AQA A-LEVEL CHEMISTRY · 7405

CHEMISTRY



EXAM QUESTION PACK

3.1.6 CHEMICAL EQUILIBRIA, LE CHATELIER'S PRINCIPLE AND KC

SCORE	PERCENTAGE
/552	%

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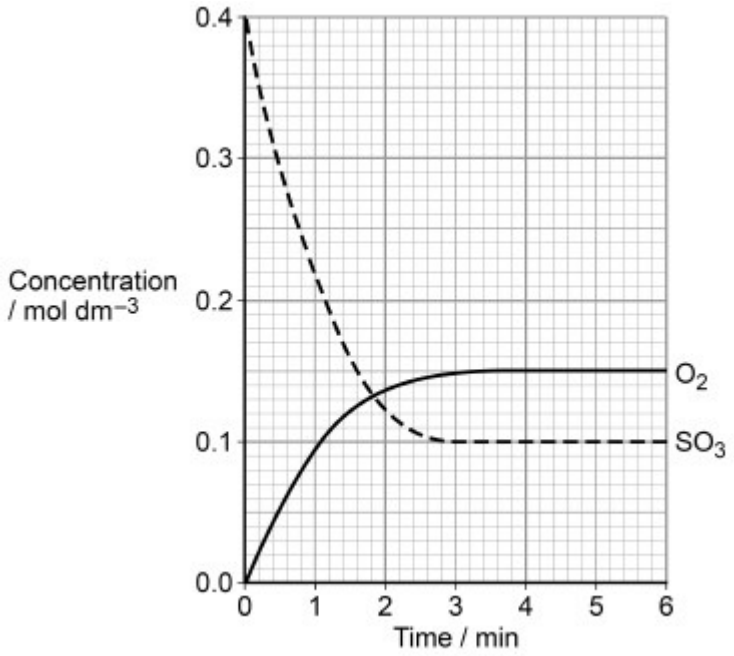
Q1.

This question is about equilibrium.

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

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

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}

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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.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(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.

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K_c _____ mol^{-2} dm^6

(3)

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

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

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 $K_c = 0.825$ mol^{-2} 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?

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -46 \text{ kJ mol}^{-1}$$

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)

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Q4.

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

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

(a) A beaker contained 40 cm^3 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 5.00×10^2 cm^3 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.

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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?

$$W(g) + X(g) \rightleftharpoons 2Y(g) + Z(g) \qquad \Delta H = +47 \text{ kJ mol}^{-1}$$

A High pressure and high temperature ⬭

B High pressure and low temperature ⬭

C Low pressure and high temperature ⬭

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D Low pressure and low temperature ⬭

(Total 1 mark)

Q6.

The forward reaction in this equilibrium is endothermic

$$COCl_2\,(g) \rightleftharpoons CO(g) + Cl_2\,(g)$$

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.

Figure 1

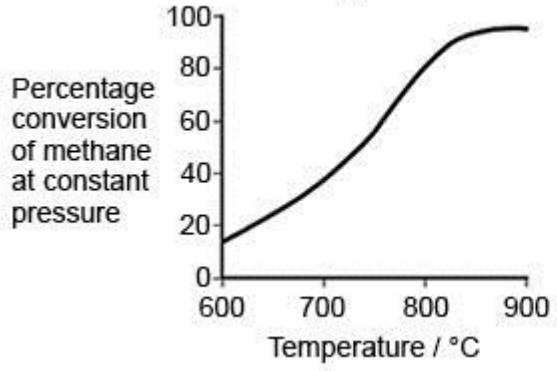
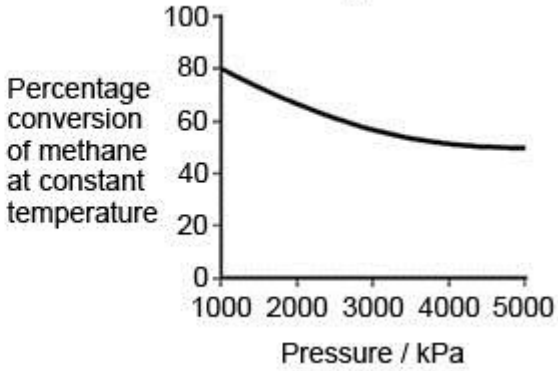


Figure 2



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

Explain your deductions.

_____

_____

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_____

_____

_____

_____

_____

_____

(6)

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

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

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)

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Q8.

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

$$M_2(g) + R(g) \rightleftharpoons RM_2(g) \quad \Delta H = +150 \text{ kJ mol}^{-1}$$

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 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.

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

(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.

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	$CH_4(g)$	$H_2O(g)$	$CO(g)$	$H_2(g)$
$\Delta_f H^\theta$ / kJ mol^{-1}	−75	−242	−111	0
Sθ / J K^{-1} 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.

ethanoic acid + ethanol $\rightleftharpoons$ ethyl ethanoate + water

(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.

_____

_____

_____

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(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 mol dm^{-3} sodium hydroxide solution required to react completely with the acids in the equilibrium mixture.

Volume = _____ cm^3

(6)

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(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.

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

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

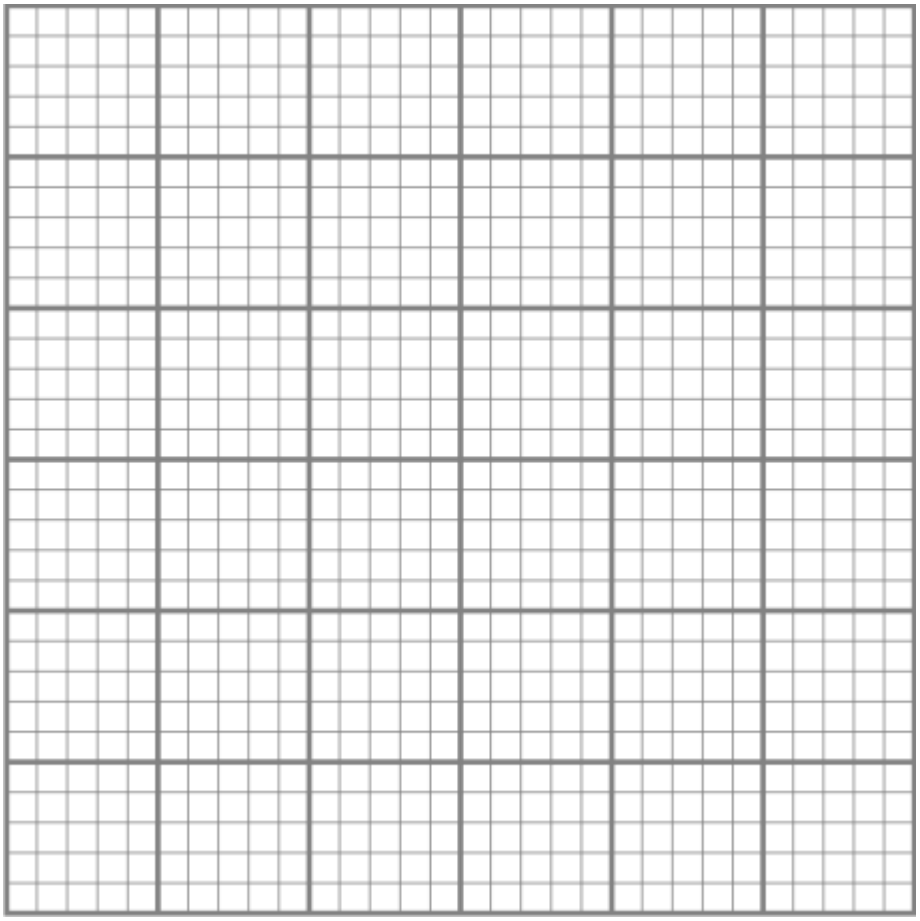
(a) Deduce the amounts of **X**(aq) and **Y**(aq) at equilibrium.

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

(2)

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

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(3)

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

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

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

(3)

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

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

Colour change_____

Reason _____

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_____

_____

_____

(3)

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

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

_____

_____

(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.

Reaction 1

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

Reaction 2

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

Polymer **Y**

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

Name _____

Functional group isomer

(2)

(b) Identify compound **X**.

_____

(1)

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(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.

_____

_____

_____

_____

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_____

_____

_____

(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.

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

Some mean bond enthalpies are shown in the following table.

Bond	C=O	C–H	C–O	O–H

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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.

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_____

_____

_____

(1)

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

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

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

K_p = _____ Units = _____

(7)

(Total 16 marks)

Q14.

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

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

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

Change	Effect on equilibrium	Effect on value of K_c

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		yield of $H_2(g)$		
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 NO_2 and N_2O_4 is allowed to reach equilibrium in a sealed gas syringe according to the following equation.

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

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

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

Which of the following statements is correct?

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

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

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

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

(Total 1 mark)

Q16.

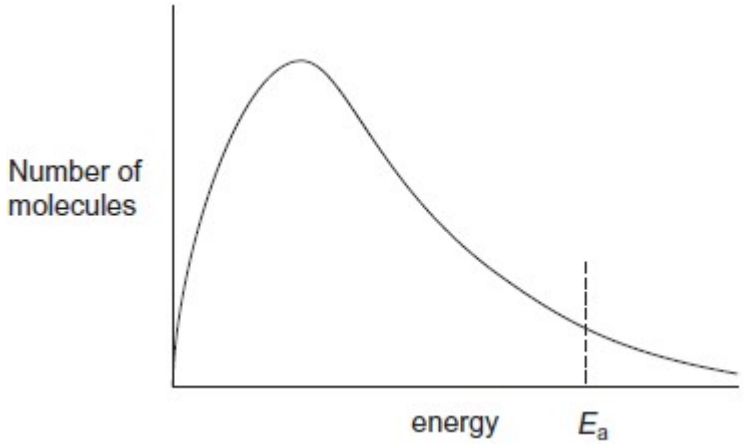
Methanol, for use as a fuel, can be produced by the reaction of carbon monoxide with hydrogen.

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

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

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

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

(1)

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

_____

_____

_____

_____

(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.

_____

_____

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_____

_____

_____

_____

(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

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

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

Temperature _____

Explanation _____

_____

_____

_____

_____

_____

_____

(3)

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

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

_____

_____

_____

_____

_____

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_____

(2)

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

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

_____

_____

_____

_____

_____

(2)

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

The equation for this reaction is

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

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

Effect _____

Explanation _____

_____

_____

_____

_____

(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}

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Enthalpy of hydration of magnesium ions = –1920 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.

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

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

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

Moles of **E** _____

Moles of **F** _____

(2)

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(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 ofvolume 1.50 dm^3. This equilibrium mixture contained 2.50 mol of **E**, 1.20 mol of **F** and 0.85 mol of **G**.

Calculate a value of K_c for the equilibrium at temperature T_1

_____

_____

_____

_____

_____

_____

(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 _____

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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

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

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

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

_____

_____

_____

_____

(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.

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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.

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

_____

_____

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(3)

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

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

_____

(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.

_____

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(1)

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

_____

(1)

(c) Consider the following equilibrium reactions.

				$\Delta H^{\ominus}$ / kJ mol^{-1}
P	$H_2(g) + I_2(g)$	⇌	$2HI(g)$	−10
Q	$CO_2(g) + 3H_2(g)$	⇌	$CH_3OH(g) + H_2O(g)$	−49
R	$N_2O_4(g)$	⇌	$2NO_2(g)$	+58
S	$N_2(g) + 3H_2(g)$	⇌	$2NH_3(g)$	−92
T	$C_2H_4(g) + H_2O(g)$	⇌	$CH_3CH_2OH(g)$	−42

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

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

☐

(1)

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

☐

(1)

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

☐

(1)

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

☐

(1)

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

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(1)

(Total 11 marks)

Q22.

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

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

	$CO_2(g)$	$H_2(g)$	$CH_3OH(g)$	$H_2O(g)$
$\Delta H_f^{\ominus}$/kJ mol^{-1}	– 394	0	– 201	– 242

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

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

_____

_____

_____

_____

_____

_____

_____

(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.

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

Effect on yield _____

Explanation _____

_____

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_____

_____

_____

_____

(3)

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

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

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

Effect on yield _____

Explanation _____

_____

_____

_____

_____

_____

(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.

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

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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 dm^3. The mixture was left to reach equilibrium as shown by the following equation.

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

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

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

Moles of hydrogen _____

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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)

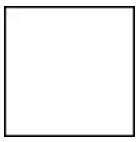
(b) This question concerns changes made to the four equilibria shown in parts (b)(i) to (b)(iv).
In each case, use the information in the table to help you choose from the letters **A** to **E** the best description of what happens as a result of the change described. Write your answer in the box.

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

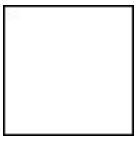
(i) Change: increase the temperature of the equilibrium mixture at constant pressure.

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

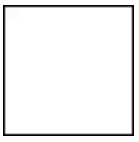
(1)

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

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

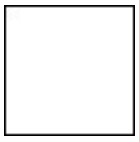
(1)

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

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

(1)

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

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

(1)

(Total 10 marks)

Q24.

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

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

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

Feature 1 _____

_____

_____

_____

Feature 2 _____

_____

_____

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_____

(2)

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

_____

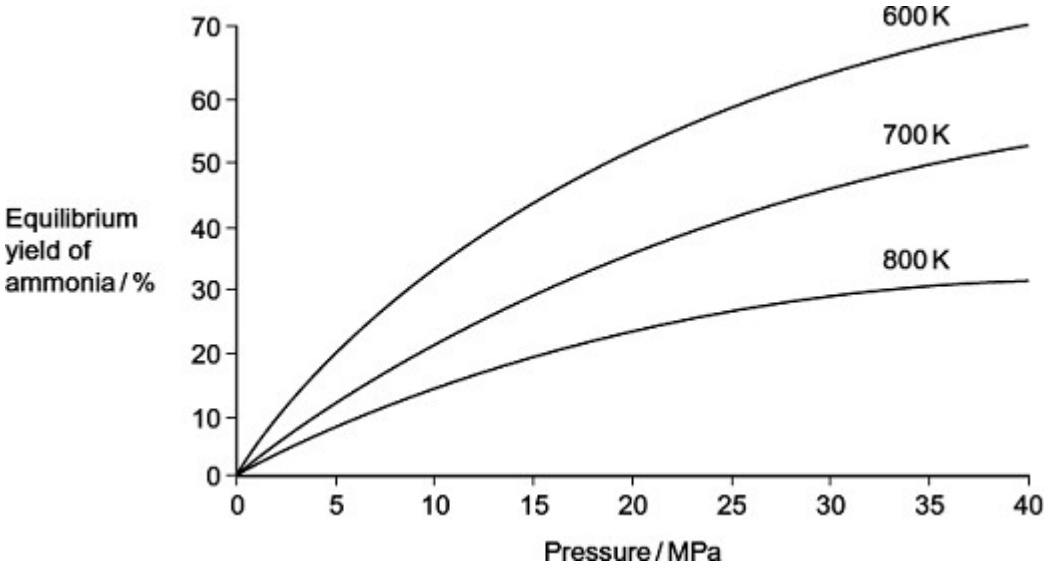
_____

_____

_____

(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.

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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 (NO_2) was prepared by the reaction of copper with concentrated nitric acid.

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

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

(1)

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

HNO_3 _____

NO_2 _____

(2)

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

_____

(1)

(b) The following equilibrium is established between colourless dinitrogen tetraoxide

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gas (N_2O_4) and dark brown nitrogen dioxide gas.

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

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

Feature 1 _____

_____

_____

_____

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)

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Q26.

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

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

(a) In an experiment, 8.0mol of sulfur trioxide were placed in a container of volume 12.0 dm^3 and allowed to come to equilibrium.
At temperature T_1 there were 1.4 mol of oxygen in the equilibrium mixture.

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

Amount of sulfur trioxide _____

Amount of sulfur dioxide _____

(2)

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

_____

_____

(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

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_____

(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.

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

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

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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

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

(1)

(Total 12 marks)

Q28.

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

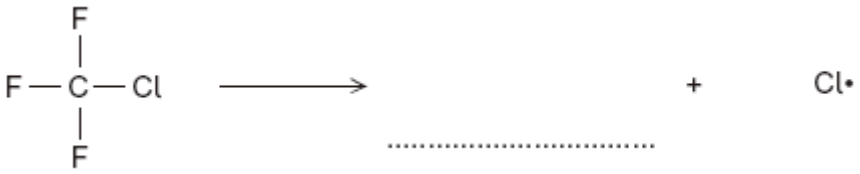
(a) (i) Give the IUPAC name of CF_3Cl

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_____

(1)

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



(1)

(iii) State what the • represents in Cl•

_____

(1)

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

Equation 1 _____

Equation 2 _____

(2)

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

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

(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.

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_____

_____

(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.

$$.....FeS_2 + ...O_2 \rightarrow .....Fe_2O_3 + ...SO_2$$

(1)

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

SO_2 _____

FeS_2 _____

(2)

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

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

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

Effect of increase in temperature on yield _____

Explanation _____

_____

_____

(3)

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

Equation _____

Role of the carbon monoxide _____

(2)

(Total 8 marks)

Q30.

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

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

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

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

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

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

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

Extraction process 3
The modern process uses the electrolysis of aqueous solutions of very pure zinc sulfate. The first step in this process is the same as the first step in Extraction process **2**. The second step uses sulfuric acid made from the SO_2 collected in the first step. The third step involves the electrolysis of zinc sulfate solution to form pure zinc.

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

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

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

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

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

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

_____

_____

_____

_____

_____

_____

(3)

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

_____

_____

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(3)

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

(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.

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_____

_____

(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.

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

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

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

Moles of methane _____

Moles of steam _____

Moles of hydrogen _____

(3)

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

_____

_____

(1)

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

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

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

_____

_____

_____

(1)

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

Calculation _____

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_____

_____

_____

Units of K_c _____

(3)

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

Effect on amount of hydrogen _____

Explanation _____

_____

_____

_____

(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.

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_____

_____

(1)

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



oleic acid stearic acid

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

_____

(1)

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

_____

(1)

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

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

(i) State Le Chatelier's principle.

_____

_____

(1)

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

_____

_____

_____

_____

(2)

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

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

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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.

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

(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.

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_____

(1)

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

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

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

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

(i) 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**

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

Extraction Process **2**

The reaction of solid potassium bromide with concentrated sulfuric acid.

Extraction Process **3**

The reaction of aqueous potassium bromide with chlorine gas.

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

_____

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(3)

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

(5)

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

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

Give the oxidation state of bromine in HBr and in HBrO

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

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_____

_____

_____

(4)

(Total 12 marks)

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Q1.

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

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

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

Low temperature _____

_____

_____

High pressure _____

_____

_____

(4)

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

(i) Justify the use of a compromise temperature.

_____

_____

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

_____

(3)

(Total 7 marks)

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

_____

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(3)

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

(8)

(Total 11 marks)

Q3.

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

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

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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*.

_____

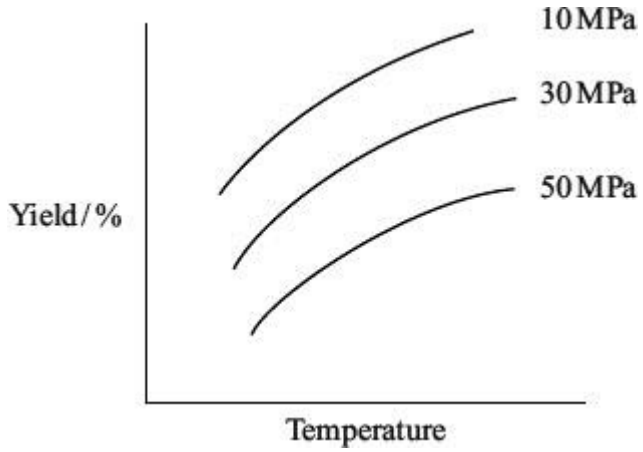
(5)

(Total 11 marks)

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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 dm^3, the following equilibrium was established at 700 K.

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

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

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

Number of moles of iodine _____

Number of moles of hydrogen iodide _____

_____

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

_____

_____

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

_____

_____

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

_____

_____

_____

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

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

_____

_____

(7)

(Total 13 marks)

Q5.

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

A increasing the temperature and increasing the pressure

B increasing the temperature and decreasing the pressure

C decreasing the temperature and increasing the pressure

D decreasing the temperature and decreasing the pressure

(Total 1 mark)

Q6.

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

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

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

_____

(1)

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

Effect of an increase in pressure on the yield _____

Explanation _____

_____

_____

_____

_____

Effect of an increase in temperature on the yield _____

Explanation _____

_____

_____

(6)

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

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

NO _____

NO_3^- _____

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

_____

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

_____

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

_____

(5)

(Total 12 marks)

Q7.

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

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

(i) Write an equation for the forward reaction.

_____

(ii) Deduce the units of K_c

_____

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

_____

(3)

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

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

The equilibrium mixture was found to contain 0.180 mol of N_2O_4

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

_____

_____

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

_____

_____

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

Expression for K_c _____

_____

Calculation _____

_____

_____

_____

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

Effect on the position of equilibrium _____

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Effect on the value of K_c _____

(9)

(Total 12 marks)

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.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H^o = +210$ kJ mol^{-1}

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.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$

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.

_____

_____

_____

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(8)

(Total 14 marks)

Q9.

(a) State and explain the effect of a catalyst on the rate and on the equilibrium yield in a reversible reaction.

(5)

(b) Explain the terms *heterogeneous* and *active sites* as applied to a catalyst. Give **two** reasons why a ceramic support is used for the catalyst in catalytic converters in cars. Explain how lead poisons this catalyst.

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(7)

(c) In aqueous solution, Fe^{2+} ions act as a homogeneous catalyst in the reaction between I^- and $S_2O_8^{2-}$ ions. Give **one** reason why the reaction is slow in the absence of a catalyst. Write equations to show how Fe^{2+} ions act as a catalyst for this reaction.

(5)

(Total 17 marks)

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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

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} = -11 \text{ kJ mol}^{-1}, \qquad \Delta S^{\ominus} = +20 \text{ J K}^{-1} \text{ mol}^{-1}$$

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

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

_____

_____

_____

_____

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(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.

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

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

(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*.

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_____

(3)

(c) The standard enthalpies of combustion of carbon monoxide and of hydrogen are –283 kJ mol^{-1} and –286 kJ mol^{-1}, respectively. Use these data and the enthalpy change for *Stage 2* to calculate a value for the standard enthalpy of combustion of gaseous methanol.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

(3)

(Total 15 marks)

Q13.

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

$$2CHClF_2(g) \rightleftharpoons C_2F_4(g) + 2HCl(g) \qquad \Delta H^{o} = +128 kJ\ mol^{-1}$$

(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 _____

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(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.

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

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)

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(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

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

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

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(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)

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(Total 13 marks)

Q16.

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

$2W(g) + X(g) \rightleftharpoons 3Y(g) + 2Z(g) \qquad \Delta H = -200 \text{ kJ mol}^{-1}$

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.

(7)

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

Reaction 1

$CH_3COOH(l) + C_2H_5OH(l) \rightleftharpoons CH_3COOC_2H_5(l) + H_2O(l) \qquad \Delta H^{\ominus} = -2.0 \text{ kJ mol}^{-1}$

Reaction 2

$CH_3COCl(l) + C_2H_5OH(l) \rightarrow CH_3COOC_2H_5(l) + HCl(g) \qquad \Delta H^{\ominus} = -21.6 \text{ kJ mol}^{-1}$

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

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_____

(2)

(ii) Use the information given above and the data below to calculate values for the standard entropy change, $\Delta S^{\ominus}$, and the standard free-energy change, $\Delta G^{\ominus}$, for **Reaction 2** at 298 K.

	$CH_3COCl(l)$	$C_2H_5OH(l)$	$CH_3COOC_2H_5(l)$	$HCl(g)$
$S^{\ominus}$/JK^1mol^1	201	161	259	187

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

(6)

(Total 15 marks)

Q17.

Hydrogen is produced on an industrial scale from methane as shown by the equation below.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus} = +205 \text{ kJ mol}^{-1}$$

(a) State Le Chatelier's principle.

_____

_____

(1)

(b) The following changes are made to this reaction at equilibrium. In each case, predict what would happen to the yield of hydrogen from a given amount of methane. Use Le Chatelier's principle to explain your answer.

(i) The overall pressure is increased.

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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.

$$SO_2Cl_2(g) \rightleftharpoons SO_2(g) + Cl_2(g) \qquad \Delta H^{\ominus} = +93 \text{ kJ mol}^{-1}$$

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.

_____

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_____

(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.

Reaction 1 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ $\Delta H^{\ominus} = -909$ kJ mol^{-1}

Reaction 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H^{\ominus} = -115$ kJ mol^{-1}

Reaction 3 $3NO_2(g) + H_2O(l) \rightleftharpoons 2HNO_3(aq) + NO(g)$ $\Delta H^{\ominus} = -117$ kJ mol^{-1}

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

A the pressure is increased.

B the pressure is decreased.

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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.

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

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.

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

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

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

_____

_____

(2)

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

_____

_____

(2)

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

Reason 1 _____

Reason 2 _____

_____

(2)

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

Effect _____

Explanation _____

_____

_____

(3)

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

_____

(1)

(Total 10 marks)

Q22.

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

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

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

_____

_____

_____

_____

_____

_____

_____

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_____

_____

_____

_____

(6)

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

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time.

_____

_____

_____

_____

_____

_____

_____

_____

(4)

(Total 10 marks)

Q23.

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

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

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

Thermodynamic data are given below.

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

Which one of the following statements applies to this equilibrium?

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

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

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

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

(Total 1 mark)

Q24.

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

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

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

Rates _____

Concentrations _____

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

Equilibrium yield _____

Explanation _____

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

_____

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

_____

_____

(8)

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

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

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

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

_____

_____

_____

_____

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

_____

_____

_____

_____

(6)

(Total 14 marks)

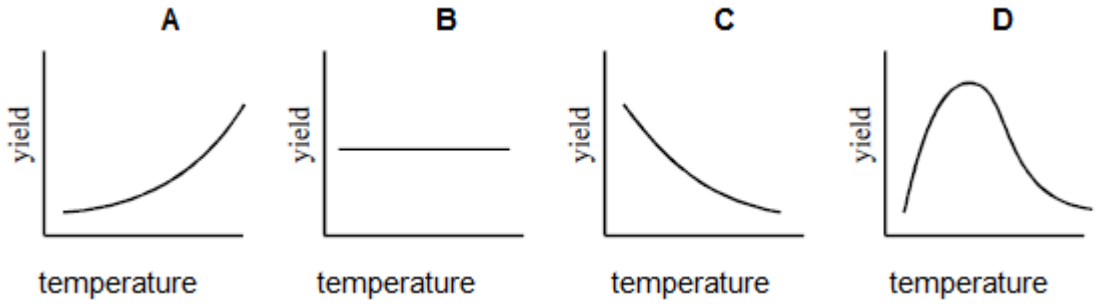
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Q25.

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

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

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



(Total 1 mark)

Q26.

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

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

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

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

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

C Less ozone is formed at high pressure.

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

(Total 1 mark)

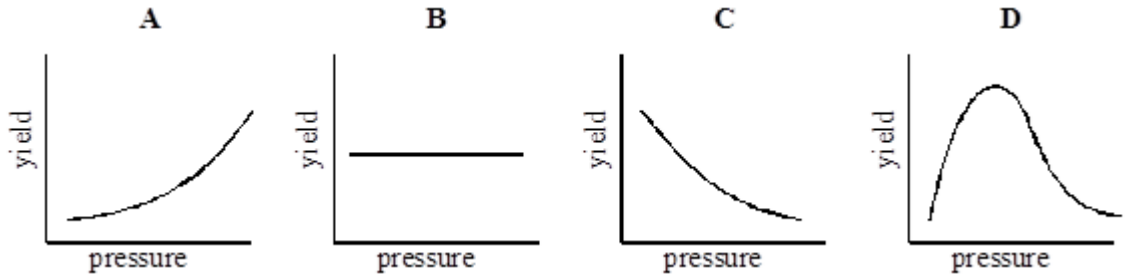
Q27.

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

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

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

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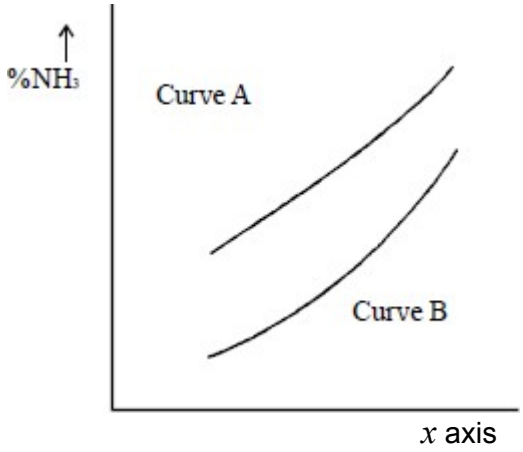


(Total 1 mark)

Q28.

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

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



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

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

(Total 1 mark)

Q29.

A weak acid HA dissociates in aqueous solution as shown below

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

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

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A addition of a little aqueous sodium hydroxide solution

B raising the temperature of the solution

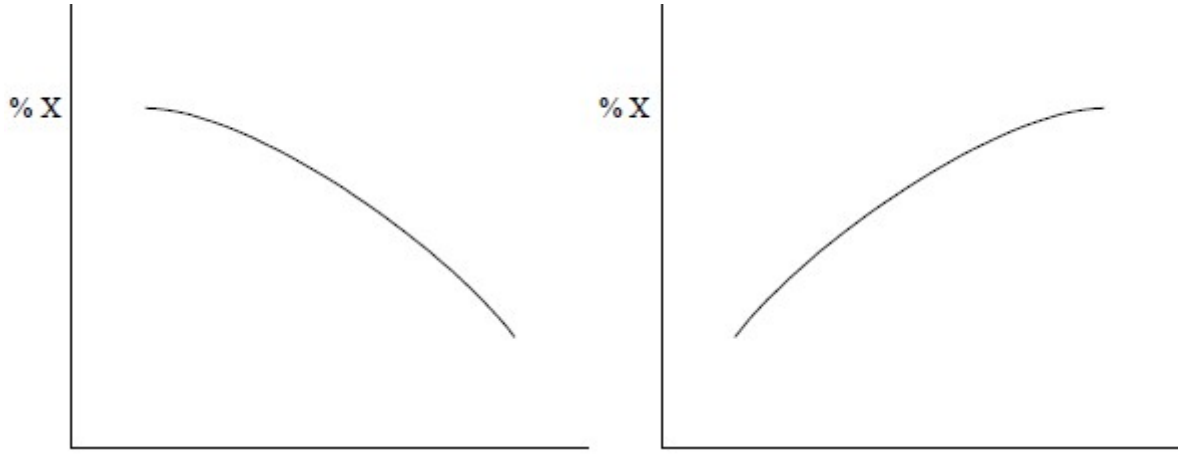
C dissolving a little of the sodium salt, NaA, in the solution

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.



Temperature 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.

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

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

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

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

C Increase in pressure causes an increase in the concentration of chlorine atoms

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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)

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