1. NO(g), H_2(g), N_2(g) and H_2O(g) exist in equilibrium:

$$2NO(g) + 2H_2(g) \rightleftharpoons N_2(g) + 2H_2O(g)$$

At room temperature and pressure, the equilibrium lies well to the right-hand side.

Which of the following could be the equilibrium constant for this equilibrium?

A. 1.54×10^{-3} mol dm^{-3}
B. 6.50×10^{2} mol dm^{-3}
C. 1.54×10^{-3} dm^{3} mol^{-1}
D. 6.50×10^{2} dm^{3} mol^{-1}

Your answer ☐

[1]

2. Two students set up the equilibrium system below.

$$CH_3COOC_2H_5(l) + H_2O(l) \rightleftharpoons C_2H_5OH(l) + CH_3COOH(l)$$

The students titrated samples of the equilibrium mixture with sodium hydroxide, NaOH(aq), to determine the concentration of CH_3COOH.

The students used their results to calculate a value for K_c.
The students' values for K_c were different.

Which of the reason(s) below could explain why the calculated values for K_c were different?

1: Each student carried out their experiment at a different temperature.
2: Each student used a different concentration of NaOH(aq) in their titration.
3: Each student titrated a different volume of the equilibrium mixture.

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

Your answer ☐

[1]

3(a). 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.

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

(b). A chemist mixes together 0.450 mol N_2 with 0.450 mol H_2 in a sealed container.

The mixture is heated and allowed to reach equilibrium.

At equilibrium, the mixture contains 0.400 mol N_2 and the total pressure is 500 kPa.

Calculate K_p. Show **all** your working.

Include units in your answer.

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

4. The equilibrium system below is set up.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = +14\ kJ\ mol^{-1}$$

The equilibrium system is compressed at constant temperature.

What is the effect on the value of K_c and the amount, in moles, of CH_3OH?

	K_c	**Amount in moles of CH_3OH**
A	increases	increases
B	decreases	decreases
C	no change	no change
D	no change	increases

Your answer ☐

[1]

5(a). A research chemist investigates how the value of K_c changes with temperature.

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

- The chemist mixes 0.800 mol of $N_2(g)$ and 2.400 mol of $H_2(g)$ and leaves the mixture to reach equilibrium at 300 °C.
- The total volume of the equilibrium mixture is 5.00 dm^3.
- At equilibrium, 0.360 mol of $NH_3(g)$ has formed.

Calculate the value of K_c under these conditions.

Show all your working.

K_c = ... units .... **[6]**

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

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

- 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.

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]

6(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.

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

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]

7. A chemist investigated methods to improve the synthesis of sulfur trioxide from sulfur dioxide and oxygen.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The chemist:

- mixed together 1.00 mol SO_2 and 0.500 mol O_2 with a catalyst at room temperature
- compressed the gas mixture to a volume of 250 cm^3
- allowed the mixture to reach equilibrium at constant temperature and without changing the total gas volume.

At equilibrium, 82.0% of the SO_2 had been converted into SO_3.

i. Determine the concentrations of SO_2, O_2 and SO_3 present at equilibrium and calculate K_c for this reaction.

K_c = ... units .... **[6]**

ii. Explain what would happen to the pressure as the system was allowed to reach equilibrium.

[1]

iii. The value of K_c for this equilibrium decreases with increasing temperature.

Predict the sign of the enthalpy change for the forward reaction. State the effect on the equilibrium yield of SO_3 of increasing the temperature at constant pressure.

ΔH:
....

Effect on SO_3 yield: ....
[1]

iv. The chemist repeated the experiment at the same temperature with 1.00 mol SO_2 and an excess of O_2.
The gas mixture was still compressed to a volume of 250 cm³.

State and explain, in terms of K_c, how the equilibrium yield of SO_3 would be different from the yield in the first experiment.

[3]

8(a). Iodine, I_2, is a grey-black solid that is not very soluble in water.

Equilibrium 1 is set up with the equilibrium position well to the left.

$I_2(s) \rightleftharpoons I_2(aq)$ **Equilibrium 1**

Solid iodine is much more soluble in an aqueous solution of potassium iodide, KI(aq), than in water.

Equilibrium 2 is set up.

$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq)$ **Equilibrium 2**

A student dissolves I_2 in KI(aq).

The resulting 200 cm³ equilibrium mixture contains:

4.00×10^{-5} mol $I_2(aq)$

9.404×10^{-2} mol $I^-(aq)$

1.96×10^{-3} mol $I_3^-(aq)$.

Calculate K_c for **equilibrium 2**.

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

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

(b). The student adds an excess of aqueous silver nitrate, $AgNO_3$(aq), to the equilibrium mixture.

Predict what would be observed.

Explain the observations in terms of both **equilibrium 1** and **equilibrium 2** and any species formed.

[4]

9. Ammonia, NH_3, is formed in the reversible reaction below.

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

A mixture at equilibrium contains 0.320 mol N_2, 0.960 mol H_2 and 0.120 mol NH_3.

What is the mole fraction of H_2 in the equilibrium mixture?

A	0.279
B	0.686
C	0.837
D	2.06

Your answer ☐

[1]

10. Methane is an important raw material for manufacturing chemicals. Hydrogen can be manufactured from methane and steam as shown below in **equation 17.1**.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g) \qquad \Delta H = +210\ \text{kJ mol}^{-1} \qquad \textbf{Equation 17.1}$$

The rate of reaction is increased by using a catalyst.

A chemist investigates the equilibrium shown in **equation 17.1** as outlined below.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g) \qquad \Delta H = +210\ \text{kJ mol}^{-1} \qquad \textbf{Equation 17.1}$$

- A chemist mixes together 1.000 mol CH_4 and 1.400 mol of H_2O in a sealed container.
- The mixture is heated to constant temperature and allowed to reach equilibrium. The equilibrium mixture contains 0.200 mol of CH_4 and the total pressure is 30.0 atm.

Use this information to calculate K_p for the equilibrium in **equation 17.1**.

Show all your working.

[7]

11. A mixture of N_2 and O_2 gases has a total pressure of 1.42 atm.

The mole fraction of N_2 is 0.700.

What is the partial pressure, in atm, of O_2 in the mixture?

A 0.211

B 0.426

C 0.493

D 0.994

Your answer ☐ **[1]**

12. Peroxycarboxylic acids are organic compounds with the COOOH functional group.

Peroxyethanoic acid, CH_3COOOH, is used as a disinfectant.

i. Suggest the structure for CH_3COOOH.
The COOOH functional group must be clearly displayed.

[1]

ii. Peroxyethanoic acid can be prepared by reacting hydrogen peroxide with ethanoic acid.
This is a heterogeneous equilibrium.

$$H_2O_2(aq) + CH_3COOH(aq) \rightleftharpoons CH_3COOOH(aq) + H_2O(l) \qquad K_c = 0.37\ dm^3\ mol^{-1}$$

A 250 cm^3 equilibrium mixture contains concentrations of 0.500 mol dm^{-3} $H_2O_2(aq)$ and 0.500 mol dm^{-3} $CH_3COOH(aq)$.

Calculate the amount, in mol, of peroxyethanoic acid in the equilibrium mixture.

amount = ______________________________ mol **[3]**

13. Iron can be extracted from its ore Fe_3O_4 using carbon.

Several equilibria are involved including **equilibrium 18.1**, shown below.

equilibrium 18.1	$Fe_3O_4(s) + 4C(s) \rightleftharpoons 3Fe(s) + 4CO(g)$	$\Delta H = +676.4\ \text{kJ mol}^{-1}$ $\Delta S = +703.1\ \text{J K}^{-1}\ \text{mol}^{-1}$

i. Why is **equilibrium 18.1** a *heterogeneous* equilibrium?

____

[1]

ii. Write the expression for K_p for **equilibrium 18.1**.

[1]

iii. The forward reaction in **equilibrium 18.1** is only feasible at high temperatures.

- ○ Show that the forward reaction is **not** feasible at 25 °C.
- ○ Calculate the minimum temperature, in K, for the forward reaction to be feasible.

minimum temperature = K **[3]**

iv. Another equilibrium involved in the extraction of iron from Fe_3O_4 is shown below.

$Fe_3O_4(s) + 4CO(g) \rightleftharpoons 3Fe(s) + 4CO_2(g)$ $\Delta H = -13.5\ kJ\ mol^{-1}$

Enthalpy changes of formation, $\Delta_f H$, for $Fe_3O_4(s)$ and $CO_2(g)$ are shown in the table.

Compound	**$\Delta_f H$ / kJ mol^{-1}**
$Fe_3O_4(s)$	−1118.5
$CO_2(g)$	−393.5

Calculate the enthalpy change of formation, $\Delta_f H$, for CO(g).

$\Delta_f H$, for CO(g) = kJ mol^{-1} **[3]**

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

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

- 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]**

15. The reversible reaction of sulfur dioxide and oxygen to form sulfur trioxide is shown below

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

An equilibrium mixture contains 2.4 mol SO_2, 1.2 mol O_2 and 0.4 mol SO_3.
The total pressure is 250 atm.

What is the partial pressure of SO_3?

A 15 atm
B 25 atm
C 100 atm
D 200 atm

Your answer ☐ **[1]**

16(a). Nitrogen monoxide, NO, and oxygen, O_2, react to form nitrogen dioxide, NO_2, in the reversible reaction shown in **equilibrium 18.1**.

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

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

17. Succinic acid $(CH_2COOH)_2$ is esterified by ethanol, C_2H_5OH, in the presence of an acid catalyst to form an equilibrium mixture.
Succinic acid is esterified by ethanol, C_2H_5OH, in the presence of an acid catalyst to form an equilibrium mixture.

The equilibrium constant, K_c, for this equilibrium can be calculated using the amounts, in moles, of the components in the equilibrium mixture, using **expression 5.1**.

$$K_c = \frac{n((CH_2COOC_2H_5)_2) \times n(H_2O)^2}{n((CH_2COOH)_2) \times n(C_2H_5OH)^2}$$ **Expression 5.1**

A student carries out an experiment to determine the value of K_c for this equilibrium.

- The student mixes together 0.0500 mol of succinic acid and 0.150 mol of ethanol, with a small amount of an acid catalyst.
- The mixture is allowed to reach equilibrium.
- The student determines that 0.0200 mol of succinic acid are present in the equilibrium mixture.

i. Which technique could be used to determine the equilibrium amount of succinic acid?

[1]

ii. Write the equation for the equilibrium reaction that takes place.

[1]

iii. Draw the skeletal formula of the ester present in the equilibrium mixture.

[1]

iv. K_c is the equilibrium constant in terms of equilibrium concentrations.

Why can **expression 5.1** be used to calculate K_c for this equilibrium?

[1]

v. Calculate the value of K_c for this reaction.

Show your working.

K_c = **[3]**

18. What is the partial pressure of O_2 (in Pa) in a gas mixture containing 21% O_2 by volume and with a total pressure of 1.0×10^5 Pa?

partial pressure of O_2 = ... Pa **[1]**

19(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
Kp	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.

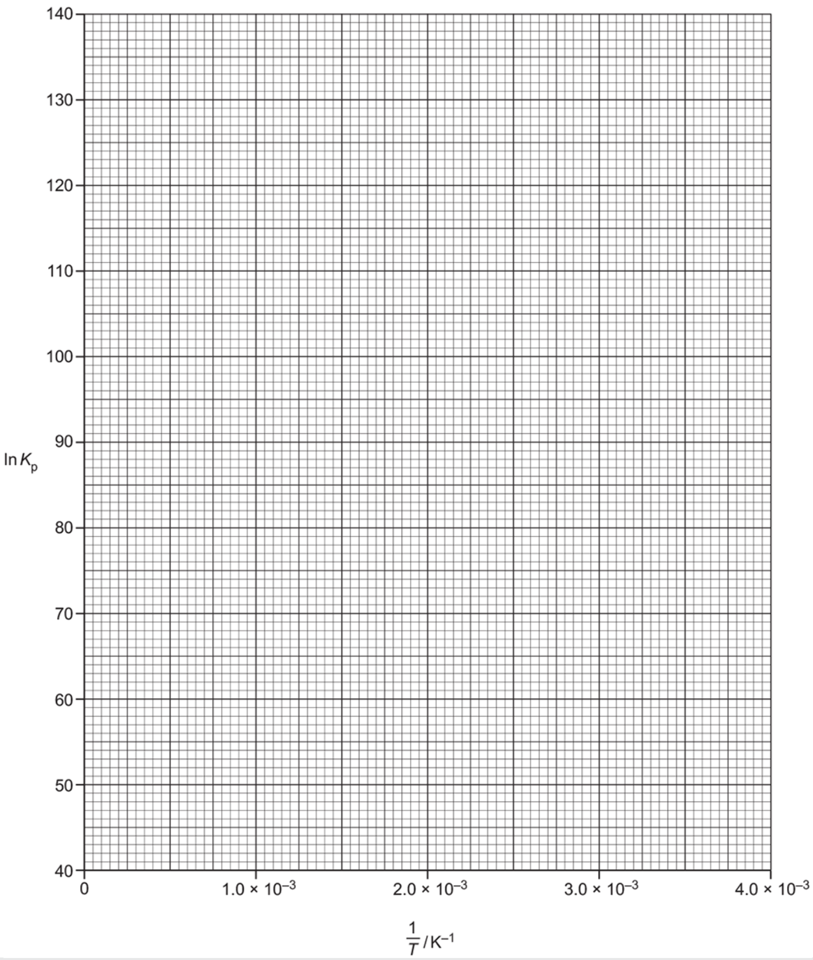
Use your graph and **equation 5.1** to determine Δ*H*, in kJ mol^{-1}, for this equilibrium.

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

Δ*H* = ... kJ mol^{-1} **[4]**

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

[2]



20. The reversible reaction of nitrogen and hydrogen to form ammonia is shown below.

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

In the equilibrium mixture, the partial pressure of N_2 is 18.75 MPa and the partial pressure of H_2 is 2.50 MPa.
The total pressure is 25 MPa.

What is the value of K_p, in MPa^{-2}?

A 1.2×10^{-4}
B 0.048
C 0.075
D 21

Your answer ☐ **[1]**

21. 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]**

22. 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**

At 298 K, the free energy change, Δ*G*, for the production of methanol in **equilibrium 1** is -2.48×10^4 J mol^{-1}.

ΔG is linked to K_p by the relationship: $\Delta G = -RT \ln K_p$.

R = gas constant
T = temperature in *K*.

Calculate K_p for **equilibrium 1** at 298 K.

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

K_p = ... units .... **[3]**

23. 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]**

24. An equilibrium system is shown below.

$CO(g) + NO_2(g) \rightleftharpoons CO_2(g) + NO(g)$

Different amounts of CO, NO_2, CO_2 and NO are added to four containers, as shown below.

Container	CO / mol	NO_2 / mol	CO_2 / mol	NO / mol
A	1	1	0	0
B	1	0	1	1
C	1	1	1	0
D	0	1	1	1

Which container would have the largest concentration of CO(g) at equilibrium?

Your answer ☐ **[1]**

25. 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 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = -114\ kJ\ mol^{-1}$

$\Delta S = -147\ J\ mol^{-1}\ K^{-1}$

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]

26(a). A flask contains 110 g CO_2 and 120 g O_2 at a pressure of 50.0 atm.

What is the partial pressure of the CO_2?

partial pressure of CO_2 = ... atm **[2]**

(b). Pure PCl_5 is placed in a sealed container which is heated to 200 ºC.

An equilibrium is set up: $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$

Under these conditions:

- $K_c = 8.00 \times 10^{-3}$ mol dm^{-3}
- equilibrium concentration of $PCl_5 = 0.0500$ mol dm^{-3}.

Calculate the concentrations of PCl_3 and Cl_2 at equilibrium.

concentration of PCl_3 = ... mol dm^{-3}

concentration of Cl_2 = ... mol dm^{-3}

[2]

27. 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

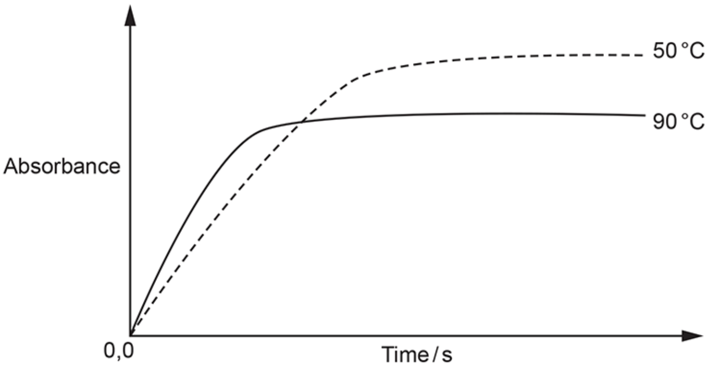
The students are supplied with the equilibrium mixture in **Equilibrium 4.1** at room temperature.

- 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 Δ*H* for the forward reaction in **Equilibrium 4.1**.

[4]

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

***** Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.

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

29. This question is about acids and bases.

A student reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} hydrochloric acid, HCl.

The student also reacts an excess of magnesium with 25.0 cm^3 of 0.500 mol dm^{-3} ethanoic acid, CH_3COOH.

i. Construct an ionic equation for the reaction of magnesium with an acid.

[1]

ii. Explain why these two reactions of magnesium produce the same volume of gas but at different rates.

[3]

30. In the UK, most sulfuric acid, H_2SO_4, is manufactured by the Contact process.

One stage in the Contact process involves the equilibrium between sulfur dioxide, oxygen and sulfur trioxide.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

This equilibrium is investigated:

Step 1 5.82×10^{-2} mol of SO_2 is mixed with 7.40×10^{-2} mol of O_2 in a 2.00 dm^3 container.

Step 2 The container is sealed and allowed to reach equilibrium at constant temperature.

Step 3 At equilibrium, 5.20×10^{-2} mol of SO_3 is formed.

Determine the equilibrium concentrations and calculate K_c, including units.

K_c = ... units .... **[5]**

31. 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**.

$SO_3(g) \rightleftharpoons SO_2(g) + \frac{1}{2}O_2(g)$ $\Delta H = +99\ \text{kJ mol}^{-1}$ **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 = ...

units .... **[5]**

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

Temperature	$\mathbf{K_p}$
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]

32. Chloroethanoic acid, $ClCH_2COOH$, is a weak monobasic acid.

i. Write the expression for the acid dissociation constant, K_a, of $ClCH_2COOH$.

[1]

ii. The expression for the acid dissociation constant, K_a, of $ClCH_2COOH$ can be simplified to:

$$K_a = \frac{[H^+]^2}{[ClCH_2COOH]}$$

Expression 19.1

State one approximation that allows the expression from **(a)(i)** to be simplified to **Expression 19.1**.

---

[1]

iii. A student carries out an experiment to determine the pK_a value of a solution of $ClCH_2COOH$.

- The concentration of $ClCH_2COOH$ is 0.090 mol dm^{-3}.
- The pH of $ClCH_2COOH$ is 1.95.

Use **Expression 19.1** to calculate the pK_a value of $ClCH_2COOH$.

Give your answer to **2** decimal places.

pK_a = ... **[3]**

Mark scheme

Question			Answer/Indicative content	Marks	Guidance
1			D	1	
			Total	**1**	
2			D	1	
			Total	**1**	
3	a		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
	b		**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 2.37×10^{-6} kPa^{-2} award 5 marks **IF** answer = 2.37×10^{-6} with incorrect units award 4 marks At equilibrium, $n(H_2) = 0.300$ (mol) **AND** $n(NH_3) = 0.100$ (mol) (1) $p(N_2) = \frac{0.400}{0.800} \times 500 = 250$ kPa **AND** $p(H_2) = \frac{0.300}{0.800} \times 500 = 187.5$ kPa **AND** $p(NH_3) = \frac{0.100}{0.800} \times 500 = 62.5$ kPa (1) $K_p = \frac{p(NH_3)^2}{p(N_2) \times p(H_2)^3} = \frac{62.5^2}{250 \times 187.5^3}$ (1) $= 2.37 \times 10^{-6}$ (1) kPa^{-2} (1)	5	Final answer must be correct and have the correct units to score all five marks **allow** calculator value for K_p correctly rounded to three or more significant figures. **If there is an alternative answer, check to see if there is any ECF credit possible using working below** Correct values substituted into correct expression for K_p gains first three marks.
			Total	**7**	
4			D	1	

			Total	**1**	
5	a		**FIRST CHECK THE ANSWER ON ANSWER LINE** **IF** answer = 0.812 $dm^6\ mol^{-2}$, award **6 marks** **IF** answer = 0.812 with incorrect units, award **5 marks** …………………………………………………… **Equilibrium amounts in mol** **2 MARKS** $n(N_2) = 0.62(0)$ $n(N_2) = 1.86$ **Equilibrium concentrations in mol dm^{-3} (mol ÷ 5)** **1 MARK** N_2 = 0.124 **AND** H_2 = 0.372 **AND** NH_3 = 0.072 **Calculation of K_c and units** **3 MARKS** $K_c = \frac{[NH_3(g)]^2}{[N_2(g)] \times [H_2(g)]^3}$ **OR** $\frac{0.072^2}{0.124 \times 0.372^3}$ = 0.812 $dm^6\ mol^{-2}$ *At least 3SF is required*	6	**FULL ANNOTATIONS NEEDED** **IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below …………………………………………………… **ALLOW ECF** from incorrect moles of N_2, H_2 **AND / OR** NH_3 **ALL three** concentrations required for mark **ALLOW ECF** from incorrect concentrations **OR** use of moles (omitting conc stage) **NO ECF** for numerical value with a square **AND / OR** cube missing For K_c, **ALLOW** 3 significant figures up to calculator value of 0.8121093077 correctly rounded For units, **ALLOW** $mol^{-2}\ dm^6$ **DO NOT ALLOW** dm^6/mol^{-2} …………………………………………………… **COMMON ERRORS** 0.0325 ***3 marks + units mark*** from N_2 = 0.620, H_2 = 1.86, NH_3 = 0.360 (mol)

	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 increases ***yield of NH_3 linked to K_c*** Chemist is correct **AND** denominator decreases **OR** numerator increases to restore equilibrium K_c	3	**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **IF** 1st marking point has been awarded, **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	N_2 obtained from the air **AND** H_2 must be manufactured / does not occur naturally	1	N_2 is more readily available **not** insufficient. **ALLOW** an example of H_2 manufacture, e.g. from oil / gas / water **BOTH** responses required for mark.
			Total	**10**	
6	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 × 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 × 9.36 × 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 $mol^2\ dm^{-6}$, award **3 marks** **IF** answer = 0.153 with incorrect units, award **2 marks** .... **IF answer from 3(b)(i) for *n*(H_2) ≠ 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** $K_c = \frac{4.20\times10^{-2}\times(0.126)^3}{(2.34\times10^{-2})^2}$ = 0.153 ✓ $mol^2\ dm^{-6}$ ✓ **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] = $\frac{9.36\times10^{-2}}{4}$ mol dm^{-3} **AND** [C_2H_2] = $\frac{0.168}{4}$ mol dm^{-3} **AND** [H_2] = $\frac{0.504}{4}$ 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** $dm^{-6}\ mol^2$ **DO NOT ALLOW** mol^2/dm^6 **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 = $9.36 \times 10^{-2} + 2 \times 0.168$ = 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

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<table>
<tr><th>Change</th><th>K_c</th><th>Equilibrium amount of C_2H_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>
</td>
<td>3</td>
<td>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.</td>
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<td>Total</td>
<td>9</td>
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<tr>
<td>7</td>
<td></td>
<td>i</td>
<td>FIRST, CHECK THE ANSWER ON ANSWER LINE
IF answer = 57.6 $dm^3\ mol^{-1}$, award 6 marks
IF answer = 57.6 with incorrect units, award 5 mark
…………………………………………………

Equilibrium amounts in mol 2 MARKS

$n(SO_2)$ = 0.180 (mol) ALL 3 correct: ✓✓
$n(O_2)$ = 0.090 (mol) ANY 2 correct: ✓
$n(SO_3)$ = 0.820 (mol)

Equilibrium concentrations (moles × 4) 1 MARK</td>
<td>6</td>
<td>FULL ANNOTATIONS NEEDED

IF there is an alternative answer, check to see if there is any ECF credit possible using working below
……………………………………………………

ALLOW ECF from incorrect moles of SO_2, O_2 AND SO_2

ALL three concentrations required for this mark

ALLOW ECF from incorrect concentrations</td>
</tr>
</table>

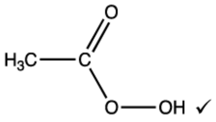
			SO_2 = 0.720 (mol dm^{-3}) **AND** O_2 = 0.360 (mol dm^{-3}) **AND** SO_3 = 3.28 (mol dm^{-3}) ✓ **Calculation of K_c and units 3 MARKS** $K_c = \frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ **OR** $\frac{3.28^2}{(0.720)^2 \times (0.360)}$ ✓ = 57.6 ✓ dm^3 mol^{-1} ✓ *At least 3SF is required*		**NO ECF** for numerical value with a square missing For K_c, **ALLOW** 3 significant figures up to calculator value of 57.64746228 correctly rounded For units, **ALLOW** mol^{-1} dm^3 **DO NOT ALLOW** dm^3 / mol **ALLOW ECF** from incorrect K_c expression for both calculation and units **COMMON ERRORS** 0.0294 ***3 marks + units mark*** from SO_2 = 0.820, O_2 = 0.410, SO_3 = 0.180 (mol) **Examiner's Comments** Many candidates are now well-rehearsed for this type of question. Candidates were expected to determine the equilibrium amounts, convert to concentrations by multiplying by 4 or dividing by 0.250, and to use the concentration values to obtain the $K_c$value. Three easy marks were available for the K_c expression, a correct calculation using calculated concentrations, and the units. As expected the equilibrium amounts caused the biggest problems for candidates. Most correctly obtained 0.180 mol for SO_2 and 0.820 mol for SO_3 (although some had these reversed or even the same). The amount of O_2 was often incorrect with 0.410 mol (0.500 – 0.090), rather than 0.090 mol, being commonly seen. The majority used 1000/250 or ÷ 0.250 to calculate concentrations from their equilibrium amounts. Some omitted this stage whilst other just divided by 250 or multiplied instead of dividing. Throughout,

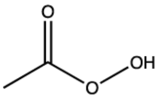
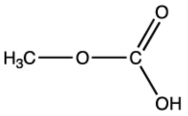
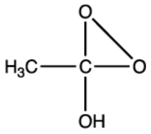
					the examiners marked consequentially so that an individual error was not repeatedly penalised. Consequently the majority of candidates scored 4–6 marks for this part. Answer: K_c = 57.6 $dm^3\ mol^{-1}$
		ii	(Pressure) decreases **AND** fewer molecules / moles ✓	1	For fewer moles, **ALLOW** 3 mol → 2 mol **ALLOW** more moles of **reactants** **Examiner's Comments** Surprisingly this part presented problems to many candidates. The examiners were expecting to see a response in terms of a decreased pressure from the presence of fewer gas molecules. However, many candidates responded with an increase or even the same pressure. This question discriminated extremely well.
		iii	ΔH is negative / '−' / −ve **AND** yield of SO_3 decreases ✓	1	**IGNORE** exothermic and endothermic **Examiner's Comments** Candidates had far more success with this part, with the vast majority responding with a negative ΔH value and decreased yield of SO^3. Weaker candidates often used exothermic (or even endothermic) instead and obtained the incorrect effect.
		iv	**IGNORE** le Chatelier responses .... ***Each marking point is independent*** ***K_c*** K_c does not change (with pressure / concentration) ✓		**FULL ANNOTATIONS NEEDED** **ALLOW** K_c **only** changes with temperature **IF** 1st marking point has been

			Comparison of conc terms with more O_2 $[O_2]$ / concentration of oxygen is greater **OR** denominator / bottom of K_c expression is greater ✓ ***QWC: yield of SO_3 linked to K_c*** (Yield of) SO_3 is greater / increases **AND**		awarded, **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. **IGNORE** O_2 is greater / increases **ALLOW** **(Yield of) SO_3 is greater / increases AND**
		iv	numerator / top of K_c expression is greater / increases ✓	3	to reach / restore K_c value ✓ **Examiner's Comments** Explaining shifts in equilibrium in terms of K_c is far more difficult that the simpler le Chatelier approach. The examiners were impressed by the responses from able candidates with some excellent explanations comparing the values of the denominator and numerator between the two experiments and the consequential effect on the concentration of SO^3. Many responses did state that K_c is unaffected by changes in concentration or pressure but the explanation then used le Chatelier's principle. This part discriminated extremely well and unfortunately weaker candidates often failed to score.
			Total	**11**	
8	a		**FIRST, CHECK THE ANSWER ON ANSWER LINE** **IF K_c = 104 $dm^3\ mol^{-1}$ award 4 marks:** ***3 for calculation of 104 from data, 1 for units*** .... **Equilibrium concentrations (mol × 5)** **(1 mark)**	4	***FULL ANNOTATIONS MUST BE USED*** .... Throughout, at least **3SF** but **ALLOW** absence of trailing zeroes e.g. for 9.80×10^{-3} **ALLOW** 9.8×10^{-3}

			$I_2 = 4.00 \times 10^{-5} \times \mathbf{5} = 2.00 \times 10^{-4}$ (mol dm^{-3}) **AND** $I^- = 9.404 \times 10^{-2} \times \mathbf{5} = 0.4702$ (mol dm^{-3}) ✓ **AND** $I_3^- = 1.96 \times 10^{-3} \times \mathbf{5} = 9.80 \times 10^{-3}$ (mol dm^{-3}) **Calculation of K_c and units** **(3 marks)** $K_c = \frac{[I_3^-(aq)]}{[I_2(aq)] \times [I^-(aq)]}$ **OR** $\frac{9.80 \times 10^{-3}}{2.00 \times 10^{-4} \times 0.4702}$ ✓ = 104 ✓ **Must be 3 SF** dm^3 mol^{-1} **OR** mol^{-1} dm^3 ✓		**FOR I^-** 0.4702, **ALLOW** 0.47(0) (mol dm^{-3}) still → 104 for calc State symbols **not** required in K_c expression **ALLOW ECF** from incorrect concentrations Any **ECF** value **MUST** be to **3 SF** for K_c value …………………………………… **COMMON ERRORS** **104.2 → 104.2109741 (calc)** *> 3 SF* **2 marks + units** **521** *no × 5 for concs* **2 marks + units** **521.1 → 521.0548703** as above and > 3SF **1 mark + units** **2610** *÷ 5 instead of × 5 for concs* **2 marks + units** **9.60×10^{-3}** K_c upside down, correct concs **2 marks + units** **1.92×10^{-3}** K_c upside down, no *× 5 for concs* **1 mark + units** **NOTE**: With K_c upside down, units become mol dm^{-3} by **ECF** **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine.

					Most candidates are comfortable with calculations of equilibrium constants. The correct numerical answer of 104 and units of dm^3 mol^{-1} were seen often. The commonest calculation error was use of the equilibrium moles, rather than concentrations, giving 521. This question asked for the final value to be expressed to the most appropriate number of significant figures. Candidates should use the least significant number of significant figures in the provided data, in this case 3. Many candidates lost a mark by using more than 3 significant figures (e.g. 104.2 and 104.21). Answer: $K_c = 104$ dm^3 mol^{-1}
	b		Ag^+ / silver nitrate reacts with I^- to form AgI / silver iodide **OR** $Ag^+ + I^- \rightarrow AgI$ ✓ yellow precipitate / solid forms ✓ **Equilibrium 2** shifts to the left ✓ **Equilibrium 1** shifts to left **AND** I_2 comes out of solution / less I_2 dissolves / I_2 precipitates / black solid / grey solid / violet solid ✓	4	***FULL ANNOTATIONS MUST BE USED*** .... **DO NOT ALLOW** cream **OR** cream73–yellow **ALLOW** just 'yellow' if supported by AgI(s) somewhere **Examiner's Comments** This question was about equilibrium, set in the context of the solubility of iodine. This part required candidates to apply their knowledge and understanding of equilibria to a novel situation. Candidates were expected to predict that $Ag^+(aq)$ and $I^-(aq)$ ions would react together to form AgI(s), a yellow precipitate, shifting equilibrium 2 to the left. Equilibrium 1 would then shift to the left forming solid iodine. Responses in terms of equilibrium 2 were seen far more often than for Equilibrium 1.
			Total	**8**	

9			**B**	1	
			Total	**1**	
10			**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 5184/5180 atm^2 award 7 marks **IF** answer = 5184/5180 with incorrect units award 6 marks **Equilibrium amounts in mol 2 MARKS** 3 correct ✓✓ 2 correct ✓ $n(H_2O)$ = 0.600 mol $n(H_2)$ = 2.40 mol $n(CO)$ = 0.800 mol **Partial pressures** Total moles = 4.(00) (mol) ✓ $p(CH_4) = \frac{0.200}{4.00} \times 30.0 = 1.50$ atm **AND** $p(H_2O) = \frac{0.600}{4.00} \times 30.0 = 4.50$ atm **AND** $p(H_2) = \frac{2.40}{4.00} \times 30.0 = 18.0$ atm **AND** $p(CO) = \frac{0.800}{4.00} \times 30.0 = 6.00$ atm ✓ **K_p calculation** $k_p = \frac{p(H_2)^3 \times p(CO)}{p(CH_4) \times p(H_2O)}$ **OR** $\frac{18.0^3 \times 6.00}{1.50 \times 4.50}$ ✓ k_p = 5184 **OR** 5180 atm^2 ✓ units = atm^2 ✓	7	Final answer must be correct and have the correct units to score all seven marks **If there is an alternative answer, check to see if there is any ECF credit possible using working below** **ALLOW ECF** from equilibrium amounts **OR/AND** incorrect total number of moles Correct values substituted into correct expression for K_p gains first five marks. **ALLOW ECF** with answer 3 or more **SF** up to calculator value, correctly rounded
			Total	**7**	
11			**B**	1	**ALLOW** 0.426 in the box
			Total	**1**	
12		i	 ✓	**1**	**ALLOW**

			ALLOW skeletal **OR** displayed formula **OR** mixture of the above as long as non-ambiguous, e.g. 		 **OR**  Structure must include OH as part of COOOH group **ALLOW** –O^- H^+ in structure **Examiner's Comment:** This part was attempted well, with many providing a structure containing the correct COOOH functional group. The mark scheme did allow alternatives provided that the three O atoms were bonded to the C atom, e.g. H_3C-O-COOH
		ii	**FIRST CHECK THE ANSWER ON THE ANSWER LINE** **IF** answer = 0.023(125) (mol) award 3 marks for calculation .... ***K_c expression*** $(K_c =) \frac{[CH_3COOOH]}{[H_2O_2]\,[CH_3COOH]}$ ✓ **$[CH_3COOOH]$** = 0.37 × 0.500 × 0.500 = 0.0925 (mol dm^{-3}) ✓ *Subsumes K_c expression* ***n*(CH_3COOOH)** $= 0.0925 \times \frac{250}{1000} = 0.023(125)$ (mol) ✓	3	**If there is an alternative answer, check for any ECF credit** .... **ALLOW** $0.37 = \frac{[CH_3COOOH]}{0.500 \times 0.500}$ **ALLOW ECF** but **ONLY** if 0.37 **AND** 0.5 × 0.5 have been used **Common errors** **0.076** **2 marks** *Use of $[CH_3COOOH]^2$* **0.675** **2 marks** *Use of 0.5 for $[H_2O]$ on K_c* **0.169** **2 marks**

					Inverted K_c **0.338** **1 mark** *Inverted K_c AND 0.5 for $[H_2O]$* **5.78×10^{-3}** **2 marks** *$\times \frac{250}{1000}$ before $[CH_3COOOH]$* **Examiner's Comment:** Many candidates obtained the correct answer but water was often seen in the K_c expression. Candidates then assigned arbitrary values to the concentration of the water, often the same as CH_3COOH, unity, or even 55.6 from 1000/18. The mark scheme allowed some credit by use of error carried forwards. Answer: 0.023 mol
			Total	**4**	
13		i	(Species have) different states / phases ✓	1	**Examiner's Comments** All but a few candidates realised that the term heterogeneous equilibrium could be applied because carbon monoxide was in a different physical state to the other reactants and products.
		ii	(K_p =) $p(CO(g))^4$ ✓	1	Allow species without state symbols and without brackets, e.g. Pco^4, $ppCO^4$, PCO^4, $p(CO^4)$ etc.

					DO NOT ALLOW square brackets **Examiner's Comments** Marks were awarded for less than perfect versions of $K_p = p(CO(g))^4$. As long as a 'p' or a 'P' was seen and curved, rather than square, brackets, along with the correct power, the mark was awarded. This was to differentiate between the candidates who knew that only the partial pressures of gaseous species should feature in a K_p expression from the candidates who used all four species to write the expression.
		iii	ΔG at 25 *C* $\Delta G = \Delta H - T\Delta S = 676.4 - (298 \times 0.7031)$ = (+) 467 (kJ mol^{-1}) **OR** (+) 466876 (J mol^{-1}) ✓ *Non-feasibility statement* Non-feasible when $\Delta G > 0$ **OR** $\Delta G > 0$ **OR** $\Delta H > T\Delta S$ ✓ *Minimum temperature* minimum temperature = $\frac{\Delta H}{\Delta S} = \frac{676.4}{0.7031}$ = 962(.0) K ✓	3	**IGNORE** units **ALLOW** (+) 467 up to calculator value of 466.8762 correctly rounded ECF for any positive value determined in M1 **ALLOW** 962 up to calculator value of 962.0253165 correctly rounded **Examiner's Comments** Candidates coped well with the calculation and, apart from a significant number of rounding errors, could provide a positive value of ΔG and therefore could show the reaction to not be feasible.

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>Candidates were also able to calculate that the minimum temperature required for the reaction to be feasible was 962.023165 K which was sensibly rounded to 962 K.
A significant number of candidates chose to give 963 K as the final answer despite showing a correct value to several decimal places in their working.</td></tr>
<tr><td></td><td></td><td>iv</td><td>FIRST, CHECK THE ANSWER ON ANSWER LINE
IF answer = −110.5, Award 3 marks.
………………………………………………………
Correct expression
$-13.5 = (4 \times -393.5) - (-1118.5 + 4 \times \Delta_fH(CO))$ ✓

Correct subtraction using ΔH and $\Delta_fH(Fe_3O_4)$
$4 \times \Delta_fH(CO) = (4 \times -393.5) - (-1118.5) + 13.5$
$= \mathbf{-442(.0)}$ (kJ mol^{-1}) ✓

Calculation of $\Delta_fH(CO)$ formation
$\Delta_fH(CO) = -\frac{442}{4} = \mathbf{-110.5}$ (kJ mol^{-1}) ✓</td><td>3</td><td>For answer,
ALLOW −111 (kJ mol^{-1})

…………………………………………………………
NOTE: IF any values are omitted, DO NOT AWARD any marks. e.g. −393.5 OR −13.5 may be missing

…………………………………………………………

Common errors
<table>
<tr><td>(+)110.5</td><td><i>wrong / omitted sign</i></td><td>2 marks</td></tr>
<tr><td>(+)184.625 / 184.63 / 184.6 / 185</td><td><i>No 4CO$_2$</i></td><td>2 marks</td></tr>
<tr><td>(+)738.5 / 739</td><td><i>No 4CO$_2$ and no CO/4</i></td><td>1 mark</td></tr>
<tr><td>−117.25 / −117.3 / −117</td><td><i>Wrong cycle</i></td><td>2 marks</td></tr>
<tr><td>−469</td><td><i>Wrong cycle, no CO/4</i></td><td>1 mark</td></tr>
</table></td></tr>
</table>

					(+)177.875 / 177.88 / 177.9 / 178 *Wrong cycle, no 4CO2* **1 mark** **−360.5** *Used 118.5* **2 marks** Any other number: **CHECK** for **ECF** from 1st marking point for expressions using **ALL** values with **ONE** error only e.g. one transcription error:, e.g.395.3 for 393.5 **Examiner's Comments** The general method of determining $\Delta_f H$(CO) was known to most candidates, but many examples of avoidable errors were seen. For example, transcription errors in recording $\Delta_f H$ values (−393 for −393.5 and −118.5 for −1118.5). Candidates should be advised to show every step in their calculation. This would allow method marks to be applied in the absence of a correct final answer.
			Total	**8**	
14		i	$(K_c =)\ \frac{[SO_3]^2}{[SO_2]^2\,[O_2]}$ ✓ 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.
		ii	**FIRST, CHECK THE ANSWER ON ANSWER LINE**	4	**FULL ANNOTATIONS NEEDED**

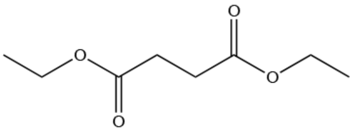
			IF answer = 2.45, Award **4 marks.** …………………………………………………… **Equilibrium concentrations (moles** x **2.5)** **1 MARK** SO_2 = 0.135 (mol dm^{-3}) **AND** O_2 = 0.0675 (mol dm^{-3}) ✓ **Calculation of [SO_3(g)]** **2 MARKS** $[SO_3] = \sqrt{(K_c \times [SO_2]^2 \times O_2)}$ **OR** $\sqrt{((3.045 \times 10^4) \times 0.135^2 \times 0.0675)}$ ✓ = 6.12039291 (mol dm^{-3}) ✓ *Answer scores both [SO_3] marks automatically* **Calculation of *n*(SO_3) in 400 cm^3** **1 MARK** $n(SO_3)$ = 6.12039291/2.5 = 2.45 (mol) ✓		**IF** there is an alternative answer, check to see if there is any **ECF** credit possible using working below …………………………………………………… **ALLOW ECF** from incorrect concentrations of SO_2 and / or O_2 **ALLOW ECF** from incorrect [SO_3] **ALLOW 3 SF,** 6.12, up to calculator value of 6.12039291 correctly rounded. **Common errors** **37.5** **1 mark** *No √for [SO_3]^2 and no scaling by 1/2.5* **15.0** **2 marks** *No √for [SO_3]^2* **0.619** **3 marks** *Use of mol of SO_2 and O_2* **1.55** **2 marks** *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	**6**	
15			**B**	**1 (AO 1.3)**	**Examiner's Comments** This was a very successful multiple choice question for nearly all candidates.
			Total	**1**	
16	a		$K_c = \frac{[NO_2]^2}{[NO]^2\ [O_2]}$ ✓ 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.**	**4**	***ANNOTATIONS MUST BE USED*** For **all** parts, **ALLOW** numerical answers from 2 significant figures up to the calculator value

			$[NO] = \frac{0.40}{4.0} = 0.1(0)\ (mol\ dm^{-3})$ **AND** $[O_2] = \frac{0.80}{4.0} = 0.2(0)\ (mol\ dm^{-3})$ ✓ $[NO_2]^2 = 45 \times 0.102 \times 0.20$ **OR** = 0.09(0) ✓ $[NO_2] = \sqrt{(45 \times 0.10^2 \times 0.20)}$ **OR** = 0.3(0) (mol dm^{-3}) ✓ amount $NO_2 = 0.30 \times 4 = 1.2$ (mol) ✓		Ignore rounding errors after second significant figure 1st mark is for realising that concentrations need to be calculated. **ALLOW ECF** **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

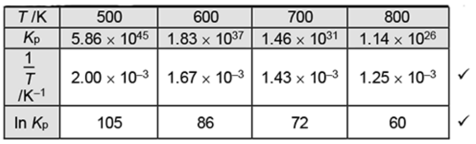
					presented in a coherent manner, even here, partial credit was awarded.
	c	i	Exothermic AND K_p decreases as temperature increases ✓	**1**	**ALLOW** K_c for K_p **ALLOW** Equilibrium shifts to left hand side as temperature increases **Examiner's Comments** Most candidates knew the forward reaction was 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**	
17		i	Titration ✓	1	**IGNORE** type of titration **Examiner's Comments** Candidates found this part difficult and only higher ability candidates identified that a titration could easily determine the concentration of succinic acid. The answers seen covered most of the techniques encountered in the course. Candidates should consider the information provided in a practical context to arrive at an informed response rather than what sometimes seemed to be a guess.
		ii	$(CH_2COOH)_2 + 2C_2H_5OH \rightleftharpoons (CH_2COOC_2H_5)_2 + 2H_2O$ ✓	1	**ALLOW** → instead of ⇌ sign **ALLOW** molecular formulae or hybrid formulae *Structures provided on QP* e.g. $C_4H_6O_4 + 2C_2H_6O \rightleftharpoons C_8H_{14}O_4 + 2H_2O$ **Examiner's Comments** Candidates were required to derive the equation from which

					the supplied K_c expression had been written. Overall, this part was answered well but some candidates struggled with the brackets or used CH_2COOH_2 for succinic acid.
		iii	 ✓	1	**IGNORE** displayed formulae **<u>Examiner's Comments</u>** This part discriminated extremely well with many candidates finding it difficult to convert the bracketed structural formula into a skeletal formula. Common errors were drawing of the mono-ester or omitting a carbon atom in the centre of the structure. Even when incorrect, most attempted answers were skeletal formulae.
		iv	Volume cancels **OR** Same number of moles on each side of equation ✓	1	**ALLOW** units cancel **ALLOW** (sum of) balancing numbers/coefficients on each side of equation are the same **OR** same number of (moles of) reactants and products **IGNORE** volume is the same; K_c has no units **<u>Examiner's Comments</u>** Many candidates did not seem to realise that the supplied equation used moles, not concentrations. Those who did often stated that the mole representation could be used because the volume was the same for all. Of those who went on to state that the volume would cancel, only a few explained why that was true in this particular case.

					This challenging part discriminated very well. The best responses showed the units as n/V in the expression and showed that the volumes cancel.
		v	**Moles of equilibrium products** ***1 mark*** $n((CH_2COOC_2H_5)_2)$ = 0.0300 (mol) **AND** $n(H_2O)$ = 0.0600 (mol) ✓ **Moles of C_2H_5OH** ***1 mark*** $n(\mathbf{C_2H_5OH})$ = 0.150 − 0.060 = 0.0900 (mol) ✓ **K_c calculated** ***1 mark*** $= \frac{0.03 \times 0.06^2}{0.02 \times 0.09^2}$ = 0.667 **OR** 0.67 ✓ **NOTE**: 0.02 must be used for *n*(succinic acid)	3	**ALLOW ECF** **ALLOW** 0.66, 0.666, etc. (**2 SF** and more) *Treated as meaning 0.6 recurring* **ALLOW** 2/3 **IGNORE** any units **<u>Examiner's Comments</u>** Overall, this part discriminated well with many candidates obtaining the correct answer of 0.67. Common errors included a one significant figure answer of 0.6 or 0.7 and 0.375, by using 0.12 mol instead of 0.09 mol for the moles of ethanol. Many successful answers were well-presented and included a table of initial and final values. This gave a systematic way of deriving the equilibrium moles.
			Total	**7**	
18			$p(O_2) = 0.21 \times 1.00 \times 10^5$ = **21,000 / 2.1 × 10^4** (Pa)✓	1 AO 2.2	**<u>Examiner's Comments</u>** This question tested an understanding of 'partial pressure' as a concept. Most candidates obtained the correct response of 21,000 Pa or 2.1 ×

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td>10^4 Pa. Scaling proved to be a common error with 2.1 × 10^{-4} Pa being seen, presumably from dividing, instead of multiplying, 0.21 by 1 × 10^4.

In calculations, candidates are advised to think about whether their answer is sensible, rather than relying just on the answer displayed on the calculator.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>1</td><td></td></tr>
<tr><td>19</td><td>a</td><td></td><td>

<table>
<tr><th><i>T</i> /K</th><th>500</th><th>600</th><th>700</th><th>800</th><th></th></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><td></td></tr>
<tr><td>$\frac{1}{T}$ /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><td>✓</td></tr>
<tr><td>ln K_p</td><td>105</td><td>86</td><td>72</td><td>60</td><td>✓</td></tr>
</table>

<i>Calculator values</i>
<table>
<tr><td>1/<i>T</i> /10^{-3}</td><td>2.00</td><td>1.66 recurring</td><td>1.428571429</td><td>1.25</td></tr>
<tr><td>ln K_p</td><td>105.3844788</td><td>85.79996441</td><td>71.75857432</td><td>59.99824068</td></tr>
</table>
</td><td>2
(AO 1.2×2)</td><td>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
<i>Check with calculator values below table</i>

BUT DO NOT ALLOW whole number errors, e.g. 85 for 86

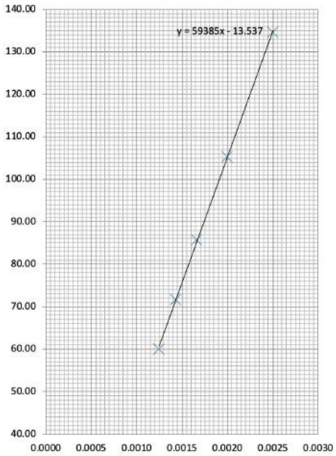
<u>Examiner's Comments</u>

Candidates were expected to complete values for 1/<i>T</i> and ln K_p from supplied <i>T</i> and K_p values. Candidates were supplied with an example and this enabled most candidates to obtain both available marks.</td></tr>
<tr><td></td><td>b</td><td></td><td>Equilibrium (position) shifts to the left
AND
(forward) reaction is exothermic ✓</td><td>1
(AO 2.2)</td><td>ALLOW 'favours reverse reaction'
<i>Implies shift to left</i>

ALLOW 'shifts in endothermic direction' BUT only if (forward) reaction stated as exothermic

<u>Examiner's Comments</u>

Most candidates were aware that a decrease in K_p with</td></tr>
</table>

					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** **<u>All</u>** 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)** 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})*	4 (AO 3.1) (AO 3.1) (AO 3.2) (AO 3.2)	 **ALLOW** 4 points on graph Tolerance 1 small square **ALLOW** ΔH in range: –480 → –530 *(kJ mol^{-1})* **This mark subsumes gradient mark** **<u>Examiner's Comments</u>** 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 $= \frac{\Delta S}{R}$ **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: $= \frac{\Delta S}{R} = \ln K_p - \text{gradient} \times 1/T$ **OR** $135 - 60000 \times 2.50 \times 10^{-3}$ $= -15$ ✓ **<u>Examiner's Comments</u>** 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 Δ*S*/*R*. They then stated that Δ*S* 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**	

20			**B**	1 (AO 2.6)	
			Total	**1**	
21			**B**	1 (AO 1.1)	
			Total	**1**	
22			**FIRST CHECK THE ANSWER ON ANSWER LINE If answer =** 2.22 × 10^4 **award first 2 marks** -- $\ln K_p = -\Delta G/RT = \frac{2.48 \times 10^4}{8.314 \times 298} = 10.01$ ✓ K_p = 2.22 × 10^4 (**3SF required**) ✓ Units = atm^{-2} ✓	3 (AO 3.1×2) (AO 1.2×1)	**ALLOW ECF** for transcription errors in first sum **ALLOW** 10 up to calculator value of 10.00979992 **ALLOW** 22200 **ALLOW** 2.20 × 10^4 **OR** 22000 (use of 10) **ALLOW** alternatives (k)Pa^{-2} **OR** N^{-2} m^4 **OR** $mmHg^{-2}$ **OR** PSI^{-2} **OR** *bar^{-2}* ***Common errors for 1 mark:*** *22400 (use of 8.31)* *4.50 x 10^{-5} (use of -10.01)* ***Examiner's Comments*** *This was an unfamiliar expression linking ΔG and K_p. Many candidates correctly calculated this number. Some candidates calculated ln K_p as 10.0 but then put a – in front for the e calculation. The question required the answer to 3 significant figures. Higher-attaining candidates were able to work out the units as any pressure unit $^{-2}$.*
			Total	**3**	
23			**FIRST CHECK THE ANSWER ON ANSWER LINE** **If answer = 7.4 award 4 marks** --- **Initial moles of reactants 1 mark**	4	**ALLOW** minimum of **2SF** throughout

			$n(CH_3OH)_{initial} = \frac{9.6}{32} = 0.3$ (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) ✓ $n(CH_3COOCH_3)_{equil}$ = 0.17 (mol) **AND** $n(H_2O)_{equil}$ = 0.17 (mol) ✓ **K_c calculation 1 marks** $K_c = \frac{0.17/V \times 0.17/V}{0.13/V \times 0.03/V} = 7.4$ ✓	(AO 1.2×1) (AO 2.8×3)	**ALLOW ECF** from initial moles **ALLOW ECF** from equilibrium moles Use of V not required but Kc expression must be correct **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**	
24			B	1 (AO2.2)	
			Total	**1**	
25		i	**FIRST, CHECK FOR VALUE OF K_p.** **IF** answer = 20.7 (MPa^{-1}), award **4 marks** --- *Equilibrium amounts* $n(NO)$ = 0.4 (mol)	4 (AO2.4×4)	***FULL ANNOTATIONS MUST BE USED*** --- **ALLOW ECF throughout**

<table>
<tr>
<td></td>
<td></td>
<td></td>
<td>**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
$p(NO) = \frac{0.4}{2.5} \times 1.21 = 0.1936$ (MPa)

AND $p(O_2) = \frac{0.9}{2.5} \times 1.21 = 0.4356$ (MPa)

AND $p(NO_2) = \frac{1.2}{2.5} \times 1.21 = 0.5808$ (MPa) ✓

K_p value
$Kp = \frac{0.5808^2}{0.1936^2 \times 0.4356} = 20.7$ **to 3 SF** (MPa^{-1}) ✓</td>
<td></td>
<td>**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

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.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ii</td>
<td><table><tr><th>Change</th><th>K_p</th><th>Equilibrium amount of NO_2</th><th>Initial rate</th></tr></table></td>
<td>3
(AO1.2×3)</td>
<td>Mark by **COLUMN**

ALLOW obvious alternatives for greater/smaller/same,</td>
</tr>
</table>

<table>
<tr>
<td></td><td></td><td></td>
<td>
<table>
<tr><td>Temperature increased</td><td>smaller</td><td>smaller</td><td>greater</td></tr>
<tr><td>Pressure increase</td><td>same</td><td>greater</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>
</td>
<td></td>
<td>e.g.
increases/decreases/ more/less</td>
</tr>
<tr>
<td></td><td></td><td></td><td>Total</td><td>7</td><td></td>
</tr>
<tr>
<td>26</td><td>a</td><td></td>
<td>FIRST CHECK THE ANSWER ON ANSWER LINE
If answer = 20 award 2 marks

$n(CO_2) = \frac{110}{44}$ OR 2.5 (mol)

AND
$n(O_2) = \frac{120}{32}$ OR 3.75 (mol) ✓

$p(CO_2) = \frac{2.5}{6.25} \times 50.0$ OR 0.4 × 50.0

= 20(.0) (atm) ✓</td>
<td>2 (AO1.1 × 2)</td>
<td>ALLOW ECF
from incorrect Σ ($n(CO_2) + n(O_2)$) ONLY

<u>Examiner’s Comments</u>

Candidates were assessed on their understanding of partial pressure.
Most candidates worked out the number of moles of CO_2 and O_2 as 2.5 and 3.75 respectively and then multiplied the mole fraction by the total pressure as 2.5/6.25 × 50 to obtain the correct response of 20 atm.

A common error was to see a mass fraction multiplied by the pressure as 110/230 × 50 = 23.9 atm. Such candidates needed to develop more detailed knowledge of partial pressures, as per the specification.</td>
</tr>
<tr>
<td></td><td>b</td><td></td>
<td>FIRST CHECK THE ANSWER ON ANSWER LINES
If $[PCl_3] = [Cl_2] = 0.02(00)$ award 2 marks

$K_c = \frac{[PCl_3]\,[Cl_2]}{[PCl_5]}$ OR with number(s), e.g. $K_c = \frac{[PCl_3]\,[Cl_2]}{0.05(00)}$ ✓

$[PCl_3] = [Cl_2] = \sqrt{(K_c \times [PCl_5])}$
$= \sqrt{(8.00 \times 10^{-3} \times 0.0500)}$
$= \sqrt{(4.00 \times 10^{-4})}$
$= \mathbf{2.00 \times 10^{-2}}$ (mol dm^{-3}) ✓</td>
<td>2
(AO1.1)
(AO2.2)</td>
<td>Square brackets required

Common errors
2.00×10^{-4} from $K_c = \frac{[PCl_3]\,[Cl_2]}{[PCl_5]}$ 1 mark
<i>÷2 instead of √</i>

2.5 from $K_c = \frac{[PCl_5]}{[PCl_3]\,[Cl_2]}$ 1 mark
<i>Inverse K_c expression</i>

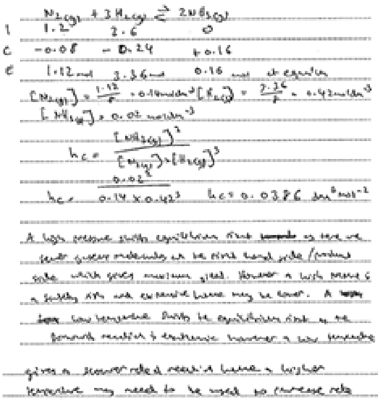
<u>Examiner’s Comments</u>

Candidates were required to apply their understanding of K_c to a novel context requiring</td>
</tr>
</table>

					some mathematical awareness. Most candidates wrote the correct K_c expression and were able to rearrange the expression to show that $[PCl_3]\ [Cl_2] = 8.00 \times 10^{-3} \times 0.0500 = 4.00 \times 10^{-3}$. Candidates needed to realise that the concentrations of PCl_3 and Cl_2 would be the same and the correct concentrations would be obtained by taking the square root of 4.00×10^{-3} to obtain 0.0200 mol dm^{-3}. While some candidates did this, many omitted this stage, choosing 4.00×10^{-3} as their response.
			Total	**4**	
27			**At 90 °C**/higher temperature • Faster rate **AND** more frequent collisions ✓ • More particles have the activation energy/E_a or greater ✓ • $[Co(H_2O)_6]^{2+}$ is lower ✓ • (forward reaction) ΔH -ve **OR** exothermic ✓	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 **<u>Examiner's Comments</u>** 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.
			Total	**4**	
28	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)** 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.*	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** $K_c = \frac{[NH_3]^2}{[N_2] \times [H_2]^3}$ $K_c = \frac{0.0200^2}{0.140 \times 0.420^3} = 0.0386$ *Calculator: 0.03856417851* **Units:** dm^6 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

					 $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ I 1.2 2.6 0 C −0.08 −0.24 +0.16 E 1.12 mol 3.36 mol 0.16 mol at equilibrium $[N_{2(g)}] = \frac{1.12}{8} = 0.14\ mol\ dm^{-3}$ $[H_{2(g)}] = \frac{3.36}{8} = 0.42\ mol\ dm^{-3}$ $[NH_{3(g)}] = 0.02\ mol\ dm^{-3}$ $Kc = \frac{[NH_{3(g)}]^2}{[N_{2(g)}] \times [H_{2(g)}]^3}$ $Kc = \frac{0.02^2}{0.14 \times 0.42^3}$ $Kc = 0.0386\ dm^6 mol^{-2}$ 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 **<u>Examiner's Comments</u>** 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 **<u>Examiner's Comments</u>** 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**	
29		i	$Mg + 2H^+ \rightarrow Mg^{2+} + H_2$ ✓	1 (AO 2.6)	**ALLOW** multiples **ALLOW** Mg^{+2} **IGNORE** state symbols **<u>Examiner's Comments</u>** Ionic equations still present candidates with a challenge. A few candidates scored the mark but many candidates gave a full equation or one that contained a mismatch of spectator ions as well as the correct ions.
		ii	HC*l* is a strong acid/completely dissociates **AND** CH_3COOH is a weak acid/partially dissociates ✓ Greater H^+ concentration in HC*l*	3 (AO 1.1 × 1) (AO 3.1 × 2)	**IGNORE** HCl is a strong**<u>er</u>** acid than ethanoic acid. **ALLOW** ORA

			AND More frequent collisions / faster rate of reaction ✓ More CH_3COOH dissociates until same number of moles of H^+ released **OR** same total moles H^+ produced (by the end) **OR** (Both acids are monobasic) and have the same number of moles of acid ✓		**DO NOT ALLOW** dibasic/tribasic **Examiner's Comments** This question proved challenging for the candidates to identify the three ideas: Those of comparing acids, comparing moles and comparing rates. Very few candidates were able to score the 3 marks. Most candidates recognised the different strength of the two acids, but some only used comparative language. Some linked the moles of acid used to the volume of gas produced but many simply restated the same volume and concentration which is given within the question. Only a few candidates linked the higher initial $[H^+]$ in HCl to the increased rate through more frequent collisions. A common issue was describing the rate of dissociation rather than the $[H^+]$ present in determining the rate of the reactions or mentioning that it dissociates more but not linking this to the H+ concentration.
			Total	**4**	
30			**FIRST CHECK THE ANSWERS ON ANSWER LINE** **If K_c value = 2931 OR 2930 award 4 calc marks** **If units = $dm^3\ mol^{-1}$ OR $mol^{-1}\ dm^3$ award 1 unit mark** --- **SO_2 and O_2 equilibrium moles** **$n(SO_2) = 6.20 \times 10^{-3}$** ($5.82 \times 10^{-2} - 5.20 \times 10^{-2}$) **AND $n(O_2) = 4.80 \times 10^{-2}$** ✓ ($7.4 \times 10^{-2} - \frac{5.20 \times 10^{-2}}{2}$)	5 (AO 2.6 ×3) (AO 1.2 ×2)	**Use of fractions is fine but final answer MUST be shown using normal numbers** **COMMON ERRORS** **K_c = 1,465** (2,930/2) → ***3 calc marks*** Moles **not** converted to concentration (No ÷2)

			Equilibrium concentrations (moles ÷ 2) [SO$_2$] = **3.10 × 10^{-3}** $\frac{6.20 \times 10^{-3}}{2}$ (mol dm^{-3}) **AND** [O$_2$] = **2.40 × 10^{-2}** $\frac{4.80 \times 10^{-2}}{2}$ (mol dm^{-3}) **AND** [SO$_3$] = **2.60 × 10^{-2}** ✓ $\frac{5.20 \times 10^{-2}}{2}$ (mol dm^{-3}) **K_c calculation** $K_c = \frac{(2.60 \times 10^{-2})^2}{(3.10 \times 10^{-3})^2 (2.40 \times 10^{-2})}$ ✓ = 2,930 **OR** 2,931 ✓ **At least 3 SF** required *Calc value from unrounded values: 2,930.974679* **Units** dm^3 mol^{-1} ✓ **DO NOT ALLOW** dm^3 mol^{-} **For units, ALLOW ECF** using incorrect K_c expression Units must match K_c expression used		$\frac{(5.20 \times 10^{-2})^2}{(6.2 \times 10^{-3})^2 (4.80 \times 10^{-2})}$ --- **K_c = 21.6** ***→ 3 calc marks*** Original values used, $\frac{(2.60 \times 10^{-2})^2}{(2.91 \times 10^{-2})^2 (3.70 \times 10^{-2})}$ --- **K_c = 10.8** ***→ 2 calc marks*** Original values used and no ÷2, $\frac{(5.20 \times 10^{-2})^2}{(5.82 \times 10^{-3})^2 (7.40 \times 10^{-2})}$ --- **K_c = 732.74** **→ 3 calc marks** × 2 instead of ÷ 2 for concentration $\frac{(0.104)^2}{(0.0124)^2 (0.096)}$ --- **K_c = 112729.8** **→ 3 calc marks** 2.60 × 10^{-2} not squared $\frac{(2.60 \times 10^{-2})}{(3.10 \times 10^{-3})^2 (2.40 \times 10^{-2})}$ ---

					K_c = 3.41… × 10^{-4} → 3 calc marks Calculator 3.41183432 × 10^{-4} Inverted K_c $\frac{(3.10 \times 10^{-3})^2 (2.40 \times 10^{-2})}{(2.60 \times 10^{-2})^2}$ Units mol dm^{-3} **Examiner's Comments** As with the stock titration calculation in Question 5 (a), candidates were much more comfortable in tackling a stock K_c calculation. These have been assessed in several previous H432/01 exams and many excellent responses were seen, gaining all 5 marks. Error carried forwards allowed for an early slip in the calculation to be credited subsequently for a correct method. The hardest part of the calculation was the initial determination of the equilibrium moles and concentrations. The equilibrium moles of O_2 was the main error, presumably from the 2:1:2 stoichiometry. Some candidates multiplied by 2 instead of dividing by 2 for the concentration. A common error was for candidates to use a partial pressure approach. These errors lost intermediate marks by credit could then be awarded for using the correct K_c expression to generate a K_c value with correct units. Very few candidates did not gain any marks.
			Total	**5**	
31		i	**FIRST CHECK THE ANSWER ON ANSWER LINE**	5	**IF** there is an alternative answer, check for any

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 ✓

$p(SO_3)$	$\frac{1.35}{2.7(0)} \times 2.80$ **OR** 1.4(0)
$p(SO_2)$	$\frac{0.900}{2.7(0)} \times 2.80$ **OR** 0.933
$p(O_2)$	$\frac{0.450}{2.7(0)} \times 2.80$ **OR** 0.467

$(K_p) = \frac{p(SO_2)\ p(O_2)^{1/2}}{p(SO_3)}$

OR $(K_p =)\ \frac{(0.933) \times (0.467)^{1/2}}{(1.40)}$ ✓ ✓

Answer to 3 SF
K_p= 0.455 ✓

Units
Substitution of units into correct K_p expression
$\frac{atm^1 \times atm^{1/2}}{atm^1} = atm^{½}$ ✓ ✓

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 $(K_p) = \frac{p(SO_2)\ p^{1/2}(O_2)}{p(SO_3)}$

ALLOW
$K_p^2 = \frac{p(SO_2)^2 \times p(O_2)}{p(SO_3)^2}$

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 √atm

Common errors
4 marks
(3 marks for calculation + unit mark)

0.207 (from expression $\frac{p(SO_2)^2 \times p(O_2)}{p(SO_3)^2}$) Unit: a

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

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td><u>Examiner’s Comments</u>

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.</td></tr>
<tr><td></td><td></td><td>iii</td><td>One mark per correct row ✓ ✓

<table><tr><th>Change</th><th>Decrease</th><th>No change</th><th>Increase</th></tr><tr><td>No catalyst</td><td></td><td>✓</td><td></td></tr><tr><td>Increased pressure</td><td></td><td>✓</td><td></td></tr></table></td><td>2</td><td><u>Examiner’s Comments</u>

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.</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>9</td><td></td></tr>
<tr><td>32</td><td></td><td>i</td><td>$(K_a) = \frac{[H^+]\,[ClCH_2COO^-]}{[ClCH_2COOH]}$</td><td>1</td><td>DO NOT ALLOW without square brackets

DO NOT ALLOW $\frac{[H^+]^2}{[ClCH_2COOH]}$

DO NOT ALLOW $\frac{[H^+][A^-]}{[HA]}$

<u>Examiner’s Comments</u>

Most candidates scored the marking point. They realised that the full formulae were needed although some candidates left off the square brackets or used HA or $[H]^2$. Care should be taken in checking the correct amount and location of H in the formula. As an acid dissociates to form a H^+, it is important to acknowledge only one H^+ is</td></tr>
</table>

					dissociated from the correct part of the molecule.
		ii	$[H^+] = [A^-]$ **OR** $[H^+]$ from water is negligible **OR** dissociation of water is negligible ✓	1	Answer must be in terms of concentration **ALLOW** $[H^+] \approx [A^-]$ **IGNORE** $HA \rightleftharpoons H^+ + A^-$ is a 1:1 mole ratio. **<u>Examiner's Comments</u>** This question required the candidate to understand that the dissociation of water to produce H^+ ions had no effect on the overall $[H^+]$ of the solution, leading to $[H^+] = [A^-]$. This was mostly answered well but some candidates used the idea of $[H^+] = [OH^-]$.
		iii	**FIRST CHECK ANSWER ON ANSWER LINE** **If answer = 2.85 OR 2.86 OR 2.87 award 3 marks** --- ---- $([H^+] =)\ 10^{-1.95}$ **OR** $= 1.1(22\ldots) \times 10^{-2}$ ✓ $(K_a) = (\frac{[H^+]^2}{[ClCH_2COOH]})$ $= \frac{(1.122\ldots\ \text{x}10^{-2})^2}{(0.090)}$ **OR** $\frac{(1.12\ \text{x}10^{-2})^2}{(0.090)}$ **OR** $\frac{(1.1\ \text{x}10^{-2})^2}{(0.090)}$ $= 1.4(0) \times 10^{-3}$ **OR** $= 1.39 \times 10^{-3}$ **OR** $= 1.34 \times 10^{-3}$ ✓ $(pK_a = -\log_{10}(K_a) =)$ 2.85, 2.86 OR 2.87 (**2DP**) ✓	3	**ALLOW ECF** throughout **ALLOW** $[H^+] = 1.1 \times 10^{-2}$ up to calculator value **ALLOW** 2 sig figs up to calculator value. **ALLOW** calculations based on finding the $[HA]_{equ}$ $\frac{(1.122\ldots\ \text{x}10^{-2})^2}{(0.079)}$ **OR** $\frac{(1.12\ \text{x}10^{-2})^2}{(0.079)}$ **OR** $\frac{(1.1\ \text{x}10}{(0.079}$ $= 1.59 \times 10^{-3}$ **OR** $= 1.59 \times 10^{-3}$ **OR** $= 1.53 \times 10^{-3}$ ✓ $(pK_a = -\log_{10}(K_a) =)$ 2.80 **OR** 2.80 **OR** 2.81 (**2DP**) ✓ **Must be 2DP** **Common error:** **2 marks** 0.90 (not using $[H^+]^2$) **<u>Examiner's Comments</u>** Candidates made good progress with this calculation, many gaining 2 or 3 marks, including error carried forward. Common

					errors included, in various combinations: using -log[-1.95]; using an incorrect value for the concentration of $ClCH_2COOH$; and using 10^{-Ka}.
			Total	**5**	