1)**

An "equilibrium statement" needed e.g. low temp favours the reaction
Do not allow answers based on cost of higher temperature etc

(ii) Higher pressure gives a higher yield **(1)**
4 moles of gaseous reactant form 2 moles of gaseous product **(1)**
Higher pressure generation or equipment is expensive to produce **(1)**

Equilibrium statement required
Cost factor
N.B. NOT a safety answer

6

[14]

44 A **[1]**

45 D **[1]**

46 B **[1]**

47 A **[1]**

48 C **[1]**

49 D **[1]**

50 B **[1]**

51 A **[1]**

52 C **[1]**

53 A **[1]**

54 D **[1]**

55 (a) rate forward reaction = rate backward reaction **(1)**
concentration remains constant **(1)**

NOT 'Equal',
Allow 'The same' if clear that means constant

2

(b) fewer moles (of gas) on R.H.S **(1) (or converse)**
(methanol favoured) by reducing applied pressure **(1)**

Or removing constraint

2

(c) Power / energy required to provide high pressure / pumping **(1)**
Strong pressure vessel / or equipment **(1)**

*High maintenance costs **(1)***
*High insurance costs **(1)***
Any two

2

(d) Effect: decreases **(1)**
Explanation: reaction exothermic (or reverse reaction endothermic) **(1)**
system tries to lower T or remove constraint or
oppose the change
or endothermic reaction favoured

3

(e) to speed up reaction **(1)**

or otherwise to slow
or takes too long
or to give more molecules $E > E_A$

1

[10]

56 (a) (i) *Number of moles of O_2 at equilibrium:* $\frac{7.04}{32}$ = 0.22 **(1)**

Number of moles of NO at equilibrium: 0.44 **(1)**
OR 2 × mol of oxygen

3

(ii) *Original number of moles of NO_2:* $\frac{21.3}{46}$ = 0.46(3) **(1)**

Number of moles of NO_2 at equilibrium:
0.46(3) – 0.44 = 0.02(3) **(1)**
OR conseq on mol NO above

1

(b) *Expression for K_C*: $K_C = \frac{[NO]^2[O_2]}{[NO_2]}$ **(1)**

Calculation: $K_C = \frac{\left(\frac{0.44}{11.5}\right)^2 \times \left(\frac{0.22}{11.5}\right)}{\left(\frac{0.023}{11.5}\right)^2}$ = 7.0(0) mol dm^{-3}

(1) (1) (1)

If mol NO_2 = 0.02; K_C = 9.26 (9.3)
or conseq on values from (a)
If vol missed, score only K_C and units
If K_C wrong: max 2 for correct use of vol and conseq units
If K_C wrong and no vol: max 1 for conseq units

3

(c) pV = nRT **(1)**

$T = \frac{pV}{nR} = \frac{(3.30 \times 10^5) \times (11.5 \times 10^{-3})}{0.683 \times 8.31}$ (1) =

(1) for using 11.5 × 10^{-3} as V

T = 669 K **(1)**

4

(d) *Yield of oxygen:* increased **(1)**
Value of K_c: no effect **(1)**

2

[13]

57 (a) **Increase in temperature:**

Yield is increased **(Allow if for H_2 (g) or products) (1)**
Reaction endothermic **(1)**
Equilibrium moves to the right **OR** forward, **OR** Equilibrium moves to oppose change **OR** to absorb heat **(1)**

If "Yield statement" incorrect allow max one if reaction stated to be endothermic

Increase in pressure:

Yield is decreased **(Allow if for H_2 (g) or products) (1)**
Increase in moles of gas **or** 2 moles increased to 4 moles **or** more moles on right **(1)**
Equilibrium moves to the left **OR** backwards, **OR** Equilibrium moves to oppose change **OR** to reduce pressure **(1)**

If "Yield statement" incorrect allow max one if number of moles change is correct.

6

(b) **Equilibrium yield:**
Unaffected **or** equilibrium unchanged **(1)**
Rate or speed increased **(1)**
Forward and backwards reactions equally or by the same amount **(1)**

Amount of hydrogen produced:
More hydrogen produced (1)

4

[10]