1. Carbon monoxide reacts with steam in the following reaction equation:

$$CO(g) + H_2O\ (g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -40\ kJ\ mol^{-1}$$
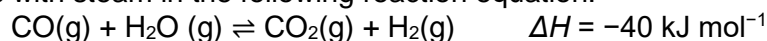
Which change will shift the position of equilibrium to the right hand side of the equation?

    A. decrease in pressure
    B. increase in pressure
    C. decrease in temperature
    D. increase in temperature

Your answer ☐

[1]

2. Which statement is **not** correct for a system in dynamic equilibrium?

    A.   The concentrations of products and reactants are the same.
    B.   The equilibrium can be achieved from both sides.
    C.   The rate of the forward reaction is equal to the rate of the reverse reaction.
    D.   The system is closed.
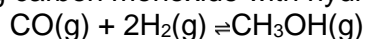
Your answer ☐

[1]

3(a). This question looks at equilibrium reactions used by industry for preparing important chemicals.

Methanol can be manufactured by reacting carbon monoxide with hydrogen.

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

An equilibrium mixture contains 3.10×10^{-3} mol dm^{-3} CO, 2.40×10^{-3} mol dm^{-3} H$_2$ and an unknown concentration of CH$_3$OH.

   i.   Write an expression for the equilibrium constant, K_c.

[1]

ii.   The value of K_c for this equilibrium is 14.6 dm^6 mol^{-2}.

Determine the equilibrium concentration methanol, CH$_3$OH(g).

Give your answer to **three** significant figures.

equilibrium concentration of CH$_3$OH(g) = ... dm^6 mol^{-2} **[2]**

(b). Ammonia is used in the manufacture of nitric acid. The first stage of this process is a dynamic equilibrium.
$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$
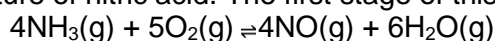
i.   When the temperature is increased, K_c for this reaction decreases.

State the effect, if any, on the equilibrium yield of NO in this reaction.

Explain your answer.

_____

[1]

ii.   Which element has been oxidised and which element has been reduced in the reaction?

Include signs with the oxidation numbers.

Oxidised ....   Oxidation number change from .... to ....
Reduced ....   Oxidation number change from .... to ....

[2]

4. Chloroethene, $CH_2=CHCl$, is prepared in the presence of a solid catalyst using the equilibrium reaction below.

$$CH_2ClCH_2Cl(g) \rightleftharpoons CH_2=CHCl(g) + HCl(g) \quad \Delta H = +51 \text{ kJ mol}^{-1}$$

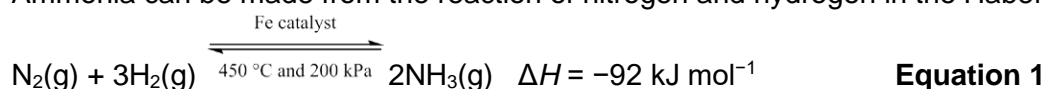Which change would result in an increased equilibrium yield of chloroethene?

    A. increasing the pressure
    B. increasing the surface area of the catalyst
    C. increasing the temperature
    D. use of a homogeneous catalyst

Your answer ☐

[1]

5. Ammonia is a gas with covalently-bonded molecules consisting of nitrogen and hydrogen atoms.

Ammonia can be made from the reaction of nitrogen and hydrogen in the Haber process.

$$N_2(g) + 3H_2(g) \underset{450\,°C \text{ and } 200 \text{ kPa}}{\overset{Fe \text{ catalyst}}{\rightleftharpoons}} 2NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1} \qquad \textbf{Equation 1}$$

What effect will increasing the temperature have on the composition of the equilibrium mixture **and** on the value of the equilibrium constant?

Explain your answer.

_____

_____

_____

[2]

6(a). Ammonia, NH_3, is manufactured by the chemical industry from nitrogen and hydrogen gases.

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

- An iron catalyst is used which provides several benefits for sustainability.
- The chemical industry uses operational conditions that are different from the conditions predicted to give a maximum equilibrium yield.

Use your understanding of Chemistry to explain the above statements.

Your response should be well-developed, showing a line of reasoning which is clear and logically structured.

_____

_____

_____

_____

_____

[6]

(b). The chemist adds more nitrogen to the equilibrium mixture in **(b).**

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

The temperature is kept at 300 K and the volume at 5.00 dm^3.

The chemist predicts that the addition of nitrogen will increase the proportion of H$_2$(g) that reacts.

i.   Explain whether the chemist's prediction is correct.

_____

_____

_____

[3]

ii.   Suggest why the chemist is more concerned with increasing the proportion of H$_2$ that reacts rather than the proportion of N$_2$ that reacts.
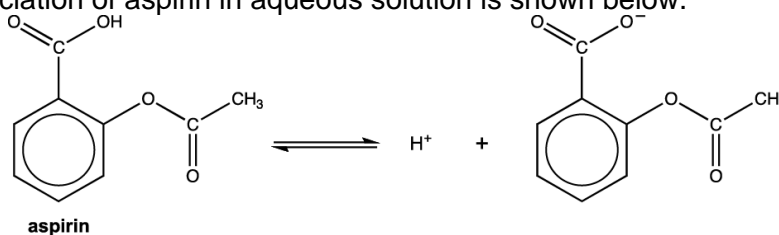
_____

_____

[1]

7. The following reaction is used in industry to make sulfur trioxide gas, SO_3.

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

This preparation is carried out in the presence of a catalyst.

* Explain the conditions of temperature and pressure that could be used to obtain the maximum equilibrium yield of sulfur trioxide.
Discuss the importance of a compromise between equilibrium yield and reaction rate when deciding the operational conditions for this process.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

8. Aspirin is a weak acid with a pK_a value of 3.40 and a solubility in water of 1.00×10^{-2} g cm^{-3} at body temperature (37 °C).

The equation for the dissociation of aspirin in aqueous solution is shown below.

aspirin

i.   Calculate the pH of a saturated solution of aspirin in water at body temperature.

pH = ... **[4]**

ii.   'Soluble aspirin' is usually sold as the sodium or calcium salt of aspirin.

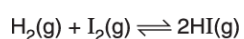Suggest why salts of aspirin are more soluble than aspirin in water.

_____

_____

[1]

iii.   The stomach contains hydrochloric acid at a pH of about 1–3.

Explain why swallowing soluble aspirin may lead to irritation of the stomach lining.

_____

_____

_____

[2]

9. A student mixes hydrogen and iodine at room temperature and pressure and allows the mixture to reach dynamic equilibrium.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9 \text{ kJ mol}^{-1} \qquad \textbf{equilibrium 3.1}$$

i.   A closed system is required for dynamic equilibrium to be established.

State **one** other feature of this dynamic equilibrium.

_____

[1]

ii.   The student heats the equilibrium mixture keeping the volume constant.

Predict how the composition of the equilibrium mixture changes on heating.

Explain your answer.

_____

_____

_____

[2]

iii.   Predict and explain what effect, if any, an increase in the pressure would have on the position of the equilibrium.

effect

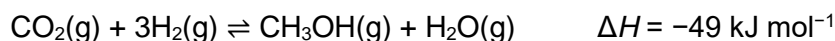...

explanation

....

[1]

10(a). State le Chatelier's principle.

_____

_____

[1]

(b). Methanol, CH_3OH, is an important feedstock for the chemical industry.

In the manufacture of methanol, carbon dioxide and hydrogen are reacted together in the reversible reaction shown below.

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

High pressures and low temperatures would give a maximum equilibrium yield of methanol.

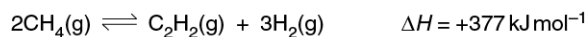i.   Explain this statement in terms of le Chatelier's principle.

_____

_____

_____

_____

_____

_____

[3]

ii.   Explain why the actual conditions used by the chemical industry might be different.

_____

_____

_____

[2]

11(a). Ethyne gas, C_2H_2, is manufactured in large quantities for a variety of uses.

Much of this ethyne is manufactured from methane as shown in the equation below.

$$2CH_4(g) \rightleftharpoons C_2H_2(g) + 3H_2(g) \qquad \Delta H = +377 \, kJ \, mol^{-1}$$

Write an expression for K_c for this equilibrium.

[1]

(b). A research chemist investigates how to improve the synthesis of ethyne from methane at a high temperature.

- The chemist adds CH_4 to a 4.00 dm^3 container.
- The chemist heats the container and allows equilibrium to be reached at constant temperature. The total gas volume does not change.
- The equilibrium mixture contains 9.36×10^{-2} mol CH_4 and 0.168 mol C_2H_2.

i. Calculate the amount, in mol, of H_2 in the equilibrium mixture.

amount of H_2 = ... mol **[1]**

ii. Calculate the equilibrium constant, K_c, at this temperature, including units.

Give your answer to **three** significant figures.

K_c = ... units .... **[3]**

iii. Calculate the amount, in mol, of CH_4 that the chemist originally added to the container.

amount of CH_4 = ... mol **[1]**

(c). The chemist repeats the experiment three times.
In each experiment the chemist makes **one** change but uses the **same** initial amount of CH_4.

Complete the table to show the predicted effect of each change compared with the original experiment.

Only use the words **greater, smaller** or **same**.

Change	K_c	Equilibrium amount of $C_2H_2(g)$ / mol	Initial rate
The container is heated at constant pressure			
A smaller container is used			
A catalyst is added to CH_4 at the start			

[3]

12(a). Sulfur trioxide, SO_3, is used for the industrial manufacture of sulfuric acid.

SO_3 is produced by reacting sulfur dioxide, SO_2, and oxygen, O_2, as shown in **equilibrium 25.1** below.

Equilibrium 25.1 $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H = -197$ kJ mol^{-1}

Le Chatelier' s principle can be used to predict how different conditions affect the equilibrium position.

- Using le Chatelier' s principle, show that a low temperature and a high pressure should be used to obtain a maximum **equilibrium** yield of SO_3.
- Explain why the actual conditions used in industry may be different from the conditions needed for a maximum equilibrium yield.

[5]

(b). Under certain conditions, K_c for **equilibrium 25.1** is 0.160 dm^3 mol^{-1}.

The equilibrium mixture under these conditions has the following concentrations of SO_2 and O_2.

Species	Equilibrium concentration / mol dm^{-3}
SO_2	2.00
O_2	1.20

- Using the value of K_c, explain whether the equilibrium position will be towards the right or towards the left under these conditions.
- Calculate the concentration of SO_3 in the equilibrium mixture.

_____

_____

_____

_____

_____

_____

_____

_____

[4]

13(a). This question is about equilibrium and catalysts.

The equilibrium between NO_2 and N_2O_4 gases is set up in a gas syringe at room temperature.
The two gases are different in appearance.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -58 \, kJ \, mol^{-1}$$
$$\text{brown} \qquad \text{colourless}$$
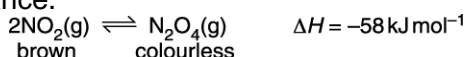
Using le Chatelier's principle, predict and explain how the following changes would affect the appearance of the equilibrium mixture.

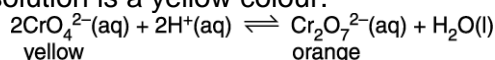i. The gas mixture is compressed by pushing in the plunger of the gas syringe.

_____

_____

[2]

ii. The gas syringe is placed in a warm water bath.

_____

_____

[2]

(b). When potassium chromate(VI), K_2CrO_4, is dissolved in water an equilibrium is set up. The position of equilibrium is well to the left and the solution is a yellow colour.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
$$\text{yellow} \qquad\qquad\qquad \text{orange}$$

The addition of aqueous acid turns the solution an orange colour.
Aqueous alkali is then added and the solution turns a yellow colour.

Explain these observations in terms of le Chatelier's principle.

_____

_____

_____

_____

_____

_____

[2]

14. Hydrogen iodide, HI(g), is formed in the reversible reaction below.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad\qquad \Delta H = -9 \text{ kJ mol}^{-1}$$

Which statement(s) is/are correct?

    1   This is a redox reaction.
    2   The equilibrium yield of HI(g) is changed by increasing the pressure.
    3   The equilibrium yield of HI(g) increases as the temperature is increased.

A   1, 2 and 3
B   Only 1 and 2
C   Only 2 and 3
D   Only 1

Your answer ☐

[1]

15. When heated with dilute acid, $MnO_4^{2-}(aq)$ ions disproportionate into MnO_4^- and MnO_2.

    i.   Balance the equation for this disproportionation reaction.

        ...... $MnO_4^{2-}(aq)$ + ... $H^+(aq)$ $\rightleftharpoons$ ...... $MnO_4^-(aq)$ + ... $MnO_2(s)$ + ... $H_2O(l)$
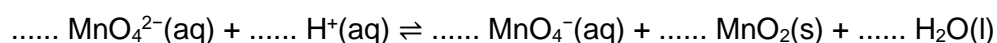
[1]

ii.   Although MnO_4^{2-}(aq) ions disproportionate in acidic conditions, MnO_4^{2-}(aq) ions are stable under alkaline solutions.

Explain this difference in stability, in terms of equilibrium.

_____

_____

_____

_____

[2]

16. When concentrated sulfuric acid is added to water, dissociation takes place in two stages.

Stage 1: $H_2SO_4 \rightarrow H^+ + HSO_4^-$

Stage 2: $HSO_4^- \rightleftharpoons H^+ + SO_4^{2-}$

i.   0.100 mol dm^{-3} sulfuric acid has a pH of 0.96.

Explain this observation. Your answer should include a calculation.

_____

_____

_____

_____

_____

[3]

ii.   A student adds an excess of aqueous sodium carbonate to dilute sulfuric acid.
- Predict what the student would observe.
- Explain what happens to the equilibrium in **Stage 2** as the aqueous sodium carbonate is added.

Observation

....

Explanation

....

_____

_____

[2]

17. The reversible reaction below is allowed to reach equilibrium.

$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\quad\quad\quad\quad\quad \Delta H = -9.4$ kJ mol^{-1}

Which change in conditions would be expected to shift the equilibrium position towards the products?

A decrease the pressure
B decrease the temperature
C increase the pressure
D increase the temperature

Your answer [   ] **[1]**

18. A chemist investigates the equilibrium that produces methanol:

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH (g)$
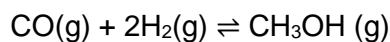
The chemist mixes CO(g) with $H_2(g)$ and leaves the mixture to react until equilibrium is reached.
The equilibrium mixture is analysed and found to contain the following concentrations.

Substance	Concentration/mol dm^{-3}
CO (g)	0.310
H_2(g)	0.240
CH_3OH(g)	0.260

Calculate the numerical value of K_c for this equilibrium.

Give your answer to an **appropriate** number of significant figures.

K_c = ... dm^6 mol^{-2} **[2]**

19(a). This question is about equilibrium reactions.

Hydrogen gas is manufactured by the chemical industry using the reaction of methane and steam. This is a reversible reaction, shown in **equilibrium 20.1** below.

equilibrium 20.1 $\qquad$ $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\qquad$ $\Delta H = +210$ kJ mol^{-1}
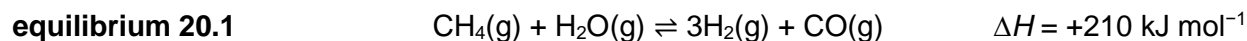
Explain, in terms of le Chatelier's principle, the conditions of pressure and temperature for a maximum yield of hydrogen from **equilibrium 20.1**, and explain why the operational conditions used by the chemical industry may be different.

_____

_____

_____

_____

_____

_____

_____

_____

[4]

(b). A chemist investigates the equilibrium reaction between sulfur dioxide, oxygen, and sulfur trioxide, shown below.

$\quad$ $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$
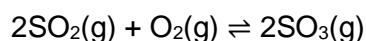
- The chemist mixes together SO_2 and O_2 with a catalyst.
- The chemist compresses the gas mixture to a volume of 400 cm^3.
- The mixture is heated to a constant temperature and is allowed to reach equilibrium without changing the total gas volume.

The equilibrium mixture contains 0.0540 mol SO_2 and 0.0270 mol O_2.

At the temperature used, the numerical value for K_c is 3.045×10^4 dm^3 mol^{-1}.

i. Write the expression for K_c and the units of K_c for this equilibrium.
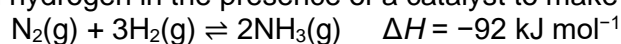
[2]

ii. Determine the amount, in mol, of SO_3 in the equilibrium mixture at this temperature.

Give your final answer to an **appropriate** number of significant figures.

Show all your working.

equilibrium amount of SO_3 _____ mol **[4]**

20. Nitrogen can be reacted with hydrogen in the presence of a catalyst to make ammonia in the Haber process.

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

A mixture of N_2 and H_2 was left to react until it reached equilibrium. The equilibrium mixture had the following composition:

N_2	1.20 mol dm^{-3}
H_2	2.00 mol dm^{-3}
NH_3	0.877 mol dm^{-3}

i. Calculate a value for K_c for this equilibrium.

$K_c = $ ....dm^6 mol^{-2} **[3]**

ii.   Explain how the following changes would affect the amount of NH₃ present in the equilibrium mixture.

Use of a catalyst:

_____

_____

A higher temperature:

_____

_____

[3]

21(a). The reaction of ammonia, NH₃, with oxygen to form nitrogen monoxide, NO, is an important industrial process.

The equation for this reaction is shown in **equilibrium 4.1** below.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \quad \Delta H = -905 \text{ kJ mol}^{-1}$$ **Equilibrium 4.1**

Write an expression for the equilibrium constant, K_c, in **equilibrium 4.1**.

[1]

(b). Predict the conditions of temperature and pressure for a maximum equilibrium yield of nitrogen monoxide in **equilibrium 4.1**.

*   Explain your prediction in terms of le Chatelier's principle.
*   State and explain how these conditions could be changed to achieve a compromise between equilibrium yield, rate and other operational factors.

_____

_____

_____

_____

_____

_____

_____

_____

_____

[5]

22(a). Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **equilibrium 18.1**.
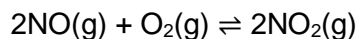
$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \textbf{Equilibrium 18.1}$$

Write an expression for K_c for this equilibrium and state the units.

$K_c =$

Units = ...   **[2]**

(b). A chemist mixes together nitrogen and oxygen and pressurises the gases so that their total gas volume is 4.0 dm^3.

- The mixture is allowed to reach equilibrium at constant temperature and volume.
- The equilibrium mixture contains 0.40 mol NO and 0.80 mol O_2.
- Under these conditions, the numerical value of K_c is 45.

Calculate the amount, in mol, of NO_2 in the equilibrium mixture.

amount of NO_2 = ... mol **[4]**

(c). The values of K_p for **equilibrium 18.1** at 298 K and 1000 K are shown below.
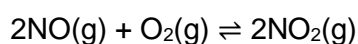
$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \textbf{Equilibrium 18.1}$$

Temperature / K	K_p / atm^{-1}
298	$K_p = 2.19 \times 10^{12}$
1000	$Kp = 2.03 \times 10^{-1}$

i.   Predict, with a reason, whether the forward reaction is exothermic or endothermic.

_____

[1]

ii.   The chemist increases the pressure of the equilibrium mixture at the same temperature.

State, and explain in terms of K_p, how you would expect the equilibrium position to change.

_____

_____

_____

_____

_____

_____

[3]

23. Cobalt(II) forms complex ions with water ligands and with chloride ligands.

*   With water ligands, cobalt(II) forms a pink octahedral complex ion, $[Co(H_2O)_6]^{2+}$.
*   With chloride ligands, cobalt(II) forms a blue tetrahedral complex ion.

A student dissolves cobalt(II) sulfate in water in a boiling tube. A pink solution forms.

Experiment 1
The student places the boiling tube in a water bath at 100 °C.
Concentrated hydrochloric acid is added dropwise.
The colour of the solution changes from pink to blue.

Experiment 2
The student places the boiling tube from **experiment 1** in an ice/water bath at 0 °C.
The colour of the solution changes from blue to pink.

i. Write the equilibrium equation for the reaction that takes place when the colour of the solution changes.

[1]

ii. Explain the observations and predict whether the formation of the blue colour is exothermic or endothermic.

_____

_____

_____

_____

[2]

24. The reversible reaction below is at equilibrium.
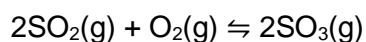
$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -197 \text{ kJ mol}^{-1}$$

Which changes in pressure and temperature would shift the equilibrium position towards the products?

	Pressure	Temperature
A	Decrease	Decrease
B	Decrease	Increase
C	Increase	Decrease
D	Increase	Increase

Your answer ☐ [1]

25. The reversible reaction below is at equilibrium.
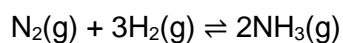
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

What is the expression for K_c?

A $\dfrac{[N_2(g)] \, [H_2(g)]^3}{[NH_3(g)]^2}$

B $\dfrac{[NH_3(g)]^2}{[N_2(g)] \, [H_2(g)]^3}$

C $\dfrac{[N_2(g)] + 3[H_2(g)]}{2[NH_3(g)]}$

D $\dfrac{2[NH_3(g)]}{[N_2(g)] + 3[H_2(g)]}$

Your answer [ ] **[1]**

26. A catalyst is added to a system in equilibrium.

What is the effect on the rates of the forward and reverse reactions?

A	There is no effect on the rate in either direction.
B	Both rates increase by the same factor.
C	The rate in the forward direction increases by a greater factor than the reverse direction.
D	The rate in the reverse direction increases by a greater factor than the forward direction.

Your answer [ ] **[1]**

27. This question is about ammonia, NH_3.

In industry, ammonia is made from nitrogen and hydrogen. This is a reversible reaction, as shown in **equilibrium 24.1** below.
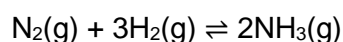
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1} \qquad \textbf{Equilibrium 24.1}$$

i.   Explain how le Chatelier's principle can be used to predict the conditions of temperature and pressure for a maximum **equilibrium** yield of ammonia.

_____

_____

_____

_____

_____

_____

_____

[4]

ii.   Using certain conditions, **equilibrium 24.1** has the equilibrium concentrations in the table.

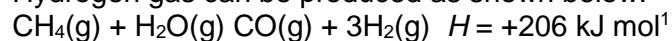| Substance	Equilibrium concentration / mol dm^{-3}
$N_2(g)$	1.25
$H_2(g)$	2.75
$NH_3(g)$	0.862

Calculate the numerical value for K_c for **equilibrium 24.1** under these conditions.

Give your answer to an **appropriate** number of significant figures and in **standard form**.

K_c = ... **[2]**

28.
Hydrogen gas can be produced as shown below.
$CH_4(g) + H_2O(g) \; CO(g) + 3H_2(g)$ $H = +206 \text{ kJ mol}^1$
Which conditions produce the greatest equilibrium yield of hydrogen?

A   Low temperature and high pressure
B   Low temperature and low pressure
C   High temperature and high pressure
D   High temperature and low pressure

Your answer ☐   **[1]**

29.
The reversible reaction below is in equilibrium.

$2SO_2(g) + O_2(g) \; 2SO_3(g)$
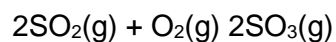
The equilibrium concentrations are shown in the table.

Substance	$SO_2(g)$	$O_2(g)$	$SO_3(g)$
Equilibrium concentration / mol dm^3	4.00	2.40	1.44

What is the numerical value of K_c?

A   0.0375
B   0.0540
C   0.150
D   18.5

Your answer [ ] **[1]**

30. Nitrosyl chloride, NOCl , is used in the industrial manufacture of nylon.

Nitrosyl chloride, NOC*l*, dissociates into nitrogen monoxide and chlorine as in the equilibrium below.

$2NOCl(g)$ $2NO(g) + Cl_2(g)$ $\Delta H = +77.0kJmol^{-1}$

Nitrosyl chloride is added to a container, which is then sealed.
The container is heated to 400 °C, and equilibrium is allowed to be reached.

   i.   Write the expression for the equilibrium constant, K_c, for this equilibrium.

[1]

  ii.   In the equilibrium mixture at 400 °C, the equilibrium concentration of $Cl_2(g)$ is found to be 0.17 mol dm^{-3}.

        The student calculates that the equilibrium concentration of NO(g) is 0.34 mol dm^{-3}.

        Explain how the student obtained this value for [NO(g)].

_____

_____

[1]

 iii.   At 400 °C, K_c = 0.015 moldm^{-3}.

        Calculate the equilibrium concentration of NOC*l*(g) at 400°C.

                     equilibrium concentration of NOC*l*(g) = ... mol dm^{-3} **[2]**

  iv.   The temperature of the equilibrium mixture is increased above 400 °C while keeping the pressure constant.

        State and explain the effect on the equilibrium concentration of nitrogen monoxide, NO(g), with these new conditions.

_____

_____

[2]

31(a). The equilibrium constant K_p and temperature T (in K) are linked by the mathematical relationship shown in **equation 5.1** (R = Gas constant in J mol^{-1} K^{-1} and ΔH is enthalpy change in J mol^{-1}).

$$\ln K_p = -\frac{\Delta H}{R} \times \frac{1}{T} + \frac{\Delta S}{R}$$ **Equation 5.1**

The table shows the values of K_p at different temperatures for an equilibrium.

Complete the table by adding the missing values of $\frac{1}{T}$ and ln K_p.

Temperature, T / K	400	500	600	700	800
K_p	3.00×10^{58}	5.86×10^{45}	1.83×10^{37}	1.46×10^{31}	1.14×10^{26}
$\frac{1}{T}$ / K^{-1}	2.50×10^{-3}	....	....	....	....
ln K_p	135	....	....	....	....

[2]

(b). State and explain how increasing the temperature affects the position of this equilibrium and whether the forward reaction is exothermic or endothermic.

_____

_____

[1]

(c). Plot a graph of ln K_p against $\frac{1}{T}$ using the axes provided on the opposite page.

Use your graph and **equation 5.1** to determine ΔH, in kJ mol^{-1}, for this equilibrium.

Give your answer to **3** significant figures.

ΔH = ... kJ mol^{-1} **[4]**

(d). Explain how ΔS could be calculated from a graph of $\ln K_p$ against $\frac{1}{T}$.

[2]

$\frac{1}{T}/K^{-1}$
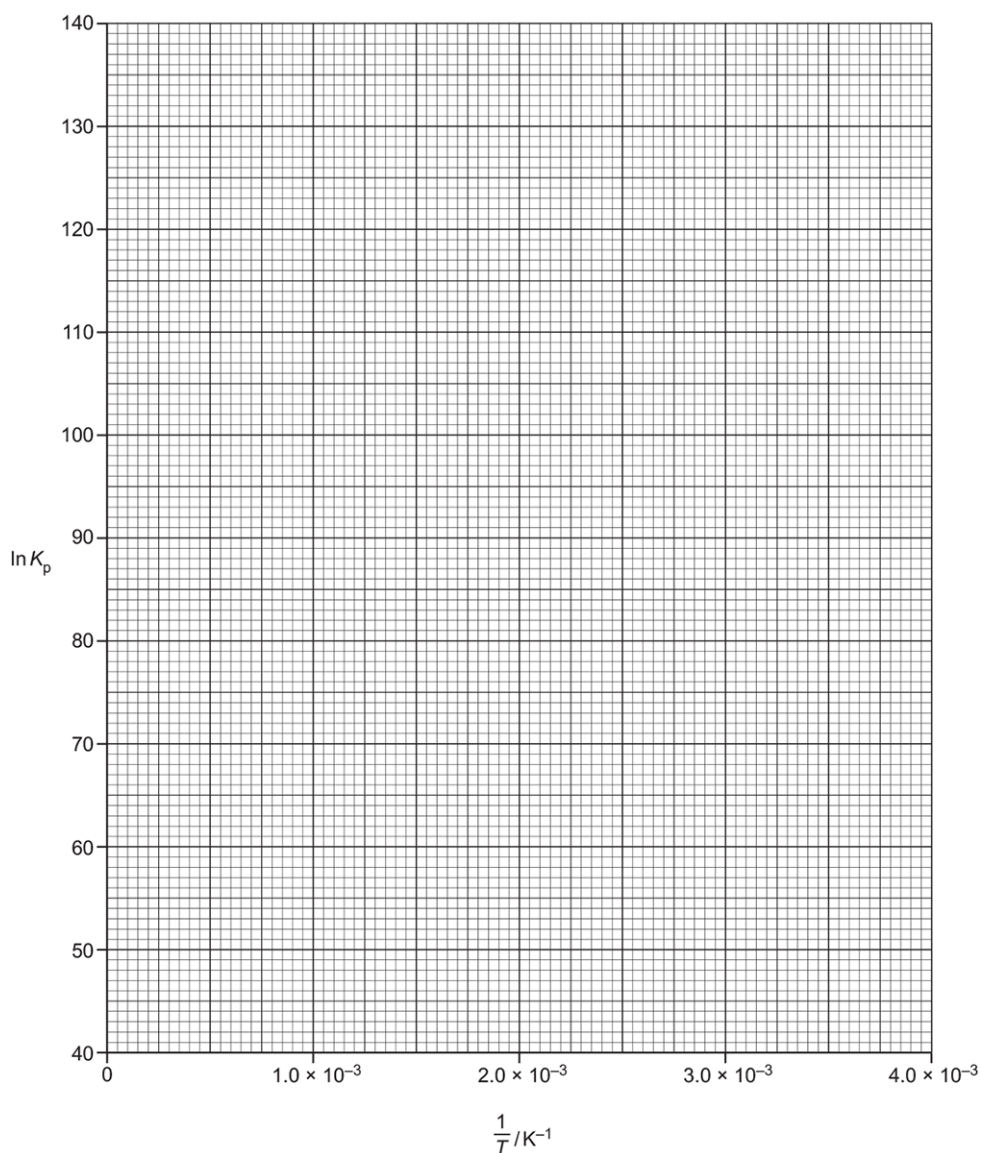
32. Which statement(s) is/are correct when a catalyst is added to a system in dynamic equilibrium?

  1   The rates of the forward and reverse reactions increase by the same amount.
  2   The concentrations of the reactants and products do not change.
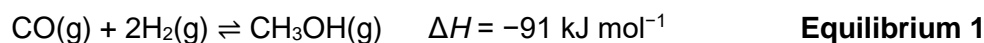 3   The value of K_c increases

A   1, 2 and 3
B   Only 1 and 2
C   Only 2 and 3
D   Only 1

Your answer ☐   **[1]**

33. Methanol, CH3OH, can be made industrially by the reaction of carbon monoxide with hydrogen, as shown in **equilibrium 1**.

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

Predict the conditions of pressure and temperature that would give the maximum equilibrium yield of CH_3OH in **equilibrium 1**.

Explain your answer.

_____

_____

_____

_____

_____

                                                                                                    [3]

34. A student investigates the reaction between ethanoic acid, $CH_3COOH(l)$ and methanol, $CH_3OH(l)$, in the presence of an acid catalyst. The equation is shown below.

$CH_3COOH(l) + CH_3OH(l) \rightleftharpoons CH_3COOCH_3(l) + H_2O(l)$
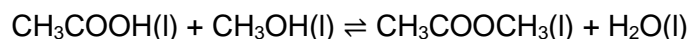
The student carries out an experiment to determine the value of K_c for this reaction.

The student mixes 9.6 g of CH_3OH with 12.0 g of CH_3COOH and adds the acid catalyst.

When the mixture reaches equilibrium, 0.030 mol of CH_3COOH remains.

Calculate K_c for this equilibrium.

K_c = ... **[4]**

35. Which statement about dynamic equilibrium is **not** correct?

A   A catalyst increases the rate of both forward and reverse reactions by the same amount.
B   Dynamic equilibrium exists only in a closed system.
C   The concentrations of the reactants and products are equal.
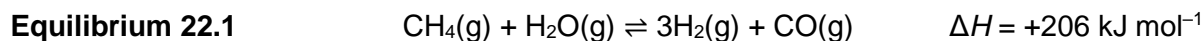**D**   The rate of the forward reaction is equal to the rate of the reverse reaction.

Your answer [ ]   **[1]**

36. This question is about enthalpy changes.

Hydrogen, H_2, can be manufactured by the reaction of methane and steam.
This is a reversible reaction, as shown in **Equilibrium 22.1** below.

Equilibrium 22.1 $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +206 \text{ kJ mol}^{-1}$

Explain how le Chatelier's principle can be used to predict the conditions of pressure and temperature for a maximum **equilibrium** yield of hydrogen in **Equilibrium 22.1**.

_____

_____

_____

_____

_____

_____

_____

_____

[4]

37. This question is about halogens.

Chlorine is used to kill bacteria in drinking water.

State **one** risk in using chlorine in drinking water.

[1]

38(a). Methanol, CH_3OH, is manufactured by the reaction of carbon monoxide, CO, with hydrogen, H_2.

$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H = -91$ kJ mol^{-1}
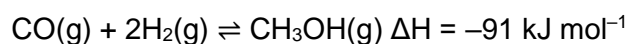
Write the expression for the equilibrium constant, K_c, for this equilibrium.

[1]

(b). A chemist mixes CO and H_2 in a container.
The mixture is heated to 200 °C and left to reach equilibrium.

The equilibrium concentrations of CO and H_2 are shown in the table.

Compound	Equilibrium concentration / mol dm^{-3}
CO(g)	0.57
H$_2$(g)	0.40

The numerical value of K_c for this equilibrium is 15.4.

   i.   Calculate the equilibrium concentration of $CH_3OH(g)$.

concentration = ... mol dm^{-3} **[2]**

   ii.   What does the numerical value of K_c tell you about the position of equilibrium?

[1]

39(a). This question is about chemical equilibrium.

Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **Equilibrium 20.1**.
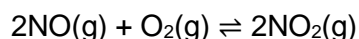
Equilibrium 20.1 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -114 \text{ kJ mol}^{-1}$
                                                                                                $\Delta S = -147 \text{ J mol}^{-1} \text{ K}^{-1}$

A dynamic equilibrium exists in a closed system.

State **one** other feature of a dynamic equilibrium.

_____

[1]

(b). A chemist investigates the equilibrium shown in **Equilibrium 20.1**.

The chemist mixes together 1.60 mol of NO(g) and 1.50 mol of O_2(g) in a container and the mixture is allowed to reach equilibrium.

At equilibrium:

- 75% of the NO(g) has been converted to NO_2(g)
- the total pressure is 1.21 MPa.

   i.   Calculate K_p, in MPa^{-1}, for **Equilibrium 20.1**.

         Give your answer to 3 significant figures.

K_p = ... MPa^{-1} **[4]**

   ii.   The chemist then repeats the experiment three times. In each experiment, the chemist makes **one** change but uses the same initial amounts of NO and O_2.

         Complete the table to show the predicted effect of each change compared with the original experiment.

         Only use the words **greater, smaller** or **same**.

Change	K_p	Equilibrium amount of $NO_2(g)$	Initial rate
Temperature increase			
Pressure increase			
Catalyst added			

[3]

40(a). Two students plan to investigate **Equilibrium 4.1**, shown below.

$CoCl_4^{2-}(aq) + 6H_2O(l)$ $\rightleftharpoons$ $[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq)$ **Equilibrium 4.1**

   blue   pink
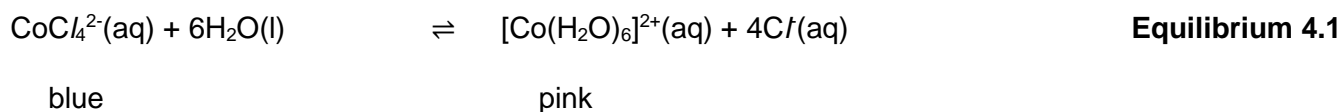
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- One student heats 20 cm^3 of the mixture to 50°C.
- The other student heats 20 cm^3 of the mixture to 90°C.

The students use colorimetry to observe how the colour of the equilibrium mixture changes over time.

- The colorimeter is set up so that the greater the absorbance, the greater the concentration of $[Co(H_2O)_6]^{2+}$.
- The initial absorbance is set to zero.
- The absorbance is recorded every 30 seconds.

The students plot the graph below from the results of the experiment.
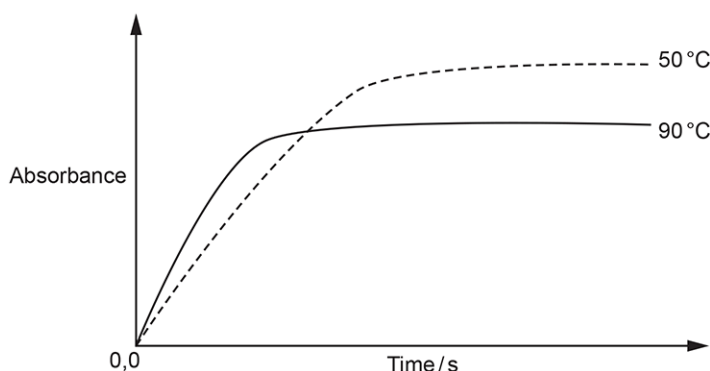
Use the graph and relevant chemical theory to answer the following. Include all reasoning:

- Explain the different initial rates at 50°C and 90°C.
- Predict the sign of ΔH for the forward reaction in **Equilibrium 4.1**.

_____

_____

_____

_____

_____

_____

[4]

(b). The students investigate how addition of aqueous silver nitrate, $AgNO_3(aq)$, affects the equilibrium position in **Equilibrium 4.1**.

The graph shows the changes in the equilibrium concentrations of $CoCl_4{}^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after addition of the $AgNO_3(aq)$.

The $AgNO_3(aq)$ is added at time = t_1
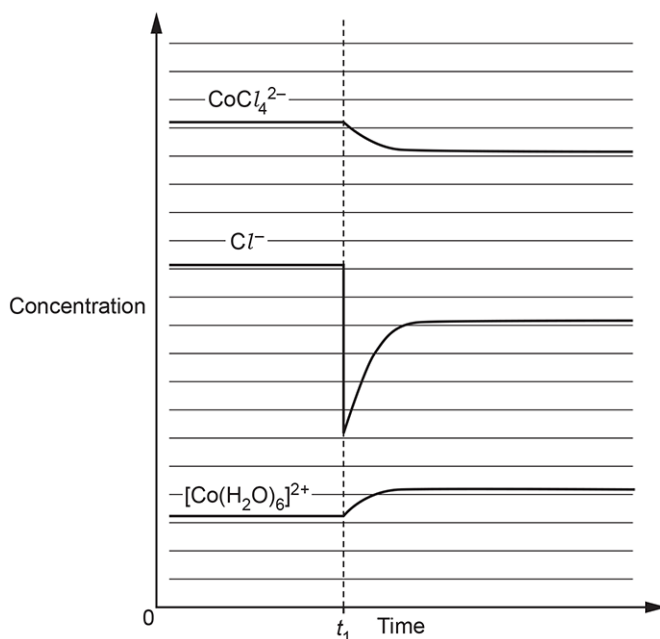
i. Explain why the Cl^- concentration drops sharply at time = t_1.

_____

_____

[1]

ii. Explain the changes in concentration of $CoCl_4{}^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after time = t_1.
Refer to **Equilibrium 4.1** in your answer.

_____

_____

_____

_____

[3]

41. This question is about the manufacture of hydrogen, H_2.

In industry, hydrogen is manufactured from methane, as shown in **Equilibrium 4.1**.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206$ kJ mol^{-1} **Equilibrium 4.1**

The industrial process is carried out at 15 atmospheres pressure and at a temperature of 800°C using an excess of steam. A nickel catalyst is used.

i. * Explain why these conditions are used industrially.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

ii.   A chemist mixes $CH_4(g)$ and $H_2O(g)$ and leaves the mixture to reach equilibrium.
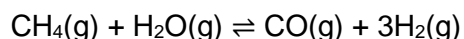
$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +206$ kJ mol^{-1} **Equilibrium 4.1**

The equilibrium mixture contains the following concentrations.

Substance	Concentration/mol dm^{-3}
$CH_4(g)$	0.111
$H_2O(g)$	0.682
$CO(g)$	0.510
$H_2(g)$	1.530

Write an expression for the equilibrium constant, K_c, for **Equilibrium 4.1** and calculate the numerical value of K_c.

Give your answer to **3** significant figures.

K_c = ... mol^2 dm^{-6} **[2]**

42(a). This question is about equilibria involving hydrogen.

* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.
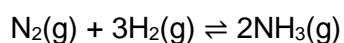
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92$kJ mol^{-1} **Equilibrium 20.1**

1.20 mol $N_2(g)$ is mixed with 3.60 mol $H_2(g)$ in a 8.00 dm^3 container.

The mixture is heated to 550 °C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3.

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

(b). In industry, hydrogen is used to reduce the iron oxide Fe_3O_4 as shown in **Equilibrium 20.2**.

The reaction is carried out at 500 °C.

$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$ **Equilibrium 20.2**
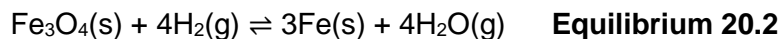
  i.   When the temperature is decreased, the value of K_p decreases.
       Determine whether the forward reaction is exothermic or endothermic.
       Explain your answer.

_____

_____

_____

[1]

  ii.   Two students are discussing the effect of pressure on the equilibrium position of **Equilibrium 20.2**.

       Student 1 says:

       "There are more moles of products than reactants, so increasing the pressure will shift the equilibrium to the left hand side."

       Student 2 disagrees.

       Determine which student is correct. Justify your answer.

_____

_____

_____

[1]

43. Which prediction can be made using le Chatelier's principle?

A   The effect of a catalyst on the reaction rate.
B   The effect of a catalyst on the equilibrium position.
C   The effect of temperature on the reaction rate.
D   The effect of concentration on the equilibrium position.

Your answer   ☐   **[1]**

44. Four equilibrium reactions are set up

The concentration of each gas in the equilibrium mixtures is 0.1 mol dm^{-3}.

Which equilibrium has a numerical K_c value of 0.01?

A $CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$
B $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
C $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$
D $2NO_2(g) \rightleftharpoons N_2O_4(g)$

Your answer ☐ **[1]**

45(a). The reaction between sulfur dioxide, $SO_2(g)$ and oxygen, $O_2(g)$, to form sulfur trioxide, $SO_3(g)$, is a key step in the industrial manufacture of sulfuric acid.

This is a reversible reaction, shown in **Equilibrium 24.1**:
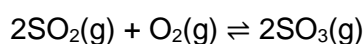
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ 　　　　$\Delta H = -197$ kJ mol^{-1} 　　　　**Equilibrium 24.1**

Why is **Equilibrium 24.1** a homogeneous equilibrium?

_____

[1]

(b). Le Chatelier's principle can be used to predict how different conditions affect the equilibrium position in **Equilibrium 24.1**.

Explain how changing pressure, temperature and using a catalyst affect the equilibrium yield of SO_3.

In your answer, use le Chatelier's principle and other chemical concepts, where appropriate.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[5]

(c). A mixture of $SO_2(g)$ and $O_2(g)$ is allowed to reach equilibrium at a constant temperature.

The equilibrium concentrations are shown in the table.

Substance	Equilibrium concentration / mol dm^{-3}
$SO_2(g)$	3.0×10^{-3}
$O_2(g)$	3.5×10^{-3}
$SO_3(g)$	5.0×10^{-2}

i.   Write the expression for K_c and calculate the numerical value for K_c in **Equilibrium 24.1** at this constant temperature.

Give your answer to an **appropriate** number of significant figures and in **standard form**.

K_c = ... dm^3 mol^{-1} **[2]**

ii.   In the industrial production of SO_3, an excess of $O_2(g)$ is used rather than a 2:1 proportion of $SO_2(g)$ to $O_2(g)$ which would match the stochiometry in **Equilibrium 24.1**.

Suggest, in terms of equilibrium, why an excess of $O_2(g)$ is used industrially.

_____

_____

[1]

46. Chlorine trifluoride can be decomposed into its elements forming the equilibrium mixture below.

$2ClF_3(g) \rightleftharpoons Cl_2(g) + 3F_2(g) \qquad \Delta H = +318 \text{ kJ mol}^{-1}$

colourless   green   yellow
gas   green   yellow
                  gas   gas
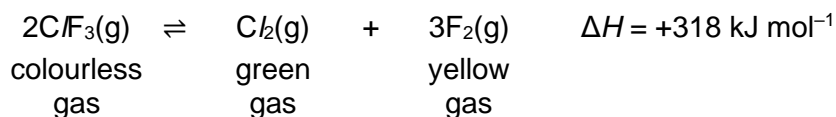
Which statement(s) is/are correct?

1 The decomposition is a redox reaction.
2 When the equilibrium mixture is cooled, the colour fades.
3 The decomposition has a negative entropy change.
A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer ☐   **[1]**

47. Bromine, Br_2, can be produced by the reaction:

$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$
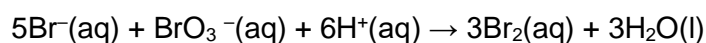
A student investigates the rate of this reaction by carrying out four experiments at the same temperature. The student's results are shown below.

Experiment	$[Br^-]$ / mol dm^{-3}	$[BrO_3^-]$ / mol dm^{-3}	$[H+]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	2.00×10^{-2}	1.20×10^{-1}	8.00×10^{-2}	2.52×10^{-4}
2	6.00×10^{-2}	1.20×10^{-1}	8.00×10^{-2}	7.56×10^{-4}
3	4.00×10^{-2}	6.00×10^{-2}	8.00×10^{-2}	2.52×10^{-4}
4	2.00×10^{-2}	6.00×10^{-2}	4.00×10^{-1}	3.15×10^{-3}

Explain how the reaction orders can be determined from the student's results, and determine the rate equation and rate constant for this reaction.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

48(a). This question is about oxides of nitrogen.

An investigation is carried out on the equilibrium system shown below.

$2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H = -57.4 \text{ kJ mol}^{-1}$

  i.   A sealed flask containing 6.00 moles of $NO_2(g)$ is heated to a constant temperature and allowed to reach equilibrium.

        The equilibrium mixture contains 5.40 mol of $NO_2(g)$, and the total pressure is 5.00 atm.

        Determine the value of K_p and give your answer to **3** significant figures.

        Include an expression for K_p and the units of K_p in your answer.

K_p = ... units ....[5]

ii. The sealed flask in **(a)(i)** is then heated to a higher temperature at an increased pressure. The system is allowed to reach equilibrium again.

Explain why it is difficult to predict how these changes in reaction conditions affect the amount of $N_2O_4(g)$ formed at equilibrium.

_____

_____

_____

_____

_____

_____

[3]

(b). N_2O_4 reacts fully with oxygen to form a different oxide of nitrogen, oxide **A**, as the only product.

Oxide **A** is collected and cooled to 75.0 °C at a pressure of 101 kPa.

Under these conditions, oxide **A** is a gas that occupies a volume of 74.0 cm^3 and has a mass of 0.280 g.

Calculate the molar mass of oxide **A** and suggest its molecular formula.

molar mass = ... g mol^{-1}
molecular formula = ...
[5]

49. The reversible reaction between hydrogen and iodine to form hydrogen iodide is $H_2(g) + I_2(g) \leftrightharpoons 2HI(g)$

The graph shows how the concentrations of the reactants and product change as the reaction reaches a dynamic equilibrium.

At which point on the graph is the equilibrium reached?
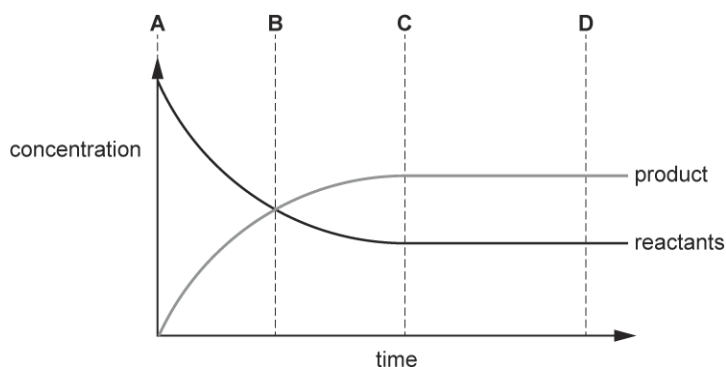
Your answer ☐ **[1]**

50. This question is about two oxides of sulfur: sulfur dioxide, SO_2, and sulfur trioxide, SO_3.

SO_3 decomposes to form SO_2 and O_2, as shown in **Equilibrium 18.1**.
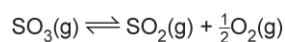
$$SO_3(g) \rightleftharpoons SO_2(g) + \tfrac{1}{2}O_2(g)$$ $\Delta H = +99\text{ kJ mol}^{-1}$ **Equilibrium 18.1**

i.   2.25 moles of SO_3 is heated to 550 °C in the presence of a catalyst and the resulting mixture allowed to reach equilibrium.

The equilibrium mixture contains 0.900 mol of SO_2 and the total pressure is 2.80 atm.

Calculate the numerical value for K_p for **Equilibrium 18.1** under these conditions and state the units of K_p.

Give your answer to **3** significant figures.

$$K_p = \text{..}$$

$$\text{units .... } \textbf{[5]}$$

ii.   The numerical values of K_p for **Equilibrium 18.1** at temperatures T_1 and T_2 are shown below.

Temperature	K_p
T_1	3.3×10^{-5}
T_2	7.7×10^{-2}

Explain why T_2 is a higher temperature than T_1.

_____

_____

_____

_____

[2]

iii.   Suggest how the value of K_p would change if the reaction was repeated with no catalyst added and the pressure of the system increased.

Tick (✓) one box in each row.

Change	Decrease	No change	Increase
No catalyst			
Increased pressure			

[2]

51. The reversible reaction below is at equilibrium.
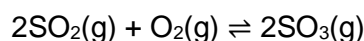
$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

What is the expression for K_c?

A $\dfrac{[SO_2(g)]^2\,[O_2(g)]}{[SO_3(g)]^2}$

B $\dfrac{[SO_3(g)]^2}{[SO_2(g)]^2\,[O_2(g)]}$

C $\dfrac{2[SO_2(g)] + [O_2(g)]}{2[SO_3(g)]}$

D $\dfrac{2[SO_3(g)]}{2[SO_2(g)] + [O_2(g)]}$

Your answer [ ] **[1]**

52. This question is about covalent compounds of nitrogen.

Ammonia, NH_3, is manufactured by reacting nitrogen and hydrogen gases. This is a reversible reaction and the equilibrium is shown below.

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

  i. This is an example of a dynamic equilibrium.

   State **2** features of a dynamic equilibrium.

1 _____

2 _____

[2]

ii.   State and explain the conditions of temperature and pressure that would produce a large equilibrium yield of NH_3.

_____

_____

_____

_____

_____

_____

[3]

END OF QUESTION PAPER

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	**1**	
2			A	1	
			Total	**1**	
3	a	i	$K_c = \dfrac{[CH_3OH]}{[CO][H_2]^2}$	1	
		ii	$[CH_3OH] = 14.6 \times (3.10 \times 10^{-3}) \times (2.40 \times 10^{-3})^2$ (1) $= 2.61 \times 10^{-7}$ (mol dm^{-3}) (1)	2	
	b	i	Yield decreases **AND** Equilibrium (position) has moved to the left	1	**allow** moved towards reactants **OR** moved towards CO and H_2
		ii	Oxidised Nitrogen **AND** −3 **AND** +2 (1) Reduced Oxygen **AND** 0 **AND** −2 (1)	2	
			Total	**6**	
4			C	1	
			Total	**1**	
5			The forward reaction is exothermic, so an increase in temperature favours the backward reaction *(owtte)* … (1) … therefore there will be more N_2 and H_2 **OR** less NH_3 in the equilibrium mixture, **AND** therefore the value of the equilibrium constant will decrease *(owtte)* (1)	2	**allow** names of compounds **allow** reactants / product instead of compounds 2nd mark only available if deduced from 1st mark **allow ecf** for 2nd mark
			Total	**2**	
6	a		* *Please refer to the marking instruction point 10 for guidance on how to mark this question.* **Level 3 (5–6 marks)** A comprehensive conclusion which correctly links pressure to moles, temperature to Δ*H* **AND** correctly identifies problems with use of low	6	**Indicative scientific points may include:** **MAXIMUM EQUILIBRIUM YIELD Pressure:**

			temperature and high pressure with reasons **AND** explains one benefit of using a catalyst. *There is a well-developed conclusion showing a line of reasoning which is clear and logically structured, linking pressure and temperature with equilibrium shift to the right, giving two reasons for operational conditions different and a positive sustainability comment from use of catalyst.* **Level 2 (3–4 marks)** Reaches a simple conclusion that correctly links pressure to moles, temperature to ΔH Correctly identifies problems with use of low temperature and high pressure with at least one reason **OR** explains one benefit of using a catalyst. *The conclusion has a line of reasoning presented with some structure, linking pressure and temperature with equilibrium shift to the right and either giving two reasons for problems and a positive sustainability comment from use of catalyst.* **Level 1 (1–2 marks)** Reaches a simple conclusion that correctly links pressure to moles, temperature to ΔH. **OR** explains one benefit of using a catalyst. *The information selected is communicated in an unstructured way which links pressure and temperature with equilibrium shift to the right.* **0 marks** No response or no response worthy of credit.		• Right-hand side has fewer number of (gaseous) moles **Temperature:** • (Forward) reaction is exothermic / gives out heat **OR** reverse reaction is endothermic / takes in heat **Conditions AND equilibrium shift** • Low temperature **AND** high pressure **AND** equilibrium (position) shifts to right **ACTUAL CONDITIONS** • Low temperature give slow rate **OR** high temperatures to increase rate • High pressure is expensive **OR** high pressure provides a safety risk **CATALYST: ONE** benefit from: • reactions take place at lower temperatures with lower energy demand OR reduce CO_2 emissions / burning fossil fuel
	b	i	**IGNORE** le Chatelier responses .... *Each marking point is independent* K_c K_c does not change (with pressure / concentration) *Comparison of conc terms with more N_2* [N_2] increases **OR** denominator / bottom of K_c expression	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **IF** 1st marking point has been awarded,

		increases *yield of NH₃ linked to Kc* Chemist is correct **AND** denominator decreases **OR** numerator increases to restore equilibrium K_c			**IGNORE** comments about 'K_c decreasing' or 'K_c increasing' and assume that this refers to how the ratio subsequently changes. i.e. **DO NOT CON** 1st marking point.
	ii	N₂ obtained from the air **AND** H₂ must be manufactured / does not occur naturally	1		N₂ is more readily available **not** insufficient. **ALLOW** an example of H₂ manufacture, e.g. from oil / gas / water **BOTH** responses required for mark.
		Total	**10**		
7		* *Please refer to the marking instruction point 10 for guidance on how to mark this question.* **(Level 3)** All/most points covered and clearly linked. Must have points taken across all of the headings in the indicative points for Level 3. *The explanations show a well-developed line of reasoning linked to appropriate suggestions which is clear and logically structured. The compromises are relevant and well thought out and clearly linked to the explanations.* (5–6 marks) **(Level 2)** Suggests correct conditions with explanations **OR** comments on compromises with reference to yield **AND** rate effect. *The explanations are linked to appropriate suggestions and show a line of reasoning with some structure. The compromises are relevant but may not be clearly linked to the explanation.* (3–4 marks) **(Level 1)** Comments on conditions with some explanation **OR** comments on compromise with reference to yield	6		**Indicative scientific points may include** Yield • Increasing pressure increases yield of SO₃ • Decreasing temperature increases yield of SO₃ Explanation • (pressure) more moles / molecules on the reactant side **ORA** • (temp.) the forward reaction is exothermic **ORA** Rate • Increasing pressure increases rate • Increasing temperature increases rate Compromise • Choose a higher temperature which creates a reduced

			OR rate.		yield but in a shorter space of time
			The comments about yield / rate with explanation are basic and communicated in an unstructured way. The compromises may not be relevant with lack of reasoning.		**ignore** reference to increase pressure leading to safety / cost issues
			(1–2 marks)		
			No response or no response worthy of credit. (0 marks)		
			Total	**6**	
8	i		**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **If** answer = 2.33 **award 4 marks** $K_a = 10^{-3.40} = 3.98 \times 10^{-4}$ (mol dm^{-3}) Concentration of aspirin $= \dfrac{1.00 \times 10^{-2}}{180} \times 1000$ = 0.0556 (mol dm^{-3}) $[H^+] = \sqrt{(K_a \times [HA])} = \sqrt{(3.98 \times 10^{-4} \times 0.0556)} = 4.70 \times 10^{-3}$ (mol dm^{-3}) pH = $-\log 4.70 \times 10^{-3} = 2.33$	4	**ALLOW ECF** **ALLOW ECF only** from [H$^+$] calculation using $[H^+] = \sqrt{(K_a \times [HA])}$
	ii		Salts are ionic **AND** attracted to polar H_2O	1	
	iii		COO$^-$ reacts with H$^+$ forming COOH Aspirin precipitates out	2	**ALLOW** equilibrium shifts to left
			Total	**7**	
9	i		Rate of the forward reaction is equal to the rate of the reverse reaction ✓ **OR** concentrations do not change ✓	1	**ALLOW** both reaction**s** occur at same rate **IGNORE** conc. of reactants = conc. of products **Examiner's Comments** A good proportion of candidates recognised the need to provide one of the key features of a dynamic equilibrium as outlined in the specification.

	ii	More H_2 and I_2 OR less HI ✓ (equilibrium position shifts) to the left **AND** (Forward) reaction is exothermic **OR** reverse reaction is endothermic **OR** in the endothermic direction✓	2	**Mark each point independently** **ALLOW** more reactants **OR** less products **Note: ALLOW** suitable alternatives for to the left e.g. towards reactants **OR** towards H_2 / I_2 **OR** in reverse direction **OR** favours the left. **ALLOW** gives out heat for exothermic **ALLOW** takes in heat for endothermic **IGNORE** responses in terms of rate **Examiner's Comments** This question required candidates to apply le Chatelier's Principle to the equilibrium and in addition predict the effect it would have on the composition of the mixture. Most candidates were able to predict and explain the shift in the position of equilibrium and the most able stated the effect on the composition of the mixture. Candidates should be encouraged to read questions carefully to ensure they address all aspects in their response.
	iii	No effect **AND** Same number of (gaseous) moles on both sides ✓	1	**ALLOW** same number of molecules on each side **Examiner's Comments** This question was answered very well and most candidates picked up this mark.
		Total	**4**	

1 0	a		The (position of a dynamic) equilibrium shifts to minimise (the effect of) any change ✓	1	**ALLOW** suitable alternatives for 'shifts' and 'minimises' **IGNORE** 'reaction shifts' **Examiner's Comments** Most candidates were able to describe le Chatelier's principle.
	b	i	**Pressure:** Right-hand side has fewer (gaseous) moles / molecules **OR** left-hand side has more (gaseous) moles / molecules ✓ **Temperature**: Statement that: (Forward) reaction is exothermic **OR** (forward) reaction gives out heat **OR** reverse reaction is endothermic **OR** reverse reaction takes in heat ✓ **Equilibrium** Lower temperature / cooling **AND** increasing pressure shifts (equilibrium position) to the right ✓	3	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** fewer atoms on right-hand side **OR** more atoms on left-hand side. **IGNORE** comments about the 'exothermic side' or 'endothermic side' **Equilibrium mark** is for stating that **BOTH** low temperature and high pressure shift equilibrium to the right (Could be separate statements) **Note: ALLOW** suitable alternatives for 'to right' , e.g.: towards products **OR** towards CH_3OH / H_2O **OR** in forward direction **OR** favours the right **IGNORE** Increases yield of CH_3OH / products (*in question*) **IGNORE** responses in terms of rate **Examiner's Comments** A good discrimination was achieved by this question. The most able candidates gave succinct responses which related the low temperature and high pressure to the change in equilibrium position. Candidates are encouraged to write as accurately as

			possible in this type of question. For example, the effect of pressure is best explained by reference the relative number of moles on each side of the equation. A statement about the nature of the forward reaction, in this case exothermic, is appropriate to explain the effect of temperature.		
	ii	Low temperature gives a slow rate **OR** high temperatures needed to increase rate ✓ High pressure is expensive (to generate) **OR** high pressure provides a safety risk ✓	2	**ALLOW** high pressure is dangerous **IGNORE** high pressure is explosive **Examiner's Comments** Most candidates identified high pressures as either dangerous or requiring expensive equipment. The strongest responses linked low temperature with a slow rate of reaction.	
		Total	**6**		
11	a	$(K_c =) \dfrac{[C_2H_2][H_2]^3}{[CH_4]^2}$ ✓	1	Square brackets are **essential** State symbols **not** required. **IGNORE** incorrect state symbols **Examiner's Comments** The K_c expression was shown correctly by almost all candidates, the only mistakes being the very occasional inverted expression or use of "+' within the denominator.	
	b	i	amount of $H_2 = 3 \times 0.168$ = 0.504 (mol) ✓	1	**Examiner's Comments** The correct answer of 0.504 mol was seen in the majority of scripts but examiners were also presented with many other responses. The key was use of the 1:3 molar ratio of C_2H_2 and H_2 formed in the equilibrium mixture, with simple multiplication of 0.168 by 3 giving the correct answer. The commonest incorrect answer

					was 0.1404 from $3/2 \times 9.36 \times 10^{-2}$: from use the molar ratio of moles CH_4 formed and H_2 formed. Answer: 0.504 mol
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.153 mol² dm⁻⁶, award **3 marks** **IF** answer = 0.153 with incorrect units, award **2 marks** .... **IF answer from 3(b)(i) for $n(H_2) \neq 0.504$, mark by ECF.** **Equilibrium concentrations** (from $n(H_2)$ = 0.504 mol dm⁻³) $[CH_4]$ = 2.34 × 10⁻² (mol dm⁻³) **AND** $[C_2H_2]$ = 4.20 × 10⁻² (mol dm⁻³) **AND** $[H_2]$ = 0.126 (mol dm⁻³) ✓ **Calculation of K_c and units** $K_c = \dfrac{4.20 \times 10^{-2} \times (0.126)^3}{(2.34 \times 10^{-2})^2}$ = 0.153 ✓ mol² dm⁻⁶ ✓ **3 significant figures** are required	3	*FULL ANNOTATIONS MUST BE USED* .... **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below .... **ALLOW** ÷ by 4 of equilibrium amounts in all expressions, i.e. **ALLOW** $[CH_4] = \dfrac{9.36 \times 10^{-2}}{4}$ mol dm⁻³ **AND** $[C_2H_2] = \dfrac{0.168}{4}$ mol dm⁻³ **AND** $[H_2] = \dfrac{0.504}{4}$ mol dm⁻³ ✓ **ALLOW ECF** from incorrect concentrations or from moles From moles: 9.36 × 10⁻², 0.168 and 0.504, K_c = 2.45 by **ECF** **ALLOW** dm⁻⁶ mol² **DO NOT ALLOW** mol²/dm⁶ **ALLOW ECF** from incorrect K_c expression for both calculation and units .... **COMMON ECF** From **3(b)(i)** answer of 0.1404, K_c = 3.32 x 10⁻³ 2 marks + units K_c = 0.0531 No ÷ 4 throughout 1 mark + units **Examiner's Comments** Many candidates are well-rehearsed for this type of question. Candidates were expected to use the equilibrium amounts, convert to concentrations

					by dividing by 4 and to use these values to obtain the K_c value. A common mistake was omission of the concentration stage, leading to a value of 2.45. More calculator errors were seen than in the past, perhaps caused by the cubed power within the numerator. Candidates without a cubed function key on the calculator can simply multiply a value with itself three times. Few candidates failed to express their numerical value for K_c to three significant figures. The units caused few problems although some inverted units were seen. Answer: 0.153 mol^2 dm^{-6}
		iii	**Initial amount of CH$_4$** amount of CH$_4$ = 9.36×10^{-2} + 2 x 0.168 = 0.4296 **OR** 0.43(0) (mol) ✔	1	**NO ECF** possible (all data given in question) **Examiner's Comments** Although this part was more challenging than the initial molar ratio in (b)(i), many candidates were able to work out the amount of CH$_4$ that had reacted as $2 \times 9.36 \times 10^{-2}$ and to then add this to the remaining amount of CH$_4$: 9.36×10^{-2}. This part did cause a lot of difficult for weaker candidates with a range of incorrect numerical answers being seen. Answer: 0.4296 mol
	c		<table><tr><th>Change</th><th>K_c</th><th>Equilibrium amount of C$_2$H$_2$ / mol</th><th>Initial rate</th></tr><tr><td>temperature increased</td><td>greater</td><td>greater</td><td>greater</td></tr><tr><td>smaller container</td><td>same</td><td>smaller</td><td>greater</td></tr><tr><td>catalyst added</td><td>same</td><td>same</td><td>greater</td></tr><tr><td></td><td>✔</td><td>✔</td><td>✔</td></tr></table>	3	Mark by **COLUMN** **ALLOW** obvious alternatives for greater / smaller / same, e.g. increases / decreases; more / less **Examiner's Comments** This part tested candidates understanding of how three quantities would change from changes to experimental conditions.

					This was marked by column. Of the three quantities, K_c and rate were correct more often than the equilibrium amount of C_2H_2. This question discriminated extremely well. Strangely, some candidates chose to use their own words instead of those provided and examiners often saw words such as 'increases' and 'decreases'. As the meaning was clear, such responses were still credited.	
		Total		**9**		
1 2	a		**EQUILIBRIUM CONDITIONS 3 MAX** **4 marking points → 3 max** ✓✓✓ *Mark first three* **CORRECT** *responses seen* **Temperature:** (Forward) reaction is exothermic/Δ*H* is negative **OR** (Forward) reaction gives out heat ✓ **Pressure:** Right-hand side has fewer (gaseous) moles **OR** 3 (gaseous) moles form 2 (gaseous) moles ✓ **Equilibrium shift** Correct equilibrium shift in terms of **temperature** ✓ Correct equilibrium shift in terms of **pressure** ✓ ──────────────────────────── **INDUSTRIAL CONDITIONS** Low temperature gives a slow rate/slower reaction **OR** high temperatures needed to increase rate ✓□ (High) pressure provides a safety risk **OR** (High) pressure is expensive (to generate) /uses a lot of energy ✓□	5	**FULL ANNOTATIONS MUST BE USED** ──────────────────────── **ALLOW** suitable alternatives for 'towards right', e.g.: towards SO_3/products **OR** in forward direction **OR** 'favours the right' **ALLOW reverse** reaction is endothermic /Δ *H* is positive/takes in heat For moles, **ALLOW** molecules/particles **ORA for** reverse reaction **IGNORE** responses in terms of activation energy **ALLOW** high pressure is dangerous/explosive **ALLOW** 'These conditions are expensive' *Statement subsumes* **pressure** *as 'these' will apply to* **pressure** *(required for this mark) and* **temperature**

				ALLOW ORA e.g. Lower pressure → less danger/uses less energy **IGNORE** 'It's expensive *Link with pressure required* **Examiner's Comments** This longer answer was answered very well with the majority of candidates able to score 4 or 5 marks. Most candidates explained how the position of equilibrium shifts in response to low temperature and high pressure. The commonest omission was the link between low temperature and a slow reaction rate.
	b		4	**FULL ANNOTATIONS MUST BE USED** _____ **ALLOW** suitable alternatives for 'towards left, e.g.: towards SO_2/O_2 **OR** towards reactants **OR** in reverse direction **OR** 'favours the left

Value of K_c 1 mark
K_c is small **OR** $K_c < 1$
AND equilibrium (position) is towards left ✓

Calculation: **FIRST CHECK ANSWER**
IF [SO₃] = 0.876 OR 0.88 (mol dm⁻³)
award all 3 marks available for calculation
_____

K_c expression 1 mark
$\dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$ **OR** $\dfrac{[SO_3]^2}{2.00^2 \times 1.20}$ ✓

Evaluation of K_c $[SO_2]^2[O_2]$ 1 mark

$K_c[SO_2]^2[O_2] = 0.160 \times 2.00^2 \times 1.20$

$= 0.768$ ✓

Calculation of [SO₃]
ONLY *available from* **correct** *evaluation for 2nd mark*
$[SO_3] = \sqrt{(0.160 \times 2.00^2 \times 1.20)}$
$= 0.876$ (mol dm⁻³) ✓

Square brackets required in K_c expression

ALLOW ECF from $\dfrac{[SO_3]}{[SO_2]^2[O_2]}$, i.e. no $[SO_3]^2$

ALLOW 0.77 (2 SF)

ALLOW 0.88 (2 SF) up to calculator value of 0.876356092 correctly rounded

IF K_c expression is inverted 2nd and 3rd marks are available by **ECF**:

$[SO_3]^2 = \dfrac{2.00^2 \times 1.20}{0.160}$ **OR** 30 ✓

					$[SO_3] = \sqrt{30} = 5.48$ **OR** 5.5 ✓
					Any other K_c expression → **NO MARKS,** e.g. $\dfrac{[SO_3]^2}{[SO_2]^2 + [O_2]} \rightarrow \sqrt{0.832} \rightarrow 0.912$ **NO** Marks
					Examiner's Comments
					Given that K_c is new to AS level in the reformed specification, this part was attempted well. However, writing a correct K_c did cause problems for weaker candidates, who sometimes inverted the expression, used the + sign from the equation, obtaining a denominator of $[SO_2]^2 + [O_2]$, or omitted the square from $[SO_2]^2$ and $[SO_3]^2$.
					Some excellent answers were seen and this part differentiated very well between candidates of different abilities.
					Answer: $[SO_3]$ = 0.876 mol dm^{-3}
			Total	**9**	
13	a	i	Equilibrium (position) shifts to right **AND** turns paler (brown) ✓ Right-hand side has fewer (gaseous) moles / molecules **OR** left-hand side has more (gaseous) moles / molecules ✓	2	**ALLOW** turns colourless **IGNORE** initially goes darker (brown) **Note: ALLOW** suitable alternatives for 'to right', e.g.: towards products **OR** towards N_2O_4 **OR** in forward direction **OR** favours the right **IGNORE** responses in terms of rate **Examiner's Comments** The effect of pressure on the position of an equilibrium is well known by candidates. Most were able to apply le Chatelier's principle accurately stating the equilibrium shifted to the right as that was the

					side with fewest moles of gas. However a significant proportion of the cohort did not comment on the effect on the appearance of the equilibrium mixture.
		ii	Equilibrium (position) shifts to left **AND** turns darker / deeper (brown) ✓ (Forward) reaction is exothermic **OR** (forward) reaction gives out heat **OR** reverse reaction is endothermic **OR** reverse reaction takes in heat ✓	2	**ALLOW** turns brown **Note: ALLOW** suitable alternatives for 'to left', e.g.: towards reactants **OR** towards NO_2 **OR** in reverse direction **OR** favours the left **IGNORE** comments about the 'exothermic side' or 'endothermic side' **ALLOW** 'equilibrium (position) shifts left **AND** in the endothermic direction' for second marking point **IGNORE** responses in terms of rate **Examiner's Comments** As with part (a)(i), candidates demonstrated an excellent grasp of le Chatelier's principle but it was only the most able candidates who referred to the appearance of the equilibrium mixture. Candidates should be encouraged to read questions carefully to ensure they include all the required information in their responses.
	b		**Addition of acid** $[H^+]$ **OR** H^+ increases **AND** equilibrium (position) shifts to right ✓ **Addition of alkali**	2	**ANNOTATE ANSWER WITH TICKS AND CROSSES** **IGNORE** amount of acid increases *(in question)* **ALLOW** (added) acid reacts with CrO_4^{2-} **Note: ALLOW** suitable alternatives for 'to right', e.g.: towards products **OR** towards $Cr_2O_7^{2-}$ / H_2O **OR** in forward direction **OR** favours the right

| | | | Alkali reacts with H⁺ **OR** alkali removes H⁺ **AND** equilibrium (position) shifts to left ✓ | | **ALLOW** $H^+ + OH^- \rightarrow H_2O$ **ALLOW** alkali reacts with (added) acid |

Alkali reacts with H^+ **OR** alkali removes H^+
AND
equilibrium (position) shifts to left ✓

ALLOW $H^+ + OH^- \rightarrow H_2O$
ALLOW alkali reacts with (added) acid

Note: ALLOW suitable alternatives for 'to left', e.g.: towards reactants **OR** towards CrO_4^{2-} / H^+
OR in reverse direction
OR favours the left

IGNORE just H^+ concentration decreases *(needs role of alkali)*
IGNORE concentration of water increases *(needs role of alkali)*

Examiner's Comments

This question discriminated well and the strongest candidates provided succinct responses with the correct level of scientific content. The first mark was awarded for recognition that adding an acid would increase the concentration of H^+ ions, causing the equilibrium to shift to the right. Most candidates realised this was the case. However, it was not uncommon to see vague responses that simply re-stated the information in the question, rather than focussing on the effect it would have on the species in the equilibrium equation. The second mark proved more difficult. The strongest candidates identified that the added alkali would remove H^+ ions from the equilibrium mixture, and some supported this statement with an equation. Many however, simply stated that the equilibrium would shift left to reduce the concentration of the alkali without attempting to relate it to the equation provided. Candidates are advised to consider the chemical equations provided with a question

					as they will help form the basis from which to build a response.
		Total		6	
14		**D**		1	
		Total		1	
15	i	$3\ MnO_4^{2-} + 4\ H^+ \rightarrow 2\ MnO_4^- + MnO_2 + 2\ H_2O$ ✓		1	**ALLOW** 1 in front of MnO_2
	ii	**In acidic conditions** (Concentration of) H^+ increases **AND** equilibrium (position) shifts to the right to reduce concentration of H^+/remove H^+ ✓ **In alkaline conditions** OH^- reacts with H^+ **AND** equilibrium (position) shifts to the left to increase concentration of H^+/add H^+ ✓		2	**ALLOW** $H^+ + OH^- \rightarrow H_2O$
		Total		3	
16	i	Complete dissociation would give $[H^+] = 0.2$ (mol dm^{-3}) ✓ pH from complete dissociation = $-\log 0.2 = 0.7$ **OR** actual $[H^+] = 10^{-0.96} = 0.11$ (mol dm^{-3})✓ **Stage 1** is complete dissociation **AND** **Stage 2** is partial dissociation ✓		3	**IGNORE Stage** 1 is a strong acid **AND Stage 2** is a weak acid.
	ii	Observation: fizzing ✓ H^+ reacts with carbonate **AND** (Stage 2) equilibrium shifts to the right ✓		2	**ALLOW** effervescence/'bubbling'
		Total		5	
17		B		1	**Examiner's Comments** This question discriminated very well

			with most able candidates obtaining the correct answer.		

		Total	**1**	

1 8		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF answer = 14.6 (dm² mol⁻⁶) award 2 marks** -- K_c **expression** $(K_c =)\ \dfrac{[CH_3OH]}{[CO]\ [H_2]^2}$ **OR** $\dfrac{0.26}{0.31 \times 0.24^2}$ **OR** 14.56 …… ✓ **Answer to 3 SF** 14.6 (dm⁶ mol⁻²) ✓	**2**	**FULL ANNOTATIONS MUST BE USED** --- **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below. --- **ALLOW** calculated value 14.5609319 correctly rounded to 3 or more SF for 1st marking point **ALLOW ECF to 3 SF ONLY** from inverted K_c expression → 0.0687 **DO NOT ALLOW** $\dfrac{[CH_3OH]}{[CO] + [H_2]^2}$ = 0.707 (no marks) **Examiner's Comments** Most candidates were able to obtain a value of 14.56 using a correct K_c expression, but a significant number of candidates were unable to give their answer to an appropriate number of significant figures. Candidates should use the least accurate data provided, here three significant figures, and to indicate the appropriate number of significant figures in the final answer. Other common errors included the inverted K_c expressions and use of [CO] + [2H₂], rather than [CO] [H₂]², as the denominator. Answer = 14.6 dm⁶ mol⁻²

		Total	**2**	

1 9	a	**Conditions** Low / decreased pressure **AND** high / increased temperature ✓ **Pressure:**	**4**	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **DO NOT ALLOW** more atoms on

		Right-hand / product side has more (gaseous) moles / molecules **OR** left-hand side / reactant side has fewer (gaseous) moles / molecules ✓ **Temperature:** (Forward) reaction is endothermic / takes in heat **OR** reverse reaction is exothermic / gives out heat ✓ Low pressure gives a slow rate **OR** High temperature uses a large amount of energy / fuel ✓		right-hand side **OR** fewer atoms on left-hand side. **DO NOT ALLOW** incorrect shift direction **ORA** **IGNORE** 'expensive' **IGNORE** use of catalyst **Examiner's Comments** The generous nine answer lines allowed for an answer to this question served to elicit many correct but rambling responses in which the candidates repeated the same point many times. Many candidates, after exhausting their thoughts upon simple equilibria shifts, completely forgot to suggest why operational conditions may be different.
b	i	$(K_c =)\ \dfrac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ ✓ Units: $dm^3\ mol^{-1}$ S	2	**IGNORE** state symbols in K_c expression, even if wrong. For units, **ALLOW** $mol^{-1}\ dm^3$ **DO NOT ALLOW** dm^3/mol **NOTE:** If K_c upside down, units become $mol\ dm^{-3}$ by **ECF** No other **ECF** allowed for units. **Examiner's Comments** The expression and the units were almost universally known by the candidates.

		FIRST, CHECK THE ANSWER ON ANSWER LINE **IF** answer = 2.45, Award **4 marks.**			**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below ....
		Equilibrium concentrations (moles x **2.5)** **1 MARK**			
		$SO_2 = 0.135$ (mol dm^{-3})			**ALLOW ECF** from incorrect concentrations of SO_2 and / or O_2
		AND $O_2 = 0.0675$ (mol dm^{-3}) ✓			**ALLOW ECF** from incorrect [SO_3]
		Calculation of [SO$_3$(g)] **2 MARKS**			**ALLOW 3 SF,** 6.12, up to calculator value of 6.12039291 correctly rounded.
		$[SO_3] = \sqrt{(K_c \times [SO_2]^2 \times O_2)}$			**Common errors**
	ii	**OR** $\sqrt{(3.045 \times 10^4) \times 0.135^2 \times 0.0675}$ ✓		4	**37.5** **1 mark** *No $\sqrt{}$ for $[SO_3]^2$ and no scaling by 1/2.5*
		$= 6.12039291$ (mol dm^{-3}) ✓			**15.0** **2 marks** *No $\sqrt{}$ for $[SO_3]^2$*
		Answer scores both [SO$_3$] marks automatically			**0.619** **3 marks** *Use of mol of SO_2 and O_2*
		Calculation of n(SO$_3$) in 400 cm^3 **1 MARK**			**1.55** **2 marks**
		$n(SO_3) = 6.12039291/2.5 = 2.45$ (mol) ✓			*No conc used and Use of mol of SO_2 and O_2*
		3SF required (Appropriate number)			**Examiner's Comments** There were three steps to this calculation:

					• Conversion of molar quantities of SO_2 and O_2 to molar concentrations. • Insertion into the K_c expression and determining of the molar concentration of SO_3. • Conversion of the molar concentration of SO_3 to a molar quantity including an appropriate number of significant figures. Steps 1 and / or 3 of the calculation were occasionally omitted but as long as the calculation was presented in a coherent manner, partial credit was awarded.
		Total		**10**	
20	i	*Expression:* $K_c = [NH_3]^2 / [H_2]^3[N_2]$ (1) *Calculation:* $= (0.877)^2/(2.00)^3(1.20)$ (1)		3	square brackets required
	i	$= 0.0801$ ✓ $(dm^6\ mol^{-2})$			**allow** from 1 sig fig up to calculator display correct answer alone scores all marks
	ii	*Catalyst:* No effect, it only changes the rate of reaction (1) *Higher temperature:* Forward reaction is exothermic (1) so position of equilibrium moves to the left and there will be less NH_3 (1)		3	
		Total		**6**	
21	a	$(K_c =)\ \dfrac{[NO(g)]^4\ [H_2O(g)]^6}{[NH_3(g)]^4\ [O_2(g)]^5}$ ✓		1	Square brackets required **IGNORE** state symbols **Examiner's Comments** Generally, this question was well

					answered with only a small proportion of candidates adding the values together instead of multiplying.
	b		**EQUILIBRIUM CONDITIONS** **Temperature: 1 mark** (Forward) reaction is exothermic/ΔH is negative **OR** (Forward) reaction gives out heat ✓ **Pressure: 1 mark** Left-hand side has fewer (gaseous) moles **OR** 9 (gaseous) moles form 10 (gaseous) moles ✓ *OPTIMUM EQUILIBRIUM CONDITIONS:* **1 mark** (for maximum yield of NO) Low temperature **AND** low pressure ✓ *RATE:* **1 mark** Low temperature/pressure gives a slow rate/slower reaction so high temperatures / higher pressure needed to increase **rate OR frequency of collisions** ✓ *INDUSTRIAL CONDITIONS* **/ OPERATIONAL FACTORS: 1 mark** High pressure provides a safety risk **OR** Higher temperatures increase energy costs / reduce yield / shift equilibrium to left **OR** (High) pressure is expensive (to generate) / uses a lot of energy ✓		5	**ANNOTATE ANSWER WITH TICKS AND CROSSES ETC** **ALLOW reverse arguments** Answer **MUST** relate temp/pressure to rate / frequency of collisions **ALLOW** Temperature / pressure not too high because yield reduced **IGNORE** stated temperatures and pressures **IGNORE** catalyst **Examiner's Comments** Most candidates answered this question very well, with the most common mark being 4/5. Many candidates put a lot of effort into explaining, in depth, Le Chatelier's principle, which was not required. The first three marking points were credited to most candidates. Responses were confident in their descriptions of equilibrium shifts and many candidates then went on to qualify their answers with operational factor considerations and/or rate. The explanation for pressure was described less commonly than temperature and many candidates did not appreciated that increased

					rate would lead to a decreased equilibrium yield. **Exemplar 3** This candidate scored all five marks for this well-reasoned approach to the question.
		Total		**6**	
22	a	$K_c = \dfrac{[NO_2]^2}{[NO]^2\,[O_2]}$ ✓ Units = $dm^3\ mol^{-1}$ ✓		**2**	Must be square brackets **IGNORE** state symbols **ALLOW** $mol^{-1}\ dm^3$ **ALLOW** $mol\ dm^{-3}$ as ECF from inverted K_c expression **Examiner's Comments** The expression and the units were almost universally known by the candidates.
	b	**FIRST CHECK THE ANSWER ON THE ANSWER LINE IF answer = 1.2 (mol) award 4 marks** **Unless otherwise stated, marks are for correctly calculated values. Working shows how values have been derived.** $[NO] = \dfrac{0.40}{4.0} = 0.1(0)\ (mol\ dm^{-3})$ **AND** $[O_2] = \dfrac{0.80}{4.0} = 0.2(0)\ (mol\ dm^{-3})$ ✓ $[NO_2]^2 = 45 \times 0.10^2 \times 0.20$ **OR** $= 0.09(0)$ ✓		**4**	*ANNOTATIONS MUST BE USED* For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value Ignore rounding errors after second significant figure 1st mark is for realising that concentrations need to be calculated. **ALLOW ECF**

			$[NO_2] = \sqrt{(45 \times 0.10^2 \times 0.20)}$ **OR** $= 0.3(0)$ (mol dm⁻³) ✓ amount $NO_2 = 0.30 \times 4 = 1.2$ (mol) ✓		**Correct numerical answer with no working would score all previous calculation marks** Making point 2 subsumes point 1 Making point 3 subsumes points 2 and 1 Common errors $9.6 = 3$ marks mol of NO and O_2 used $0.36 = 3$ marks mol of NO_2 calculated from $[NO_2]^2$ $2.4 = 2$ marks mol of NO and O_2 used and no mol of NO_2 calculated **Examiner's Comments** There were three steps to this calculation: Conversion of molar quantities of NO and O_2 to molar concentrations. Insertion into the K_c expression and determination (via a square root calculation) of the molar concentration of NO_2. Conversion of the molar concentration of NO_2 to a molar quantity. Steps 1 and/or 3 of the calculation were occasionally omitted but if the calculation was presented in a coherent manner, even here, partial credit was awarded.
	c	i	Exothermic AND K_p decreases as temperature increases ✓	1	**ALLOW** K_c for K_p **ALLOW** Equilibrium shifts to left hand side as temperature increases **Examiner's Comments**

					Most candidates knew the forward reaction was exothermic due to K_p decreasing as temperature increased. A common error was to write vague responses such as 'K_p decreases with temperature'.
		ii	**Equilibrium shift** (Equilibrium position) shifts to right / forward / towards products ✓ *Effect of increased pressure on K_p expression* Ratio (in Kp expression) decreases **OR** Denominator/bottom of K_p expression increases more (than numerator/top) ✓ *Equilibrium shift (K_p expression)* Ratio (in K_p expression) increases **to restore K_p** **OR** **Numerator/top of K_p expression increases to restore K_p** ✓	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c for K_p throughout the response. **ALLOW** K_p (initially) decreases for second marking point **IF** K_p is seen to be restored later in the process. **ALLOW** more NO_2 / product formed to restore K_p **ALLOW** ratio adjusts to restore K_p **Examiner's Comments** Candidates almost universally secured the first mark for equilibrium shifting to the right. Many scored this by simple application of Le Chatelier's principle, and then went on to incorrectly explain K_p increased because of this shift. Very few realised that (a constant) K_p drives Le Chatelier's principle (and not the other way around). An increase of pressure will increase the value of the partial pressures in the bottom half of the K_p expression more than the top half, thus (initially) decreasing the K_p ratio. Therefore, to **restore** K_p, the amount of NO_2 present must increase;

					consequently, the equilibrium shifts to the right.
			Total	**10**	
2 3		i	**Equation** $[Co(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CoCl_4]^{2-} + 6H_2O$ **OR** $[Co(H_2O)_6]^{2+} + 4HCl \rightleftharpoons [CoCl_4]^{2-} + 6H_2O + 4H^+$ ✓	1	**ALLOW** reverse equation: $[CoCl_4]^{2-} + 6H_2O \rightleftharpoons [Co(H_2O)_6]^{2+} + 4Cl^-$ but take care for subsequent explanations **IGNORE** state symbols (even if wrong) For $[CoCl_4]^{2-}$, **ALLOW** $CoCl_4^{2-}$, $(CoCl_4)^{2-}$ For other representations, contact TL **Examiner's Comments** In this part, candidates needed to apply their knowledge and understanding of ligand substitution and equilibrium to a novel situation. The best equations used Cl^- ions to form $CoCl_4^{2-}$. Some candidates used HCl instead and then H+ was often omitted in the equation. As with 2b, candidates are recommended to check that their completed equations are balanced.
		ii	**Equilibrium shift** • equilibrium (shifts) **to right** at high **temperature**/100°C OR equilibrium shifts to left at low temperature/0°C ✓ **CARE: Direction of shift** depends on direction of equilibrium equation from 2c(i). Either look back or see the equation copied at bottom of 2c(ii) marking zone. ――――――――――――――――― **Enthalpy change** • Endothermic ✓	2	**Mark independently** **ALLOW** suitable alternatives for 'to right' e.g. towards products **OR** in forward direction **OR** 'favours the right' **ORA** for 'to left' **Temperature** required but **ALLOW** 'in ice for low temperature **OR** 'in boiling/hot water' for high temperature **IGNORE** shift to blue side or pink side ――――――――――――――――――――

			Examiner's Comments Candidates were expected to determine the type of energy change by linking their equilibrium equation in 2b(i) with the colour changes at different temperatures. Most candidates correctly concluded that the formation of a blue colour is endothermic. Many candidates did not explain this in terms of a shift in equilibrium position, considering bond breaking and bond making instead.		
		Total		**3**	
24		**C**		**1**	**Examiner's Comments** This question was a good discriminator with well-prepared candidates usually selecting the correct option of C. Incorrect responses were reasonably evenly split across the other options, suggesting guesses and poor preparation.
		Total		**1**	
25		**B**		**1**	**Examiner's Comments** Most candidates responded with the correct response of B. The most common incorrect response was the inverse expression shown in A.
		Total		**1**	
26		**B**		1 (AO1.1)	
		Total		**1**	
27	i			4	FULL ANNOTATIONS MUST BE USED --- **ALLOW** suitable alternatives for right-hand side, e.g.: towards NH_3/products **OR** forward direction

					OR increases yield	

Pressure:
Right-hand side has fewer (gaseous) moles
OR 4 (gaseous) moles form 2 (gaseous) moles ✓

High pressure ✓

(AO1.2)

(AO2.1)

For moles, **ALLOW** molecules/particles

Temperature:
(Forward) reaction is exothermic/ΔH is negative
OR (Forward) reaction gives out heat ✓

(AO1.2)

Low temperature ✓

(AO2.1)

ALLOW reverse reaction is endothermic /ΔH is positive/takes in heat

ORA for reverse reaction

Examiner's Comments

This question was answered well with many candidates being given all 4 marks. Most candidates identified that there are fewer gaseous moles of products and that an increase the pressure will shift the equilibrium position to the right. Although the exothermic nature of the forward reaction was usually identified, candidates sometimes muddled the temperature conditions required, with 'higher temperature' being seen often instead of 'low temperature'. Lower attaining candidates often seemed to confuse equilibrium (in this question) with rates.

---

ii

FIRST CHECK THE ANSWER ON ANSWER LINE
IF answer = 2.86 × 10⁻² award 2 marks
--−
K_c **expression**

$(K_c =) \dfrac{[NH_3]^2}{[N_2][H_2]^3}$ **OR** $\dfrac{0.862^2}{1.25 \times 2.75^3}$
OR 0.02858 .... ✓

2
(AO2.6× 2)

IF there is an alternative answer, check for any
ECF credit possible using working below.

ALLOW calculated value 0.02858291 correctly rounded to 3 or more SF for 1st marking point

| | | | **Answer to 3 SF and in standard form** $Kc = 2.86 \times 10^{-2}$ ✓ | | **ALLOW ECF to 3 SF and standard form ONLY** from inverted K_c expression → 3.50×10^1 |

DO NOT ALLOW $\dfrac{[NH_3]^2}{[N_2] + [H_2]^3}$

= 0.0337 (no marks)

IGNORE attempts at units

Examiner's Comments

Exemplar 5

$K_c = \dfrac{[NH_3]^2}{[H_2]^3[N_2]} \rightarrow \dfrac{[0.862]^2}{[2.75]^3[1.25]}$

$= 0.029$ to 2sf. → 2.9×10^{-2}

$K_c = 2.9 \times 10^{-2}$ to 2sf. [2]

This part discriminated well. Most candidates were able to write the correct expression for K_c as the starting point of the calculation. Candidates often got into a muddle in calculating K_c, perhaps due to issues inputting the calculation into their calculators. The question asked for 'an appropriate number of significant figures and in standard form'. As the provided data was all to 3 significant figures, this also indicates the required number of significant figures in the answer. A calculated value to 2 significant figures was often seen (see the response); also 0.0286 rather than the standard form: 2.86×10^{-2}. Some responses showed K_c inverted or added, rather than multiplying the two reactants in the denominator. Other candidates wrote the correct equilibrium expression but were then used 2.75^2, rather than 2.75^3, to obtain the standard form answer of 7.786×10^{-2} or 0.0786 with no standard form. Candidates are advised to check back through

					calculations to see if they have made any such errors.
		Total		**6**	
28		**D**		1 (AO1.1)	**Examiner's Comments** D was the correct answer, with C being the main distractor. This straightforward question was answered correctly by only about half the candidates.
		Total		**1**	
29		**B**		1 (AO1.2)	**ALLOW** 0.054(0)
		Total		**1**	
30	i	$(K_c =) \dfrac{[NO]^2[Cl_2]}{[NOCl]^2}$ ✓		1 (AO1.2× 1)	**DO NOT ALLOW** curved brackets **Examiner's Comments** A wide range of responses, including addition signs, 2x, curved brackets, inverse. Candidates must take care to write the formulae correctly: C*l* rather than C*l₂* was seen a number of times.
	ii	From equation, $n(NO)$ is 2 × $n(Cl_2)$ **OR** Ratio NO:Cl₂ is 2:1		1 (AO3.1× 1)	Response **MUST** refer to stoichiometry of equation and compare molar ratio of both NO and Cl_2 **Examiner's Comments** Most recognised that the value for NO was 2 x Cl_2 but some struggled to explain why. Answers needed to show clear evidence that they had taken into account the stoichiometry of the equation. Some gave responses such as using moles and volume to calculate or to put values into the K_c expression.
	iii	**FIRST CHECK ANSWER ON THE ANSWER LINE** **If answer = $\sqrt{1.31}$ = 1.1 (mol dm⁻³) award 2 marks**		2 (AO2.6× 2)	**ALLOW** 1.1 up to calculator value of 1.144552314 **ALLOW ECF** from inverted K_c

			$[NOCl]^2 = [NOCl]^2 = \dfrac{[NO]^2[Cl_2]}{K_c}$ **OR** $\dfrac{0.34^2 \times 0.17}{0.015}$ **OR** 1.3 ✓ $[NOCl] = \sqrt{1.3} = 1.1$ (mol dm^{-3}) ✓			expression in **(ii)** 2.9(478) x 10^{-4} 1 mark 0.017(1691584) 2 marks **Examiner's Comments** Those candidates that were able to give the correct expression in (i) were often able to obtain the correct value here, demonstrating a good understanding of this topic. Some forgot to take the square root so only obtained one mark.
		iv	As T increases, equilibrium (position) shifts to right **AND** (forward) reaction is endothermic ✓ Equilibrium concentration of NO increases ✓	2 (AO2.5× 2)		**ALLOW** 'favours the right', for 'shifts to right' **ALLOW** moves to right in endothermic direction **Examiner's Comments** Candidates need to be well versed in how to tackle this type of question. Some, despite explaining what would happen, forgot to then state what would happen to the concentration of NO. Some said that the reaction would shift to the right but did not state that the reaction was endothermic. A small number of candidates thought that the reaction was exothermic, despite the + sign by the reaction, and some discussed other factors such as rate or changing pressure.
			Total	6		
3 1	a		<table><tr><td>T /K</td><td>500</td><td>600</td><td>700</td><td>800</td></tr><tr><td>K_p</td><td>5.86 × 10^{45}</td><td>1.83 × 10^{37}</td><td>1.46 × 10^{31}</td><td>1.14 × 10^{26}</td></tr><tr><td>$\dfrac{1}{T}$ /K^{-1}</td><td>2.00 × 10^{-3}</td><td>1.67 × 10^{-3}</td><td>1.43 × 10^{-3}</td><td>1.25 × 10^{-3} ✓</td></tr><tr><td>ln K_p</td><td>105</td><td>86</td><td>72</td><td>60 ✓</td></tr></table> *Calculator values* 1/T /10^{-3} 2.00 1.66 recurring 1.428571429 1.25 ln K_p 105.3844788 85.79996441 71.75857432 59.99824068	2 (AO 1.2×2)		Mark by row **ALLOW** 2 SF or more for 1/T but ignore trailing zeroes **ALLOW** whole numbers (±1) for ln Kp **ALLOW** 1 small slip in each row. e.g. 1.66 for 1.67; 71.7 for 71.8 *Check with calculator values below table*

		BUT DO NOT ALLOW whole number errors, e.g. 85 for 86 **Examiner's Comments** Candidates were expected to complete values for $1/T$ and $\ln K_p$ from supplied T and K_p values. Candidates were supplied with an example and this enabled most candidates to obtain both available marks.
b	Equilibrium (position) shifts to the left **AND** (forward) reaction is exothermic ✓	1 (AO 2.2)	**ALLOW** 'favours reverse reaction' *Implies shift to left* **ALLOW** 'shifts in endothermic direction' BUT only if (forward) reaction stated as exothermic **Examiner's Comments** Most candidates were aware that a decrease in K_p with increasing temperature signals that the forward reaction is exothermic. The question also asked for the effect on the equilibrium position. A significant number of candidates omitted this part of the question. Candidates are advised to check back to all the requirements in a question.

c	**Plotting of graph**
	    All points correctly plotted **AND** best-fit straight line ✓
	
	Gradient
	    Correct gradient of best-fit straight line within the range ±57000 → ±63000 ✓
	
	ΔH calculation (subsumes mark for gradient)
		4
		(AO 3.1)
		
		(AO 3.1)
			
			ALLOW 4 points on graph
			Tolerance 1 small square

		ΔH = (–) gradient × 8.31(4) **OR** calculated value ✓
		
		e.g. from ±60000, ΔH = (+)498840 (J) **OR** *±498.840 (kJ)*
		
		ΔH in kJ mol^{-1}
		    ΔH correct in kJ mol^{-1}
		    AND 3SF
		    AND – sign ✓
		    e.g. from ±498840, ΔH = –499 (kJ mol^{-1})
			(AO 3.2)
			
			(AO 3.2)
				ALLOW ΔH in range: –480 → –530 (kJ mol^{-1})
				This mark subsumes gradient mark
				
				Examiner's Comments
				
				Candidates were required to plot a graph using their calculated values from the above part. The axes for the graph had been provided. It was expected that the plotting of 5 points, with a best-fit straight line, would be straightforward. Many candidates plotted one or more points incorrectly, particularly the point at $1/T$ = 1.25 × 10^{-3}.
				
				Candidates then needed to recognise that the gradient is equal to $-\Delta H/R$ from **Equation 5.1**, to measure the gradient, and then to determine ΔH. Most candidates recognised that the gradient needed to be measured but its value was then not taken any further. The higher-attaining candidates correctly multiplied the gradient by R but did not always convert the calculated J mol^{-1} value into kJ mol^{-1}, or to express their value to 3 significant figures, as required in the question.
				
				Significantly, nearly a third of candidates did not collect any of the four available marks. The question was an excellent discriminator.

d		Extrapolate line to (*y*) intercept **OR** Measure/Use (*y*) intercept ✓ Intercept $= \dfrac{\Delta S}{R}$ **OR** $\Delta S = R \times$ (*y*) intercept ✓ *This statement automatically subsumes 1st mark* **NOTE**: If 'x' intercept, **DO NOT ALLOW** 1st mark but 2nd mark available for × R as **BOD**	2 (AO 3.1x2)	**ALLOW** substitute values of ln K_p, $1/T$ and gradient into **Equation 5.1** ✓ From provided values and gradient = 60000: $= \dfrac{\Delta S}{R}$ = ln K_p – gradient × $1/T$ **OR** 135 – 60000 × 2.50 × 10^{-3} = – 15 ✓

					Examiner's Comments Mathematically able candidates used the $y = mx + c$ equation for a straight line with the supplied mathematical relationship (**Equation 5.1**) to identify the y intercept as $\Delta S/R$. They then stated that ΔS could be determined by multiplying the value of the y intercept by R. Many candidates found the mathematical requirements of the above parts difficult. Responses for this part were often in terms of the gradient instead of 'intercept'.
		Total		**9**	
32		**B**		1 (AO 1.1)	
		Total		**1**	
33		High pressure **AND** low temperature ✓ Right-hand side has fewer (gaseous) moles/molecules **OR** left-hand side has more (gaseous) moles/molecules ✓ (Forward) reaction is exothermic/gives out heat **OR** reverse reaction is endothermic/takes in heat ✓		3 (AO 1.2×1) (AO 1.1×2)	Marks are independent **ORA** throughout **ALLOW** RHS **ALLOW** suitable alternatives for RHS e.g. product side
		Total		**3**	

34		**FIRST CHECK THE ANSWER ON ANSWER LINE**
		If answer = 7.4 award 4 marks
		-- 	
		
		    Initial moles of reactants 1 mark
		$n(CH_3OH)_{initial} = \frac{9.6}{32} = 0.3\,(mol)$
		AND
		$n(CH_3COOH)_{initial} = \frac{12}{60} = 0.2\,(mol)$ ✓
		
		    Equilibrium moles 2 marks
		$n(CH_3COOH)$ reacted $= 0.2 - 0.03 = 0.17\,(mol)$
		AND
		$n(CH_3OH)_{equil} = 0.3 - 0.17 = 0.13\,(mol)$ ✓
				4
				
				(AO 1.2×1)
					ALLOW minimum of **2SF** throughout
					
					ALLOW ECF from initial moles
					
					ALLOW ECF from equilibrium moles
					Use of V not required but Kc expression must be correct

			$n(CH_3COOCH_3)_{equil}$ = 0.17 (mol) **AND** $n(H_2O)_{equil}$ = 0.17 (mol) ✓ K_c **calculation** **1 marks** $K_c = \dfrac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4$ ✓	(AO 2.8×3)	**ALLOW** up to calculator answer of 7.41025641 **Examiner's Comments** This question asked the candidate to calculate K_c. Higher-attaining students tended to gain full marks. Some candidates made full use of tables (e.g. RICE: Reaction, Initial concentration, Change in concentration, Equilibrium concentration) which allowed for credit to be given through error carried forward. Some candidates did not use 0.03 as the change, and lower-attaining candidates did not use water in the K_c expression. Candidates should remember to provide written indications of what it is they are working out – presenting the calculations without any annotations can make it harder for error carried forward marks to be given if there is an error in their calculation.
			Total	**4**	
35			**C**	1 AO1.1	
			Total	**1**	
36			**Pressure**: Right-hand side has more (gaseous) moles **OR** 2 (gaseous) moles form 4 (gaseous) moles ✓ Low pressure **OR** decrease pressure ✓ **Temperature**: (Forward) reaction is endothermic/ΔH is positive **OR** (Forward) reaction takes in heat ✓ High temperature **OR** increase temperature ✓	4 AO1.2 AO2.1 AO1.2 AO2.1	FULL ANNOTATIONS MUST BE USED --- **ALLOW** suitable alternatives for right-hand side, e.g. towards H_2/products **OR** forward direction **OR** increases yield For moles, **ALLOW** molecules/particles **ORA** for reverse reaction, e.g. **ALLOW reverse** reaction is

					exothermic /ΔH is negative/gives out heat
			Total	**4**	
37			toxic/poisonous **OR** forms chlorinated hydrocarbons **OR** forms carcinogenic compounds / toxic compounds ✓	1 AO1.1	**IGNORE** 'harmful'/'dangerous' **IGNORE** chlorine is carcinogenic/causes cancer dangerous for health/causes breathing problems
			Total	**1**	
38	a		$K_c = \dfrac{[CH_3OH]}{[CO] \times [H_2]^2}$ ✓	1 (AO1.2)	Multiplication sign is not required **DO NOT ALLOW** curved brackets
	b	i	**FIRST CHECK THE ANSWER ON ANSWER LINE** If answer = 1.4…….. (mol dm^{-3}) award 2 marks -- $[CH_3OH]$ $= 15.4 \times 0.57 \times 0.40^2$ ✓ $= 1.40448$ (mol dm^{-3})✓	2 (AO2.2 × 2)	**ALLOW ECF** from incorrect expression in **(a)** **ALLOW** 1.4 up to calculator value of 1.40448
		ii	To the right ✓	1 (AO1.1)	**ALLOW** towards the product/CH_3OH
			Total	**4**	
39	a		rate of forwards reaction = rate of backwards reaction **OR** concentrations/pressure/temperature are constant /do not change ✓	1 AO1.1	**DO NOT ALLOW** "are the same"

	b	i	**FIRST, CHECK FOR VALUE OF K$_p$.**
			IF answer = 20.7 (MPa^{-1}), award **4 marks**
			--- 	
			Equilibrium amounts
			   n(NO) = 0.4 (mol)
			   AND n(O$_2$) = 0.9 (mol)
			   AND n(NO$_2$) = 1.2 (mol) ✓
			
			Total moles at equilibrium
			   n_{tot} = 2.5(mol) ✓
			
			Partial pressures
			   p(NO) = $\dfrac{0.4}{2.5} \times 1.21 = 0.1936$ (MPa)
			
			   AND p(O$_2$) = $\dfrac{0.9}{2.5} \times 1.21 = 0.4356$ (MPa)
			
			   AND p(NO$_2$) = $\dfrac{1.2}{2.5} \times 1.21 = 0.5808$ (MPa) ✓
				4 (AO2.4× 4)	**FULL ANNOTATIONS MUST BE USED**
					-- 	
					ALLOW ECF throughout
					
					ALLOW 20.6 from 3 SF partial pressures, 0.194, 0.436 and 0.581
					
					IF there is an alternative answer, check to see if there is any **ECF** credit possible using working below
					-- 	
					
					Look for values to 3 SF here:
					0.194, 0.436 and 0.581

K_p value

$$Kp = \frac{0.5808^2}{0.1936^2 \times 0.4356} = 20.7 \text{ to 3}$$

SF (MPa^{-1}) ✓

ALLOW
25.0 as ECF (from omission of partial pressures for **3 marks)**

Examiner's Comments
This question asked the candidate to calculate K$_p$. Some candidates made full use of tables which allowed for credit to be given through error carried forward. Some candidates did not successfully calculate the number of moles at equilibrium but completed the subsequential steps.

Lower-attaining candidates divided the mole fraction by the partial pressure rather than performing a multiplication and omitted the square relationship within the K$_p$ expression. Candidates should remember to provide written indications of what it is they are working out – presenting the calculations without any annotations and structure can make it harder for error carried forward marks to be given.

Change	K_p	Equilibrium amount of NO$_2$	Initial rate
Temperature increased	smaller	smaller	greater
Pressure increase	same	greater	greater
Catalyst added	same	same	greater
	✓	✓	✓

ii

3 (AO1.2× 3)

Mark by **COLUMN**

ALLOW obvious alternatives for greater/smaller/same,
e.g.
increases/decreases/ more/less

Total | 8

At 90 °C/higher temperature

- Faster rate **AND** more frequent collisions ✓
- More particles have the activation energy/E_a or greater ✓
- [Co(H$_2$O)$_6$]$^{2+}$ is lower ✓
- (forward reaction) ΔH -ve **OR** exothermic ✓

40 a

4 (1 ×AO2.7) (1 ×AO1.2) (1 ×AO2.3) (1 ×AO1.2)

ORA for 50 °C
IGNORE more successful collisions
ALLOW more molecules have enough energy to react
ALLOW atoms/molecules/ions
ALLOW decreases

Examiner's Comments

This question asked candidates to

					explain the different rates from a novel experiment carried out at 50°C and 90°C, and to predict the ΔH sign for the forward reaction. Candidate explanations for the rates were often superficial, solely in terms of greater energy at 90°C. Many responses referred neither to the different frequency of collisions nor the greater number of particles exceeding the activation energy at 90°C. Most candidates predicted that ΔH would have a negative sign. Candidates were expected to link the evidence from the absorbance data in the graph to less $[Co(H_2O)_6]^{2+}$ being present at 90°C. When experimental information has been presented, candidates are advised to look for the evidence responsible in their explanations.
	b	i	Cl /It/They react with $AgNO_3$ / Ag^+ /silver ions **OR** AgCl formed **OR** $Ag^+ + Cl \rightarrow AgCl$ ✓	1 (AO3.2)	**IGNORE** chlorine/Cl for chloride ion **IGNORE** $AgCl_2$ **Examiner's Comments** Almost all candidates realised that Cl⁻ ions would react with the added $AgNO_3$ at time = t_1.
		ii	$[CoCl_4^{2-}]$ decreases **AND** $[Co(H_2O)_6]^{2+}$ increases ✓ Cl increase is 4 × change in $[CoCl_4^{2-}]$ / $[Co(H_2O)_6]^{2+}$ ✓ Equilibrium shifts to right ✓	3 (2 ×AO3.1) (1 ×AO3.2)	**IGNORE** missing charges and small slips in formulae, e.g. $CoCl_4$ missing bracket, etc **IGNORE** Cl for changes in concentration **ALLOW** suitable alternatives for 'shifts to right', e.g. towards products **OR** in forward direction **OR** 'favours the right' **Examiner's Comments** In contrast with Question 4 (a), most candidates did interpret the graphical information provided and related this to the reduced concentration of $CoCl_4^{2-}$ ions and the increased concentration of $[Co(H_2O)_6]^{2+}$ ions. Most candidates also referred to

					Equilibrium 4.1 to conclude that the equilibrium shifts to the right. Only the very best candidates recognised that the increase in Cl⁻ concentration following the initial addition of $AgNO_3$ was 4 times greater than the increase in the concentration of $Co(H_2O)_6]^{2+}$, arising from the 4 : 1 ratio in the stoichiometry in the equation.
		Total		**8**	
41		i	**Level 3 (5-6 marks)** A comprehensive explanation of effect of temperature **AND** pressure on equilibrium is given with some details about rate **AND** operating conditions *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** The candidate attempts three scientific points, but explanations are incomplete. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)** A simple description based on at least two of the main scientific points. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response or no response worthy of credit.	6 (AO 1.2 × 3) (AO 2.5 × 3)	**Indicative scientific points may include:** **ALLOW** reverse arguments throughout **Effect of Temperature on equilibrium position** • (Forward) reaction is endothermic/ΔH is +ve • High temperature shifts equilibrium to right **Effect of Pressure on equilibrium position** • Left-hand side has fewer (gaseous) moles • **OR** 2 (gaseous) moles form 4 (gaseous) moles • Low pressure shifts equilibrium to right **Effect on rate of reaction** • High temp increases rate • Low pressure reduces rate • Catalyst increases rate • Catalyst lowers activation energy • Discussion using collision theory to support arguments

Operating conditions (not inclusive)

- Compromise conditions needed
- High temperatures increase energy demand/costs
- Slightly higher pressure used than optimum
- Higher pressures unsafe
- Catalyst reduces need for higher temperatures
- Catalyst doesn't effect the position of equilibrium
- Excess steam shifts equilibrium to right

Examiner's Comments

Only a small number of candidates were given all 6 marks for their response. Many responses made little or no reference to equilibrium, considering only the rate of reaction. A clear understanding of the difference between rate and equilibrium was essential to scoring highly on this question.

Excellent descriptions were given regarding the role of the catalyst on the rate of reaction, possibly influenced by the previous question. Some gave detailed responses in terms of the impact of both pressure and temperature on the equilibrium position but then did not give the changes made by industry such as reducing temperature due to energy demand or increasing pressure to increase rate.

Some candidates indicated that 15atm was a low pressure including reference to it being "lower than normal atmospheric pressure" which suggested that they did not

understand either the measurement in atmospheres and/or scale of pressure. A common incorrect response was to suggest that a higher pressure gives increased yield as more moles on right/products.

Some stated that the reaction was exothermic, clearly confusing the enthalpy change signs. Some also described the "endothermic side" demonstrating a lack of understanding that enthalpy changes require a difference between products and reactants. Many did not correctly consider the use of excess of steam to increase concentration of reactant and shift equilibrium to products/right but talked in terms of limiting reagents, e.g. "This is used so all of the methane is reacted" or increased collisions.

Many were prone generalisations, e.g. "These conditions are used industrially to achieve the most hydrogen efficiently with the least amount of undesired (waste) products". Candidates need to be encouraged to plan their answers, even using subheadings to organise information and follow the key approach: point, evidence, explain. Candidates should also be encouraged to re-read their answers to check communication is clear and accurate without any contradictory statements.

Many included irrelevant or inaccurate information such as describing the toxicity of carbon monoxide, so reducing yield of that being beneficial, or "using a catalyst improves atom economy".

<table>
<tr>
<td></td>
<td colspan="2">

(i) **OCR support**

This question was good at highlighting candidates understanding of the impact of different conditions on equilibrium reactions. We have produced a delivery guide to help with teaching about equilibrium:

https://www.ocr.org.uk/Images/261544-equilibrium.pdf

Exemplar 2

A catalyst is used to lower energy costs because reactions with catalysts can be conducted at lower temperatures. Less pollutants could be produced as well as a result of using a catalyst.

The overall reaction is endothermic hence higher temperature would produce a high higher maximum % yield of hydrogen as the equilibrium can then a shift to favour the forward reaction. However, lower temperatures should be used industrially as maintaining high temperatures are costly and if the temperature should not be too low as to avoid having a very to low rate of reaction. Lower pressure should be used to to maximise the yield of hydrogen as there are more number of moles on the product side of the equation. Nevertheless, a higher pressure should be used to increase the rate of reaction and not too high as to becoming to costly and creating an unsafe workplace environment.

Additional answer space if required.

Therefore a temperature and pressure must reach a compromise in order to maximise the yield of hydrogen while a catalyst is used to reduce costs and pollutants produced.

This exemplar shows a candidate who achieved L3 with all 6 marks given. They have considered both the effect of temperature and pressure on equilibrium and potential compromises used industrially. They have also considered the impact of using a catalyst. Their response is logically structured and has a clear line of reasoning.

</td>
</tr>
<tr>
<td>ii</td>
<td>

FIRST CHECK THE ANSWER ON ANSWER LINE
IF answer = 24.1, **award 2 marks**

K_c **expression**

$(K_c =) \dfrac{[CO][H_2]^3}{[CH_4][H_2O]}$ **OR** $\dfrac{(0.510)(1.53)^3}{(0.111)(0.682)}$

OR 24.12.............. ✓

</td>
<td>

2
(AO2.5)
(AO 2.6)

</td>
<td>

IF there is an alternative answer, check for any **ECF** credit possible using working below.

ALLOW calculated value 24.12887731 correctly rounded to 3 or more SF for 1st marking point

</td>
</tr>
</table>

			Answer to 3 SF $K_c = 24.1$ ✓		**ALLOW ECF to 3 SF** **ONLY** from inverted K_c expression → 0.0414 **DO NOT ALLOW** $\frac{[CO] + [H_2]^3}{[CH_4] + [H_2O]}$ (no marks) **IGNORE** attempts at units **Examiner's Comments** This question was well answered with most candidates scoring both marks. Common errors seen included: inverse K_c expression, final answer not to 3 significant figures, adding rather than multiplying concentrations, calculator error ($[H_2]^2$ instead of $[H_2]^3$) or transcription errors (e.g. using 0.11 rather than 0.111).
			Total	**8**	
4 2	a		**Level 3 (5–6 marks)** Uses correct method to calculate K_c **AND** explains why most operational condition is different with few omissions in the explanation. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Uses correct method to calculate K_c with few errors **OR** Derives a correct expression for K_c with an attempt at the K_c calculation **AND** explains why an operational condition is different with some omissions. *There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.* **Level 1 (1–2 marks)**	6(AO2.4 ×4 AO1.2×2)	**Indicative scientific points may include:** **IGNORE trailing zeroes** **Equilibrium amounts** $n(N_2)$: 1.20 − 0.08 = 1.12, $n(H_2)$: 3.60 − 0.24 = 3.36 **Equilibrium concentrations** $[N_2] = \frac{1.12}{8.00} = 0.140$ (mol dm⁻³) $[H_2] = \frac{3.36}{8.00} = 0.420$ (mol dm⁻³) $[NH_3] = \frac{0.160}{8.00} = 0.0200$ (mol dm⁻³) **Equilibrium expression and K_c value wih units** $K_c = \frac{[NH_3]^2}{[N_2] \times [H_2]^3}$

| | | | Derives a correct expression for K_c **AND** explains why one operational condition is different with some omissions.
OR
explains why most operational conditions are different

There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.

0 marks
No response or no response worthy of credit. | | $K_c = \dfrac{0.0200^2}{0.140 \times 0.420^3} = 0.0386$

Calculator: 0.03856417851 **Units:** $\text{dm}^6 \text{ mol}^{-2}$

Explanation for operational differences.
Temperature

• Low temperature for maximum yield: (ΔH −ve \exothermic)
• High temperature to increase rate
Pressure

• High pressure for maximum yield (fewer (gaseous) moles/molecules of products)
• High pressure expensive to generate **OR** high pressure is a safety hazard
Catalyst

• Allows a lower temperature to be used for maximum yield.
• Reducing fuel expense **OR** increasing rate
Examiner's Comments

This Level of Response question was generally well answered with many candidates achieving maximum marks by simply considering what was required in the question. Responses were often split between a calulation on the main paper and the conditions explanation on extra pages. The calculation errors included no shift or incorrect shift in the equilibrium values. Not calculating the concentration or incorrectly multiplying by 8 rather than dividing by 8. Some candidates attempted a 'hybrid' calculation of Kp by trying to calculate a mole fraction and partial pressures. There was a number of candidates who confidently worked out the value of |

K_c. There were also some very good analyses of the operational conditions. Many of those who had done well on the calculation treated the explanation as an afterthought, not giving it enough attention to give them an answer that would access Level 3.

Exemplar 2

An example of a complete answer, showing a good level of communication in the description and the calculation layout, achieving Level 3 (6 marks) is shown above.

This candidate gave a clear method using an "ICE" table to calculate the number of moles at equilibrium. The calculation of the new concentrations can be seen by the use of [ ] and division by 8. The candidate then shows the Kc expression and substitutes the numerical values before successfully calculating the value and includes the units. This is followed by a concise explanation of the conditions used by industry.

b	i	Equilibrium (position) shifts to the left (as T is decreased) **AND** (forward) reaction is endothermic ✓	1(AO1.2)	**ALLOW** 'favours backward reaction' *Implies shift to left* **ALLOW** 'shifts in exothermic direction' BUT only if (forward) reaction stated as endothermic **Examiner's Comments**

					Candidates coped well with this question, but many candidates did not gain the mark due to ambiguous statements. Some identified the forward reaction as endothermic, but stated that Kp decreased which was given in the question. Others simply stated that the forward reaction was endothermic as the reverse reaction was exothermic.
		ii	Student 2 is correct **AND** same number of **gas** particles/ **gas(eous)** molecules/moles of **gas** on each side (of equation) ✓	1(AO3.2)	**ALLOW AW** that suggests student 2 is correct **Examiner's Comments** Many candidates gave the correct reason to agree with student 2. Those who agreed with student 1 did not see the equation as a heterogeneous equilibrium system. There were a small number of responses agreeing with student 2 but for the wrong reason – such as a confusion about how the position of equilibrium can change when the value of K_p stays constant. Candidates are advised to read through and address all parts of the question as a minority of students didn't identify which student was correct but gave a correct explanation.
			Total	**8**	
4 3			**D**	1(AO1.1)	**Examiner's Comments** Candidates produced a variety of responses with just over half choosing the correct option D. Option C was the main distractor.
			Total	**1**	
4 4			**A**	1(AO2.6)	**Examiner's Comments** This question discriminated very well. Evidence from annotations showed that the successful candidates substituted the 0.1 mol dm^{-3} concentration into the K_c

					expression for each equilibrium and calculated K_c by calculator. This method should guarantee the correct answer.
		Total		**1**	
45	a	All reaction species have same state/phase **OR** Reactants **AND** products has same state ✓		1 (AO1.1)	**ALLOW** SO_2 **AND** O_2 **AND** SO_3 for all species **OR** reactants and products are gases **OR** the molecules are all gases **IGNORE** reactants and catalyst have same state **Examiner's Comments** Only about half the candidates obtained this mark suggesting that this term had not been recalled by many. A common error stated that the catalyst and reactants were in the same state. Responses from lower-attaining candidates sometimes had the appearance of guesses.
	b	**Throughout,** $\quad$ **ALLOW** suitable alternatives for right-hand side, $\qquad$ e.g. towards SO_3/products $\qquad\quad$ **OR** forward direction --- **Pressure** $\quad$ **2 marks** $\quad$ **Increased** pressure shifts equilibrium **to right** $\qquad\qquad$ **OR** favours the **right** $\qquad\qquad$ **OR increases** yield (of SO_3) ✓ Right-hand side has fewer (gaseous) moles **OR** 3 (gaseous) moles → 2 (gaseous) moles ✓ **Temperature** $\quad$ **2 marks**		5 (AO1.1) (AO1.2) (AO1.2) (AO1.1) (AO1.2) (AO1.2)	**FULL ANNOTATIONS MUST BE USED** -- **ORA for** reverse reaction e.g. decreased pressure shifts equilibrium to left For moles, **ALLOW** molecules/particles **ORA for** reverse reaction e.g. decreased temperature shifts equilibrium to right **ALLOW reverse** reaction is endothermic /ΔH is positive/takes in heat

			Increased temperature shifts equilibrium **to left** OR favours the **left** **OR decreases** yield (of SO_3) ✓ (Forward) reaction is exothermic/ΔH is negative **OR** (Forward) reaction gives out heat ✓ **Catalyst 1 mark** No shift in equilibrium **OR** no effect on yield (of SO_3) ✓		**ALLOW** rates of forward and reverse reaction increase **by same** amount **IGNORE** 'no increase in yield' *Yield could still decrease* **Examiner's Comments** This long-answer question was approached very well and there were some excellent and concise answers. Only the less successful responses did not identify the main trends. Marks were often lost for responses in general terms, rather than related to the scenario in the question. For example, some candidates stated that the equilibrium would shift in the direction with fewer moles, without stating what that direction was for this equilibrium. Some candidates contradicted themselves due to a lack of fully understanding how Le Chatelier's Principle should be applied. It was also common to see lengthy responses in which candidates discussed the effect of rate and compromise (not asked for in this question) and then confused equilibrium yield with overall yield.
c	i		**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF answer = 7.9×10^4 award 2 marks** -- K_c **expression** $(K_c =) \dfrac{[SO_3]^2}{[SO_2]^2 [O_2]}$ **OR** $\dfrac{(5.0 \times 10^{-2})^2}{(3.0 \times 10^{-3})^2 \times (3.5 \times 10^{-3})}$ OR 79365. .... ✓	2 (AO2.6 ×2)	**IF** there is an alternative answer, check for any **ECF** credit possible using working below. -- Square brackets required for K_c expression **ALLOW ECF to 2 SF and standard form** **ONLY** from inverted K_c expression

					$\rightarrow 1.3 \times 10^{-5}$
			Answer to 2 SF and in standard form $K_c = 7.9 \times 10^4$ ✓		**DO NOT ALLOW** $\dfrac{[SO_3]^2}{[SO_2]^2 + [O_2]}$ (no marks) **IGNORE** attempts at units **Examiner's Comments** The K_c expression was written well by many inverted the expression or added rather than multiplying the values. Indices were usually included. Many candidates gave responses to more than 2 significant figures (2SF) and some did not give the response in standard form. Candidates should be made aware that the term in the question of 'most appropriate' means that the final response should be shown to the least number of significant figures in the supplied data. In this scenario, all values were provided to 2SF and so the final response should also be expressed to 2SF. (i) **OCR support** The [Mathematical Skills Handbook](#) provides guidance on the use of significant figures which can be shared with students.
		ii	Equilibrium **shifts** to the right/towards products/SO_3 ✓	1 (AO3.1)	**ALLOW** equilibrium favours the right **Examiner's Comments** Few candidates successfully answered this difficult application question. Some candidates considered

			ensuring complete combustion, or not wasting reactants, or various environmental reasons. The question did supply a hint: 'in terms of equilibrium' but this was ignored by most candidates. The idea of equilibrium shift to the right was essential.		
		Total		**9**	
46		**B**		1 (AO 2.1)	**Examiner's Comments** This question was for the most part answered correctly with B. Errors came from not recognising the reaction is endothermic and therefore its equilibrium would shift to the left when the temperature decreases, ruling out option 2. **Assessment for learning** Practice multiple choice questions can improve the skill in solving and identifying the distractors. Exposure to this type of question style will decrease the time taken over each question. These can often form the basis of end of topic tests. Multiple choice question quizzes can be found via the resource-finder on Teach Cambridge and there are instructions on how to use the online versions of the multiple choice quizzes.
		Total		**1**	
47		**Level 3 (5–6 marks)** ALL 3 correct orders linked to explanations **AND** rate equation **AND** rate constant *There is a well-developed line of reasoning which is*		6 (AO 3.1 × 3) (AO 3.2 × 3)	**Indicative scientific points may include** <u>**Orders**</u> • 1st order wrt Br^- • 1st order wrt BrO_3^-

clear and logically structured.

Level 2 (3–4 marks)

Three correct orders
AND two out of:
some evidence of an explanation linked to an order
rate equation
rate constant

OR

Three correct orders
with an attempt at:
Some evidence of an explanation link to an order
rate equation
rate constant

OR

Two correct orders linked to explanations
AND rate equation
AND rate constant consistent with the candidate's orders

There is a line of reasoning with some structure and supported by some evidence.

Level 1 (1–2 marks)

Two correct orders
OR
One correct order
AND attempts to determine rate equation **OR** rate constant.
OR
One correct order
AND attempts an explanation.

There is an attempt at a logical structure with a reasoned conclusion from the evidence.

0 mark *No response worthy of credit.*

- 2nd order wrt H^+

Rate equation

- rate = $k[Br^-][BrO_3^-][H^+]^2$

Calculation of k from any row of data, e.g.

$$k = \frac{Rate}{[Br^-][BrO_3^-][H^+]^2}$$

$$k = \frac{2.52 \times 10^{-4}}{0.020 \times 0.120 \times (0.080)^2} = 16.4(0625)$$

Explanations from results e.g.

Br^-	$[Br^-] \times 3$	rate $\times$ 3	Expts 1 and 2
BrO_3^-	$[Br^-] \times 2$ **AND** $[BrO_3^-] \div 2$		
	rate: no change		Expts 1 and 3
	OR		
	$[Br^-] \times 2/3$ **AND** $[BrO_3^-] \div 2$		
	rate: $\times$ 1/3		Expts 2 and 3
H^+	$[BrO_3^-] \div 2$ **AND** $[H^+] \times 5$		
	rate $\times$ 12.5		Expts 1 and 4
	OR		
	$[Br^-] \div 3$ and $[BrO_3^-] \div 2$ and $[H^+] \times 5$		
	rate $\times$ 4.17		Expts 2 and 4
	OR		
	$[Br^-] \div 2$ and $[H^+] \times 5$		
	rate $\times$ 12.5		Expts 3 and 4

ALLOW a sequential approach where they apply known orders first

ALLOW minor slips as we are looking for an holistic approach to LoR marking

NOTE: A clear and logically structured response would link

orders to the experiment and experimental results provided. They could provide units

Units
$dm^9\ mol^{-3}\ s^{-1}$
ALLOW any order, e.g. $mol^{-3}\ dm^9\ s^{-1}$

Examiner's Comments

The first Level of Response question in the paper was answered well. Almost all candidates were able to conclude that the experimental results showed that they were consistent with first order with respect to Br^-. Some candidates were able to use a sequential approach to determine the orders with respect to BrO_3^- and H^+, reaching a Level 3, but others found this more problematic. Some did not notice that more than one concentration had been changed between experiments. This led to many determining the rate to be 0 order with respect to $[BrO_3^-]$ and $[H^+]$. Candidates should focus on the quality of their descriptions when linking data to their conclusions with some candidates creating their own data set to fit their explanations. Having determined orders, nearly all candidates were able to give a corresponding rate equation and could calculate a value for the rate constant, albeit with frequent omission of units. Some candidates confused the rate equation with a K_c expression.

				Total	6	
4 8	a	i	$(K_p) = \dfrac{p(N_2O_4(g))}{p(NO_2(g))^2}$ ✓ **Units** atm^{-1} ✓	5 (AO 1.2 × 1) (AO 1.2 × 1) (AO 2.6 × 3)	**ALLOW** species without state symbols and without brackets. e.g., pSO_3^2 , $ppSO_3^2$, PSO_3^2, $p(SO_3)^2$ $(pSO_3)^2$ etc. **DO NOT ALLOW** square brackets **ALLOW** atm as **ECF** if K_p is upside

CHECK THE ANSWER ON ANSWER LINE
if answer = 1.17×10^{-2} OR 1.18×10^{-2} award 3 calculation marks
----

Calculation

- $nN_2O_4 = 0.3(00)$ (mol)
  AND $n$total = 5.7(0) (mol) ✓
- $pNO_2 = (\frac{5.4(0)}{5.7(0)} \times 5.00 =) 4.74$ (atm)
  AND $pN_2O_4 = (\frac{0.3(00)}{5.7(0)} \times 5.00 =) 0.263$ (atm) ✓
- **K_p to 3 SF**
  $(K_p = \frac{0.263}{4.74^2} =) 1.17 \times 10^{-2}$ ✓

down

ALLOW ECF throughout
ALLOW 3 SF up to the calculated value.
IGNORE RE after 3SF

Calculator value
$pNO_2 = 4.7368……$
$pN_2O_4 = 0.26315….$

Mark use of 2SF in working as incorrect **once** and then allow ECF
Answer MUST be 3 SF

Common error for 2 calculation marks:
2.47×10^{-2} (using 0.6 mol N_2O_4)

Examiner's Comments

Candidates tend to find K_p calculations difficult and so a strategy to work their way through them could include:

- write the K_p expression, with units, ensuring square brackets are not used. Common mistakes with units included atm^{-1} mol^{-1}, mol^{-1} dm^3, kPa^{-1}
- calculation of initial moles present, with careful consideration of the use of appropriate significant figures
- calculation of the change in moles present
- deduction of the number of moles present at equilibrium
- determination of total moles present at equilibrium.

These steps are often best completed as RICE tables (Ratio, Initial, Change, Equilibrium) and

					should look to use the appropriate amount of significant figures: • calculation of mole fractions at equilibrium • calculation of partial pressures at equilibrium • inserting partial pressure vales into the K_p expression and avoiding any unnecessary unit conversions • writing an answer to the required number of significant figures.
		ii	**Higher temperature** ΔH is negative / exothermic (for forward reaction) **AND** equilibrium shifts to left/to LHS/decreases yield ✓ **Higher pressure** 2 (gaseous) moles form 1 (gaseous) mole/ to side with fewer moles **AND** Equilibrium shifts to right /RHS/increases yield ✓ **Comparison** Difficult to predict relative contributions of two opposing factors ✓	3 (AO 2.1 × 2) (AO 3.1 × 1)	**ORA** **ALLOW** correct equilibrium shifts without explanations for 1 mark **ALLOW** opposing effects may not be the same size **ALLOW** effects could cancel each other out **ALLOW** effects oppose one another **DO NOT ALLOW** if both equilibrium shifts are in the same direction **DO NOT ALLOW** just 'it is difficult to predict equilibrium position' (in question) For the **3rd mark**, we are assessing the idea that we don't know which factor is dominant **Examiner's Comments** This question was answered for the most part correctly with many candidates scoring 2 marks for the explanations of the effect on the equilibrium position by the changing of the temperature and pressure. Most candidates were able to recognise the changes had opposite

				effects but could not score the final mark, as their response needed the concept of opposing factors, or 'we don't know which factor is dominant'. Some did not write anything about equilibrium and attempted answers based on rate, or loss of energy/chemicals to the surroundings.
	b	**Rearranging ideal gas equation** $n = \frac{pV}{RT}$ ✓ **Unit conversion AND substitution into** $n = \frac{pV}{RT}$: - $R = 8.314$ **OR** 8.31 - V in $m^3 = 74 \times 10^{-6}$ - T in $K = 348$ - P in $Pa = 101 \times 10^3$ *e.g.* $\frac{101 \times 10^3 \times 74.0 \times 10^{-6}}{8.314 \times 348}$ ✓ **Calculation of n** $n = 2.58............ \times 10^{-3}$ *(mol)* ✓ **Calculation of M** $M = (0.28 \div 2.58.... \times 10^{-3}) = 108(............)$ ✓ **Molecular formula** that is the closest to the calculated M_r value. e.g. M_r 108 = N_2O_5 ✓	5 (AO 2.1 × 1) (AO 2.6 × 3) (AO 3.2 × 1)	**FULL ANNOTATIONS MUST BE USED** --- **ALLOW ECF** throughout if all values have been used to calculate n **IF** $n = \frac{pV}{RT}$ is omitted, **ALLOW** when values are substituted into rearranged ideal gas equation **CARE:** Correct n value subsumes first marking point **only** as two incorrect unit conversions can lead to correct n Calculator value: from 8.314 $n = 2.583234483 \times 10^{-3}$ from 8.31 $n = 2.584477917 \times 10^{-3}$ Calculator value: M from 8.314 = 108.3912443 *M from 8.31 = 108.3390955* M from $0.28 \div 2.58 \times 10^{-3}$ = 108.5 **OR** 109 **ALLOW ECF** from calculation of *n provided formula of oxide contains at least one N i.e. NO (Mr = 30)* -- **Use of 24 dm³**: Final 2 marks possible by **ECF**

e.g. $n = \frac{74.0}{24000} = 3.08 \times 10^{-3}$

No mark (*calculation much simpler*)

$M = \frac{0.28}{3.08 \times 10^{-3}} = 90(.8)$ **ECF**

N_3O_3 **ECF**

DO NOT ALLOW N_2O_4 (in question)

ALLOW ECF matching calculated M

Examiner's Comments

This question was well answered by nearly all candidates and many scored all 5 marks. A number used the wrong units for the pressure and the volume so used both kPa and dm^3. This resulted in the correct number of moles and scored 4 marks as error carried forward. Most candidates were able to find the formula from the molar mass and very few used the incorrect molar volume route.

	Total	13	

49	C	1	**Examiner's Comments** The correct answer was C. This was a well answered question with most candidates gaining the mark. The most common error was B, where reactants and product concentration became equal. It is important that candidates can apply definitions and theory to diagrams. **(?) Misconception** Dynamic equilibrium exists in a

					closed system when the rate of the forward reaction is equal to the rate of the reverse reaction and the concentrations of reactants and products <u>do not change</u>. It is a misconception that equilibrium is at the point where reactants and product concentration became <u>equal</u>.
		Total		**1**	

50	i	**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF answer = 0.455 award 4 marks** **AND IF units = $atm^{1/2}$ award 5 marks** --- Equilibrium moles ✓ $N\,SO_3 = 1.35$, $n\,O_2 = 0.45(0)$ **AND** n total = 2.7(0) Partial pressures ✓ <table><tr><td>$p(SO_3)$</td><td>$\dfrac{1.35}{2.7(0)} \times 2.80$ **OR** 1.4(0)</td></tr><tr><td>$p(SO_2)$</td><td>$\dfrac{0.900}{2.7(0)} \times 2.80$ **OR** 0.933</td></tr><tr><td>$p(O_2)$</td><td>$\dfrac{0.450}{2.7(0)} \times 2.80$ **OR** 0.467</td></tr></table> $(K_p) = \dfrac{p(SO_2)\ p(O_2)^{1/2}}{p(SO_3)}$ **OR** $(K_p =)\ \dfrac{(0.933) \times (0.467)^{1/2}}{(1.40)}$ ✓ ✓ **Answer to 3 SF** $K_p = 0.455$ ✓ **Units** Substitution of units into correct K_p expression $\dfrac{atm^1 \times atm^{1/2}}{atm^1} = atm^{1/2}$ ✓ ✓		5	**IF** there is an alternative answer, check for any **ECF** credit possible using working below. --- **ALLOW** 3SF or more unless there is a trailing zero e.g. **ALLOW** $p(SO_3) = 1.4$, n total = 2.7 **ALLOW** all marks to be awarded if atmospheres are converted into other pressure units e.g. to kPa. **ALLOW** use of fractions for intermediate working **ALLOW** $(K_p) = \dfrac{p(SO_2)\ p^{1/2}(O_2)}{p(SO_3)}$ **ALLOW** $K_p^2 = \dfrac{p(SO_2)^2 \times p(O_2)}{p(SO_3)^2}$ **IGNORE** [ ] (we are just looking for the calculation) **ALLOW ECF** for units of an incorrect K_p expression **ALLOW** $atm^{0.5}$ **DO NOT ALLOW** $\sqrt{atm}$ **Common errors** **4 marks** (3 marks for calculation + unit mark) 0.207 (from expression $\dfrac{p(SO_2)^2 \times p(O_2)}{p(SO_3)^2}$) Unit: atm

2.20 (from inverted expression) Unit: $atm^{-1/2}$

Examiner's Comments

Candidates tend to find Kp calculations difficult and so a strategy to work their way through them could include:

- Write the Kp expression using the molar ratio given in the question. Care should be taken not to change the molar ratio to help an easier calculation. Square brackets should not be used as these represent concentration.
- Calculation of initial moles present, with careful consideration of the use of appropriate significant figures
- Calculation of the change in moles present
- Deduction of the number of moles present at equilibrium
- Determination of total moles present at equilibrium

These steps are often best completed as RICE tables (Ratio, Initial, Change, Equilibrium) and should look to use the appropriate amount of significant figures to avoid having a rounding error in the final answer.

(?)   **Misconception**

K_p values are for the equation as stated. Candidates should recognise that changing the stoichiometry of the equation changes the K_p value.

	ii	ΔH is +ve / endothermic (in forward direction). **AND** (At higher temperature,) equilibrium shifts to right hand side ✓ (T_2) has greater K_p value **OR** $7.7 \times 10^{-2} > 3.3 \times 10^{-5}$ ✓		2	**ORA** throughout **ALLOW** towards the products for right hand side **ALLOW** increases yield of products **DO NOT ALLOW** T_1 has greater K_p value **Examiner's Comments** Candidates performed well with this question and many stated that K_p would increase. Some identified the forward reaction as endothermic but did not link this to equilibrium being shifted to the right, thus increasing the ratio within the K_p expression. A few candidates sought to incorrectly explain the effect by using Le Chatelier effect on pressure.
	iii	One mark per correct row ✓ ✓ | Change	Decrease	No change	Increase
---	---	---	---
No catalyst		✓	
Increased pressure		✓				2	**Examiner's Comments** This proved a challenging question where candidates did not stick to the principle that K_p (or K_a) values only change due to temperature changes. Only a few candidates scored both marks with many having the K_p value changing due to increased pressure.
		Total		**9**	
5 1		**B**		1	**Examiner's Comments** Almost all candidates were aware of how to express the K_c expression for an equilibrium, choosing the correct option B.
		Total		**1**	
5 2	i	Two (✓ ✓) from: • **rate** of forward reaction = **rate** of reverse reaction		2	**IGNORE** reactions take place together/reversible reaction **ALLOW** backward for reverse

			• Concentrations (of reactants and products) do not change/are constant • In a closed system/environment		**DO NOT ALLOW** concentration of reactants = concentration of products **ALLOW** 'nothing can leave/enter' **Examiner's Comments** Most candidates identified at least one feature of a dynamic equilibrium. 'In a closed system' was given marks most often, and other mark-worthy features were 'the same rate for forward and reverse reactions' and 'concentrations do not change'. Less successful responses that were not given marks included 'reversible reaction' and 'concentrations are the **same**'.
		ii	**Temperature:** (Forward) reaction is exothermic/ΔH is negative/ (Forward) reaction gives out heat **AND** Low temperature ✓ **Pressure:** Right-hand side has fewer (gaseous) moles/ 4 (gaseous) moles form 2 (gaseous) moles **AND** High pressure ✓ **Equilibrium shift:** Equilibrium/system/equation shift expressed correctly seen **at least once** ✓	3	*FULL ANNOTATIONS MUST BE USED* **ALLOW reverse** reaction is endothermic / ΔH is positive **OR** reverse reaction takes in heat **ALLOW decrease** temperature for **low** temperature For moles, **ALLOW** molecules/particles **ORA for** reverse reaction **DO NOT ALLOW** gaseous atoms **ALLOW increase** pressure for **high** pressure **For shifts**, **ALLOW** 'shifts/moves/pushes' towards right'/NH_3/products **OR** in favours the forward direction **OR** favours the right **Examiner's Comments** This long-response question was approached very well and there were some excellent and concise responses.

					Only the less successful responses did not identify the main trends. Candidates are well-versed with tackling this type of question and most were able to write sensible explanations. However, marks could not be given for insufficiently specific responses. For example, some candidates stated that increased pressure would shift the equilibrium in the direction with fewer moles, without stating what that direction was for this equilibrium. It was also common to see explanations that contradicted earlier statements. Responses could be improved if candidates read through what they write to see if it makes cohesive sense. Nearly half of the scripts were given the full 3 marks, the question proving to be a good discriminator.
		Total		**5**	