2017 MJC H1 Chemistry Prelim Paper 2

Section A

Answer **all** the questions in this section in the spaces provided.

1 Vitamins and minerals are essential nutrients that perform many roles in the body. They help to build bones, heal wounds, bolster the immune system and convert food into energy. Young children require many essential minerals such as calcium, magnesium, iodine, iron and zinc to develop and grow.

Table 1.1 shows the recommended daily intake of some essential minerals for children.

Table 1.1

mineral	recommended daily intake for children / mg	
	age group	
	1 – 3 years	4 – 8 years
Calcium	500	700
Iodine	0.090	0.090
Iron	9	10
Magnesium	80	130
Phosphorus	460	500
Zinc	3	4

Table 1.2 shows part of a nutrition label on a tin of powdered milk formula.

Table 1.2

Nutrition Information Standard Dilution (per 100 mL)	
Nutrients:	
Protein	2.2 g
Fat	5.1 g
Carbohydrate	11.2 g
Minerals:	
Sodium	39 mg
Potassium	106 mg
Chloride	79 mg
Calcium	119 mg
Phosphorus	69 mg
Magnesium	7.8 mg
Iron	1.03 mg
Zinc	0.7 mg
Copper	0.056 mg
Manganese	0.0094 mg
Iodine	0.011 mg

(a) Zinc helps the immune system to fight off invading bacteria and viruses.

A 2–year old child takes an average of 3 feeds of milk formula per day, with a quantity of 180 mL per feed.

Using the information provided, determine if the zinc obtained from the milk formula meets the recommended quantity for daily intake and comment if there is a need for the child to supplement his diet with zinc from other sources.

[2]

Many of the minerals in formula milk are compounds of the elements found in the Periodic Table.

(b) **L** and **M** are unknown elements of increasing atomic number in Period 3 of the Periodic Table. Each of these elements has an atomic number below 20.

(i) The successive ionisation energies, in kJ mol^{-1}, of element **L** are given below.

494 4560 6940 9540

Deduce which Group element **L** belongs to.

[2]

(ii) Hence, write the full electronic configuration of element **L** in its ground state.

[1]

(iii) The oxide of **M** dissolves partially in water to give an alkaline solution while its chloride readily dissolves in water to give a slightly acidic solution.

1. Identify element **M**.

[1]

2. State the pH of the resultant solution when the oxide and chloride of **M** are added to water separately. Write appropriate equations to support your answer.

[3]

	equations for reaction with water	pH of resultant solution
oxide of **M**		
chloride of **M**		

(c) Aluminium and sulfur are elements in Period 3.

(i) Their oxides show different behaviours in acids and bases.

With the aid of appropriate equations, describe the acid–base nature of Al_2O_3 and SO_3.

[3]

(ii) State and explain the difference in the *first* ionisation energy between aluminium and sulfur.

[2]

[Total: 14]

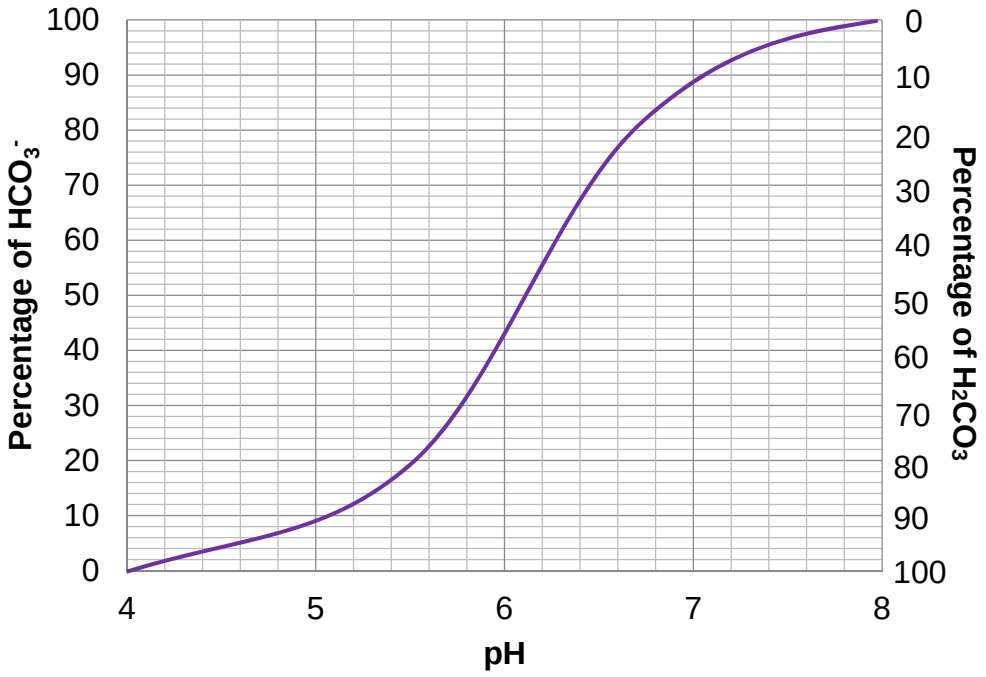
2 Many of the chemical reactions that occur in living systems are extremely sensitive to changes in pH. As a result, the human body maintains a remarkably intricate system of buffers, both within tissue cells and in the fluids that transport blood cells.

The buffer system that is used to control the pH of blood is the carbonic acid–hydrogen carbonate buffer system in the blood plasma.

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3$$

(a) **Graph 2.1** shows how the percentage of carbonic acid and hydrogen carbonate in blood plasma responds to changes in pH.

Graph 2.1



(i) Using information from the graph above, calculate the ratio of $\frac{[HCO_3^-]}{[H_2CO_3]}$ in the blood plasma for the body to function properly at a pH of 7.4.

[1]

(ii) Explain with the aid of equations, how the buffer system in blood plasma helps to control pH.

[3]

(b) Plasma contains mostly water, which accounts for 91.5% of the plasma content. Salts such as sodium, potassium, and hydrogen carbonate which are soluble in plasma can perform many important biological processes.

(i) Draw the dot–and–cross diagram for HCO_3^-.

[1]

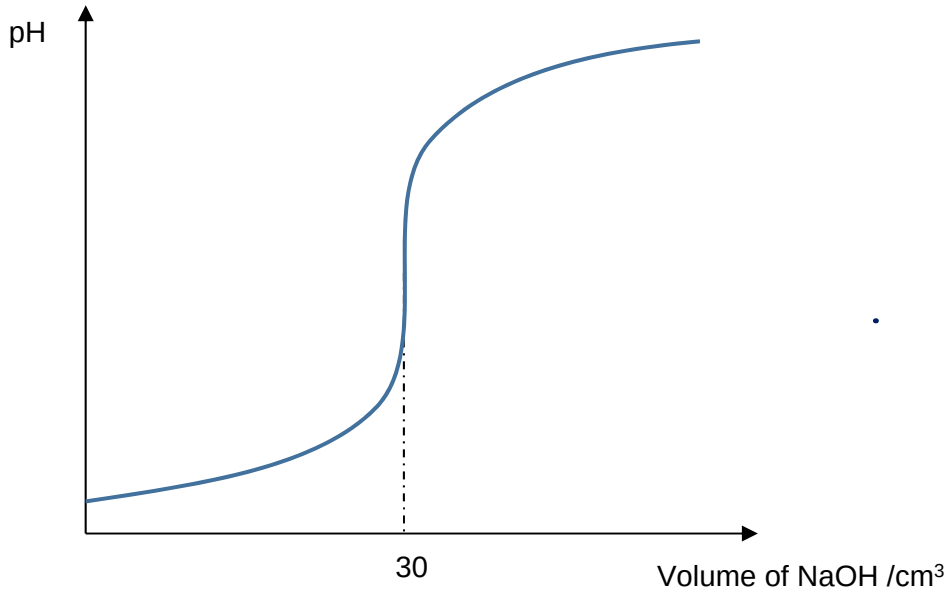
(ii) Explain why HCO_3^- is soluble in plasma. Support your answer using a labelled sketch of the interactions present.

[2]

(c) Both sulfuric acid, H_2SO_4, and carbonic acid, H_2CO_3, are dibasic acids which undergo neutralisation with sodium hydroxide.

(i) 25 cm^3 of sulfuric acid was titrated against 0.25 mol dm^{-3} sodium hydroxide. The change in pH during the titration is shown in **Graph 2.2**.

Graph 2.2



Calculate the initial pH of the sulfuric acid that is used in this experiment.

[2]

(ii) The pH of two separate samples of carbonic acid and sulfuric acid of identical concentrations are measured using a pH meter.

Explain why the sample of carbonic acid registers a higher pH value than that of sulfuric acid.

[2]

[Total: 11]

3 The Contact process is the current method of producing sulfuric acid in the industry. The key reaction in the process is as follows.

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

When a 2:1 ratio of SO_2 and O_2 at a total initial amount of 3 moles is passed over V_2O_5 catalyst in a closed 5.00 dm^3 reaction chamber at 430 ^oC, 1.9 moles of SO_3 is formed at equilibrium.

(a) Calculate the concentrations of SO_2 and O_2 formed at equilibrium.

[2]

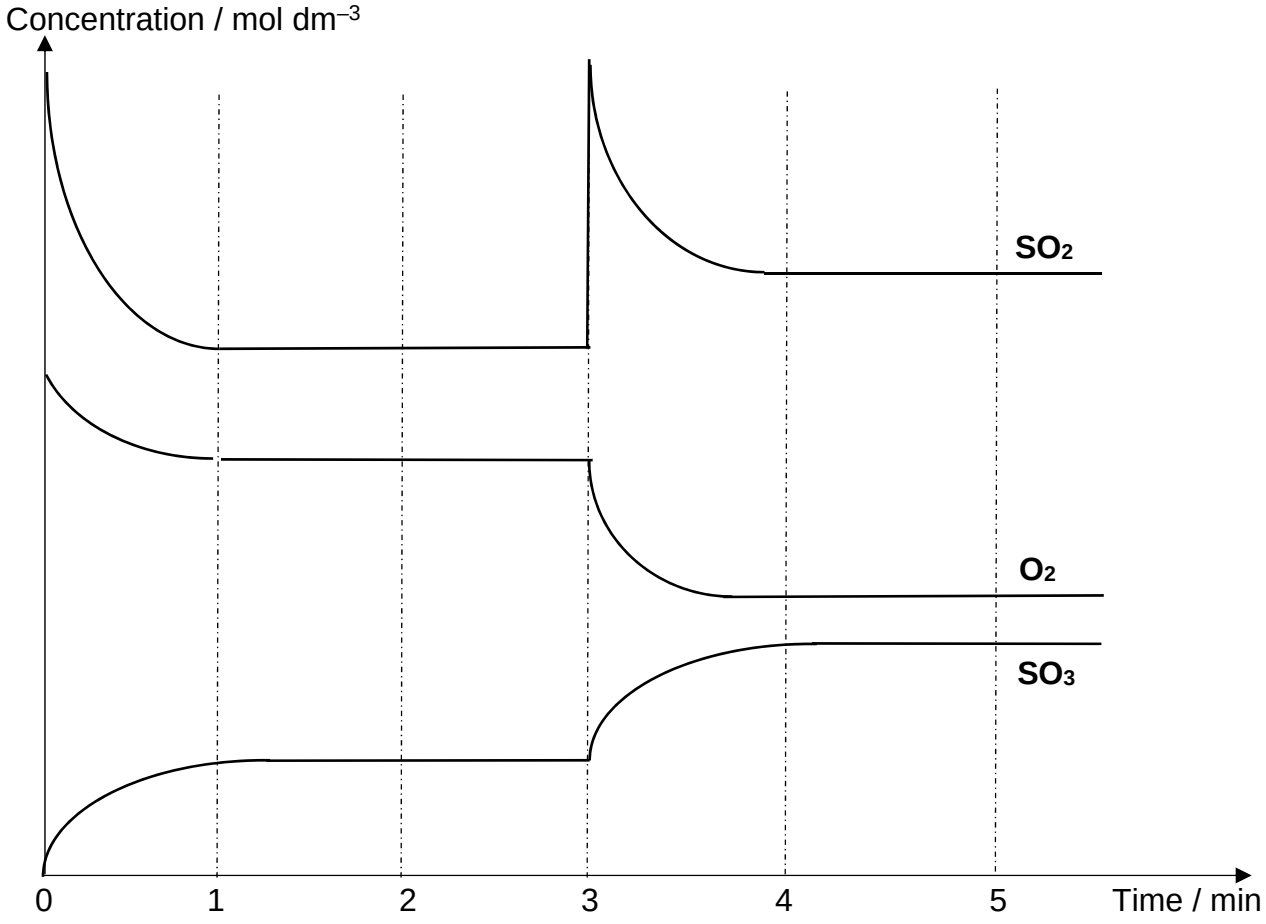
(b) Write an expression for the equilibrium constant, K_c' of the **reverse reaction** for the formation of SO_2 and O_2 at 430 ^oC. Calculate the value of K_c', stating its units.

[2]

(c) When a sample of SO_2 and O_2 were was in a closed vessel, the system was allowed to reach equilibrium.

The concentrations of all gases were measured at one minute intervals. At t = 3 min, one of the operating conditions was altered. The effects are shown graphically below.

Graph 3.1

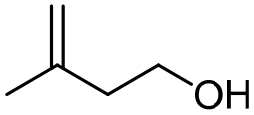


What change to the operating condition of the system has been made at t = 3 min? Account for the observed changes in the concentrations of the gases as a result of this change.

[3]

[Total: 7]

4(a) Ylang–ylang essential oil and lemongrass are often used as insect repellents. 3–methyl–3–buten–1–ol is a constituent of Ylang–ylang oil.



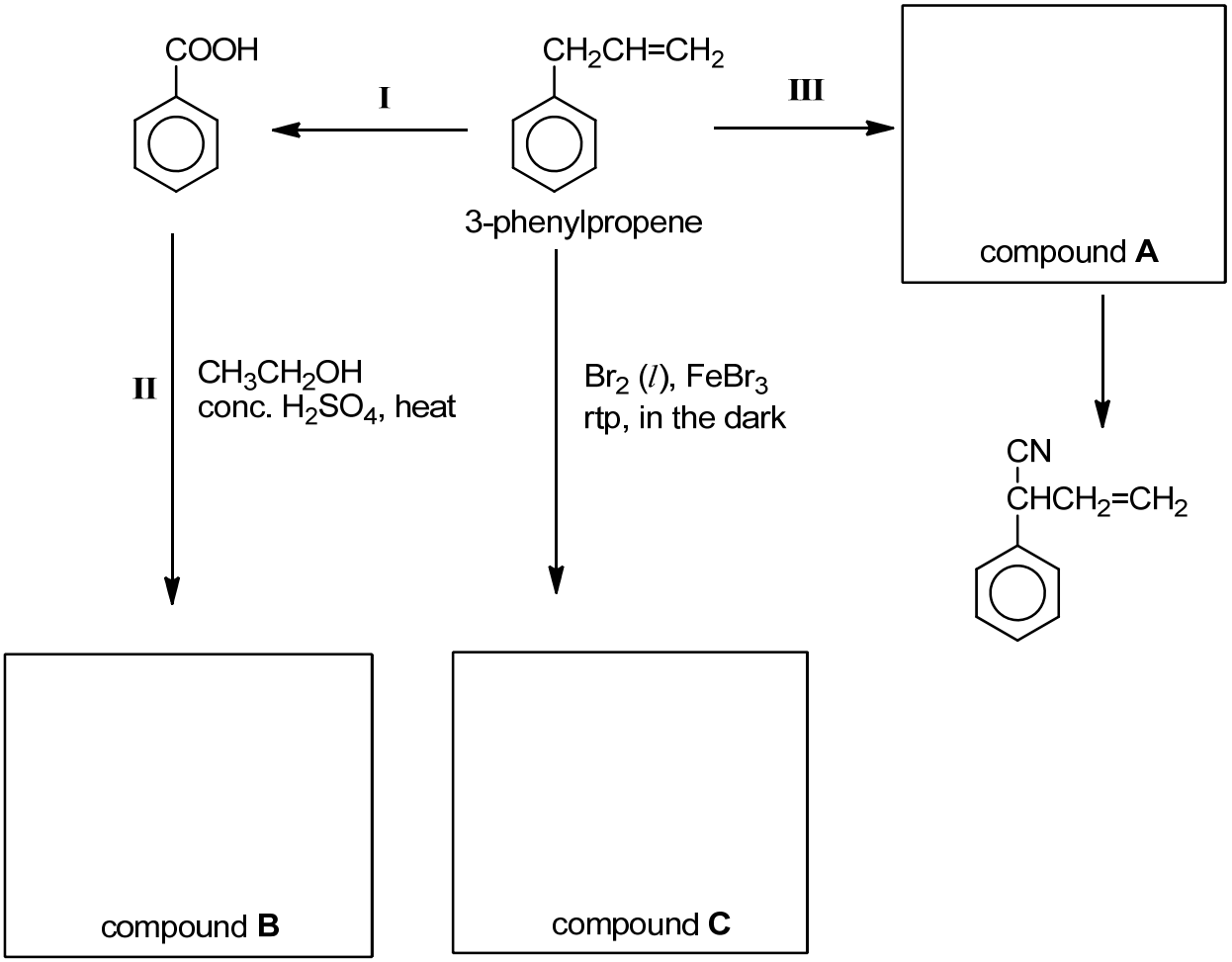
3–methyl–3–buten–1–ol

Draw the structure of the organic products formed when 3–methyl–3–buten–1–ol reacts with each of the following reagents.

reagents and conditions	organic product(s) formed
cold alkaline $KMnO_4$	
excess concentrated H_2SO_4, heat	

[2]

(b) Another ingredient that can be found in insecticides is 3–phenylpropene. It can be converted to various products as shown below.



(i) Draw the structures of compounds **A**, **B** and **C** in the boxes provided.

[3]

(ii) State the reagents and conditions for the conversion in reactions **I** and **III.**

[2]

Reaction **I**:

Reaction **III**:

(iii) Name the type of reaction for **II**.

[1]

[Total: 8]

End of Section A

Section B: Free Response Questions

Answer **two** questions from this section on separate answer papers.

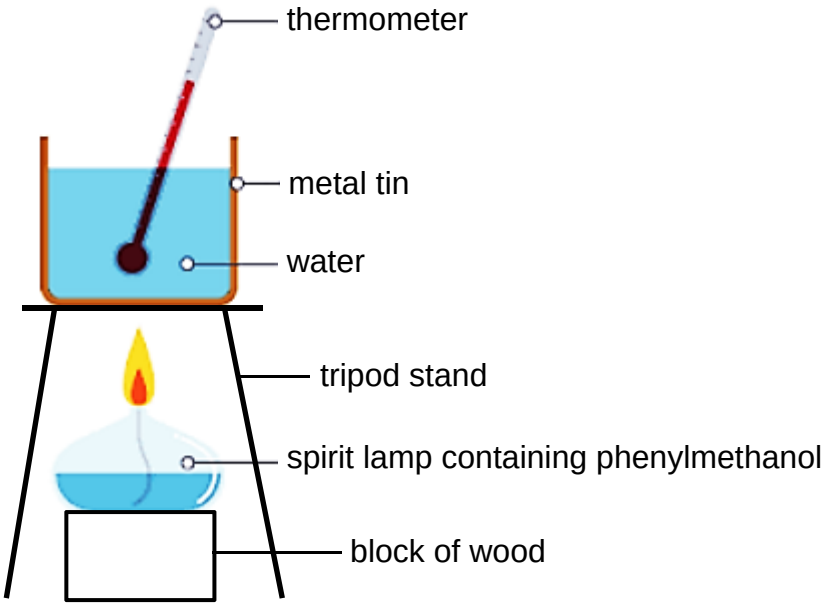
5 The *Cannizzaro* reaction which produces phenylmethanol and a benzoate salt is first discovered in 1853 by Stanislao Cannizzaro.

$$\underset{\text{benzaldehyde}}{2C_6H_5CHO} + KOH \rightarrow \underset{\text{phenylmethanol}}{C_6H_5CH_2OH} + \underset{\text{benzoate salt}}{C_6H_5CO_2K}$$

(a) In the *Cannizzaro* reaction, benzaldehyde is simultaneously reduced and oxidised when reacted with a strong base. Name the type of reaction taking place.

[1]

(b) A sample of phenylmethanol in a spirit lamp is used to heat 200 cm^3 of water in a metal tin.



The data for the experiment are as shown below.

mass of spirit lamp with phenylmethanol before heating	= 113.25 g
mass of spirit lamp with phenylmethanol after heating	= 112.22 g
temperature of water before heating	= 27.8 ^oC
temperature of water after heating	= 40.6 ^oC
molar mass of phenylmethanol	= 108 g mol^{-1}

(i) Define what is meant by *standard enthalpy change of combustion*.

[1]

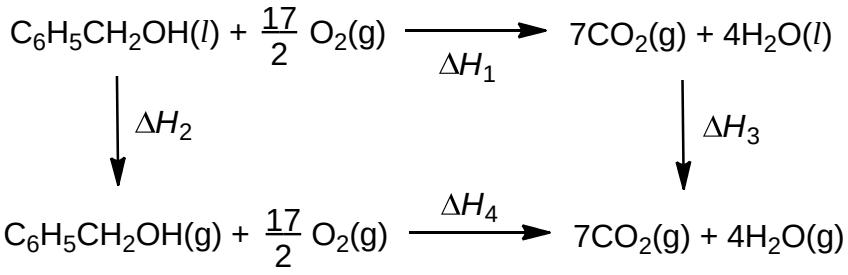
(ii) Calculate the standard enthalpy change of combustion of phenylmethanol. The reaction is known to be only 30% efficient.

[2]

(iii) State one assumption you have made in your calculation.

[1]

(c) Another value for the enthalpy change of combustion of phenylmethanol can be calculated using the following energy cycle.



(i) Using relevant data from the *Data Booklet*, calculate a value for ΔH_4.

[3]

(ii) Enthalpy change of vapourisation, ΔH_{vap}, of a substance is the energy absorbed when one mole of the substance is vapourised from the liquid to the gaseous state. Using the following enthalpy changes of vapourisation, your answer in **(c)(i)** and the given energy cycle above, calculate the enthalpy change of combustion of phenylmethanol, ΔH_1.

[2]

$\Delta H_{vap}(C_6H_5CH_2OH) = +63 \text{ kJ mol}^{-1}$
$\Delta H_{vap}(H_2O) = +41 \text{ kJ mol}^{-1}$

(iii) Sketch a clearly labelled reaction pathway diagram for the combustion reaction of phenylmethanol.

[2]

(d) The two products of the *Cannizzaro* reaction, $C_6H_5CH_2OH$ and $C_6H_5CO_2K$, can be used for ester formation. The benzoate salt is first converted to benzoic acid before esterification takes place.

(i) The acid dissociation constant, K_a, of benzoic acid and phenylmethanol are given in **Table 5.1**.

Table 5.1

compound	acid dissociation constant, K_a / mol dm^{-3}
benzoic acid, $C_6H_5CO_2H$	6.3×10^{-5}
phenylmethanol, $C_6H_5CH_2OH$	4.0×10^{-16}

Explain the large difference in the K_a values between benzoic acid and phenylmethanol.

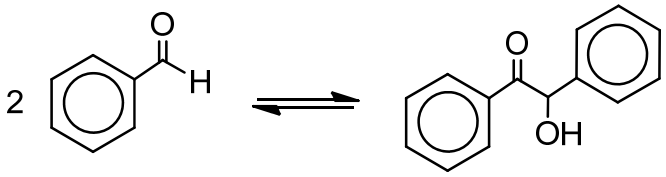
[3]

(ii) Isotope labelling is employed such that the oxygen atom in phenylmethanol is oxygen–18 (i.e. $C_6H_5CH_2{}^{18}OH$), while that in benzoic acid is oxygen–16.

Draw the structure of the organic product of the esterification reaction, labelling clearly the oxygen–18 in the product.

[1]

(e) Besides the *Cannizaro* reaction, another reaction involving benzaldehyde is the benzoin condensation shown below.



compound **J**

(i) Describe a simple chemical test to distinguish between the benzaldehyde and compound **J**.

[2]

(ii) The molecular formula of compound **J** is $C_{14}H_{12}O_2$. Compound **K** is an aromatic structural isomer of compound **J**. Compound **K** can exhibit cis–trans isomerism. Draw and label the isomers of compound **K**.

[2]

[Total: 20]

6 This question is about aldehydes, a class of organic compounds.

(a) The *Hydroformylation* reaction is an industrial process in which an alkene combines directly with carbon monoxide and hydrogen under high temperature and pressure to form an aldehyde. The reaction with ethene is shown below.

$$CH_2{=}CH_2 + CO + H_2 \xrightarrow{\text{catalyst}} CH_3CH_2CHO$$

A series of experiments is carried out to investigate the kinetics of the *Hydroformylation* reaction with ethene. The following results are obtained.

Table 6.1

experiment	$[CH_2{=}CH_2]$ / mol dm^{-3}	[CO] / mol dm^{-3}	$[H_2]$ / mol dm^{-3}	time / s
1	0.100	0.200	1.000	250
2	0.200	0.400	0.250	250
3	0.200	0.400	0.500	125

It is determined that the *order of reaction* with respect to carbon monoxide is 1.

(i) Explain the meaning of *order of reaction*.

[1]

(ii) What is the relationship between the time taken for the reaction and the initial rate of the reaction?

[1]

(iii) Using data from the table above, determine the order of reaction with respect to $CH_2{=}CH_2$ and H_2.

[3]

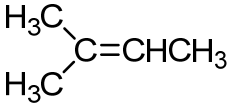
(iv) Hence, write the rate equation for the reaction.

[1]

(v) Explain quantitatively how the rate of reaction will change if the concentration of ethene is tripled while the concentration of carbon monoxide and hydrogen is each halved simultaneously.

[1]

(vi) Draw the structural formula of the product of the *Hydroformylation* reaction if the starting alkene used is 2–methylbut–2–ene instead.



[1]

(vii) The *Hydroformylation* reaction can be catalysed using platinum metal. Explain the catalytic effect on the rate of reaction with the aid of the Maxwell–Boltzmann distribution curve.

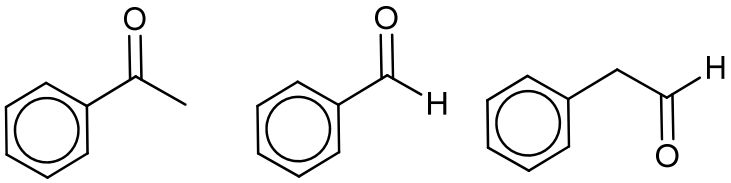
[3]

(b) Besides using the *Hydroformylation* reaction, propanal can be prepared from bromoethane, using propanoic acid as one of the intermediates.

Propose a reaction pathway, of **not more than 4 steps**, for this conversion. Your answer should include the reagents and conditions, as well as the structures of the intermediates formed.

[3]

(c) The labels of three test–tubes containing the individual compounds **P**, **Q** and **R** were mixed up.



compound **P** compound **Q** compound **R**

(i) Suggest how you can carry out two chemical tests to distinguish the three compounds. For each test, state the reagents, conditions and their observations.

[4]

(ii) One of the above three compounds reacts with $NaBH_4$ in ethanol to give compound **D**, C_7H_8O. Name the reaction and suggest the structure of compound **D**.

[1]

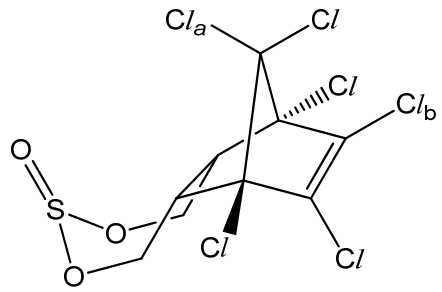
(iii) Compound **P** reacts with 2,4–DNPH to give an orange crystalline solid. Write the equation for this reaction.

[1]

[Total: 20]

7(a) *Endosulfan* is an off–patent organochlorine insecticide. It was recommended for use in India as a means of pest control against the *common lime caterpillar*, which has caused widespread damage to the agriculture in India. However, due to its threats to human health and the environment, a global ban on the manufacture and use of *endosulfan* was negotiated under the Stockholm Convention in April 2011**.**

The structure of *endosulfan* is shown below.



(i) *Endosulfan* has a solubility of 0.32 mg/L in water. However, it has a solubility of 2.40 mg/L in hexane.

Using structure and bonding, explain why *endosulfan* has a higher solubility in hexane but a lower solubility in water.

[3]

(ii) Predict and explain the bond angle and shape about the sulfur atom in *endosulfan*.

[5]

(iii) The reactivity of the organochlorine functional groups in *endosulfan* was investigated by treating separate samples of *endosulfan* with nitric acid, followed by silver nitrate solution. The results obtained were shown in **Table 7.1**.

Table 7.1

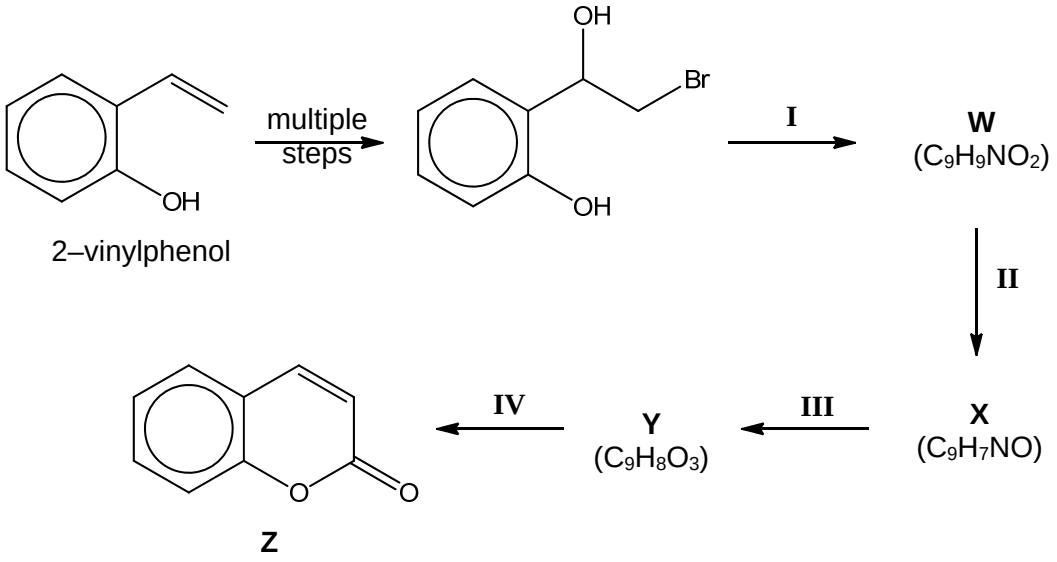
chlorine atom being reacted	time taken for white precipitate to form
Cl$_a$	≈ 1 hour
Cl$_b$	≈ 15 hours

Explain why the relative rate of formation of the white precipitate for Cl$_b$ is much slower than Cl$_a$.

[2]

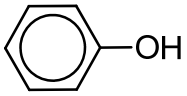
(b) *Cassia* is commonly used in traditional Chinese medicine.

The organic compound **Z** shown below, is present in *cassia*, and may be toxic to humans if consumed in large amounts. Compound **Z** can be prepared using 2–vinylphenol as the starting material using the following synthetic scheme.



(i) Chemical tests were conducted on compounds **X** and **Y**. It was found that compound **X** decolourises bromine water while effervescence was observed when solid sodium carbonate was added to compound **Y**.

Using the information given above, deduce the structural formula for compounds **W**, **X** and **Y** and explain the chemistry of the reaction involved.

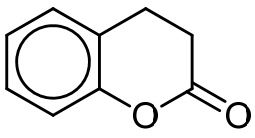
The phenol group,  may be considered to be unreactive from steps **I** to **III**.

[5]

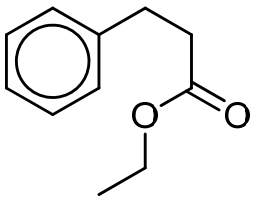
(ii) Hence, or otherwise, state the reagents and conditions needed for steps **I**, **II** and **III**.

[3]

(iii) Describe a chemical test that would allow you to distinguish between compounds **Z** and **A**, giving a positive result for compound **A**.



compound **Z**



compound **A**

[2]

[Total: 20]

End of Section B