SL Paper 2

An example of a homogeneous reversible reaction is the reaction between hydrogen and iodine.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

Propane can be formed by the hydrogenation of propene.

$$CH_3CH{=}CH_2(g) + H_2(g) \rightarrow CH_3CH_2CH_3(g)$$

a.i. Outline the characteristics of a homogeneous chemical system that is in a state of equilibrium. [2]

a.ii. Deduce the expression for the equilibrium constant, K_c. [1]

a.iii. Predict what would happen to the position of equilibrium and the value of K_c if the pressure is increased from 1 atm to 2 atm. [2]

a.iv. The value of K_c at 500 K is 160 and the value of K_c at 700 K is 54. Deduce what this information tells us about the enthalpy change of the forward reaction. [1]

a.v. The reaction can be catalysed by adding platinum metal. State and explain what effect the addition of platinum would have on the value of the equilibrium constant. [2]

b.i. State the conditions necessary for the hydrogenation reaction to occur. [2]

b.ii. Enthalpy changes can be determined using average bond enthalpies. Define the term *average bond enthalpy*. [2]

b.iii. Determine a value for the hydrogenation of propene using information from Table 10 of the Data Booklet. [2]

b.iv. Explain why the enthalpy of hydrogenation of propene is an exothermic process. [1]

c.i. Describe a chemical test that could be used to distinguish between propane and propene. In **each** case state the result of the test. [2]

c.ii. Under certain conditions propene can polymerize to form poly(propene). State the type of polymerization taking place and draw a section of the polymer to represent the repeating unit. [2]

c.iii. Other than polymerization, state **one** reaction of alkenes which is of economic importance. [1]

Factors that affect the rate of a chemical reaction include particle size, concentration of reactants and the temperature of the reaction.

Propan-1-ol and propan-2-ol are two structural isomers of C_3H_8O.

a.i. Define the term *rate of a chemical reaction*. [1]

a.ii. List the **three** characteristic properties of reactant particles which affect the rate of reaction as described by the collision theory. [3]

a.iii. On the axes below sketch **two** Maxwell-Boltzmann energy distribution curves for the same sample of gas, one at a temperature T and another at a higher temperature T'. Label both axes. Explain why raising the temperature increases the rate of a chemical reaction. [5]

a.iv. Explain why coal dust burns much faster than a large piece of coal with the same mass. [1]

b.i. State the equation for the complete combustion of C_3H_8O. [2]

b.ii. Both propan-1-ol and propan-2-ol can be oxidized in aqueous solution by potassium dichromate(VI). State any necessary conditions for the oxidation to occur and describe the colour change during the oxidation process. [3]

b.iii. State the name(s) and structure(s) of the organic product(s) that can be formed when each of the alcohols is oxidized and suggest why one of the alcohols gives two organic products and the other only gives one organic product. [5]

Consider the following reaction taking place at 375 °C in a $1.00\ \mathrm{dm^3}$ closed container.

$$\mathrm{Cl_2(g) + SO_2(g) \rightleftharpoons SO_2Cl_2(g)} \quad \Delta H^\ominus = -84.5\ \mathrm{kJ}$$

A solution of hydrogen peroxide, H_2O_2, is added to a solution of sodium iodide, NaI, acidified with hydrochloric acid, HCl. The yellow colour of the iodine, I_2, can be used to determine the rate of reaction.

$$\mathrm{H_2O_2(aq) + 2NaI(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + I_2(aq) + 2H_2O(l)}$$

The experiment is repeated with some changes to the reaction conditions. For each of the changes that follow, predict, stating a reason, its effect on the rate of reaction.

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

a.ii. If the temperature of the reaction is changed to 300 °C, predict, stating a reason in each case, whether the equilibrium concentration of SO_2Cl_2 and the value of K_c will increase or decrease. [3]

a.iii. If the volume of the container is changed to $1.50\ \mathrm{dm^3}$, predict, stating a reason in each case, how this will affect the equilibrium concentration of SO_2Cl_2 and the value of K_c. [3]

a.iv. Suggest, stating a reason, how the addition of a catalyst at constant pressure and temperature will affect the equilibrium concentration of SO_2Cl_2. [2]

b. Graphing is an important method in the study of the rates of chemical reaction. Sketch a graph to show how the reactant concentration changes with time in a typical chemical reaction taking place in solution. Show how the rate of the reaction at a particular time can be determined. [4]

c.i. The concentration of H_2O_2 is increased at constant temperature. [2]

c.ii. The solution of NaI is prepared from a fine powder instead of large crystals. [2]

d. Explain why the rate of a reaction increases when the temperature of the system increases. [3]

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]

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.

$$CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$$

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

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

After one week, a $5.00 \pm 0.05\ cm^3$ sample of the final equilibrium mixture was pipetted out and titrated with $0.200\ mol\,dm^{-2}$ 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 $0.200\ mol\,dm^{-3}$ 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. The standard enthalpy change of three combustion reactions are given below. [4]

$$\begin{array}{ll} H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) & \Delta H = -286\ \text{kJ mol}^{-1} \\ C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l) & \Delta H = -2219\ \text{kJ mol}^{-1} \\ C(s) + O_2(g) \rightarrow CO_2(g) & \Delta H = -394\ \text{kJ mol}^{-1} \end{array}$$

Determine the change in enthalpy, ΔH, in kJ mol^{-1}, for the formation of propane in the following reaction.

$3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$

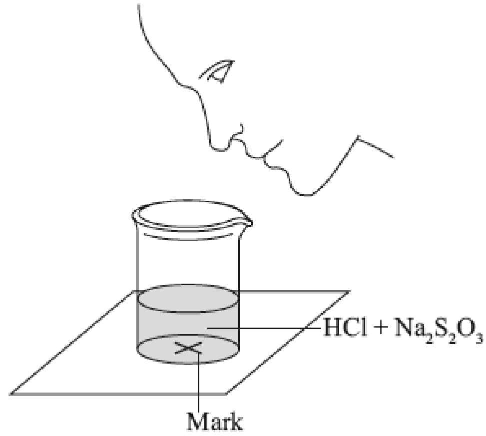
b. A catalyst provides an alternative pathway for a reaction, lowering the activation energy, E_a. Define the term *activation energy*, E_a. [1]

c. Sketch **two** Maxwell–Boltzmann energy distribution curves for a fixed amount of gas at two different temperatures, T_1 and T_2 $(T_2 > T_1)$ and label **both** axes. [3]

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

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

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]

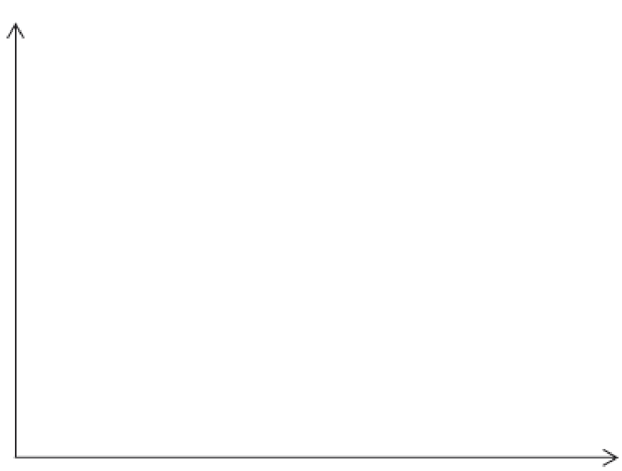
b. (i) State the volumes of the liquids that should be mixed. [4]

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.

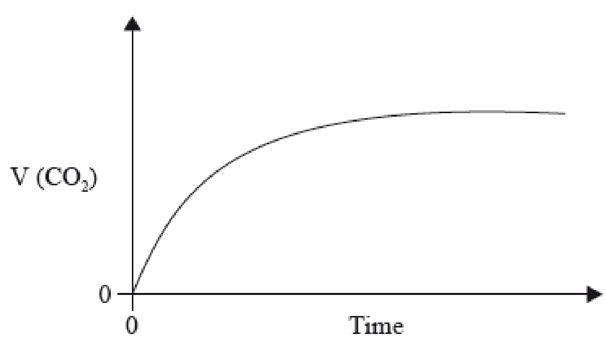
e. (i) Calculate the volume of sulfur dioxide, in cm^3, that the original reaction mixture would produce if it were collected at $1.00 \times 10^5\ \mathrm{Pa}$ and 300 K. [4]

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

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

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

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 $\mathrm{OH^-}$ 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 [2] following dynamic equilibrium exists.

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

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.

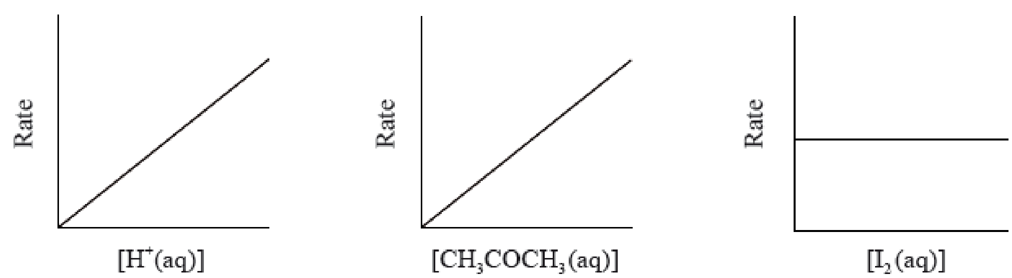
Alex and Hannah were asked to investigate the kinetics involved in the iodination of propanone. They were given the following equation by their

teacher.

$$CH_3COCH_3(aq) + I_2(aq) \xrightarrow{H^+(aq)} CH_2ICOCH_3(aq) + HI(aq)$$

Alex's hypothesis was that the rate will be affected by changing the concentrations of the propanone and the iodine, as the reaction can happen without a catalyst. Hannah's hypothesis was that as the catalyst is involved in the reaction, the concentrations of the propanone, iodine and the hydrogen ions will all affect the rate.

They carried out several experiments varying the concentration of one of the reactants or the catalyst whilst keeping other concentrations and conditions the same. Their results are shown graphically below.



(a) Discuss whether either Alex's or Hannah's hypothesis is correct.

(b) Explain why the reaction rate will increase with increasing temperature.

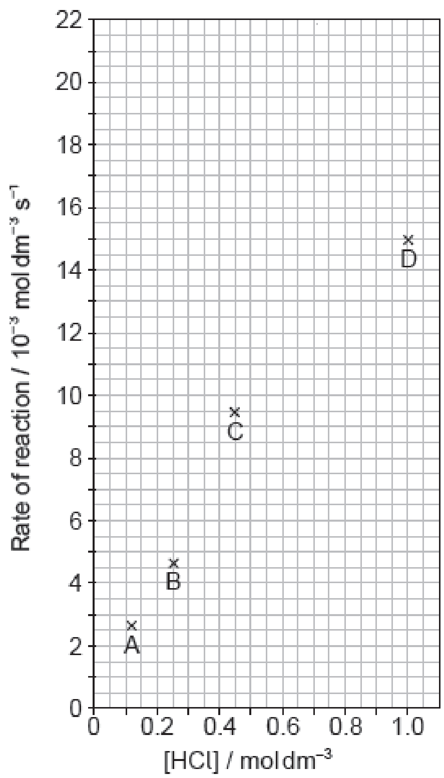
(c) (i) This reaction uses a catalyst. Sketch and annotate the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst on labelled axes below.

(ii) Describe how a catalyst works.

Calcium carbonate reacts with hydrochloric acid.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

The results of a series of experiments in which the concentration of HCl was varied are shown below.



a. Outline **two** ways in which the progress of the reaction can be monitored. No practical details are required. [2]

b.i. Suggest why point D is so far out of line assuming human error is not the cause. [1]

b.ii. Suggest the relationship that points A, B and C show between the concentration of the acid and the rate of reaction. [1]

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 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]

$$K_2O(s) + Na_2O(s) + SiO_2(s) \rightarrow Na_2K_2SiO_4(s)$$

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]

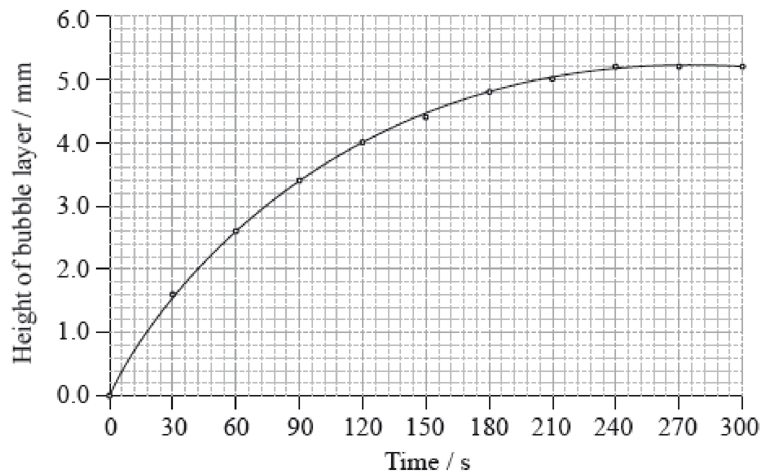
d.ii. The students also discovered that a small increase in temperature (*e.g.* 10 °C) causes a large increase (*e.g.* doubling) in the rate of this reaction. [1]

State **one** reason for this.

Hydrogen peroxide, $H_2O_2(aq)$, releases oxygen gas, $O_2(g)$, as it decomposes according to the equation below.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

$50.0\ cm^3$ of hydrogen peroxide solution was placed in a boiling tube, and a drop of liquid detergent was added to create a layer of bubbles on the top of the hydrogen peroxide solution as oxygen gas was released. The tube was placed in a water bath at 75 °C and the height of the bubble layer was measured every thirty seconds. A graph was plotted of the height of the bubble layer against time.



The experiment was repeated using solid manganese(IV) oxide, $MnO_2(s)$, as a catalyst.

The decomposition of hydrogen peroxide to form water and oxygen is a redox reaction.

a. Explain why the curve reaches a maximum. [1]

b. Use the graph to calculate the rate of decomposition of hydrogen peroxide at 120 s. [3]

c. (i) Draw a curve on the graph opposite to show how the height of the bubble layer changes with time when manganese(IV) oxide is present. [3]

(ii) Explain the effect of the catalyst on the rate of decomposition of hydrogen peroxide.

d. (i) Deduce the oxidation numbers of oxygen present in each of the species below. [4]

Species	Oxidation number of oxygen
H_2O_2	
H_2O	
O_2	

(ii) State two half-equations for the decomposition of hydrogen peroxide.

Oxidation:

Reduction:

Methanol may be produced by the exothermic reaction of carbon monoxide gas and hydrogen gas.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H^{\ominus} = -103 \text{ kJ}$$

State and explain the effect of changing the following conditions on the amount of methanol present at equilibrium:

a. State the equilibrium constant expression, K_c, for the production of methanol. [1]

b.i. increasing the temperature of the reaction at constant pressure. [2]

b.iii. increasing the pressure of the reaction at constant temperature. [2]

c. The conditions used in industry during the production of methanol are a temperature of 450 °C and pressure of up to 220 atm. Explain why these conditions are used rather than those that could give an even greater amount of methanol. [2]

d. A catalyst of copper mixed with zinc oxide and alumina is used in industry for this production of methanol. Explain the function of the catalyst. [1]

Consider the following equilibrium:

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \quad \Delta H^\ominus = -909 \text{ kJ}$$

Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H^\ominus = -92.6 \text{ kJ}$$

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

a.ii. Predict the direction in which the equilibrium will shift when the following changes occur. [4]

The volume increases.

The temperature decreases.

$H_2O(g)$ is removed from the system.

A catalyst is added to the reaction mixture.

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

c. Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism. [2]

$$\begin{aligned} & O_3 \rightarrow O_2 + O\bullet \\ & O_3 + NO \rightarrow NO_2 + O_2 \\ & NO_2 + O\bullet \rightarrow NO + O_2 \\ \text{Overall:} \quad & 2O_3 \rightarrow 3O_2 \end{aligned}$$

State and explain whether or not NO is acting as a catalyst.

d.i. Define the term *endothermic reaction*. [1]

d.ii. Sketch the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst, and label both axes. [3]

e.i. Define the term *rate of reaction*. [1]

f. Iron, used as the catalyst in the Haber process, has a specific heat capacity of $0.4490 \text{ J g}^{-1}\text{K}^{-1}$. If 245.0 kJ of heat is supplied to 8.500 kg of iron, initially at a temperature of 15.25 °C, determine its final temperature in K. [3]

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

b. State **two** conditions necessary for a reaction to take place between two reactant particles. [2]

c. Sketch an enthalpy level diagram to describe the effect of a catalyst on an *exothermic* reaction. [3]

Consider the following equilibrium.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^\ominus = -198\ kJ\ mol^{-1}$$

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

a.ii. State and explain the effect of increasing the temperature on the yield of sulfur trioxide. [2]

a.iii. State the effect of a catalyst on the value of K_c. [1]

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

b.i. Define *oxidation* in terms of oxidation numbers. [1]

b.ii. Describe using a labelled diagram, the essential components of an electrolytic cell. [3]

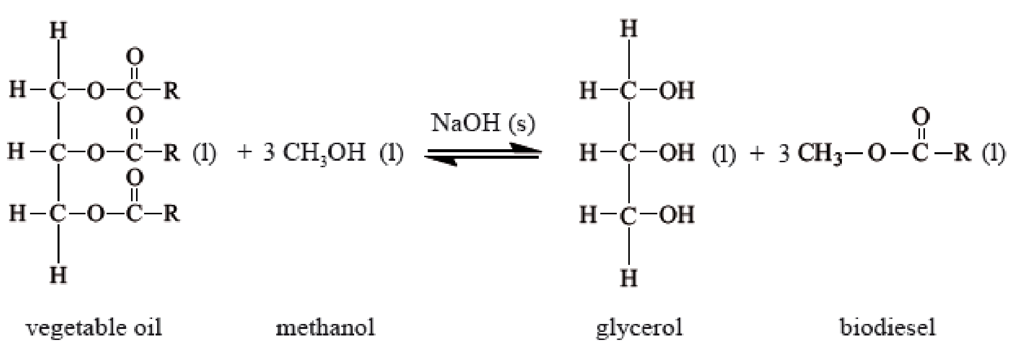
b.iii. Explain why solid sodium chloride does not conduct electricity but **molten** sodium chloride does. [2]

b.iv. Molten sodium chloride undergoes electrolysis in an electrolytic cell. For each electrode deduce the half-equation and state whether oxidation or reduction takes place. Deduce the equation of the overall cell reaction including state symbols. [5]

b.v. Electrolysis has made it possible to obtain reactive metals such as aluminium from their ores, which has resulted in significant developments in engineering and technology. State **one** reason why aluminium is preferred to iron in many uses. [1]

b.vi. Outline **two** differences between an electrolytic cell and a voltaic cell. [2]

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.



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]

$$\begin{aligned} &\text{Mass of oil} && = 1013.0 \text{ g} \\ &\text{Mass of methanol} && = 200.0 \text{ g} \\ &\text{Mass of sodium hydroxide} && = 3.5 \text{ g} \\ &\text{Mass of biodiesel produced} && = 811.0 \text{ g} \end{aligned}$$

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]

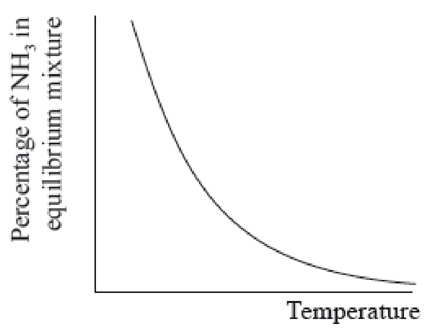
e. Calculate the percentage yield of biodiesel obtained in this process. [2]

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 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. [3]

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

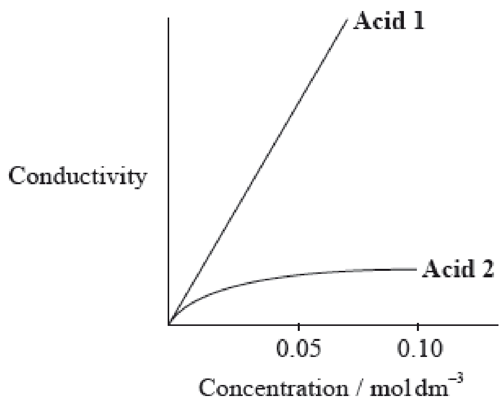
d. A small piece of magnesium ribbon is added to solutions of nitric and nitrous acid of the same concentration at the same temperature. Describe [2]

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 $15.0\ \text{cm}^3$ solution of $0.10\ \text{mol dm}^{-3}$ 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 $0.20\ \text{mol dm}^{-3}$ 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.

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:

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

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

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

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

$50.0 \pm 0.1\ \text{cm}^3$ 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 cm^3, of the volume of the reaction mixture. [1]

h. The colour change occurs when 1.00×10^{-4} 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]

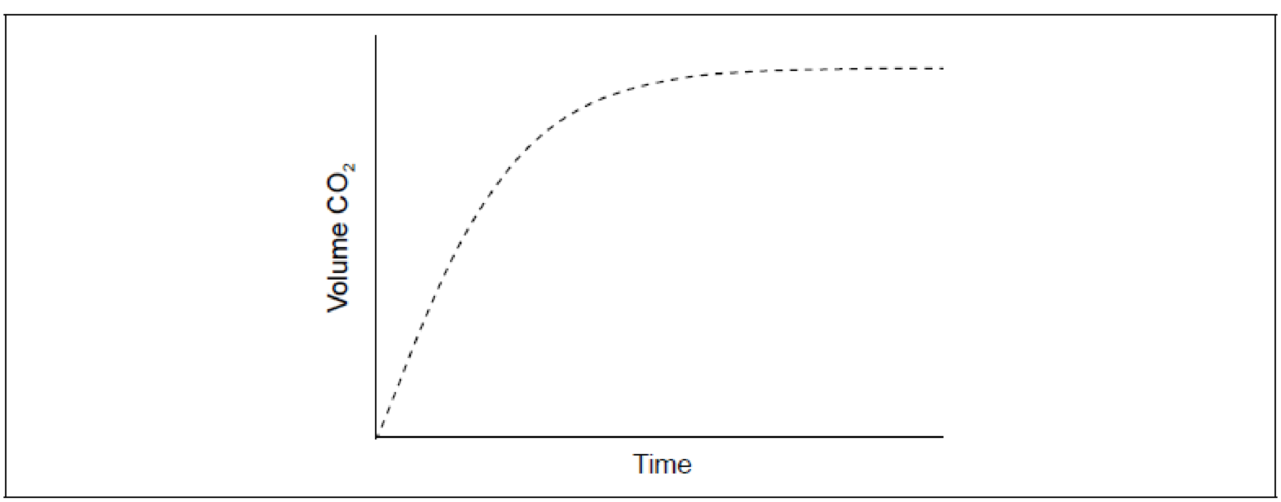
i. In a second experiment, the concentration of the hydrogen peroxide was decreased to 1.00 mol dm^{-3} while all other concentrations and volumes remained unchanged. The colour change now occurred after 100 seconds. Explain why the reaction in this experiment is slower than in the original experiment.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

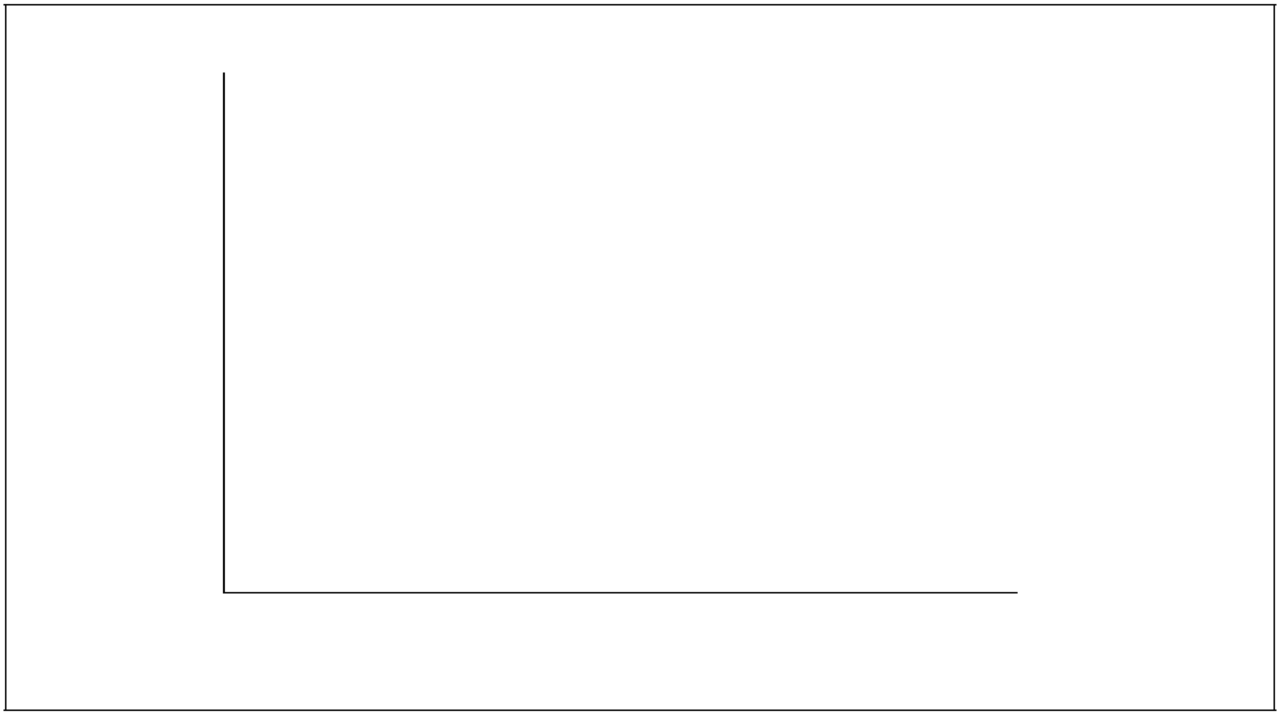
k. Explain why increasing the temperature also decreases the time required for the colour to change. [2]

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]

The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, $SO_3(g)$.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H^\ominus = -198 \text{ kJ}$$

a. Define the term *rate of reaction*. [1]

b. Describe the collision theory. [3]

The Contact process involves an exothermic reversible reaction.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad K_c \gg 1 \text{ at 200 °C and 1 atm}$$

a. Deduce the extent of the reaction at 200 °C and 1 atm. [1]

b. The Contact process operates at a temperature of 450 °C and a pressure of 2 atm as optimum conditions for the production of SO_3. Outline the reasons for choosing these conditions. [4]

Temperature:

Pressure:

c. An engineer at a Contact process plant hypothesized that using pure oxygen, instead of air, would increase the profits. Comment on whether or not her hypothesis is valid, giving your reasons. [2]

Chemical equilibrium and kinetics are important concepts in chemistry.

The oxidation of sulfur dioxide is an important reaction in the Contact process used to manufacture sulfuric acid.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -198.2 \text{ kJ}$$

Vanadium(V) oxide, V_2O_5, is a catalyst that can be used in the Contact process. It provides an alternative pathway for the reaction, lowering the activation energy, E_a.

a. A glass container is half-filled with liquid bromine and then sealed. The system eventually reaches a dynamic equilibrium. State **one** characteristic of a system in equilibrium. [1]

b. (i) Deduce the equilibrium constant expression, K_c. [4]

(ii) Predict how each of the following changes affects the position of equilibrium and the value of K_c.

	Position of equilibrium	Value of K_c
Decrease in temperature		
Increase in pressure		
Addition of a catalyst		

c. (i) Define the term *activation energy*, E_a. [4]

(ii) Sketch the **two** Maxwell–Boltzmann energy distribution curves for a fixed amount of gas at two different temperatures, T_1 and T_2 $(T_2 > T_1)$. Label **both** axes.

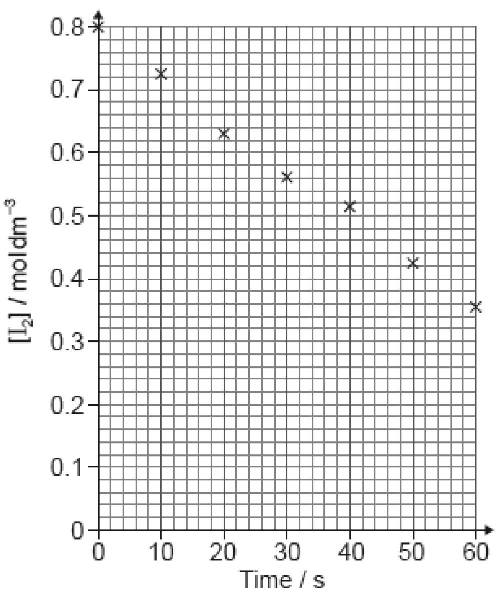
The rate of the acid-catalysed iodination of propanone can be followed by measuring how the concentration of iodine changes with time.

$$I_2(aq) + CH_3COCH_3(aq) \rightarrow CH_3COCH_2I(aq) + H^+(aq) + I^-(aq)$$

a.i. Suggest how the change of iodine concentration could be followed. [1]

a.ii. A student produced these results with $[H^+] = 0.15 \text{ mol dm}^{-3}$. Propanone and acid were in excess and iodine was the limiting reagent. [2]

Determine the relative rate of reaction when $[H^+] = 0.15 \text{ mol dm}^{-3}$.



b. The student then carried out the experiment at other acid concentrations with all other conditions remaining unchanged. [2]

$[H^+]$ / mol dm^{-3}	Relative rate of reaction
0.05	0.0025
0.10	0.0051
0.20	0.0100

State and explain the relationship between the rate of reaction and the concentration of acid.

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.

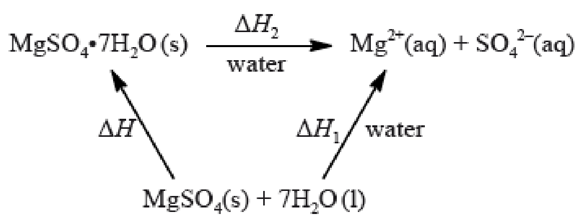
$$Mg(s) + H_2SO_4(aq) \rightarrow H_2(g) + MgSO_4(aq)$$

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

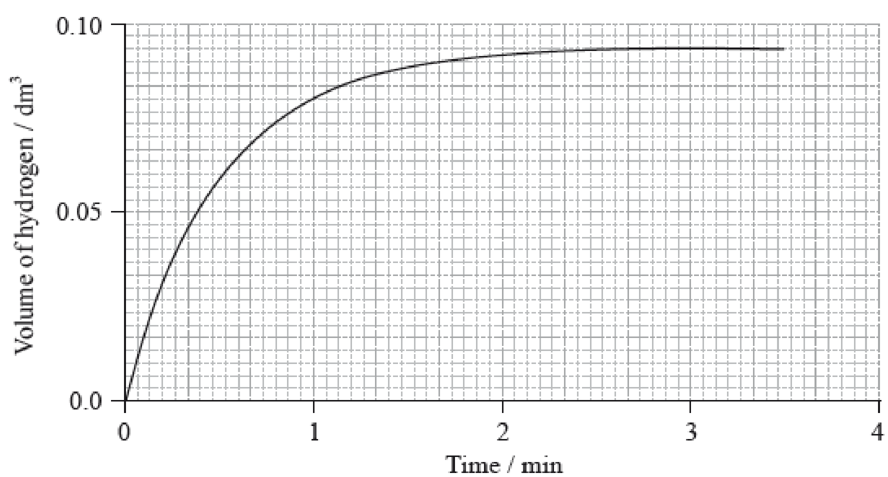
The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, $MgSO_4 \bullet 7H_2O(s)$, and $50.0\ cm^3$ of water. They found the enthalpy change, ΔH_2, to be $+18\ kJ\ mol^{-1}$.

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 $50\ cm^3$ of $0.500\ mol\ dm^{-3}$ 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:

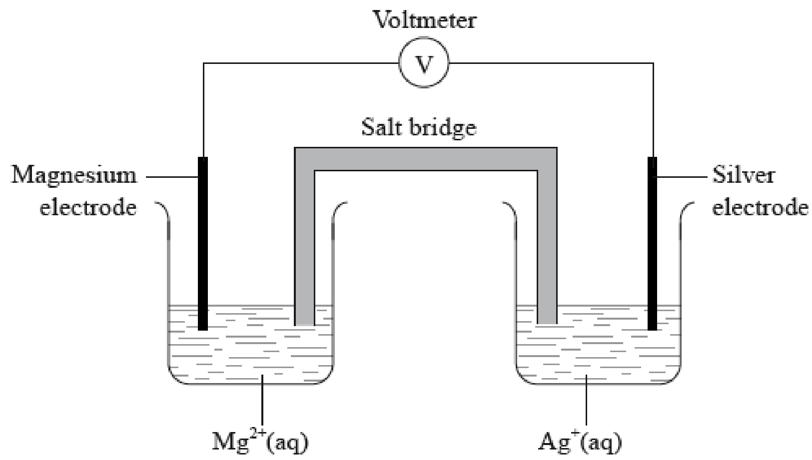
Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide, $Fe_2O_3 \bullet nH_2O$, as the final product.

The half-equations involved for the first step of rusting are given below.

Half-equation 1: $\mathrm{Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-}$

Half-equation 2: $\mathrm{O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)}$

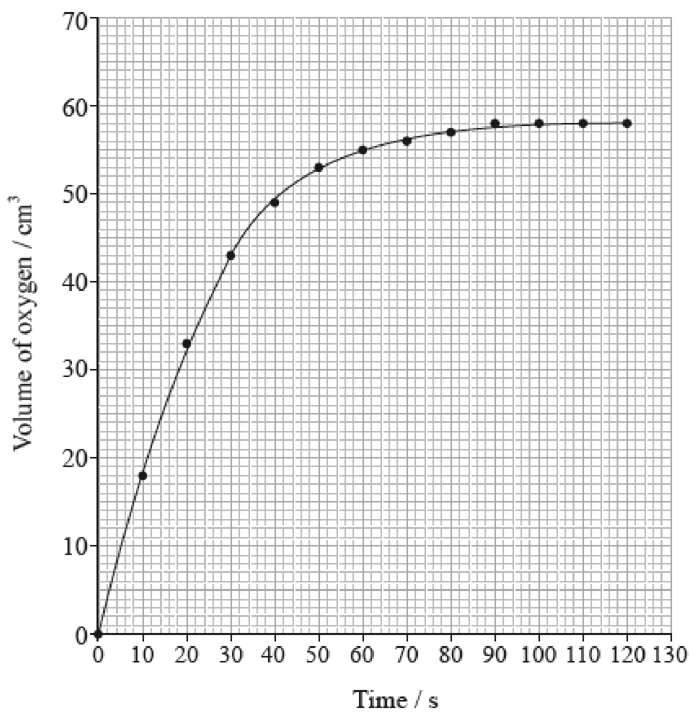
A voltaic cell is made from a half-cell containing a magnesium electrode in a solution of magnesium nitrate and a half-cell containing a silver electrode in a solution of silver(I) nitrate.



Hydrogen peroxide decomposes according to the equation below.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The rate of the decomposition can be monitored by measuring the volume of oxygen gas released. The graph shows the results obtained when a solution of hydrogen peroxide decomposed in the presence of a CuO catalyst.



a. (i) Identify whether half-equation 1 represents oxidation or reduction, giving a reason for your answer. [5]

(ii) Identify the oxidation number of each atom in the three species in half-equation 2.

$$O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)$$

(iii) Deduce the overall redox equation for the first step of rusting by combining half-equations 1 and 2.

(iv) Identify the reducing agent in the redox equation in part (iii).

b. The oxygen in half-equation 2 is atmospheric oxygen that is found dissolved in water in very small concentrations. Explain, in terms of intermolecular forces, why oxygen is not very soluble in water. [2]

c. (i) Given that magnesium is more reactive than silver, deduce the half-equations for the reactions occurring at each electrode, including state symbols. [3]

Negative electrode (anode):

Positive electrode (cathode):

(ii) Outline **one** function of the salt bridge.

d. (i) State the property that determines the order in which elements are arranged in the periodic table. [3]

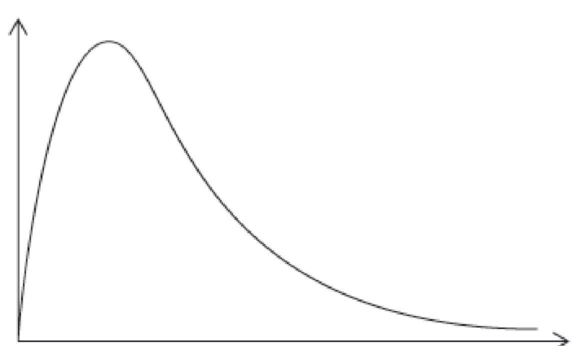
(ii) State the relationship between the electron arrangement of an element and its group and period in the periodic table.

e. (i) The experiment is repeated with the same amount of a more effective catalyst, MnO_2, under the same conditions and using the same concentration and volume of hydrogen peroxide. On the graph above, sketch the curve you would expect. [7]

(ii) Outline how the initial rate of reaction can be found from the graph.

(iii) Outline a different experimental procedure that can be used to monitor the decomposition rate of hydrogen peroxide.

(iv) A Maxwell–Boltzmann energy distribution curve is drawn below. Label both axes and explain, by annotating the graph, how catalysts increase the rate of reaction.



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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.

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]

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

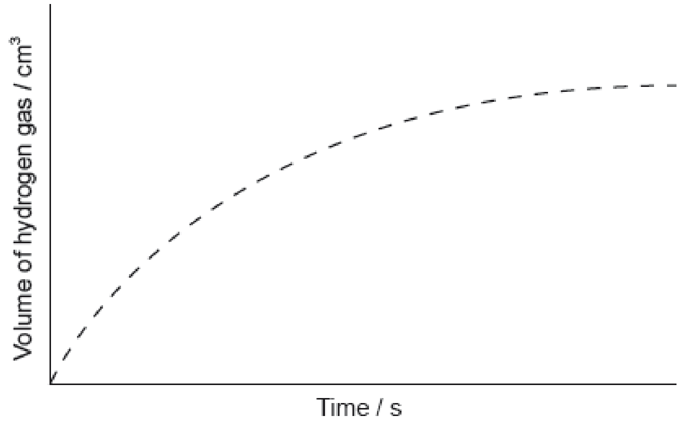
Acid	Conjugate base
....	....
....	....

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

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.

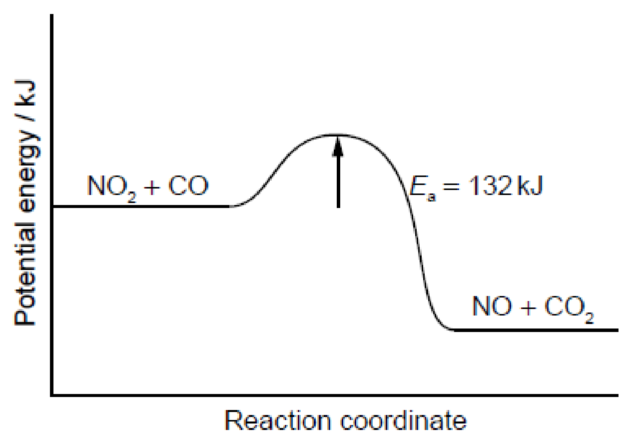


a.i. Outline why the rate of the reaction decreases with time. [1]

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]

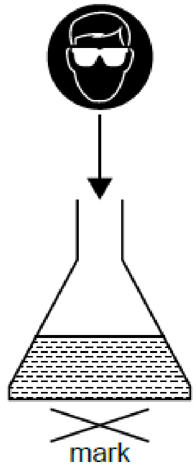
Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

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

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.

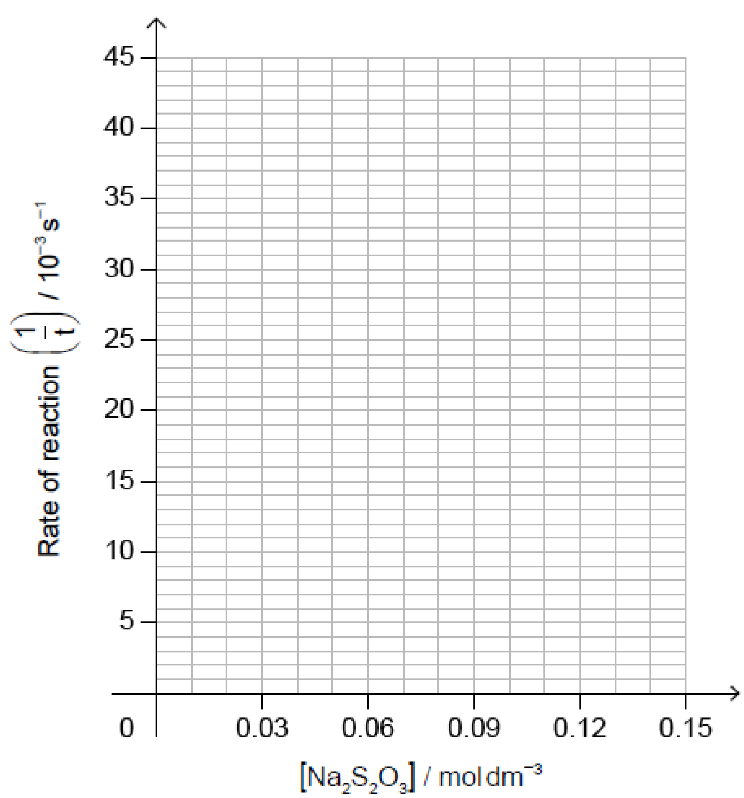
Experiment	**$[Na_2S_2O_3(aq)]$ / mol dm^{-3}**	**Time, t, for mark to disappear / s ± 1 s**	**$\frac{1}{t}$* / 10^{-3} s^{-1}**
1	0.150	23	43.5
2	0.120	27	37.0
3	0.090	36	27.8
4	0.060	60	16.7
5	0.030	111	9.0

* 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]

Phosgene, $COCl_2$, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

$$CO\,(g) + Cl_2\,(g) \rightleftharpoons COCl_2\,(g) \qquad \Delta H = -108\,kJ$$

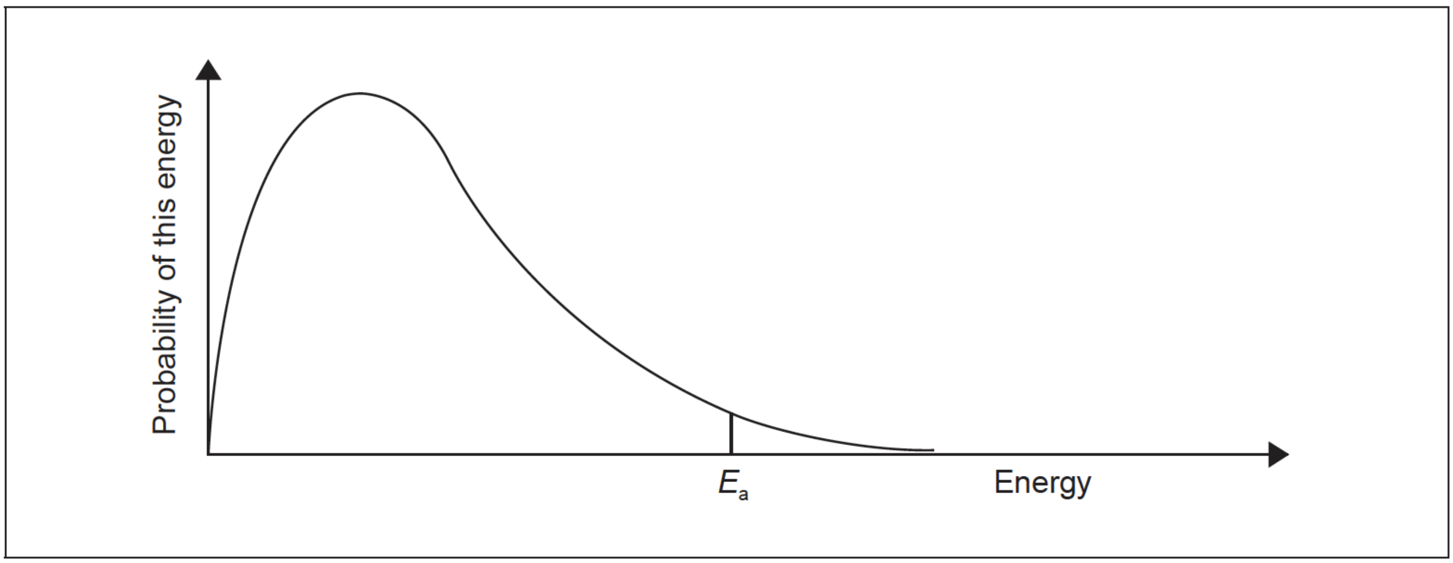
a. (i) Deduce the equilibrium constant expression, K_c, for this reaction. [2]

(ii) State the effect of an increase in the total pressure on the equilibrium constant, K_c.

b. (i) Sketch the potential energy profile for the synthesis of phosgene, using the axes given, indicating both the enthalpy of reaction and activation energy. [6]

(ii) This reaction is normally carried out using a catalyst. Draw a dotted line labelled “Catalysed” on the diagram above to indicate the effect of the catalyst.

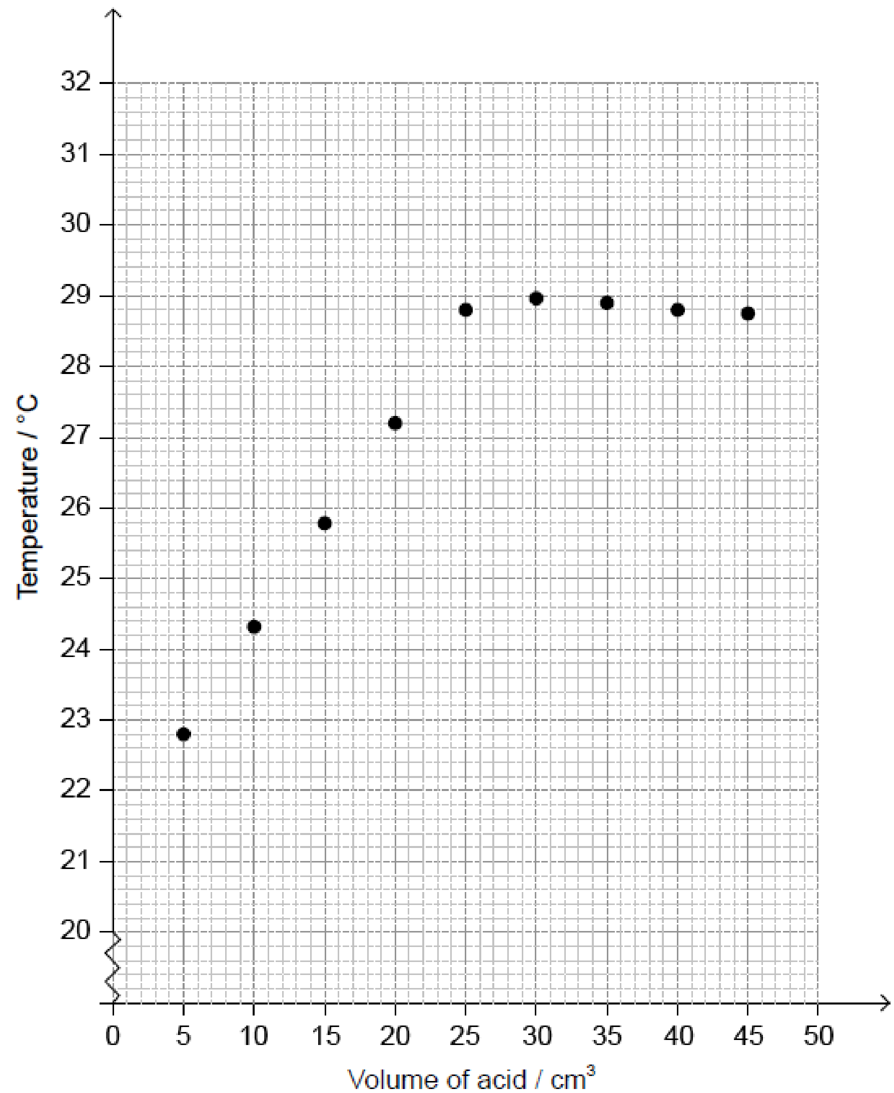
(iii) Sketch and label a second Maxwell–Boltzmann energy distribution curve representing the same system but at a higher temperature, T_{higher}.



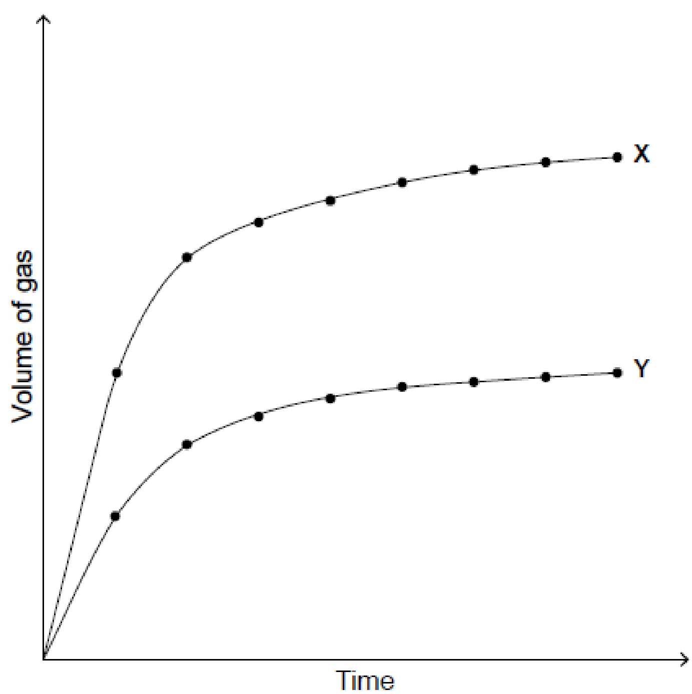
(iv) Explain why an increase in temperature increases the rate of this reaction.

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]