SL Paper 2

Explain why:

a.i. Define the term *first ionization energy*. [2]

a.ii. Explain why the first ionization energy of magnesium is higher than that of sodium. [2]

b.i. calcium has a higher melting point than potassium. [2]

b.ii. sodium oxide has a higher melting point than sulfur trioxide. [3]

c.i. Define the terms *acid* and *base* according to the Brønsted-Lowry theory **and** state **one** example of a weak acid and **one** example of a strong base. [2]

c.ii. Describe **two** different methods, one chemical and one physical, other than measuring the pH, that could be used to distinguish between ethanoic acid and hydrochloric acid solutions of the same concentration. [4]

c.iii. Black coffee has a pH of 5 and toothpaste has a pH of 8. Identify which is more acidic **and** deduce how many times the $[H^+]$ is greater in the more acidic product. [2]

d. Samples of sodium oxide and sulfur trioxide are added to separate beakers of water. Deduce the equation for **each** reaction **and** identify each oxide as acidic, basic or neutral. [3]

Chloroethene, C_2H_3Cl, is an important organic compound used to manufacture the polymer poly(chloroethene).

a.i. Draw the Lewis structure for chloroethene and predict the H–C–Cl bond angle. [2]

a.ii. Draw a section of poly(chloroethene) containing six carbon atoms. [1]

a.iii. Outline why the polymerization of alkenes is of economic importance and why the disposal of plastics is a problem. [2]

b.i. Chloroethene can be converted to ethanol in two steps. For each step deduce an overall equation for the reaction taking place. [2]

Step 1:

Step 2:

b.ii. State the reagents and conditions necessary to prepare ethanoic acid from ethanol in the laboratory. [2]

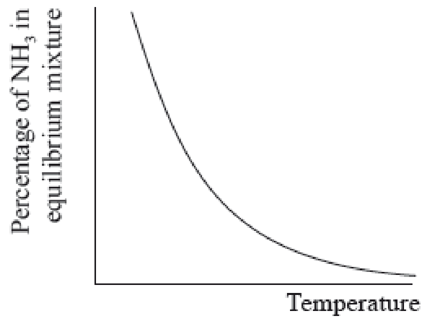
b.iii. State an equation, including state symbols, for the reaction of ethanoic acid with water. Identify a Brønsted-Lowry acid in the equation and its conjugate base. [3]

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, $\mathrm{NO_3^-}$, and nitrite, $\mathrm{NO_2^-}$, 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. [3]

Distinguish between the terms *strong* and *weak acid* and state the equations used to show the dissociation of each acid in aqueous solution.

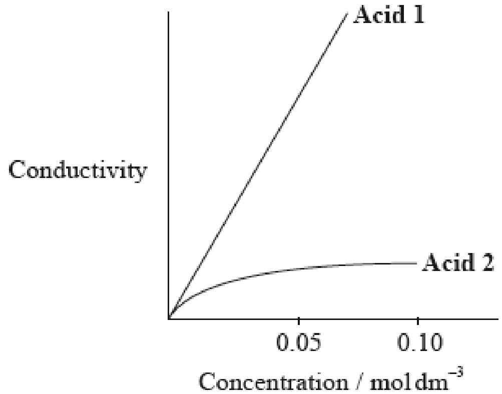
d. A small piece of magnesium ribbon is added to solutions of nitric and nitrous acid of the same concentration at the same temperature. Describe [2]

two observations that would allow you to distinguish between the two acids.

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]

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

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

Arsenic and nitrogen play a significant role in environmental chemistry. Arsenous acid, H_3AsO_3, can be found in oxygen-poor (anaerobic) water, and nitrogen-containing fertilizers can contaminate water.

Nitric acid, HNO_3, is strong and nitrous acid, HNO_2, is weak.

a. (i) Define *oxidation* and *reduction* in terms of electron loss or gain. [9]

Oxidation:

Reduction:

(ii) Deduce the oxidation numbers of arsenic and nitrogen in each of the following species.

$\mathrm{As_2O_3}$:

$\mathrm{NO_3^-}$:

$\mathrm{H_3AsO_3}$:

$\mathrm{N_2O_3}$:

(iii) Distinguish between the terms *oxidizing agent* and *reducing agent*.

(iv) In the removal of arsenic from contaminated groundwater, $\mathrm{H_3AsO_3}$ is often first oxidized to arsenic acid, $\mathrm{H_3AsO_4}$.

The following **unbalanced** redox reaction shows another method of forming $\mathrm{H_3AsO_4}$.

$$\mathrm{As_2O_3(s) + NO_3^-(aq) \rightarrow H_3AsO_4(aq) + N_2O_3(aq)}$$

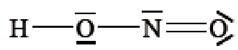
Deduce the balanced redox equation in **acid**, and then identify both the oxidizing and reducing agents.

b.i. Define an *acid* according to the Brønsted–Lowry and Lewis theories. [2]

Brønsted–Lowry theory:

Lewis theory:

b.ii. The Lewis (electron dot) structure of nitrous acid is given below. [1]



Identify which nitrogen-oxygen bond is the shorter.

b.iii. Deduce the approximate value of the hydrogen-oxygen-nitrogen bond angle in nitrous acid and explain your answer. [2]

b.iv. Distinguish between a *strong acid* and a *weak acid* in terms of their dissociation in aqueous solution. [1]

b.v. Ammonia, NH_3, is a weak base. Deduce the Lewis (electron dot) structure of NH_3. State the name of the shape of the molecule and explain why NH_3 is a polar molecule. [3]

b.vi. When lime was added to a sample of soil, the pH changed from 5 to 7. Calculate the **factor** by which the hydrogen ion concentration changes. [1]

b.vii. One common nitrogen-containing fertilizer is ammonium sulfate. State its chemical formula. [1]

Ammonia, $\mathrm{NH_3}$, is a base according to both the Brønsted–Lowry and the Lewis theories of acids and bases.

The equation for the reaction between sodium hydroxide, NaOH, and nitric acid, $\mathrm{HNO_3}$, is shown below.

$$\mathrm{NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)} \quad \Delta H = -57.6\ \mathrm{kJ\,mol^{-1}}$$

a. Distinguish between the terms *strong base* and *weak base*, and state one example of each. [3]

b.i. State the equation for the reaction of ammonia with water. [1]

b.ii. Explain why ammonia can act as a Brønsted–Lowry base. [1]

b.iii. Explain why ammonia can also act as a Lewis base. [1]

c. (i) When ammonium chloride, $\mathrm{NH_4Cl(aq)}$, is added to excess solid sodium carbonate, $\mathrm{Na_2CO_3(s)}$, an acid–base reaction occurs. Bubbles of gas are produced and the solid sodium carbonate decreases in mass. State **one** difference which would be observed if nitric acid, $\mathrm{HNO_3(aq)}$, was used instead of ammonium chloride. [5]

(ii) Deduce the Lewis structures of the ammonium ion, $\mathrm{NH_4^+}$, and the carbonate ion, $\mathrm{CO_3^{2-}}$.

Ammonium ion | Carbonate ion

(iii) Predict the shapes of $\mathrm{NH_4^+}$ and $\mathrm{CO_3^{2-}}$.

NH_4^+:

CO_3^{2-}:

d. (i) Sketch and label an enthalpy level diagram for this reaction. [6]

(ii) Deduce whether the reactants or the products are more energetically stable, stating your reasoning.

(iii) Calculate the change in heat energy, in kJ, when $50.0\ \mathrm{cm^3}$ of $2.50\ \mathrm{mol\,dm^{-3}}$ sodium hydroxide solution is added to excess nitric acid.

e. When 5.35 g ammonium chloride, $NH_4Cl(s)$, is added to $100.0\ \mathrm{cm^3}$ of water, the temperature of the water decreases from 19.30 °C to 15.80 °C. Determine the enthalpy change, in $\mathrm{kJ\,mol^{-1}}$, for the dissolving of ammonium chloride in water. [3]

Predict the shape and bond angles for the following species:

Ethanoic acid, CH_3COOH, is a weak acid.

a.i. Draw the Lewis structures for carbon monoxide, CO, carbon dioxide, CO_2 and methanol, CH_3OH. [3]

a.ii. List, with an explanation, the three compounds in order of increasing carbon to oxygen bond length (shortest first). [2]

b.i. CO_2 [2]

b.ii. CO_3^{2-} [2]

b.iii. BF_4^- [2]

c.i. Define a Brønsted-Lowry acid. [1]

c.ii. Deduce the two acids and their conjugate bases in the following reaction: [2]

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

d.i. Define the term *weak acid* and state the equation for the reaction of ethanoic acid with water. [2]

d.ii. Vinegar, which contains ethanoic acid, can be used to clean deposits of calcium carbonate from the elements of electric kettles. State the equation for the reaction of ethanoic acid with calcium carbonate. [2]

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 hydroxide. The equation for the reaction is: [10]

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

(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.

Acids play a key role in processes in everyday life.

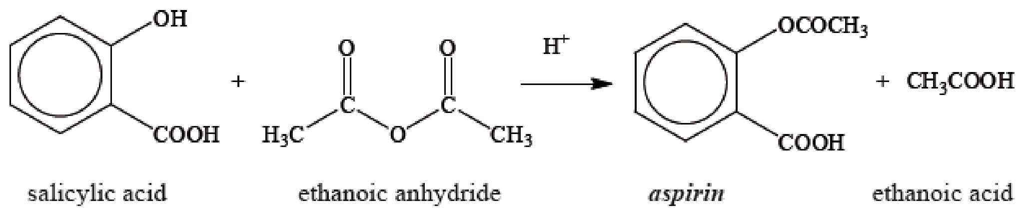
The wine industry is important to the economy of many countries. Wine contains ethanol. In a laboratory in Chile, chemists tested the pH of a bottle of wine when opened and found it to have a pH of 3.8. After a few days, the pH had decreased to 2.8.

a.i. Deduce the change in hydrogen ion concentration, $[\mathrm{H^+}]$. [1]

a.ii. State the name of the compound formed that is responsible for this decreased pH value. [1]

b. Sulfuric acid present in acid rain can damage buildings made of limestone. Predict the balanced chemical equation for the reaction between limestone and sulfuric acid including state symbols. [2]

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]

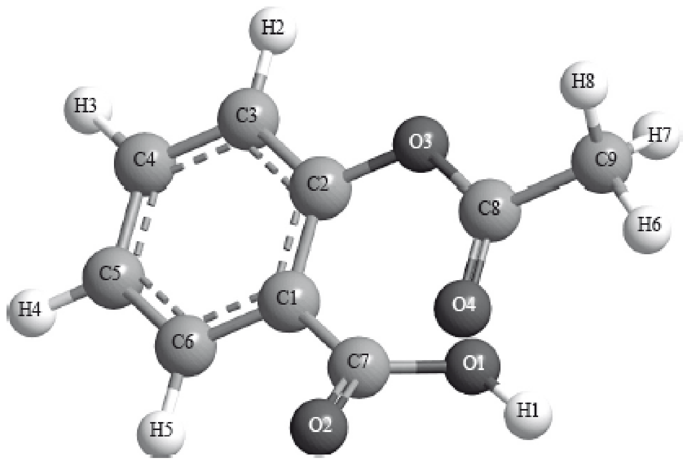
b.ii. Calculate the theoretical yield, in g, of aspirin, $C_6H_4(OCOCH_3)COOH$. [2]

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

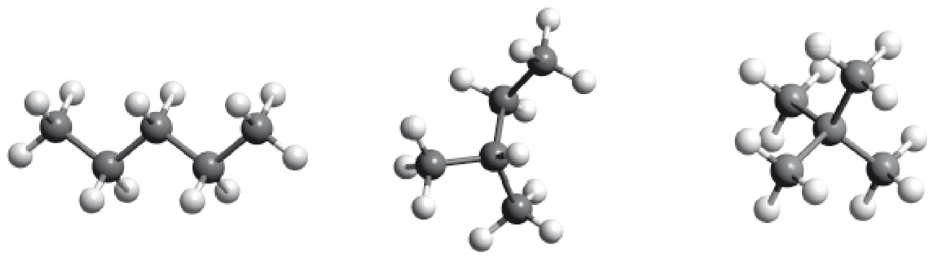
The following hypothesis was suggested by the student: "*Since all the measured carbon-carbon bond lengths are equal, all the carbon-oxygen bond lengths must also be equal in aspirin. Therefore, the C8–O4 bond length must be 1.4 × 10^{-10} m*". Comment on whether or not this is a valid hypothesis.

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:

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]

In acidic solution, ions containing titanium can react according to the half-equation below.

$$TiO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons Ti^{3+}(aq) + H_2O(l)$$

A reactivity series comparing titanium, cadmium and europium is given below.

Least reactive Cd < Ti < Eu Most reactive

The half-equations corresponding to these metals are:

$Eu^{2+}(aq) + 2e^- \rightleftharpoons Eu(s)$

$Ti^{3+}(aq) + 3e^- \rightleftharpoons Ti(s)$

$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$

Some students were provided with a $0.100\ mol\ dm^{-3}$ solution of a monobasic acid, HQ, and given the problem of determining whether HQ was a weak acid or a strong acid.

a.i. State the initial and final oxidation numbers of titanium and hence deduce whether it is oxidized or reduced in this change. [2]

Initial oxidation number	Final oxidation number	Oxidized / reduced

a.ii. Considering the above equilibrium, predict, giving a reason, how adding more acid would affect the strength of the TiO^{2+} ion as an oxidizing agent. [2]

b.i. Deduce which of the species would react with titanium metal. [1]

b.ii. Deduce the balanced equation for this reaction. [1]

b.iii. Deduce which of the six species is the strongest oxidizing agent. [1]

b.iv. A voltaic cell can be constructed using cadmium and europium half-cells. State how the two solutions involved should be connected and outline how this connection works. [2]

c.i. Define a *Brønsted–Lowry acid*. [1]

c.ii. Distinguish between the terms *strong acid* and *weak acid*. [1]

c.iii. Neelu and Charles decided to solve the problem by determining the volume of $0.100\ mol\ dm^{-3}$ sodium hydroxide solution needed to neutralize $25.0\ cm^3$ of the acid. Outline whether this was a good choice. [2]

c.iv. Neelu and Charles decided to compare the volume of sodium hydroxide solution needed with those required by known $0.100\ mol\ dm^{-3}$ strong and weak acids. Unfortunately they chose sulfuric acid as the strong acid. Outline why this was an unsuitable choice. [1]

c.v. State a suitable choice for both the strong acid and the weak acid. [2]

Strong acid:

Weak acid:

c.vi. Francisco and Shamiso decided to measure the pH of the initial solution, HQ, and they found that its pH was 3.7. Deduce, giving a reason, the strength (weak or strong) of the acid HQ. [2]

c.vii. Suggest a method, other than those mentioned above, that could be used to solve the problem and outline how the results would distinguish between a strong acid and a weak acid. [2]

Some of the most important processes in chemistry involve acid-base reactions.

a. Describe the acid-base character of the oxides of each of the period 3 elements, Na to Cl. [3]

b. State **one** example of an acidic gas, produced by an industrial process or the internal combustion engine, which can cause large-scale pollution to lakes and forests. [1]

c. Suggest **one** method, other than measuring pH, which could be used to distinguish between solutions of a strong acid and a weak acid of the same molar concentration. State the expected results. [2]

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

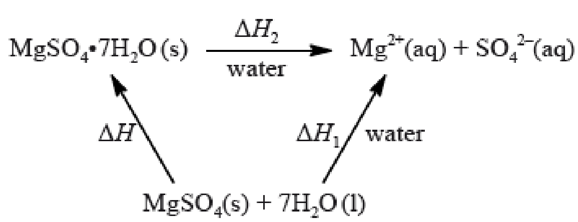
$$\mathrm{Mg(s) + H_2SO_4(aq) \rightarrow H_2(g) + MgSO_4(aq)}$$

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, $\mathrm{MgSO_4(s)}$, 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

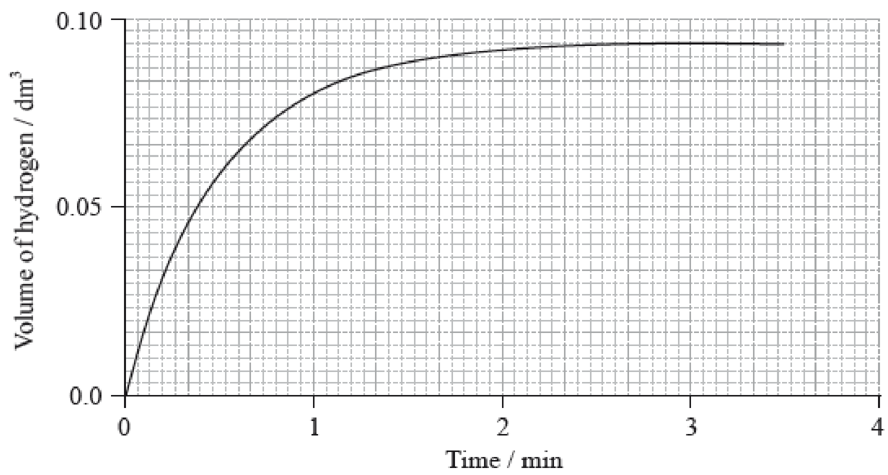
The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, $\mathrm{MgSO_4 \bullet 7H_2O(s)}$, and $50.0\ \mathrm{cm}^3$ of water. They found the enthalpy change, ΔH_2, to be $+18\ \mathrm{kJ\ mol}^{-1}$.

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, $MgSO_4$. [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:

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.

A student used a pH meter to measure the pH of different samples of water at 298 K.

Sample	pH ± 0.1
Rain water	5.1
River water	4.4
Tap water	6.5
Bottled water	7.1

a. Use the data in the table to identify the most acidic water sample. [1]

b. Calculate the percentage uncertainty in the measured pH of the rain water sample. [1]

c. Determine the ratio of $[H^+]$ in bottled water to that in rain water. [2]

$$\frac{[H^+]\ in\ bottled\ water}{[H^+]\ in\ rain\ water}$$

d. The acidity of non-polluted rain water is caused by dissolved carbon dioxide. State an equation for the reaction of carbon dioxide with water. [1]

The equations of two acid-base reactions are given below.

Reaction **A** $\quad NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

The reaction mixture in **A** consists mainly of reactants because the equilibrium lies to the left.

Reaction **B** $\quad NH_2^-(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + OH^-(aq)$

The reaction mixture in **B** consists mainly of products because the equilibrium lies to the right.

Two acidic solutions, **X** and **Y**, of equal concentrations have pH values of 2 and 6 respectively.

a.i. For each of the reactions **A** and **B**, deduce whether water is acting as an acid or a base and explain your answer. [2]

a.ii. In reaction **B**, identify the stronger base, NH_2^- or OH^- and explain your answer. [2]

a.iii. In reactions **A** and **B**, identify the stronger acid, NH_4^+ or NH_3 (underlined) and explain your answer. [2]

b. Describe **two** different experimental methods to distinguish between aqueous solutions of a strong base and a weak base. [5]

c.i. Calculate the hydrogen ion concentrations in the two solutions and identify the stronger acid. [2]

c.ii. Determine the ratio of the hydrogen ion concentrations in the two solutions **X** and **Y**. [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]

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

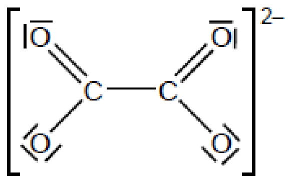
The mean value of the titre was 14.0 cm^3.

(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.

Group 7 of the periodic table contains a number of reactive elements such as chlorine, bromine and iodine.

Bleaches in which chlorine is the active ingredient are the most common, although some environmental groups have concerns about their use. In aqueous chlorine the equilibrium below produces chloric(I) acid (hypochlorous acid), HOCl, the active bleach.

$$Cl_2(aq) + H_2O(l) \rightleftharpoons HOCl\ (aq) + H^+(aq) + Cl^-(aq)$$

Aqueous sodium chlorate(I), NaOCl, the most common active ingredient in chlorine based bleaches, oxidizes coloured materials to colourless products while being reduced to the chloride ion. It will also oxidize sulfur dioxide to the sulfate ion.

a. (i) Describe the colour change that occurs when aqueous chlorine is added to aqueous sodium bromide. [3]

(ii) Outline, with the help of a chemical equation, why this reaction occurs.

b. The colour change in the reaction between aqueous chlorine and aqueous sodium iodide is very similar, but it differs with an excess of aqueous chlorine. Describe the appearance of the reaction mixture when **excess** aqueous chlorine has been added to aqueous sodium iodide. [1]

c.i. Chloric(I) acid is a weak acid, but hydrochloric acid is a strong acid. Outline how this is indicated in the equation above. [1]

c.ii. State a balanced equation for the reaction of chloric(I) acid with water. [1]

c.iii. Outline, in terms of the equilibrium above, why it is dangerous to use an acidic toilet cleaner in combination with this kind of bleach. [2]

c.iv. Suggest why a covalent molecule, such as chloric(I) acid, is readily soluble in water. [2]

c.v. Draw the Lewis (electron dot) structure of chloric(I) acid. [1]

c.vi. Predict the H–O–Cl bond angle in this molecule and explain this in terms of the valence shell electron pair repulsion (VSEPR) theory. [3]

d. (i) Deduce the coefficients required to balance the half-equations given below. [6]

$$\_\_\ ClO^- + \_\_\ H^+ + \_\_\ e^- \rightleftharpoons \_\_\ H_2O + \_\_\ Cl^-$$
$$\_\_\ SO_4^{2-}\ \_\_\ H^+ + \_\_\ e^- \rightleftharpoons \_\_\ SO_2 + \_\_\ H_2O$$

(ii) State the initial and final oxidation numbers of both chlorine and sulfur in the equations in part (i).

Element	Initial oxidation number	Final oxidation number
Chlorine		
Sulfur		

(iii) Use the half-equations to deduce the balanced equation for the reaction between the chlorate(I) ion and sulfur dioxide.

Calcium nitrate contains both covalent and ionic bonds.

Nitrogen also forms oxides, which are atmospheric pollutants.

a.i. State the formula of **both** ions present and the nature of the force between these ions. [2]

Ions:

Nature of force:

a.ii. State which atoms are covalently bonded. [1]

b.i. Outline the source of these oxides. [1]

b.ii. State **one** product formed from their reaction with water. [1]

b.iii. State **one** environmental problem caused by these atmospheric pollutants. [1]

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 $100.0\ \mathrm{cm^3}$ solution in a volumetric flask. A $25.0\ \mathrm{cm^3}$ sample of this solution reacted with $12.1\ \mathrm{cm^3}$ of a $0.100\ \mathrm{mol\,dm^{-3}}$ 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]

When nitrogen gas and hydrogen gas are allowed to react in a closed container, the following equilibrium is established.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92.6\ kJ$$

a. Outline **two** characteristics of a reversible reaction in a state of dynamic equilibrium. [2]

b. Deduce the equilibrium constant expression, K_c, for the reaction. [1]

c. Predict, with a reason, how each of the following changes affects the position of equilibrium. [2]

The volume of the container is increased.

Ammonia is removed from the equilibrium mixture.

d.i. Define the term *activation energy*, E_a. [1]

d.ii Ammonia is manufactured by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the rate of reaction. [2]

d.iii Sketch the Maxwell–Boltzmann energy distribution curve for a reaction, labelling both axes and showing the activation energy with and without a catalyst. [2]

e. Typical conditions used in the Haber process are 500 °C and 200 atm, resulting in approximately 15% yield of ammonia. [3]

(i) Explain why a temperature lower than 500 °C is **not** used.

(ii) Outline why a pressure higher than 200 atm is **not** often used.

f.i. Define the term *base* according to the Lewis theory. [1]

f.ii. Define the term *weak base* according to the Brønsted-Lowry theory. [1]

f.iii. Deduce the formulas of conjugate acid-base pairs in the reaction below. [2]

$$CH_3NH_2(aq) + H_2O(l) \rightleftharpoons CH_3NH_3^+(aq) + OH^-(aq)$$

Acid	Conjugate base
....	....
....	....

f.iv. Outline an experiment and its results which could be used to distinguish between a strong base and a weak base. [3]

Across period 3, elements increase in atomic number, decrease in atomic radius and increase in electronegativity.

a. Define the term *electronegativity*. [1]

b. Explain why the atomic radius of elements decreases across the period. [2]

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

c.ii. Suggest the pH of the solutions formed in part (c) (i). [2]

d. Describe **three** tests that can be carried out in the laboratory, and the expected results, to distinguish between $0.10 \text{ mol dm}^{-3} \text{ HCl(aq)}$ and $0.10 \text{ mol dm}^{-3} \text{ CH}_3\text{COOH(aq)}$. [3]

e. Explain whether BF_3 can act as a Brønsted-Lowry acid, a Lewis acid or both. [2]

f.i. Describe the bonding and structure of sodium chloride. [2]

f.ii. State the formula of the compounds formed between the elements below. [2]

Sodium and sulfur:

Magnesium and phosphorus:

g. Covalent bonds form when phosphorus reacts with chlorine to form PCl_3. Deduce the Lewis (electron dot) structure, the shape and bond angle in PCl_3 and explain why the molecule is polar. [4]

Lewis (electron dot) structure:

Name of shape:

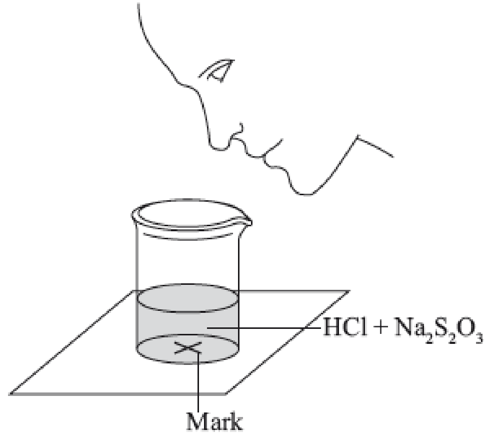
Bond angle:

Explanation of polarity of molecule:

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

$$\text{Na}_2\text{S}_2\text{O}_3\text{(aq)} + 2\text{HCl(aq)} \rightarrow 2\text{NaCl(aq)} + \text{SO}_2\text{(g)} + \text{S(s)} + \text{H}_2\text{O(l)}$$

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 $10.0\ \mathrm{cm}^3$ of $0.500\ \mathrm{mol\,dm}^{-3}$ hydrochloric acid and then added $40.0\ \mathrm{cm}^3$ of $0.0200\ \mathrm{mol\,dm}^{-3}$ 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 $2.50\ \mathrm{dm}^3$ 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]

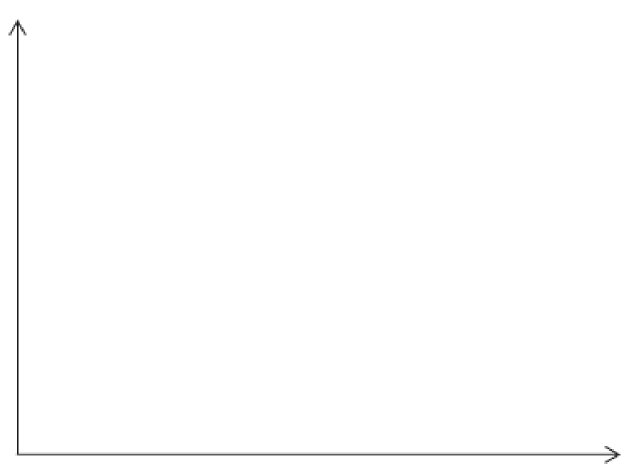
b. (i) State the volumes of the liquids that should be mixed. [4]

Liquid	$0.500\ \mathrm{mol\,dm}^{-3}\ HCl$	$0.0200\ \mathrm{mol\,dm}^{-3}\ Na_2S_2O_3$	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.

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

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 $1.01 \times 10^5\ \mathrm{Pa}$. Once it had reached equilibrium, the gas volume was measured as $95.0\ \mathrm{cm}^3$.

Bromoethane, $\mathrm{CH_3CH_2Br}$, undergoes a substitution reaction to form ethanol, $\mathrm{CH_3CH_2OH}$.

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

Ammonia, NH_3, is a weak base.

Iron is more reactive than copper.

a.i. Draw the Lewis structure of ammonia and state the shape of the molecule and its bond angles. [3]

a.ii. The conjugate acid of ammonia is the ammonium ion, NH_4^+. Draw the Lewis structure of the ammonium ion and deduce its shape and bond angles. [3]

a.iv. Describe **two** different properties that could be used to distinguish between a 1.00 mol dm^{-3} solution of a strong monoprotic acid and a 1.00 mol dm^{-3} solution of a weak monoprotic acid. [2]

a.v. Explain, using the Brønsted-Lowry theory, how water can act either as an acid or a base. In **each** case identify the conjugate acid or base formed. [2]

b.i. Draw a labelled diagram of a voltaic cell made from an $Fe(s)/Fe^{2+}(aq)$ half-cell connected to a $Cu(s)/Cu^{2+}(aq)$ half-cell. In your diagram identify the positive electrode (cathode), the negative electrode (anode) and the direction of electron flow in the external circuit. [4]

b.ii. Deduce the half-equations for the reactions taking place at the positive electrode (cathode) and negative electrode (anode) of this voltaic cell. [2]

b.iii. Deduce the overall equation for the reaction taking place in the voltaic cell and determine which species acts as the oxidizing agent and which species has been reduced. [2]

Limescale, $CaCO_3(s)$, can be removed from water kettles by using vinegar, a dilute solution of ethanoic acid, $CH_3COOH(aq)$.

a. Predict, giving a reason, a difference between the reactions of the same concentrations of hydrochloric acid and ethanoic acid with samples of calcium carbonate. [2]

b. Dissolved carbon dioxide causes unpolluted rain to have a pH of approximately 5, but other dissolved gases can result in a much lower pH. [1]

State one environmental effect of acid rain.

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, $\Delta H_c^\ominus = -750\,\mathrm{kJ\,mol^{-1}}$

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

(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 $285\,\mathrm{g mol^{-1}}$. 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.

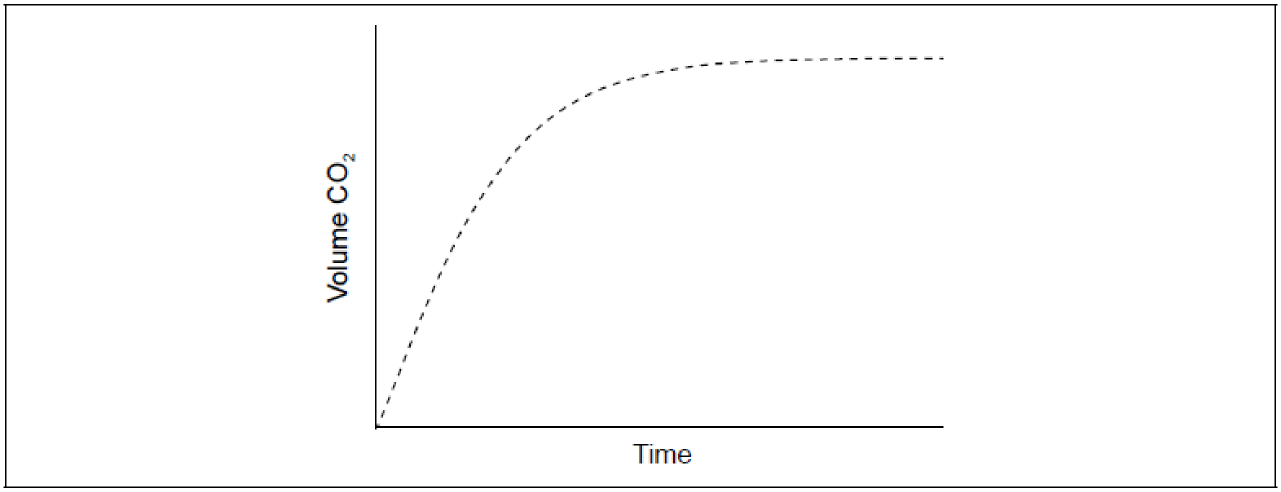
(iv) The levels of sulfur dioxide, a major contributor to acid deposition, can be minimized by either pre-combustion and post-combustion methods. Outline **one** technique of each method.

Pre-combustion:

Post-combustion:

Graphing is an important tool in the study of rates of chemical reactions.

Excess hydrochloric acid is added to lumps of calcium carbonate. The graph shows the volume of carbon dioxide gas produced over time.



a. Sketch a Maxwell–Boltzmann distribution curve for a chemical reaction showing the activation energies with and without a catalyst. [3]

b.i. Sketch a curve on the graph to show the volume of gas produced over time if the same mass of crushed calcium carbonate is used instead of lumps. All other conditions remain constant. [1]

b.ii. State and explain the effect on the rate of reaction if ethanoic acid of the same concentration is used in place of hydrochloric acid. [2]

c. Outline why pH is more widely used than $[H^+]$ for measuring relative acidity. [1]

d. Outline why H_3PO_4/HPO_4^{2-} is not a conjugate acid-base pair. [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 ${}^{48}_{22}\mathrm{Ti}$ atom. [1]

Protons:

. . . .

Neutrons:

. . . .

Electrons:

. . . .

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

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]

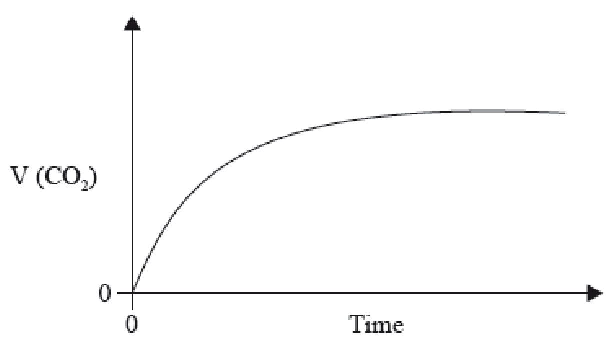
b.ii. Calculate the molar mass of the acid. [1]

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

Water is an important substance that is abundant on the Earth's surface. Water dissociates according to the following equation.

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

The graph below shows how the volume of carbon dioxide formed varies with time when a hydrochloric acid solution is added to **excess** calcium carbonate in a flask.



a. (i) State the equilibrium constant expression for the dissociation of water. [7]

(ii) Explain why even a very acidic aqueous solution still has some OH^- ions present in it.

(iii) State and explain the effect of increasing temperature on the equilibrium constant above given that the dissociation of water is an endothermic process.

(iv) The pH of a solution is 2. If its pH is increased to 6, deduce how the hydrogen ion concentration changes.

b. In carbonated drinks containing dissolved carbon dioxide under high pressure, the following dynamic equilibrium exists. [2]

$$CO_2(aq) \rightleftharpoons CO_2(g)$$

Describe the effect of opening a carbonated drink container and outline how this equilibrium is affected.

c. (i) Explain the shape of the curve. [11]

(ii) Copy the above graph on your answer sheet and sketch the curve you would obtain if **double** the volume of hydrochloric acid solution of **half** the concentration as in the example above is used instead, with all other variables kept constant from the original. Explain why the shape of the curve is different.

(iii) Outline **one** other way in which the rate of this reaction can be studied in a school laboratory. Sketch a graph to illustrate how the selected variable would change with time.

(iv) Define the term *activation energy* and state **one** reason why the reaction between calcium carbonate and hydrochloric acid takes place at a reasonably fast rate at room temperature.

Consider the following reactions.

$$\begin{tikzcd} \underset{\mathbf{X}}{(CH_3)_2CH(CH_2)_3OH} \arrow[r] \arrow[d] & \underset{\mathbf{Y}}{(CH_3)_2CH(CH_2)_2CHO} \\ \underset{\mathbf{Z}}{(CH_3)_2CH(CH_2)_2COOH} & \end{tikzcd}$$

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 $131.38\ \mathrm{g\,mol^{-1}}$. Deduce the molecular formula of **J**. [3]

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.

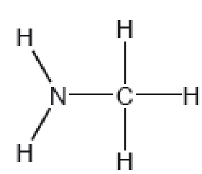
Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide.

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]

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 $8.0 \times 10^{-3}\ \mathrm{g\,dm^{-3}}$.

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.)

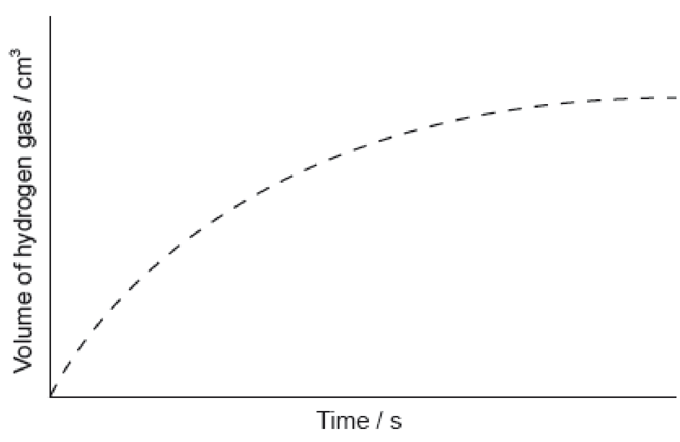
h.i. Calculate, showing your working, the mass of hydrazine needed to remove all the dissolved oxygen from 1000 dm^3 of the sample. [3]

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]

Magnesium reacts with sulfuric acid:

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

The graph shows the results of an experiment using excess magnesium ribbon and dilute sulfuric acid.

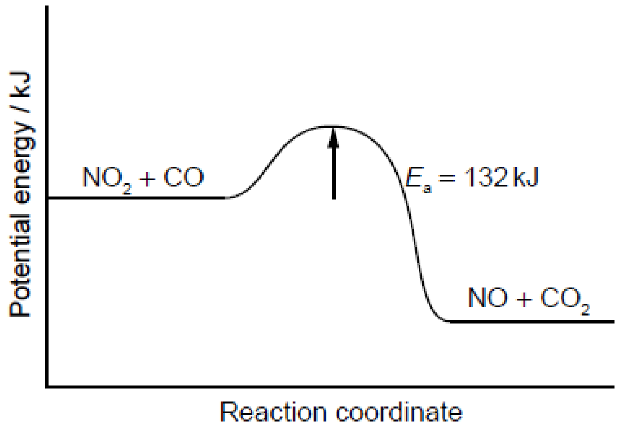


a.i. Outline why the rate of the reaction decreases with time. [1]

a.ii. Sketch, on the same graph, the expected results if the experiment were repeated using powdered magnesium, keeping its mass and all other variables unchanged. [1]

b. Nitrogen dioxide and carbon monoxide react according to the following equation: [1]

$$NO_2(g) + CO(g) \rightleftharpoons NO(g) + CO_2(g) \qquad \Delta H = -226 \text{ kJ}$$



Calculate the activation energy for the reverse reaction.

c. State the equation for the reaction of NO_2 in the atmosphere to produce acid deposition. [1]

Many reactions are in a state of equilibrium.

The equations for two acid-base reactions are given below.

$$HCO_3^- (aq) + H_2O (l) \rightleftharpoons H_2CO_3 (aq) + OH^- (aq)$$
$$HCO_3^- (aq) + H_2O (l) \rightleftharpoons CO_3^{2-} (aq) + H_3O^+ (aq)$$

a. The following reaction was allowed to reach equilibrium at 761 K. [2]

$$H_2 (g) + I_2 (g) \rightleftharpoons 2HI (g) \qquad \Delta H^{\theta} < 0$$

Outline the effect, if any, of each of the following changes on the position of equilibrium, giving a reason in each case.

	Effect	**Reason**
Increasing the volume, at constant temperature	....	....
Increasing the temperature, at constant pressure	....	....

b.i. Identify two different amphiprotic species in the above reactions. [1]

b.ii. State what is meant by the term conjugate base. [1]

b.iii. State the conjugate base of the hydroxide ion, OH^-. [1]

c. A student working in the laboratory classified HNO_3, H_2SO_4, H_3PO_4 and $HClO_4$ as acids based on their pH. He hypothesized that “all acids contain oxygen and hydrogen”. [2]

Evaluate his hypothesis.

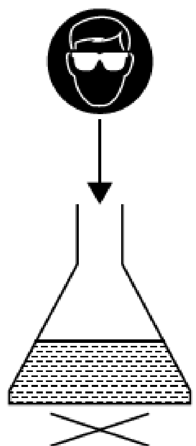
Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

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

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.

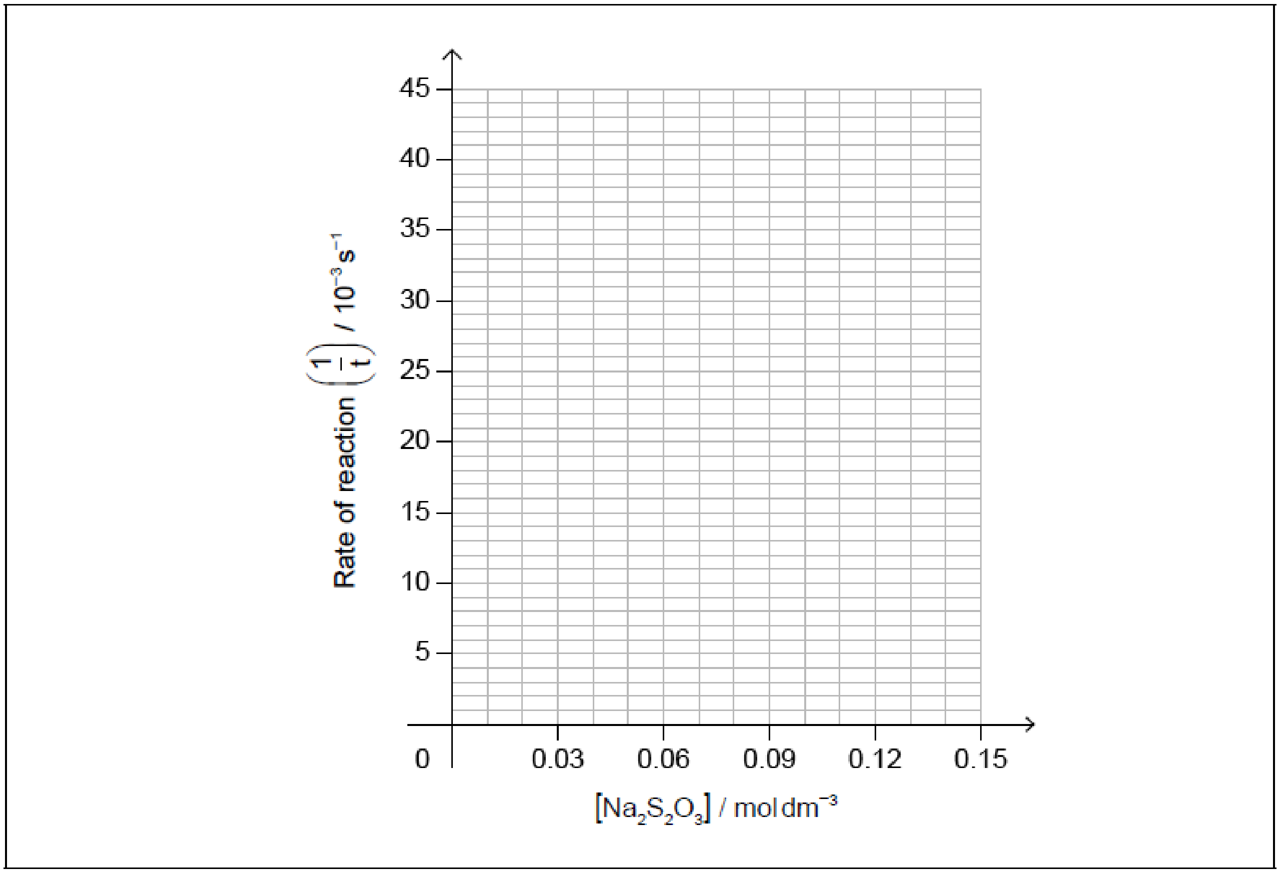
Experiment	**$[Na_2S_2O_3\,(aq)]$ / mol dm^{-3}**	**Time, t, for mark to disappear / s ± 1 s**	**$\frac{1}{t}$* / $10^{-3}\,s^{-1}$**
1	0.150	23	43.5
2	0.120	27	37.0
3	0.090	36	27.8
4	0.060	60	16.7
5	0.030	111	9.0

* 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.

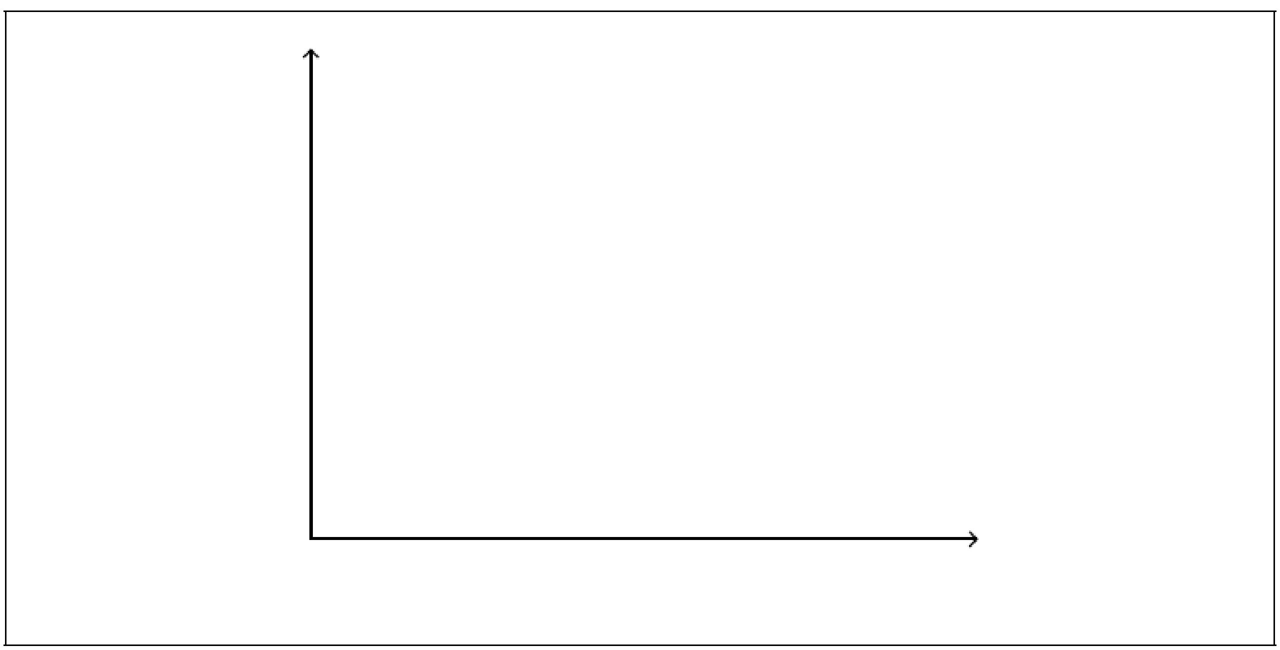
d. Draw the best fit line of $\frac{1}{t}$ against concentration of sodium thiosulfate on the axes provided. [2]



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]