

OCR A-LEVEL CHEMISTRY B (SALTERS) • H433

CHEMISTRY



EXAM QUESTION PACK

THE CHEMICAL INDUSTRY (CI)

SCORE

/322

PERCENTAGE

%

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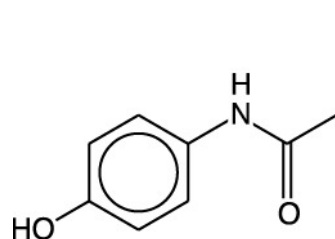
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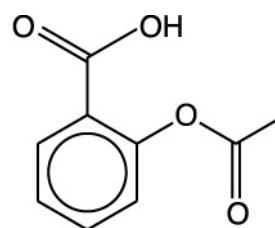
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- 1 Disprin Extra is a medicine containing the active compounds **C** and **D**.



compound C



compound D

Disprin Extra tablets have to be stored in a cool dry place. Compound **D** hydrolyses slowly in moist air at room temperature.

A student studies how the rate of the hydrolysis in water varies with the concentration of **D** at 37 °C and a pH of 7.0. The student measures the concentration of **D** at different time intervals. Some of the results obtained are given below.

time / hours	concentration of D / mol dm ⁻³
0	5.55×10^{-3}
30	4.96×10^{-3}
100	3.83×10^{-3}
220	2.48×10^{-3}
290	1.92×10^{-3}

- (i) Use data from the table to show, without using a graph, that the rate of hydrolysis is firstorder with respect to **D**.

Give your reasoning.

[3]

(ii) Calculate the **average rate** of reaction over the first 290 hours.

average rate of reaction = _____ mol dm⁻³ hr⁻¹ [1]

(iii) Under the conditions of the experiment the rate equation is

$$\text{rate} = k \times [\text{D}]$$

The rate of reaction after 30 hours is 4.96×10^{-9} mol dm⁻³ s⁻¹

Calculate the rate constant.

Give the units of the rate constant.

$k =$ _____ units _____ [2]

2(a) Research is being conducted into chemical reactions that can be used on other planets such as Mars.

One reaction being studied is shown below.



The atmosphere of Mars consists mainly of carbon dioxide. Hydrogen is initially brought from Earth.

Suggest, with reasons, what effect increasing temperature and pressure would have on the **equilibrium yield** of carbon monoxide and water in **equation 1.1**.



In your answer you should use appropriate technical terms, spelled correctly.

[4]

(b) A catalyst of iron and chromium is used.

State why a catalyst is used, giving its effect on K_c .

[2]



(c) At 500 K, the equilibrium constant for **equation 1.1** is 7.76×10^{-3} .

In an equilibrium mixture at 500 K, the concentrations of hydrogen and carbon dioxide are:

$$[\text{H}_2] = 1.00 \times 10^{-5} \text{ mol dm}^{-3}$$

$$[\text{CO}_2] = 3.46 \times 10^{-5} \text{ mol dm}^{-3}$$

Calculate the equilibrium concentrations of H_2O and CO at 500 K.

Assume the H_2O and CO come solely from this reaction.

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

$$[\text{H}_2\text{O}(\text{g})] = \text{-----} \text{ mol dm}^{-3} \quad [\text{CO}(\text{g})] = \text{-----} \text{ mol dm}^{-3} \quad [4]$$

(d) The water is electrolysed to regenerate the hydrogen.

(i) Suggest a source of the energy needed to electrolyse water.

----- [1]

(ii) Suggest a reason why the electrolysis of water is beneficial to sustaining life on Mars.

----- [1]



(e) The entropies of the gases involved in **equation 1.1** are:

Gas	Entropy, $S/\text{J mol}^{-1} \text{ K}^{-1}$
CO	+198
CO ₂	+214
H ₂ O	+189
H ₂	+131

(i) Calculate the entropy change, ΔS_{sys} , of the forward reaction in **equation 1.1**.

$$\Delta S_{\text{sys}} = \text{-----} \text{ J mol}^{-1} \text{ K}^{-1} \text{ [1]}$$

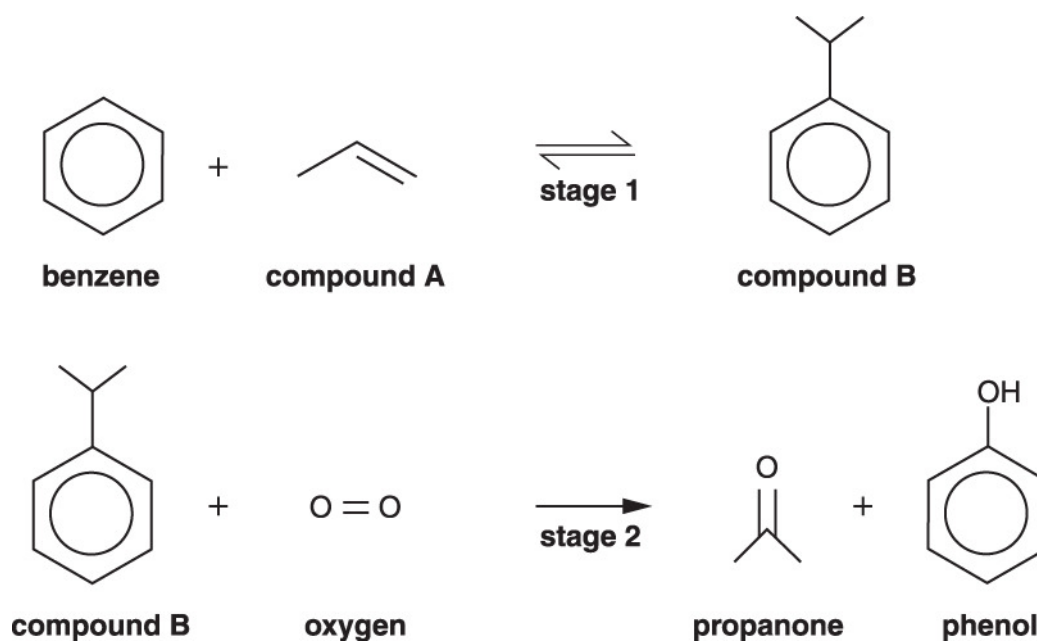
(ii) Calculate the temperature at which $\Delta S_{\text{tot}} = 0$, giving the units.

$$T = \text{-----} \text{ units -----} \text{ [3]}$$

(iii) What can you conclude about the equilibrium when $\Delta S_{\text{tot}} = 0$?

 ----- [1]

3(a) Propanone and phenol are useful organic compounds. They are both manufactured from benzene by the two-stage process shown below.



(i) Name compound A.

----- [1]

(ii) The reaction in **stage 1** is described as a *Friedel-Crafts* reaction.

Give **one** similarity and **one** difference between this reaction and most other Friedel-Crafts reactions. Give your answer in terms of the **reactants** and **products**.

Similarity -----

Difference -----

[2]

(b) **Stage 1** is carried out at 250 °C and 30 atmospheres pressure in the gas phase. The reaction is exothermic.

- (i) Describe and explain the effect of increased pressure on the reaction in **stage 1**.

Answer in terms of the equilibrium yield and rate.



In your answer, you should relate your explanation to the equation for the reaction.

[4]

- (ii) Describe and explain the effect (if any) of increasing the temperature on the **equilibrium constant** for **stage 1**.

Suggest why a temperature lower than 250 °C is **not** used.

[2]

- (iii) What is the atom economy of the whole process (stages 1 and 2 taken together)?

Explain why this is beneficial to the environment.

[2]

4(a) Calcium carbide, CaC_2 , can be made by reacting calcium oxide with carbon at high temperatures.

Write a possible equation for the formation of calcium carbide from calcium oxide, CaO .

[1]

- (b) Calcium carbide is heated with nitrogen under pressure. Calcium cyanamide is formed.



Calcium cyanamide is used as a fertiliser because it reacts with water to give ammonia, NH_3 .

- (i) Suggest an equation for the reaction of calcium cyanamide with water.

[2]

- (ii) The formation of calcium cyanamide is an example of 'nitrogen fixation' as it converts atmospheric nitrogen to its compounds.

Suggest and explain why there are not many nitrogen fixation reactions.

[1]

- (iii) Explain why nitrogen fixation is important for plants.

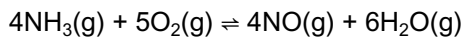
[1]

- (iv) Calculate the percentage by mass of nitrogen in calcium cyanamide.

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

Percentage = _____ % [2]

(c) Ammonia reacts with oxygen to form NO in the presence of a platinum catalyst at 850 °C.



(i) Give the oxidation states of nitrogen in NH₃ and NO.

NH₃ _____ NO _____

[1]

(ii) Give the systematic name of NO.

_____ [1]

(iii) A mixture of 50 cm³ of ammonia and 50 cm³ of oxygen is allowed to reach equilibrium. The total volume is then 105 cm³. All volumes are measured at the same temperature (above 100°C) and pressure.

Calculate the percentage of ammonia that has been converted to NO.

Percentage = _____ % [2]

(iv) At room temperature, a sample of NO immediately turns brown when released into the air.

Explain why this happens.

_____ [2]

- 5 Four gases, **W**, **X**, **Y** and **Z**, are known to be N_2 , NO , NH_3 and O_2 .
It is not known which gas is which.

When gases **X** and **Y** are mixed a brown gas is formed.

Gas **Y** relights a glowing splint.

Gases **W**, **X** and **Z** extinguish a burning splint.

Gas **Z** turns red litmus paper blue.

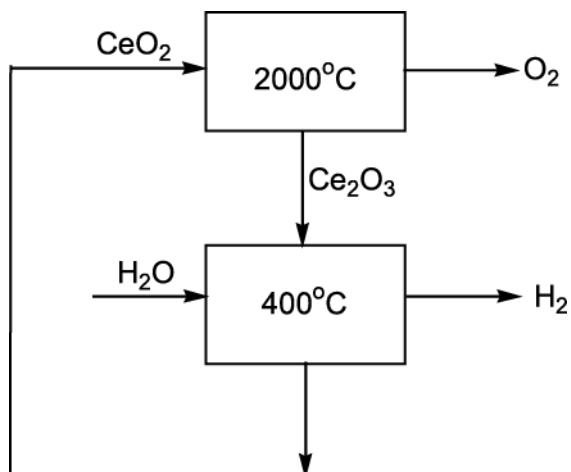
Which gas is N_2 ?

- A Gas **W**
- B Gas **X**
- C Gas **Y**
- D Gas **Z**

Your answer

[1]

- 6 Ceria, CeO_2 , is used in a thermochemical cycle for splitting water. A simplified diagram of the process is shown below.



- (i) Give the systematic name for ceria.

----- [1]

- (ii) Give chemical equations for the **two** reactions involved in the cycle.

State symbols are not required.

equation 1: -----

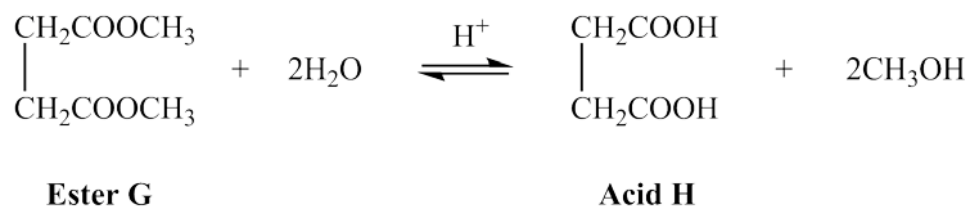
equation 2: ----- [2]

- (iii) One of the reactions in the cycle is endothermic.

What data for each reactant and product is required to decide which reaction is endothermic?

----- [1]

- 7 Ester **G** is a fruit-flavoured additive for some ice cream and chewing gum. Ester **G** can be hydrolysed to form acid **H** and methanol.



A mixture of ester **G** and water is left to reach equilibrium with a small amount of acid catalyst.
The initial concentrations are:

- Ester **G**: 2.0 mol dm^{-3}
- Water: 5.0 mol dm^{-3}

The equilibrium concentration of ester **G** is 1.4 mol dm^{-3} .

Calculate the value of K_c for this equilibrium.

Show **all** your working.

$K_c = \text{-----}$ [4]

- 8 Raspberry ketone, extracted from various berries, is widely used as a flavouring, a constituent of perfumes and as a diet supplement. The cost of natural raspberry ketone is often over 2000 times the cost of raspberry ketone manufactured synthetically.

Suggest a reason why natural raspberry ketone is expensive to produce.

----- [1]

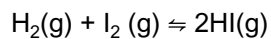
- 9 Which change is oxidation?

- A $\text{NO}_3^- \rightarrow \text{NH}_3$
B $\text{NO}_2^- \rightarrow \text{NO}_3^-$
C $\text{HNO}_3 \rightarrow \text{NO}_3^-$
D $\text{NH}_4^+ \rightarrow \text{NH}_3$

Your answer

[1]

10 The equation for the reaction between hydrogen and iodine is shown below.



The value of K_c is 46.9 at 760 K.

At equilibrium at 760 K the concentrations of the reactant gases are shown in the table.

What is the concentration of hydrogen iodide?

Gas	Concentration / mol dm^{-3}
I_2	0.00220
H_2	0.00920

- A $4.32 \times 10^{-7} \text{ mol dm}^{-3}$
- B $6.57 \times 10^{-4} \text{ mol dm}^{-3}$
- C $9.49 \times 10^{-4} \text{ mol dm}^{-3}$
- D $3.08 \times 10^{-2} \text{ mol dm}^{-3}$

Your answer

[1]

11 What are the units of the rate constant for a reaction that is third order overall?

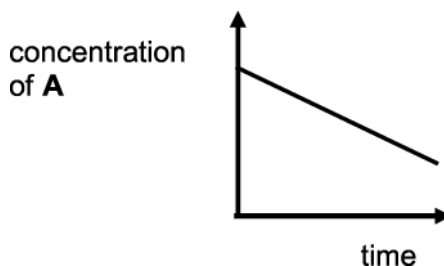
- A $\text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$
- B $\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-2}$
- C $\text{dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$
- D $\text{dm}^3 \text{ mol}^{-1} \text{ s}$

Your answer

[1]

12 Some students study the reaction $A + B + C \rightarrow \text{products}$.

Their graph of the concentration of reagent A against time is shown below.



What can be deduced from this graph?

- A The reaction is first order with respect to reagent A.
- B The reaction is zero order with respect to reagent A.
- C The reaction is first order overall.
- D Reagents B and C are not present in excess.

Your answer

[1]

13 Here are some data for the reaction $W + X \rightarrow \text{products}$.

Reagent	Order with respect to the reagent	Initial concentration / mol dm^{-3}
W	1	0.015
X	2	0.020

Some students measure the initial rate of reaction as $1.3 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$.

What is the numerical value of the rate constant?

- A 0.046
- B 0.43
- C 2.3
- D 22

Your answer

[1]

14(a)

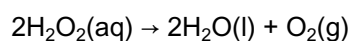
Some students investigate the decomposition of hydrogen peroxide in the presence of catalase. They measure the volume of oxygen produced at known times as the reaction proceeds.

- (i) Describe how they could use these results to find the rate of reaction at a certain time.

----- [2]

- (ii) The students are given '20 volume' hydrogen peroxide.

This means 1.0 cm^3 of the solution produces 20 cm^3 oxygen at room temperature and pressure when it breaks down.



Calculate the concentration of '20 volume' hydrogen peroxide (in mol dm^{-3}).

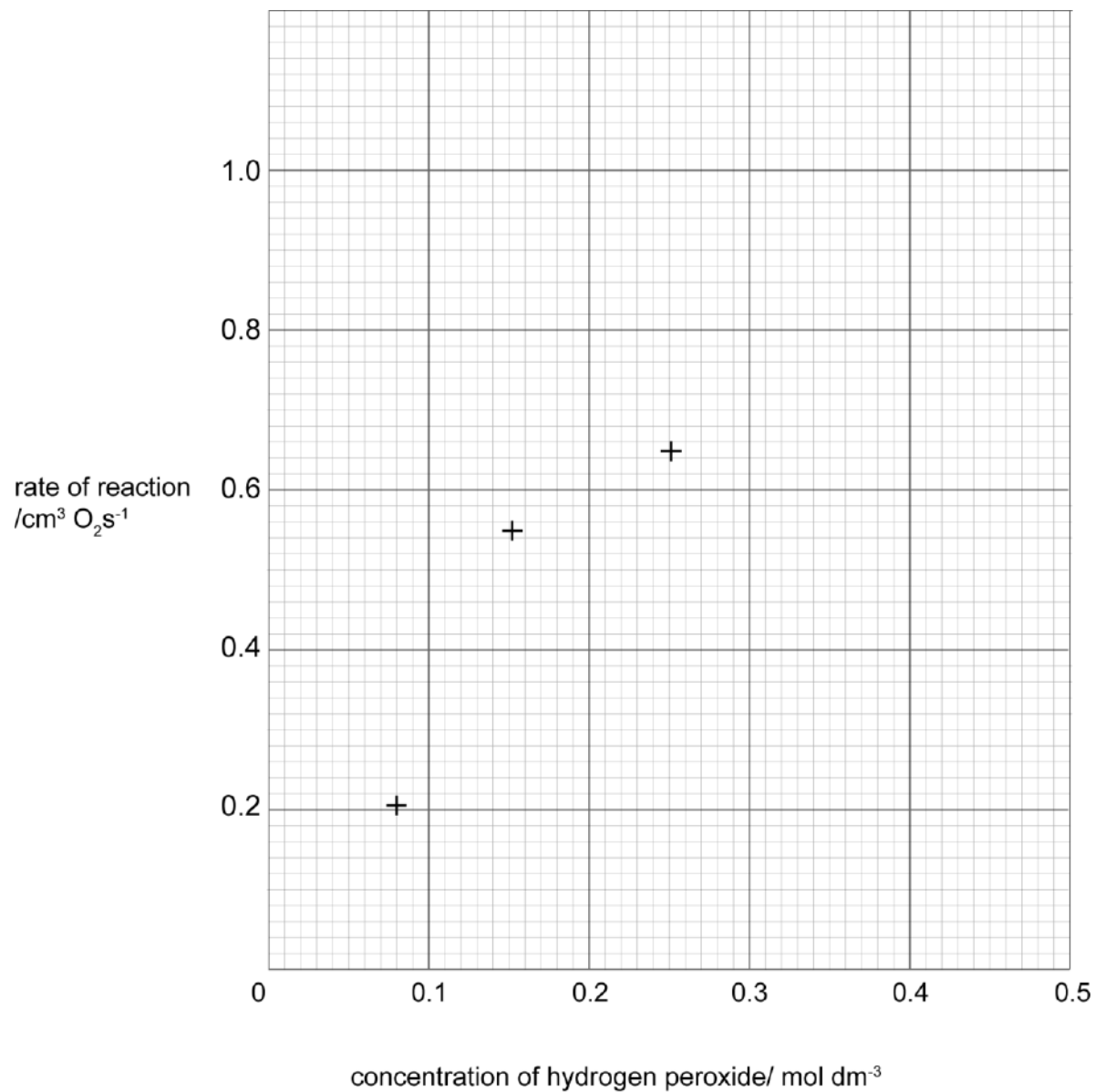
concentration = _____ mol dm^{-3} [2]

- (b) The students carry out a series of experiments with different concentrations of hydrogen peroxide and catalase with a concentration of 1%. They obtain the results shown in the table below.

Concentration of hydrogen peroxide / mol dm^{-3}	Rate of reaction / $\text{cm}^3 \text{O}_2 \text{s}^{-1}$
0.08	0.201
0.15	0.552
0.25	0.645
0.33	0.833
0.42	0.900
0.50	0.911

Complete the plot of rate against concentration on the grid below and draw the line of best fit.

[2]



- Comment on the students' conclusions, using evidence from the graph.
Give the correct chemistry where necessary.

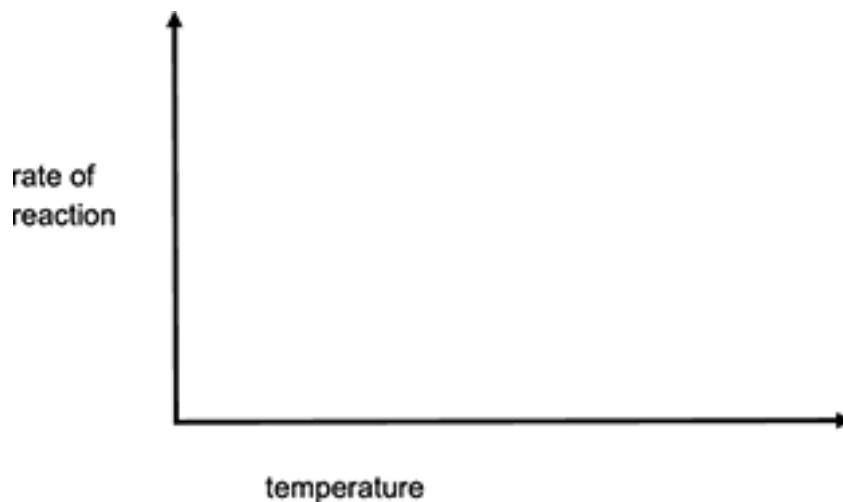
Comment on the students' conclusions, using evidence from the graph.
Give the correct chemistry where necessary.

[6]

(d) Catalase is an enzyme.

The students carry out the reaction at different temperatures and measure the initial rate of reaction.

Sketch the graph of the expected results and explain your answer.



----- [3]

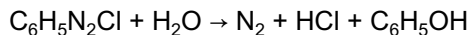
(e) Give **one** advantage and **one** disadvantage of using enzymes in industrial processes.

Advantage -----

Disadvantage -----

----- [2]

15 A compound with the formula $\text{C}_6\text{H}_5\text{N}_2\text{Cl}$ decomposes in dilute aqueous solution.



Some chemists investigate the rate of this decomposition. They collect the nitrogen gas in a graduated syringe at different initial concentrations of the $\text{C}_6\text{H}_5\text{N}_2\text{Cl}$ solution. They time how long it takes for 50 cm^3 of nitrogen to be collected. The volume of solution used in each experiment is 100 cm^3 .

(i) Two of the chemists' results are given in the table below.

Initial concentration / mol dm^{-3}	0.020	0.040
Initial rate / $\text{mol dm}^{-3} \text{ s}^{-1}$	8.70×10^{-7}	1.74×10^{-6}

Use these data to calculate the rate constant for the reaction. Include units in your answer.

Assume that the reaction is zero order with respect to water.

Show **all** your working.

rate = _____ units _____ [3]

(ii) The chemists could have measured the time to produce a much larger volume of nitrogen.

Suggest why it would have been inappropriate to measure the time to collect larger volumes of gas, particularly in the experiments with lower concentrations of $\text{C}_6\text{H}_5\text{N}_2\text{Cl}$.

----- [2]

(iii) The progress of the reaction can also be followed with a pH meter.

What is the pH of the solution once 50 cm^3 of nitrogen have been collected?

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

- (iv) Besides gas collection and measuring pH, suggest **one** other method with which the chemists could measure the progress of the reaction.

----- [1]

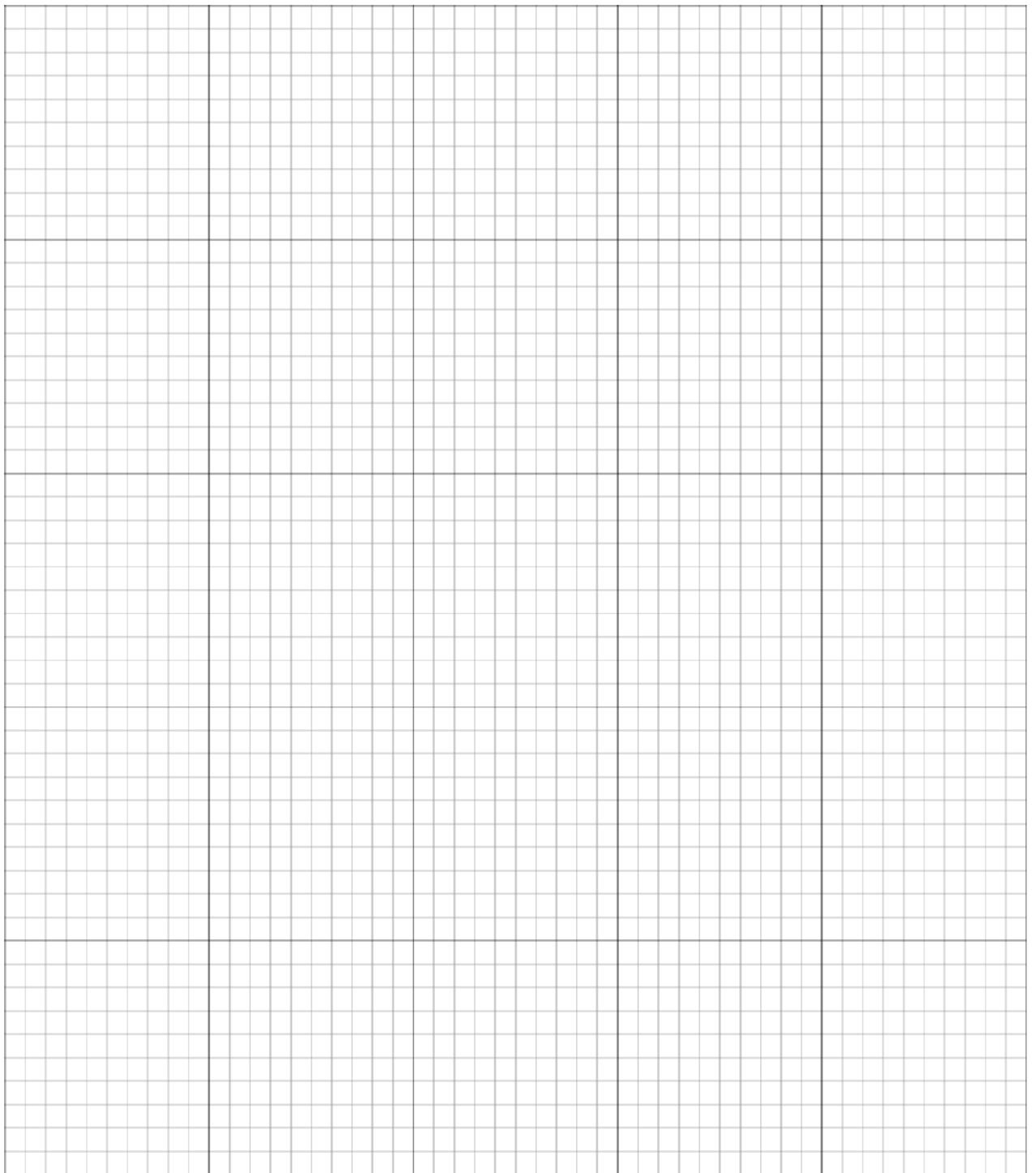
- (v) The chemists carried out the reaction at several temperatures and obtained the results in the left-hand two columns of **Table 1.1**.

Table 1.1

Temperature, T/K	rate constant, k/s^{-1}	$1/T/K^{-1}$	$\ln k$
278	1.5×10^{-6}	3.60×10^{-3}	-13.41
298	4.1×10^{-5}		-10.10
308	2.0×10^{-4}	3.25×10^{-3}	
323	1.4×10^{-3}	3.10×10^{-3}	-6.57

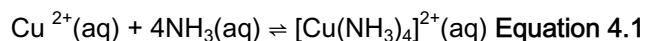
Calculate the missing values in **Table 1.1** and plot a graph of $\ln k$ against $1/T$ on the graph paper below.

Use your graph to calculate a value for the activation enthalpy of the reaction.



activation enthalpy = ... kJ mol^{-1}

- 16 A complex ion forms when ammonia solution is added to copper(II) sulfate solution.
The equation for the reaction can be represented as below.



- (i) High concentrations of ammonia in horse's urine can be a sign of infection. Adding a fixed amount of copper(II) sulfate solution to a given volume of urine produces the deep blue / purple ion, $[\text{Cu}(\text{NH}_3)_4]^{2+}(\text{aq})$ in equation 4.1.

Suggest how the production of this ion can be used as a measure of the ammonia content in the horse's urine.

----- [2]

- (ii) Write an equation for the equilibrium constant, K_c , of the reaction in equation 4.1.

[1]

- (iii) A solution initially contains 0.10 mol dm^{-3} of $\text{Cu}(\text{II})$ ions and 0.40 mol dm^{-3} of ammonia. At equilibrium, the concentration of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ formed is x .

Write an expression for the equilibrium constant K_c in terms of x .

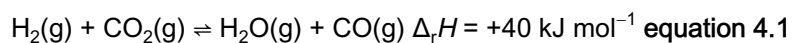
[2]

- (iv) Two students wanted to measure the concentration of ammonia in the complex solution at equilibrium. One suggested that they titrate samples of the complex solution with standard sulfuric(VI) acid. The other said the results would be inaccurate.

Comment on who is correct and give a reason for your answer.

17(a) Research is being conducted into chemical reactions that can be used on other planets such as Mars.

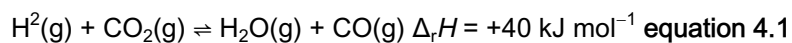
One reaction being studied is shown below.



The atmosphere of Mars consists mainly of carbon dioxide.

Hydrogen is initially brought from Earth.

At 500 K the equilibrium constant for **equation 4.1** is 7.76×10^{-3} .



A mixture containing the **initial** concentrations shown below is allowed to reach equilibrium at 500 K.

$$[\text{H}_2(\text{g})]_{\text{init}} = 1.16 \times 10^{-5} \text{ mol dm}^{-3}$$

$$[\text{CO}_2(\text{g})]_{\text{init}} = 1.16 \times 10^{-5} \text{ mol dm}^{-3}$$

Calculate the equilibrium concentration of $\text{H}_2\text{O}(\text{g})$ in the mixture.

equilibrium concentration of $\text{H}_2\text{O}(\text{g}) = \text{-----} \text{ mol dm}^{-3}$ [4]

(b) The water is electrolysed to regenerate the hydrogen.

(i) Energy is needed to electrolyse water.

Suggest a source of energy that is available on Mars.

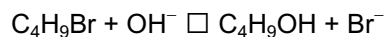
-----[1]

(ii) Suggest a reason why the electrolysis of water is beneficial to sustaining life on Mars.

-----[1]

18(a) A group of students set out to investigate the rate of hydrolysis of 1-bromobutane.
The reaction is relatively slow with water but much quicker with hydroxide ions (OH^-).

1-bromobutane reacts with sodium hydroxide solution as follows:



(i) Name the mechanism of this reaction.

-----[2]

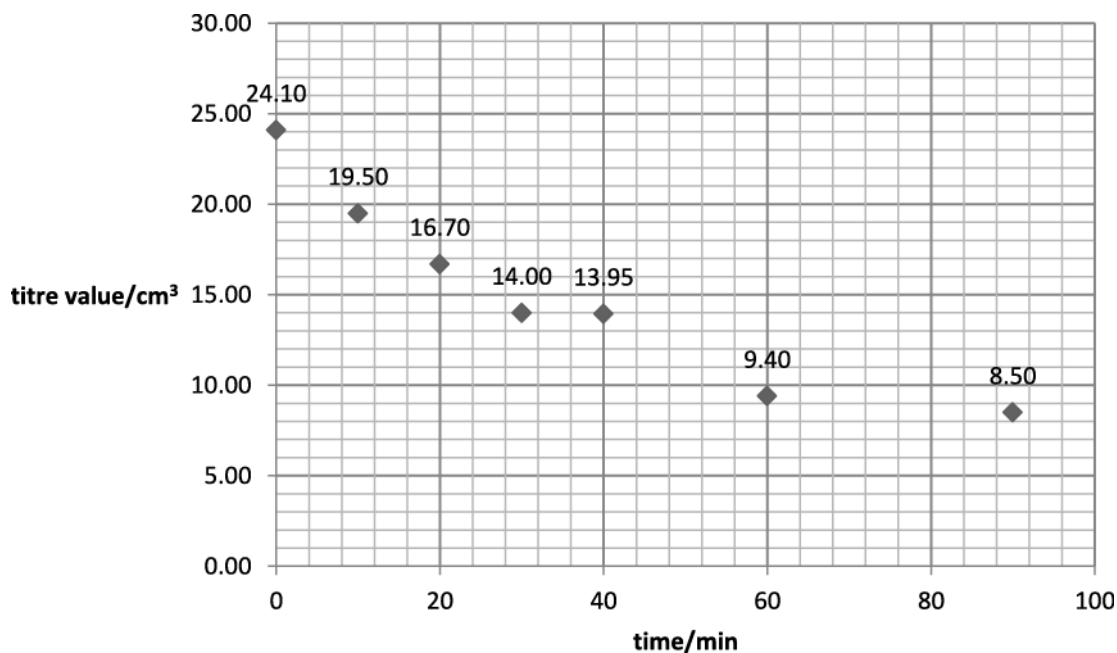
(ii) Name the **type** of bond fission occurring in this reaction.

-----[1]

(b) Equimolar quantities of 1-bromobutane and sodium hydroxide are mixed at 40°C.

The concentration of hydroxide ions is determined at various times by removing 10.0 cm³ of the mixture, adding it to 20 cm³ of iced water in a conical flask, and titrating with a 0.125 mol dm⁻³ solution of hydrochloric acid.

The group's results are plotted below.



(i) Suggest why the reactant mixture was added to a larger volume of iced water.

-----[1]

(ii) Use the information given and the data on the graph to calculate the initial concentration of the sodium hydroxide solution.

initial concentration = _____ mol dm⁻³ [2]

(iii) Further investigations by the group suggested that the reaction was second order **overall**.

Write **two** rate equations which would be consistent with this suggestion.

rate = _____

rate = _____

[1]

- (iv) Use the graph to calculate the initial rate of reaction, in $\text{mol dm}^{-3} \text{ min}^{-1}$.

Show on the graph how you calculated the initial rate.

rate = _____ $\text{mol dm}^{-3} \text{ min}^{-1}$ [3]

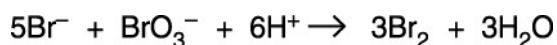
- (v) Use the initial rate, along with your answer to (ii) above, to calculate the value of the rate constant, k , including the units, for this reaction at 40°C .

rate constant, k = _____ units _____ [2]

- Describe and explain how they can use aqueous silver nitrate in their investigation, and what conclusions they should be able to make.

[6]

- 19 A student investigates the reaction rate at room temperature of Br^- with BrO_3^- in excess acid to form bromine and water.



- (i) Suggest an appropriate method for following the progress of this reaction in a student laboratory at room temperature.

Measure the concentration of _____

by (method) _____

The reason for choosing method is

[3]

- (ii) The student then carries out an initial rate study on the reaction. The results are shown below.

Experiment	$[\text{BrO}_3^-] / \text{mol dm}^{-3}$	$[\text{Br}^-] / \text{mol dm}^{-3}$	$[\text{H}^+] / \text{mol dm}^{-3}$	Relative rate of reaction
1	6.95×10^{-4}	1.39×10^{-3}	6.95×10^{-4}	4
2	6.95×10^{-4}	6.95×10^{-4}	6.95×10^{-4}	2
3	1.39×10^{-3}	1.39×10^{-3}	3.48×10^{-4}	2
4	6.95×10^{-4}	1.39×10^{-3}	3.48×10^{-4}	1

Determine the rate equation for the reaction.

rate = _____ [3]

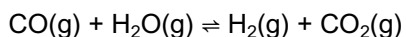
- (iii) The student repeats the experiment on a very hot day. The student is concerned that the high temperature will make volatile substances escape from the solution.

Discuss how this would affect the measured rate of reaction.

Give reasons for your answer.

[3]

20(a) A reaction that is much used in industry is shown in **Equation 3.1**.



Equation 3.1

The reaction is first carried out at high temperature (around 800 K) using one set of catalysts. Then the gases are cooled to around 500 K and passed over other catalysts.

For the reaction in **equation 3.1**, K_c values are as shown in the table.

Temperature/K	K_c
500	58
800	5

- (i) Is it correct to quote K_c without units for this reaction?

Justify your answer.

----- [1]

- (ii) Use the data to state whether the forward reaction in **equation 3.1** is endothermic or exothermic.

Explain your reasoning.

----- [1]

- (iii) Suggest why the reaction is carried out at high temperature and then at low temperature.

----- [2]

- (b) The conditions are designed to leave only a small concentration of CO in the mixture.

An initial mixture of CO and excess $\text{H}_2\text{O}(\text{g})$ has a CO concentration of $1.5 \times 10^{-3} \text{ mol dm}^{-3}$.

At equilibrium at 500 K, the concentration of CO is $4 \times 10^{-5} \text{ mol dm}^{-3}$.

The equilibrium concentration of hydrogen can be taken to be $1.5 \times 10^{-3} \text{ mol dm}^{-3}$.

- (i) Explain why the equilibrium concentration of hydrogen can be taken to be $1.5 \times 10^{-3} \text{ mol dm}^{-3}$.

----- [2]

- (ii) Calculate the concentration of $\text{H}_2\text{O}(\text{g})$ in the equilibrium mixture at 500 K.

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

$[\text{H}_2\text{O}(\text{g})] = \text{-----} \text{ mol dm}^{-3}$ [3]

- (iii) Calculate the pressure (in atmospheres) that gives a gas a concentration of $1.5 \times 10^{-3} \text{ mol dm}^{-3}$ at 'room temperature'.

The volume of one mole of a gas at room temperature and 1 atmosphere pressure is 24 dm^3 .

pressure = ... atm [1]

(c) Hydrogen is used in the manufacture of ammonia.

Ammonia reacts with nitric acid to form ammonium nitrate, NH_4NO_3 , a fertiliser.

(i) Draw a '*dot-and-cross*' diagram for the NO_3^- ion and give the oxidation state of nitrogen in the ion.

NO_3^- has a nitrogen atom surrounded by three oxygen atoms. Show outer electron shells only.

oxidation state _____ [3]

(ii) Ammonium nitrate is potentially explosive.

When it is heated carefully, water and an oxide of nitrogen are formed.

Write the equation for this reaction. Give the name and appearance of the oxide of nitrogen.

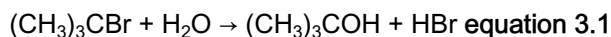
Equation:

Name of oxide _____

Appearance of oxide _____ [2]

21(a) 't-butyl bromide', $(\text{CH}_3)_3\text{CBr}$, is used in industry to make other organic chemicals such as 't-butyl alcohol', $(\text{CH}_3)_3\text{COH}$.

Some students carry out an experiment to follow the hydrolysis of $(\text{CH}_3)_3\text{CBr}$ with water.
Since the haloalkane is not soluble in water, they use a mixture of propanone and water as a solvent.



The students carry out the reaction in a conical flask. They follow the reaction by titrating samples with NaOH.

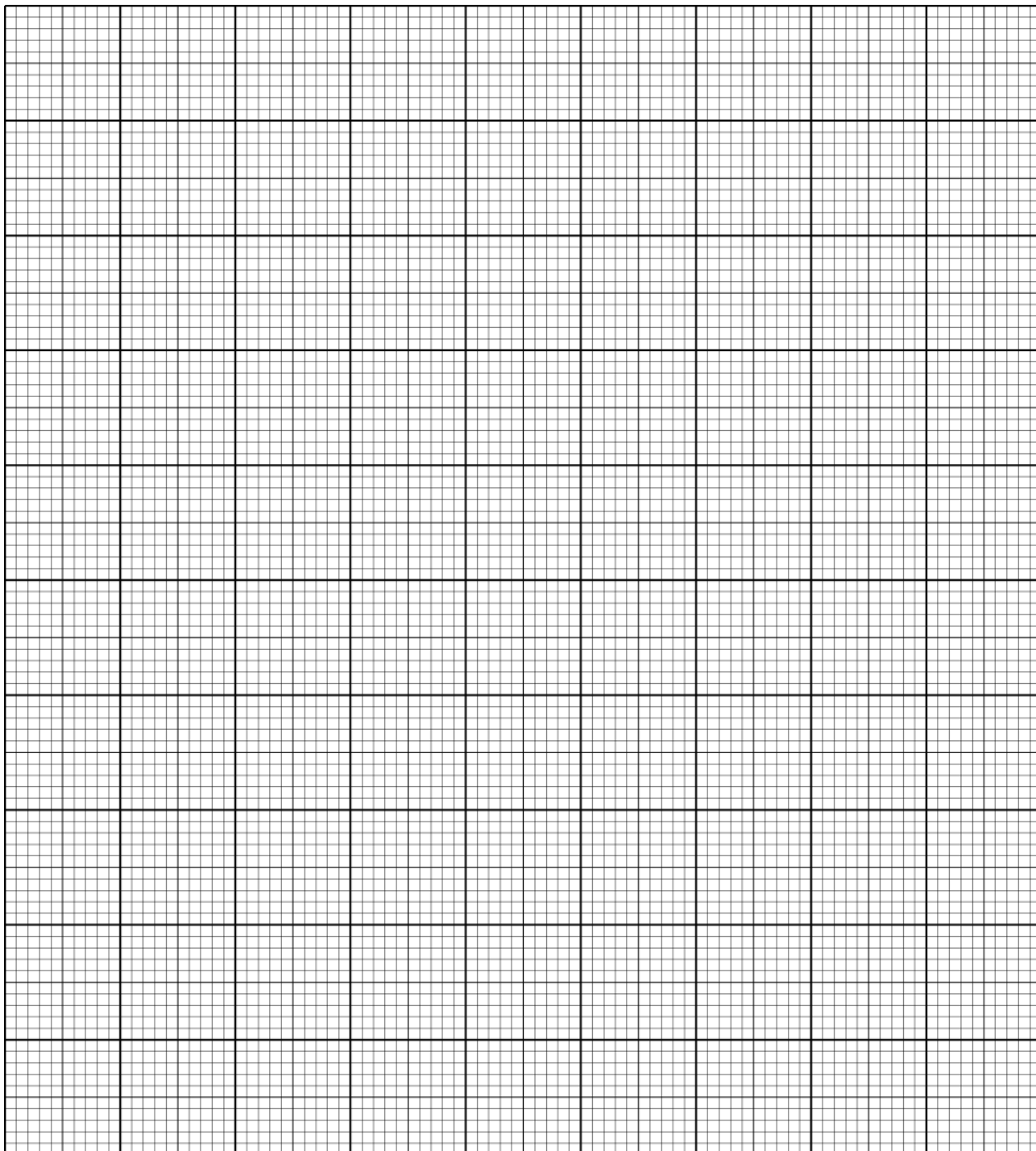
Suggest practical details for the students' method of following the reaction.

[3]

(b) The students produce the results in the table below.

Time / minutes	Amount of $(\text{CH}_3)_3\text{CBr}$ / mol
2	8.80×10^{-3}
5	6.90×10^{-3}
10	6.65×10^{-3}
14	5.70×10^{-3}
20	4.60×10^{-3}
25	3.78×10^{-3}
30	3.23×10^{-3}
45	1.85×10^{-3}

(i) Plot the points on the grid below and draw the curve or straight line of best fit.

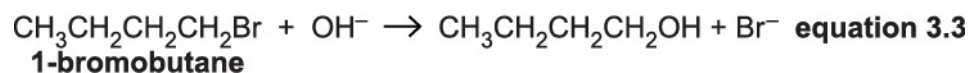
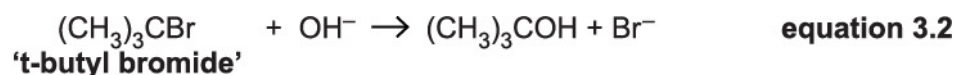


[4]

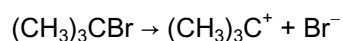
- (ii) Use the graph to show that the reaction in **equation 3.1** is first order with respect to the haloalkane.
Show working on the graph and give your reasoning below.

[2]

(c) *t-butyl bromide and 1-bromobutane, an isomer, react with hydroxide ions as shown.



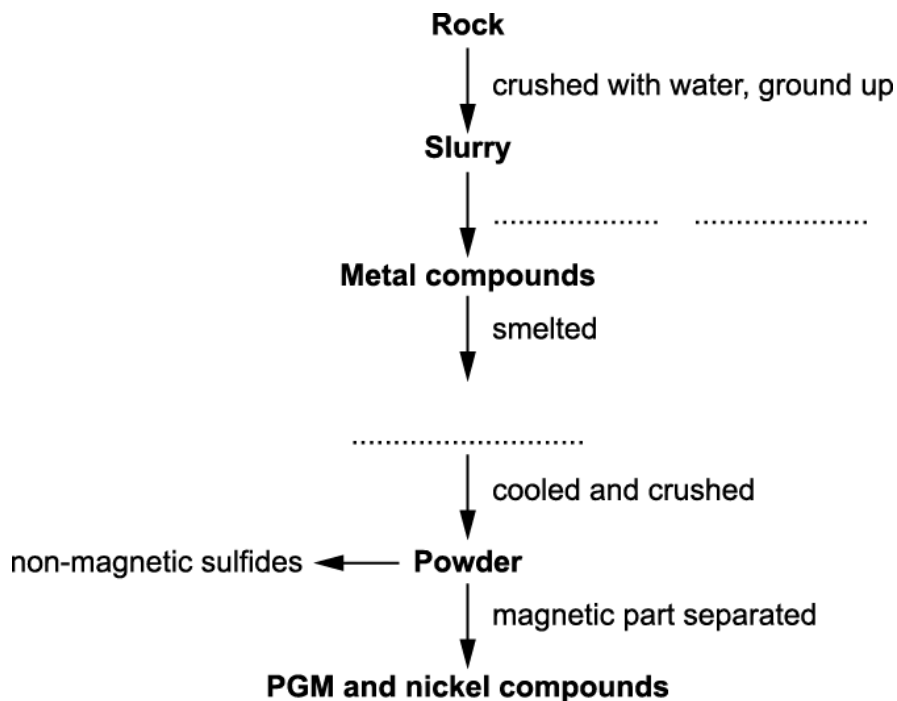
The reaction in **equation 3.2** has the rate-determining step shown below.



The reaction in **equation 3.3** occurs in a single step.

What can be deduced from this information about the mechanisms, orders of reaction and rate equations of the two reactions?

- (i) Write words on the dotted lines to complete the flowchart below to summarise the extraction of PGM from rocks.



[1]

- (ii) Suggest an equation for the reaction of one of the 'non-magnetic sulfides' with sulfuric acid to form a sulfate.

[1]

- (iii) How is the metal obtained from the solution of its sulfate?

[1]

(b)

- (i) Suggest **two** reasons why PGM are used in catalytic converters rather than other equally effective catalysts.

----- [1]

- (ii) Write the equation for a reaction in which both CO and NO are removed from exhaust gases in a catalytic converter.

[1]

- (c) Complete the electron configuration of Rh^{3+} , by comparison with Co^{3+} .

[Kr] ----- [1]

(d)

- (i) $[\text{Ru}_2\text{OCl}_{10}]^{4-}$ has an oxygen atom connecting two Ru atoms.

Draw a three-dimensional diagram to suggest the shape of this ion. Give the co-ordination number of Ru in your structure.

co-ordination number ----- [2]

- (ii) Suggest a **name** for the shape of $[\text{AuCl}_4]^-$.

----- [1]

- (e) Give the formula of a 'bulky organic monocation' from the article and explain why three such species are needed by $[\text{MC}_6]^{3-}$.

----- [2]

(f) Estimate how much faster $[\text{Ag}(\text{H}_2\text{O})_2]^+$ exchanges chloride ions compared with $[\text{Ru}(\text{H}_2\text{O})_6]^{3+}$.

----- [1]

(g) Give the equation for a ligand exchange reaction of copper involving ammonia. Give the starting and finishing colours involved.

[2]

(h) A student says that silver(I) salts are colourless because the d subshells are not split by the ligands.

Discuss this statement. (Ag has the same outer electron configuration as Cu.)

----- [3]

- [6]

[6]

- $$2\text{H}_2\text{O}(\text{g}) \rightleftharpoons 2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \quad \Delta_r H = +484 \text{ kJ mol}^{-1}$$

	Temperature	Pressure
A	High	High
B	High	Low
C	Low	Low
D	Low	High

1

[1]

- 24 In order to find the activation enthalpy for a reaction, a student must plot a graph. In one experiment the rate constant, k , was $4.50 \times 10^{-3} \text{ s}^{-1}$ and the temperature was 60.0°C .

What point would the student plot for this result?

- A $(-5.40, 3.61 \times 10^{-4})$
- B $(-2.35, 3.00 \times 10^{-3})$
- C $(-5.40, 3.00 \times 10^{-3})$
- D $(-2.35, 1.67 \times 10^{-2})$

Your answer

[1]

- 25 Which statement(s) about nitrogen compounds is / are correct?

- 1 The ammonium ion has a H—N—H bond angle of 109.5° .
- 2 The ammonia molecule has a tetrahedral shape.
- 3 N_2O reacts with air to form a brown gas.

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

Your answer

[1]

26(a) Esters have many uses in organic chemistry, including in polymers.

Some students want to determine the equilibrium constant for the esterification reaction in **equation 33.1** in acidic conditions.



They set up their experiment with known masses of ethanol, ethanoic acid and concentrated sulfuric acid catalyst.

They place the reactants in a stoppered bottle and wait a week for equilibrium to be established.

Suggest how the students could find the amount of ethanoic acid in the bottle at equilibrium.

----- [2]

- (b) By using the method from (a), the students find that the amount of ethanoic acid present at equilibrium is 0.123 mol.

They produce the table below.

Substance	Mass present at the start / g	Amount present at the start / mol	Amount present at equilibrium / mol
ethanol	15.8		
ethanoic acid	21.0		0.123
ethyl ethanoate	0	0	
water	0	0	

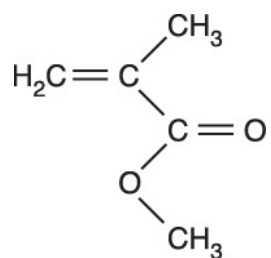
Carry out appropriate calculations to fill in the blanks in the table.

Use figures from the table to work out a value for the equilibrium constant, K_c , of the reaction in equation 33.1.

$K_c =$ _____ [4]

- (c) Another ester is the monomer for the polymer polymethyl methacrylate or PMMA. PMMA is often used to make lightweight transparent materials as a replacement for glass.

The monomer has the structure shown below.



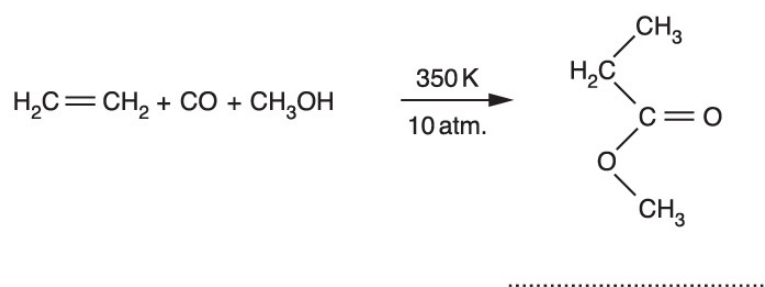
Draw the structural formula for **one** repeating unit of the polymer.

[1]

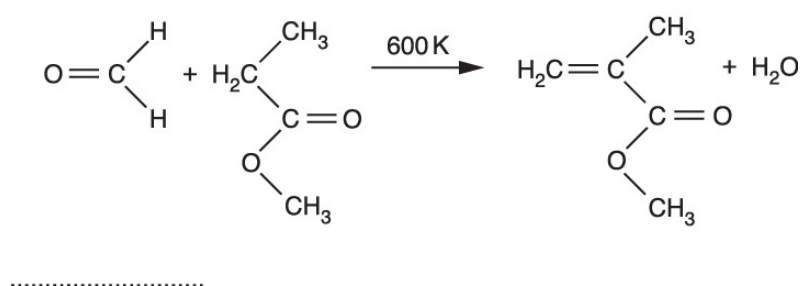
(d) The monomer can be made in the following reaction sequence.

Give the systematic names of two of the compounds on the dotted lines below their structures.

Stage 1:



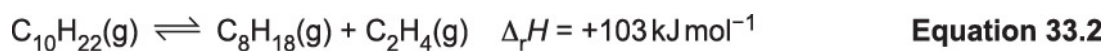
Stage 2:



[1]

- (e) The ethene used in **stage 1** comes from thermal cracking of long chain alkanes from crude oil in the presence of steam.

One such reaction is shown below.



Substance	Entropy / $\text{J mol}^{-1} \text{K}^{-1}$
$\text{C}_{10}\text{H}_{22}$	+425.9
C_8H_{18}	+361.1
C_2H_4	+219.5

Use the entropy values given to find the minimum temperature needed for the forward reaction to be feasible.
Give your answer to an **appropriate** number of significant figures.

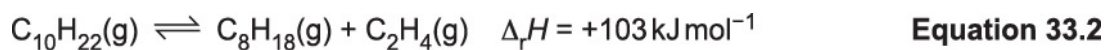
minimum temperature = _____ K [3]

- (f) Give the effects that the following changes have on the value of K_c for the reaction in **equation 33.2**.

Change	Increased temperature	Increased pressure	Use of a catalyst
Effect on K_c			

[2]

(g) The yield of the reaction in **equation 33.2** is typically 50%.



Calculate the volume (in dm^3) of ethene produced when 25.0 kg of decane are cracked at 900 K and a pressure of 150 kPa.

volume of ethene = _____ dm^3 [3]

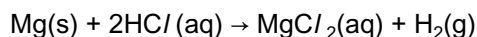
(h) An alternative method of obtaining ethene is catalytic cracking using zeolite catalysts.

Explain the advantage to the environment of this method over steam cracking.

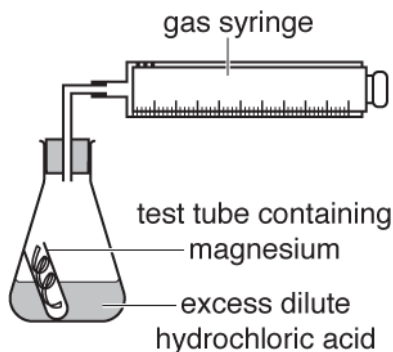
----- [1]

28(a) Two students decide to study the reaction of magnesium with dilute hydrochloric acid to find the order of this reaction with respect to the acid.

The equation for the reaction is:



The students use the following apparatus:



The students run **five** experiments each using a different concentration of hydrochloric acid.

They use the same length of magnesium ribbon each time.

(i) Why was the length of the magnesium ribbon kept the same?

----- [1]

(ii) 50 cm³ acid is used each time.

The concentration ranged from 0.1 to 0.5 mol dm⁻³.

Calculate the **maximum** mass of magnesium ribbon that would completely react with the acid in **all** five experiments.

mass = ----- g [3]

- (iii) Calculate the maximum length of magnesium ribbon needed to completely react with the acid in all the experiments.

The mass per unit length of Mg ribbon = $1.3 \times 10^{-2} \text{ g cm}^{-1}$

length = ----- cm [1]

- (b) The students predict that the reaction will be second order with respect to acid.

Write the rate equation that would be appropriate for this prediction.

----- [1]

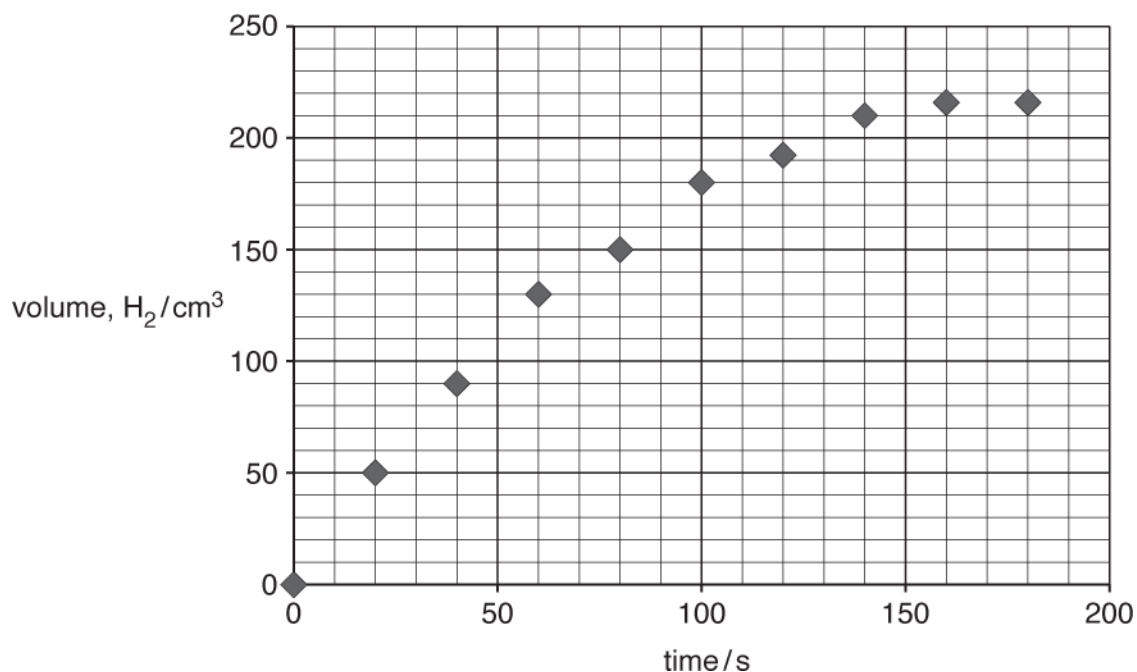
- (c) The students plot a graph of volume of hydrogen against time.

The graph of the results when the concentration of hydrochloric acid is 0.5 mol dm^{-3} is shown below.

Draw a line of best fit on the graph.

Use your line of best fit to calculate the initial rate of reaction at this concentration and give the units.

Show your working on the graph.



initial rate ----- units ----- [5]

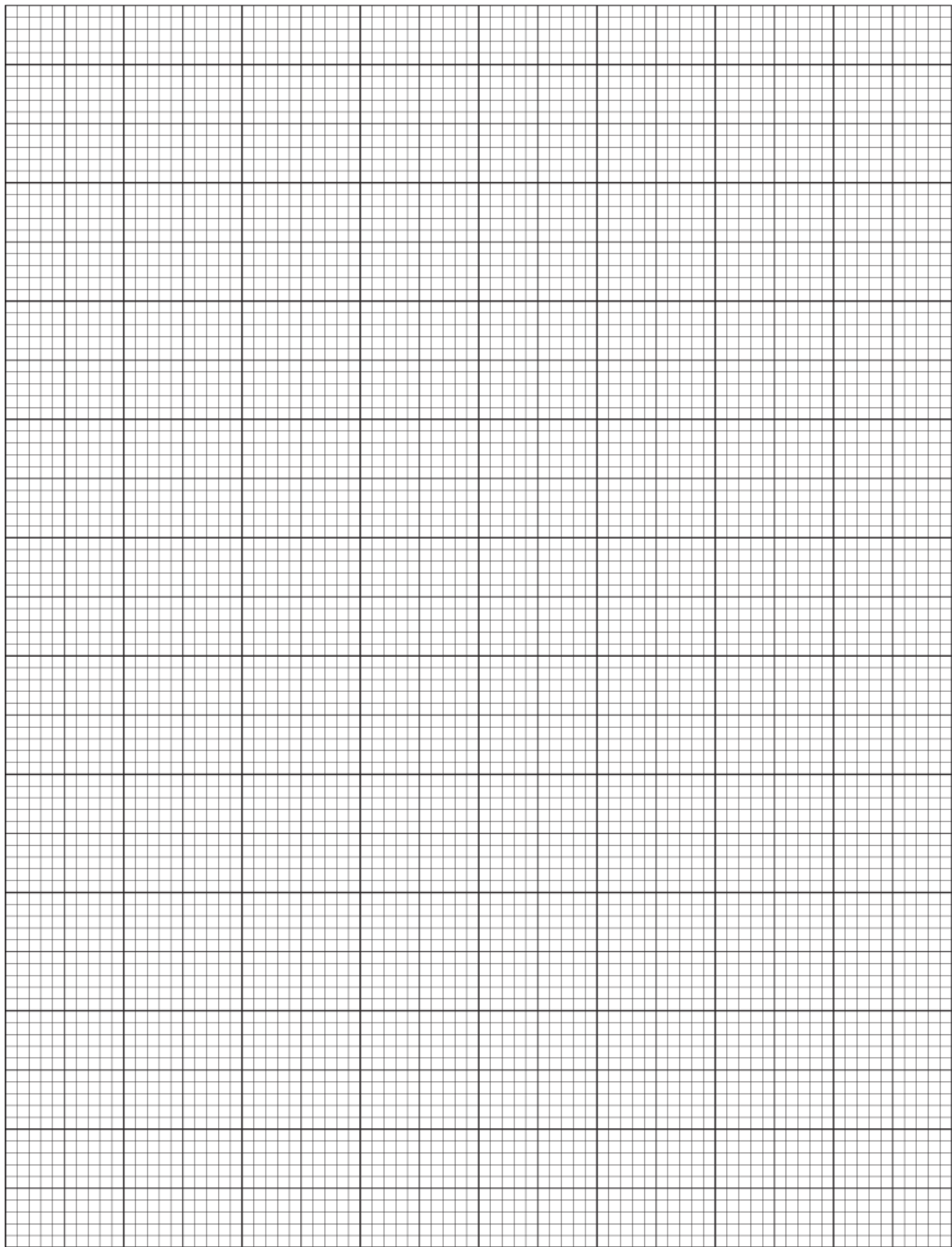
- (d) The students decide to measure the activation enthalpy for the reaction.

They repeat the experiment at different temperatures using a fixed concentration of acid.

The following table shows the data from their experiments.

$\ln k$	Temperature / °C	Temperature, T/K	$1/T / \text{K}^{-1} (\times 10^{-3})$
-5.46	15.6	288.6	3.47
-4.92	30.3	303.3	3.30
-4.34	45.0	318.0	3.14
-3.73	65.0	338.0	2.96

Use the data to plot a suitable graph on page 9 and work out the activation enthalpy for the reaction.



activation enthalpy = ----- kJ mol⁻¹ [6]

- 29 Which statement about testing for nitrate(V) ions is correct?
- A They give off ammonia gas when warmed with sodium hydroxide solution.
 - B Ammonia is detected because it turns blue litmus paper red.
 - C Aluminium is used to reduce nitrate(V).
 - D Nitrate(V) ions are oxidised.

Your answer

[1]

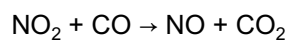
- 30 Which process is **not** oxidation?

- A $\text{NH}_4^+ \rightarrow \text{NO}_2^-$
- B $\text{NO}_3^- \rightarrow \text{N}_2$
- C $\text{N}_2 \rightarrow \text{NO}$
- D $\text{NO}_2^- \rightarrow \text{NO}_3^-$

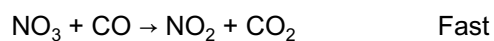
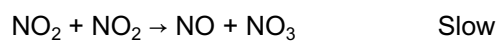
Your answer

[1]

31 Nitrogen dioxide reacts with carbon monoxide as in the equation below.



The mechanism is:



Which expression is the correct rate equation?

A $\text{Rate} = k [\text{NO}_2] [\text{CO}]$

B $\text{Rate} = k [\text{NO}_2]^2 [\text{CO}]$

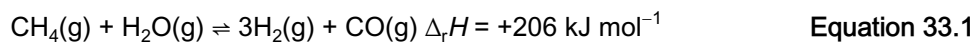
C $\text{Rate} = k [\text{CO}]$

D $\text{Rate} = k [\text{NO}_2]^2$

Your answer

[1]

32(a) An important source of hydrogen is from the steam reforming reaction shown below.



The position of equilibrium can be changed by altering the conditions.

Complete the table to show the effects on the yield of hydrogen and the value of the equilibrium constant, K_c

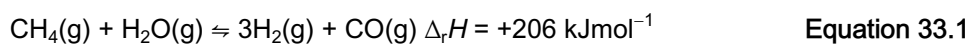
	Increasing temperature	Increasing pressure
Effect on yield of hydrogen		
Effect on the value of K_c		

[2]

- (b) 2.00 moles of methane and 1.00 mole of steam are allowed to reach equilibrium in a 1.00 dm³ container. At equilibrium 0.66 mole of steam remains.

Calculate a value for the equilibrium constant and give its units.

$K_c =$ ----- units ----- [3]



(c) The steam reforming reaction shown in **equation 33.1** makes hydrogen. Much of the hydrogen is used in the manufacture of ammonia.

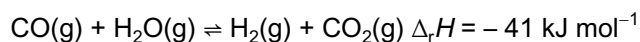
(i) Calculate the atom economy of the reaction in **equation 33.1** when making hydrogen.

atom economy = ----- % [1]

(ii) How is carbon monoxide described when it is formed alongside the required product (hydrogen)?

----- [1]

(d) The carbon monoxide can be used in the exothermic water gas shift reaction.



The water gas shift reaction often takes place in the same industrial plant as steam reforming.

Suggest **two** advantages of the water gas shift reaction taking place with steam reforming.

1

2

----- [2]

33 Which statement about a by-product of an industrial reaction is correct?

- A It is formed in the same reaction as the product.
- B It is formed when the reactants react in a different way.
- C It is in the equation for the reaction.
- D It is a minor reactant in the reaction.

Your answer

[1]

34 Which statement about the rate determining step of a reaction is correct?

- A It is the fast step.
- B It cannot involve a catalyst.
- C It does not involve zero order reagents.
- D It is always between two first-order reagents.

Your answer

[1]

35 Which statement about the Arrhenius equation is correct?

- A A plot of $\ln k$ against T gives a straight line.
- B When T is very large $\ln k$ almost equals $\ln A$.
- C E_a is the gradient of a plot of $\ln k$ against $1/T$.
- D A plot of k against $1/T$ gives a straight line.

Your answer

[1]

36(a)

Plants need nitrogen to synthesise proteins, but most plants cannot use atmospheric nitrogen.

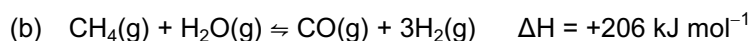
Ammonium nitrate is often used as a fertiliser as it contains nitrogen in a form that plants can absorb.

The first step in the process of making ammonium nitrate is the synthesis of ammonia from atmospheric nitrogen.

This synthesis reaction has a very high activation enthalpy.

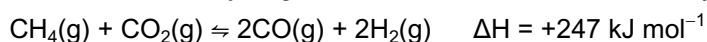
Explain this in terms of the bonding in nitrogen.

[1]



Equation 36.1

Another source of hydrogen is from the reaction shown in equation 36.2.



Equation 36.2

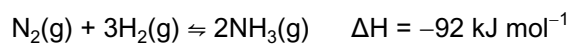
This is claimed to be a much greener process than that in equation 36.1.

Comment on the validity of this statement, considering:

- the raw materials used
- the operating conditions
- the mole ratios.

[3]

(c) The Haber process for the manufacture of ammonia is shown in **equation 36.3**.



Equation 36.3

At a certain temperature, a mixture of nitrogen and hydrogen was allowed to reach equilibrium in a container of fixed volume. Chemists found the concentrations shown in the table.

Substance	Concentration at the start / mol dm ⁻³	Concentration at equilibrium / mol dm ⁻³
N ₂	1.00	0.90
H ₂	1.00	
NH ₃	0.00	

Calculate the equilibrium concentrations of H₂ and NH₃.

Use these values to calculate a value for K_c at the temperature of the experiment and give the units.

K_c = ----- units ----- [3]

- (d) In order to make the ammonium nitrate fertiliser, some of the ammonia is oxidised to nitric acid in several stages shown by **equations 36.4–36.6**.



The nitric acid formed is reacted with more ammonia.



- (i) Use oxidation states or some other method to balance **equation 36.4**. [1]
- (ii) The overall yield of the reactions in **equations 36.4 – 36.6** is 77%.
The yield of ammonium nitrate in **equation 36.7** can be taken as 100%.

What mass (in tonnes) of ammonia is needed to make 25 tonnes of ammonium nitrate?

mass of ammonia needed = ... tonnes [4]

- (iii) Describe a test that would identify nitrate ions.

.....

.....

..... [4]

37(a) Why does human hair turn grey? Studies have shown that this is caused by lower levels of the enzyme catalase in hair follicles. Catalase catalyses the breakdown of hydrogen peroxide as shown in **equation 3.1**.

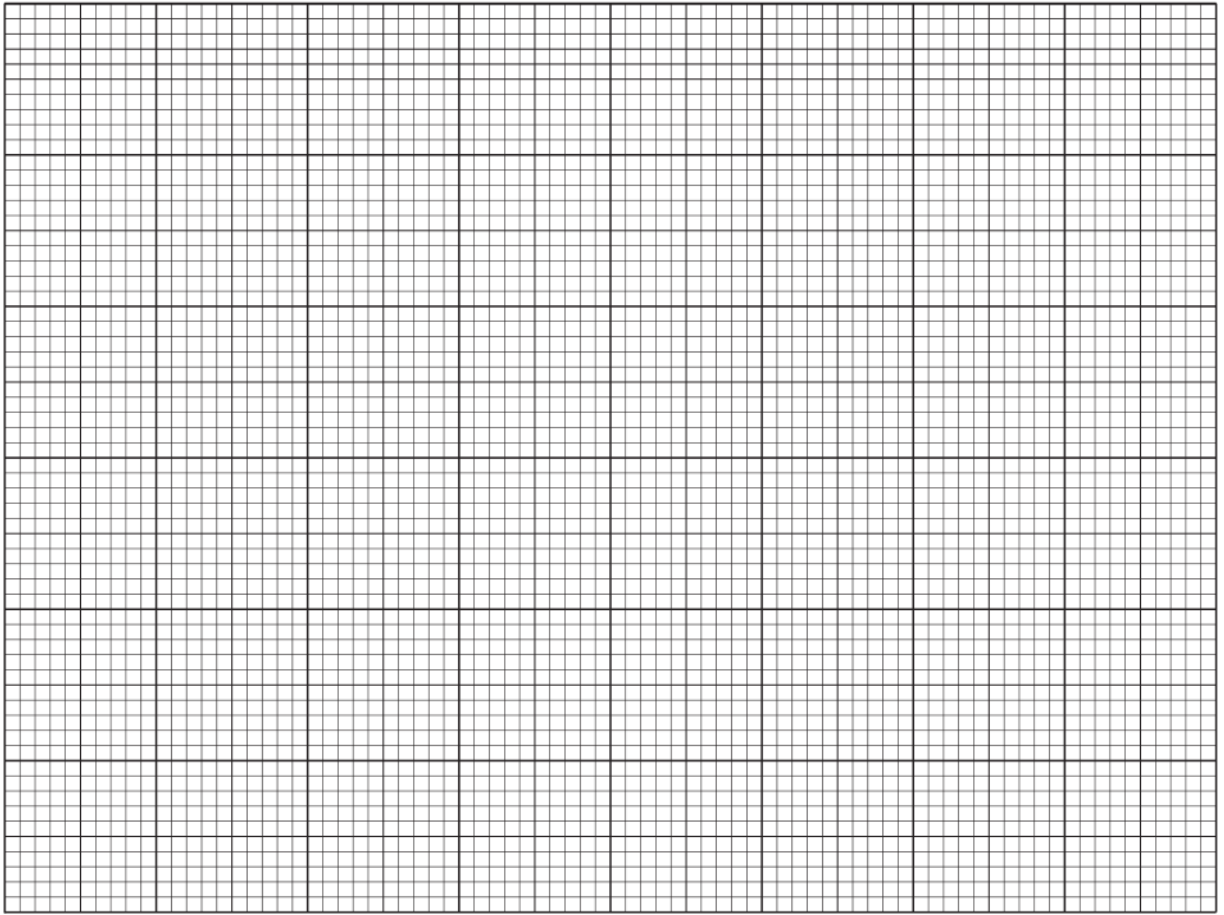


When levels of hydrogen peroxide increase, the melanin (dye) in the hair is bleached.

*Some students are given a solution of catalase and solutions of hydrogen peroxide of different concentrations. They study the rate of reaction in **equation 3.1**.

They determine the relative initial rates of reaction at the different hydrogen peroxide concentrations, using the volume of oxygen produced.

Suggest the procedure they follow, including how the students should process their results. You may include a diagram as part of your answer.



[4]

(c) A student says that the graph shows that the decomposition of hydrogen peroxide is first order with respect to both the hydrogen peroxide concentration and the catalase concentration.

- (i) Write the rate equation that would follow from the student's statement.
Give the units of the rate constant.

Rate equation:

Units of rate constant -----

[2]

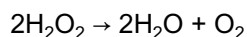
- (ii) Explain why the student is incorrect and give the correct information.

[3]

- (d) Hydrogen peroxide concentration is often measured as 'volume strength'.
1 cm³ of '1 volume' hydrogen peroxide produces 1 cm³ of oxygen at RTP.

Calculate the 'volume strength' of the 0.35 mol dm⁻³ hydrogen peroxide used by the students.

Equation 3.1



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

'volume strength' = ----- volume [3]

- (e) The students have 20.0 cm³ 0.35 mol dm⁻³ H₂O₂ and wish to make a 0.05 mol dm⁻³ solution.

How much water should they add?

volume of water to add = ----- cm³ [2]

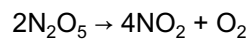
38 Which statement about enzyme catalysed reactions is correct?

- A The rate determining step is always the formation of an enzyme substrate complex.
- B They always speed up at higher temperatures.
- C The rate equation can vary depending on the substrate concentration.
- D They are zero order with respect to enzyme concentration.

Your answer

[1]

39(a) In the troposphere, dinitrogen pentoxide decomposes as shown below.

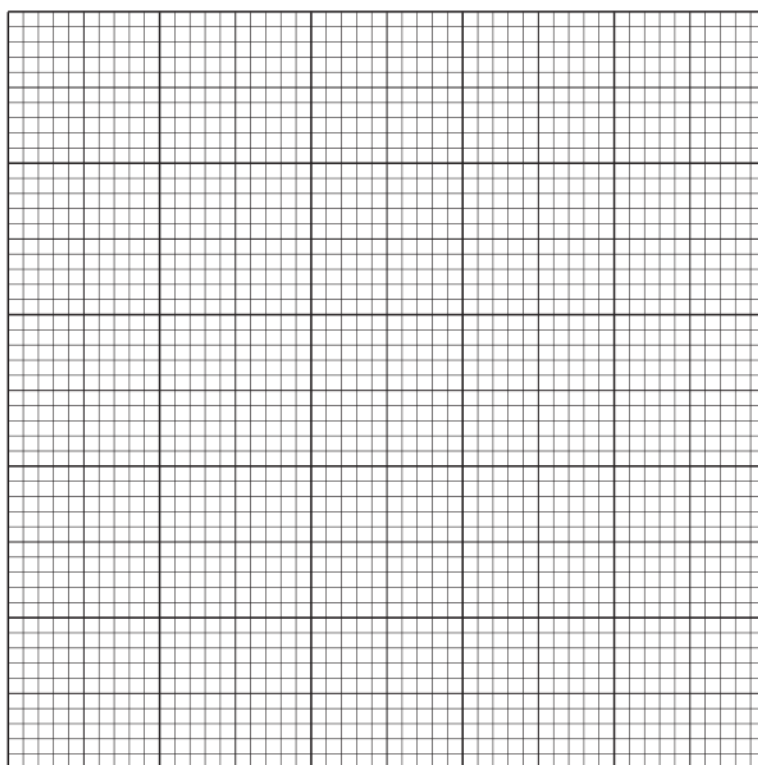


Equation 4.1

The table shows how the concentration of $2\text{N}_2\text{O}_5$ varies with time at 315 K.

Time/s	$[\text{N}_2\text{O}_5]/\text{mol dm}^{-3}$
0	0.330
1000	0.210
2000	0.124
3000	0.078
4000	0.048

(i) Use the data in the table to plot a graph to determine the half-life for the reaction. Label the axes.

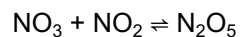
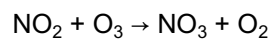


half-life = ... s [4]

(ii) How does the graph show that the reaction in **equation 4.1** is first order with respect to N_2O_5 ?

Draw construction lines on the graph to explain your answer.

- (b) Dinitrogen pentoxide, N_2O_5 is an oxide of nitrogen that is formed in the stratosphere by reactions such as those shown below.



The dinitrogen pentoxide acts as a 'sink' for NO_2 , stopping it breaking down ozone.

The gradient of the graph at 1000 s is $9.8 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$.

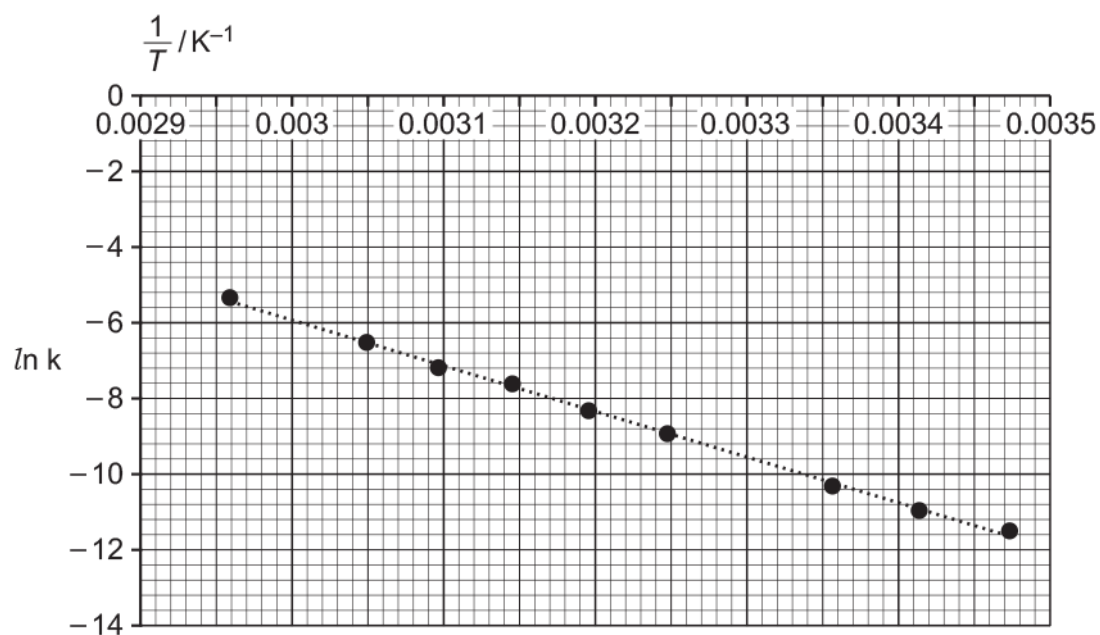
Work out the rate constant for the reaction in **equation 4.1** at 315 K.

Give the units in your answer.

rate constant = ... units [2]

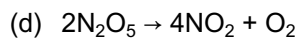
(c) The reaction in **equation 4.1** was repeated with a fixed concentration of N_2O_5 at different temperatures.

A graph of $\ln k$ against $\frac{1}{T}$ for the reaction in **equation 4.1** is given below.



Use the graph to work out a value for the activation enthalpy (in kJ mol^{-1}) for the reaction.

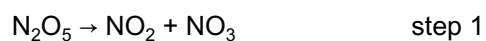
$E_a = \dots\dots\dots \text{kJ mol}^{-1}$ [3]



Equation 4.1

A student suggests the following mechanism for the reaction in equation 4.1.

The reaction is first order with respect to N_2O_5 .



Show that this is a possible mechanism.

Consider which step(s) could be rate-determining.

[3]

[3]

40 A student is investigating the properties of some s-block metals and their compounds.

* Group 2 carbonates react with hydrochloric acid as shown in **equation 1.1**.



A student investigates whether there is a trend in Group 2 of the rate of this reaction.

The student uses a method involving collection of the carbon dioxide given off.

Describe a suitable procedure that the student should follow and how the results can be interpreted.

----- [6]

- 41 A student plots $\ln k$ (y-axis) against $1/T$ (in K^{-1}) for a reaction. The student gets a straight line graph that corresponds to the Arrhenius equation:

$$\ln k = -E_a/RT + \ln A$$

Which statement is correct?

- A The intercept on the x-axis is $\ln A$.
- B The intercept on the y-axis is $\ln A$.
- C The slope is E_a .
- D The slope is E_a/R .

Your answer

[1]

- 42 'Fumaric acid' is used as an acidity regulator in food. 'Maleic acid' is a stereoisomer of fumaric acid. The structure of the two acids are shown in Fig. 4.1.

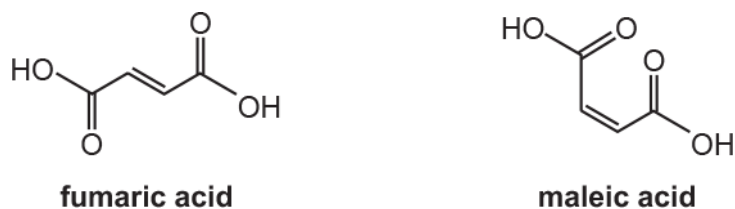
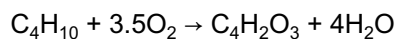
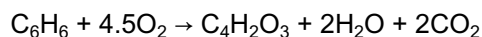


Fig. 4.1

Maleic anhydride, $C_4H_2O_3$, can be made industrially by oxidising butane or benzene.



Reaction 1



Reaction 2

- (i) Use calculated atom economies to suggest, with a reason, which reaction is used more.

----- [2]

- (ii) Suggest another reason why the reaction selected in (g)(i) is preferred.

----- [1]

- (iii) Calculate the maximum mass of maleic anhydride, $C_4H_2O_3$, (in kg) that could be made from 15 m^3 of butane (measured at RTP).

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

mass of maleic anhydride = ... kg [2]

43(a) One of the components of diesel fuel for cars is cetane, $C_{16}H_{34}$.

There is a high air concentration in the air-fuel mix of diesel engines. This makes the formation of oxides of nitrogen more likely. The catalyst is not effective at removing oxides of nitrogen.

One oxide of nitrogen formed is nitrogen oxide, $NO(g)$, which oxidises in air to form $NO_2(g)$.

- (i) State the appearance of NO and describe what is seen as it comes out of the exhaust pipe of a car.

----- [2]

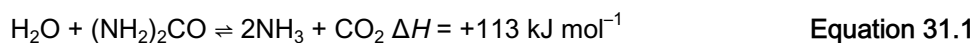
- (ii) Write an equation for the formation of NO in the engine.

[1]

- (b) There is a high air concentration in the air-fuel mix of diesel engines. This makes the formation of oxides of nitrogen more likely.

Urea, $(NH_2)_2CO$, is used in the exhaust system to remove oxides of nitrogen.

The urea reacts in the exhaust system as shown in **equation 31.1**.



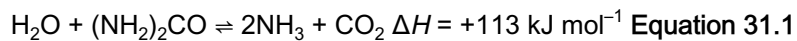
- (i) The forward reaction in **equation 31.1** is only feasible above a certain temperature.

Use the entropy values in the table to calculate this temperature.

Substance	Entropy, $S/J \text{ mol}^{-1} \text{ K}^{-1}$
H_2O	+ 69.9
$(NH_2)_2CO$	+ 173.9
NH_3	+ 192.3
CO_2	+ 213.6

temperature = ... K [3]

(ii) Equation 31.1 is repeated again below.



The ammonia produced in equation 31.1 reacts with oxygen and NO in the presence of a catalyst. Water and nitrogen are formed.

Construct the equation for this reaction.

[1]

(c) It has been stated that cars cause the most pollution on short journeys.

Evaluate this statement in terms of the rate and equilibrium position of the reaction shown in equation 31.1.

[4]

- (d) The urea used in the exhaust system is manufactured from ammonia and carbon dioxide.
The production of ammonia is given by **equation 31.2**.



In an experiment 5.0 moles of nitrogen and 12.0 moles of hydrogen are allowed to reach equilibrium in a 1.0 dm³ container.

When analysing the equilibrium mixture, it was found that 6.0 moles of ammonia have been formed.

Calculate the concentrations of each gas at equilibrium and find the equilibrium constant for the equilibrium in **equation 31.2** under these conditions.

Include the units in your answer.

$K_c = \dots\dots\dots$ units $\dots\dots\dots$ [4]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	for concentration to half: 1. 4.96×10^{-3} to $2.48 \times 10^{-3} = 220 - 30 = 190$ hours ✓ 2. 3.83×10^{-3} to $1.92 \times 10^{-3} = 290 - 100 = 190$ hours ✓ half-life constant (means 1st order) ✓ OR every 70 hours, 1. from 30-100 hours = about 23% of conc. Is used up ✓ 2. from 220-290 hours = about 23% of conc. Is used up ✓ same proportion of starting conc. used up (means 1st order) ✓ OR every 70 hours (a set time interval) for 1st order the concentration drop will be a constant ratio ✓ 1. from 30-100 hours = about 1.295 ✓ 2. from 220-290 hours = about 1.292 ✓	3	units required for half-lives at least once otherwise 1 mark only for both times correct DO NOT ALLOW half-life MARK if no relevant data given IGNORE units IGNORE units NOTE any data referring to actual rates cannot be relevant / meaningful Examiner's Comments This discriminated well, with many just not using the data or trying some random calculations to conclude that the half-life is constant. However those who keyed into the relevant data provided excellent explanations.
		ii	average rate of reaction = $(5.55 - 1.92) \times 10^{-3} / 290$ ✓ = 1.25×10^{-5}	1	Give mark for getting the working correct, may make an error with calculator IGNORE units for rate of reaction Examiner's Comments There were some strange ways of calculating an average rate, many showed no working, while quite a few got the wrong answer but correct working. Perhaps, this was one for those candidates with a modicum of mathematical knowledge outside of the usual 'moles' remit, which many did not appear to have. Answer: 1.25×10^{-5}

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$k = 4.96 \times 10^{-9} / 4.96 \times 10^{-3} = 1.0 \times 10^{-6} \checkmark$ $s^{-1} \checkmark$	2	ALLOW 1.00×10^{-6} or 1×10^{-6} or 10^{-6} Examiner's Comments The majority got the units correct and could calculate the rate constant. Answer: $1.0 \times 10^{-6} s^{-1}$
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
2	a		temp: increased yield / more products ✓ forward reaction [stated or implied] is endothermic (ora) ✓ pressure: no effect on yield AW ✓ same number of (gaseous) moles / molecules on each side (of equation) AW✓	4	ALLOW 'it increases' IGNORE 'equilibrium (position) moves to right' QWC: endothermic (or exothermic for ora) must be used and spelled correctly to score second mark ALLOW 'no effect on position of equilibrium' ALLOW 'no change of yield' / 'no increase of yield' NOT 'little effect on yield' etc No ecf but mark separately within each pair. Examiner's Comments This was a nice gentle start. Most candidates realised that temperature increased the yield and that pressure had no effect and were able to explain these in terms of the endothermic reaction and the same number of moles on each side.
	b		speeds up achievement of equilibrium OR speeds up both (forward and back) reactions ✓ no effect on K_c (AW) ✓	2	Can score this alternative for the first marking point while explaining effect on K_c Examiner's Comments Most candidates knew that a catalyst had no effect on K_c and some were able to extend their knowledge that catalysts speed up reactions to say that equilibrium would be reached faster.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$(K_c = [\text{H}_2\text{O}] [\text{CO}] / [\text{H}_2] [\text{CO}_2])$ 1. $[\text{H}_2\text{O}] [\text{CO}] = 2.68496 \times 10^{-12}$ (3 or more sf) ✓ 2. either concentration = $1.63858.... \times 10^{-6}$ (2 or more sf) ✓ 3. both concentrations to 3 sf (1.64×10^{-6}) ✓ 4. concentrations equal ✓	4	award 1. if later answers correct 3. award for any numbers to 3sf 1.64×10^{-6} twice on the answer lines scores 4 marks without reference to working. Examiner's Comments This calculation was often done well, especially if candidates wrote out their method carefully. The main error was halving the product of the H_2O and CO concentrations, rather than taking the square root.
	d	i	the sun OR burning CO ✓	1	ALLOW 'uv' Examiner's Comments Some candidates were able to envisage the situation on Mars and suggest the Sun, rather than burning fossil fuels, the commonest wrong answer.
		ii	oxygen (is formed) ✓	1	any mention of oxygen that makes sense IGNORE references to CO_2 and / or hydrogen Examiner's Comments Again, some candidates realised that oxygen was also produced, though many talked about hydrogen removing carbon dioxide.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	e	i	+42 ✓	1	plus sign essential Examiner's Comments Most candidates correctly gave +42 as the answer and the commonest error was omitting the plus sign.
		ii	1. $42 = 40000/T$ ✓ 2. $T = 950$ ✓ 3. K / Kelvin ✓	3	ALLOW ecf from a positive (or no sign) value from (i) for 1. and 2. ($T = 40000/\text{ans to (i)}$). award both marks 1. and 2. if correct answer for T given ALLOW two sf up to calculator value (952.38...)(correctly rounded) 0.95/0.95238 etc scores 1 mark for 2. (but not 1.) no other ecf from 1. to 2. 3. mark separately • ALLOW 'k' • IGNORE + sign for temperature (– is CON) • NOT degree sign before K Examiner's Comments There was a good success rate on this question and most candidates realised that the enthalpy change was in kJ.
		iii	equilibrium const / $K_c = 1$ OR reaction (equally) balanced / in the middle OR no tendency to go in either direction AW ✓	1	ALLOW rate of forward reaction = rate of back reaction Examiner's Comments Only a few realised that the equilibrium was exactly balanced at this point.
			Total	17	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a	i	propene ✓	1	NOT prop-1-ene
		ii	similarity: C-C bond formed / C atom attached to benzene OR alkylation OR hydrocarbon (chain)(AW) attached / substituted / added ✓ difference: no use of halogen compound OR only one product / no HC/ (or H⁺) formed / lost ✓	2	IGNORE references to alkenes as reactants ALLOW 'eliminated' Examiner's Comments Most named the compound correctly as propene and many could compare the reaction with a normal Friedel Crafts reaction.
	b	i	1. more / greater / higher yield OR more / greater amount of compound B / product ✓ 2. fewer molecules / particles / moles on right-hand side / product <i>ora</i> ✓ 3. molecules / particles.... in smaller volume / space (not area) OR ...closer together OR ...more concentrated AW ✓ 4. greater frequency of collisions AND faster rate (of reaction) AW ✓	4	IGNORE 'equilibrium moves to the right' unless it indicates which side has fewer moles QWC marking point 1 depends on marking point 2 being scored 'molecules have increased energy' CONs this point marking points 3 and 4 can be marked separately 4. frequency must be implied (not just 'more collisions') IGNORE 'chance of collision' Examiner's Comments Was the physical part and many scored full marks. Errors in part (i) included a failure to say which was the side with fewer moles, that the concentration of the particles was greater and that the frequency of collisions was greater.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	(Forward) reaction exothermic (ora) AND equilibrium constant smaller AW ✓ Rate (too) slow(er)/takes too long to reach equm below 250 AW ✓	2	IGNORE 'equilibrium moves to the left' but 'equilibrium moves to left (AW) in endothermic direction' will score first part of marking point. IGNORE 'compromise' Examiner's Comments Most scored the marks.
		iii	100% ✓ no waste (product) (to be disposed of) ✓	2	IGNORE 'high' IGNORE reference to toxic / harmful NOT 'no by-product' Examiner's Comments This showed a good understanding of atom economy. The rare error was to hedge bets by saying 'less waste', rather than 'no waste'.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
4	a		$\text{CaO} + 3\text{C} \rightarrow \text{CO} + \text{CaC}_2$ OR $2\text{CaO} + 5\text{C} \rightarrow \text{CO}_2 + 2\text{CaC}_2 \checkmark$	1	IGNORE state symbols Examiner's Comments Required understanding of inorganic chemistry that was possessed by some candidates. Many gave oxygen as a possible product, which candidates should have realised would not form in the presence of hot carbon.
	b	i	$\text{CaCN}_2 + 3\text{H}_2\text{O} \rightarrow \text{CaCO}_3 + 2\text{NH}_3 \checkmark \checkmark$	2	<i>For one mark:</i> • correct substances but unbalanced equation • the correct balanced equation with an error (eg $\text{Ca}(\text{CO}_3)$) • $\text{CaCN}_2 + 3\text{H}_2\text{O} \rightarrow \text{CaO} + \text{CO}_2 + 2\text{NH}_3$ • $\text{CaCN}_2 + 4\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{CO}_2 + 2\text{NH}_3$ Examiner's Comments Required understanding of inorganic chemistry that was possessed by some candidates. Many gave oxygen as a possible product in part (a) which candidates should have realised would not form in the presence of hot carbon.
		ii	(nitrogen is unreactive / inert) (nitrogen) has a (strong) triple bond ~~($\text{O}=\text{N}=\text{N}$)~~ $\checkmark$ OR high (AW) (activation) energy / enthalpy... ... to break bond	1	Examiner's Comments Was better, with more candidates suggesting that CaO and CO₂ would be formed, though CaCO₃ was the more likely product. Many candidates correctly suggested a triple (or strong) bond between the nitrogen atoms and some went on to say that nitrogen compounds were needed for plant growth.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	nitrogen compounds are needed (by plants) for: growth / making protein / making amino acids / DNA ✓	1	ALLOW for 'nitrogen compounds': named (appropriate) nitrogen compounds or 'nitrates' or 'ammonium ions' (or formulae) IGNORE references to fertilisers Examiner's Comments Lack of the word 'compounds' caused some loss of the mark.
		iv	$(28 \times 100 / 80.1 =) 35.0\%$ ✓ to 3sf ✓	2	Any answer that rounds to 35 scores first mark Second mark is for correct answer to 3sf i.e. 35.0 Examiner's Comments Involved a simple mole calculation, which most got right. Realisation that atomic mass data is to three significant figures was slightly more complicated.
	c	i	$-3 + 2$ ✓	1	signs must precede numbers Examiner's Comments Had two easy parts to start with and few faltered here.
		ii	nitrogen monoxide ✓	1	ALLOW nitrogen(II) oxide (allow gaps), NOT nitrogen(II) monoxide no ecf from (c)(i) Examiner's Comments Had two easy parts to start with and few faltered here.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$(50-4x) + (50-5x) + 4x + 6x = 105$ $x = 5$ $\% \text{ conversion} = (20 \times 100/50) = 40\% \checkmark \checkmark$	2	40% on answer line scores 2 marks without reference to working. ALLOW , for 1 mark, one of: • $(50-4x) + (50-5x) + 4x + 6x = 105$ • $(50-x) + (50-1.25x) + x + 1.5x = 105$ • 20 cm ³ of NH ₃ reacted OR 30 cm ³ of NH ₃ left Examiner's Comments Had two easy parts to start with and few faltered here. On the other hand, was only scored by a handful of candidates.
		iv	NO is oxidised by oxygen / reacts with oxygen to form NO ₂ • NO ₂ is brown •	2	ALLOW 'it' for 'NO' Examiner's Comments Had two easy parts to start with and few faltered here. was high-scoring again, though some failed to say it was oxygen that oxidised the NO to NO ₂ and others did not mention that the latter was brown.
			Total	13	
5			A	1	
			Total	1	
6		i	Cerium(IV) oxide ✓	1	ALLOW without parentheses
		ii	$4\text{CeO}_2 \rightarrow 2\text{Ce}_2\text{O}_3 + \text{O}_2$ OR $2\text{CeO}_2 \rightarrow \text{Ce}_2\text{O}_3 + 0.5\text{O}_2 \checkmark$ $\text{Ce}_2\text{O}_3 + \text{H}_2\text{O} \rightarrow 2\text{CeO}_2 + \text{H}_2 \checkmark$	2	
		iii	Enthalpy changes of formation ✓	1	ALLOW bond enthalpies / energies
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
7			FIRST CHECK ANSWER ON ANSWER LINE Answer = 0.043 award 4 marks concentration of H_2O = $5.00 - 1.20 = 3.80$ (mol dm^{-3}) ✓ concentration of acid H = 0.60 (mol dm^{-3}) AND concentration of CH_3OH = 1.20 (mol dm^{-3}) ✓ $K_c (= \frac{[(\text{CH}_2\text{COOH})_2][\text{CH}_3\text{OH}]^2}{[(\text{CH}_2\text{COOCH}_3)_2][\text{H}_2\text{O}]^2}) = \frac{0.6 \times 1.2^2}{1.4 \times 3.8^2}$ ✓ = 0.043 ✓ (no units)	4	ALLOW 2 or more sig figs
			Total	4	
8			Only small amount of raspberry ketone present in raspberries difficult / high cost to extract ✓	1	
			Total	1	
9			B	1	
			Total	1	
10			D	1	
			Total	1	
11			C	1	
			Total	1	
12			B	1	
			Total	1	
13			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14	a	i	Draw a graph of volume of oxygen against time. ✓ Draw tangent and its gradient gives the rate. ✓	2	
		ii	FIRST CHECK ANSWER ON ANSWER LINE answers rounding to 1.67 (mol dm ⁻³) award 2 marks 20 cm ³ O ₂ = 20/24000 mol ✓ Conc of H ₂ O ₂ (= (1000 × 2 × 20)/24000) = 1.67 (mol dm ⁻³) ✓	2	ALLOW 2 or more sf
	b		Correctly plots points ✓ Line of best fit drawn ✓	2	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Learners fully analyse the scientific information shown on the graph concerning orders of reaction. They correctly evaluate the learners' comments and interpret them in terms of the correct chemistry. <i>The explanation is relevant and logically structured and contains no errors.</i> Level 2 (3–4 marks) Learners partially analyse the scientific information on the graph concerning orders of reaction AND they partially correct the learners' conclusion. OR they do one aspect fully and the other weakly. <i>The explanation is generally relevant and logically structured and contains few errors.</i> Level 1 (1–2 marks) Learners show some ability to analyse the graph or to correct the learners' conclusion <i>A partial explanation is attempted and has some structure.</i> 0 marks No response or no response worthy of credit.	6	Indicative scientific points may include: <i>Orders of reaction</i> - graph is a straight line / shows proportionality for low substrate concentrations - shows reaction is first order initially - then graph has zero slope / rate does not change as substrate conc increases - so zero order wrt substrate at high substrate conc - no conclusions can be drawn about order wrt enzyme as concentration is not changed <i>Rate determining steps</i> - mechanism is $E + S \rightarrow ES \rightarrow E + \text{products}$ - Rate determining step at low substrate concentration is $E + S \rightarrow ES$ - since this indicates first order - Explanation of ES - This is not the rate-determining step at high substrate concentration - Here it is $ES \rightarrow \text{products}$ or enzyme is saturated with substrate

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		 Shape of graph: rises to peak, then falls ✓ Initially as temperature increases more collisions above E_A, so increasing rate ✓ then the kinetic energy breaks imbs in active site and it loses its specific shape and substrate can't bind. ✓	3	ALLOW enzyme becomes denatured
	e		Advantage: Allows faster reaction at lower temp / saves fuel ✓ Disadvantage: easily denatured / inhibited / sensitive to pH / difficult to recover after use. ✓	2	
			Total	17	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15		i	FIRST CHECK THE ANSWER ON THE ANSWER LINE rate = 4.35×10^{-5} award 2 marks rate = 4.35×10^{-5} AND units = s^{-1} award 3 marks rate doubles with concentration so reaction 1st order to $\text{C}_6\text{H}_5\text{N}_2\text{C}/$ rate = $k[\text{C}_6\text{H}_5\text{N}_2\text{C}]$ ✓ $k = \text{rate} / [\text{C}_6\text{H}_5\text{N}_2\text{C}] = 4.35 \times 10^{-5}$ ✓ s^{-1} ✓	3	Answer can be calculated using either data set.
		ii	only know concentration at start / initial concentration ✓ (therefore) collecting larger volumes would not give initial rate ✓	2	IGNORE references to actual percentages
		iii	FIRST CHECK THE ANSWER ON THE ANSWER LINE pH = 1.68 (2 d.p.) award 2 marks $n(\text{N}_2) = 0.050 / 24.0 = 0.00208$ mol concentration $\text{HC}/ = 0.00208 \times 10 = 0.0208$ mol dm^{-3} ✓ pH = 1.68 (2 d.p.) ✓	2	
		iv	<i>One from</i> ✓ (Measure) loss of mass Titrate $\text{HC}/$	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		v	two missing values: 3.36×10^{-3} and -8.52 ✓ axes drawn, labels correct x-axis: $1/T / K^{-1}$ y-axis: $\ln k$ scales that use over half of each axis ✓ all points plotted correctly with best straight line drawn through points ✓ measurement of slope ($1.33 \pm 0.05 \times 10^4$) ✓ multiplication by 8.314, division by 10^3 and change of sign to give E_a in kJ units [$+111 \text{ (kJ mol}^{-1}\text{)}$] ✓	5	units of $1/T$ can be missing ALLOW no sign but not minus sign for last mark ALLOW 2 or more sig figs ALLOW any answer rounding to 106–115 (calculated correctly from slope)
			Total	13	

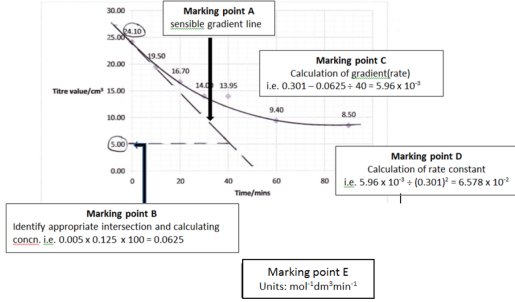
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16		i	intensity of colour OR absorbance of (suitable wavelength) light ✓ gives a measure of concentration (of complex / ammonia) OR (directly) proportional to concentration (of complex / ammonia) ✓	2	
		ii	$= \frac{[\text{Cu}(\text{NH}_3)_4]^{2+}}{[\text{Cu}^{2+}][\text{NH}_3]^4}$ ✓	1	
		iii	$\frac{x}{(0.1 - x)(0.4 - 4x)^4}$ correct apart from a wrong value for $[\text{NH}_3]$ ✓ (0.4 - 4x) for $[\text{NH}_3]$ ✓	2	ALLOW ECF from (ii)
		iv	Inaccurate / second student correct because Reaction of (OH ⁻ in) ammonia solution with H ₂ SO ₄ causes equilibrium to move so all the ammonia is neutralised (AW) OR equilibrium 4.1 shifts to the left as the acid reacts with the ammonia ✓ so titre / measured concentration will be too large ✓	2	
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		FIRST CHECK ANSWER ON ANSWER LINE IF $K_a = 9.39 \times 10^{-7}$ (mol dm⁻³) award 4 marks $H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$ init Both 1.16×10^{-5} eqm Both $1.16 \times 10^{-5} - x \quad x \quad x$ ✓ $\sqrt{K_c} = x/(1.16 \times 10^{-5} - x)$ ✓ $x = \sqrt{7.76 \times 10^{-3}(1.16 \times 10^{-5} - x)}$ or $x = 0.088(1.16 \times 10^{-5} - x)$ ✓ $(1.088x = 1.02 \times 10^{-6} \text{ so } x = 9.39 \times 10^{-7}$ (mol dm⁻³) ✓	4	<i>First marking point:</i> some indication of how concentrations of products linked to remaining concentration of reactants <i>Second:</i> relation of concs to K_c <i>Third:</i> rearrangement of formula <i>Fourth:</i> value of x. ALLOW 9.38×10^{-7} from early rounding If answer is correct on answer line, award 4 marks without reference to working. 1.02×10^{-6} (treating initial concentrations as equilibrium ones) scores 2
	b	i	the Sun OR burning CO ✓	1	ALLOW 'uv'
		ii	oxygen (is formed)	1	any mention of oxygen that makes sense IGNORE references to CO ₂ and / or hydrogen
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18	a	i	substitution ✓ nucleophilic ✓	2	
		ii	heterolytic ✓	1	
	b	i	slow down reaction (so time for titration) ✓	1	ALLOW 'stop reaction' IGNORE quench
		ii	FIRST CHECK THE ANSWER ON THE ANSWER LINE IF initial concentration = 0.301(25) (mol dm ⁻³) award 2 marks 24.10 × 0.125 × 10 ⁻³ = 3.0125 × 10 ⁻³ mole of acid ✓ conc. of OH ⁻ = 3.0125 × 10 ⁻³ × 100 = 0.301(25) (mol dm ⁻³) ✓	2	ALLOW 2 or more sf
		iii	Two of; Rate = k[RBr][OH ⁻] Rate = k[RBr] ² Rate = k[OH ⁻] ² ✓	1	
		iv	(A) curve drawn with gradient line cutting y axis at t = 0 ✓ (B) concentration calculated at appropriate intercept with y axis see scan ✓ (C) calculating gradient(rate) = difference in concentration ÷ 40 ✓	3	ALLOW ECF from part ii Graph scan 
		v	(D) correct substitution in k = rate ÷ (0.301) ² and evaluation ✓ (E) correct units mol ⁻¹ dm ³ min ⁻¹ ✓	2	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	* Please refer to point 10 of the marking instructions of this mark scheme for guidance on how to mark this question. Level 3: 5–6 marks Learners demonstrate knowledge and understanding of the method with an explanation of the steps followed AND Learners describe some of the observations AND Learners suggest a sound conclusion. <i>The ideas are logical and well-structured providing significant clarity in the communication of the science.</i> Level 2: 3–4 marks Learners demonstrate knowledge and understanding of the method with some explanation of the steps followed AND EITHER Learners describe some of the observations OR Learners suggest a sound conclusion. <i>There is partial structuring of the ideas with the communication of the science generally clear.</i> Level 1: 1–2 marks Learners demonstrate knowledge and understanding of the method with no explanation of the steps followed AND EITHER Learners describe some of the observations OR Learners suggest a sound conclusion. <i>The ideas expressed are poorly structured and do not contribute to the communication of the science.</i> Level 0: (no marks) <i>No response or no response worthy of credit.</i>	6	Expected chemical / practical points include: Method • dissolve halogenoalkanes in ethanol in test tubes • stand in beaker of hot water • add solution of silver nitrate • start timing Explanation of steps ➤ ethanol – co-solvent / halogeno's don't dissolve in water ➤ hot water needed reaction too slow in cold ➤ equal amounts / volumes of reactant for 'fair test' Observations • precipitate forms / tubes go cloudy • note time on first appearance Explanation of observations ➤ precipitates caused by halide ions reacting with silver ions / formation of insoluble silver halides ➤ colours and equations Conclusion ➤ shorter time means faster rate • rate of hydrolysis in order iodo(fastest), bromo and chloro. ➤ bond strengths increase in above order

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	18	
19		i	bromine / Br ₂ ✓ colorimetry OR titration ✓ bromine (solution) is yellow / orange/(red) brown OR bromine decolourised in titration (phenol and with methyl orange) ✓	3	Only 2nd mark is independent ALLOW titration of bromine with a solution of alkene with known bromine number DO NOT ALLOW titrate with alkali, method not appropriate ALLOW bromine is the only coloured substance / reactants are colourless bromine coloured Examiner's Comments Mostly well done although some did not appreciate that measuring pH / acidity would be inappropriate.
		ii	(Rate =) $k \times [\text{BrO}_3^-] \times [\text{Br}^-] \times [\text{H}^+]$ ✓ ✓	3	ALLOW capital K one order incorrect gets 1 mark of the last two marks ALLOW if signs missing on ions but orders are correct IGNORE bracket type Examiner's Comments Often good, k very occasionally omitted and $[\text{H}^+]^2$ sometimes omitted.
		iii	some bromine escapes / bromine is volatile ✓ slower / smaller value / rate (appears to) decreases ✓ since rate measured as $[\text{Br}_2] \text{ s}^{-1}$ ✓	3	IGNORE discussion of effect of temperature increase Examiner's Comments Most talked in generic terms about evaporation and hence loss of reactants leading to a decrease in rate, thus only gaining 1 mark. A few realised the significance of bromine loss and how the rate would appear to decrease because of lower absorbance readings.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
20	a	i	Yes, and equal moles on each side OR units cancel	1	ALLOW 'particles' or 'molecules' or 'species' for 'moles' Examiner's Comments Most agreed that there should be no units because the units cancelled.
		ii	exothermic AND K_c is lower/ eqm moves to the left/ conc of reactants is higher at higher temperatures ✓	1	
		iii	High temp to increase reaction rate ✓ Low temp to increase yield/ more products/ equilibrium(position) moves to right ✓	2	ALLOW on its own mark separately Examiner's Comments Most noted that the K_c was lower at higher temperature and stated that this pointed to an exothermic forward reaction. The main error was to forecast an endothermic reaction in spite of this.
	b	i	Ratio of CO (reacted) to H_2 (formed) is 1:1 OR H_2 formed is $1.5 \times 10^{-3} - 4 \times 10^{-5}$ ✓ Small amount of CO left/ 4×10^{-5} can be ignored OR 1.46×10^{-3} is 1.5×10^{-3} to 2 sf ✓	2	ALLOW same number of molecules/moles/amounts IGNORE CO and H_2O are 1:1 ALLOW 'virtually all CO converted/reacted' Examiner's Comments This was a question where candidates' powers of expression were tested. Some correctly explained the given value for $[H_+]$ by saying that only a small amount of CO was left and that the ratio of CO initially to hydrogen was 1:1. Other answers, especially using numbers, were more elegant. Sometimes it was not clear what the ratio referred to, or water was mentioned instead of hydrogen.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$[H_2] = [CO_2] \checkmark$ $[H_2O] = (1.5 \times 10^{-3})^2 / 4 \times 10^{-5} \times 58 = 9.70 \times 10^{-4}$ (one or more sf) $\checkmark$ Answer to 1 sf = $1 \times 10^{-3} \checkmark$	3	scores if $(1.5 \times 10^{-3})^2$ seen in working. Correct answer to any sf scores 2 and correct answer to 1sf scores 3 without reference to working. ALLOW 10×10^{-4} Any answer to 1sf scores last mark separately Examiner's Comments Here most candidates spotted that $[H_2] = [CO_2]$ at equilibrium. Many went on to do the calculation correctly. Very few realised that, since one piece of data was to one significant figure, this was the 'appropriate' value for the answer. This significant figure mark was one of the least likely to be scored on the whole paper.
		iii	concentration at 1 atm = $1/24 = 0.042 \text{ mol dm}^{-3}$. $1.5 \times 10^{-3} / 0.042$ = $0.0357 / 0.04 \text{ atm} \checkmark$	1	Answer alone scores mark ALLOW 1 or more sf Examiner's Comments Many recognised that the pressure would need to be smaller than 1 atmosphere to get this concentration and obtained the correct answer. Quite a number got the reciprocal of the correct answer.

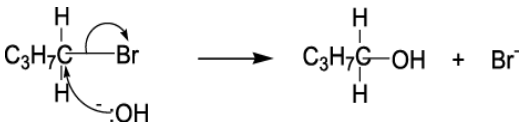
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	five electrons from N ✓; completely correct ✓ +5 ✓	3	oxygen atoms can be in any position; the left-hand one (here) can be with a minus, as shown or an extra cross or another symbol. IGNORE brackets and minus signs Expansion of the octet does not score second mark NOT 5+ or 5 Examiner's Comments A few candidates managed to negotiate this tricky dot-and-cross diagram, showing a dative bond from the nitrogen to one oxygen and a double bond to another, with a single bond to the oxygen with the 'extra' electron (shown in a variety of ways). Many 'expanded the octet' which nitrogen cannot do. They and others benefited from an intermediate mark for 'five electrons round the N atom' which was widely scored. The oxidation state was almost invariably correct.
		ii	$\text{NH}_4\text{NO}_3 \rightarrow 2\text{H}_2\text{O} + \text{N}_2\text{O}$ ✓ dinitrogen (mon)oxide or (di)nitrogen(I) (mon)oxide AND colourless (gas) ✓	2	IGNORE state symbols ALLOW halves and multiples IGNORE gaps in name second mark depends on N_2O being formed ALLOW ecf from NO or NO_2 formed in the equation. Examiner's Comments Many could derive the equation and, of these, most could name and describe the dinitrogen monoxide formed. Some thought that oxygen ought to feature in the equation. <i>Numerical answers: 3b(ii) $1 \times 10^{-3} \text{ mol dm}^{-3}$; 3b(iii) 0.036 atm;</i>
			Total	15	

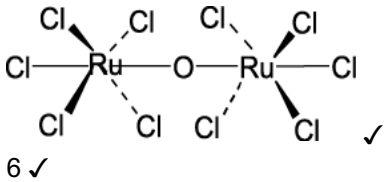
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a		withdraw (sample) using pipette at given times ✓ run into (conical) flask ✓ titrate (quickly) with standard/know concentration of NaOH (in burette) ✓	3	
	b	i	axes and labels: y: $(\text{CH}_3)_3\text{CBr}$ / mol; x: time/ mins ✓ scale: uses at least two-thirds of paper ✓ plotting ✓ curve of best fit going through all points except anomalous one (second) ✓	4	10^{-3} must be in units or included in scale
		ii	construction for two half-lives on graph ✓ half-lives constant ✓	2	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	c	<i>*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Detailed deductions about the mechanisms, orders of reaction and rate of both equations 3.2 and 3.3. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Outline comments about the mechanisms, orders of reaction and rate of both equations 3.2 and 3.3 but some detail excluded. OR Detailed deductions about the mechanism, order of reaction and rate of either equation 3.2 or 3.3. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited comments about the mechanisms, orders of reaction and rate of both equations 3.2 and 3.3, no detail. OR Outline comments about the mechanism, order of reaction and rate of either equation 3.2 or 3.3. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit	6	Indicative scientific points include: Mechanism Equation 3.2 - second step is $(\text{CH}_3)_3\text{C}^+ + \text{OH}^- \rightarrow (\text{CH}_3)_3\text{COH}$ - this is fast (not rate-determining) Equation 3.3 - occurs in a step in which Br^- leaves as OH^- enters AW - since only one step Orders of reaction Equation 3.2 - first order with respect to $[\text{RBr}]$ RBr occurs in rds - zero order with respect to $[\text{OH}^-]$ $[\text{OH}^-]$ occurs in fast step (only) Equation 3.3 - both RBr and OH^- are first order RBr and OH^- both appear once in the single step Rate equations Equation 3.2 – Rate = $k [\text{RBr}]$ Equation 3.3 – Rate = $k [\text{RBr}][\text{OH}^-]$ Mechanism 
		Total	15	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
22	a	i	froth/detergent flotation AND matte ✓	1	
		ii	$\text{NiS} + \text{H}_2\text{SO}_4 \rightarrow \text{NiSO}_4 + \text{H}_2\text{S}$ OR $\text{CuS} + \text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{H}_2\text{S}$	1	IGNORE state symbols
		iii	electrolysis	1	
	b	i	high melting AND unreactive	1	
		ii	$2\text{CO} + 2\text{NO} \rightarrow \text{N}_2 + 2\text{CO}_2$	1	ALLOW halves or multiples IGNORE state symbols
	c		$4d^6$	1	
	d	i		2	ALLOW bridging oxygen bonding in axial or equatorial positions IGNORE brackets and charges.
		ii	square planar OR tetrahedral	1	
	e		R_2NH_2^+ ✓ 3 + balances 3– (AW) ✓	2	
	f		$10^7 - 10^{10}$ or any value in that range ✓	1	
	g		$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ ✓ (light)blue dark blue/violet/purple/mauve ✓	2	ALLOW $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 6\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_6]^{2+} + 6\text{H}_2\text{O}$ IGNORE state symbols
	h		Wrong: d subshells still split ✓ Ag^+ is d^{10} OR Ag has full d subshell ✓ so no movement possible (AW) ✓	3	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	i	<i>*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Describes in detail the methods of extraction and gives chemical details from the article of all three compounds. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Describes in detail the methods of extraction of all three compounds AND Gives the chemical details from the article for either Pd, Pt or Os <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1–2 marks) Outlines the methods of extractions for of all three compounds AND Gives the chemicals details from the article for either Pd, Pt or Os. OR Describes in detail the method of extraction for one of the compounds and gives chemical details from the article concerning this compound. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit	6	Indicative Scientific points include: Description of extraction of Pd: - extracted by ligand exchange - followed by dissolving in organic solvent Chemical details from article concerning Pd: - equation, eg $[\text{Pd}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{Cl}^-(\text{aq}) \rightarrow [\text{PdCl}_4]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$ - this reaction is much slower for other PGMs Description of extraction of Pt: - anion exchange - reacted with $\text{R}_2\text{NH}_2^+ \text{Cl}^-$. Chemical details from article concerning Pt: $2[\text{R}_2\text{NH}_2^+ \text{Cl}^-] + [\text{PtCl}_6]^{2-}(\text{aq}) \rightleftharpoons (\text{R}_2\text{NH}_2^+)_2 [\text{PtCl}_6]^{2-} + 2\text{Cl}^-$ $(\text{R}_2\text{NH}_2^+)_2 [\text{PtCl}_6]^{2-}$ is soluble in organic solvents whereas the equivalent salts of other PGMs have lower solubility. Description of extraction of Os: - oxidation - oxide volatile and can be removed by heating Chemical details from article concerning Os: - oxidised to OsO_4 - may be mixed with RuO_4
		Total	23	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
23			B	1	
			Total	1	
24			C	1	
			Total	1	
25			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance																				
26	a		Titrate the equilibrium mixture with alkali/NaOH of known concentration (to find total moles of acid) ✓ Subtract moles of (H ₂ SO ₄) catalyst ✓	2																					
	b		FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 3.61 award 4 marks <table><tr><th>Sub-stance</th><th>Mass at start</th><th>Amount present at the start</th><th>Amount present at equilibrium</th></tr><tr><td>ethanol</td><td>15.8</td><td>15.8/46 (= 0.343)</td><td>(0.343 – [0.35 – 0.123]) = 0.116</td></tr><tr><td>ethanoic acid</td><td>21.0</td><td>21.0/60 (= 0.35(0))</td><td>0.123</td></tr><tr><td>ethyl ethan-oate</td><td>0</td><td>0</td><td>[0.35–0.123 =] 0.227</td></tr><tr><td>Water</td><td>0</td><td>0</td><td>0.227</td></tr></table> One mark for both amounts at start ✓ One mark for amount of ethanol at equilibrium ✓ One mark for amounts of ester and water at equilibrium ✓ $K_c = 0.227^2 / (0.123 \times 0.116) = 3.61$ ✓	Sub-stance	Mass at start	Amount present at the start	Amount present at equilibrium	ethanol	15.8	15.8/46 (= 0.343)	(0.343 – [0.35 – 0.123]) = 0.116	ethanoic acid	21.0	21.0/60 (= 0.35(0))	0.123	ethyl ethan-oate	0	0	[0.35–0.123 =] 0.227	Water	0	0	0.227	4	ALLOW ecf throughout ALLOW other answers (to 2 or more sf) by using various rounding during calculation.
Sub-stance	Mass at start	Amount present at the start	Amount present at equilibrium																						
ethanol	15.8	15.8/46 (= 0.343)	(0.343 – [0.35 – 0.123]) = 0.116																						
ethanoic acid	21.0	21.0/60 (= 0.35(0))	0.123																						
ethyl ethan-oate	0	0	[0.35–0.123 =] 0.227																						
Water	0	0	0.227																						
	c		$\begin{array}{c} \text{H} \quad \text{CH}_3 \\ \quad \\ \text{---C---C---} \\ \quad \\ \text{H} \quad \text{CO} \\ \quad \\ \quad \text{OCH}_3 \end{array} \checkmark$	1	ALLOW any unambiguous structure IGNORE brackets or 'n'																				
	d		Methyl propanoate AND methanal ✓	1																					

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance								
	e		FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = (+)666(K) award 3 marks $\Delta S_{\text{sys}} = (+) 154.7 \text{ (J K}^{-1} \text{ mol}^{-1}) \checkmark$ $T = \Delta H/\Delta S_{\text{sys}}$ OR $T = 103000/154.7 \checkmark$ $T = (+)666 \text{ (K)} \checkmark$	3									
	f		<table border="1"><tr><td>Change</td><td>Increase d temper ature</td><td>Increase d pressure</td><td>Use of a catalyst</td></tr><tr><td>Effect on K_c</td><td>Increase</td><td>No change</td><td>No change</td></tr></table> $\checkmark \checkmark$	Change	Increase d temper ature	Increase d pressure	Use of a catalyst	Effect on K_c	Increase	No change	No change	2	All 3 correct 2 2 correct 1
Change	Increase d temper ature	Increase d pressure	Use of a catalyst										
Effect on K_c	Increase	No change	No change										
	g		FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 4390(dm ³) award 3 marks Unit conversion, $n = 25000/142$, $p = 150000, \checkmark$ Use of $pV = nRT$ and 50% yield, $V = 0.5 \times 25000 \times 8.314 \times 900/142 \times 150000 \checkmark$ Evaluation and conversion to dm ³ 4390 $\checkmark$	3	ALLOW 2 or more sf								
	h		Allows reaction to occur at lower temp AND less energy used $\checkmark$	1									
			Total	17									

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
27	<i>*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Describes the set-up of the experiment in detail. AND States and explains some of the expected observations in detail. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Describes the set-up of the experiment in detail. AND States a number of observations. OR States and explains a few of the expected observations in detail. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1–2 marks) Describes the set-up of the experiment in outline. AND States a couple of observations. OR States and explains an expected observation.	6	Indicative scientific points may include: Set-up of experiment in detail: • Suitable means of collecting hydrogen produced, can exemplified via a diagram • Collection method has volume measurements • Idea of measuring vol of hydrogen per unit time. • Fair testing, same no of moles of metal, same surface area, same temperature etc. Observations: • Gas bubbles produced • Metal decreases in size/disappears • Faster rate of reaction for Ba • Ca cloudier than Ba (AW) Explanations: • Both metals react to produce hydroxides and hydrogen gas • Equation eg $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$ • Hydroxides more soluble down the group • Rate of reaction increases down the group as electrons lost more easily down the group • Weaker attraction between outer electron and nucleus as atomic radius increases.

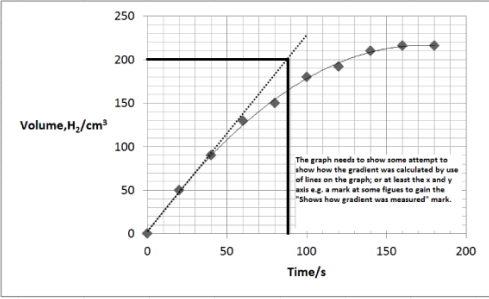
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			<i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> 0 marks No response or no response worthy of credit.		
			Total	6	

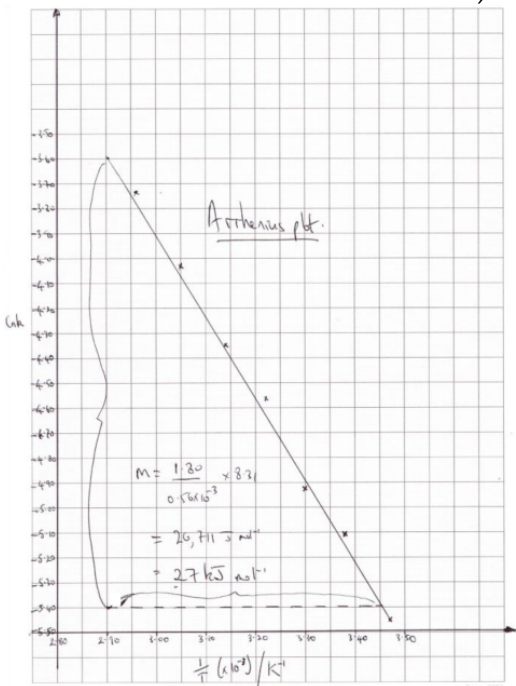
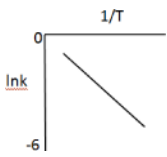
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a	i	Any one of: ✓ - amount / mass of Mg remains constant - only changes in acid concentration affect rate - surface area of magnesium is constant	1	ALLOW Because it is the limiting reactant DO NOT ALLOW 'fair test' / <i>to keep the variables the same</i> Examiner's Comments This question was straightforward but candidates should be made aware that vague answers such as 'fair test' will not receive credit at this level.
		ii	FIRST CHECK ANSWER LINE If answer = 0.06(075) (g) award 3 marks Moles acid at lowest concentration = $0.05 \times 0.1 = 0.005$ ✓ moles Mg will be half above = 0.0025 ✓ mass $0.0025 \times 24.3 = 0.06(075)$ (g) ✓	3	any sig figs ALLOW ecf's from MP1 – typically the use of 0.5 as the acid concentration (gives a value of 0.3(...); award two marks) Examiner's Comments A large number of candidates chose to base their calculation on the highest concentration of acid used in the experiment instead of the lowest, nevertheless error carried forward marks were commonly scored.
		iii	Length = m / d $0.06 / 1.3 \times 10^{-2} = 4.6 / 4.67 / 4.7$ (cm) ✓	1	ecf on ii (the above 0.3 value gives 23(.....)here) Examiner's Comments This question was straightforward and well answered.
	b		Rate = $k[\text{acid}]^2$ ✓	1	ALLOW H^+ or hydrochloric acid or HCl(aq) for 'acid' Presence of Mg in eqn is a CON unless $[\text{Mg}]^0$ Examiner's Comments This question was well answered. The most common mistake was the inclusion of magnesium in the equation.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
c	Draws a tangent to curve ✓ tangent line runs through zero ✓ Shows how gradient measured eg 230/100 (see graph below) ✓  2.30 (+/- 0.5) cm³s⁻¹ ✓	5	Without the curve drawn first mark cannot be scored Expect to see <u>lines on graph</u> for this mark (often tricky – scanning) DO NOT ALLOW “tangents” which cut the curve ecf’s on gradient DO NOT ALLOW Conversion to moles (dm⁻³) for either of last two marks Examiner’s Comments Candidates generally scored well on this question; however a significant number could have scored more marks if they had followed the instruction in the stem to ‘show your working on the graph’. In this question, to access all the marking points, examiners were expecting to see a tangent line to a curve drawn through the data points, as well as construction lines showing how the slope of the tangent had been calculated. The units were simply cm³s⁻¹.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
d	Axes correct (lnk and 1/T and unit for 1/T)✓ Scales sensible ✓ Straight line plot ✓ $-E_a/R$ or Gradient $\times R = E_a$✓ Evaluation: Sign + or no sign ✓ Numerical Value 27 +/- 3 when rounded to two sf kJmol⁻¹) ✓ 	6	- As in answer! - Scales should take up at least half graticule and be evenly distributed - Data points should cluster around / on line (graph does DO NOT ALLOW need to be extrapolated to show intercept or start at zero) - Mark for correct relationship i.e Gradient = $-E_a / R$ or Gradient $\times R$ (or shown with the numbers eg grad $\times 8.31$) - Correct evaluation and conversion to kJ (NO ecf from gradient mark) The graph opposite is plotted in the same fashion as Fig 7 in the CI 4 in the text book, it could also of course be plotted as in Fig 8 in the text book i.e.  Award 4 marks for correct answer on answer line + MP's 1 and 2 if scored Correct answer with negative sign scores 3 (+ MP's 1 and 2) Examiner's Comments This question, requiring the transfer of data from one form to another before analysis, was pleasingly well attempted by many candidates. There were marks available not only for the numerical answer, but also for the way the data had been transferred to the graticule, including labelling of axes, use of graph area, point plotting and line of best fit. Candidates should note that an activation energy value will not have a minus sign.
Total		17	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29			C	1	
			Total	1	
30			B	1	
			Total	1	
31			D	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance									
32	a		<table><tr><td></td><td>Increasing temp</td><td>Inc pressure</td></tr><tr><td>Effect of Yield</td><td>Increase / more hydrogen</td><td>Decrease / less hydrogen</td></tr><tr><td>Effect of K_c</td><td>increase</td><td>No change</td></tr></table>		Increasing temp	Inc pressure	Effect of Yield	Increase / more hydrogen	Decrease / less hydrogen	Effect of K _c	increase	No change	2	ALLOW 1 mark for a correct row if neither column correct. ALLOW up arrows (↑) for increase and down arrows for decrease. Examiner Comments This question was very well done. The effect of conditions on K_c was well understood.
	Increasing temp	Inc pressure												
Effect of Yield	Increase / more hydrogen	Decrease / less hydrogen												
Effect of K _c	increase	No change												
	b		FIRST CHECK ANSWER ON ANSWER LINE If answer = 0.33 award 2 marks (mark units separately) Calculating eqm concs, CH₄= 1.66, H₂O = 0.66, CO = 0.34, H₂=1.02 ✓ Substitution into correct expression for K_c and calculating, (1.02)³ x 0.34/1.66 x 0.66 = 0.33 ✓ Units: mol² dm⁻⁶ ✓	3	ALLOW ecf from concentrations ALLOW any number rounding to 0.33 1Amounts at equilibrium 2Substitution into K_c and evaluation 3Units Incorrect concentrations substituted into correct K_c expression and correctly evaluated score second mark No ecf from wrong K_c for units. Examiner Comments This question was well done. The greatest difficulty was working out the equilibrium concentrations of each gas, but most were able to correctly substitute their values into a correct expression for K_c and give the correct units.									
	c	i	6 x 100/ (16 + 18) = 17.6/17.65/18 ✓	1	ALLOW 2 or more sf Examiner Comments This question was well done, although a few people did not account for 3 moles of hydrogen being formed.									
		ii	Co-product ✓	1	ALLOW 'waste product' DO NOT ALLOW By-product Examiner Comments Co-product is a term that many candidates did not know.									

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		Any 2 from: ✓✓ - Stops the release of/removes toxic/poisonous/dangerous/polluting CO OR no need to transport/remove CO OR uses up/re-uses CO (Exothermic) reaction provides heat, saving fuel/heating steam reforming/endothermic reaction - Higher yield of hydrogen/more hydrogen/higher atom economy/less waste.	2	Any 2 from: 1 relating to utilisation of CO 2 energy considerations 3 yield of hydrogen/atom economy/waste NOT 'no waste'/100% atom economy as CO₂ is still a waste product. If more than 2 reasons are given, mark the first 2. Examiner Comments Many candidates listed impacts linked to the use of the CO but often missed the second marking point by not emphasising that more H₂ is produced or that one reaction is exothermic and hence can provide energy for the other endothermic reaction.
			Total	9	
33			B	1	<u>Examiner's Comments</u> This is a topic that candidates have found difficult on the previous occasions it has been asked. Response A was the most frequently seen incorrect answer.
			Total	1	
34			C	1	
			Total	1	
35			B	1	<u>Examiner's Comments</u> Candidates were mostly confident enough to pick the correct answer here. A and C were the most frequently seen incorrect answers.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
36	a		Triple bond between N atoms requires a lot of energy to break (AW) /has a high bond enthalpy ✓	1	IGNORE very strong
	b		CO₂ is used in 36.2 so it removes a greenhouse gas from the atmosphere, (this is greener) ✓ Plus 2 from: ✓✓ - Both reactions need high T as both are endothermic but become more feasible at higher T as both have + ΔS, so no difference - Both reactions give a higher yield at lower T - Both need low pressure as 2 moles → 4, so no difference 36.2 produces less hydrogen per mole of methane, so less green/ Atom economy is lower in 36.2. (ORA)	3	ALLOW 36.2 requires more energy than 36.1, so less green Comments about 36.2 producing more toxic CO must be qualified (burn off → CO₂ or use as fuel) to score. Toxicity alone does not score. <u>Examiner's Comments</u> There were some very good answers, but others were vague and concentrated on the wrong things. Many identified the advantage of using CO₂ as a raw material but did not say why or used vague terms such as 'pollutant'. A lot focused on the CO produced, rather than the moles of hydrogen produced or atom economy.
	c		FIRST CHECK ANSWER ON ANSWER LINE If answer= 0.13 units dm⁶ mol⁻² award 3 marks (0.1 moles of N₂ react so 0.3 moles of H₂ used and) 0.2 moles NH₃ form, 0.7 moles H₂ left ✓ ([NH₃]²/[N₂][H₂]³ K_c= 0.22/0.9 × 0.7³) evaluated = (0.13) ✓ units dm⁶ mol⁻² ✓	3	ALLOW ECF from incorrect concentrations but not from incorrect K_c expression ALLOW 2 or more sf ALLOW mol⁻² dm⁶ <u>Examiner's Comments</u> There were a large number of perfectly correct answers here. Others were not able to get the correct equilibrium concentrations but were able to use their values to find a value for K_c.
	d	i	4NH ₃ + 5O ₂ → 4NO + 6H ₂ O ✓	1	ALLOW multiples, halves

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	FIRST CHECK ANSWER ON ANSWER LINE If answer = 12 (tonnes) award 4 marks Moles of NH_4NO_3 needed = $25 \times 10^6 / 80$ $(= 3.125 \times 10^5)$ ✓ Moles of NH_3 needed to make nitric acid = $(100 \times 3.125 \times 10^5) / 77$ ✓ Total moles of ammonia = $3.125 \times 10^5 +$ $(100 \times 3.125 \times 10^5) / 77 = 7.18 \times 10^5$ moles ✓ Mass = $7.18 \times 10^5 \times 17 = 1.22 \times 10^7$ g, 12 (tonnes) ✓	4	ALLOW 2 or more sf ALLOW ECF between stages MP1 convert to tonnes and then divide by 80 MP2 $\times 100 / 77$ MP3 Total moles ammonia (to make nitric acid + ammonia needed for salt) MP4 $\times 17$ and evaluation and conversion to tonnes <u>Examiner's Comments</u> This was designed to be a high demand question and relatively few scored the full 4 marks. However, there were scores of 1-3 on many occasions. The first mark was relatively easy, but to get the correct number of moles of ammonium nitrate the tonnes had to be converted to grams and this was not always done.
		iii	Add NaOH and Devarda's alloy or Al powder and warm ✓ Test gas with indicator paper/ red litmus/ rod dipped in HCl turns blue/ dense white fumes (due to ammonia) ✓	2	Reagents and heat needed Test and positive result for ammonia needed ALLOW Brown Ring Test (add Fe_2SO_4 solution followed by conc H_2SO_4) – a brown ring forms at the layer interface <u>Examiner's Comments</u> There were instances where candidates had simply forgotten this factual information. In other cases, marks were lost for omitting one of the reagents or not heating. Sometimes the colour change of the litmus paper was the incorrect way round.
			Total	14	

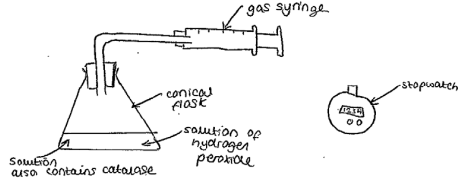
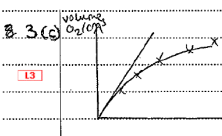
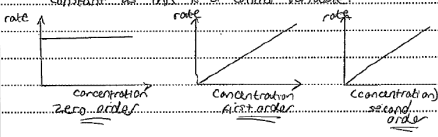
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
37	a	<i>Please refer to the marking instructions on page 6 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5 – 6 marks) Detailed procedure with most key variables identified and includes some relevant fine detail (may or may not include a diagram). AND Explains clearly how to process results. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Workable procedure with some variables identified may include some relevant fine detail (may or may not include a diagram). AND Attempts to explain how to process results. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Outline of procedure with some variables given (may or may not include a diagram). OR Attempts to explain how to process results. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> Level 0 <i>No response or no response worthy of credit.</i>	6	Indicative scientific points include: AO3.3 Development of a practical procedure by analysing information <i>Key variables may include:</i> • flask with peroxide; • same volume of peroxide solutions • keep concentration (and volume) of catalase • constant • vary peroxide concentration; • volume of oxygen measured in gas syringe or • over water; <i>Fine detail may include:</i> • means of adding catalase / starting reaction; • time for certain volume of oxygen to be produced • record volume of oxygen produced at fixed time • intervals • suitable apparatus for measuring volumes of solutions • suggests appropriate volume of gas to be collected • suggests appropriate time intervals for measuring volume of gas AO3.1 Processing results <i>Makes reference to</i> (plots) graph of volume of oxygen produced • against time; • measures slope at the origin / time $t = 0$; • rate proportional to $1/\text{time}$ for a small volume of • oxygen to be produced • uses $\text{rate} = \text{vol of oxygen}/\text{time}$ • use of smallest rate value to calculate relative • rates NB: Some of the above indicative science may be addressed as part of a labelled

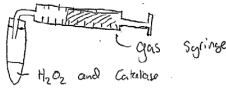
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					diagram – accept any relevant diagram even if poorly drawn. Allow sketch graph labelled as evidence of method used to process experimental data collected. <u>Examiner's Comments</u> This Level of Response question was well tackled by the vast majority of candidates. Most candidates scored at Level 2, with higher ability candidates regularly scoring at Level 3. There were two strands to this question that candidates needed to address; (i) designing a suitable procedure giving essential details (including some relevant fine detail), and (ii) explaining how they would process the data that they had collected. This is a practical procedure that candidates should be familiar with. Candidates should be able to describe a suitable workable method for this reaction, and indeed this was often the case. Many candidates produced diagrams of the apparatus which were a good indicator that their response was likely to be at least at Level 2 in the first strand. The second strand of this question provided an element of discrimination. Candidates were required to explain how they would process their results; some produced outlines of the graphs that they would plot indicating the tangent to be drawn, which again gave examiners a quick idea of what the appropriate level was likely to be. However, whilst many knew that they needed to produce a graph, they often suggested using a concentration vs rate graph, which was incorrect within the context of this question. This often meant that candidates who had produced a very detailed method were limited to Level 2 as the processing strand was weak. Where candidates did not address one of the strands within their response,

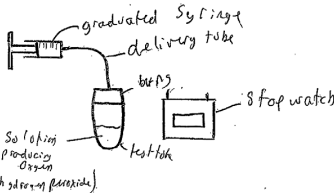
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			unfortunately this resulted in them being limited to Level 1. Exemplar 6  known • Measure out equal volumes of different concentrations of hydrogen peroxide solution (e.g. 25.0 cm³) using a burette or volumetric pipette. A clean, dry pipette can be used to run the solution into a clean conical flask. • Add a fixed volume of enzyme ~~catalase~~ catalase solution to the conical flask, stopper the flask and start the stopwatch. The conical flask should be connected to a gas syringe to collect the oxygen gas formed. • At equal time intervals (e.g. every 10 seconds) measure the volume of oxygen in the gas syringe to the nearest 0.05 cm³. • Keep doing this for 2 minutes, or until no more gas is produced. Repeat this procedure for all different concentrations of hydrogen peroxide. • Record results in a table of volume of oxygen (cm³) against time (s) and use this to plot a graph of volume of oxygen against time. * Please see back page for the rest *  Draw a line of best fit Draw a tangent to the curve at time $t=0$ and use the gradient to work out the initial rate of reaction. Then plot a graph of initial rate (y-axis) against concentration of hydrogen peroxide. This will tell you the rate of reaction with H_2O_2. The amount of catalase needs to be kept constant as this is a control variable.  rate concentration zero order concentration first order concentration second order Level 3 response, scoring 6 marks. This includes all key variables, and a significant amount of fine detail, explaining clearly how to process the results collected. The answer continues onto additional space of answer booklet. Whilst this was a Level 3 response, the candidate could have made their answer more succinct. Candidates are advised that

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			the answer space provided should be sufficient to gain full marks for Level of Response questions, without needing to continue onto the additional answer space. In this case, the candidate could have omitted the superfluous discussion and diagrams of rate-concentration graphs they have included at the end of their response. The suggested procedure could also have been written more concisely whilst retaining sufficient detail to receive full credit. Exemplar 7  The student will fully produce equal moles of Catalase and H_2O_2 and the same concentration of Catalase. They will be used. Produce at least 5 different H_2O_2 concentrations. The student will measure the volume of gas being produced for each different concentration of H_2O_2 for a set interval of time (2 mins) using a stopwatch. This means for each concentration of H_2O_2 you will have the volume of O_2 produced by the recordings of the Gas Syringe after the set time of 20 minutes. Repeat the procedure 10 times for each H_2O_2 concentration. The student can plot a graph of ~~Concentration~~ Volume of O_2 produced vs time (x-axis). Next plot the Volume of O_2 produced vs H_2O_2 concentration. Draw a line of best fit for each of the graphs produced for each H_2O_2 concentration. Next produce a tangent at $t=0$ for each H_2O_2 concentration graph and calculate gradient of tangents ($\frac{\Delta y}{\Delta x}$) and therefore you will have the initial rate of reactions for each H_2O_2 concentration. Level 2 response, scoring 4 marks. A workable procedure is outlined, but lacks fine detail which would have allowed the candidate to progress to Level 3. Good explanation of processing of results.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance																
					Exemplar 8  <u>Method</u> 1) Place a known volume of hydrogen peroxide in the test tube. Add the catalyst. Start the timer and place the bung in the top of the test tube. 2) Record how long 50 cm³ of oxygen takes to be produced. Record the final time. 3) Repeat 3 times with the same volume. 4) Increase volume of hydrogen peroxide by 10 cm³ and repeat for 6 results. <u>Process results</u> - 15 of oxygen = 1 cm³ - find moles of O₂ produced with $n = \frac{pV}{RT}$ - 1:2 ratio. ~~double~~ the n_{O_2} for moles of H₂O₂ - $n = CV$ - concentration of hydrogen peroxide = $\frac{\text{moles}}{\text{Volume}}$ Level 1 response scoring 2 marks. Provides an outline of a method that might work but makes no reference to the use of time to calculate a rate value.																
	b	i	<table><tr><th>[H₂O₂]/ mol dm⁻³</th><th>(relative) rate</th></tr><tr><td>0.05</td><td>1.0</td></tr><tr><td>0.10</td><td>2.1</td></tr><tr><td>0.15</td><td>3.0</td></tr><tr><td>0.20</td><td>3.8</td></tr><tr><td>0.25</td><td>4.0</td></tr><tr><td>0.30</td><td>4.1</td></tr><tr><td>0.35</td><td>4.1</td></tr></table>	[H ₂ O ₂]/ mol dm ⁻³	(relative) rate	0.05	1.0	0.10	2.1	0.15	3.0	0.20	3.8	0.25	4.0	0.30	4.1	0.35	4.1	2	First mark for labelled columns (or rows). ALLOW 'concentration of H₂O₂' for [H₂O₂], Evidence of units required for Hydrogen peroxide. Accept 'au/arb' for relative rate but no other units allowed. Other units = CON Second mark for correct values, all concentration values to 2 dp, rate values to 1dp. IGNORE inclusion of temperature
[H ₂ O ₂]/ mol dm ⁻³	(relative) rate																				
0.05	1.0																				
0.10	2.1																				
0.15	3.0																				
0.20	3.8																				
0.25	4.0																				
0.30	4.1																				
0.35	4.1																				

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	labelled axes (ignore units) with rate as y-axis✓ plot points correctly✓ draws best fit line ✓ (must go through the origin) each scale chosen to take up more than half axis ✓	4	ALLOW +/- ½ small square Line should pass through at least 5 points / pass within 1 small square of their plotted points <u>Examiner's Comments</u> This question was generally well answered, with most candidates scoring at least 4 marks, and many scoring the full 6 marks. The only common errors were in part (i) the inclusion of some units for the rate of reaction column, and in (ii) reversing the x and y axis. Some candidates did lose one mark in part (ii) for failing to choose an appropriate scale to use that should have taken up a minimum of half the space available.
	c	i	Rate = $k[\text{H}_2\text{O}_2]$ ✓ [catalase] ✓ $\text{dm}_3 \text{ mol}^{-1} \text{ s}^{-1}$ ✓	2	ALLOW [enzyme] for [catalase], (must have 'rate =' at start of their expression) ALLOW units in any order <u>Examiner's Comments</u> This was a tricky question for many candidates. Most struggled to work out the units for the rate constant. The only other common error was the omission of "rate =" at the start of the rate equation.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	peroxide: first order initially ✓ then zero order ✓ catalase: no evidence since concentration not changed (AW)✓	3	ALLOW concentration of catalase kept constant <u>Examiner's Comments</u> There were a lot of varied responses to this question. The majority of candidates scored at least one mark, but very few scored all three. Many candidates used the graph in d(ii) to state that 'up to 0.2mol dm^{-3} (or, at low concentration) the reaction is first order with respect to hydrogen peroxide as the graph is a straight line'. Some also scored a second mark for realising that when the graph levelled off the rate became zero order as no matter how the concentration of peroxide changed, there was no further change in rate. They then tended to link this to the idea of the active sites being saturated. Very few candidates identified that the statement was incorrect with regard to catalase as the catalase concentration was kept constant in this reaction.
	d		FIRST CHECK ANSWER ON ANSWER LINE If answer = 4.2 award 3 marks $(0.35/2 =) 0.175 \text{ mol oxygen per dm}^3$ peroxide ✓ volume strength $(= 24 \times 0.175) = 4.2$ ✓ answer to 2sf ✓	3	If answer = 8.4 award 2 marks for candidate failing to convert 0.35 to 0.175 ALLOW ecf from incorrect calculation of number of moles Any calculated value to 2sf scores 1 mark. <u>Examiner's Comments</u> This question was a good discriminator , producing a full range of marks from 3 to 0. Lower ability candidates often struggled to score any marks here. Higher ability candidates also found this challenging. The most common mark was credited for

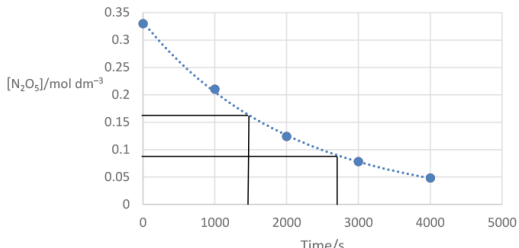
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			identifying that the molar ratio between the peroxide and oxygen was 2:1, and so the moles of O₂ should be 0.175 (or 1.75×10^{-4} if converted from dm³ to cm³). Where candidates subsequently lost marks was in the next step for not realising that because oxygen is a gas, they needed to multiply their calculated number of moles by 24(dm³) or 24000(cm³) to then arrive at the final answer. This question included a mark that was for displaying their working, in order that where a candidate had not spotted the molar ratio, or had calculated the number of moles of oxygen by a different method, then examiners could award a mark for the use of '× 24 (or 24,000)' as an error carried forward with the final mark being for converting their calculated value to 2 significant figures. A candidate who simply gave an incorrect final answer to this question scored 0, whereas candidates who did not arrive at the correct final answer but had displayed their working often scored 2 marks. Exemplar 9 be rate = k [catalase] as this is two different step - rate determining step. (f) Hydrogen peroxide concentration is often measured as 'volume strength'. 1 cm³ of 1 volume hydrogen peroxide produces 1 cm³ of oxygen at RTP. Calculate the 'volume strength' of the 0.35 mol/dm³ hydrogen peroxide used by the students. $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ Equation 3.1 Give your answer to an appropriate number of significant figures. $\text{O}_2 = 1 \text{ cm}^3 = 1 \times 10^{-3} \text{ dm}^3$ 24000 = 1 mole $1 \times \frac{1}{24000} = 4.1667 \times 10^{-5} \text{ moles of O}_2$ 2 sig fig in Q.A. $n = 8.3333 \times 10^{-5} \text{ moles of H}_2\text{O}_2$ $c = 0.35 \text{ mol/dm}^3$ $V = \frac{8.3333 \times 10^{-5}}{0.35} = 2.38095 \times 10^{-4} \text{ 'volume strength'}$ 2.4 × 10⁻⁴ volume [3] Calculation showing working being given credit, even though final answer is incorrect.
e	FIRST CHECK ANSWER ON ANSWER LINE If answer = 120 (cm³) award 2 marks (total volume =) $20 \times 0.35/0.05$ OR 140 (cm³) ✓ volume to add = 120 (cm³) ✓	2	ALLOW 140(cm³) even on the answer line for 1 mark Examiner's Comments Generally well answered. Most candidates scored at least one mark for arriving at an answer of 140 cm³, as they did not subtract the initial 20 cm³ of peroxide solution.
	Total	22	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
38			C	1 AO 1.1	<u>Examiner's Comments</u> This was well answered, some annotations showed candidates eliminating the incorrect answers, such as 'denaturing' opposite B. A was a frequently seen incorrect answer.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
39	a	i	 axes round right way and labelled correctly ✓ scale to fill 2/3 of area ✓ plot with line of best fit ✓ measurement of one half-life = 1400 s ± 100 ✓	4(AO2.8 x 4)	Should be a curve that touches at least 4 points. Mark half-life by answer given, no construction lines needed for this part. Examiner's Comments This combination of questions was generally well answered by the majority of candidates, with many scoring full marks or at least scoring 4 of the 5 marks that were available. The only commonly seen error was failing to label the axes correctly on their graph. There were a small number of candidates who scored all 4 marks for drawing their graph, but then gave an incorrect answer to (ii), often stating that the fact that the graph showed a curve with the concentration decreasing as time increased was evidence for a first order reaction.
		ii	'Half lives constant' AND At least two half-lives constructed ✓	1(AO2.7)	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		$(k = 9.8 \times 10^{-5} / 0.210 =) 4.7 \times 10^{-4} \checkmark$ units $\text{s}^{-1} \checkmark$	2(AO2.4 x 2)	ALLOW 2 or more sf Mark units separately <u>Examiner's Comments</u> Having been told in (b)(ii) that the reaction is first order with respect to N_2O_5, candidates should have been able to deduce a suitable rate expression, i.e. $\text{Rate} = k[\text{N}_2\text{O}_5]$, and then use it to determine the rate constant. However, because equation 4.1 tells them that the reaction uses 2 moles of N_2O_5, many candidates wrote the expression as $\text{Rate} = k[\text{N}_2\text{O}_5]^2$, and then derived their value and units from this expression. Rather than simply penalising candidates fully for a recognisable error, it was decided that if they could derive appropriate units from this expression then we would allow the units marks to stand separately. This would be consistent with the marks given at 2(e)(ii) where a mark for derivation of units was previously allowed for a similar scenario. This allowed some candidates to access one mark where otherwise they would have scored 0 for a single error.

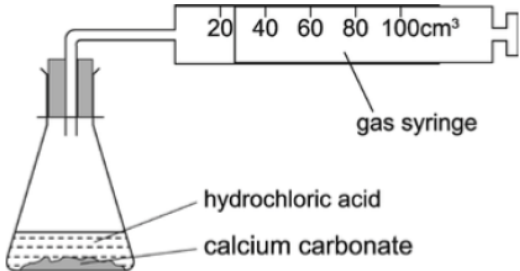
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		FIRST CHECK THE ANSWER ON ANSWER LINE If answer = (+)100±10 (any sf) (kJ mol⁻¹) award 3 marks slope = -12000±500 ✓ Ea = 12000 x 8.314 = (+)99768 (J) ✓ = (+)99.8 (kJ mol⁻¹) ✓	3(AO2.6 x 3)	ALLOW one or more sf ALLOW ECF MP1 is for calculating the gradient MP2 is for multiplying by R and evaluating MP3 is for converting from J to kJ <u>Examiner's Comments</u> This calculation was broken down into three recognisable steps where candidates could gain credit by marking them as independent steps. First of all they were required to calculate the gradient of the line drawn on the graph. Secondly, they had to multiply their value by R (8.314 J mol⁻¹K⁻¹) and then finally to convert their value from joules into kilojoules. By using this approach most of the candidates attempted this calculation scored at least two marks as they often scored marking points 2 and 3. There were a few candidates who struggled to calculate the gradient of the line, inverting the numerator and denominator, but then continued with their calculation and scored either marking point 2 or 3. Others calculated the gradient correctly but then multiplied it by R and then divided it by 1/T. Others still chose a fixed point from the graph and used a single value of <i>lnk</i> and its corresponding value of 1/T to attempt to calculate a value for Ea. In each of these cases if it could be clearly identified that marking points 2 and 3 were evident then credit was given.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	d		(this is a possible mechanism because) reactions add to overall equation / $2\text{N}_2\text{O}_5 \rightarrow 4\text{NO}_2 + \text{O}_2$ ✓ step 1 could be rate determining because it uses N_2O_5 as a reactant / N_2O_5 decomposes ✓ step 3 could be rate determining because it uses N_2O_5 as a reactant / could be slow compared to steps 1 and 2 ✓	3(AO3.1 x 3)	ALLOW cannot be step 2 as N_2O_5 does not appear in the equation for 1 mark if no reference made to either step 1 or step 3. ALLOW BOTH step 1 and step 3 could be RDS with a reason scores 2 marks BOTH step 1 and step 3 with no reason scores 1 mark <u>Examiner's Comments</u> The first mark here was for identifying that the three steps outlined cancelled down to give the reaction shown in equation 4.1. Many candidates did this by adding the steps up to give a single equation and then crossed out substances that appeared on both sides of their equation to derive a final equation. However, having done this, they then struggled to identify which step(s) was(were) the rate determining step(s) as they did not appreciate the significance of the statement in the stem of the question informing them that the reaction is first order with respect to N_2O_5. From this statement they should have been able to deduce that the rate determining step had to involve N_2O_5 as a reactant. Therefore it had to be either step 1 or step 3. A significant number of responses did identify step 1 with a reason but said that step 3 could not be a rate determining step as it also contained NO as a reactant and there was no information available for NO in the rate equation.
			Total	13	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
40	<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Give some credit for thermal decomposition / stability but only to level 1 (1 – 2 marks) Level 3 (5 – 6 marks) Describes full procedure (words or diagram) with most fine detail. AND Describes in full how the results should be interpreted, with most fine detail. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3 – 4 marks) Describes full procedure (words or diagram) with most fine detail. OR Describes the procedure with some fine detail omitted. AND Describes in how the results should be interpreted, with some fine detail omitted. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1 – 2 marks) Describes procedure and interpretation of results with no fine detail. OR Describes the procedure with some fine detail omitted. OR Describes in how the results should be interpreted, with some fine detail omitted. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant and correct.</i>	6 (AO3.1) (AO3.2 × 2)(AO3.3) (AO3.4 × 2)	indicative scientific points may include:  Procedure AO3.3/4 (could all be from diagram and labels) • apparatus as above (or collection over water) • Use of at least three named Group 2 carbonates • Add (hydrochloric) acid to carbonate flask or vice versa <i>Fine detail:</i> • rapid stoppering of flask after adding acid. • same concentration of acid • same volume of acid • same amount and particle size of carbonate • accept mass Results and interpretation: AO3.1/2 either • measure time to collect a certain volume of gas • shorter time means faster rate <i>fine detail</i> • volume to collect is specified • rate is proportional to 1/time (subsumes second point) • relating times / rates to trend down group or • plot graph of volume against time • gradient shows rate

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Level 0 (no marks) No response or no response worthy of credit		<i>fine detail</i> • sketch of graph • gradient at origin • relating rates to trend down group
			Total	6	
41			B	1 (AO2.8)	
			Total	1	
42		i	Atom economies $(98/170) = 58\%$ AND $(98/222) = 44\%$ ✓ Identifies butane / reaction 1 should be used because it has the larger atom economy / produces less waste ✓	2 (AO2.6) (AO3.1)	ALLOW 0.58 AND 0.44 <u>Examiner's Comments</u> Parts(i) and (ii) were well answered by most candidates, although (iii) saw marks being lost for use of an inappropriate number of significant figures in the final answer.
		ii	Benzene toxic / more expensive / butane more available from cracking / doesn't produce CO ₂ (ORA for reaction 2)✓	1 (AO3.1)	ALLOW ecf from (i) eg butane more flammable
		iii	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 61 (kg) award 2 marks amt butane = $15000/24 = 625 \text{ mol}$ ✓ mass maleic anh = $625 \times 98/1000 = 61(\text{kg})$ (2sf) ✓	2 (AO2.8 × 2)	61.3 or 61.2 score 1 Correct use of gas equation can score both marks
			Total	5	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
43	a	i	Colourless gas ✓ turns brown ✓	2 (AO1.1 × 2)	
		ii	$\text{N}_2 + \text{O}_2 \rightarrow 2\text{NO}$ ✓	1 (AO1.1)	If state symbols are shown they must be correct (all (g))
	b	i	FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 319 (K) award 3 marks $\Delta S_{\text{sys}} = \text{products} - \text{reactants}$ ✓ $= 213.6 + (2 \times 192.3) - 69.9 - 173.9$ $= (+) 354.4$ ✓ temp = $113000/354.4$ 318.8 K ✓	3 (AO2.6 × 3)	ALLOW 2 or more sf ALLOW ecf on incorrect ΔS_{sys} Second mark subsumes first 354.4 gains 2 marks
		ii	$4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}$ OR $2\text{NH}_3 + \text{NO} + \text{O}_2 \rightarrow 1\frac{1}{2}\text{N}_2 + 3\text{H}_2\text{O}$ ✓	1 (AO2.1)	ALLOW halves / multiples IGNORE state symbols
	c		On short journeys the engine has not yet reached high temperature ✓ (Equation 31.1 is) <u>endothermic</u> so (position of) eqm will be on the left ✓ Less ammonia available to remove oxides of nitrogen ✓ At lower temp the <u>rate</u> of formation of <u>ammonia</u> will be slower ✓	4 (AO3.1) (AO2.5) (AO3.1) (AO2.5)	ORA
	d		FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = $0.67 \text{ dm}^6 \text{ mol}^{-2}$ award 4 marks Expression for K_c ✓ Eqm conc of hydrogen = $3 (\text{mol dm}^{-3})$ AND Eqm conc of nitrogen = $2 (\text{mol dm}^{-3})$ ✓ $(K_c = 6^2/2 \times 3^3) = 0.67$ ✓ units $\text{dm}^6 \text{ mol}^{-2}$ ✓	4 (AO2.6 × 4)	ALLOW one or more sf. ALLOW ecf on incorrect $[\text{N}_2]$ and $[\text{H}_2]$ MP1 expression, MP2 concs of both, MP3 evaluation, MP4 units If an expression for K_c contains only numbers, it must be clear which substance they relate to for MP1 ALLOW units in either order

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	15	