SL Paper 2

A student determined the percentage of the active ingredient magnesium hydroxide, $Mg(OH)_2$, in a 1.24 g antacid tablet.

The antacid tablet was added to 50.00 cm^3 of 0.100 mol dm^{-3} sulfuric acid, which was in excess.

a. Calculate the amount, in mol, of H_2SO_4. [1]

b. Formulate the equation for the reaction of H_2SO_4 with $Mg(OH)_2$. [1]

c. The excess sulfuric acid required 20.80 cm^3 of 0.1133 mol dm^{-3} NaOH for neutralization. [1]

Calculate the amount of excess acid present.

d. Calculate the amount of H_2SO_4 that reacted with $Mg(OH)_2$. [1]

e. Determine the mass of $Mg(OH)_2$ in the antacid tablet. [2]

f. Calculate the percentage by mass of magnesium hydroxide in the 1.24 g antacid tablet to three significant figures. [1]

Consider the following sequence of reactions.

$$\mathrm{RCH_3} \xrightarrow{reaction 1} \mathrm{RCH_2Br} \xrightarrow{reaction 2} \mathrm{RCH_2OH} \xrightarrow{reaction 3} \mathrm{RCOOH}$$

$\mathrm{RCH_3}$ is an unknown alkane in which R represents an alkyl group.

The mechanism in *reaction 2* is described as S_N2.

Propan-1-ol has two structural isomers.

a. The alkane contains 81.7% by mass of carbon. Determine its empirical formula, showing your working. [3]

b. Equal volumes of carbon dioxide and the unknown alkane are found to have the same mass, measured to an accuracy of two significant figures, at the same temperature and pressure. Deduce the molecular formula of the alkane. [1]

c. (i) State the reagent and conditions needed for *reaction 1*. [2]

(ii) State the reagent(s) and conditions needed for *reaction 3*.

d. *Reaction 1* involves a free-radical mechanism. Describe the stepwise mechanism, by giving equations to represent the initiation, propagation and termination steps. [4]

e. (i) State the meaning of each of the symbols in S_N2. [4]

(ii) Explain the mechanism of this reaction using curly arrows to show the movement of electron pairs, and draw the structure of the transition state.

f. (i) Deduce the structural formula of each isomer. [4]

(ii) Identify the isomer from part (f) (i) which has the higher boiling point and explain your choice. Refer to both isomers in your explanation.

Consider the following reactions.

$$\underset{\mathbf{X}}{(CH_3)_2CH(CH_2)_3OH} \longrightarrow \underset{\mathbf{Y}}{(CH_3)_2CH(CH_2)_2CHO}$$

$$\downarrow$$

$$\underset{\mathbf{Z}}{(CH_3)_2CH(CH_2)_2COOH}$$

An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, **J**, and found it to contain the elements carbon, hydrogen and chlorine only. The chemical composition of **J** was determined using different analytical chemistry techniques.

Combustion Reaction:

Combustion of 1.30 g of **J** gave 0.872 g CO_2 and 0.089 g H_2O.

Precipitation Reaction with $AgNO_3$(aq):

0.535 g of **J** gave 1.75 g AgCl precipitate.

a. One example of a homologous series is the alcohols. Describe **two** features of a homologous series. [2]

b.i. The IUPAC name of **X** is 4-methylpentan-1-ol. State the IUPAC names of **Y** and **Z**. [2]

Y:

Z:

b.ii. State the reagents and reaction conditions used to convert **X** to **Y** and **X** to **Z**. [2]

X to **Y**:

X to **Z**:

b.iii. **Z** is an example of a weak acid. State what is meant by the term *weak acid*. [1]

b.iv. Discuss the volatility of **Y** compared to **Z**. [2]

d.i. Determine the percentage by mass of carbon and hydrogen in **J**, using the combustion data. [3]

d.ii. Determine the percentage by mass of chlorine in **J**, using the precipitation data. [1]

d.iii. The molar mass was determined to be $131.38 \text{ g mol}^{-1}$. Deduce the molecular formula of **J**. [3]

Vanadium, another transition metal, has a number of different oxidation states.

a. Determine the oxidation state of vanadium in each of the following species. [2]

V_2O_5:

. . . .

VO^{2+}:

. . . .

b. Formulate an equation for the reaction between VO^{2+}(aq) and V^{2+}(aq) in acidic solution to form V^{3+}(aq). [1]

An acidic sample of a waste solution containing Sn^{2+}(aq) reacted completely with $K_2Cr_2O_7$ solution to form Sn^{4+}(aq).

a.i. State the oxidation half-equation. [1]

a.ii. Deduce the overall redox equation for the reaction between acidic Sn^{2+}(aq) and $Cr_2O_7^{2-}$(aq), using section 24 of the data booklet. [1]

b.i. Calculate the percentage uncertainty for the mass of $K_2Cr_2O_7$(s) from the given data. [1]

Mass of weigh boat / g ±0.001 g	1.090
Mass of weigh boat + $K_2Cr_2O_7$(s) / g ±0.001 g	14.329

b.ii. The sample of $K_2Cr_2O_7$(s) in (i) was dissolved in distilled water to form 0.100 dm^3 solution. Calculate its molar concentration. [1]

b.iii. 10.0 cm^3 of the waste sample required 13.24 cm^3 of the $K_2Cr_2O_7$ solution. Calculate the molar concentration of Sn^{2+}(aq) in the waste sample. [2]

An organic compound, **X**, with a molar mass of approximately $88\ \mathrm{g\,mol^{-1}}$ contains 54.5% carbon, 36.3% oxygen and 9.2% hydrogen by mass.

a. (i) Distinguish between the terms *empirical formula* and *molecular formula*. [9]

Empirical formula:

Molecular formula:

(ii) Determine the empirical formula of **X**.

(iii) Determine the molecular formula of **X**.

(iv) **X** is a straight-chain carboxylic acid. Draw its structural formula.

(v) Draw the structural formula of an isomer of **X** which is an ester.

(vi) The carboxylic acid contains two different carbon-oxygen bonds. Identify which bond is stronger and which bond is longer.

Stronger bond:

Longer bond:

b. (i) State and explain which of propan-1-ol, $CH_3CH_2CH_2OH$, and methoxyethane, $CH_3OCH_2CH_3$, is more volatile. [5]

(ii) Propan-1-ol, $CH_3CH_2CH_2OH$, and hexan-l-ol, $CH_3(CH_2)_4CH_2OH$, are both alcohols. State and explain which compound is more soluble in water.

c. Graphite is used as a lubricant and is an electrical conductor. Diamond is hard and does not conduct electricity. Explain these statements in terms of the structure and bonding of these allotropes of carbon. [6]

Graphite:

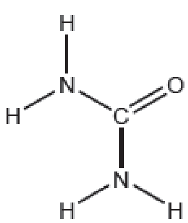
Diamond:

Urea, $(H_2N)_2CO$, is excreted by mammals and can be used as a fertilizer.

a.i. Calculate the percentage by mass of nitrogen in urea to two decimal places using section 6 of the data booklet. [2]

a.ii. Suggest how the percentage of nitrogen affects the cost of transport of fertilizers giving a reason. [1]

b. The structural formula of urea is shown. [3]



Predict the electron domain and molecular geometries at the nitrogen and carbon atoms, applying the VSEPR theory.

	Electron domain geometry	**Molecular geometry**
Nitrogen	....	....
Carbon	....	trigonal planar

c. Urea can be made by reacting potassium cyanate, KNCO, with ammonium chloride, NH_4Cl. [2]

$$KNCO(aq) + NH_4Cl(aq) \rightarrow (H_2N)_2CO(aq) + KCl(aq)$$

Determine the maximum mass of urea that could be formed from 50.0 cm^3 of 0.100 mol dm^{-3} potassium cyanate solution.

d. Urea can also be made by the direct combination of ammonia and carbon dioxide gases. [1]

$$2NH_3(g) + CO_2(g) \rightleftharpoons (H_2N)_2CO(g) + H_2O(g) \qquad \Delta H < 0$$

Predict, with a reason, the effect on the equilibrium constant, K_c, when the temperature is increased.

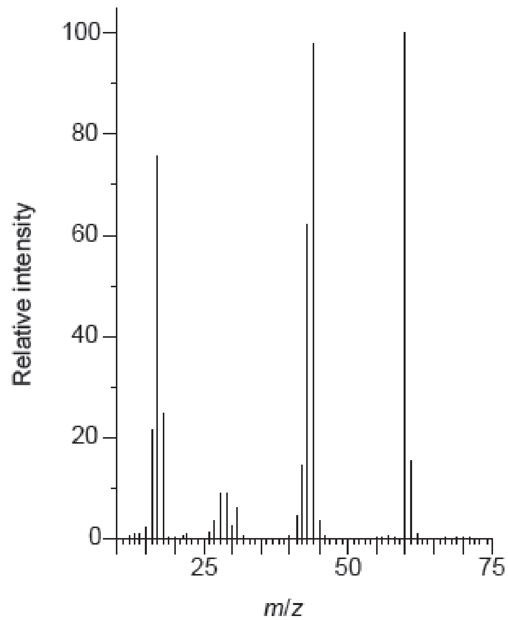
e.i. Suggest one reason why urea is a solid and ammonia a gas at room temperature. [1]

e.ii. Sketch **two** different hydrogen bonding interactions between ammonia and water. [2]

f. The combustion of urea produces water, carbon dioxide and nitrogen. [2]

Formulate a balanced equation for the reaction.

g. The mass spectrum of urea is shown below. [2]



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in *NIST Chemistry WebBook*, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, doi:10.18434/T4D303, (retrieved May 31, 2018).]

Identify the species responsible for the peaks at m/z = 60 and 44.

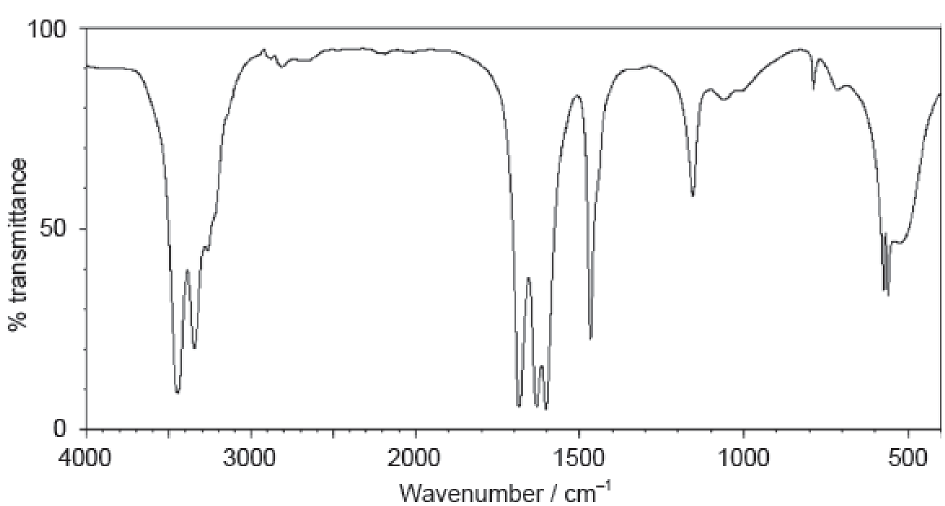
60:

....

44:

....

h. The IR spectrum of urea is shown below. [2]



[Source: SDBS, National Institute of Advanced Industrial Science and Technology]

Identify the bonds causing the absorptions at 3450 cm^{-1} and 1700 cm^{-1} using section 26 of the data booklet.

3450 cm^{-1}:   ....   1700 cm^{-1}:   ....

i. Predict the number of signals in the ^1H NMR spectrum of urea. [1]

There are many oxides of silver with the formula Ag_xO_y. All of them decompose into their elements when heated strongly.

a.i. After heating 3.760 g of a silver oxide 3.275 g of silver remained. Determine the empirical formula of Ag_xO_y. [2]

a.ii. Suggest why the final mass of solid obtained by heating 3.760 g of Ag_xO_y may be greater than 3.275 g giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

b. Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag. [1]

The relative atomic mass of silver is 107.87. Show that isotope ^{107}Ag is more abundant.

c.i. Some oxides of period 3, such as Na_2O and P_4O_{10}, react with water. A spatula measure of each oxide was added to a separate 100 cm^3 flask containing distilled water and a few drops of bromothymol blue indicator. [3]

The indicator is listed in section 22 of the data booklet.

Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide.

Flask containing	**Colour of solution**	**Product formula**
Na_2O	....	....
P_4O_{10}	....	....

c.ii. Explain the electrical conductivity of molten Na_2O and P_4O_{10}. [2]

d. Outline the model of electron configuration deduced from the hydrogen line emission spectrum (Bohr's model). [2]

Brass is a copper containing alloy with many uses. An analysis is carried out to determine the percentage of copper present in three identical samples of brass. The reactions involved in this analysis are shown below.

$$\text{Step 1: } Cu(s) + 2HNO_3(aq) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)$$
$$\text{Step 2: } 4I^-(aq) + 2Cu^{2+}(aq) \rightarrow 2CuI(s) + I_2(aq)$$
$$\text{Step 3: } I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

(a) (i) Deduce the change in the oxidation numbers of copper and nitrogen in step 1.

Copper:

Nitrogen:

(ii) Identify the oxidizing agent in step 1.

(b) A student carried out this experiment three times, with three identical small brass nails, and obtained the following results.

$$\text{Mass of brass} = 0.456\ \text{g} \pm 0.001\ \text{g}$$

Titre	1	2	3
Initial volume of 0.100 mol dm^{-3} $S_2O_3^{2-}$ ($\pm 0.05\ cm^3$)	0.00	0.00	0.00
Final volume of 0.100 mol dm^{-3} $S_2O_3^{2-}$ ($\pm 0.05\ cm^3$)	28.50	28.60	28.40
Volume added of 0.100 mol dm^{-3} $S_2O_3^{2-}$ ($\pm 0.10\ cm^3$)	28.50	28.60	28.40
Average volume added of 0.100 mol dm^{-3} $S_2O_3^{2-}$ ($\pm 0.10\ cm^3$)	28.50		

(i) Calculate the average amount, in mol, of $S_2O_3^{2-}$ added in step 3.

(ii) Calculate the amount, in mol, of copper present in the brass.

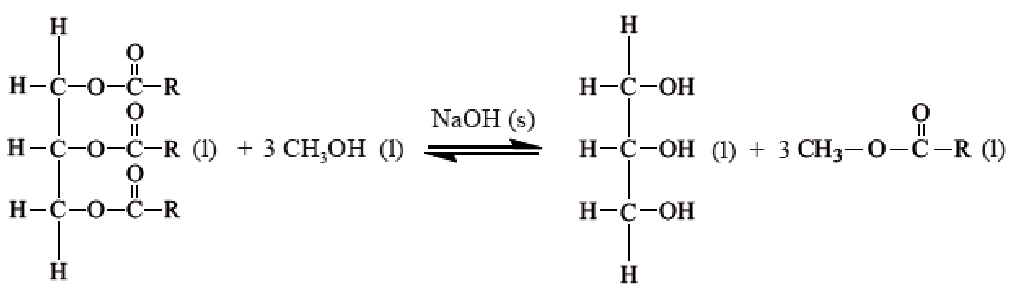
(iii) Calculate the mass of copper in the brass.

(iv) Calculate the percentage by mass of copper in the brass.

(v) The manufacturers claim that the sample of brass contains 44.2% copper by mass. Determine the percentage error in the result.

(c) With reference to its metallic structure, describe how brass conducts electricity.

Biodiesel makes use of plants' ability to fix atmospheric carbon by photosynthesis. Many companies and individuals are now using biodiesel as a fuel in order to reduce their carbon footprint. Biodiesel can be synthesized from vegetable oil according to the following reaction.



vegetable oil methanol glycerol biodiesel

The reversible arrows in the equation indicate that the production of biodiesel is an equilibrium process.

a. Identify the organic functional group present in both vegetable oil and biodiesel. [1]

b. For part of her extended essay investigation into the efficiency of the process, a student reacted a pure sample of a vegetable oil (where $R = C_{17}H_{33}$) with methanol. The raw data recorded for the reaction is below. [3]

Mass of oil	$= 1013.0$ g
Mass of methanol	$= 200.0$ g
Mass of sodium hydroxide	$= 3.5$ g
Mass of biodiesel produced	$= 811.0$ g

The relative molecular mass of the oil used by the student is 885.6. Calculate the amount (in moles) of the oil and the methanol used, and hence the amount (in moles) of excess methanol.

c.i. State what is meant by the term *dynamic equilibrium*. [1]

c.ii. Using the abbreviations [vegetable oil], [methanol], [glycerol] and [biodiesel] deduce the equilibrium constant expression (K_c) for this reaction. [1]

c.iii Suggest a reason why excess methanol is used in this process. [1]

c.iv State and explain the effect that the addition of the sodium hydroxide catalyst will have on the position of equilibrium. [2]

d. The reactants had to be stirred vigorously because they formed two distinct layers in the reaction vessel. Explain why they form two distinct layers and why stirring increases the rate of reaction. [2]

e. Calculate the percentage yield of biodiesel obtained in this process. [2]

A student decided to determine the molecular mass of a solid monoprotic acid, HA, by titrating a solution of a known mass of the acid.

The following recordings were made.

Mass of bottle / g ± 0.001 g	1.737
Mass of bottle + acid HA / g ± 0.001 g	2.412

a. Calculate the mass of the acid and determine its absolute and percentage uncertainty. [2]

b. This known mass of acid, HA, was then dissolved in distilled water to form a $100.0\ \text{cm}^3$ solution in a volumetric flask. A $25.0\ \text{cm}^3$ sample of this solution reacted with $12.1\ \text{cm}^3$ of a $0.100\ \text{mol dm}^{-3}$ NaOH solution. Calculate the molar mass of the acid. [3]

c. The percentage composition of HA is 70.56% carbon, 23.50% oxygen and 5.94% hydrogen. Determine its empirical formula. [2]

d. A solution of HA is a weak acid. Distinguish between a *weak acid* and a *strong acid*. [1]

e. Describe an experiment, other than measuring the pH, to distinguish HA from a strong acid of the same concentration and describe what would be observed. [2]

---

a. Explain why the relative atomic mass of argon is greater than the relative atomic mass of potassium, even though the atomic number of potassium is greater than the atomic number of argon. [1]

b. Deduce the numbers of protons and electrons in the K^+ ion. [1]

The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined

by titration with a standard solution of sodium hydroxide, NaOH (aq).

a. Distinguish between a weak acid and a strong acid. [1]

Weak acid:

Strong acid:

b. Suggest why it is more convenient to express acidity using the pH scale instead of using the concentration of hydrogen ions. [1]

c. 5.00 g of an impure sample of hydrated ethanedioic acid, $(COOH)_2 \cdot 2H_2O$, was dissolved in water to make 1.00 dm^3 of solution. 25.0 cm^3 samples of this solution were titrated against a 0.100 mol dm^{-3} solution of sodium hydroxide using a suitable indicator. [5]

$$(COOH)_2\,(aq) + 2NaOH\,(aq) \rightarrow (COONa)_2\,(aq) + 2H_2O\,(l)$$

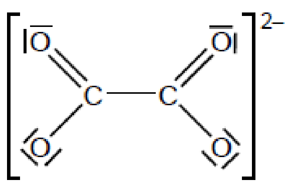
The mean value of the titre was 14.0 cm^3.

(i) Calculate the amount, in mol, of NaOH in 14.0 cm^3 of 0.100 mol dm^{-3} solution.

(ii) Calculate the amount, in mol, of ethanedioic acid in each 25.0 cm^3 sample.

(iii) Determine the percentage purity of the hydrated ethanedioic acid sample.

d. The Lewis (electron dot) structure of the ethanedioate ion is shown below. [2]



Outline why all the C–O bond lengths in the ethanedioate ion are the same length and suggest a value for them. Use section 10 of the data booklet.

Iron tablets are often prescribed to patients. The iron in the tablets is commonly present as iron(II) sulfate, $FeSO_4$.

Two students carried out an experiment to determine the percentage by mass of iron in a brand of tablets marketed in Cyprus.

Experimental Procedure:

- The students took five iron tablets and found that the **total mass** was 1.65 g.
- The five tablets were ground and dissolved in $100\ cm^3$ dilute sulfuric acid, $H_2SO_4(aq)$. The solution and washings were transferred to a $250\ cm^3$ volumetric flask and made up to the mark with deionized (distilled) water.
- $25.0\ cm^3$ of this $Fe^{2+}(aq)$ solution was transferred using a pipette into a conical flask. Some dilute sulfuric acid was added.
- A titration was then carried out using a $5.00 \times 10^{-3}\ mol\,dm^{-3}$ standard solution of potassium permanganate, $KMnO_4(aq)$. The end-point of the titration was indicated by a slight pink colour.

The following results were recorded.

	Rough titre	First accurate titre	Second accurate titre
Initial burette reading / $cm^3 \pm 0.05$	1.05	1.20	0.00
Final burette reading / $cm^3 \pm 0.05$	20.05	18.00	16.80

This experiment involves the following redox reaction.

$$5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+(aq) \rightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l)$$

a. When the $Fe^{2+}(aq)$ solution was made up in the $250\ cm^3$ volumetric flask, deionized (distilled) water was added until the bottom of its meniscus corresponded to the graduation mark on the flask. It was noticed that one of the two students measured the volume of the solution from the top of the meniscus instead of from the bottom. State the name of this type of error. [1]

b. State what is meant by the term *precision*. [1]

c. When the students recorded the burette readings, following the titration with $KMnO_4$ (aq),the top of the meniscus was used and not the bottom. Suggest why the students read the top of the meniscus and not the bottom. [1]

d.i. Define the term *reduction* in terms of electrons. [1]

d.ii. Deduce the oxidation number of manganese in the $MnO_4^-(aq)$ ion. [1]

e.i. Determine the amount, in mol, of $MnO_4^-(aq)$, used in each accurate titre. [2]

e.ii. Calculate the amount, in mol, of $Fe^{2+}(aq)$ ions in $250\ cm^3$ of the solution. [1]

e.iii. Determine the total mass of iron, in g, in the $250\ cm^3$ solution. [1]

e.iv. Determine the percentage by mass of iron in the tablets. [1]

f.i. One titration was abandoned because a brown precipitate, manganese(IV) oxide, formed. State the chemical formula of this compound. [1]

Reaction kinetics can be investigated using the iodine clock reaction. The equations for two reactions that occur are given below.

Reaction A: $H_2O_2(aq) + 2I^-(aq) + 2H^+(aq) \rightarrow I_2(aq) + 2H_2O(l)$

Reaction B: $I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

Reaction B is much faster than reaction A, so the iodine, I_2, formed in reaction A immediately reacts with thiosulfate ions, $S_2O_3^{2-}$, in reaction B, before it can react with starch to form the familiar blue-black, starch-iodine complex.

In one experiment the reaction mixture contained:

$5.0 \pm 0.1\ cm^3$ of $2.00\ mol\,dm^{-3}$ hydrogen peroxide (H_2O_2)

$5.0 \pm 0.1\ cm^3$ of 1% aqueous starch

$20.0 \pm 0.1\ cm^3$ of $1.00\ mol\,dm^{-3}$ sulfuric acid (H_2SO_4)

$20.0 \pm 0.1\ cm^3$ of $0.0100\ mol\,dm^{-3}$ sodium thiosulfate $(Na_2S_2O_3)$

$50.0 \pm 0.1\ cm^3$ of water with 0.0200 ± 0.0001 g of potassium iodide (KI) dissolved in it.

After 45 seconds this mixture suddenly changed from colourless to blue-black.

a. Calculate the amount, in mol, of KI in the reaction mixture. [1]

b. Calculate the amount, in mol, of H_2O_2 in the reaction mixture. [1]

c. The concentration of iodide ions, I^-, is assumed to be constant. Outline why this is a valid assumption. [1]

d. For this mixture the concentration of hydrogen peroxide, H_2O_2, can also be assumed to be constant. Explain why this is a valid assumption. [2]

e. Explain why the solution suddenly changes colour. [2]

f. Apart from the precision uncertainties given, state **one** source of error that could affect this investigation and identify whether this is a random error or a systematic error. [2]

g. Calculate the total uncertainty, in $\mathrm{cm^3}$, of the volume of the reaction mixture. [1]

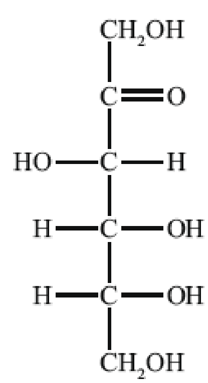
h. The colour change occurs when $1.00 \times 10^{-4}\ \mathrm{mol}$ of iodine has been formed. Use the total volume of the solution and the time taken, to calculate the rate of the reaction, including appropriate units. [4]

i. In a second experiment, the concentration of the hydrogen peroxide was decreased to $1.00\ \mathrm{mol\,dm^{-3}}$ while all other concentrations and volumes remained unchanged. The colour change now occurred after 100 seconds. Explain why the reaction in this experiment is slower than in the original experiment. [2]

j. In a third experiment, 0.100 g of a black powder was also added while all other concentrations and volumes remained unchanged. The time taken for the solution to change colour was now 20 seconds. Outline why you think the colour change occurred more rapidly and how you could confirm your hypothesis. [2]

k. Explain why increasing the temperature also decreases the time required for the colour to change. [2]

The open-chain structure of D-fructose is shown below.



a. State the names of **two** functional groups in D-fructose. [1]

b. Deduce the empirical formula of D-fructose. [1]

c. Calculate the percentage composition by mass of D-fructose. [2]

d. State a balanced equation for the complete combustion of D-fructose. [2]

A student added 7.40×10^{-2} g of magnesium ribbon to $15.0\ cm^3$ of $2.00\ mol\ dm^{-3}$ hydrochloric acid. The hydrogen gas produced was collected using a gas syringe at 20.0 °C and 1.01×10^5 Pa.

Calculate the theoretical yield of hydrogen gas:

a. State the equation for the reaction between magnesium and hydrochloric acid. [1]

b. Determine the limiting reactant. [3]

c. (i) in mol. [3]

(ii) in cm^3, under the stated conditions of temperature and pressure.

d. The actual volume of hydrogen measured was lower than the calculated theoretical volume. [2]

Suggest **two** reasons why the volume of hydrogen gas obtained was less.

Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate and silicon dioxide have been used in one design of airbag.

[Source: www.hilalairbag.net]

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.

Using the simulation programme, the students entered the following data into the computer.

Temperature (T) / °C	Mass of NaN_3(s) (m) / kg	Pressure (p) / atm
25.00	0.0650	1.08

The chemistry of the airbag was found to involve three reactions. The first reaction involves the decomposition of sodium azide to form sodium and nitrogen. In the second reaction, potassium nitrate reacts with sodium.

$$2KNO_3(s) + 10Na(s) \rightarrow K_2O(s) + 5Na_2O(s) + N_2(g)$$

An airbag inflates very quickly.

a. Sodium azide involves ionic bonding, and metallic bonding is present in sodium. Describe ionic and metallic bonding. [2]

b.i. State the number of significant figures for the temperature, mass and pressure data. [1]

T:

m:

p:

b.ii. Calculate the amount, in mol, of sodium azide present. [1]

b.iii. Determine the volume of nitrogen gas, in $\mathrm{dm^3}$, produced under these conditions based on this reaction. [4]

c.i. Suggest why it is necessary for sodium to be removed by this reaction. [1]

c.ii. The metal oxides from the second reaction then react with silicon dioxide to form a silicate in the third reaction. [2]

$$\mathrm{K_2O(s) + Na_2O(s) + SiO_2(s) \rightarrow Na_2K_2SiO_4(s)}$$

Draw the structure of silicon dioxide and state the type of bonding present.

Structure:

Bonding:

d.i. It takes just 0.0400 seconds to produce nitrogen gas in the simulation. Calculate the average rate of formation of nitrogen in (b) (iii) and state its units. [1]

d.ii. The students also discovered that a small increase in temperature (*e.g.* 10 °C) causes a large increase (*e.g.* doubling) in the rate of this reaction. State **one** reason for this. [1]

The percentage by mass of calcium carbonate in eggshell was determined by adding excess hydrochloric acid to ensure that all the calcium carbonate had reacted. The excess acid left was then titrated with aqueous sodium hydroxide.

(a) A student added $27.20\ \mathrm{cm^3}$ of $0.200\ \mathrm{mol\,dm^{-3}}$ HCl to 0.188 g of eggshell. Calculate the amount, in mol, of HCl added.

(b) The excess acid requires $23.80\ \mathrm{cm^3}$ of $0.100\ \mathrm{mol\,dm^{-3}}$ NaOH for neutralization. Calculate the amount, in mol, of acid that is in excess.

(c) Determine the amount, in mol, of HCl that reacted with the calcium carbonate in the eggshell.

(d) State the equation for the reaction of HCl with the calcium carbonate in the eggshell.

(e) Determine the amount, in mol, of calcium carbonate in the sample of the eggshell.

(f) Calculate the mass **and** the percentage by mass of calcium carbonate in the eggshell sample.

(g) Deduce **one** assumption made in arriving at the percentage of calcium carbonate in the eggshell sample.

Menthol is an organic compound containing carbon, hydrogen and oxygen.

a. Complete combustion of 0.1595 g of menthol produces 0.4490 g of carbon dioxide and 0.1840 g of water. Determine the empirical formula of the compound showing your working. [3]

b. 0.150 g sample of menthol, when vaporized, had a volume of 0.0337 dm^3 at 150 °C and 100.2 kPa. Calculate its molar mass showing your working. [2]

$25.0\ cm^3$ of $0.200\ mol\,dm^{-3}$ ethanoic acid were added to $30.0\ cm^3$ of a $0.150\ mol\,dm^{-3}$ sodium hydrogencarbonate solution, $NaHCO_3(aq)$.

The molar mass of a volatile organic liquid, **X**, can be determined experimentally by allowing it to vaporize completely at a controlled temperature and pressure. 0.348 g of **X** was injected into a gas syringe maintained at a temperature of 90 °C and a pressure of $1.01 \times 10^5\ Pa$. Once it had reached equilibrium, the gas volume was measured as $95.0\ cm^3$.

Bromoethane, CH_3CH_2Br, undergoes a substitution reaction to form ethanol, CH_3CH_2OH.

a. Outline how electrical conductivity can be used to distinguish between a $0.200\ mol\,dm^{-3}$ solution of ethanoic acid, CH_3COOH, and a $0.200\ mol\,dm^{-3}$ solution of hydrochloric acid, HCl. [1]

b. (i) State an equation for the reaction of ethanoic acid with a solution of sodium hydrogencarbonate. [5]

(ii) Determine which is the limiting reagent. Show your working.

(iii) Calculate the mass, in g, of carbon dioxide produced.

c. (i) Determine the amount, in mol, of **X** in the gas syringe. [4]

(ii) Calculate the molar mass of **X**.

d. (i) Identify the reagent necessary for this reaction to occur. [4]

(ii) Deduce the mechanism for the reaction using equations and curly arrows to represent the movement of electron pairs.

e.ii. Determine the enthalpy change, in kJ mol^{-1}, for this reaction, using Table 10 of the Data Booklet. [3]

f. Bromoethene, CH_2CHBr, can undergo polymerization. Draw a section of this polymer that contains six carbon atoms. [1]

A sample of magnesium contains three isotopes: magnesium-24, magnesium-25 and magnesium-26, with abundances of 77.44%, 10.00% and 12.56% respectively.

Phosphorus(V) oxide, P_4O_{10} $(M_r = 283.88)$, reacts vigorously with water $(M_r = 18.02)$, according to the equation below.

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$$

a.i. Calculate the relative atomic mass of this sample of magnesium correct to **two** decimal places. [2]

a.iii. Predict the relative atomic radii of the three magnesium isotopes, giving your reasons. [2]

b. Describe the bonding in magnesium. [2]

c. State an equation for the reaction of magnesium oxide with water. [1]

d.i. A student added 5.00 g of P_4O_{10} to 1.50 g of water. Determine the limiting reactant, showing your working. [2]

d.ii. Calculate the mass of phosphoric(V) acid, H_3PO_4, formed in the reaction. [2]

d.iii. State a balanced equation for the reaction of aqueous H_3PO_4 with excess aqueous sodium hydroxide, including state symbols. [2]

d.iv. State the formula of the conjugate base of H_3PO_4. [1]

e. (i) Deduce the Lewis structure of PH_4^+. [4]

(ii) Predict, giving a reason, the bond angle around the phosphorus atom in PH_4^+.

(iii) Predict whether or not the P–H bond is polar, giving a reason for your choice.

Ethanol is used as a component in fuel for some vehicles. One fuel mixture contains 10% by mass of ethanol in unleaded petrol (gasoline). This mixture is often referred to as Gasohol E10.

Assume that the other 90% by mass of Gasohol E10 is octane. 1.00 kg of this fuel mixture was burned.

$$\begin{array}{ll} CH_3CH_2OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l) & \Delta H^\ominus = -1367\ \text{kJ mol}^{-1} \\ C_8H_{18}(l) + 12\tfrac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l) & \Delta H^\ominus = -5470\ \text{kJ mol}^{-1} \end{array}$$

a.i. Calculate the mass, in g, of ethanol and octane in 1.00 kg of the fuel mixture. [1]

a.ii. Calculate the amount, in mol, of ethanol and octane in 1.00 kg of the fuel mixture. [1]

a.iii Calculate the total amount of energy, in kJ, released when 1.00 kg of the fuel mixture is completely burned. [3]

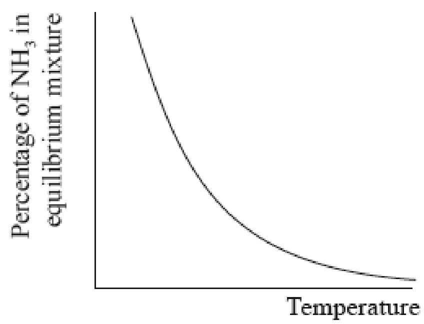
b. If the fuel blend was vaporized before combustion, predict whether the amount of energy released would be greater, less or the same. Explain your answer. [2]

The Haber process enables the large-scale production of ammonia needed to make fertilizers.

The equation for the Haber process is given below.

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

The percentage of ammonia in the equilibrium mixture varies with temperature.



Fertilizers may cause health problems for babies because nitrates can change into nitrites in water used for drinking.

A student decided to investigate the reactions of the two acids with separate samples of $0.20\ \mathrm{mol\,dm^{-3}}$ sodium hydroxide solution.

a. (i) Use the graph to deduce whether the forward reaction is exothermic or endothermic and explain your choice. [6]

(ii) State and explain the effect of increasing the pressure on the yield of ammonia.

(iii) Explain the effect of increasing the temperature on the rate of reaction.

b. (i) Define *oxidation* in terms of oxidation numbers. [2]

(ii) Deduce the oxidation states of nitrogen in the nitrate, NO_3^-, and nitrite, NO_2^-, ions.

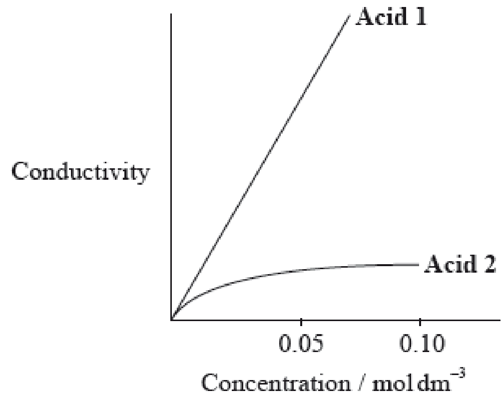
c. The nitrite ion is present in nitrous acid, HNO_2, which is a weak acid. The nitrate ion is present in nitric acid, HNO_3, which is a strong acid. Distinguish between the terms *strong* and *weak acid* and state the equations used to show the dissociation of each acid in aqueous solution. [3]

d. A small piece of magnesium ribbon is added to solutions of nitric and nitrous acid of the same concentration at the same temperature. Describe **two** observations that would allow you to distinguish between the two acids. [2]

e. (i) Calculate the volume of the sodium hydroxide solution required to react exactly with a $15.0\ \mathrm{cm^3}$ solution of $0.10\ \mathrm{mol\,dm^{-3}}$ nitric acid. [2]

(ii) The following hypothesis was suggested by the student: "Since nitrous acid is a weak acid it will react with a smaller volume of the $0.20\ \mathrm{mol\,dm^{-3}}$ sodium hydroxide solution." Comment on whether or not this is a valid hypothesis.

f. The graph below shows how the conductivity of the two acids changes with concentration. [2]



Identify **Acid 1** and explain your choice.

g. Nitric acid reacts with silver in a redox reaction. [3]

$$\_\_ Ag(s) + \_\_ NO_3^-(aq) + \_\_\_ \rightarrow \_\_\_ Ag^+(aq) + \_\_ NO(g) + \_\_\_$$

Using oxidation numbers, deduce the complete balanced equation for the reaction showing all the reactants and products.

The data below is from an experiment used to determine the percentage of iron present in a sample of iron ore. This sample was dissolved in acid and all of the iron was converted to Fe^{2+}. The resulting solution was titrated with a standard solution of potassium manganate(VII), $KMnO_4$. This procedure was carried out three times. In acidic solution, MnO_4^- reacts with Fe^{2+} ions to form Mn^{2+} and Fe^{3+} and the end point is indicated by a slight pink colour.

Titre	**1**	**2**	**3**
Initial burette reading / cm^3	1.00	23.60	10.00
Final burette reading / cm^3	24.60	46.10	32.50

Mass of iron ore / g	3.682×10^{-1}
Concentration of $KMnO_4$ solution / mol dm^{-3}	2.152×10^{-2}

a. Deduce the balanced redox equation for this reaction in **acidic** solution. [2]

b. Identify the reducing agent in the reaction. [1]

c. Calculate the amount, in moles, of MnO_4^- used in the titration. [2]

d. Calculate the amount, in moles, of Fe present in the 3.682×10^{-1} g sample of iron ore. [2]

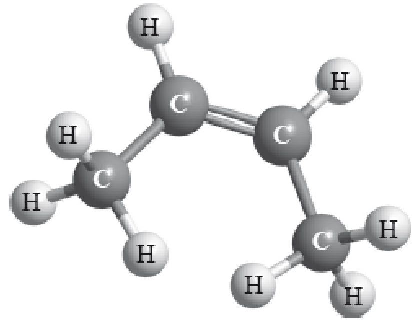
e. Determine the percentage by mass of Fe present in the 3.682×10^{-1} g sample of iron ore. [2]

Alkenes, alcohols and esters are three families of organic compounds with many commercial uses.

Esters are often used in perfumes. Analysis of a compound containing the ester functional group only, gives a percentage composition by mass of C: 62.0% and H: 10.4%.

a.ii. State the meaning of the term *structural isomers*. [1]

a.iii. **X** is an isomer of C_4H_8 and has the structural formula shown below. [3]



Apply IUPAC rules to name this isomer. Deduce the structural formulas of **two** other isomers of C_4H_8.

a.iv. State the balanced chemical equation for the reaction of **X** with HBr to form **Y**. [1]

a.v. **Y** reacts with aqueous sodium hydroxide, NaOH(aq), to form an alcohol, **Z**. Identify whether **Z** is a primary, secondary or tertiary alcohol. [1]

a.vi. Explain **one** suitable mechanism for the reaction in (v) using curly arrows to represent the movement of electron pairs. [4]

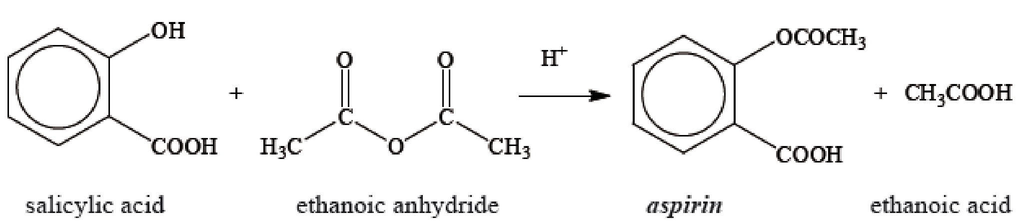
a.vii. Deduce the structural formula of the organic product formed when **Z** is oxidized by heating under reflux with acidified potassium dichromate(VI) **and** state the name of the functional group of this organic product. [2]

b.i. Draw the ester functional group. [1]

b.ii. Determine the empirical formula of the ester, showing your working. [4]

b.iii. The molar mass of the ester is $116.18\ \mathrm{g\,mol^{-1}}$. Determine its molecular formula. [1]

Aspirin, one of the most widely used drugs in the world, can be prepared according to the equation given below.



A student reacted some salicylic acid with excess ethanoic anhydride. Impure solid aspirin was obtained by filtering the reaction mixture. Pure aspirin was obtained by recrystallization. The following table shows the data recorded by the student.

Mass of salicylic acid used	3.15 ± 0.02 g
Mass of pure aspirin obtained	2.50 ± 0.02 g

a. State the names of the **three** organic functional groups in aspirin. [3]

b.i. Determine the amount, in mol, of salicylic acid, $C_6H_4(OH)COOH$, used. [2]

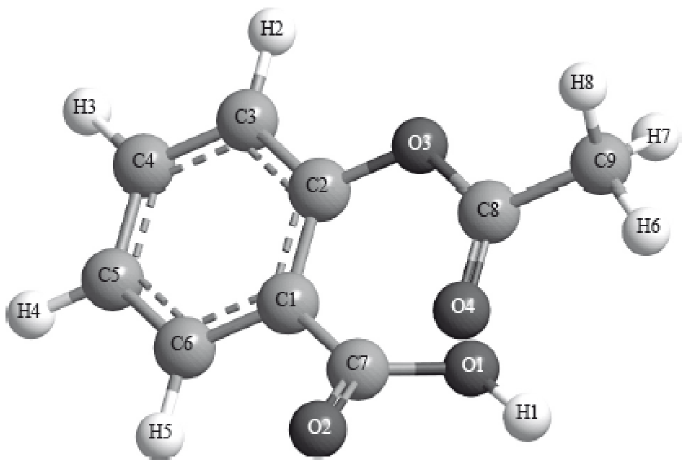
b.ii. Calculate the theoretical yield, in g, of aspirin, $C_6H_4(OCOCH_3)COOH$. [2]

b.iii. Determine the percentage yield of pure aspirin. [1]

b.iv. State the number of significant figures associated with the mass of pure aspirin obtained, and calculate the percentage uncertainty associated with this mass. [2]

b.v. Another student repeated the experiment and obtained an experimental yield of 150%. The teacher checked the calculations and found no errors. Comment on the result. [1]

b.vi. The following is a three-dimensional computer-generated representation of aspirin. [2]



A third student measured selected bond lengths in aspirin, using this computer program and reported the following data.

Bond	Bond length / $\times 10^{-10}$ m
C1–C2	1.4
C2–C3	1.4
C3–C4	1.4
C4–C5	1.4
C5–C6	1.4
C6–C1	1.4
C2–O3	1.4

The following hypothesis was suggested by the student: "*Since all the measured carbon-carbon bond lengths are equal, all the carbon-oxygen bond lengths must also be equal in aspirin. Therefore, the C8–O4 bond length must be 1.4 $\times$ 10^{-10} m*". Comment on whether or not this is a valid hypothesis.

b.vii. The other product of the reaction is ethanoic acid, CH_3COOH. Define an acid according to the Brønsted-Lowry theory and state the conjugate base of CH_3COOH. [2]

Brønsted-Lowry definition of an acid:

Conjugate base of CH_3COOH:

Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

a. State the nuclear symbol notation, ${}^{A}_{Z}X$, for magnesium-26. [1]

b. Mass spectroscopic analysis of a sample of magnesium gave the following results: [2]

	% abundance
Mg-24	78.60
Mg-25	10.11
Mg-26	11.29

Calculate the relative atomic mass, A_r, of this sample of magnesium to two decimal places.

c. Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water. [1]

d. Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine. [2]

e. In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound [1]

f. Describe the structure and bonding in solid magnesium oxide. [2]

g. Magnesium chloride can be electrolysed. [2]

Deduce the half-equations for the reactions at each electrode when **molten** magnesium chloride is electrolysed, showing the state symbols of the products. The melting points of magnesium and magnesium chloride are 922 K and 987 K respectively.

Anode (positive electrode):

Cathode (negative electrode):

Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH_3.

a. (i) Draw a Lewis (electron dot) structure of phosphine. [6]

(ii) Outline whether you expect the bonds in phosphine to be polar or non-polar, giving a brief reason.

(iii) Explain why the phosphine molecule is not planar.

(iv) Phosphine has a much greater molar mass than ammonia. Explain why phosphine has a significantly lower boiling point than ammonia.

b. Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium [10]

hydroxide. The equation for the reaction is:

$$P4\ (s) + 3OH^-\ (aq) + 3H_2O\ (l) \rightarrow PH_3\ (g) + 3H_2PO_2^-\ (aq)$$

(i) Identify one other element that has allotropes and list **two** of its allotropes.

Element:

Allotrope 1:

Allotrope 2:

(ii) The first reagent is written as P_4, not 4P. Describe the difference between P_4 and 4P.

(iii) The ion $H_2PO_2^-$ is amphiprotic. Outline what is meant by amphiprotic, giving the formulas of both species it is converted to when it behaves in this manner.

(iv) State the oxidation state of phosphorus in P_4 and $H_2PO_2^-$.

P_4:

$H_2PO_2^-$:

(v) Oxidation is now defined in terms of change of oxidation number. Explore how earlier definitions of oxidation and reduction may have led to conflicting answers for the conversion of P_4 to $H_2PO_2^-$ and the way in which the use of oxidation numbers has resolved this.

c. 2.478 g of white phosphorus was used to make phosphine according to the equation: [4]

$$P_4(s) + 3OH^-(aq) + 3H_2O(l) \rightarrow PH_3(g) + 3H_2PO_2^-(aq)$$

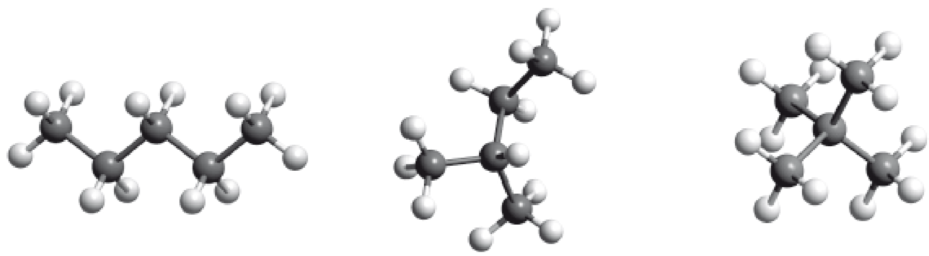
(i) Calculate the amount, in mol, of white phosphorus used.

(ii) This phosphorus was reacted with 100.0 cm^3 of 5.00 mol dm^{-3} aqueous sodium hydroxide. Deduce, showing your working, which was the limiting reagent.

(iii) Determine the excess amount, in mol, of the other reagent.

(iv) Determine the volume of phosphine, measured in cm^3 at standard temperature and pressure, that was produced.

The boiling points of the isomers of pentane, C_5H_{12}, shown are 10, 28 and 36 °C, but not necessarily in that order.



A B C

a.i. Identify the boiling points for each of the isomers **A**, **B** and **C** and state a reason for your answer. [3]

Isomer	A	B	C
Boiling point			

a.ii. State the IUPAC names of isomers **B** and **C**. [[N/A

B:

C:

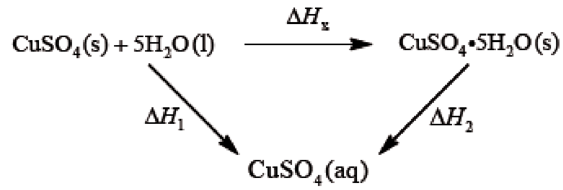
b. Both C_5H_{12} and $C_5H_{11}OH$ can be used as fuels. Predict which compound would release a greater amount of heat per gram when it undergoes complete combustion. Suggest **two** reasons to support your prediction. [3]

c. In many cities around the world, public transport vehicles use diesel, a liquid hydrocarbon fuel, which often contains sulfur impurities and undergoes incomplete combustion. All public transport vehicles in New Delhi, India, have been converted to use compressed natural gas (CNG) as fuel. Suggest **two** ways in which this improves air quality, giving a reason for your answer. [3]

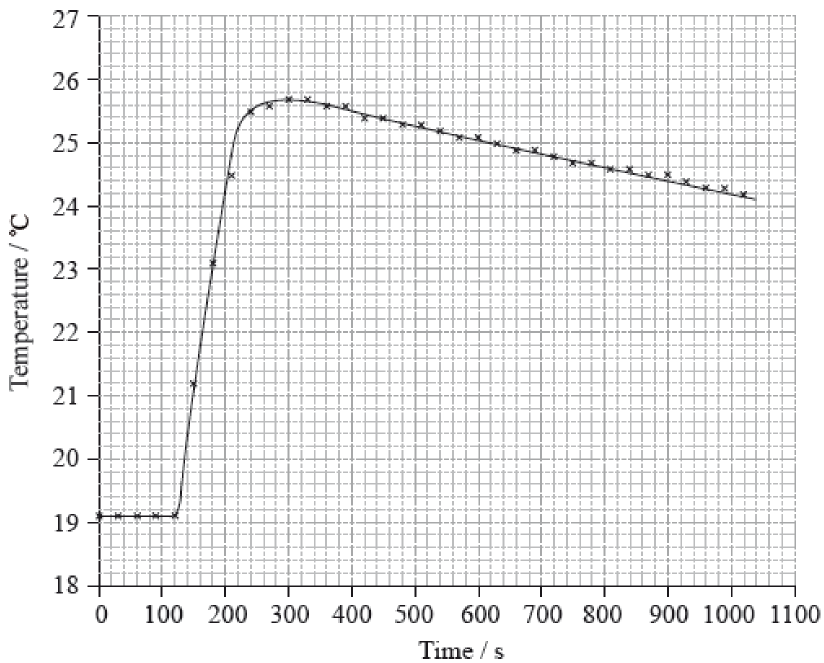
If white anhydrous copper(II) sulfate powder is left in the atmosphere it slowly absorbs water vapour giving the blue pentahydrated solid.

$$\underset{\text{(anhydrous)}}{CuSO_4(s)} + 5H_2O(l) \rightarrow \underset{\text{(pentahydrated)}}{CuSO_4{\bullet}5H_2O(s)}$$

It is difficult to measure the enthalpy change for this reaction directly. However, it is possible to measure the heat changes directly when both anhydrous and pentahydrated copper(II) sulfate are separately dissolved in water, and then use an energy cycle to determine the required enthalpy change value, ΔH_x, indirectly.



To determine ΔH_1 a student placed 50.0 g of water in a cup made of expanded polystyrene and used a data logger to measure the temperature. After two minutes she dissolved 3.99 g of anhydrous copper(II) sulfate in the water and continued to record the temperature while continuously stirring. She obtained the following results.



To determine ΔH_2, 6.24 g of pentahydrated copper(II) sulfate was dissolved in 47.75 g of water. It was observed that the temperature of the solution decreased by 1.10 °C.

The magnitude (the value without the $+$ or $-$ sign) found in a data book for ΔH_x is 78.0 kJ mol^{-1}.

a.i. Calculate the amount, in mol, of anhydrous copper(II) sulfate dissolved in the 50.0 g of water. [1]

a.ii. Determine what the temperature rise would have been, in °C, if no heat had been lost to the surroundings. [2]

a.iii. Calculate the heat change, in kJ, when 3.99 g of anhydrous copper(II) sulfate is dissolved in the water. [2]

a.iv. Determine the value of ΔH_1 in kJ mol^{-1}. [1]

b.i. Calculate the amount, in mol, of water in 6.24 g of pentahydrated copper(II) sulfate. [2]

b.ii. Determine the value of ΔH_2 in kJ mol^{-1}. [2]

b.iii. Using the values obtained for ΔH_1 in (a) (iv) and ΔH_2 in (b) (ii), determine the value for ΔH_x in kJ mol^{-1}. [1]

c.i. Calculate the percentage error obtained in this experiment. (If you did not obtain an answer for the experimental value of ΔH_x then use the value $70.0\ \mathrm{kJ\,mol^{-1}}$, but this is **not** the true value.) [1]

c.ii. The student recorded in her qualitative data that the anhydrous copper(II) sulfate she used was pale blue rather than completely white. Suggest a reason why it might have had this pale blue colour and deduce how this would have affected the value she obtained for ΔH_x. [2]

Two groups of students (Group A and Group B) carried out a project* on the chemistry of some group 7 elements (the halogens) and their compounds.

** Adapted from J Derek Woollins, (2009), Inorganic Experiments and Open University, (2008), Exploring the Molecular World.*

In the first part of the project, the two groups had a sample of iodine monochloride (a corrosive brown liquid) prepared for them by their teacher using the following reaction.

$$I_2(s) + Cl_2(g) \rightarrow 2ICl(l)$$

The following data were recorded.

Mass of $I_2(s)$	10.00 g
Mass of $Cl_2(g)$	2.24 g
Mass of $ICl(l)$ obtained	8.60 g

The students reacted ICl(l) with CsBr(s) to form a yellow solid, $CsICl_2(s)$, as one of the products. $CsICl_2(s)$ has been found to produce very pure CsCl(s) which is used in cancer treatment.

To confirm the composition of the yellow solid, Group A determined the amount of iodine in 0.2015 g of $CsICl_2(s)$ by titrating it with $0.0500\ \mathrm{mol\,dm^{-3}}\ Na_2S_2O_3(aq)$. The following data were recorded for the titration.

Mass of $CsICl_2(s)$ taken (in g $\pm$ 0.0001)	0.2015
Initial burette reading of $0.0500\ \mathrm{mol\,dm^{-3}}\ Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	1.05
Final burette reading of $0.0500\ \mathrm{mol\,dm^{-3}}\ Na_2S_2O_3(aq)$ (in $cm^3 \pm 0.05$)	25.25

a. (i) State the number of significant figures for the masses of $I_2(s)$ and ICl(l). [6]

$I_2(s)$:

ICl (l):

(ii) The iodine used in the reaction was in excess. Determine the theoretical yield, in g, of ICl(l).

(iii) Calculate the percentage yield of ICl(l).

(iv) Using a digital thermometer, the students discovered that the reaction was exothermic. State the sign of the enthalpy change of the reaction, ΔH.

b. Although the molar masses of ICl and Br_2 are very similar, the boiling point of ICl is 97.4 °C and that of Br_2 is 58.8 °C. Explain the difference in these boiling points in terms of the intermolecular forces present in each liquid. [2]

c. (i) Calculate the percentage of iodine by mass in $CsICl_2(s)$, correct to **three** significant figures. [6]

(ii) State the volume, in cm^3, of $0.0500\ mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ used in the titration.

(iii) Determine the amount, in mol, of $0.0500\ mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ added in the titration.

(iv) The overall reaction taking place during the titration is:

$$CsICl(s) + 2Na_2S_2O_3(aq) \rightarrow NaCl(aq) + Na_2S_4O_6(aq) + CsCl(aq) + NaI(aq)$$

Calculate the amount, in mol, of iodine atoms, I, present in the sample of $CsICl_2(s)$.

(v) Calculate the mass of iodine, in g, present in the sample of $CsICl_2$

(vi) Determine the percentage by mass of iodine in the sample of $CsICl_2(s)$, correct to **three** significant figures, using your answer from (v).

Ethene belongs to the homologous series of the alkenes.

A bromoalkane, C_4H_9Br, reacts with a warm, aqueous sodium hydroxide solution, NaOH.

The time taken to produce a certain amount of product using different initial concentrations of C_4H_9Br and NaOH is measured. The results are shown in the following table.

Reaction	$[C_4H_9Br]$ / 10^{-2} $mol\,dm^{-3}$	[NaOH] / 10^{-3} $mol\,dm^{-3}$	t / s
A	1.0	2.0	46
B	2.0	2.0	23
C	2.0	4.0	23

a.i. Outline **three** features of a homologous series. [3]

a.ii. Describe a test to distinguish ethene from ethane, including what is observed in **each** case. [2]

a.iii. Bromoethane can be produced either from ethene or from ethane. State an equation for **each** reaction. [2]

b.i. State the equation for the reaction of C_4H_9Br with NaOH. [1]

b.ii. Suggest what would happen to the pH of the solution as the reaction proceeds. [1]

c.i. Deduce the effect of the concentration of C_4H_9Br and NaOH on the rate of reaction. [2]

C_4H_9Br:

NaOH:

c.ii. Suggest why **warm** sodium hydroxide solution is used. [1]

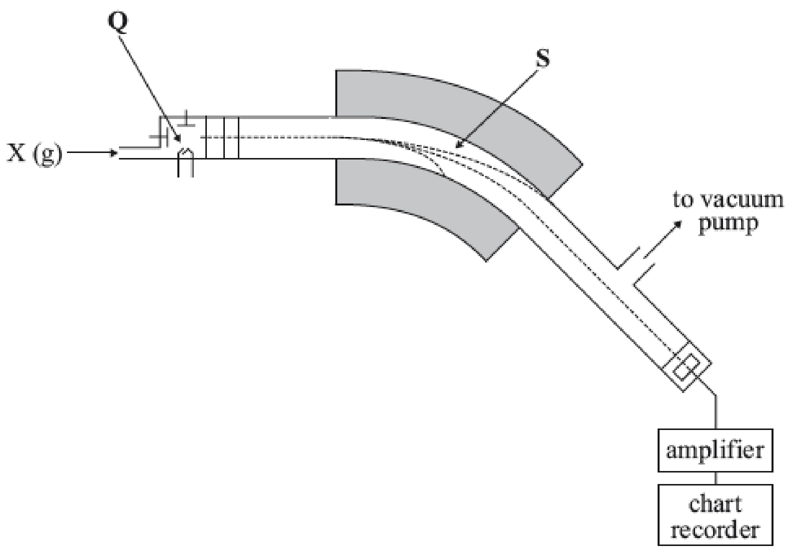
c.iii. Deduce whether C_4H_9Br is a primary or tertiary halogenoalkane. [2]

c.iv. Determine the structural formula of C_4H_9Br. [1]

c.v. Describe, using an equation, how C_4H_9Br can be converted into $C_4H_8Br_2$. [1]

d. Explain the mechanism for the reaction in (c) of C_4H_9Br with NaOH, using curly arrows to represent the movement of electron pairs. [4]

Magnesium has three stable isotopes, ^{24}Mg, ^{25}Mg and ^{26}Mg. The relative abundance of each isotope is 78.99%, 10.00% and 11.01% respectively, and can be determined using a mass spectrometer.



(i) Define the term *relative atomic mass*.

(ii) Calculate, showing your working, the relative atomic mass, A_r, of magnesium, giving your answer to **two** decimal places.

Both sodium and sodium chloride can conduct electricity.

a. Compare how electric current passes through sodium and sodium chloride by completing the table below. [3]

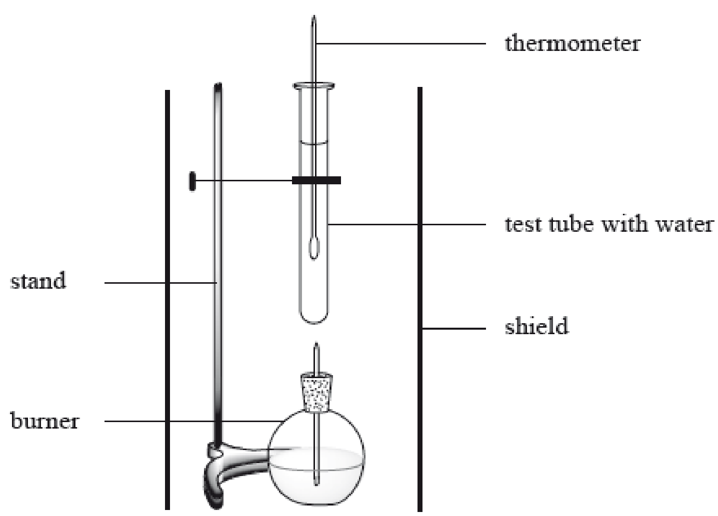
	Sodium	Sodium chloride
State of matter	. . . .	. . . .
Particles that conduct the current	. . . .	. . . .
Reaction occurring	. . . .	. . . .

b. Sodium can be obtained by electrolysis from molten sodium chloride. Describe, using a diagram, the essential components of this electrolytic cell. [3]

Methanol is made in large quantities as it is used in the production of polymers and in fuels. The enthalpy of combustion of methanol can be determined theoretically or experimentally.

$$CH_3OH(l) + 1\frac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

The enthalpy of combustion of methanol can also be determined experimentally in a school laboratory. A burner containing methanol was weighed and used to heat water in a test tube as illustrated below.



The following data were collected.

Initial mass of burner and methanol / g	80.557
Final mass of burner and methanol / g	80.034
Mass of water in test tube / g	20.000
Initial temperature of water / °C	21.5
Final temperature of water / °C	26.4

The Data Booklet value for the enthalpy of combustion of methanol is $-726\ \mathrm{kJ\ mol^{-1}}$. Suggest why this value differs from the values calculated in parts (a) and (b).

a. Using the information from Table 10 of the Data Booklet, determine the theoretical enthalpy of combustion of methanol. [3]

b.i. Calculate the amount, in mol, of methanol burned. [2]

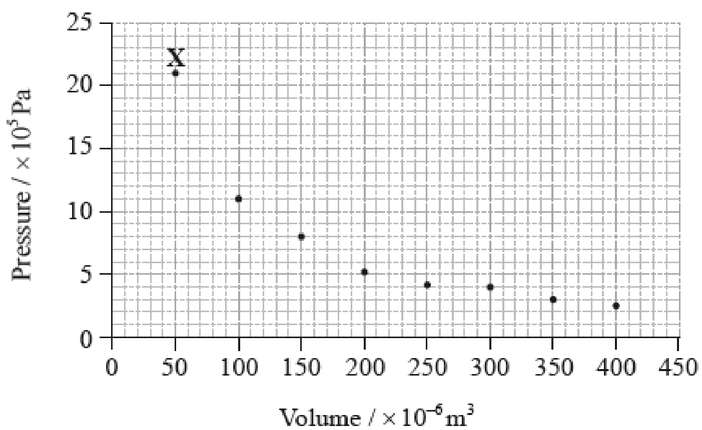
b.ii. Calculate the heat absorbed, in kJ, by the water. [3]

b.iii. Determine the enthalpy change, in $\mathrm{kJ\ mol^{-1}}$, for the combustion of 1 mole of methanol. [2]

c.i. Part (a) [1]

c.ii. Part (b) [1]

The graph below shows pressure and volume data collected for a sample of carbon dioxide gas at 330 K.



a. Draw a best-fit curve for the data on the graph. [1]

b. Deduce the relationship between the pressure and volume of the sample of carbon dioxide gas. [1]

c. Use the data point labelled **X** to determine the amount, in mol, of carbon dioxide gas in the sample. [3]

The element antimony, Sb, is usually found in nature as its sulfide ore, stibnite, Sb_2S_3. This ore was used two thousand years ago by ancient Egyptian women as a cosmetic to darken their eyes and eyelashes.

One method of extracting antimony from its sulfide ore is to roast the stibnite in air. This forms antimony oxide and sulfur dioxide. The antimony oxide is then reduced by carbon to form the free element.

a.i. Deduce the oxidation number of antimony in stibnite. [1]

a.ii. Deduce **one** other common oxidation number exhibited by antimony in some of its compounds. [1]

b.i. Deduce the chemical equations for these **two** reactions. [2]

Ethanol has many industrial uses.

a. (i) State an equation for the formation of ethanol from ethene and the necessary reaction conditions. [4]

Equation:

Conditions:

(ii) Deduce the volume of ethanol, in dm^3, produced from $1.5\ dm^3$ of ethene, assuming both are gaseous and at the same temperature and pressure.

b.i. Define the term *average bond enthalpy*. [2]

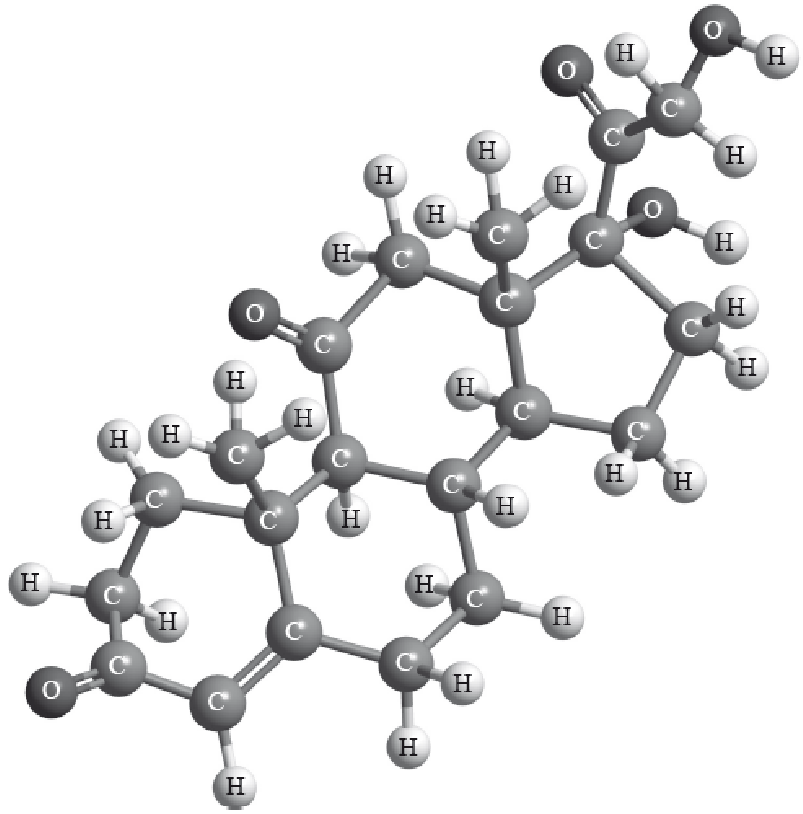
b.ii. Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in $kJ\ mol^{-1}$, using the values in table 10 of the data booklet, assuming all reactants and products are gaseous. [4]

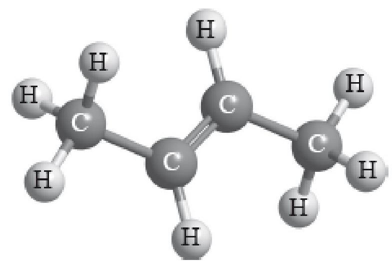
b.iii. Suggest why the value of the enthalpy of combustion of ethanol quoted in table 12 of the data booklet is different to that calculated using bond enthalpies. [1]

b.iv. Explain why the reaction is exothermic in terms of the bonds involved. [1]

c. Identify the homologous series to which ethanol belongs and state **two** features of a homologous series. [3]

Cortisone is a therapeutic drug whose three-dimensional structure is represented below.





P

Menthol can be used in cough medicines. The compound contains 76.84% C, 12.92% H and 10.24% O by mass.

a.i. Identify the names of **two** functional groups present in cortisone. [2]

1.

2.

a.ii. Draw a circle around each of these **two** functional groups in the structure above and label them 1 and 2 as identified in (a) (i). [1]

b. Describe what is meant by the term *structural isomers*. [1]

c.i. Apply IUPAC rules to state the name of **P**. [1]

c.ii. **X** is a straight-chain structural isomer of **P**. Draw the structure of **X**. [1]

c.iii. $CH_3CH{=}CHCH_3 \xrightarrow[\text{(2) } H_2O(l)]{\text{(1) concentrated } H_2SO_4(aq)}$ **Q** [2]

Q:

$CH_3CH{=}CHCH_3 + H_2(g) \xrightarrow{\text{catalyst}}$ **R**

R:

c.iv. Identify a suitable catalyst used in the reaction to form **R**. [1]

c.v. **P**, $CH_3CH{=}CHCH_3$, reacts with HBr to form $CH_3CHBrCH_2CH_3$. Suggest **one** suitable mechanism for the reaction of $CH_3CHBrCH_2CH_3$ with aqueous sodium hydroxide, using curly arrows to represent the movement of electron pairs. [4]

c.vi. State the structural formula of the organic product formed, **S**, when **Q** is heated under reflux with acidified potassium dichromate(VI). [1]

c.vii. Apply IUPAC rules to state the name of this product, **S**. [1]

c.viii. **P** can undergo a polymerization reaction. Draw **two** repeating units of the resulting polymer. [1]

d.i. Determine its empirical formula. [3]

d.ii. Determine its molecular formula given that its molar mass is $M = 156.30 \text{ g mol}^{-1}$. [1]

0.100 g of magnesium ribbon is added to 50.0 cm^3 of 1.00 mol dm^{-3} sulfuric acid to produce hydrogen gas and magnesium sulfate.

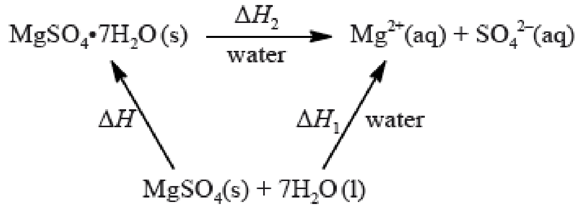
$$Mg(s) + H_2SO_4(aq) \rightarrow H_2(g) + MgSO_4(aq)$$

Magnesium sulfate can exist in either the hydrated form or in the anhydrous form. Two students wished to determine the enthalpy of hydration of anhydrous magnesium sulfate. They measured the initial and the highest temperature reached when anhydrous magnesium sulfate, $MgSO_4(s)$, was dissolved in water. They presented their results in the following table.

mass of anhydrous magnesium sulfate / g	3.01
volume of water / cm^3	50.0
initial temperature / °C	17.0
highest temperature / °C	26.7

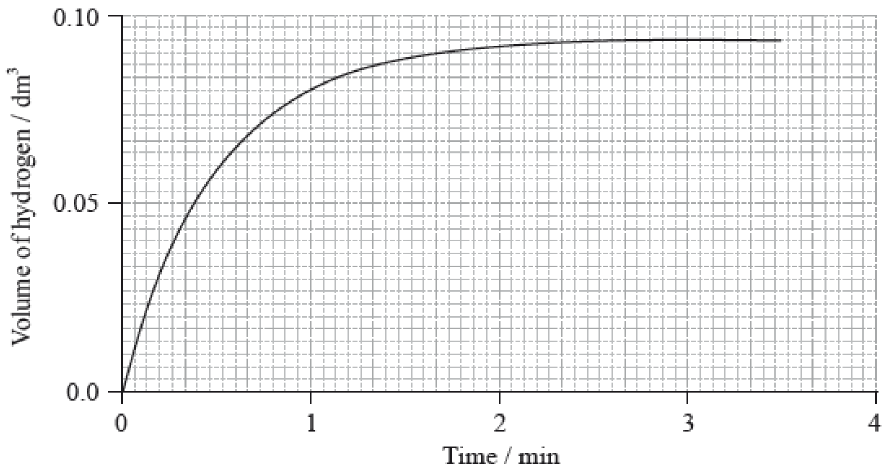
The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, $MgSO_4 \bullet 7H_2O(s)$, and 50.0 cm^3 of water. They found the enthalpy change, ΔH_2, to be $+18 \text{ kJ mol}^{-1}$.

The enthalpy of hydration of solid anhydrous magnesium sulfate is difficult to determine experimentally, but can be determined using the diagram below.



Magnesium sulfate is one of the products formed when acid rain reacts with dolomitic limestone. This limestone is a mixture of magnesium carbonate and calcium carbonate.

a. (i) The graph shows the volume of hydrogen produced against time under these experimental conditions. [3]



Sketch two curves, labelled **I** and **II**, to show how the volume of hydrogen produced (under the same temperature and pressure) changes with time when:

I. using the same mass of magnesium powder instead of a piece of magnesium ribbon;

II. 0.100 g of magnesium ribbon is added to $50\ \mathrm{cm}^3$ of $0.500\ \mathrm{mol\,dm}^{-3}$ sulfuric acid.

(ii) Outline why it is better to measure the volume of hydrogen produced against time rather than the loss of mass of reactants against time.

b. (i) Calculate the amount, in mol, of anhydrous magnesium sulfate. [3]

(ii) Calculate the enthalpy change, ΔH_1, for anhydrous magnesium sulfate dissolving in water, in $\mathrm{kJ\,mol}^{-1}$. State your answer to the correct number of significant figures.

c. (i) Determine the enthalpy change, ΔH, in $\mathrm{kJ\,mol}^{-1}$, for the hydration of solid anhydrous magnesium sulfate, $\mathrm{MgSO_4}$. [2]

(ii) The literature value for the enthalpy of hydration of anhydrous magnesium sulfate is $-103\ \mathrm{kJ\,mol}^{-1}$. Calculate the percentage difference between the literature value and the value determined from experimental results, giving your answer to **one** decimal place. (If you did not obtain an answer for the experimental value in (c)(i) then use the value of $-100\ \mathrm{kJ\,mol}^{-1}$, but this is **not** the correct value.)

d. Another group of students experimentally determined an enthalpy of hydration of $-95\ \mathrm{kJ\,mol}^{-1}$. Outline two reasons which may explain the variation between the experimental and literature values. [2]

e. (i) State the equation for the reaction of sulfuric acid with magnesium carbonate. [[N/A

(ii) Deduce the Lewis (electron dot) structure of the carbonate ion, giving the shape and the oxygen-carbon-oxygen bond angle.

Lewis (electron dot) structure:

Shape:

Bond angle:

Smog is common in cities throughout the world. One component of smog is PAN (peroxyacylnitrate) which consists of 20.2% C, 11.4% N, 65.9% O and 2.50% H by mass. Determine the empirical formula of PAN, showing your working.

Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

a. (i) 200.0 g of air was heated by the energy from the complete combustion of 1.00 mol phosphine. Calculate the temperature rise using section 1 of the data booklet and the data below. [5]

Standard enthalpy of combustion of phosphine, $\Delta H_c^{\ominus} = -750\,\text{kJ}\,\text{mol}^{-1}$

Specific heat capacity of air = $1.00\,\text{J}\,\text{g}^{-1}\text{K}^{-1} = 1.00\,\text{kJ}\,\text{kg}^{-1}\text{K}^{-1}$

(ii) The oxide formed in the reaction with air contains 43.6 % phosphorus by mass. Determine the empirical formula of the oxide, showing your method.

(iii) The molar mass of the oxide is approximately $285\,\text{g}\,\text{mol}^{-1}$. Determine the molecular formula of the oxide.

b. (i) State the equation for the reaction of this oxide of phosphorus with water. [5]

(ii) Predict how dissolving an oxide of phosphorus would affect the pH and electrical conductivity of water.

pH:

Electrical conductivity:

(iii) Suggest why oxides of phosphorus are not major contributors to acid deposition.

(iv) The levels of sulfur dioxide, a major contributor to acid deposition, can be minimized by either pre-combustion and post-combustion methods. Outline **one** technique of each method.

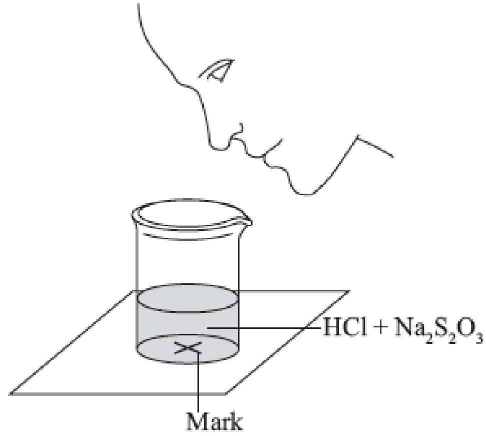
Pre-combustion:

Post-combustion:

A group of students investigated the rate of the reaction between aqueous sodium thiosulfate and hydrochloric acid according to the equation below.

$$\mathrm{Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + SO_2(g) + S(s) + H_2O(l)}$$

The two reagents were rapidly mixed together in a beaker and placed over a mark on a piece of paper. The time taken for the precipitate of sulfur to obscure the mark when viewed through the reaction mixture was recorded.



Initially they measured out $10.0\ cm^3$ of $0.500\ mol\,dm^{-3}$ hydrochloric acid and then added $40.0\ cm^3$ of $0.0200\ mol\,dm^{-3}$ aqueous sodium thiosulfate. The mark on the paper was obscured 47 seconds after the solutions were mixed.

The teacher asked the students to measure the effect of halving the concentration of sodium thiosulfate on the rate of reaction.

The teacher asked the students to devise another technique to measure the rate of this reaction.

Another group suggested collecting the sulfur dioxide and drawing a graph of the volume of gas against time.

a. The teacher made up $2.50\ dm^3$ of the sodium thiosulfate solution using sodium thiosulfate pentahydrate crystals, $Na_2S_2O_3 \bullet 5H_2O$. Calculate the required mass of these crystals. [3]

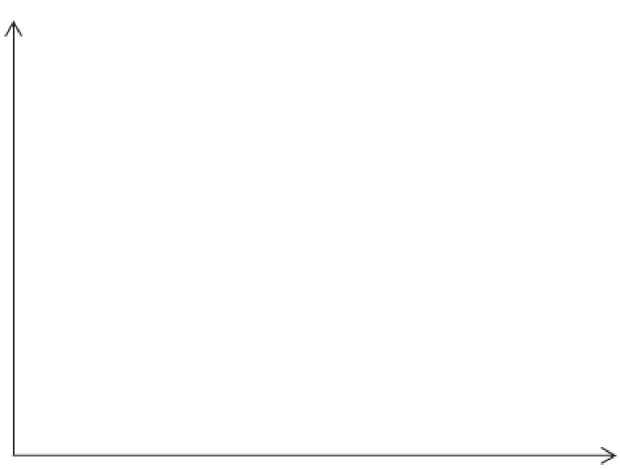
b. (i) State the volumes of the liquids that should be mixed. [4]

Liquid	$0.500\ mol\,dm^{-3}\ HCl$	$0.0200\ mol\,dm^{-3}\ Na_2S_2O_3$	Water
Volume / cm^3			

(ii) State why it is important that the students use a similar beaker for both reactions.

(iii) Explain, in terms of the collision theory, how decreasing the concentration of sodium thiosulfate would affect the time taken for the mark to be obscured.

c. (i) Sketch and label, indicating an approximate activation energy, the Maxwell–Boltzmann energy distribution curves for two temperatures, T_1 and T_2 $(T_2 > T_1)$, at which the rate of reaction would be significantly different. [6]



(ii) Explain why increasing the temperature of the reaction mixture would significantly increase the rate of the reaction.

d. (i) One group suggested recording how long it takes for the pH of the solution to change by one unit. Calculate the initial pH of the original reaction mixture. [3]

(ii) Deduce the percentage of hydrochloric acid that would have to be used up for the pH to change by one unit.

e. (i) Calculate the volume of sulfur dioxide, in cm^3, that the original reaction mixture would produce if it were collected at $1.00 \times 10^5\ \mathrm{Pa}$ and 300 K. [4]

(ii) Suggest why it is better to use a gas syringe rather than collecting the gas in a measuring cylinder over water.

---

a.i. Draw the Lewis (electron dot) structure of chloromethane. [1]

a.ii. Predict the shape of the chloromethane molecule and the H–C–H bond angle. [2]

Shape:

Bond angle:

a.iii. Explain why chloromethane is a polar molecule. [2]

a.iv. Methanol has a lower molar mass than chloromethane. Explain why the boiling point of methanol is higher than that of chloromethane. [2]

b.i. State the equation for the reaction between potassium and chlorine. [1]

b.ii. Outline the nature of the metallic bonding present in potassium. [1]

b.iii. Describe the covalent bond present in the chlorine molecule and how it is formed. [2]

b.iv. Describe the ionic bonding present in potassium chloride and how the ions are formed. [2]

b.v. Potassium also reacts with water to form hydrogen gas. Determine the volume, in cm^3, of hydrogen gas that could theoretically be produced at 273 K and $1.01 \times 10^5\ \mathrm{Pa}$ when 0.0587 g of potassium reacts with excess water. [3]

c.i. Identify the acid-base character of the oxides of each of the elements from sodium to chlorine in period 3. [2]

c.ii. State the equations for the separate reactions of sodium oxide and phosphorus(V) oxide with water. [2]

---

a. A hydrocarbon has the empirical formula C_3H_7. When 1.17 g of the compound is heated to 85 °C at a pressure of 101 kPa it occupies a volume of $400\ cm^3$. [4]

(i) Calculate the molar mass of the compound, showing your working.

(ii) Deduce the molecular formula of the compound.

b. C_5H_{12} exists as three isomers. Identify the structure of the isomer with the **lowest** boiling point and explain your choice. [2]

c.i. Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

Ethanal:

Ethanoic acid:

c.ii. Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

Ethanal:

c.iii. Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

c.iv. Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI) by combining your answer to part (c) (iii) with the following half-equation: [2]

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

d.i. Describe **two** characteristics of a reaction at equilibrium. [2]

d.ii. Describe how a catalyst increases the rate of a reaction. [2]

d.iii. State and explain the effect of a catalyst on the position of equilibrium. [2]

e. Ethanoic acid reacts with ethanol to form the ester ethyl ethanoate. [1]

$$CH_3COOH(l) + CH_3CH_2OH(l)?????CH_3COOCH_2CH_3(l) + H_2O(l)$$

The esterification reaction is exothermic. State the effect of increasing temperature on the value of the equilibrium constant (K_c) for this reaction.

Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, $HOOC–COOH \bullet xH_2O$, by titrating a known mass of the acid with a $0.100\ mol\ dm^{-3}$ solution of $NaOH(aq)$.

0.795 g of ethanedioic acid was dissolved in distilled water and made up to a total volume of $250\ cm^3$ in a volumetric flask.

$25\ cm^3$ of this ethanedioic acid solution was pipetted into a flask and titrated against aqueous sodium hydroxide using phenolphthalein as an indicator.

The titration was then repeated twice to obtain the results below.

Volume of 0.100 mol dm^{-3} NaOH / cm^3	Titration 1	Titration 2	Titration 3
Final burette reading (± 0.05)	13.00	25.70	38.20
Initial burette reading (± 0.05)	0.00	13.00	25.70
Volume added			

a. State the uncertainty of the volume of NaOH added in cm^3. [1]

b. Calculate the average volume of NaOH added, in cm^3, in titrations 2 and 3, and then calculate the amount, in mol, of NaOH added. [2]

c. (i) The equation for the reaction taking place in the titration is: [5]

$$HOOC–COOH(aq) + 2NaOH(aq) \rightarrow NaOOC–COONa(aq) + 2H_2O(l)$$

Determine the amount, in mol, of ethanedioic acid that reacts with the average volume of $NaOH(aq)$.

(ii) Determine the amount, in mol, of ethanedioic acid present in $250\ cm^3$ of the original solution.

(ii) Determine the molar mass of hydrated ethanedioic acid.

(iv) Determine the value of x in the formula $HOOC–COOH \bullet xH_2O$.

d. Identify the strongest intermolecular force in solid ethanedioic acid. [1]

e. Deduce the Lewis (electron dot) structure of ethanedioic acid, HOOC–COOH. [1]

In December 2010, researchers in Sweden announced the synthesis of N,N–dinitronitramide, $N(NO_2)_3$. They speculated that this compound, more commonly called trinitramide, may have significant potential as an environmentally friendly rocket fuel oxidant.

a. Methanol reacts with trinitramide to form nitrogen, carbon dioxide and water. Deduce the coefficients required to balance the equation for this reaction. [1]

$$\_\_ \mathrm{N(NO_2)_3(g)} + \_\_ \mathrm{CH_3OH(l)} \rightarrow \_\_ \mathrm{N_2(g)} + \_\_ \mathrm{CO_2(g)} + \_\_ \mathrm{H_2O(l)}$$

c. Calculate the enthalpy change, in $\mathrm{kJ\,mol^{-1}}$, when one mole of trinitramide decomposes to its elements, using bond enthalpy data from Table 10 of the Data Booklet. Assume that all the N–O bonds in this molecule have a bond enthalpy of $305\ \mathrm{kJ\,mol^{-1}}$. [3]

d. Outline how the length of the N–N bond in trinitramide compares with the N–N bond in nitrogen gas, $\mathrm{N_2}$. [2]

e. Deduce the N–N–N bond angle in trinitramide and explain your reasoning. [3]

f. Predict, with an explanation, the polarity of the trinitramide molecule. [2]

g.i. Methanol can also be burnt as a fuel. Describe an experiment that would allow the molar enthalpy change of combustion to be calculated from the results. [3]

g.ii. Explain how the results of this experiment could be used to calculate the molar enthalpy change of combustion of methanol. [3]

g.iii. Predict, with an explanation, how the result obtained would compare with the value in Table 12 of the Data Booklet. [2]

Chlorine occurs in Group 7, the halogens.

Two stable isotopes of chlorine are $^{35}\mathrm{Cl}$ and $^{37}\mathrm{Cl}$ with mass numbers 35 and 37 respectively.

Chlorine has an electronegativity value of 3.2 on the Pauling scale.

Chloroethene, $H_2C{=}CHCl$, the monomer used in the polymerization reaction in the manufacture of the polymer poly(chloroethene), PVC, can be synthesized in the following two-stage reaction pathway.

$$\begin{array}{ll} \text{Stage 1:} & \mathrm{C_2H_4(g) + Cl_2(g) \rightarrow ClCH_2CH_2Cl(g)} \\ \text{Stage 2:} & \mathrm{ClCH_2CH_2Cl(g) + HC{=}CHCl(g) + HCl(g)} \end{array}$$

a.i. Define the term *isotopes of an element*. [2]

a.ii. Calculate the number of protons, neutrons and electrons in the isotopes ^{35}Cl and ^{37}Cl. [2]

Isotope	Number of protons	Number of neutrons	Number of electrons
$^{35}\mathrm{Cl}$			
$^{37}\mathrm{Cl}$			

a.iii. Using the mass numbers of the two isotopes and the relative atomic mass of chlorine from Table 5 of the Data Booklet, determine the percentage abundance of each isotope. [2]

Percentage abundance ^{35}Cl:

Percentage abundance ^{37}Cl:

b.i. Define the term *electronegativity*. [1]

b.ii. Using Table 7 of the Data Booklet, explain the trends in electronegativity values of the Group 7 elements from F to I. [2]

b.iii. State the balanced chemical equation for the reaction of potassium bromide, KBr(aq), with chlorine, Cl_2(aq). [1]

b.iv. Describe the colour change likely to be observed in this reaction. [1]

c.ii. Determine the enthalpy change, ΔH, in $\mathrm{kJ\,mol^{-1}}$, for stage 1 using average bond enthalpy data from Table 10 of the Data Booklet. [3]

c.iii. State whether the reaction given in stage 1 is exothermic or endothermic. [1]

c.iv. Draw the structure of poly(chloroethene) showing **two** repeating units. [1]

c.v. Suggest why monomers are often gases or volatile liquids whereas polymers are solids. [2]

A class studied the equilibrium established when ethanoic acid and ethanol react together in the presence of a strong acid, using propanone as an inert solvent. The equation is given below.

$$\mathrm{CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O}$$

One group made the following **initial mixture**:

Liquid	Volume / cm^3
Ethanoic acid	5.00 ± 0.05
Ethanol	5.00 ± 0.05
$6.00\,\mathrm{mol\,dm^{-3}}$ aqueous hydrochloric acid	1.00 ± 0.02
Propanone	39.0 ± 0.5

After one week, a $5.00 \pm 0.05\ \mathrm{cm^3}$ sample of the final equilibrium mixture was pipetted out and titrated with $0.200\ \mathrm{mol\,dm^{-2}}$ aqueous sodium hydroxide to determine the amount of ethanoic acid remaining. The following titration results were obtained:

Titration number	1	2	3
Initial reading / cm^3 $\pm$ 0.05	1.20	0.60	14.60
Final reading / cm^3 $\pm$ 0.05	28.80	26.50	40.70
Titre / cm^3	27.60	25.90	26.10

a. The density of ethanoic acid is 1.05 g cm^{-3}. Determine the amount, in mol, of ethanoic acid present in the initial mixture. [3]

b. The hydrochloric acid does not appear in the balanced equation for the reaction. State its function. [1]

c. Identify the liquid whose volume has the greatest percentage uncertainty. [1]

d. (i) Calculate the absolute uncertainty of the titre for Titration 1 (27.60 cm^3). [4]

(ii) Suggest the average volume of alkali, required to neutralize the 5.00 cm^3 sample, that the student should use.

(iii) 23.00 cm^3 of this $0.200 \text{ mol dm}^{-3}$ aqueous sodium hydroxide reacted with the ethanoic acid in the 5.00 cm^3 sample. Determine the amount, in mol, of ethanoic acid present in the 50.0 cm^3 of final equilibrium mixture.

e. Referring back to your answer for part (a), calculate the percentage of ethanoic acid converted to ethyl ethanoate. [1]

f. Deduce the equilibrium constant expression for the reaction. [1]

g. Outline how you could establish that the system had reached equilibrium at the end of one week. [1]

h. Outline why changing the temperature has only a very small effect on the value of the equilibrium constant for this equilibrium. [1]

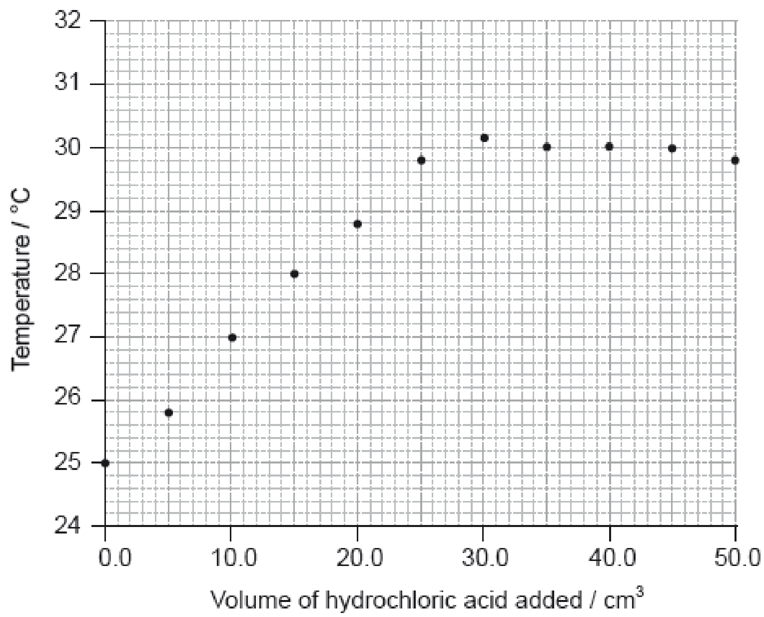
i. Outline how adding some ethyl ethanoate to the initial mixture would affect the amount of ethanoic acid converted to product. [2]

j. Propanone is used as the solvent because one compound involved in the equilibrium is insoluble in water. Identify this compound and explain why it is insoluble in water. [2]

k. Suggest **one** other reason why using water as a solvent would make the experiment less successful. [1]

A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added 5.0 cm^3 portions of hydrochloric acid to 25.0 cm^3 of 1.00 mol dm^{-3} sodium hydroxide solution in a glass beaker until the total volume of acid added was 50.0 cm^3, measuring the temperature of the mixture each time. Her results are plotted in the graph below.



The initial temperature of both solutions was the same.

a.i. By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the $25.0\ \mathrm{cm^3}$ of sodium hydroxide solution. [2]

a.ii. Determine the concentration of the hydrochloric acid, including units. [2]

b.i. Determine the change in temperature, ΔT. [1]

b.ii. Calculate the enthalpy change, in $\mathrm{kJ\ mol^{-1}}$, for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

b.iii. The accepted theoretical value from the literature of this enthalpy change is $-58\ \mathrm{kJ\ mol^{-1}}$. Calculate the percentage error correct to **two** significant figures. [1]

b.iv. Suggest the major source of error in the experimental procedure **and** an improvement that could be made to reduce it. [2]

Soluble acids and bases ionize in water.

Sodium hypochlorite ionizes in water.

$$OCl^-(aq) + H_2O(l) \rightleftharpoons OH^-(aq) + HOCl(aq)$$

A solution containing 0.510 g of an unknown monoprotic acid, HA, was titrated with 0.100 mol dm^{-3} NaOH(aq). 25.0 cm^3 was required to reach the equivalence point.

a.i. Identify the amphiprotic species. [1]

a.ii. Identify one conjugate acid-base pair in the reaction. [1]

Acid	Base
. . . .	. . . .

b.i. Calculate the amount, in mol, of NaOH(aq) used. [1]

b.ii. Calculate the molar mass of the acid. [1]

b.iii. Calculate $[H^+]$ in the NaOH solution. [1]

Titanium is a transition metal.

$TiCl_4$ reacts with water and the resulting titanium(IV) oxide can be used as a smoke screen.

a. Describe the bonding in metals. [2]

b. Titanium exists as several isotopes. The mass spectrum of a sample of titanium gave the following data: [2]

Mass number	% abundance
46	7.98
47	7.32
48	73.99
49	5.46
50	5.25

Calculate the relative atomic mass of titanium to two decimal places.

c. State the number of protons, neutrons and electrons in the $^{48}_{22}\text{Ti}$ atom. [1]

Protons:

. . . .

Neutrons:

. . . .

Electrons:

. . . .

d.i. State the full electron configuration of the $^{48}_{22}\text{Ti}^{2+}$ ion. [1]

d.ii. Explain why an aluminium-titanium alloy is harder than pure aluminium. [2]

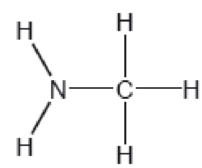
e.i. State the type of bonding in potassium chloride which melts at 1043 K. [1]

e.ii. A chloride of titanium, $TiCl_4$, melts at 248 K. Suggest why the melting point is so much lower than that of KCl. [1]

f.i. Formulate an equation for this reaction. [2]

f.ii. Suggest **one** disadvantage of using this smoke in an enclosed space. [1]

Two hydrides of nitrogen are ammonia and hydrazine, N_2H_4. One derivative of ammonia is methanamine whose molecular structure is shown below.



Hydrazine is used to remove oxygen from water used to generate steam or hot water.

$$N_2H_4(aq) + O_2(aq) \rightarrow N_2(g) + 2H_2O(l)$$

The concentration of dissolved oxygen in a sample of water is 8.0×10^{-3} g dm^{-3}.

a. Estimate the H–N–H bond angle in methanamine using VSEPR theory. [1]

b. Ammonia reacts reversibly with water. [2]

$$NH_3(g) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Explain the effect of adding H^+(aq) ions on the position of the equilibrium.

c. Hydrazine reacts with water in a similar way to ammonia. Deduce an equation for the reaction of hydrazine with water. [1]

d. Outline, using an ionic equation, what is observed when magnesium powder is added to a solution of ammonium chloride. [2]

e. Hydrazine has been used as a rocket fuel. The propulsion reaction occurs in several stages but the overall reaction is: [1]

$$N_2H_4(l) \rightarrow N_2(g) + 2H_2(g)$$

Suggest why this fuel is suitable for use at high altitudes.

f. Determine the enthalpy change of reaction, ΔH, in kJ, when 1.00 mol of gaseous hydrazine decomposes to its elements. Use bond enthalpy values in section 11 of the data booklet. [3]

$$N_2H_4(g) \rightarrow N_2(g) + 2H_2(g)$$

g. The standard enthalpy of formation of $N_2H_4(l)$ is +50.6 kJ mol^{-1}. Calculate the enthalpy of vaporization, ΔH_{vap}, of hydrazine in kJ mol^{-1}. [2]

$$N_2H_4(l) \rightarrow N_2H_4(g)$$

(If you did not get an answer to (f), use –85 kJ but this is not the correct answer.)

h.i. Calculate, showing your working, the mass of hydrazine needed to remove all the dissolved oxygen from 1000 dm^3 of the sample. [3]

h.ii. Calculate the volume, in dm^3, of nitrogen formed under SATP conditions. (The volume of 1 mol of gas = 24.8 dm^3 at SATP.) [1]

This question is about carbon and chlorine compounds.

a. Ethane, C_2H_6, reacts with chlorine in sunlight. State the type of this reaction and the name of the mechanism by which it occurs. [1]

Type of reaction:

. . . .

Mechanism:

. . . .

b. Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane. [3]

Two propagation steps:

. . . .

. . . .

. . . .

. . . .

One termination step:

. . . .

. . . .

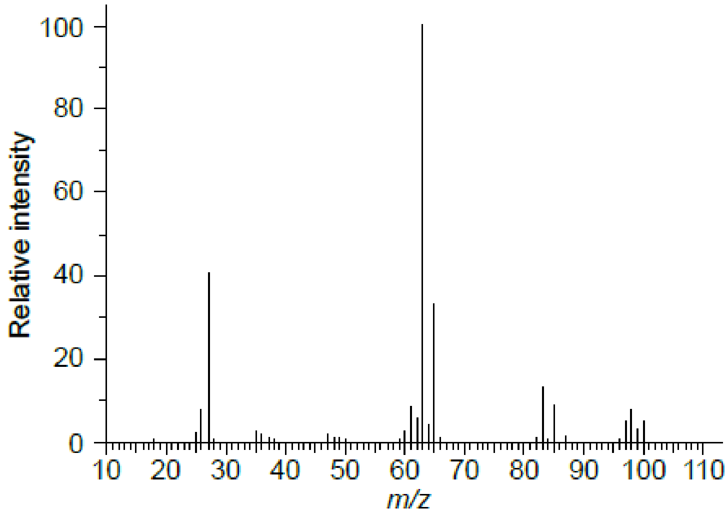
c.i. One possible product, **X**, of the reaction of ethane with chlorine has the following composition by mass: [2]

carbon: 24.27%, hydrogen: 4.08%, chlorine: 71.65%

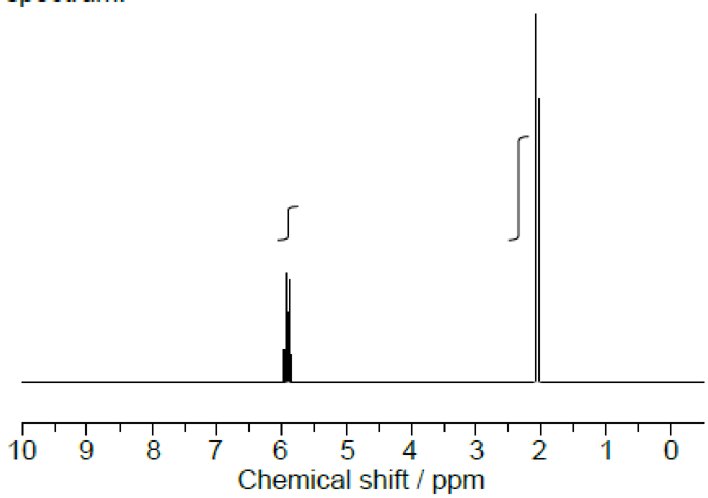
Determine the empirical formula of the product.

c.ii. The mass and ^{1}H NMR spectra of product **X** are shown below. Deduce, giving your reasons, its structural formula and hence the name of the compound. [3]

Mass spectrum:



[1]H NMR spectrum:



[Source: http://sdbs.db.aist.go.jp]

d. Chloroethene, C_2H_3Cl, can undergo polymerization. Draw a section of the polymer with three repeating units. [1]

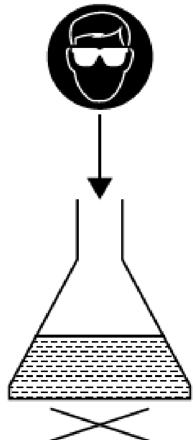
Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

$$Na_2S_2O_3\ (aq) + 2HCl\ (aq) \rightarrow S\ (s) + SO_2\ (g) + 2NaCl\ (aq) + X$$

a. Identify the formula and state symbol of X. [1]

b. Suggest why the experiment should be carried out in a fume hood or in a well-ventilated laboratory. [1]

c. The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time. [2]



10.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid was added to a 50.0 cm^3 solution of sodium thiosulfate at temperature, T1. Students measured the time taken for the mark to be no longer visible to the naked eye. The experiment was repeated at different concentrations of sodium thiosulfate.

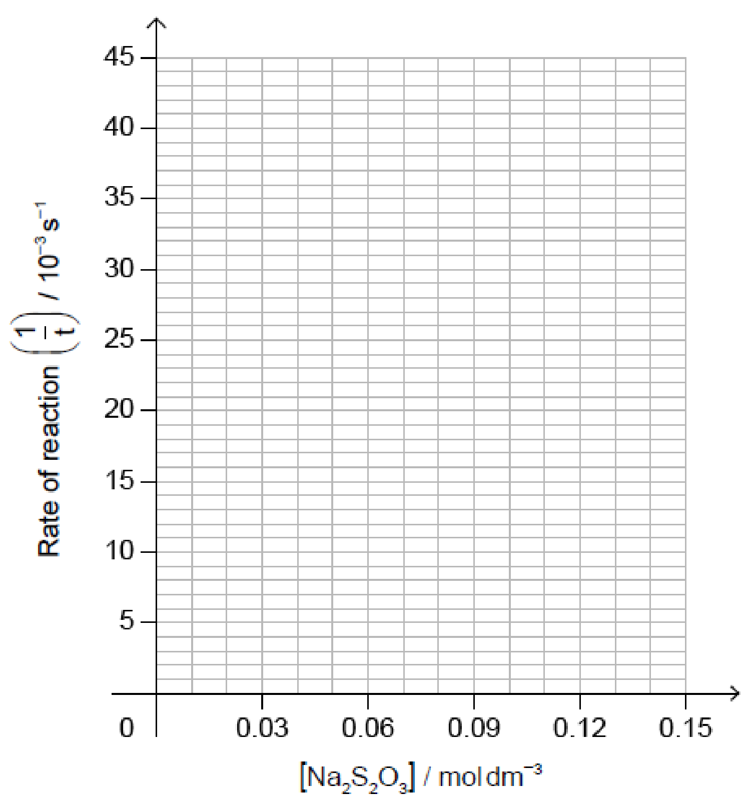
Experiment	**$[Na_2S_2O_3(aq)]$ / mol dm^{-3}**	**Time, t, for mark to disappear / s ± 1 s**	**$\frac{1}{t}$* / 10^{-3} s^{-1}**
1	0.150	23	43.5
2	0.120	27	37.0
3	0.090	36	27.8
4	0.060	60	16.7
5	0.030	111	9.0

* The reciprocal of the time in seconds can be used as a measure of the rate of reaction.

[Source: Adapted from http://www.flinnsci.com/]

Show that the hydrochloric acid added to the flask in experiment 1 is in excess.

d. Draw the best fit line of $\frac{1}{t}$ against concentration of sodium thiosulfate on the axes provided. [2]



e. A student decided to carry out another experiment using 0.075 mol dm^{-3} solution of sodium thiosulfate under the same conditions. Determine the time taken for the mark to be no longer visible. [2]

f. An additional experiment was carried out at a higher temperature, T_2. [4]

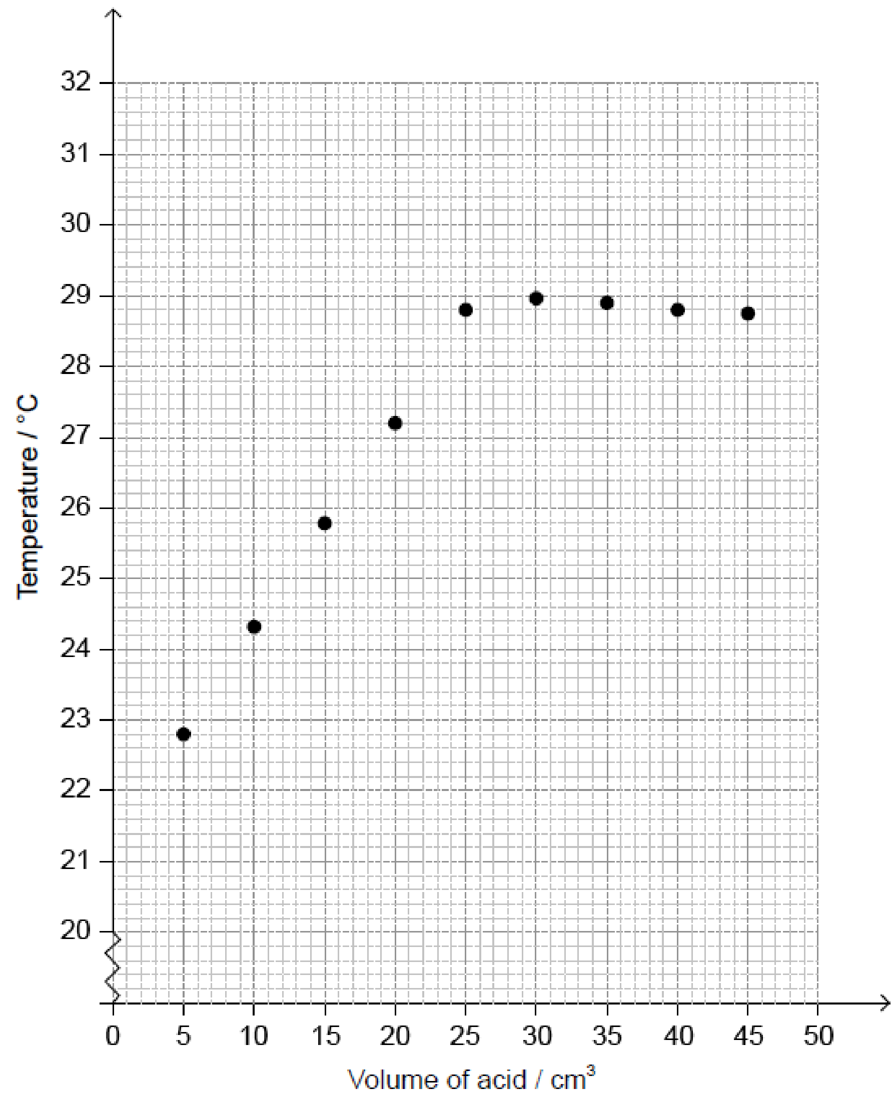
(i) On the same axes, sketch Maxwell–Boltzmann energy distribution curves at the two temperatures T_1 and T_2, where $T_2 > T_1$.

(ii) Explain why a higher temperature causes the rate of reaction to increase.

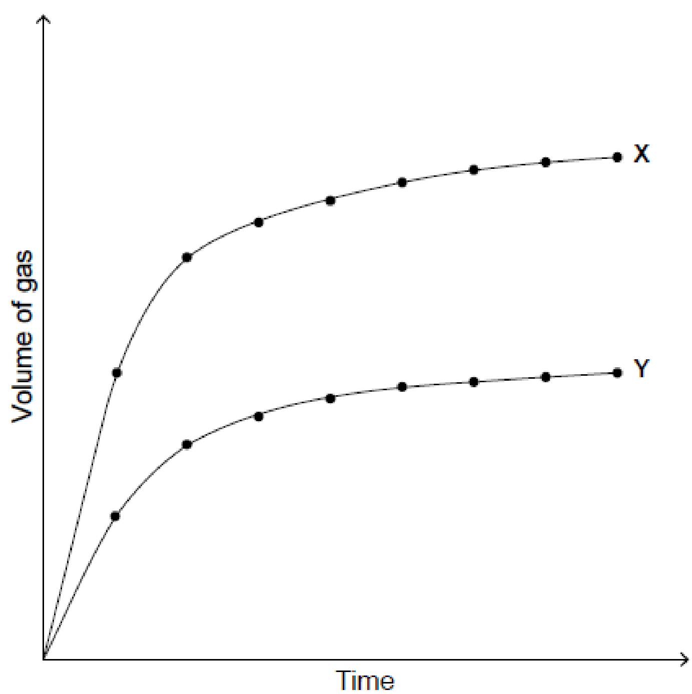
g. Suggest one reason why the values of rates of reactions obtained at higher temperatures may be less accurate. [1]

A student titrated an ethanoic acid solution, CH_3COOH (aq), against 50.0 cm^3 of 0.995 mol dm^{-3} sodium hydroxide, NaOH (aq), to determine its concentration.

The temperature of the reaction mixture was measured after each acid addition and plotted against the volume of acid.



Curves **X** and **Y** were obtained when a metal carbonate reacted with the same volume of ethanoic acid under two different conditions.



a. Using the graph, estimate the initial temperature of the solution. [1]

b. Determine the maximum temperature reached in the experiment by analysing the graph. [1]

c. Calculate the concentration of ethanoic acid, CH_3COOH, in mol dm^{-3}. [2]

d.i. Determine the heat change, *q*, in kJ, for the neutralization reaction between ethanoic acid and sodium hydroxide. [2]

Assume the specific heat capacities of the solutions and their densities are those of water.

d.ii. Calculate the enthalpy change, ΔH, in kJ mol^{-1}, for the reaction between ethanoic acid and sodium hydroxide. [2]

e.i. Explain the shape of curve **X** in terms of the collision theory. [2]

e.ii. Suggest **one** possible reason for the differences between curves **X** and **Y**. [1]