

AQA A-LEVEL CHEMISTRY • 7405

CHEMISTRY



EXAM QUESTION PACK

3.1.6 CHEMICAL EQUILIBRIA, LE CHATELIER'S PRINCIPLE AND KC

SCORE

/552

PERCENTAGE

%

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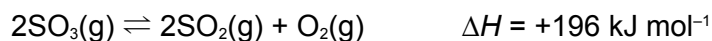
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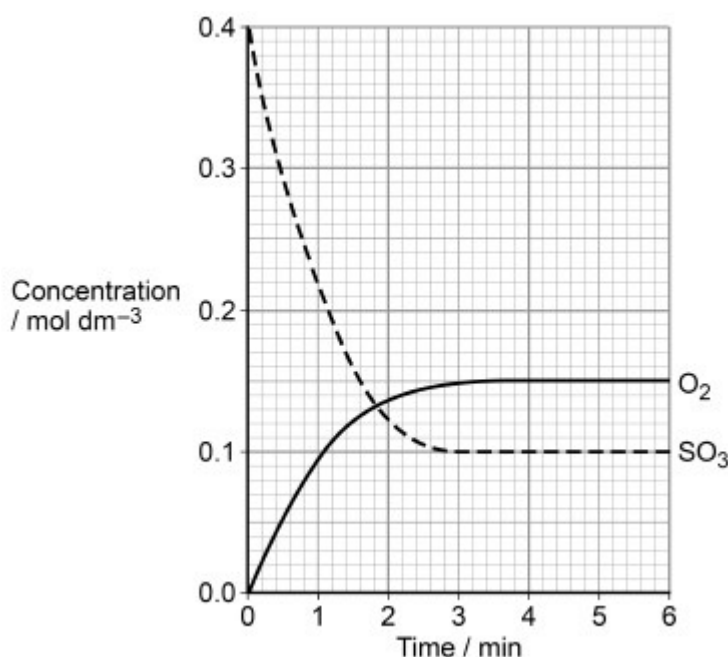
Q1.

This question is about equilibrium.

Sulfur trioxide decomposes to form sulfur dioxide and oxygen at temperature T_1 according to the equilibrium shown.



The graph shows the concentrations of sulfur trioxide and of oxygen over a period of 6 minutes at temperature T_1



- (a) State the time, to the nearest minute, when equilibrium is first established.
Explain your answer.

Time _____ minutes

Explanation _____

(2)

- (b) Sketch on the graph above how the concentration of sulfur dioxide changes over these 6 minutes at temperature T_1

(2)

- (c) The temperature of the mixture was changed to T_2 and the mixture left to establish a new equilibrium.
In the new equilibrium mixture the concentration of sulfur trioxide was found to be 0.07 mol dm^{-3}

Deduce which of T_1 and T_2 is the higher temperature.
Explain your deduction.

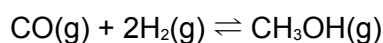
Higher temperature _____

Explanation _____

(2)
(Total 6 marks)

Q2.

Methanol can be manufactured in a reversible reaction as shown by the equation.



- (a) State and explain the effect of using a catalyst on the yield of methanol in this equilibrium.

(2)

- (b) Give an expression for the equilibrium constant (K_c) for this reaction.

(1)

- (c) A mixture of carbon monoxide and hydrogen was allowed to reach equilibrium in a container of volume 250 cm^3 at temperature T .

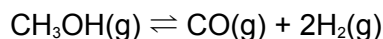
At equilibrium, the mixture contained 0.340 mol of carbon monoxide, 0.190 mol of hydrogen and 0.0610 mol of methanol.

Calculate the value of the equilibrium constant (K_c) for this reaction at temperature T .

$$K_c \text{ _____ mol}^{-2} \text{ dm}^6$$

(3)

- (d) Methanol decomposes on heating in a reaction that is the reverse of that used in its manufacture.



Use your answer from part (c) to determine the value of K_c for this equilibrium at temperature T .

State the units for this value of K_c .

(If you were unable to complete the calculation in part (c), assume a value of $K_c = 0.825 \text{ mol}^{-2} \text{ dm}^6$. This is not the correct value.)

Value of K_c _____

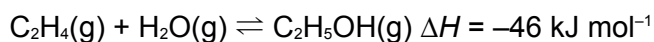
Units of K_c _____

(2)

(Total 8 marks)

Q3.

Which statement is **not** correct about the industrial preparation of ethanol by the hydration of ethene at 300 °C?

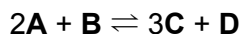


- | | |
|---|-----------------------|
| A The reaction is catalysed by an acid. | ☐ |
| B The higher the pressure, the higher the equilibrium yield of ethanol. | ☐ |
| C The higher the temperature, the higher the equilibrium yield of ethanol. | ☐ |
| D A low equilibrium yield of ethanol is acceptable because unreacted ethene is recycled. | ☐ |

(Total 1 mark)

Q4.

Compounds **A** and **B** react together to form an equilibrium mixture containing compounds **C** and **D** according to the equation



- (a) A beaker contained 40 cm³ of a 0.16 mol dm⁻³ aqueous solution of **A**.
9.5 × 10⁻³ mol of **B** and 2.8 × 10⁻² mol of **C** were added to the beaker and the mixture was left to reach equilibrium.
The equilibrium mixture formed contained 3.9 × 10⁻³ mol of **A**.

Calculate the amounts, in moles, of **B**, **C** and **D** in the equilibrium mixture.

Amount of **B** _____ mol

Amount of **C** _____ mol

Amount of **D** _____ mol

(5)

- (b) Give the expression for the equilibrium constant (K_c) for this equilibrium **and** its units.

K_c

Units _____

(2)

- (c) A different equilibrium mixture of these four compounds, at a different temperature, contained 0.21 mol of **B**, 1.05 mol of **C** and 0.076 mol of **D** in a total volume of 5.00 × 10² cm³ of solution.
At this temperature the numerical value of K_c was 116

Calculate the concentration of **A**, in mol dm⁻³, in this equilibrium mixture.
Give your answer to the appropriate number of significant figures.

Concentration of **A** _____ mol dm⁻³

(3)

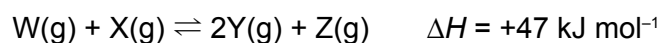
- (d) Justify the statement that adding more water to the equilibrium mixture in part (c) will lower the amount of **A** in the mixture.

(3)

(Total 13 marks)

Q5.

For this reaction at equilibrium, which combination of temperature and pressure would give the greatest equilibrium yield of products?



- A** High pressure and high temperature
- B** High pressure and low temperature
- C** Low pressure and high temperature

☐☐☐

D Low pressure and low temperature



(Total 1 mark)

Q6.

The forward reaction in this equilibrium is endothermic



Which statement is correct?

- A If the total pressure is increased at constant temperature, the proportion of COCl_2 in the equilibrium mixture will decrease
- B Use of a catalyst will increase the proportion of COCl_2 in the equilibrium mixture at constant temperature and pressure
- C Reducing the equilibrium concentration of CO will increase the value of the equilibrium constant
- D Raising the temperature from 373 K to 473 K will increase the value of the equilibrium constant

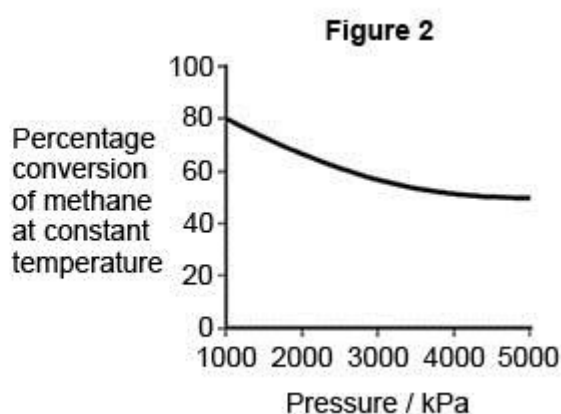
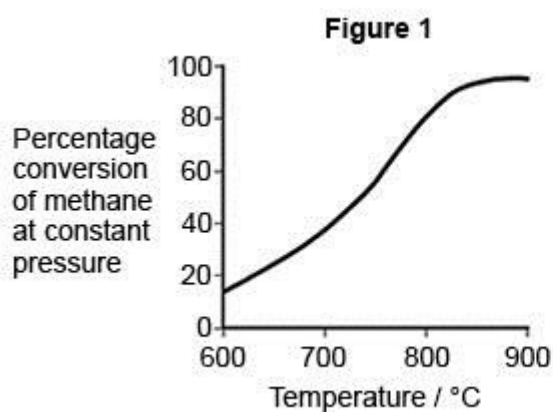


(Total 1 mark)

Q7.

There are several stages in the industrial production of methanol from methane.

- (a) The first stage involves a gaseous equilibrium between the reactants (methane and steam), and some gaseous products. **Figures 1** and **2** show the percentage conversion of methane into the gaseous products under different conditions at equilibrium.

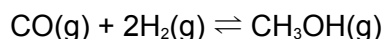


Deduce the optimum conditions for the industrial conversion of methane and steam into the gaseous products.

Explain your deductions.

(6)

- (b) The equation shows the final stage in the production of methanol.



20.1 mol of carbon monoxide and 24.2 mol of hydrogen were placed in a sealed container. An equilibrium was established at 600 K. The equilibrium mixture contained 2.16 mol of methanol.

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

Amount of carbon monoxide = _____ mol

Amount of hydrogen = _____ mol

(2)

- (c) A different mixture of carbon monoxide and hydrogen was allowed to reach equilibrium at 600 K

At equilibrium, the mixture contained 2.76 mol of carbon monoxide, 4.51 mol of hydrogen and 0.360 mol of methanol. The total pressure was 630 kPa

Calculate a value for the equilibrium constant, K_p , for this reaction at 600 K and state its units.

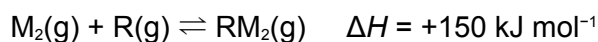
Value of K_p _____ Units _____

(6)

(Total 14 marks)

Q8.

The following equilibrium was established in a container with volume $V \text{ cm}^3$ at 393 K and 200 kPa.



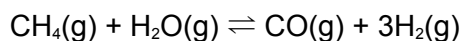
Which change would increase the yield of RM_2 ?

- | | | |
|----------|--|--------------------------|
| A | change the pressure to 150 kPa | ☐ |
| B | change the temperature to 293 K | ☐ |
| C | remove RM_2 as it is formed | ☐ |
| D | change the volume of the vessel to $2V \text{ cm}^3$ | ☐ |

(Total 1 mark)

Q9.

Hydrogen can be manufactured by the reaction of methane with steam. An equilibrium is established as shown by the equation.



- (a) Use Le Chatelier's principle to predict the effect on the equilibrium yield of hydrogen if the overall pressure is increased.
Explain your answer.

Effect on yield _____

Explanation _____

(3)

- (b) Explain why the equilibrium yield of hydrogen is unchanged if a catalyst is used in the reaction.

(2)

- (c) The table shows the standard enthalpy of formation and the standard entropy for each substance in this equilibrium reaction.

	CH ₄ (g)	H ₂ O(g)	CO(g)	H ₂ (g)
$\Delta_f H^\ominus / \text{kJ mol}^{-1}$	-75	-242	-111	0
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	186	189	198	131

Use data from the table to calculate the standard enthalpy change for this equilibrium reaction.

Standard enthalpy change _____ kJ mol⁻¹

(2)

Use your answer from part (c) and the entropy data from the table above to calculate the minimum temperature, in °C, needed for this reaction to be feasible. Give your answer to the appropriate number of significant figures.

(If you did not complete part (c) you should assume a value of 120 kJ mol⁻¹ for the standard enthalpy change. This is **not** the correct value).

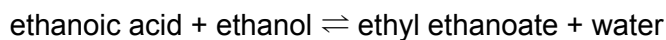
Minimum temperature _____ °C

(5)

(Total 12 marks)

Q10.

A student carried out an experiment to determine the value of the equilibrium constant (K_c) for the esterification reaction between ethanoic acid and ethanol.



- (a) Write an equation for this reaction.

(1)

- (b) Draw the skeletal formula of ethyl ethanoate.

(1)

- (c) The student used a small amount of concentrated sulfuric acid as a catalyst to increase the rate of the reaction.

State, in general terms, how a catalyst works.

(2)

- (d) The student mixed 0.0435 mol of ethanol and 0.0435 mol of ethanoic acid.
The student added 5.00×10^{-4} mol of sulfuric acid to the mixture.
This mixture was left for one week to reach equilibrium.
The equilibrium reaction was stopped by adding the mixture to water.

For this reaction, $K_c = 4.07$ at the temperature of the experiment.

Calculate the volume of $0.400 \text{ mol dm}^{-3}$ sodium hydroxide solution required to react completely with the acids in the equilibrium mixture.

Volume = _____ cm^3

(6)

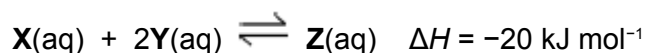
- (e) Suggest how the student could check that the mixture had reached equilibrium after one week.

(2)

(Total 12 marks)

Q11.

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



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.

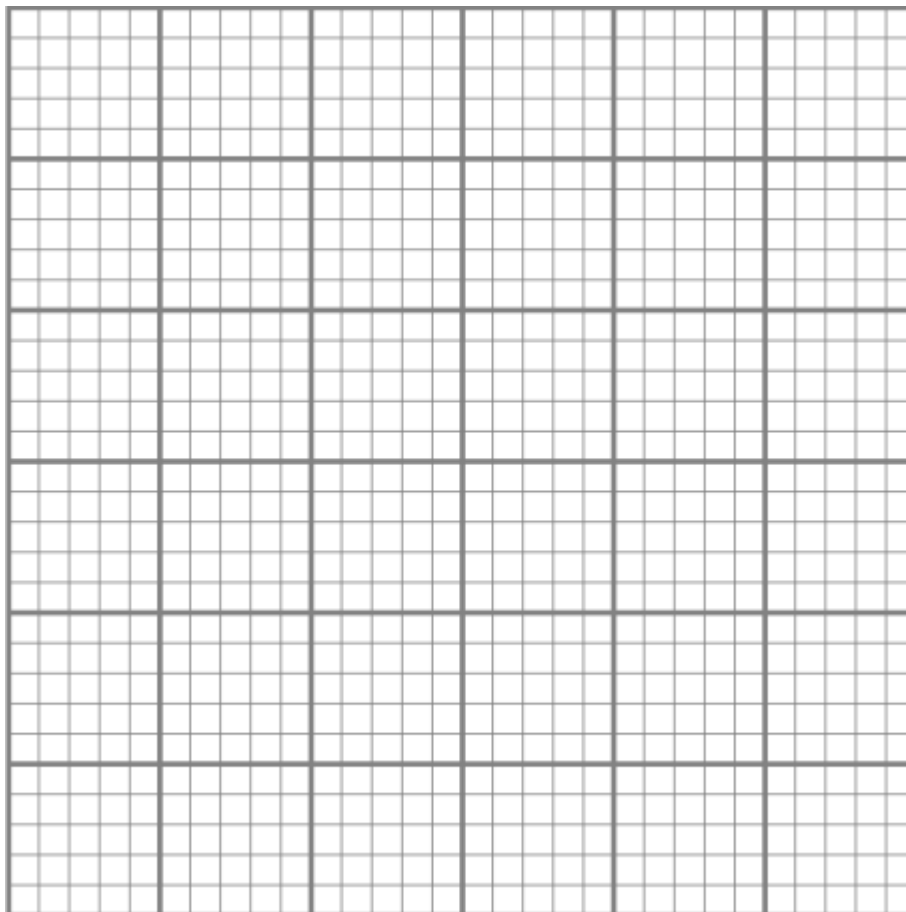
The amount of **Z(aq)** at equilibrium was 0.20 mol.

- (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 $K_c = 2.9 \text{ mol}^{-2} \text{ dm}^6$.
 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 _____

(3)

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

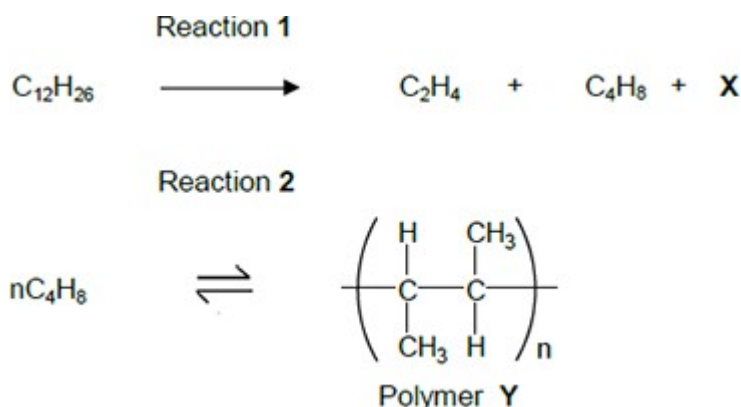
Predict the colour change, if any, when the equilibrium mixture was warmed.

(1)

(Total 12 marks)

Q12.

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.



- (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.

(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.

(1)

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

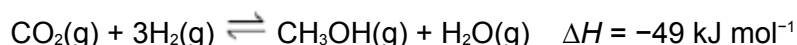
Explain the effect of a change of temperature on both the position of equilibrium and the rate of reaction, and justify why a compromise temperature is used industrially.

(6)
(Total 11 marks)

Q13.

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.



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).

(1)

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

(1)

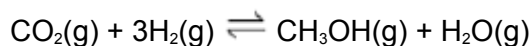
- (d) Use Le Chatelier's principle to justify why the reaction is carried out at a high pressure rather than at atmospheric pressure.

(3)

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

(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.



Calculate a value for K_p

Give your answer to the appropriate number of significant figures.

Give units with your answer.

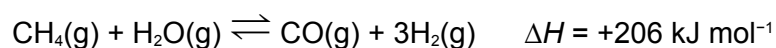
$K_p =$ _____ Units = _____

(7)

(Total 16 marks)

Q14.

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



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

Change

**Effect on
equilibrium**

**Effect on
value of K_c**

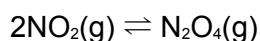
yield of H₂(g)

A	Increase pressure	decrease	decrease	☐
B	Add a catalyst	increase	no effect	☐
C	Increase temperature	increase	increase	☐
D	Remove CO(g) as formed	increase	increase	☐

(Total 1 mark)

Q15.

A pale brown mixture of NO₂ and N₂O₄ is allowed to reach equilibrium in a sealed gas syringe according to the following equation.



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

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

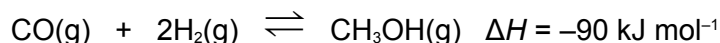
Which of the following statements is correct?

- | | | |
|----------|--|-----------------------|
| A | NO ₂ is brown and the forward reaction is exothermic. | ☐ |
| B | NO ₂ is brown and the forward reaction is endothermic. | ☐ |
| C | NO ₂ is colourless and the forward reaction is exothermic. | ☐ |
| D | NO ₂ is colourless and the forward reaction is endothermic. | ☐ |

(Total 1 mark)

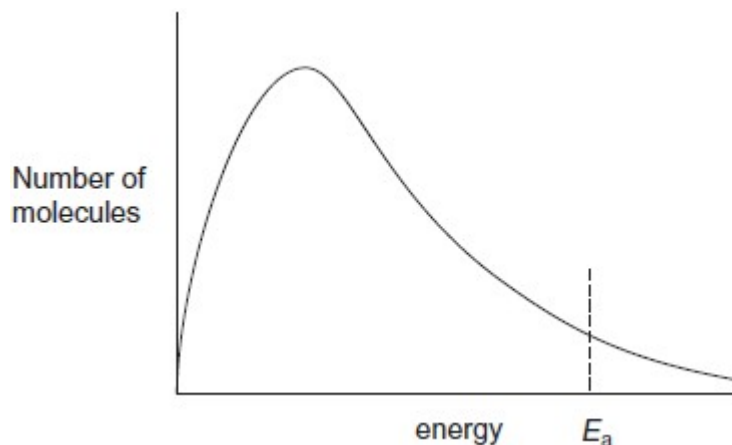
Q16.

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



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

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



- (i) Sketch a second curve on the graph to show the distribution of molecular energies in this mixture at a higher temperature.
- (ii) Explain with reference to both curves on the graph how a small change in temperature leads to a large change in the rate of reaction.

(1)

(2)

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

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

(3)

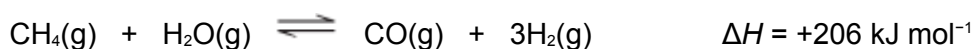
- (ii) By considering both rate and yield, state why the reaction is carried out at a temperature of 300 °C rather than at a higher temperature.

(2)
(Total 8 marks)

Q17.

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



- (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 _____

(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.

(2)

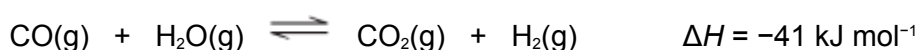
- (iii) A nickel catalyst is used in the first stage.

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

(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



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 _____

(2)

(Total 9 marks)

Q18.

This question is about magnesium chloride.

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

(1)

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

Enthalpy of lattice dissociation of MgCl_2 = +2493 kJ mol⁻¹

Enthalpy of hydration of magnesium ions = $-1920 \text{ kJ mol}^{-1}$

Enthalpy of hydration of chloride ions = -364 kJ mol^{-1}

(2)

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

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

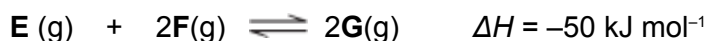
Explain your answer.

(3)

(Total 6 marks)

Q19.

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



- (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 _____

Units _____

(2)

- (c) A different mixture of **E** and **F** reached equilibrium at temperature T_1 in a container of volume 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

(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 _____

(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 _____

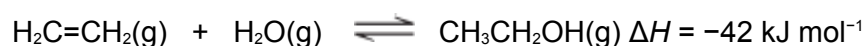
Explanation _____

(3)
(Total 12 marks)

Q20.

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



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.

(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.

(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.

(2)

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

(2)

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

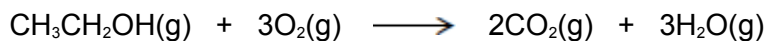
- (i) Define the term *standard enthalpy of combustion*.

(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.



(3)

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

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

(1)

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

(1)

(Total 17 marks)

Q21.

A study of equilibrium is important for understanding chemical reactions.

(a) State le Chatelier's principle.

(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* _____

How catalysts work _____

(3)

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

(1)

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

(1)

(c) Consider the following equilibrium reactions.

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

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

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

(1)

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

(1)

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

(1)

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

(1)

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



(1)
(Total 11 marks)

Q22.

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

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

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

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

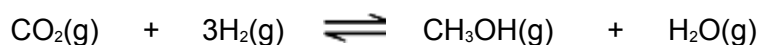


(3)

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

(1)

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

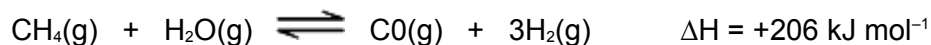


Effect on yield _____

Explanation _____

(3)

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



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

Effect on yield _____

Explanation _____

(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*.

(1)

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

(1)

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



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

Equation _____

(1)

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

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

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

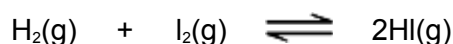
(The specific heat capacity of water is 4.18 J K⁻¹ g⁻¹).

(3)

(Total 16 marks)

Q23.

- (a) A mixture of 1.50 mol of hydrogen and 1.20 mol of gaseous iodine was sealed in a container of volume V dm³. The mixture was left to reach equilibrium as shown by the following equation.



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

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

Moles of hydrogen _____

Moles of iodine _____

(2)

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

(1)

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

(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.

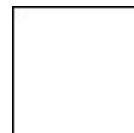
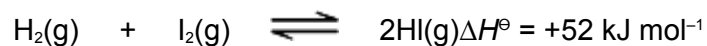
(2)

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

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

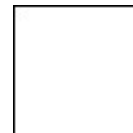
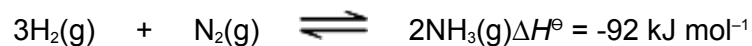
	Position of equilibrium	Value of equilibrium constant, K_c
A	remains the same	same
B	moves to the right	same
C	moves to the left	same
D	moves to the right	different
E	moves to the left	different

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



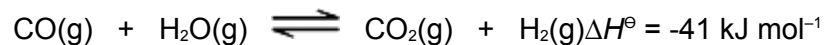
(1)

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



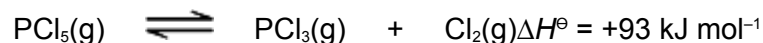
(1)

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



(1)

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

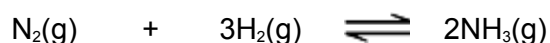


(1)

(Total 10 marks)

Q24.

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



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

Feature 1 _____

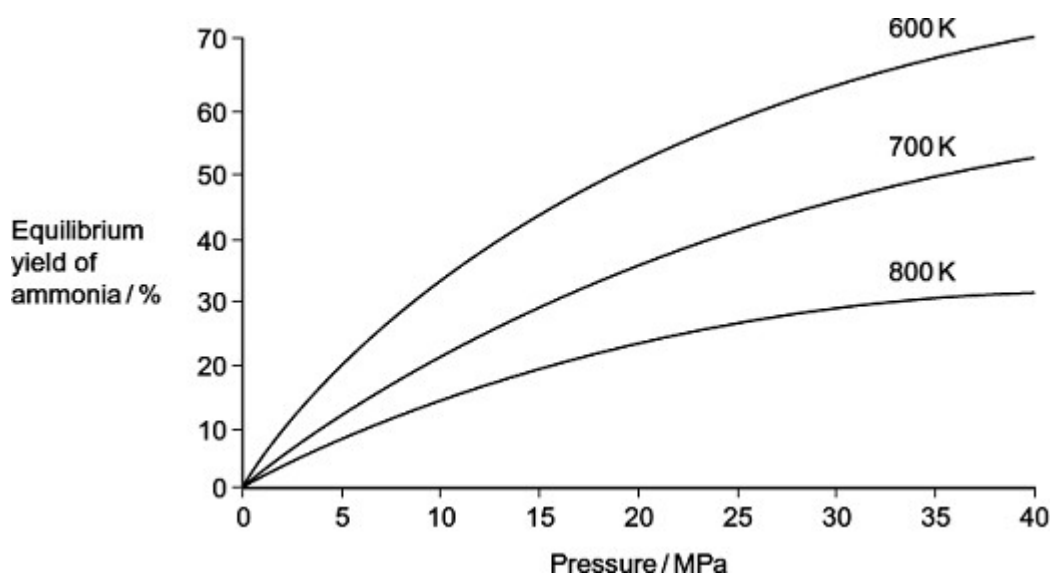
Feature 2 _____

(2)

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

(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 _____

(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 _____

(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.

(1)

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

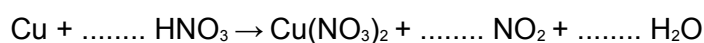
(1)

(Total 12 marks)

Q25.

A sample of nitrogen dioxide gas (NO₂) was prepared by the reaction of copper with concentrated nitric acid.

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



(1)

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

HNO₃ _____

NO₂ _____

(2)

- (iii) Deduce the half-equation for the conversion of HNO₃ into NO₂ in this reaction.

(1)

- (b) The following equilibrium is established between colourless dinitrogen tetroxide

gas (N_2O_4) and dark brown nitrogen dioxide gas.



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

Feature 1 _____

Feature 2 _____

(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.

(2)

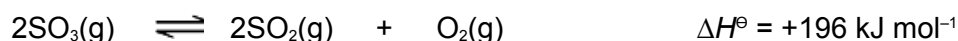
- (iii) Use Le Chatelier's principle to explain why the amount of NO_2 decreases when the pressure is increased at constant temperature.

(2)

(Total 10 marks)

Q26.

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



- (a) In an experiment, 8.0 mol of sulfur trioxide were placed in a container of volume 12.0 dm³ and allowed to come to equilibrium.

At temperature T_1 there were 1.4 mol of oxygen in the equilibrium mixture.

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

Amount of sulfur trioxide _____

Amount of sulfur dioxide _____

(2)

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

(1)

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

(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.)

(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 _____

(3)

(Total 12 marks)

Q27.

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



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

(2)

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

(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.

(4)

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

(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)

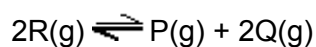
- (f) State the effect, if any, on the value of K_c of increasing the temperature. All other factors are unchanged.

(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



(1)

(Total 12 marks)

Q28.

Oxygen and ozone (O₃) both occur as gases in the upper atmosphere.

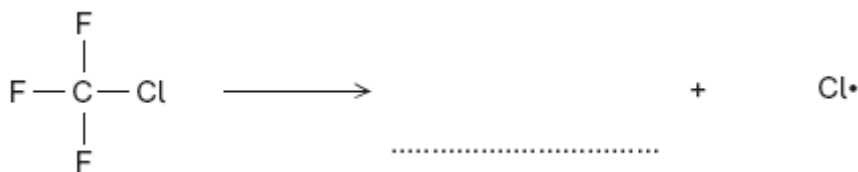
Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.

These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF₃Cl

- (a) (i) Give the IUPAC name of CF₃Cl

_____ (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 $\cdot$ represents in $\text{Cl}\cdot$

_____ (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.



- (i) State Le Chatelier's principle.

(1)

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

(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.

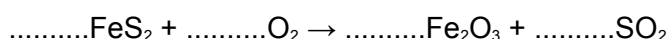
(1)
(Total 9 marks)

Q29.

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.



(1)

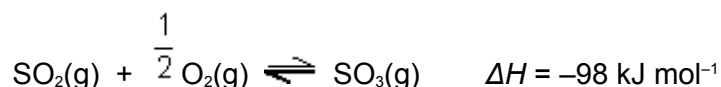
(ii) Deduce the oxidation state of sulfur in each of the following compounds.

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.



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)

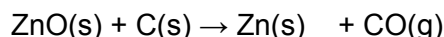
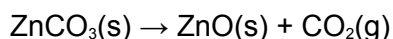
(Total 8 marks)

Q30.

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

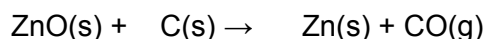
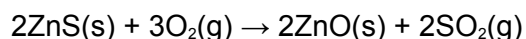
Extraction process 1

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.



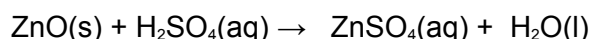
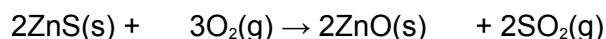
Extraction process 2

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.

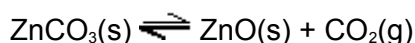


Extraction process 3

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.



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



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.

(3)

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

(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.

(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.

(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**.

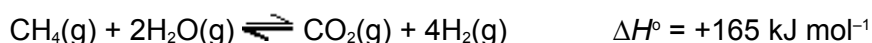
(3)

- (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.

(2)
(Total 15 marks)

Q31.

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



- (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 dm³. Calculate the concentration, in mol dm⁻³, of methane in the equilibrium mixture.

(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 ₂ O(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.

(1)

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

Calculation _____

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 _____

(3)

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

(2)

(Total 13 marks)

Q32.

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)

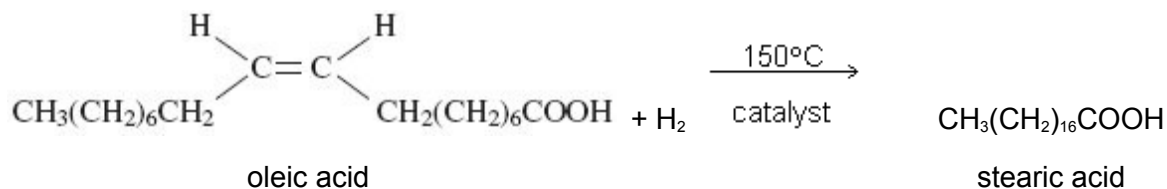
- (ii) Write an equation for this reaction.

(1)

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

(1)

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



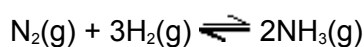
- (i) Use your knowledge of the chemistry of alkenes to deduce the type of reaction that has occurred in this conversion.

(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.



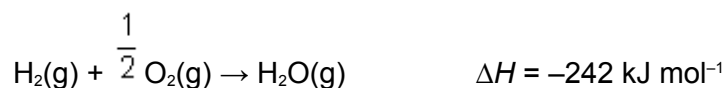
- (i) State Le Chatelier's principle.

(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.

(2)

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



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.

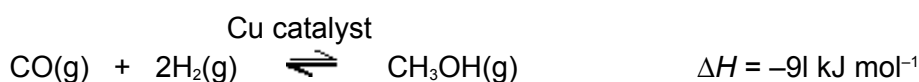
	O–H	O=O
Mean bond enthalpy / kJ mol ⁻¹	+ 463	+ 496

(3)

(Total 11 marks)

Q33.

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



- (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)

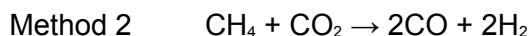
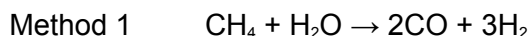
- (c) (i) State what is meant by the term *catalyst*.

(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.



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

- (i) State what is meant by the term *carbon neutral*.

(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)

Q34.

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



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.

(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.

(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.



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.

(4)

(Total 12 marks)

Mark schemes

Q1.

- (a) 3 minutes

M2 dependent on M1 or near miss

1

(At equilibrium, $\text{rate}_{\text{fwd}} = \text{rate}_{\text{back}}$ so) concentrations (of O_2 and SO_3) remain constant

Not concentrations are the same/equal

Allow (after this point) gradient is zero / curve flattens out

1

- (b) Sketch begins at origin and goes up until 3 mins

1

Levels off at 0.3 mol dm^{-3}

Mark Independently

1

- (c) T_2 (Not worth a mark alone)

T_1 , $CE=0$

Equilibrium has moved / shifted to RHS/forward in endothermic direction

Both RHS / forward and endothermic needed

1

Equilibrium has opposed the increase in T / Equilibrium moves to decrease the T

Not just to oppose the change

1

[6]

Q2.

- (a) **M1** no effect (on yield)

$CE = 0$ if yield changes

1

M2 increases rate / speed of both / forward and reverse reactions equally / by the same amount

*If no reference to effect on yield, could still score **M2***

Ignore reference to no change in position of equilibrium, and reference to lowering activation energies

M2 allow changes rate of both / forward and reverse reactions equally / by the same amount

1

- (b) $(K_c =) \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}$

Must be square brackets

Ignore state symbols

Ignore units

1

- (c) **M1** divides moles by volume (0.250 or $\frac{250}{1000}$)

M2

$$K_c = \frac{\frac{0.0610}{0.250}}{\left[\frac{0.340}{0.250}\right]\left[\frac{0.190}{0.250}\right]^2} \left(= \frac{0.244}{1.36 \times 0.76^2} \right)$$

1

M3 0.311

1

Correct answer scores 3; **M3** to at least 2sf (0.3106159 ...); ignore units

Allow ECF from **M1** to **M2** if an attempt to calculate concentration has been made by dividing by some factor of 250 cm³

Allow ECF from **M2** to **M3** for use of an expression containing each reagent in a correctly substituted K_c expression

If volume not used, then allow **M3** only for 4.97 (4.96985 ... to at least 2sf)

1

- (d) **M1** $\frac{1}{\text{Answer to (c)}} = 3.22$

M1 to at least 2sf (0.31 gives 3.2(258))

M1 = 1.21 if alternative answer to 8.3 used

If an error was made in 8.3, but the candidate produced an answer in 8.4 that did fit the inverted calculation from 8.3, then candidate could score **M1**

1

M2 mol² dm⁻⁶

(if volumes are not used, then candidate would get 0.20(12.))

1

[8]

Q3.

C

[1]

Q4.

- (a) Initial amount of A = 6.4×10^{-3}
If **M1** wrong can score max 3

M1

$$\text{Equ A} = 6.4 \times 10^{-3} - 2x \therefore x = 1.25 \times 10^{-3}$$

If incorrect x can score max 3

M2

$$\text{B} = 9.5 \times 10^{-3} - x = 8.25 \times 10^{-3}$$

Allow 2 or more sig figs

M3

$$C = 2.8 \times 10^{-2} + 3x = 0.0318$$

M4

$$D = x = 1.25 \times 10^{-3}$$

M5

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

Penalise () but mark on in (b) & (c)

1

$$\text{Units} = \text{mol dm}^{-3}$$

If K_c wrong no mark for units

1

(c) M1 for correct rearrangement $[A]^2 = \frac{[C]^3[D]}{K_c [B]}$ or $[A] = \sqrt{\frac{[C]^3[D]}{K_c [B]}}$

If K_c wrong in (b) can score 1 for dividing by correct volume

M1

M2 for division of mol of B, C and D by correct volume

If K_c correct but incorrect rearrangement can score

1 for dividing by correct volume

M2

$$[A]^2 = \frac{[1.05/0.5]^3 [0.076/0.5]}{116 \times [0.21/0.5]}$$

M3 for final answer: $[A] = 0.17$ (must be 2 sfs)

M3

(d) (All) conc fall: (ignore dilution)

OR $K_c = \text{mole ratio} \times 1/V$

1

Equm moves to side with more moles

If vol increases, mole ratio must increase

1

To oppose the decrease in conc

To keep K_c constant

If only conc of A falls CE=0

If pressure falls CE=0

1

[13]

Q5.

C

[1]

Q6.
D

[1]

Q7.

- (a) 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 (5 – 6 marks)

All stages are covered and the explanation of each stage is generally correct and virtually complete. To access Level 3, statement 3a must be considered.

Answer is communicated coherently and shows a logical progression from stage 1 (including 1b) to stage 2 and stage 3

Level 2 (3 – 4 marks)

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 from stage 1 to stage 2 and/or stage 3.

Level 1 (1 – 2 marks)

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 presented in a logical order, with sensible reasoning.

Level 0 (0 marks)

Insufficient correct chemistry to gain a mark.

Indicative chemistry content

Stage 1 – Deductions from graph

1a Yield increases as temperature increases (or converse)

1b After a certain temperature yield no longer increases

1c Yield decreases as pressure increases (or converse)

Stage 2 – Optimum temperature and explanation

2a High temperature results in high energy costs/expensive

2b (After a certain temperature) yield no longer increases therefore there is no gain in using a higher temperature

2c Optimum temperature is between 780-880oC

Stage 3 – Optimum pressure and explanation

3a Low pressure may be too slow

3b So compromise pressure required

3c Optimum pressure is 1000-2000kPa or moderate pressure used

6

- (b) Moles of carbon monoxide 17.9
Allow 17.94

1

Moles of hydrogen 19.9

Allow 19.88

1

(c)
$$K_p = \frac{pp(\text{CH}_3\text{OH})}{pp(\text{CO}) \times pp(\text{H}_2)^2}$$

ignore brackets

If K_p expression incorrect can only score M2 & M3 & M4

1

Total moles of gas = (2.76 + 4.51 + 0.36) = 7.63

If CE in M2 allow ecf for M3, M4 and M6

If no total moles calculated then can only score M1 and M6

1

$$pp(\text{CO}) = \frac{2.76}{7.63} \times 630 \text{ (kPa)} \quad (= 228 \text{ (kPa)})$$

$$pp(\text{H}_2) = \frac{4.51}{7.63} \times 630 \text{ (kPa)} \quad (= 372 \text{ (kPa)})$$

$$pp(\text{CH}_3\text{OH}) = \frac{0.36}{7.63} \times 630 \text{ (kPa)} \quad (= 29.7 \text{ (kPa)})$$

All 3 pp of CO, H₂ and CH₃OH = 2 marks

2 pp correct = 1 mark

2

$$K_p = \frac{29.7}{228 \times (372)^2} = 9.4(1) \times 10^{-7} \quad \text{or } 9.4(1) \times 10^{-13} \text{ if } pp \text{ in Pa}$$

can also score M1 from this expression

Allow 9.39 to $9.50 \times 10^{-7} \text{ (kPa}^{-2}\text{)}$

1

kPa⁻² or **Pa⁻²** (if converted to 630 000)

If no marks awarded allow M6 only for **kPa⁻²** or **Pa⁻²**

1

[14]

Q8.

C

[1]

Q9.

(a) Decrease

1

Increasing pressure moves equilibrium to the side of least moles i.e. backward reaction

1

To oppose the increase in pressure or to decrease the pressure

- (b) A catalyst speeds up the rate of the forward and backward reaction

By the same amount

- (c) $\Delta H = -111 - (-75 - 242)$

206 (kJ mol⁻¹)

- (d) $\Delta S = 3 \times 131 + 198 - (186 + 189) = 216 \text{ J K}^{-1} \text{ mol}^{-1}$

$$\Delta G = \Delta H - T\Delta S$$

$$0 = 206 - T \frac{216}{1000}$$

$$T = 953.7 \text{ or } 954 \text{ K}$$

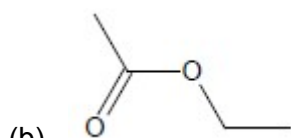
$$T = 681 \text{ (}^{\circ}\text{C)}$$

*If the value given in the question is used then the answer is
283 (}^{\circ}\text{C)}*

[12]

Q10.

- (a) $\text{CH}_3\text{COOH} + \text{CH}_3\text{CH}_2\text{OH} \rightleftharpoons \text{CH}_3\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O}$



- (c) A catalyst provides an alternative mechanism for reaction.

That has a lower activation energy.

- (d) K_c expression shown correctly e.g. $K_c = \frac{[\text{ester}][\text{water}]}{[\text{acid}][\text{alcohol}]}$

Hence $K_c = 4.07 = x^2 / (0.0435 - x)^2$ (if x = amount of ester/water produced and therefore = amount by which amounts of acid and alcohol decreased).

$$\text{So } \sqrt{4.07} = x^2 / (0.0435 - x)^2$$

$$\text{So } x = 0.0291 \text{ mol.}$$

1

$$\text{Acid left at equilibrium} = 0.0435 - 0.0291 = 0.0144 \text{ mol.}$$

1

Adding acid catalyst = $0.0144 + 2(0.0005) = 0.0154 \text{ mol}$ (adding 2×0.0005 as 0.0005 mol of H_2SO_4 added and catalyst so not used up and dibasic).

1

$$\text{Volume of alkali needed} = 1000 \times 0.0154 / 0.400 = 38.5 \text{ cm}^3.$$

1

- (e) Test several samples – at least one tested after a week.

1

Check that the result has not changed.

1

[12]

Q11.

- (a) amount of X = $0.50 - 0.20 = 0.30 \text{ (mol)}$

1

$$\text{amount of Y} = 0.50 - 2 \times 0.20 = 0.10 \text{ (mol)}$$

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

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

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

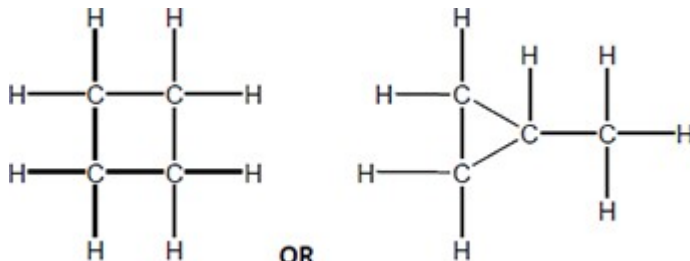
1

[12]

Q12.

- (a) Alkenes

1



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

1

- (b) C₆H₁₄ (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 $\geq$ 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 $E > E_a$
- 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]

Q13.

(a) Bonds broken = $2(\text{C}=\text{O}) + 3(\text{H}-\text{H}) = 2 \times 743 + 3 \times \text{H}-\text{H}$

Bonds formed = $3(\text{C}-\text{H}) + (\text{C}-\text{O}) + 3(\text{O}-\text{H}) = 3 \times 412 + 360 + 3 \times 463$

Both required

1

$$-49 = [2 \times 743 + 3 \times (\text{H}-\text{H})] - [3 \times 412 + 360 + 3 \times 463]$$

$$3(\text{H}-\text{H}) = -49 - 2 \times 743 + [3 \times 412 + 360 + 3 \times 463] = 1450$$

Both required

1

$$\text{H}-\text{H} = 483 \text{ (kJ mol}^{-1}\text{)}$$

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

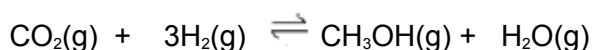
- (e) Impurities (or sulfur compounds) block the active sites

Allow catalyst poisoned

1

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

Extended response question



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

$$p_{\text{CO}_2} = \text{mol fraction} \times p_{\text{total}} = 0.14 \times 500 / 2.28 = 30.7 \text{ kPa}$$

$$p_{\text{H}_2} = \text{mol fraction} \times p_{\text{total}} = 0.42 \times 500 / 2.28 = 92.1 \text{ kPa}$$

M3 is for partial pressures of both reactants

Alternative M3 =

$$pp_{\text{CO}_2} = 0.0614 \times 500$$

$$pp_{\text{H}_2} = 0.1842 \times 500$$

1

$$p_{\text{CH}_3\text{OH}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

$$p_{\text{H}_2\text{O}} = \text{mol fraction} \times p_{\text{total}} = 0.86 \times 500 / 2.28 = 188.6 \text{ kPa}$$

M4 is for partial pressures of both products

Alternative M4 =

$$pp_{\text{CH}_3\text{OH}} = 0.3772 \times 500$$

$$pp_{\text{H}_2\text{O}} = 0.3772 \times 500$$

1

Stage 3: Equilibrium constant calculation

$$K_p = p_{\text{CH}_3\text{OH}} \times p_{\text{H}_2\text{O}} / p_{\text{CO}_2} \times (p_{\text{H}_2})^3$$

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 = kPa⁻²

1

[16]

Q14.

C

[1]

Q15.

A

[1]

Q16.

- (a) (i) Curve drawn from origin with peak clearly lower and to right.
*New curve crosses original once only, finishes above original and does **not** clearly curve up*
IGNORE relative areas

1

- (ii) (Relative areas under curves indicate) many (owtte) more molecules with E greater than or equal to E_a (at higher T)
 or reverse argument
ALLOW 'particles'
IGNORE 'atoms'

1

(Large) increase in (number of) successful (owtte) collisions per unit time
 OR 'frequency of successful collisions'

1

- (b) (i) Yield increases
Yield decreases/stays the same $CE = 0$
If not answered mark on

1

More moles/molecules (of gas) on left/fewer on right/3 on left 1 on right

1

Equilibrium shifts/moves (to right) to reduce pressure/oppose higher pressure

No M3 if 'more moles on right' in M2

IGNORE 'favours'

NOT just 'oppose the change'

QoL means that M3 is only awarded if these ideas are clearly linked in one statement

1

- (ii) Higher T would increase rate but decrease yield/make less methanol
OR

Lower T decreases rate but increases yield;

*If no mention of both rate **AND** (idea of) yield max 1*

Chosen T is a compromise/balance (between rate and yield) owtte

1

1

[8]

Q17.

(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 *Éan 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]

Q18.

(a) $\text{MgCl}_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})$

State symbols essential

Do not allow this equation with H_2O on the LHS

Ignore + aq on the LHS

Allow H_2O written over the arrow / allow equation written as an equilibrium

Allow correct equations to form $[\text{Mg}(\text{H}_2\text{O})_6]^{2+}$ ions

1

(b) $\Delta H_{\text{soln}} \text{MgCl}_2 = \text{LE} + (\Delta H_{\text{hyd}} \text{Mg}^{2+}) + 2(\Delta H_{\text{hyd}} \text{Cl}^-)$

$\Delta H_{\text{soln}} \text{MgCl}_2 = 2493 - 1920 + (2 \times -364)$

$= -155 \text{ (kJ mol}^{-1}\text{)}$

M1 for expression in words or with correct numbers

Ignore units, but penalise incorrect units

1

1

(c) M1: Solubility decreases (as temp increases)

M2: the enthalpy of solution is exothermic / reaction is exothermic / backwards reaction is endothermic

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce temperature/oppose the increase in temperature (in the endothermic direction)

If M1 is incorrect then **CE=0/3**

If answer to (b) is a +ve value, allow:

M1: Solubility increases (as temp increases)

M2: Enthalpy of solution is endothermic etc

M3: (According to Le Chatelier) the equilibrium moves to absorb heat/reduce the temperature/oppose the increase in temperature (in the endothermic direction)

1
1
1

[6]

Q19.

(a) Mol of E 1.6(00)

Ignore extra zeros.

1

Mol of F 0.2(00)

1

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

Penalise expression containing V.

Penalise missing brackets or ().

1

mol⁻¹ dm³

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

1

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

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 to	(Equilibrium) <u>shifts / moves</u> either to oppose reduction in pressure / or increase the pressure <i>M3 depends on a correct statement for M2.</i> <i>Not 'favours'.</i> <i>Allow 'to oppose change' only if reduction in pressure noted.</i>	1
(e) M1	T_1 <i>If M1 is incorrect, CE=0 for the clip.</i> <i>If M1 is blank, mark on and seek to credit the correct information in the explanation.</i>	1
M2	(Forward*) reaction is <u>exothermic</u> OR <u>Backward</u> reaction is <u>endothermic</u> <i>*Assume answer refers to forward reaction unless otherwise stated.</i>	1
M3	(at T_2 or lower temperature) (Equilibrium) <u>shifted / moved</u> to oppose reduction in temp OR at T_1 or higher temp, (Equilibrium) <u>shifted / moved</u> to oppose (increase in temp) <i>M3 depends on a correct statement for M2</i> <i>Allow "to oppose change" only if change in temperature is stated.</i> <i>Not 'favours'.</i>	1
		[12]

Q20.

- (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".
- (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.

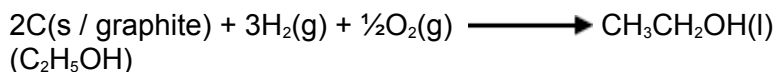
OR expensive equipment

Credit all converse arguments for M2

2

(b) M1 for balanced equation

M2 for state symbols in a correctly balanced equation



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

Penalise C₂H₆O 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

$$\Sigma B(\text{reactants}) - \Sigma B(\text{products}) = \Delta H$$

Credit 1 mark for (+) 1279 (kJ mol⁻¹)

OR

$$\text{Sum of bonds broken} - \text{Sum of bonds formed} = \Delta H$$

OR

$$B(C-C) + B(C-O) + B(O-H) + 5B(C-H) + 3B(O=O) \text{ (LHS)} \\ - 4B(C=O) - 6B(O-H) \text{ (RHS)} = \underline{\Delta H}$$

M2 (also scores **M1**)

$$348+360+463+5(412)+3(496) \text{ [LHS = 4719]} \\ (2060) \quad (1488)$$

$$- 4(805) - 6(463) \text{ [RHS = - 5998]} = \Delta H \\ (3220) \quad (2778)$$

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

$$\Delta H = \underline{- 1279} \text{ (kJ mol}^{-1}\text{)}$$

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]

Q21.

- (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

- (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]

Q22.

- (a) (i) **M1** (could be scored by a correct mathematical expression which must have

all ΔH symbols and the Σ or SUM)

M1 $\Delta H_r = \Sigma \Delta H_f(\text{products}) - \Sigma \Delta H_f(\text{reactants})$

OR a correct cycle of balanced equations with 1C, 3H₂ and 1O₂

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, 3H₂ and 1O₂
 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 /CO₂ carbon /greenhouse gas present in the atmosphere.
The idea that the carbon /CO₂ given out equals the carbon /CO₂ that was taken in from the atmosphere

1

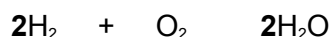
- (ii) $\text{CH}_3\text{OH} + 1\frac{1}{2} \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
Ignore state symbols
Accept multiples

1

- (iii) $3\text{H}_2 + 1\frac{1}{2} \text{O}_2 \rightarrow 3\text{H}_2\text{O}$
Ignore state symbols

OR

Accept multiples



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 $\Delta H = -399$ (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 $\Delta T = 280.5$; 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]

Q23.

(a) (i) mol H₂ = 0.47

1

mol I₂ = 0.17

If answers reversed, ie

mol H₂ = 0.17

mol I₂ = 0.47

then allow one mark (for second answer).

1

(ii)
$$\frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]}$$

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 moles (on each side of equation)

OR

equal moles (top and bottom of K_c expression)

1

(iv)
$$\frac{[1.94]^2}{[0.38][0.19]}$$

Ignore V

If K_c 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]

Q24.

(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

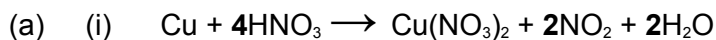
OR

Uses less expensive equipment
Ignore references to safety

1

[12]

Q25.



Or multiples

Ignore state symbols

1

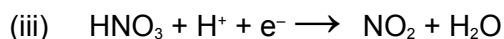


Ignore working out

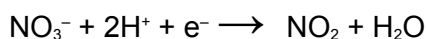
M1 Credit (V)

M2 Credit (IV)

2



OR



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]

Q26.

(a) (i) Mol SO₃ = 5.2

1

Mol SO₂ = 2.8

1

(ii)

$$\frac{[\text{SO}_2]^2 [\text{O}_2]}{[\text{SO}_3]^2}$$

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

1

(iii) mol dm⁻³

Allow conseq to their wrong K_c

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

Values from (a)(i)

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

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, T_2 , when K_c 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 Equim/reaction moves to right or towards product or towards SO₂ OR moles SO₂ increases

OR

M3 (forward) reaction is endothermic

M2 if Temp is decreased Equim/reaction moves to left or towards reagent or towards SO₃ OR moles SO₃ increases

1

[12]

Q27.

(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 K_c 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 K_c expression

*If wrong K_c 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 × 10/10³) can only score **M2** and **M5***

1

	M4 $[Q]^2 = 0.0106$ <i>Correct calculation of Q^2</i>	
		1
	M5 $[Q] = 0.10(3)$ <i>Correct taking of $\sqrt{}$</i>	
		1
(c)	cont.	
	Wrong rearrangement and no use of volume	0
	Wrong rearrangement	
	<i>For Correct use of volume M3 and Correct taking of square root M5</i>	2 max
	No use of volume	
	<i>2 max</i> answer = 0.325 <i>Ignore subsequent multiplying or dividing by 10.</i> 0.0325 or 3.25 still score max 2 <i>For Correct rearrangement M2 and</i> <i>Correct taking of square root M5</i>	
		2 max
	Use of volume but maths error e.g. using $(5.24)^2/10$ when should be $(5.24/10)^2$	
	<i>Scores 3</i> also giving answer 0.325 <i>for M2, M3 and M5</i>	
		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 <i>For Correct rearrangement M2 and</i> <i>Correct taking of square root M5</i>	
		2 max
	Wrong use of moles, e.g (5.24×2) or $(5.24 \times 10/10^3)$	
	<i>For Correct rearrangement M2 and</i> <i>Correct taking of square root M5</i>	
		2 max
	Wrong K_c used, e.g. missing powers	
	<i>For Correct use of volume M3</i>	
		1 max
(d)	Increase or more or larger	
	<i>Allow moves to left</i>	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 $K_c = 1.39 \times [Q]^2$
Not allow just 1/68.0
ignore units 1

[24]

Q28.

- (a) (i) chlorotrifluoromethane
Spelling must be correct but do not penalise "flouro"
Ignore use of 1- 1
- (ii) $\text{CF}_3\bullet$
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 "electrons"
Ignore "(free) radical" 1
- (b) **M1** $\text{Cl}\bullet + \text{O}_3 \rightarrow \text{ClO}\bullet + \text{O}_2$
M2 $\text{ClO}\bullet + \text{O}_3 \rightarrow 2\text{O}_2 + \text{Cl}\bullet$
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 C₅H₁₂"

1

[9]

Q29.

- (a) (i) $4\text{FeS}_2 + 11\text{O}_2 \longrightarrow 2\text{Fe}_2\text{O}_3 + 8\text{SO}_2$

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** $\text{Fe}_2\text{O}_3 + 3\text{CO} \longrightarrow 2\text{Fe} + 3\text{CO}_2$

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]

Q30.

(a) **M1** The yield of zinc oxide increases/greater

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

M2 Removal of the carbon dioxide results in the equilibrium
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 to replace the CO_2 /lost product

OR to make more CO₂

OR to increase concentration of CO₂

For M3, not simply “to oppose the change/to oppose the loss of CO₂/to oppose the removal of carbon dioxide.”

3

- (b) **M1** Process 2 produces/releases SO₂
OR Process 2 produces/releases CO

M2 It/Process 3 avoids the release of SO₂ OR CO
OR It/Process 3 (captures and) converts SO₂ to H₂SO₄

M3 SO₂ 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 SO₂ claimed to form acid rain, treat as contradiction

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

M2 this is justified because the product/zinc is pure
Ignore “energy”
Penalise “pure”

2

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

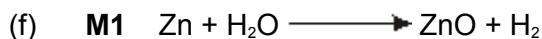
M3 It/carbon is oxidised/gains oxygen/changes oxidation state/number
from 0 to +2/increase in oxidation state/number in Process 2

Do not forget to award this mark

Ignore reference to electron loss but penalise electron gain

Ignore “carbon is a reducing agent”

3



M2 Zinc oxide and hydrogen

OR as an alternative



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]

Q31.

(a) (i) $\text{mol CH}_4 = 0.75$

1

$\text{mol H}_2\text{O} = 1.5$

1

$\text{mol H}_2 = 1(.0)$

1

(ii) $0.15 \text{ (mol dm}^{-3}\text{)}$
conseq = (mol CH_4)/5

1

(b) (i)
$$\frac{[\text{CO}_2][\text{H}_2]^4}{[\text{CH}_4][\text{H}_2\text{O}]^2}$$

not just numbers

do not penalise ()

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

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

mol² dm⁻⁶

allow 1 here for correct units from wrong K_c

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 backward 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]

Q32.

(a) (i) Reducing agent

OR

Reduce(s) (WO₃/tungsten oxide)

OR

electron donor

OR

to remove oxygen (from WO₃/tungsten oxide or to form water);

1

(ii) WO₃ + 3H₂ → W + 3H₂O

Or multiples

1

(iii) *One from*

H₂ is

- explosive
- flammable or inflammable
- easily ignited

Ignore reference to pressure or temperature

- (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 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.

Ignore "volumes" for M1

Mark independently

M2 – Explanation of response/movement in terms of pressure

Increase in pressure is opposed (or words to that effect)

OR

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

(d) $\Sigma B(\text{reactants}) - \Sigma B(\text{products}) = \Delta H$ (M1)

OR

Sum of bonds broken – Sum of bonds formed = ΔH (M1)

$B(\text{H-H}) + \frac{1}{2}B(\text{O=O}) - 2B(\text{O-H}) = -242$ (M1)

$B(\text{H-H}) = -242 - \frac{1}{2}(+496) + 2(+463)$ (this scores M1 and M2)

$B(\text{H-H}) = (+)436 \text{ (kJ mol}^{-1}\text{)}$ (M3)

Award 1 mark for – 436

Candidates may use a cycle and gain full marks.

M1 could stand alone

Award full marks for correct answer.

Ignore units.

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

3

[11]

Q33.

- (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

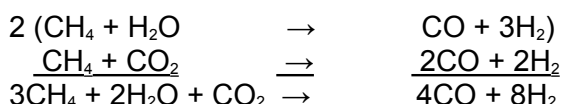
There is no change in the total amount of carbon dioxide / carbon / greenhouse gas present in the atmosphere.

The idea that the carbon / CO₂ given out equals the carbon / CO₂ 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.



Ratio = 1 : 2

1

[8]

Q34.

- (a) **M1** $\text{MnO}_2 + 4\text{H}^+ + 2\text{e}^- \rightarrow \text{Mn}^{2+} + 2\text{H}_2\text{O}$

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



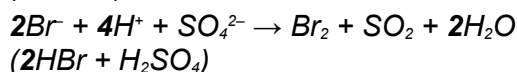
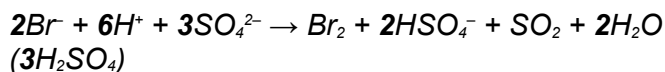
OR



1

- M3** $2\text{KBr} + \text{Cl}_2 \rightarrow 2\text{KCl} + \text{Br}_2$

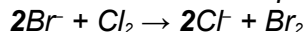
M2 Could be ionic equation with or without K^+



Accept HBr and H₂SO₄ 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⁺



1

M4 % atom economy of bromine

$$= \frac{\text{Br}_2}{2\text{KBr} + \text{Cl}_2} \times 100 = \frac{(2 \times 79.9)}{238 + 71} \times 100 = \frac{159.8}{309} \times 100$$

= **51.7% OR 52%**

M4 Ignore greater number of significant figures

1

M5 One from:

- High atom economy
- Less waste products
- Cl₂ is available on a large-scale
- No SO₂ produced
- Does not use concentrated H₂SO₄
- (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]

Examiner reports

Q1.

- (a) Most students answered this question well, with just over half of students scoring both marks, although many thought that the time that equilibrium was achieved was the point that the concentrations of SO_3 and O_2 were the same as each other.
- (b) Many students were able to sketch accurate curves although they didn't always appreciate that the SO_2 and O_2 concentrations would be in the ratio 2:1.
- (c) This proved to be demanding for many students (62.7% scored zero). Explanations and predictions in terms of Le Chatelier's Principle were often vague and did not refer to a shift in the position in equilibrium. A good number of students also confused rate arguments with equilibrium arguments when giving an explanation.

Q2.

- (a) Most students knew that a catalyst does not affect the equilibrium yield, but few could explain that this is because it increases the rate of both the forwards and reverse reactions equally.
- (b) Most students (78.5%) could write the expression for K_c .
- (c) The most common mistake in the calculation of K_c was to use the amount in moles rather the concentration of each reagent. Others failed to square the concentration of hydrogen. A good number of candidates (44.1%) did, however, gain all three marks.
- (d) The idea of the answer being equal to $(1/\text{answer to 08.3})$ was quite well known and many could deduce the units. A surprisingly high proportion of students (14.2%), however, made no attempt at this question.

Q3.

Most students (60.1%) could use Le Chatelier's principle to deduce which statement was correct.

Q4.

- (a) Many students gained high marks in this question – over 70% scored 4 or 5. Others often failed to use the mole ratio from the equation when deducing the amounts, in moles, of reagents at equilibrium.
- (b) The expression and its units were given correctly by over 82% of students.
- (c) In this question, many students were able to re-arrange the expression for K_c but significant numbers failed to divide the amounts in moles that they were given by the correct volume in dm^3 . Some failed to gain a mark by giving the answer as the amount, in moles, of A rather than its concentration. Since the least precise data in the question were given to two significant figures, the final answer for concentration should have been given to two significant figures, so some students failed to gain the final mark because the answer was given to the wrong number of significant figures.

- (d) This question was poorly answered and showed that students were unfamiliar with the idea of the equilibrium moving to the side with a larger amount, in moles, to oppose the fall in concentrations of all reagents when more water was added to the equilibrium mixture. Credit was given to those few students who adopted a mathematical approach. 65.8% of students failed to score here.

Q5.

D was the commonest incorrect response, suggesting that the effect of pressure on equilibrium position was understood better than the effect of temperature. The success rate on the final question was 76.3%.

Q6.

Students showed a good understanding of qualitative equilibrium ideas, with 64% gaining this mark.

Q7.

- (a) Students answered this question quite well, with a good awareness of the range of temperatures and pressures needed. Most students failed to describe the information given in the graph; only the best students noted that the yield plateaued over about 850°C. The relationship between pressure and rate was often missed and this also limited students' marks. Many students discussed conclusions that could be drawn from using *Le Chatelier's Principle*; this was not what the question was asking.
- (b) Only a few students did not understand what was being asked for; most errors were either arithmetic errors or rounding errors.
- (c) Many completely correct answers were seen (48.9% of students). Some students, however, could not calculate the total number of moles or could not calculate the partial pressures of the gases. Most students could write the expression for K_p but some forgot to square the partial pressure of hydrogen. Units were sometimes incorrectly given in moles.

Q14.

Many students were distracted by incorrect responses to this question due to a misunderstanding of the factors that affect the value of the equilibrium constant.

Q16.

In part (a) most students were able to sketch an appropriate curve, although some made the mistake of joining the end of their curve to the original curve or to the horizontal axis. The explanation depended on it being clear that many more molecules would have $E > E_a$ and that therefore the frequency of successful collisions would greatly increase. Too many answers simply referred to an increase in energy leading to an increase in collisions.

The first part of (b) was generally well answered although, when applying *le Chatelier's principle* to a specific situation, students must be clear that the shift in position of an equilibrium is in order to oppose a specific change. In this case the shift is to oppose the increase in pressure. In part (b)(ii) quite a lot of answers were expressed in a confused manner. Students are advised to tailor their answer to the actual question rather than repeat generic responses related to the idea. In this case the phrase in the question 'rather than at a higher temperature' was key, with the expectation being that students

would suggest that, although a higher temperature would increase the rate, it would decrease the yield so the chosen value was a compromise. Students who introduced the idea of lower temperatures could still earn credit but a mention of compromise or optimum conditions was required in order to score the second mark.

Q17.

Students have begun to demonstrate considerable ability in using Le Chatelier's principle to explain the effect of changing reaction conditions on equilibrium yield, but are less effective in their explanations concerning rates of reaction. The low demand first mark in part (a)ii proved elusive for some and the higher demand mark was marred by incomplete answers missing important ideas such as more collisions *in a given time* and more particles *in a given volume* or words to that effect in each case. In part (a)iii the idea that there is an increase in the available surface area when a catalyst is spread onto an inert honeycomb was understood by many, but the necessity to state that this would lead to an increase in *successful* collisions was often missed. Overall only about one fifth of students scored both marks in part (a)ii and part (a)iii.

Q18.

The equation in part (a) was generally well known but common errors included the formation of Mg^+ , the formation of one mole of chloride ions and the inclusion of water as a reagent. The calculation in part (b) was well done by many students; a common error was a failure to use 2x the enthalpy of hydration of the chloride ion. Students generally used their answer to part (b) to give a good explanation in part (c).

Q19.

Parts (a), (b) and (c) of this question were generally answered well, with the main error in part (b) being the inclusion of s^{-1} in the units and the main errors in part (c) being the omission or incorrect use of the volume and the incorrect rounding of $2.5 / 1.5 (= 1.666)$ to 1.6. In parts (d) and (e) respectively, most students correctly gave 'decrease' and ' T_1 ', but many struggled to give clear explanations, often repeating generic Le Chatelier statements rather than discussing these particular situations. The term 'favours' was not credited unless qualified.

Q20.

In part (a)(i), some students missed either the fact that the catalyst has to be a concentrated strong acid or that the unreacted ethene is re-circulated to achieve an overall yield of 95% and this meant that only a small number of students scored both marks. Considerable latitude was allowed in the responses for part (a)(ii), since it was clear that many students did not really understand what was happening in this process and this approach to the marking enabled the majority of students to gain at least two marks out of three. In part (a)(iii), some students recognised the possibility of poly(ethene) being formed and approximately 17% of students gained both marks.

It has been a while since a question like part (b) has been asked and it was not well answered with few students gaining full marks and over half scoring zero. Balancing the correct equation and then including the correct state symbols were both needed for full marks. Parts (c) and (d) proved straightforward for many and full marks were seen from over a third of students in each of parts (c)(i) and (c)(ii), respectively.

Q21.

This question was high scoring. In part (b)(i), almost 48% scored full marks and for those

who did not, it was the idea that catalysts alter the rate of a reaction and are chemically unchanged at the end of the reaction that was missed most often.

Q22.

The standard enthalpy change calculation in part (a) was straightforward and high scoring. In parts (b) and (c), good discrimination occurred and a great many well-articulated responses were seen. It is worth noting that no marks were scored in either of parts (b) or (c), if the effect on the yield was assigned incorrectly. The meaning of *carbon-neutral* in part (d) is spelled out in the specification and needs to refer to net emissions of carbon dioxide to the atmosphere. Parts (d)(ii) and (d)(iii) were challenging and only the best students were able to arrive at the equation for the overall reaction between hydrogen and oxygen to make water. Most students scored at least one mark in part (e); the commonest error was a failure to give the final answer a negative sign for this exothermic process.

Q23.

Most students scored highly in this question apart from part (a)(iii) where many repeated the mathematical information given in the question (that the units cancelled) and did not give a chemical explanation (that the number of moles on each side of the equation was equal). Part (b) was answered well with parts (i) and (iii) proving easier than (ii) and (iv).

Q24.

Questions that test ideas about equilibria are being answered with greater precision than in the past. In part (b), the idea that a catalyst increases the rate of the forward reaction and the rate of the reverse reaction equally was not well known and many answers either defined catalysis or explained how catalysts work. Part (c) was high scoring and most answers stated clearly the necessary information about the reaction (eg the forward reaction is exothermic) followed by the idea that the equilibrium shifts to oppose the specified change. In part (d), the idea that higher temperatures lead to higher rates of reaction was understood, but the linkage between operate at high pressures and either increase in equipment costs or increase in pumping costs was not well known.

Q25.

Candidates struggled to balance the equation in part (a)(i) with 30% failing to complete it correctly. Part (b)(i) is straight from the specification and two thirds of candidates did not have a problem. In parts (b)(ii) and (b)(iii) candidates demonstrated that they are learning how to express their ideas with clarity and some very good answers were seen. Some answers suffered from contradictory statements while others included statements that were open to different interpretations.

Q26.

The first three sections of part (a) were well answered, but in part (a)(iv) a large number of students failed to convert moles into concentration. Some also over-rounded numbers at an early stage and this led to answers outside the accepted range. Part (c) proved more challenging, with a very large number of students giving T_2 as the higher temperature.

Q27.

Most scored at least one mark in part (a). Incomplete responses noted that the forward and backward reactions both happened at the same time, but did not say that the rates were equal. Statements about the amounts of reactants and products were often missing

or in some cases these amounts were described as the same (as each other?) rather than as constant.

Most were able to write the correct expression in part (b), but part (c) proved to be very difficult. It was disappointing to see how few candidates were able to rearrange the mathematical expression for K_c and how often basic errors in mathematics cost the candidates marks. Other errors included confusion between moles and concentration for all three substances involved.

Part (h) was generally well answered, although many candidates spent time on a full calculation rather than simply taking the reciprocal of the equilibrium constant for the forward reaction.

Q28.

This question was not as high scoring as might have been expected. Candidates were unfamiliar with the equations that show how chlorine atoms catalyse the decomposition of ozone, even though these are in the specification. The ability to articulate a correct argument using Le Chatelier's principle in part (c)(ii) was well done, although candidates should be urged to refer to the "equilibrium" rather than the "system".

Q29.

This question was high scoring. In the explanation of the effect of an increase in temperature on the equilibrium, candidates often lost the final mark, because they failed to state that the equilibrium moves to lower the temperature by absorbing the heat. Too often the answer referred simply to opposing the change.

Q30.

Overall this was one of the most discriminating questions on the paper and even the weakest candidates were able to score some marks. In part (a) many candidates were able to appreciate that the equilibrium would shift to the right to replace the lost CO_2 even if they did not express the idea as fully as they might have. In part (b) most candidates could extract information from the story and appreciate that there is a significant difference between waste gases being released into the atmosphere and collecting the SO_2 and making sulfuric acid from it. The expense associated with electrolysis in part (c) was well known but candidates often missed the fact that the zinc is pure and it is this that justifies the expense. A few candidates confused yield with purity. Quite a few candidates failed to use Zn^{2+} ions in their half-equation in part (d), but most knew that the reaction occurred at the negative electrode. Part (e) proved relatively demanding despite two possible equations that were not redox. Part (f) was well answered and credit was awarded for formation of either the oxide or the hydroxide.

Q31.

This question was answered well. In part (a) most candidates calculated the amount of hydrogen in the equilibrium mixture correctly but many did not use the ratio in the equation so their answer to the amount of steam was wrong. The expression for K_c in part (b) was very well understood but it was clear that some candidates struggled to use their calculators correctly to raise values to the power of 2 or 4. In part (d), the effect on the equilibrium mixture of a change of temperature was answered better than the effect of a change of volume and therefore of pressure.

Q32.

This question took hydrogen as its theme and asked questions across the subject. Overall it was a high scoring question. The application of Le Chatelier's principle was done well with only 10% of candidates failing to score any marks. By contrast, the calculation of a value for the H-H bond enthalpy proved very demanding and half the candidates scored no marks.

Q33.

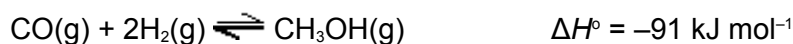
Part (a) was taken straight from the Specification but only 20% of candidates scored full marks. The explanation in part (b) was generally done well and part (c) was relatively high scoring, even though the demand in (c)(i) required reference both to the change in rate and the idea that a catalyst is not used up in the reaction. Most candidates gave a correct answer to part (d)(i), but only a minority of candidates could work out what to do in part (d)(ii).

Q34.

This question aimed to test areas of the Specification in the context of the historical methods used for the extraction of bromine and a real application of the chemistry of bromine in its use in swimming pools in France and the USA. Part (a) proved quite demanding although almost 75% of candidates gained some credit. Part (b) discriminated well with the full range of marks seen and more than half of the candidates were able to gain at least 2 marks. Candidates who could balance the equation had no difficulty with this part of the question. Part (c) was often well answered with 80% of the candidates gaining at least 2 marks.

Q1.

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



- (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 $\text{Cr}_2\text{O}_3/\text{ZnO}$ 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)

Q2.

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	$\text{N} \equiv \text{N}$	$\text{H} - \text{H}$	$\text{N} - \text{H}$
Mean bond enthalpy/ kJ mol^{-1}	945	436	391

(3)

- (8)

(Total 11 marks)

$$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \quad \Delta H^\ominus = -92 \text{ kJ mol}^{-1}$$

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.

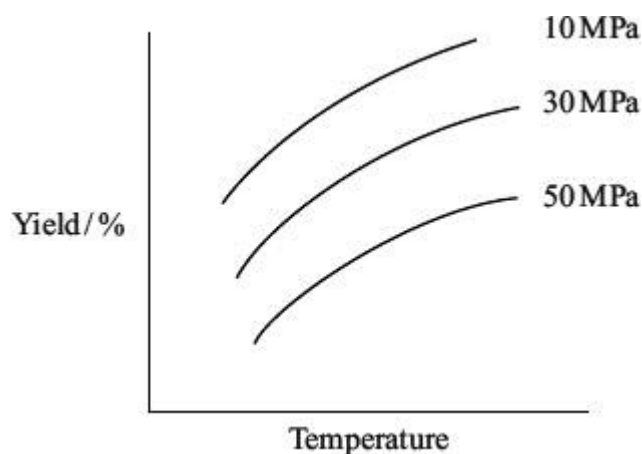
- (iii) Hence explain why 800 K is referred to as a *compromise temperature*.

(5)

(Total 11 marks)

Q4.

- (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 _____

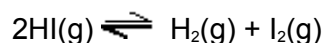
- (ii) Use the diagram to deduce whether the forward reaction is exothermic or endothermic. Explain your answer.

The forward reaction is _____

Explanation _____

(6)

- (b) When a 0.218 mol sample of hydrogen iodide was heated in a flask of volume V dm³, the following equilibrium was established at 700 K.



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 _____

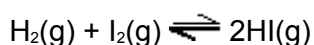
Number of moles of hydrogen iodide _____

- (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



(7)

(Total 13 marks)

Q5.

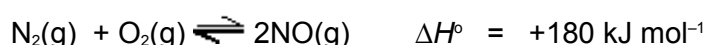
The standard enthalpy of formation, ΔH_f for $\text{O}_3(\text{g})$ is + 142 kJ mol⁻¹. In which one of the following would both the changes shown increase the amount of O_2 gas in an equilibrium mixture containing only $\text{O}_2(\text{g})$ and $\text{O}_3(\text{g})$?

- 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)

Q6.

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



- (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 $\text{Ag}^+(\text{aq})$ ions.

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

(5)

(Total 12 marks)

Q7.

- (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.



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 _____

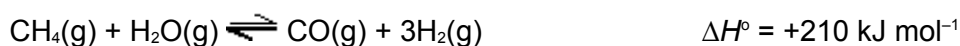
- (iv) Another 36.8 g sample of N_2O_4 was heated to the same temperature as in the original experiment, but in a larger flask. State the effect, if any, of this change on the position of equilibrium and on the value of K_c compared with the original experiment.

Effect on the position of equilibrium _____

Q8.

The manufacture of methanol can be achieved in two stages.

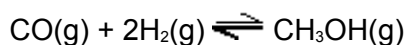
- (a) In the first stage, methane and steam react according to the following equation.



Discuss, with reasons, the effects of increasing separately the temperature and the pressure on the yield of the products and on the rate of this reaction.

(6)

- (b) In the second stage, carbon monoxide and hydrogen react according to the following equation.



A 62.8 mol sample of carbon monoxide was added to 146 mol of hydrogen. When equilibrium was reached at a given temperature, the mixture contained 26.2 mol of methanol at a total pressure of 9.50 MPa.

Write an expression for the equilibrium constant, K_p , for this reaction. Calculate a value for K_p at this temperature and give its units.

(8)

Q9.

- (5)

- Page 10 of 51

(7)

- (5)

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Q10.

Use the information about the following solutions to answer the question below.

Solution F: This is a mixture of 1 mol of propanoic acid, 1 mol of methanol and 2 mol of water.

Solution G: This was originally the same mixture as solution **F** but it has been left to reach equilibrium.

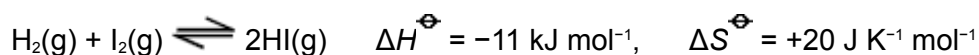
Compared to the pH of solution **F**, the pH of solution **G** will be

- A** considerably lower.
- B** slightly lower.
- C** slightly higher.
- D** exactly the same.

(Total 1 mark)

Q11.

Refer to the following reaction



Which one of the following statements is correct?

- A** This is a redox reaction.
- B** The reaction is **not** feasible below 298 K
- C** At equilibrium, the yield of hydrogen iodide is changed by increasing the pressure.
- D** At equilibrium, the yield of hydrogen iodide increases as the temperature is increased.

(Total 1 mark)

Q12.

Methanol, CH_3OH , is a convenient liquid fuel.

- (a) An experiment was conducted to determine the enthalpy of combustion of liquid methanol. The energy obtained from burning 2.12 g of methanol was used to heat 150 g of water. The temperature of the water rose from 298 K to 362 K. (The specific heat capacity of water is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$)

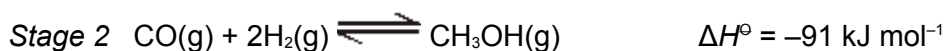
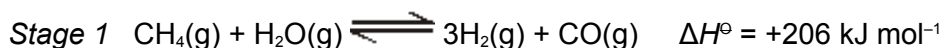
- (i) Define the term *standard enthalpy of combustion*.

(3)

- (ii) Use the data above to calculate a value for the enthalpy of combustion of one mole of liquid methanol.

(4)

- (b) Methanol can be synthesised from methane and steam by a process that occurs in two stages.



- (i) Explain why, in *Stage 1*, a higher yield of hydrogen and carbon monoxide is **not** obtained if the pressure is increased.

(2)

- (ii) *Stage 2* is carried out at a compromise temperature of 500K. By considering what would happen at higher and lower temperatures, explain why 500 K is considered to be a compromise for *Stage 2*.

-
- This image shows a single sheet of white paper with horizontal blue ruling lines. The lines are evenly spaced and run across the width of the page. There are approximately 20 lines visible. The paper has a slight shadow on the right side, suggesting it's resting on a surface.

(Total 15 marks)

Q13.

Tetrafluoroethene, C_2F_4 , is obtained from chlorodifluoromethane, CHClF_2 , according to the equation:



- (a) A 1.0 mol sample of CHClF_2 is placed in a container of volume 18.5 dm^3 and heated.

When equilibrium is reached, the mixture contains 0.20 mol of CHClF_2 .

- (i) Calculate the number of moles of C_2F_4 and the number of moles of HCl present at equilibrium.

Number of moles of C_2F_4 _____

Number of moles of HCl

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

- (iii) Calculate a value for K_c and give its units.

Calculation

Units

(6)

- (b) (i) State how the temperature should be changed at constant pressure to increase the equilibrium yield of C_2F_4

- (ii) State how the total pressure should be changed at constant temperature to increase the equilibrium yield of C_2F_4

(2)

- (c) C_2F_4 is used to manufacture the polymer polytetrafluoroethene, PTFE. Name the type of polymerisation involved in the formation of PTFE.

(1)

(Total 9 marks)

Q14.

Methanol can be formed on an industrial scale from carbon dioxide and hydrogen by a reversible reaction as shown below.



The reaction can be carried out in the presence of a chromium-based catalyst at a temperature of 700 K and a pressure of 30 MPa. Under these conditions, equilibrium is reached when 2% of the carbon dioxide has been converted.

- (a) How does the rate of the forward reaction compare with that of the backward reaction when 2% of the carbon dioxide has been converted?

(1)

- (b) (i) If the pressure was reduced but the temperature was kept the same, deduce what would happen to the equilibrium yield of methanol. Explain your answer.

Yield _____

Explanation _____

- (ii) Give two reasons why, in general, industry prefers to operate processes at pressures lower than 30 MPa.

Reason 1 _____

Reason 2 _____

(5)

- (c) If the chromium-based catalyst was replaced with a more efficient catalyst but other conditions were kept the same, deduce what would happen to the equilibrium yield of methanol. Explain your answer.

Yield _____

Explanation _____

(2)

- (d) In the presence of a very efficient copper-based catalyst, this industrial process can be operated at a lower temperature of 500 K and a pressure of 30 MPa. Under these conditions, at equilibrium, more of the carbon dioxide is converted into methanol.

Use this information to deduce the sign of the enthalpy change for the reaction. Explain your deduction.

Sign of enthalpy change _____

Explanation _____

(3)

- (e) In the processes above, the equilibrium yield of methanol is low. Suggest what is done with the unreacted carbon dioxide and hydrogen.

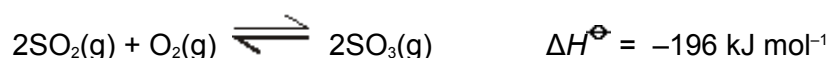
(1)

(Total 12 marks)

Q15.

Sulphur dioxide and oxygen were mixed in a 2:1 mol ratio and sealed in a flask with a catalyst.

The following equilibrium was established at temperature T_1



The partial pressure of sulphur dioxide in the equilibrium mixture was 24 kPa and the total pressure in the flask was 104 kPa.

- (a) Deduce the partial pressure of oxygen and hence calculate the mole fraction of oxygen in the equilibrium mixture.

Partial pressure of oxygen _____

Mole fraction of oxygen _____

(3)

- (b) Calculate the partial pressure of sulphur trioxide in the equilibrium mixture.

(1)

- (c) Write an expression for the equilibrium constant, K_p , for this reaction. Use this expression to calculate the value of K_p at temperature T_1 and state its units.

Expression for K_p _____

Calculation _____

Units _____

(4)

- (d) When equilibrium was established at a different temperature, T_2 , the value of K_p was found to have increased. State which of T_1 and T_2 is the lower temperature and explain your answer.

Lower temperature _____

Explanation _____

(3)

- (e) In a further experiment, the amounts of sulphur dioxide and oxygen used, the catalyst and the temperature, T_1 , were all unchanged, but a flask of smaller volume was used.

Deduce the effect of this change on the yield of sulphur trioxide and on the value of K_p .

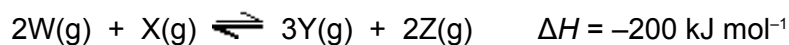
Effect on yield of SO_3 _____

Effect on K_p _____

(2)

Q16.

(a) The gaseous reactants **W** and **X** were sealed in a flask and the mixture left until the following equilibrium had been established.



Write an expression for the equilibrium constant, K_p , for this reaction.
State one change in the conditions which would both increase the rate of reaction and decrease the value of K_p . Explain your answers.

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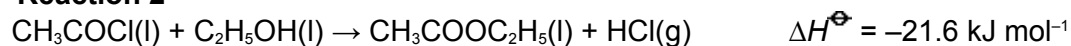
(7)

(b) Ethyl ethanoate can be prepared by the reactions shown below.

Reaction 1



Reaction 2



(i) Give one advantage and one disadvantage of preparing ethyl ethanoate by **Reaction 1** rather than by **Reaction 2**.

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(Total 15 marks)



Effect on yield of hydrogen _____

Explanation _____

- (ii) The concentration of steam in the reaction mixture is increased.

Effect on yield of hydrogen _____

Explanation _____

(6)

- (c) At equilibrium, a high yield of hydrogen is favoured by high temperature. In a typical industrial process, the operating temperature is usually less than 1200 K. Suggest two reasons why temperatures higher than this are not used.

Reason 1 _____

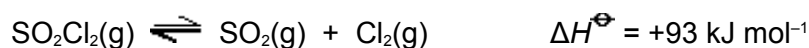
Reason 2 _____

(2)

(Total 9 marks)

Q18.

At high temperatures, SO_2Cl_2 dissociates according to the following equation.



When 1.00 mol of SO_2Cl_2 dissociates, the equilibrium mixture contains 0.75 mol of Cl_2 at 673 K and a total pressure of 125 kPa.

- (a) Write an expression for the equilibrium constant, K_p , for this reaction.

(1)

- (b) Calculate the total number of moles of gas present in the equilibrium mixture.

(2)

- (c) (i) Write a general expression for the partial pressure of a gas in a mixture of gases in terms of the total pressure.

- (ii) Calculate the partial pressure of SO_2Cl_2 and the partial pressure of Cl_2 in the equilibrium mixture.

Partial pressure of SO_2Cl_2 _____

Partial pressure of Cl_2 _____

(5)

- (d) Calculate a value for the equilibrium constant, K_p , for this reaction and give its units.

(3)

- (e) State the effect, if any, of an increase in temperature on the value of K_p for this reaction.
Explain your answer.

Effect on K_p _____

Explanation _____

(2)

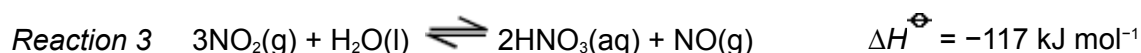
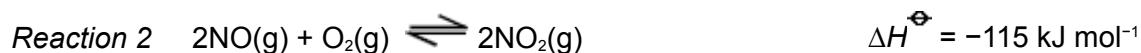
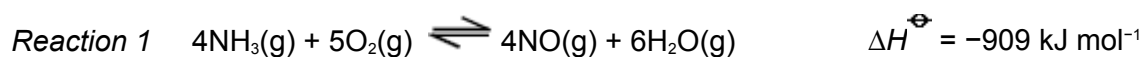
- (f) State the effect, if any, of an increase in the total pressure on the value of K_p for this reaction.

(1)

(Total 14 marks)

Q19.

The data below refer to the industrial production of nitric acid from ammonia.



The equilibrium yield in **all three** reactions is increased when

- A** the pressure is increased.
B the pressure is decreased.

- C the temperature is increased.
- D the temperature is decreased.

(Total 1 mark)

Q20.

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



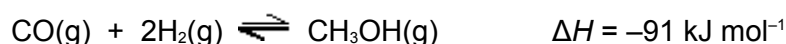
The equilibrium yield of ethanoic acid could be increased by

- A lowering the temperature.
- B adding a catalyst.
- C adding more water to the reaction mixture.
- D adding more methanol to the reaction mixture.

(Total 1 mark)

Q21.

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



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)

- (3)

- (1)

(6)

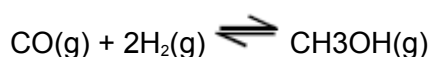
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time.

(4)
(Total 10 marks)

Q23.

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



At equilibrium, when the temperature is 68 °C, the total pressure is 1.70 MPa.
The number of moles of CO, H₂ and CH₃OH present are 0.160, 0.320 and 0.180, respectively.

Thermodynamic data are given below.

Substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
CO(g)	-110	198
H ₂ (g)	0	131
CH ₃ OH(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)

Q24.

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



- (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.



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

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

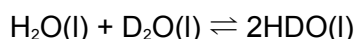
- (ii) Explain why 20 MPa is a compromise pressure.

(6)

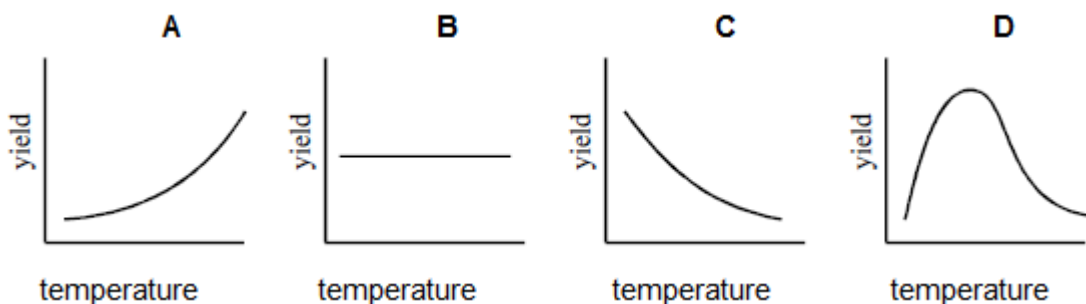
(Total 14 marks)

Q25.

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



The standard enthalpy of formation of $\text{H}_2\text{O(l)}$ is -286 kJ mol^{-1} , that of $\text{D}_2\text{O(l)}$ 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)

Q26.

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

$$K_c = \frac{[\text{N}_2][\text{O}_3]^2}{[\text{NO}]^2[\text{O}_2]^2}$$

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.

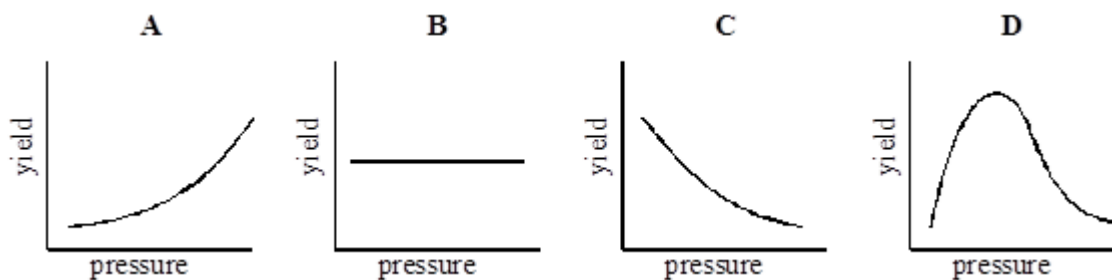
(Total 1 mark)

Q27.

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



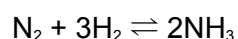
Which one of the graphs best represents the variation with pressure of the yield of chlorine at equilibrium?



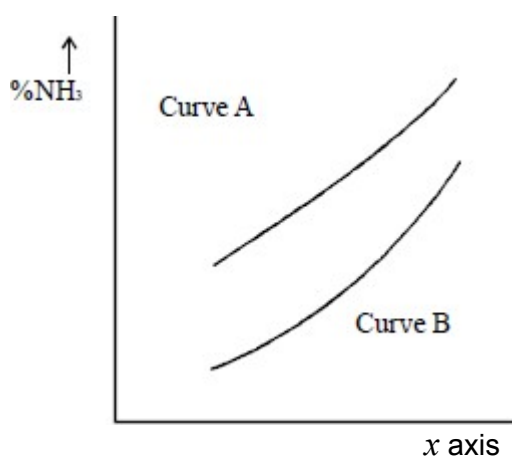
(Total 1 mark)

Q28.

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



$$\Delta H = -92 \text{ kJ mol}^{-1}$$



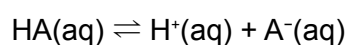
Which one of the following are correct labels for the graph?

	<i>x axis</i>	<i>Curve A</i>	<i>Curve B</i>
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)

Q29.

A weak acid HA dissociates in aqueous solution as shown below



$$\Delta H = +20 \text{ kJ mol}^{-1}$$

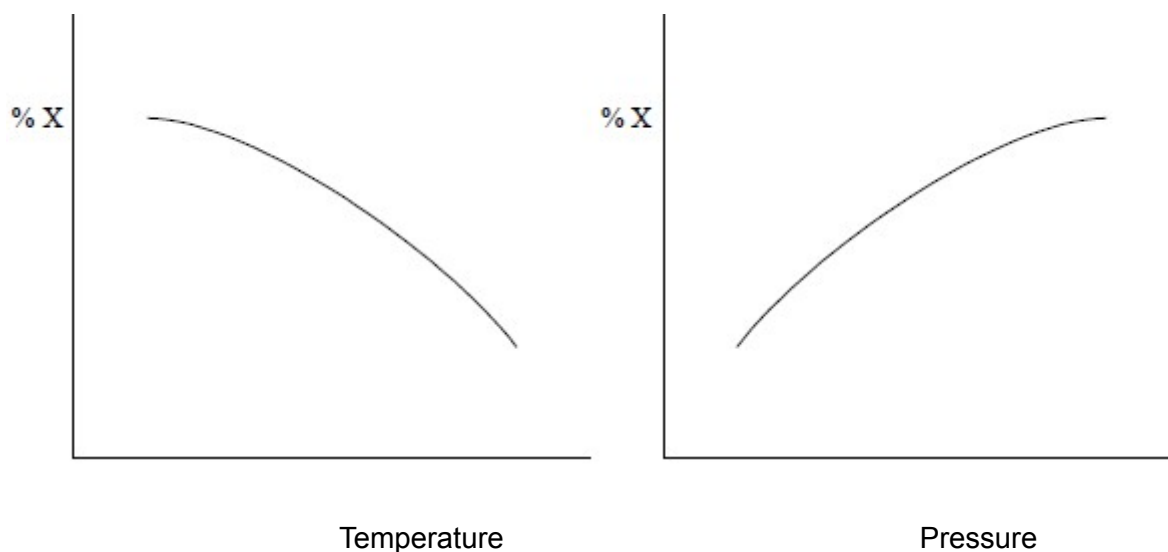
Which one of the following changes will result in a decrease in the pH of an aqueous solution of the acid?

- 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)

Q30.

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.



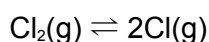
Which one of the following statements concerning the formation of **X** is correct?

- 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)

Q31.

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



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)

Mark schemes

Q1.

- (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 $\rightarrow$ 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 $\therefore$ compromise 1
- increases reaction rate/catalyst surface contact 1

[7]

Q2.

- (a) Equation $1/2\text{N}_2 + 3/2\text{H}_2 \rightarrow \text{NH}_3$ 1
- $\Delta H_f = [(945 \times 0.5) + (426 \times 1.5)] - (391 \times 3)$ 1
- $= -46.5 \text{ kJ mol}^{-1}$ 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]

Q3.

- (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 < $\text{N}_2 + \text{H}_2$ 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]

Q4.

(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 $\times 2$ missed, max 1 in part (iv)

$$(ii) K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$$

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

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

Conseq on (i)

1

$$= 0.0179 \text{ or } 1.79 \times 10^{-2}$$

Allow 0.018 or 1.8×10^{-2}

1

$$(v) \quad K_c = 55.9 \text{ or } 56$$

Conseq i.e. (answer to (iv))⁻¹

1

[13]

Q5.

D

[1]

Q6.

(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

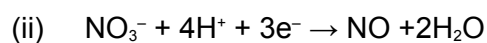
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(c) (i) +2

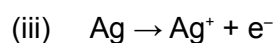
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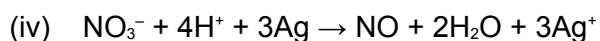
+5

1



1



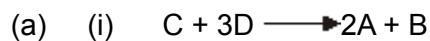


1

1

[12]

Q7.



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) $\text{mol N}_2\text{O}_4 \text{ reacted} = 0.400 - 0.180 = 0.220$

1

$\text{mol NO}_2 \text{ formed} = 0.440$

1

(iii) $K_c = \frac{(\text{NO}_2)^2}{(\text{N}_2\text{O}_4)}$

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]

Q8.

(a) (must state correct effect on yield or rate to score the reason mark)

T effect: higher temp: yield greater or shifts equilibrium to right;

1

effect: higher temp: rate increased;

1

reason: endothermic

OR

more particles have $E > E_a$

1

OR

more successful/productive collisions;

1

P effect: higher pressure: yield less or shifts equilibrium to left;

1

effect: higher pressure: rate increased;

reason: increase in gas moles L to R

OR

greater collision frequency;

(Q of L mark)

1

(b) M1 equilibrium moles of CO = $62.8 - 26.2 = 36.6$

1

M2 equilibrium moles of $H_2 = 146 - 2(26.2) = 93.6$

1

M3 total no moles = $36.6 + 93.3 + 26.2 = 156.4$

1

M4 partial pressure = mole fraction x total pressure

1

M5
$$K_p = \frac{P_{CH_3OH}}{P_{CO} \times P_{H_2}^2}$$

1

M6
$$= \frac{\left(\frac{26.2}{156.4} \times 9.50\right)}{\left(\frac{36.6}{156.4} \times 9.50\right) \times \left(\frac{93.6}{156.4} \times 9.50\right)^2}$$
$$\frac{(0.168 \times 9.5)}{(0.234 \times 9.50) \times (0.598 \times 9.5)^2}$$
$$\frac{(1.59)}{(2.22) \times (5.69)^2}$$

1

M7 0.022(1) $2.2(l) \times 10^{-8}$ $2.2(l) \times 10^{-14}$

1

M8 MPa^{-2} kPa^{-2} Pa^{-2}

1

*If no subtraction lose M1, M2 and M3)
 (If $\times 2$ missed in M2, lose both M2 and M3)
 (If M1 gained but moles of $\text{H}_2 = 73.2$ (i.e. double CO), M2 and M3 lost)
 (If M1 gained but mol $\text{H}_2 = 2(146 - 26.2)$, M2 and M3 lost)
 (If M1 and M2 correct but M3 lost for CE, penalise M6 also)
 (M4 can be gained from the numbers in the expression for M6 even if these numbers are wrong)
 (If K_p contains [] lose M5 but then mark on)
 (If chemically wrong expression for K_p , lose M5, M6 and M7 (allow M8 conseq on their K_p))
 (If divided by 9.5, or not used 9.5 at all, lose M6 and M7 (and M4))
 (If tried to convert to kPa and is factor(s) of 10 out, penalise in M6 and allow M8 for kPa^{-2})*

[14]

Q9.

(a) effect on reaction rate: catalyst provides an alternative reaction route.;

1

with a lower E_a ;

1

more molecules able to react or rate increased;

1

equilibrium: forward and backward rates changes by the same amount;

1

hence concentration of reactants and products constant or yield unchanged;

1

(b) heterogeneous: catalyst in a different phase or state to that of the reactants;

1

active site: place where reactants adsorbed or attached or bond etc.;

1

reaction occurs or an explanation of what happens;
 (allow absorbed)

1

reasons: large surface area;
 reduce cost or amount of catalyst;

2

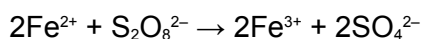
catalyst poison: lead adsorbed;

lead not desorbed or site blocked;
(lead adsorbed irreversibly scores both of these marks)

2

- (c) reaction slow as: both ions negatively charged or ions repel;

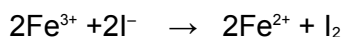
1



Species;

Balanced;

2



Species ;

Balanced;

2

[17]

Q10.

C

[1]

Q11.

A

[1]

Q12.

- (a) (i) enthalpy change when 1 mol of a substance
(or compound) (QL mark)

1

is (completely) burned in oxygen (or reacted in excess oxygen)

1

at 298 K and 100 kPa (or under standard conditions)

1

- (ii) heat produced = mass of water × Sp heat capacity
 $\times \Delta T$ (or $mc\Delta T$)

1

= $150 \times 4.18 \times 64$ (note if mass = 2.12 lose first 2 marks
then conseq) = 40100 J or = 40.1 kJ (allow 39.9 - 40.2
must have correct units)

1

moles methanol = mass/ M_r = $2.12/32$ (1)
= 0.0663

1

$\Delta H = -40.1/0.0663 = -605 \text{ kJ (mol}^{-1}\text{)}$

1

(allow -602 to -608 or answer in J)

(note allow conseq marking after all mistakes but note use of
2.12 g loses 2 marks)

- (b) (i) equilibrium shifts to left at high pressure

- because position of equilibrium moves to favour fewer moles (of gas) 1
- (ii) at high temperature reaction yield is low (or at low T yield is high) 1
- at low temperature reaction is slow (or at high T reaction is fast) 1
- therefore use a balance (or compromise) between rate and yield 1
- (c) $\Delta H = \Sigma \Delta H_c^\circ(\text{reactants}) - \Sigma \Delta H_c^\circ(\text{products})$ (or correct cycle) 1
- $\Delta H_c^\circ(\text{CH}_3\text{OH}) = \Delta H_c^\circ(\text{CO}) + 2 \times \Delta H_c^\circ(\text{H}_2) - \Delta H$ 1
- $= (-283) + (2 \times -286) - (-91)$ (mark for previous equation or this)
 $= -764 \text{ (kJ mol}^{-1}\text{)}$ (*units not essential but lose mark if units wrong*)
(note + 764 scores 1/3) 1

[15]

Q13.

- (a) (i) moles of $\text{C}_2\text{F}_2 = 0.40$ mark independently from HC1 1

moles of HC1 = 0.80 **not** consequential 1

(ii)
$$K_c = \frac{[\text{C}_2\text{F}_4][\text{HCl}]^2}{[\text{CHClF}_2]^2}$$

wrong K_c means they can only

score for units in (iii) consequ

on their K_c 1

(iii)
$$K_c = \frac{(0.40/18.5)(0.8/18.5)^2}{(0.20/18.5)^2}$$

= 0.35 1

mol dm⁻³ 1

- (b) (i) increase 1

- (ii) decrease 1
- (c) addition or radical 1

[9]

Q14.

- (a) Same 1
- (b) (i) Decreases 1
- More moles on left hand side 1
- Equilibrium moves to increase the pressure
(Or to oppose the change or to compensate for low pressure) 1
- (ii) Cost of producing high pressure (1)
Cost of plant to resist high pressure (1)
Correct safety factor with reason (1) max 2
- (c) No change 1
- Catalyst has no effect on equilibrium position
(Or catalyst affects rate of forward and backwards reactions equally) 1
- (d) Negative 1
- Reaction (or equilibrium) moves in the exothermic direction (or to the right) 1
- In order to oppose the change (or to raise the temperature) 1
- (e) Recycled (or re-used or 'put back in') 1

[12]

Q15.

- (a) 12 (kPa) 1
- pp = mole fraction × total pressure or mole fraction = 12/104 1
- = 0.115

	(allow 0.12)	1
(b)	68 (kPa)	1
(c)	$K_p = \frac{(p\text{SO}_3)^2}{(p\text{SO}_2)^2 \times (p\text{O}_2)}$ (If K_p wrong, allow consequential units only) (penalise square brackets in expression but then mark on) $= \frac{68^2}{24^2 \times 12}$ $= 0.669$ (Allow 0.67) (Allow full marks in calculation consequential on their values in (a) and (b)) kPa⁻¹	1
(d)	T_2 (Must be correct to score any marks in this section) <u>Exothermic</u> Reduce T to shift equilibrium to the right or forward reaction favoured by low T or K_p increases for low T or low T favours exothermic reaction	1
(e)	Increase None	1

[13]

Q16.

(a)	M1 $K_p = (pY)^3 \cdot (pZ)^2 / (pW)^2 \cdot (pX)$ NB [] wrong M2 temperature M3 increase	1
		1
		1

M4	particles have more energy or greater velocity/speed	1
M5	more collisions with $E > E_a$ or more successful collisions	1
M6	Reaction exothermic or converse	1
M7	Equilibrium moves in the left	1

Marks for other answers

Increase in pressure or concentration	allow M1, M5, M6	Max 3
Addition of a catalyst;	allow M1, M5, M6	Max 3
Decrease in temperature;	allow M1, M2, M6	Max 3
Two or more changes made;	allow M1, M6	Max 2

- (b) (i) Advantage; reaction goes to completion, not reversible or faster
- 1

Disadvantage; reaction vigorous/dangerous
(*exothermic must be qualified*)

or HCl(g) evolved/toxic
or CH₃COCl expensive

NB Allow converse answers

Do not allow reactions with other reagents e.g. water or ease of separation

1

- (ii) $\Delta S = \Sigma S \text{ products} - \Sigma S \text{ reactants}$
- 1

$$\Delta S = (259 + 187) - (201 + 161)$$

1

$$\Delta S = 84 \text{ (JK}^{-1} \text{ mol}^{-1}) \text{ (Ignore units)}$$

Allow – 84 to score (1) mark

1

$$\Delta G = \Delta H - T\Delta S$$

1

$$= -21.6 - 298 \times 84/1000$$

$$= -46.6 \text{ kJ mol}^{-1} \text{ or } -46\,600 \text{ J mol}^{-1}$$

1

Allow (2) for – 46.6 without units

(Mark ΔG consequentially to incorrect ΔS)

(e.g. $\Delta S = -84$ gives $\Delta G = +3.4 \text{ kJ mol}^{-1}$)

1

[15]

Q17.

- (a) An equilibrium opposes change (1)

1

- (b) (i) *Effect on yield of hydrogen: decreases (1)*

Note C.E. if not decrease, but mark on if no answer

Explanation: pressure lowered (or increase opposed) (1)
by favouring fewer moles (of gas) (1)

- (ii) *Effect on yield of hydrogen: increase (1)*

CE if wrong as above

Explanation: pressure / concentration / reactants / steam reduced (1)
by shifting to right (1)

or steam removed or forward reaction favoured

6

- (c) *Reason 1: cost of high temperature / energy (1)*

Reason 2: cost of plant (to resist high T) too high (1)
OR plant could not contain high T

2

[9]**Q18.**

(a) $K_p = \frac{P_{\text{SO}_2} \times P_{\text{Cl}_2}}{P_{\text{SO}_2\text{Cl}_2}}$ (1)

1

(b) $0.25 + 0.75 + 0.75 = 1.75$ (1) (1)

2

(c) (i) $p = \text{Total pressure} \times \text{mol fraction}$ (1)

(ii) *Partial of SO₂Cl₂: $125 \times \frac{0.25}{1.75} = 17.9 \text{ kPa}$ (1)*

Partial pressure of Cl₂: $125 \times \frac{0.75}{1.75} = 53.6 \text{ kPa}$ (1) (1)

5

(d) $K_p = \frac{53.6 \times 53.6}{17.9}$ (1) = 161 (1) kPa (1)

3

(e) *Effect on K_p: increase (1)*

Explanation: increase T sends equilibrium in endothermic direction (1)

2

(f) no effect (1)

1

Notes

- (a) If K_p has [] lose mark in (a) but allow full marks in (d)
- If K_p wrong/upside down etc, allow max 2 in (d) for substitution of numbers **(1)** and consequential units **(1)**
- (b) Mark for moles of SO_2Cl_2 can be scored in part (c) (ii) if not gained in (b)
- 1.75 get **(2)**
- If moles of $\text{SO}_2\text{Cl}_2 = 1$, this is a Chemical Error, hence a 2 mark penalty
- If total moles given in (b) = 1.75, this scores [2] in (b); but if the no moles of $\text{SO}_2\text{Cl}_2 = 1$ in (c)(ii), lose both marks in (c)(ii) for pp of $\text{SO}_2\text{Cl}_2 = (1/1.75) \times 125$, i.e. the 2 mark penalty is in (c)(ii).
 - If total moles given in (b) = 2.5, score zero in (b), but can gain full marks in (c)(ii) consequentially, i.e. the 2 mark penalty is in (b).
 - If moles of $\text{SO}_2\text{Cl}_2 = 1$ and total in (b) does not equal 2.5, still lose both in (b) but can get all 4 conseq in (c)(ii) for $1/x$ etc and $0.75/x$ etc
- (c) (i) Allow "Total pressure = sum of partial pressures" for **(1)** or $p_A = x_A \times p_{\text{tot}}$
- (ii) First mark is for mole fraction.
If either number in either mole fraction is not consequential on (b), then lose both marks for that partial p.
- (d) If p_{Cl_2} is not equal to p_{SO_2} or any number used in K_p is not conseq on (c)(ii), allow units only
- SIG FIGS; must be 3 sig figs in (b) but then allow 2 sig figs in (c) and (d); (ignore extra figs) but penalise incorrect rounding
- (e) If effect wrong, no marks for explanation.
If effect missing, e.g. answer states "equm shifts to right", mark on.
In the explanation, the word "endothermic" (or its equivalent) is essential.

[14]

Q19.

D

[1]

Q20.

C

[1]

Q21.

- (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]

Q22.

- (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]

Q23.

D

[1]

Q24.

- (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 $2 \rightarrow 4$) (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"
- (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

8

6

[14]

Q25.

B

[1]

Q26.

A

[1]

Q27.

C

[1]

Q28.

D

[1]

Q29.

B

[1]

Q30.

A

[1]

Q31.

C

[1]

Examiner reports

Q3.

There were a surprisingly large number of candidates who missed out the word rate in their answer to (a), simply stating that the forward reaction was equal to the backward reaction. Many candidates did not refer to constant concentrations of reactants and products. Parts (b) and (c) were generally well answered by most candidates. Part (d) was answered well apart from the weakest candidates. Errors included no reference to the exothermic reaction in part (d) (i) and failure to give a comparative answer in (d) (ii).

Q4.

In part (a) the changes were deduced well and although the explanations were less clear, marks on this part of the question were high. Part (b), however, differentiated well. This was particularly the case in part (b)(i) where only the best candidates correctly calculated the number of moles of HI. The expression for K_c in part (b)(ii) was well answered although a smaller number realised that the volume term cancelled in the expression because the numbers of moles of reactants and products were equal in the equation. Marks were gained in part (iv) for correct use of the data from part (i) and the better candidates were able to deduce that the answer to part (v) was the reciprocal of that to part (iv) although many repeated a K_c calculation.

Q6.

Part (a) was answered well by almost all candidates. The answers to part (b) were more discriminating. Only a few candidates realised that in order to have no change in the yield with an increase in pressure, both sides would be affected equally since there were two moles on each side of the equation. Answers involving the temperature effect were generally tackled better. The calculation of oxidation states was done well by the majority of candidates although the half equations and deduction of the final equation was only done well by the most able candidates. It is a concern that few candidates are able to write correctly balanced half equations at AS level.

Q7.

Part (a) was well done, but in part (b)(i) it was disappointing to see the considerable number of candidates who were unable to calculate the M_r correctly. In part (b)(ii), 0.22 or 0.36 were common wrong answers often given without any explanation. Only the better candidates were able to answer the question correctly. Most were able to write a correct expression for K_c , but many failed to score the calculation marks (even consequentially on their incorrect answers in part (b)) because they forgot that K_c involves concentrations rather than numbers of moles and failed to divide the number of moles by the volume in dm^3 . Part (iv) was fairly well answered.

Q8.

Part (a) was answered well as expected as the topic overlaps with qualitative equilibria in CHM2. Some candidates lost marks by discussing only the effect of increased temperature on the yield and not on the rate also. Several also suggested that the rate was unaffected or decreased by an increase of pressure. Part (b) was answered impressively by the better candidates, who were able to set out the answer clearly. Most were able to score marks for the expression for K_p or the definition of partial pressure (stated or inferred from a calculation). Too many, however, failed to realise that the amounts of the reagents at equilibrium were less than the initial amounts given. Even

those who realised that the equilibrium amount of carbon monoxide was $62.8 - 26.2$ mol did not always realise that, because of the 1:2 ratio in the equation, the equilibrium amount of hydrogen was $62.8 - (2 \times 26.2)$ mol. However if this was their only error, six marks were still available. The pressure was given in MPa and the answer for K_p was expected with units MPa^{-2} . Many attempted unnecessarily to convert the pressure into kPa or even into Pa and got into difficulties with the powers often.

Q9.

Parts (a) and (b) were both well answered and many candidates scored full, or nearly full, marks. Almost all candidates stated that the reaction between I^- and $\text{S}_2\text{O}_3^{2-}$ was slow as they were both negative and would repel each other, few gave correct equations showing the involvement of iron(II) and iron(III) ions in the reaction. Sadly some candidates, who gave correct species, lost a mark as they failed to balance the equations.

Q12.

In this question, good candidates were able to score full marks. Weaker candidates were less successful though they were usually able to pick up at least five or six marks.

Answers to part (a) usually gained all three marks. Answers to part (b) by weaker candidates were less successful. One common error in the expression $mc\Delta T$ was to use the mass of methanol (2.12 g) instead of the mass of water (100 g). Another common error was to give an incorrect sign for the final value of the enthalpy of combustion. Candidates were expected to recognise that this exothermic process should lead to a negative value for the enthalpy of combustion of methanol. Weaker candidates also lost marks for incorrect units or for giving no units. It is important for candidates to give correct units for intermediate values in the calculation as well as for the answer. In this case, if a candidate gave a wrong final answer, it was still possible to gain an intermediate mark for the heat released to the 100 g of water. However, if the candidate did not make it clear whether the intermediate value was expressed in Joules or in kJ, it was not possible to give any credit.

Answers to part (b) were of a good standard and in part (b) (i) almost all candidates were awarded the two marks. Answers to part (b) (ii) were not quite so accurate and, in particular, only the best candidates stated that 500 K achieves the best balance between rate of reaction and yield.

Good candidates found part (c) straightforward but weaker candidates often omitted to allow for two moles of hydrogen and also used the wrong sign for the enthalpy of reaction (-91 kJ mol^{-1}) relative to the enthalpies of combustion of carbon monoxide and hydrogen.

Q13.

Only the better candidates were able to calculate the number of moles of C_2F_2 and of HC1 correctly. However, if the rest of the answer used correct chemistry, no further marks were lost. The expression for K_c was well known, but there was uncertainty over the use of the volume of the container in the calculation. Many forgot to include it at all and so used a number of moles instead of the concentration in mol dm^{-3} . Some tried to include the number 18.5 dm^3 in the expression for K_c and others tried to convert the volume into m^3 . Parts (b) and (c) were well answered even by those who lost marks in the calculation in part (a).

Q14.

This question was answered reasonably well; it proved to be the easiest question on the paper. Answers to part (a) were usually correct. For part (b) (i) the decreased yield was usually correct and, as part of the explanation, most candidates mentioned that there were more moles of gas on the left hand side of the equilibrium. However, the link between increased pressure, decreased yield and the number of moles of gaseous reactants was not explained by many candidates. For part (b) (ii), in line with previous marking schemes, no credit was awarded for answers that simply stated cheaper (or less expensive) but gave no associated reason. Candidates were expected to link lower costs to the energy required for pumping and the capital investment required to manufacture pressure-resistant plant. Answers to part (c) by good candidates usually gained full marks. However, weaker candidates often gave incomplete answers such as stating that a catalyst increases the rate of a reaction but these candidates did not state that the rates of the forward and backward reactions are increased equally. In part (d), weaker candidates found it difficult to explain the sign of the enthalpy change but answers to part (e) were almost always correct.

Q15.

This question was answered well by most candidates, particularly part (a). The 2:1 ratio or moles of sulphur dioxide to moles of oxygen was sometimes reversed, but marks were allowed in this part and in part (b) for correct use of their incorrect number of moles of oxygen. Most were able to write the expression for K_p correctly in part (c), although some were penalised for the use of square brackets. Full marks were available for correct substitution of wrong partial pressure values from parts (a) and (b). No marks were allowed for the calculation if the expression for K_p was wrong, but a mark was allowed for units correctly consequential on their expression. In part (d), better candidates were able both to predict and explain that T_2 was the lower temperature using the information given that the reaction was exothermic.

In part (e) most correctly stated that the yield of SO_3 would increase, but only the better candidates remembered that K_p is independent of pressure changes.

Q16.

Many candidates gave a correct expression for the equilibrium constant, K_p , for the reaction given in part (a). Some, who gave correct indices, lost a mark as they included square brackets, which are specific used to indicate concentration, in their expression. Identifying the one change which would increase the rate of reaction and decrease the value of K_p proved challenging but part marks were awarded for answers which addressed either of the two required changes. Candidates who gave more than one change of condition were able to score one mark for a correct K_p expression. There were many vague answers to part (b)(i), some of which assumed there were other reactants present with the most common example being water in Reaction 2. By contrast, (b)(ii) was very well answered with many candidates scoring full marks. Most candidates now remember to use either kJ mol^{-1} or J mol^{-1} throughout these calculations but a small number still failed to do this. Consequential marks were awarded in each part of the calculation.

Q17.

This question was answered well by most candidates though part (c) proved to be a good discriminator. In part (a) Le Chatelier's principle was usually stated correctly. Candidates were expected to refer to an equilibrium and not just a 'system'. In parts (b) (i) and (ii) the question required candidates to 'use Le Chatelier's principle' to answer the questions. Some candidates lost marks because they restricted their answers to mentioning the direction of equilibrium-shift without mentioning that the increases in overall pressure and concentration of steam would be countered. In part (c) the cost of the energy required to

achieve a high temperature was often given correctly but a second reason was rarely correct. Common incorrect answers included erroneous references to a shift of the equilibrium to the left and hence a reduced yield of hydrogen at very high temperatures.

Q18.

This question was well answered by many candidates and full marks were common for the most able. In part (a) a few candidates were penalised for using square brackets, e.g. $[\text{SO}_2]$ meaning concentration of SO_2 instead of using p for partial pressure, and a very few wrote the expression for K_p upside down. Part (b) caused the most problems. Many candidates forgot that, in order to produce 0.75 mol of Cl_2 (and 0.75 mol of SO_2), 0.75 mol of SO_2Cl_2 would be used up leaving only 0.25 mol in the equilibrium mixture. Both of the marks in part (b) were lost for this error, but full marks could be gained subsequently in parts (c)(ii) and (d) for correct working in the calculations. In part (e) most were able to deduce and explain that an increase in temperature would cause K_p to increase. However there were many who thought, incorrectly, that pressure had a similar effect.

Q21.

This question also proved to be effective at discriminating between candidates and a wide range of marks were obtained. In part (a), most candidates gained the mark for mentioning equal rates for the forward and the backward reactions but weaker candidates failed to add that the concentrations of species remain constant at equilibrium. In part (b), most candidates stated that, on the right hand side of the equilibrium, there is a reduction in the number of moles of gas. Many, however, did not go on to explain, using the idea of Le Chatelier's Principle, why the equilibrium shifts to the right at high pressure. Part (c) was not answered well. In many cases responses by candidates were too vague to gain marks. For example, a statement saying that energy is expensive was not given credit. However, if a candidate explained that energy was used to drive the pumps that create pressure, a mark was awarded. Similarly, an answer suggesting that expensive equipment is required was not credited but candidates were awarded a mark if they gave a reason why plant or equipment is expensive if it is constructed to resist high pressure. Part (d) was answered well by most candidates. In part (e), a common error was to state that the activation energy is reduced at an increased temperature.

Q22.

This question was well answered. Many candidates in part (a) used Le Chatelier's principle to predict correctly the effect of increasing temperature and increasing pressure on the yield of hydrogen in the given equilibrium reaction. Candidates who made the wrong prediction were able to score one mark for each change if they stated correctly that the reaction was endothermic and that there was a reduction in the number of moles of gas in the reaction as written. Part (b) was also well answered but some candidates did not differentiate clearly between the equilibrium yield of hydrogen and the amount of hydrogen produced in a given time.

Q24.

Most candidates knew that the rates of forward and backward reactions are equal when a dynamic equilibrium is established but some candidates then stated incorrectly that at equilibrium the concentration of the reactants and products would also be equal. The effect of an increase in pressure on the given equilibrium, required in (a)(ii), was well known and most candidates were also able to deduce that the given reaction was endothermic. In part (a)(iv) candidates were required to explain why the equilibrium yield is unchanged when a catalyst is added. Answers such as 'a catalyst does not alter the equilibrium concentrations' were merely a restatement of the question and scored no

marks. The reasons why 450 °C and 20 MPa are compromise conditions for the production of ammonia from nitrogen and hydrogen were well known and part (b) was generally well answered.