SECTION A

1 Consider the equilibrium

$$Cl_2(g) + PCl_3(g) \rightleftharpoons PCl_5(g)$$

Which of the following is true when the total pressure of the system is increased at constant temperature?

		Value of K_p	Mole fraction of $PCl_5(g)$
☒	**A**	decreases	decreases
☒	**B**	unaltered	increases
☒	**C**	decreases	increases
☒	**D**	unaltered	unaltered

(Total for Question 1 = 1 mark)

2 In which of the following reactions is nitric acid acting as a base?

☒ **A** $HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$

☒ **B** $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$

☒ **C** $HNO_3 + H_2SO_4 \rightarrow H_2NO_3^+ + HSO_4^-$

☒ **D** $HNO_3 + NaHCO_3 \rightarrow NaNO_3 + H_2O + CO_2$

(Total for Question 2 = 1 mark)

3 Why does phenolphthalein, which is colourless in acidic solutions, turn pink in alkaline solutions?

☒ **A** It is oxidized to a pink compound by hydroxide ions.

☒ **B** It forms a pink anion by loss of H^+ ions.

☒ **C** It forms a pink anion by gain of H^+ ions.

☒ **D** It forms a pink cation by gain of H^+ ions.

(Total for Question 3 = 1 mark)

4 The dissociation of ethanoic acid in aqueous solution is represented by

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

Which of the following statements is true for this equilibrium?

☒ **A** CH_3COOH is an acid and its conjugate base is CH_3COO^-.

☒ **B** H_2O is an acid and its conjugate base is OH^-.

☒ **C** At equilibrium, the concentrations of each substance are the same.

☒ **D** At equilibrium, the reaction from left to right and the reaction from right to left have stopped.

(Total for Question 4 = 1 mark)

5 Why are aqueous solutions of sodium ethanoate slightly alkaline?

☒ **A** The sodium ions react with water to give an alkali.

☒ **B** The ethanoate ions react with water to give hydroxide ions.

☒ **C** All sodium salts give alkaline solutions.

☒ **D** The sodium ethanoate is fully ionized in solution.

(Total for Question 5 = 1 mark)

6 When ammonium nitrate crystals dissolve in water, the entropy of the system

☒ **A** remains the same.

☒ **B** falls, because the hydrated ions are more ordered than the solid.

☒ **C** rises, because the ions in the crystal become hydrated in the solution.

☒ **D** rises, because the ions are arranged more randomly in the solution than in the crystal.

(Total for Question 6 = 1 mark)

7 Which of the following molecules is a methyl ester?

☒ **A** $CH_3COOCH_2CH_3$

☒ **B** $HCOOCH_3$

☒ **C** $CH_3COCH_2CH_3$

☒ **D** CH_3COCl

(Total for Question 7 = 1 mark)

8 During the preparation of a liquid compound, samples were taken of the product at various stages in the purification procedure. Which of the following techniques would be most suitable for showing the change in composition of these samples during the purification procedure?

☒ **A** Gas-liquid chromatography

☒ **B** Fractional distillation

☒ **C** Filtration

☒ **D** Distillation

(Total for Question 8 = 1 mark)

9 Which of the following compounds would react with lithium tetrahydridoaluminate (lithium aluminium hydride) **and** also with phosphorus(V) chloride (phosphorus pentachloride)?

☒ **A** $CH_3CH_2CH_2COOH$

☒ **B** $CH_3CH_2COCH_3$

☒ **C** $CH_3CH{=}CHCH_3$

☒ **D** $CH_2{=}CHCH_2CH_2OH$

(Total for Question 9 = 1 mark)

10 In the synthesis of an ester, the use of an acyl chloride and an alcohol gives a better yield than the use of a carboxylic acid and an alcohol.

This is because the reaction between

☒ **A** an acyl chloride and an alcohol is an equilibrium.

☒ **B** an acid and an alcohol goes to completion.

☒ **C** an acid and an alcohol requires a catalyst.

☒ **D** an acyl chloride and an alcohol goes to completion.

(Total for Question 10 = 1 mark)

11 Not all molecules will absorb infrared radiation. Those that do

☒ **A** change their dipole moment when their bonds stretch or bend.

☒ **B** undergo homolytic fission.

☒ **C** must be polar.

☒ **D** are always organic substances.

(Total for Question 11 = 1 mark)

12 Which of the following methods may be used **in a single step** to make carboxylic acids?

☒ **A** Hydrolysis of an ester with an alkali.

☒ **B** Reaction of acidified potassium manganate(VII) with an alkene.

☒ **C** Hydrolysis of a nitrile with hydrochloric acid.

☒ **D** Reaction of an acyl chloride with ammonia.

(Total for Question 12 = 1 mark)

13 A solution of a weak acid cannot be titrated with a weak base using an indicator to find the end-point because

☒ **A** the pH change is too gradual close to the equivalence point.

☒ **B** there are too few H^+ ions to affect the indicator.

☒ **C** there are too few OH^- ions to affect the indicator.

☒ **D** the pH change occurs outside the range of any indicator.

(Total for Question 13 = 1 mark)

14 Which of the following reagents could be used to produce propanamide, $CH_3CH_2CONH_2$?

☒ **A** Ammonia and 1-chloropropane

☒ **B** Ammonia and propanoyl chloride

☒ **C** Methylamine and 1-chloropropane

☒ **D** Methylamine and propanoyl chloride

(Total for Question 14 = 1 mark)

15 The radio waves used in proton nmr

☒ **A** must not be absorbed by the sample.

☒ **B** cause electron transitions in the hydrogen atom.

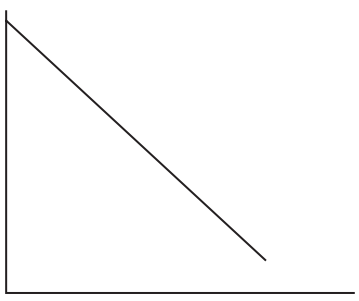
☒ **C** can only be used with organic substances.

☒ **D** cause the hydrogen nucleus to change its spin state.

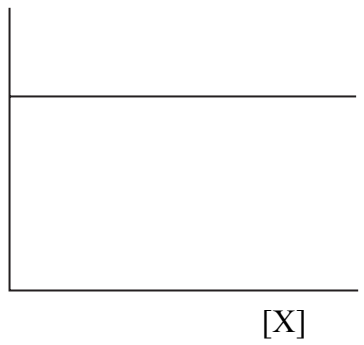
(Total for Question 15 = 1 mark)

16 Which of the following graphs shows that a reaction is first order with respect to reactant **X**?

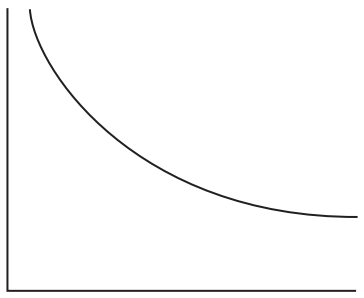
☒ **A**



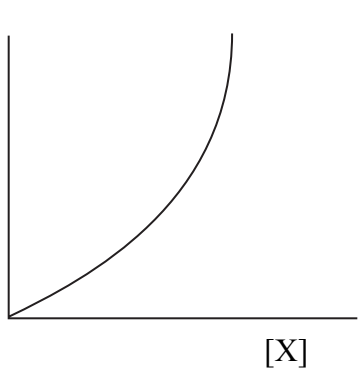
☒ **B**



☒ **C**



☒ **D**



(Total for Question 16 = 1 mark)

Turn over ▶

17 Which of the following changes will lead to the greatest increase in the **rate** of the following endothermic reaction?

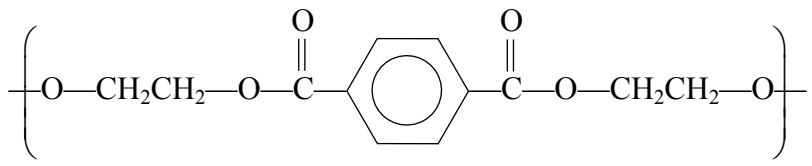
$$N_2(g) + O_2(g) \rightarrow 2NO(g) \quad \Delta H \text{ +ve}$$

		Temperature	Initial concentration of N_2 and O_2
☒	**A**	decrease by 15%	decrease by 15%
☒	**B**	increase by 15%	stay the same
☒	**C**	decrease by 15%	increase by 15%
☒	**D**	increase by 15%	increase by 15%

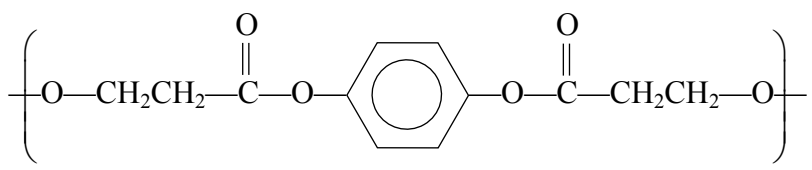
(Total for Question 17 = 1 mark)

18 The repeat unit of the polyester formed from ethane-1,2-diol, $HOCH_2CH_2OH$, and benzene-1,4-dicarboxylic acid, HOOC—C$_6$H$_4$—COOH, is

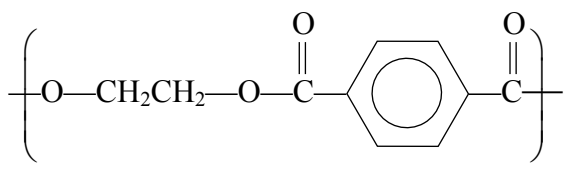
☒ **A**



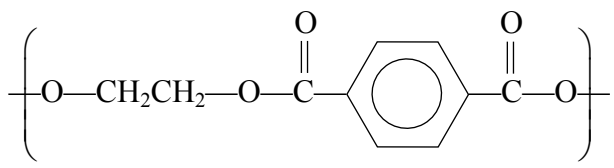
☒ **B**



☒ **C**



☒ **D**



(Total for Question 18 = 1 mark)

19 Iron and steam at high temperature react in a closed vessel to give an equilibrium mixture

$$3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$$

Which of the following is the correct expression for K_p?

☒ **A** $K_p = \dfrac{P_{H_2}}{P_{H_2O}}$

☒ **B** $K_p = \dfrac{P_{Fe_3O_4} P_{H_2}^4}{P_{Fe}^3 P_{H_2O}^4}$

☒ **C** $K_p = \dfrac{P_{H_2}^4}{P_{H_2O}^4}$

☒ **D** $K_p = P_{H_2}^4$

(Total for Question 19 = 1 mark)

20 At 100 °C, pure water has a pH of 6, whereas at 25 °C it has a pH of 7. This is because

☒ **A** the dissociation of water is endothermic, so the concentration of hydrogen ions is lower at 100 °C than it is at 25 °C.

☒ **B** the dissociation of water is exothermic, so the concentration of hydrogen ions is lower at 100 °C than it is at 25 °C.

☒ **C** the dissociation of water is endothermic, so the concentration of hydrogen ions is higher at 100 °C than it is at 25 °C.

☒ **D** at 100 °C, water has a higher concentration of hydrogen ions than of hydroxide ions.

(Total for Question 20 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

21 (a) (i) Define **pH**.

(1)

.....

(ii) Calculate the pH of 0.0100 mol dm^{-3} hydrochloric acid, which is a strong acid.

(1)

(b) Ethanoic acid is a weak acid with an acid dissociation constant, K_a, of value 1.75×10^{-5} mol dm^{-3} at 25 °C.

(i) Calculate the pH of 0.0100 mol dm^{-3} ethanoic acid at 25 °C, stating any ONE assumption that you have made.

(4)

Assumption .....

.....

.....

(ii) The pH of hydrochloric and of ethanoic acid at two different concentrations is given in the table.

	pH of 0.00100 mol dm^{-3} solution	pH of 0.000100 mol dm^{-3} solution
Hydrochloric acid	3.0	4.0
Ethanoic acid	3.9	4.4

In the case of hydrochloric acid, dilution by a factor of 10 increases the pH by one unit. Suggest why ethanoic acid behaves differently.

(2)

(c) Orange marmalade usually contains sodium citrate as a preservative. Together with the fruit in the marmalade, it forms a buffer solution which, at a suitable pH, inhibits mould growth.

(i) Define the term **buffer solution**.

(2)

(ii) What is the substance in the fruit that produces a buffer with sodium citrate?

(1)

Turn over ▶

(iii) Explain how a buffer solution works using this system or any other of your choice. Support your explanation with equations.

(4)

(Total for Question 21 = 15 marks)

22 ***(a)** Ethanol can be oxidized successively to ethanal and to ethanoic acid.

The boiling temperatures of these substances are:
ethanol 78 °C, ethanal 21 °C, ethanoic acid 118 °C.

Explain in terms of the intermolecular forces in the liquids why the order of the boiling temperature is

ethanal < ethanol < ethanoic acid

(3)

(b) State what tests you would perform in each case, and the result you would expect, to show that

(i) ethanal contains a carbonyl group.

(2)

(ii) ethanal is an aldehyde.

(2)

(c) Ethanal reacts with HCN, in the presence of a catalyst of cyanide ions from KCN, to give a cyanohydrin, $CH_3CH(OH)CN$.

(i) Give the mechanism for this reaction.

(3)

(ii) Explain why it is necessary to use HCN and KCN in this reaction, rather than HCN on its own.

(1)

*(iii) Explain why the product mixture from this reaction is **not** optically active.

(2)

(Total for Question 22 = 13 marks)

Turn over ▶

23 Iodine and propanone react in the presence of an aqueous acid catalyst as follows

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$$

To determine the rate equation for the reaction, propanone is reacted with iodine in the presence of aqueous hydrochloric acid at constant temperature. Samples are withdrawn at known times, quenched with sodium hydrogencarbonate solution, and the iodine remaining titrated with a standard solution of sodium thiosulfate.

The rate equation for the reaction is

$$\text{rate} = k[CH_3COCH_3]^1\,[H^+]^1\,[I_2]^0$$

(a) The graph of $[I_2]$ against time is a straight line, showing that the order of reaction with respect to iodine is zero.

(i) Explain why the propanone and the hydrogen ions must be in large excess in this experiment in order to give this straight line.

(2)

(ii) What further experiment could be done to show that the order of reaction with respect to propanone is one? State the effect of this change on the graph.

(2)

(iii) Explain why the minimum number of steps in the mechanism for this reaction is two.

(2)

.....

.....

.....

.....

(b) Sodium hydrogencarbonate stops the reaction by neutralizing the acid catalyst.

(i) Give the ionic equation for the reaction between sodium hydrogencarbonate and acid.

(1)

(ii) Sodium hydroxide cannot be used for neutralization because under very alkaline conditions a reaction occurs between propanone and iodine.

Write the equation for this reaction. State symbols are **not** required.

(3)

(Total for Question 23 = 10 marks)

24 Hydrogen is used in very large quantities as a fuel, as a reducing agent, and in the production of ammonia. Hydrogen is manufactured by steam reforming of methane from natural gas. Two reactions are involved, both being in equilibrium in closed systems.

Reaction I $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H = +210$ kJ mol^{-1}

Reaction II $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\Delta H = -42$ kJ mol^{-1}

(a) Write the expression for the equilibrium constant, K_p, for reaction **I**.

(1)

(b) Reaction **I** occurs at a temperature of 1000 K and a pressure of 30 atm over a nickel catalyst.

(i) State and explain the effect, if any, **on the value of K_p** of increasing the pressure on the reaction.

(1)

(ii) Explain, in terms of your answers to (a) and (b)(i), why an increase in the pressure leads to a decrease in yield in reaction **I**.

(2)

(iii) Increasing the pressure on this heterogeneously-catalysed reaction **I** has very little effect on the rate of the reaction. Suggest why this is so.

(2)

(c) The expression for K_p for reaction **II** is

$$K_p = \frac{P_{CO_2} P_{H_2}}{P_{CO} P_{H_2O}}$$

At a particular temperature and 30 atm pressure, a mixture of equal amounts of carbon monoxide and steam react to give an equilibrium mixture where 75 % of the CO has reacted.

Calculate the value of K_p showing your working.

(3)

(d) Carbon dioxide and hydrogen are separated by washing the gas with potassium carbonate solution to give potassium hydrogencarbonate solution, leaving hydrogen in the gas stream. Potassium carbonate is expensive and is regenerated by heating the potassium hydrogencarbonate and liberating the carbon dioxide.

(i) Hydrogen is often claimed to be a non-polluting fuel as it only produces water on burning.

Explain why its manufacture using reactions **I** and **II** does **not** support this claim.

(1)

(ii) Write the equation for the thermal decomposition of potassium hydrogencarbonate.

State symbols are **not** required.

(1)

(e) Although industrial processes are often discussed in terms of equilibria, they are rarely allowed to reach equilibrium.

Suggest why, apart from insufficient reaction time, this is so.

(1)

(Total for Question 24 = 12 marks)

TOTAL FOR SECTION B = 50 MARKS

SECTION C

25 The oxidation of iron metal in the presence of oxygen is spontaneous.

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

(a) Explain the meaning of **spontaneous** in a thermodynamic context.

(1)

(b) (i) Find the values of the standard molar entropies of iron and of iron(III) oxide from your data booklet.

(1)

(ii) The standard molar entropy at 298 K for oxygen molecules O_2 is +205 J mol^{-1} K^{-1}.

Calculate the standard entropy change of the system for the reaction between iron and oxygen. Include a sign and units in your answer.

(2)

(iii) The standard enthalpy change for the reaction at 25 °C is –1648 kJ mol^{-1}.

Calculate $\Delta S_{surroundings}$.

(1)

(iv) Use your answers to (b)(ii) and (iii) to calculate the total standard entropy change for the reaction. Include a sign and units in your answer.

(2)

*(v) The reaction is thermodynamically spontaneous.

Use your answers to (b)(ii), (iii) and (iv) to explain, in terms of the physical states of the substances in the reaction and the movement of the molecules in the surroundings, why this is so.

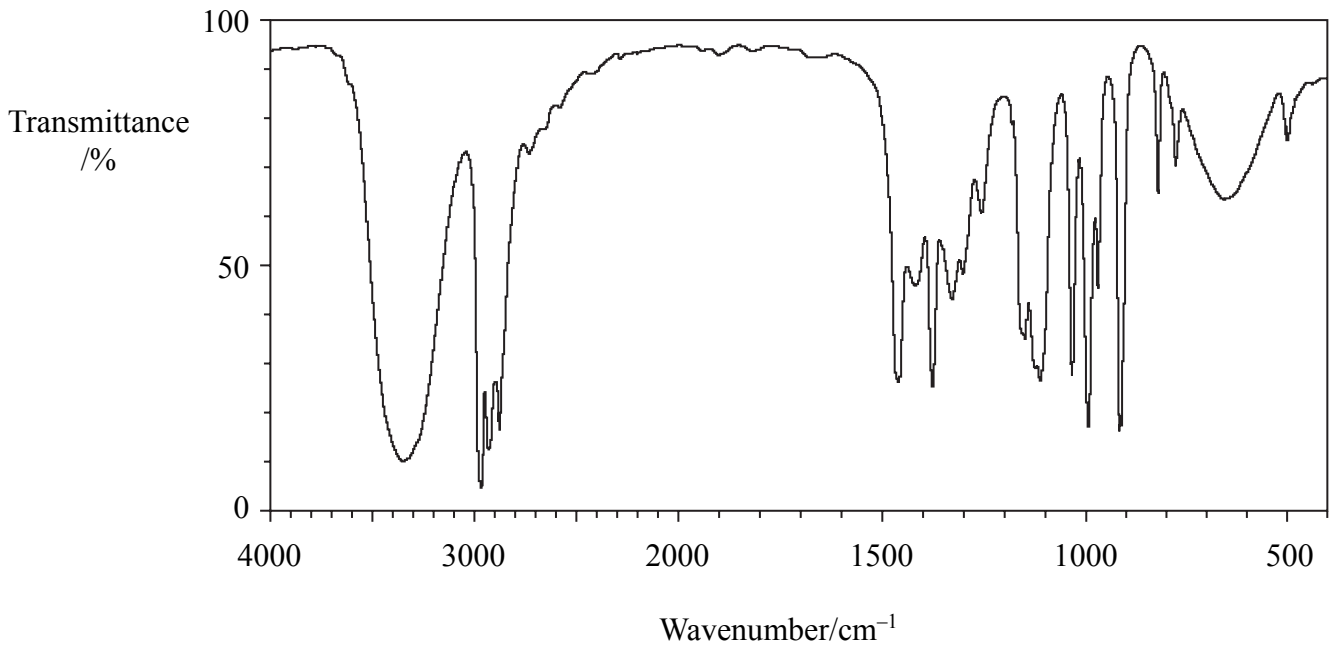
(3)

(Total for Question 25 = 10 marks)

26 This question is about compounds **X**, $C_4H_{10}O$, and **Y**, C_4H_8O.

(a) Compound **X**, $C_4H_{10}O$, can be oxidized to compound **Y**, C_4H_8O. The infrared spectrum of **X** is given below.

Infrared Spectrum of X

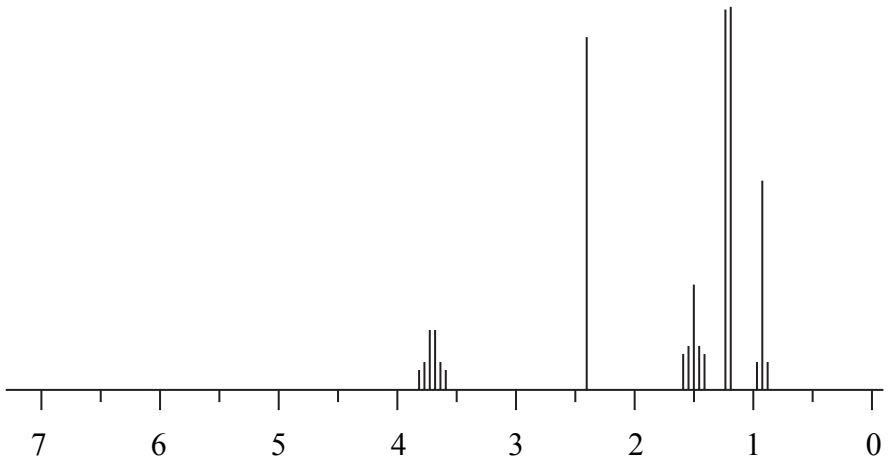


What can be deduced about the structures of **X** and **Y** using all this information and the data booklet? Justify your answer.

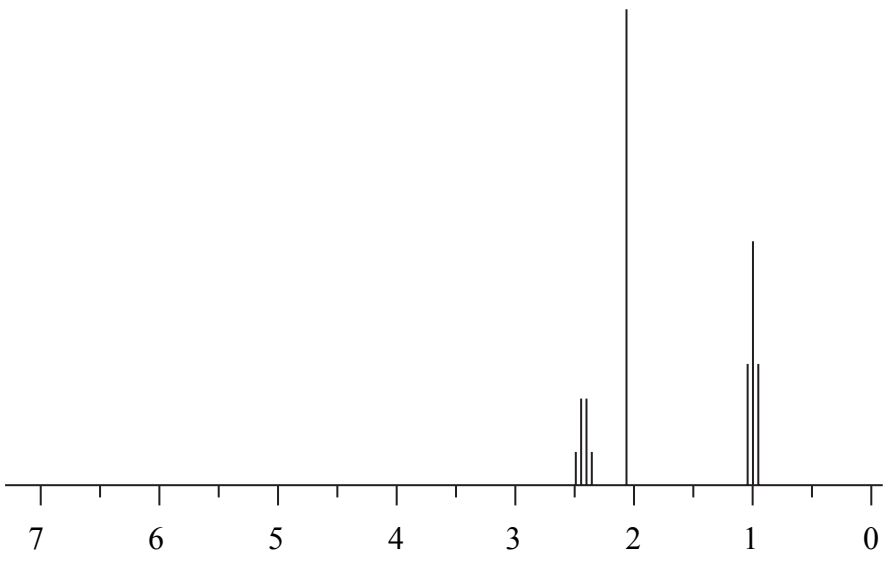
(4)

(b) Below are the nmr spectra of **X** and **Y**.

nmr spectrum of X



nmr spectrum of Y



*Use these nmr spectra and your answer to (a) to deduce the structural formulae of **X** and **Y**. Justify your answer and explain why **both** nmr spectra are consistent with these structures.

(6)

(Total for Question 26 = 10 marks)

TOTAL FOR SECTION C = 20 MARKS
TOTAL FOR PAPER = 90 MARKS

SECTION A

1 Propanone reacts with iodine in acidic solution as shown in the equation below.

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

The rate equation for the reaction is

$$\text{Rate} = k[CH_3COCH_3(aq)][H^+(aq)]$$

(a) The most appropriate technique to investigate the rate of this reaction is

(1)

☒ **A** titrating samples of reaction mixture with acid.

☒ **B** measurement of optical activity.

☒ **C** measurement of the volume of gas given off.

☒ **D** colorimetry.

(b) Which statement about the reaction is **not** correct?

(1)

☒ **A** The overall order of reaction is second order.

☒ **B** The units of the rate constant are $dm^3\ mol^{-1}\ s^{-1}$.

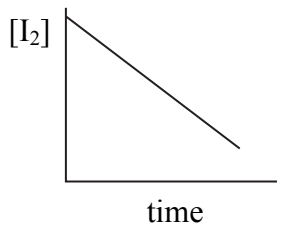
☒ **C** The rate constant increases with temperature.

☒ **D** The rate increases four times when the concentration of propanone and iodine are both doubled**.**

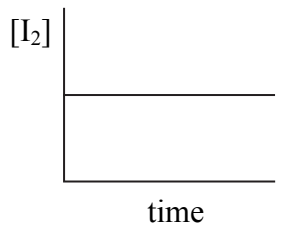
(c) The reaction is carried out using a large excess of both propanone and acid.
Which of the graphs below shows the change of iodine concentration with time?

(1)

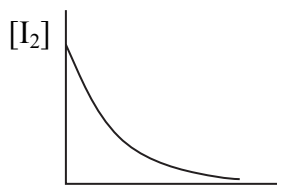
☒ **A**



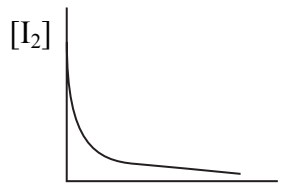
☒ **B**



☒ **C**



☒ **D**



(Total for Question 1 = 3 marks)

2 Which of the following is true for the exothermic reaction shown below?

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

☒ **A**	ΔH	positive
☒ **B**	$\Delta S_{surroundings}$	positive
☒ **C**	ΔS_{system}	negative
☒ **D**	ΔS_{total}	negative

(Total for Question 2 = 1 mark)

3 In which reaction is water acting as a Brønsted-Lowry acid?

☒ **A** $H_2O + HCl \rightarrow H_3O^+ + Cl^-$

☒ **B** $H_2O + SO_3 \rightarrow H_2SO_4$

☒ **C** $H_2O + NH_3 \rightarrow NH_4^+ + OH^-$

☒ **D** $H_2O + CO_2 \rightarrow H_2CO_3$

(Total for Question 3 = 1 mark)

4 Which of the following compounds has both optical and *E*-*Z* isomers?

☒ **A** $CH_3CH{=}CHCH_2CH_3$

☒ **B** $CH_3CHClCH{=}C(CH_3)_2$

☒ **C** $CH_3CCl{=}CClCH_3$

☒ **D** $CH_3CHBrCH{=}CHCl$

(Total for Question 4 = 1 mark)

5 Which of the following reacts with hydrogen cyanide, HCN, to make a racemic mixture?

☒ **A** Methanal, HCHO

☒ **B** Ethanal, CH_3CHO

☒ **C** Propanone, CH_3COCH_3

☒ **D** Pentan-3-one, $C_2H_5COC_2H_5$

(Total for Question 5 = 1 mark)

6 Which of the following is a redox reaction?

☒ **A** Ethanal reacting with Tollens' reagent.

☒ **B** Ethanoyl chloride reacting with ammonia.

☒ **C** Ethanoic acid reacting with ethanol.

☒ **D** Ethanoic acid reacting with sodium hydroxide.

(Total for Question 6 = 1 mark)

7 The following methods can be used to distinguish between pairs of organic compounds without further tests.

A Warm each compound with Fehling's or Benedict's solution.

B Add solid sodium carbonate to each compound.

C Add 2,4-dinitrophenylhydrazine (Brady's reagent) to each compound.

D Add water, drop by drop, to each compound.

(a) Which test would distinguish propanone from propan-1-ol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(b) Which test would distinguish between aqueous solutions of ethanoic acid and ethanol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(c) Which test would distinguish ethanoyl chloride from ethanol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 7 = 3 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

8 When propanone reacts with iodine in the presence of sodium hydroxide, the crystalline solid product has the formula

☒ **A** CH_3I

☒ **B** CHI_3

☒ **C** CH_3COCH_2I

☒ **D** CH_3COCI_3

(Total for Question 8 = 1 mark)

9 When the following reaction mixtures are warmed, which will contain ethanoic acid as one of the products?

☒ **A** Ethyl methanoate and sodium hydroxide solution.

☒ **B** Ethyl methanoate and dilute sulfuric acid.

☒ **C** Methyl ethanoate and sodium hydroxide solution.

☒ **D** Methyl ethanoate and dilute sulfuric acid.

(Total for Question 9 = 1 mark)

10 The spectra of the compounds with the formulae $CH_3CH(OH)CH_3$ and $CH_3CH_2CH_2OH$ can be distinguished by

☒ **A** the value of *m/e* of the molecular ion in the mass spectrum.

☒ **B** the presence of a fragment with *m/e* =15 in the mass spectrum.

☒ **C** the presence of an absorption peak due to O–H in the infrared spectrum.

☒ **D** the number of peaks in the nmr spectrum.

(Total for Question 10 = 1 mark)

11 Which of the following has two singlet peaks in its nmr spectrum?

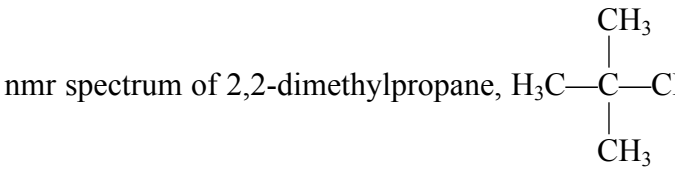
☒ **A** Methanal, HCHO

☒ **B** Methanol, CH_3OH

☒ **C** Chloromethane, CH_3Cl

☒ **D** Dichloromethane, CH_2Cl_2

(Total for Question 11 = 1 mark)

12 The nmr spectrum of 2,2-dimethylpropane,  , contains

☒ **A** one singlet peak.

☒ **B** four singlet peaks.

☒ **C** one quartet peak.

☒ **D** four quartet peaks.

(Total for Question 12 = 1 mark)

13 Which of the following solutions has the lowest pH?

☒ **A** 0.010 mol dm^{-3} hydrochloric acid.

☒ **B** 0.100 mol dm^{-3} hydrochloric acid.

☒ **C** 0.010 mol dm^{-3} ethanoic acid.

☒ **D** 0.100 mol dm^{-3} ethanoic acid.

(Total for Question 13 = 1 mark)

14 Which of the following solutions, when mixed, would make a buffer with pH more than 7?

☒ **A** Methanoic acid and sodium methanoate.

☒ **B** Sodium hydroxide and sodium chloride.

☒ **C** Ammonia and ammonium chloride.

☒ **D** Ammonium chloride and ammonium ethanoate.

(Total for Question 14 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

15 This question is about the equilibrium reaction

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92 \text{ kJ mol}^{-1}$$

Which statement is **not** correct?

☒ **A** The units of K_p are atm^{-2}.

☒ **B** K_p increases as temperature is decreased.

☒ **C** K_p increases when the pressure increases.

☒ **D** K_p increases when the total entropy change, ΔS_{total}, increases.

(Total for Question 15 = 1 mark)

16 1,2-dichloroethane decomposes in the presence of a catalyst.

$$CH_2ClCH_2Cl(g) \rightleftharpoons CH_2{=}CHCl(g) + HCl(g) \qquad \Delta H = +51 \text{ kJ mol}^{-1}$$

Which of the following would result in an increase in the equilibrium yield of chloroethene?

☒ **A** Increasing the temperature.

☒ **B** Increasing the pressure.

☒ **C** Increasing the surface area of the catalyst.

☒ **D** Changing the catalyst to a more efficient one.

(Total for Question 16 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

17 A bromoalkane has the molecular formula C_4H_9Br. The ionic equation for the hydrolysis of this compound with aqueous sodium hydroxide is shown below.

$$C_4H_9Br + OH^- \rightarrow C_4H_9OH + Br^-$$

(a) The rate of hydrolysis was investigated by mixing a large excess of the bromoalkane with aqueous sodium hydroxide, and measuring the time taken for **all** the hydroxide ions to be used up. This was carried out with different initial concentrations of the bromoalkane and the hydroxide ions. The results are shown in the table below.

Experiment	$[C_4H_9Br]$ /mol dm^{-3}	$[OH^-]$ /mol dm^{-3}	Time for OH^- to be used up/s	Initial rate /mol dm^{-3} s^{-1}
1	0.017	0.0012	42	2.9×10^{-5}
2	0.034	0.0012	21	5.7×10^{-5}
3	0.034	0.0020	35	.....

(i) Complete the missing value of the initial rate in the table.

(1)

(ii) State the order of the reaction with respect to C_4H_9Br and to OH^-. Justify each answer by reference to the concentrations of both reactants.

(3)

Order with respect to C_4H_9Br .....

Reason .....

.....

Order with respect to OH^- .....

Reason .....

.....

(iii) Deduce the rate equation for the reaction.

(1)

Rate = ...

(iv) Use the results for the first experiment in the table to calculate the rate constant and give its units.

(2)

Units .....

(b) What evidence supports the theory that there is more than one step in the reaction mechanism?

(1)

.....

.....

.....

(c) Write the mechanism for the hydrolysis of C_4H_9Br which is consistent with your rate equation. Show the structure of C_4H_9Br clearly in your mechanism.

(3)

*(d) Explain why primary and tertiary bromoalkanes are hydrolysed by different mechanisms.

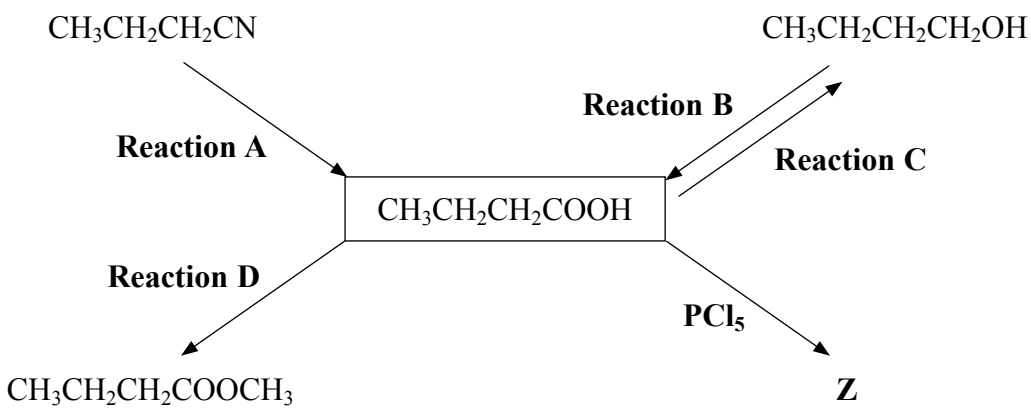
(2)

(Total for Question 17 = 13 marks)

Turn over ▶

18 This question is about butanoic acid, $CH_3CH_2CH_2COOH$.

(a) Some reactions involving butanoic acid are shown below.



(i) What type of reaction is **Reaction A**?

(1)

.....

(ii) Identify, by name or formula, the reagent which is used with sulfuric acid to carry out **Reaction B**.

(1)

.....

(iii) What reagent is used in **Reaction C**?

(1)

.....

(iv) Name the organic product of **Reaction D** and write a balanced equation for its formation.

(2)

Name .....

Equation

(v) Write the **displayed** formula for **Z**, the organic product of the reaction of butanoic acid with phosphorus(V) chloride, PCl_5.

(1)

(b) Butanoic acid and propane-1,2,3-triol are formed when fats in milk are hydrolysed. The presence of milk fat in low fat spreads is detected by hydrolysing the spread, and then analysing the products using gas chromatography (also called gas-liquid chromatography, GLC).

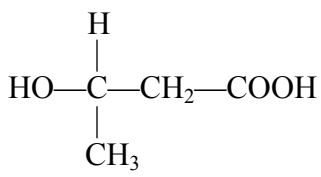
(i) Explain why nitrogen, rather than oxygen, is used as the carrier gas in GLC.

(1)

(ii) What property determines whether butanoic acid or propane-1,2,3-triol would move faster through the chromatography column?

(1)

(c) The formula of 3-hydroxybutanoic acid is shown below.



(i) 3-hydroxybutanoic acid can form a polymer which is used to make "green" packaging as it is biodegradable.

Draw a section of this polymer, showing TWO monomer units. Clearly show any double bonds.

(2)

(ii) The polymer cannot be used in acidic conditions. What reaction would occur when the polymer is in prolonged contact with an acid?

(1)

(Total for Question 18 = 11 marks)

Turn over ▶

19 Ethanoic acid can be manufactured by the following reaction, which is carried out between 150 °C and 200 °C.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(a) A mixture of 50.0 mol of methanol and 50.0 mol of carbon monoxide reaches equilibrium at a pressure of 32.0 atm. At 175 °C, the equilibrium partial pressure of ethanoic acid is 22.2 atm.

(i) Write the expression for the equilibrium constant in terms of pressure, K_p, for this reaction.

(1)

(ii) Calculate the partial pressures of methanol and carbon monoxide at equilibrium.

(2)

Methanol .....

Carbon monoxide .....

(iii) Calculate the value of K_p for this reaction at 175 °C. Include a unit in your answer and give your answer to **three** significant figures.

(2)

(b) Another sample of 50.0 mol of methanol and 50.0 mol of carbon monoxide was allowed to reach equilibrium at the same pressure of 32.0 atm, but at a lower temperature. 93.6 % of the methanol was converted at equilibrium.

(i) Complete the table below to show the number of moles of each species in the equilibrium mixture.

(2)

	CH_3OH	CO	CH_3COOH
Number of moles at start	50.0	50.0	0
Number of moles at equilibrium			

(ii) Calculate the partial pressure of ethanoic acid in the equilibrium mixture.

(1)

(iii) Is the reaction exothermic or endothermic? Explain your answer.

(1)

.....

.....

.....

.....

(c) How, if at all, does the addition of methanol to the equilibrium mixture affect the following? Justify your answers.

$$CH_3OH(g) + CO(g) \rightleftharpoons CH_3COOH(g)$$

(i) The equilibrium constant for the formation of ethanoic acid.

(1)

(ii) The equilibrium yield of ethanoic acid.

(1)

(d) In industry, catalysts are used even though they are often expensive.

State and explain ONE benefit to the **environment** resulting from the use of catalysts in industrial processes.

(2)

(Total for Question 19 = 13 marks)

Turn over ▶

20 Vinegar is used as a food preservative. It is an acidic solution containing ethanoic acid, CH_3COOH.

(a) A titration was carried out to measure the concentration of ethanoic acid in a sample of vinegar. 25.0 cm^3 of a vinegar solution was titrated with a solution of sodium hydroxide, concentration 0.250 mol dm^{-3}. The concentration of the ethanoic acid in the vinegar solution was found to be 0.125 mol dm^{-3}.

(i) Calculate the pH of 0.250 mol dm^{-3} sodium hydroxide at 298 K.

[$K_w = 1.00 \times 10^{-14}$ $mol^2\,dm^{-6}$ at 298 K.]

(2)

(ii) Write the expression for the acid dissociation constant, K_a, for ethanoic acid.

(1)

(iii) Calculate the pH of 0.125 mol dm^{-3} ethanoic acid at 298 K.

[K_a for ethanoic acid is 1.7×10^{-5} mol dm^{-3} at 298 K.]

(2)

(iv) When half the ethanoic acid is neutralized, the concentration of the remaining ethanoic acid equals the concentration of the sodium ethanoate which has formed. What is the pH of the mixture at this point? Justify your answer.

(2)

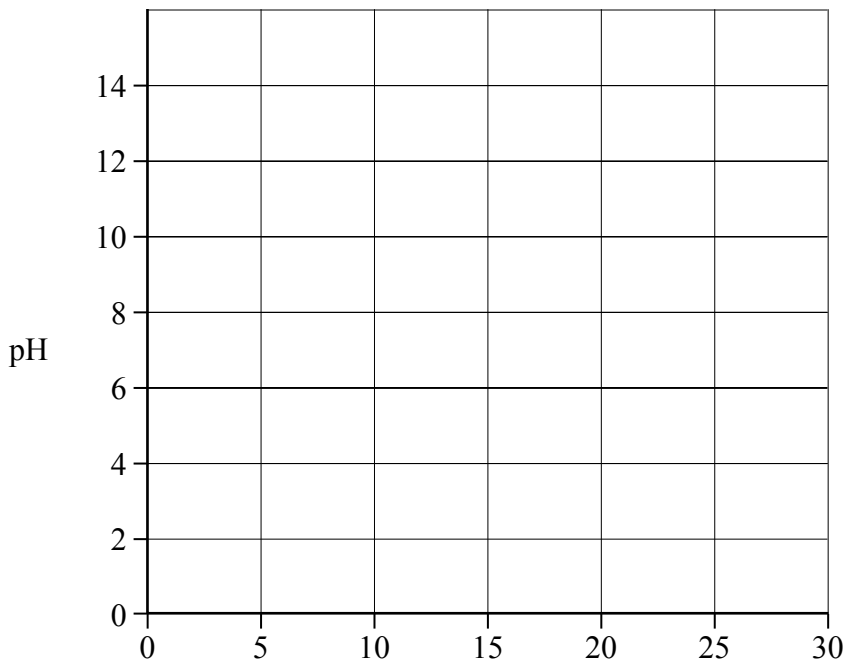
pH .....

Justification .....

.....

(v) On the axes below, sketch the titration curve for this reaction when 30 cm^3 of the sodium hydroxide is added to 25.0 cm^3 of the vinegar solution.

(3)



*(vi) The only indicators which were available for this titration were methyl yellow (in ethanol) and thymolphthalein. Explain which indicator is more suitable for this titration and why the other is unsuitable. You will need to refer to your data booklet.

(2)

.....

.....

.....

.....

.....

(b) In the food industry, ethanoic acid is described as an acidity regulator, additive number E260.

Ethanoic acid can neutralize alkalis. What substance could be mixed with ethanoic acid so that it regulates pH as a buffer in foodstuffs?

(1)

.....

(Total for Question 20 = 13 marks)

TOTAL FOR SECTION B = 50 MARKS

Turn over ▶

SECTION C

21 (a) Crystals of hydrated cobalt(II) chloride, $CoCl_2.6H_2O$, lose water when they are heated, forming anhydrous cobalt(II) chloride, $CoCl_2$.

$$CoCl_2.6H_2O(s) \rightarrow CoCl_2(s) + 6H_2O(l)$$

(i) Calculate the entropy change of the system, $\Delta S^{\ominus}_{system}$, at 298 K. Include a sign and units in your answer. You will need to refer to your data booklet.

(2)

(ii) Explain whether the sign of your answer to (a)(i) is as expected from the equation for the reaction.

(1)

(iii) The standard enthalpy change for the reaction, $\Delta H^{\ominus}$, is +88.1 kJ mol^{-1}. Calculate the entropy change in the surroundings, $\Delta S^{\ominus}_{surroundings}$, at 298 K for this reaction. Include a sign and units in your answer.

(2)

(iv) Calculate the total entropy change, $\Delta S^{\ominus}_{total}$, at 298 K for the reaction.

(1)

(v) Does your answer to (a)(iv) indicate whether hydrated cobalt(II) chloride can be stored at 298 K without decomposition? Explain your answer.

(1)

(b) A student attempted to measure the enthalpy change of solution of anhydrous cobalt(II) chloride by adding 2.00 g of cobalt(II) chloride to 50.0 cm^3 of water in a well-insulated container. A temperature rise of 1.5 °C was recorded.

The student used a balance which reads to 0.01g, a 50.0 cm^3 pipette, and a thermometer which can be read to 0.25 °C.

(i) Which measuring instrument should be changed to give a result which is closer to the accepted value? Justify your answer.

(2)

(ii) Suggest ONE **other** change the student could make to give a result which is closer to the accepted value. Justify your suggestion.

(2)

*(c) The lattice energies of magnesium chloride, $MgCl_2$, calcium chloride, $CaCl_2$, and strontium chloride, $SrCl_2$ are shown in the table below.

Chloride	Lattice energy/kJ mol^{-1}
$MgCl_2$	–2526
$CaCl_2$	–2258
$SrCl_2$	–2156

(i) Use data on ionic radii, from your data booklet, to explain the trend in these values. Estimate a value for the lattice energy of cobalt(II) chloride, giving ONE piece of data to justify your estimate.

(4)

(ii) Explain how lattice energy values, together with other data, can be used to predict the solubility of ionic compounds.

(3)

*(d) Cobalt forms another chloride, $CoCl_3$, but scientists predict that $MgCl_3$ cannot be made. Suggest a reason for this.

You should consider the enthalpy changes in the Born-Haber cycle, which provide evidence about why cobalt(III) chloride is known but magnesium(III) chloride is not.

(2)

(Total for Question 21 = 20 marks)

TOTAL FOR SECTION C = 20 MARKS
TOTAL FOR PAPER = 90 MARKS

mock papers 3

SECTION A

1 Methods for investigating reaction rates include

A colorimetry.

B measurement of change in volume.

C measurement of change of mass.

D quenching followed by titrating with acid.

Which method would be most suitable to investigate the rate of the following reactions?

(a) $HCOOCH_3(aq) + NaOH(aq) \rightarrow HCOONa(aq) + CH_3OH(aq)$

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(b) $(CH_3)_2C{=}CH_2(g) + HI(g) \rightarrow (CH_3)_3CI(g)$

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(c) $BrO_3^-(aq) + 5Br^-(aq) + 6H^+(aq) \rightarrow 3Br_2(aq) + 3H_2O(l)$

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 1 = 3 marks)

2 $2H_2(g) + 2NO(g) \rightarrow 2H_2O(g) + N_2(g)$

This reaction is first order with respect to hydrogen and second order with respect to nitrogen(II) oxide.

By what factor will the initial rate increase if the concentration of hydrogen and nitrogen(II) oxide are both tripled?

☒ **A** 3

☒ **B** 9

☒ **C** 12

☒ **D** 27

(Total for Question 2 = 1 mark)

3 Which reaction has the most positive entropy change for the system, ΔS_{system}?

☒ **A** $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

☒ **B** $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

☒ **C** $C_2H_4(g) + HCl(g) \rightarrow C_2H_5Cl(l)$

☒ **D** $C_4H_{10}(g) \rightarrow C_2H_4(g) + C_2H_6(g)$

(Total for Question 3 = 1 mark)

4 Barium carbonate decomposes in an endothermic reaction when heated to 1500 K.

$$BaCO_3(s) \rightarrow BaO(s) + CO_2(g)$$

What are the signs of the entropy changes at 1500 K?

		ΔS_{system}	$\Delta S_{surroundings}$
☒	**A**	+	+
☒	**B**	+	–
☒	**C**	–	+
☒	**D**	–	–

(Total for Question 4 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

5 What are the units of K_c for the following equilibrium?

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

☒ **A** atm

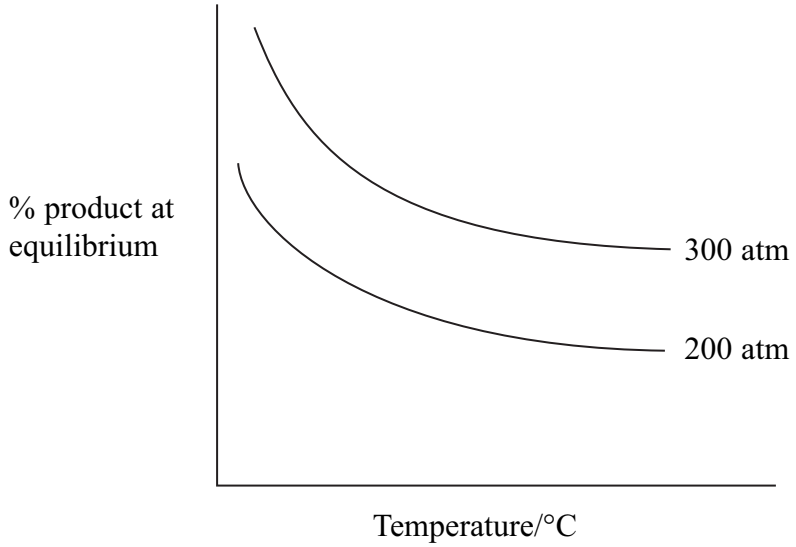
☒ **B** atm^{-1}

☒ **C** $dm^3\ mol^{-1}$

☒ **D** $mol\ dm^{-3}$

(Total for Question 5 = 1 mark)

6 The graph below shows the yield of product in a gaseous equilibrium at different temperatures and pressures.



The forward reaction in the equilibrium is

☒ **A** exothermic, and the number of moles of gas is increasing.

☒ **B** endothermic, and the number of moles of gas is increasing.

☒ **C** exothermic, and the number of moles of gas is decreasing.

☒ **D** endothermic, and the number of moles of gas is decreasing.

(Total for Question 6 = 1 mark)

7 Hydrogen cyanide, HCN, reacts with propanal, CH_3CH_2CHO, in the presence of potassium cyanide, KCN.

(a) The mechanism for this reaction is

(1)

☒ **A** nucleophilic addition.

☒ **B** nucleophilic substitution.

☒ **C** electrophilic addition.

☒ **D** electrophilic substitution.

(b) The first stage of the mechanism of this reaction is

(1)

☒ **A** the lone pair of electrons on carbon in CN^- attacking $C^{\delta+}$ of propanal.

☒ **B** the lone pair of electrons on nitrogen in CN^- attacking $C^{\delta+}$ of propanal.

☒ **C** the lone pair of electrons on oxygen in propanal attacking $C^{\delta+}$ of HCN.

☒ **D** the lone pair of electrons on oxygen in propanal attacking $H^{\delta+}$ in HCN.

(c) The product of the reaction is

(1)

☒ **A** 1-hydroxypropanenitrile.

☒ **B** 2-hydroxypropanenitrile.

☒ **C** 1-hydroxybutanenitrile.

☒ **D** 2-hydroxybutanenitrile.

(Total for Question 7 = 3 marks)

8 Which of the following does not have hydrogen bonding in a pure sample, but forms hydrogen bonds with water when it dissolves?

☒ **A** Propane

☒ **B** Propanal

☒ **C** Propanol

☒ **D** Propanoic acid

(Total for Question 8 = 1 mark)

9 Which of the following has both optical and E-Z isomers?

☒ **A** $ClCH_2CHClCH{=}CH_2$

☒ **B** $CH_2{=}CClCH_2CH_2Cl$

☒ **C** $ClCH_2CH{=}CHCH_2Cl$

☒ **D** $CHCl{=}CHCHClCH_3$

(Total for Question 9 = 1 mark)

10 One optically active isomer of 2-chlorobutane reacts with hydroxide ions to form butan-2-ol.

$$C_2H_5CHClCH_3 + OH^- \rightarrow C_2H_5CH(OH)CH_3 + Cl^-$$

The organic product is a **mixture** of enantiomers because

☒ **A** butan-2-ol contains a chiral carbon atom.

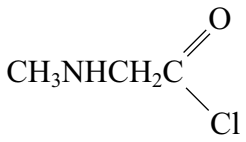
☒ **B** the reaction is a nucleophilic substitution.

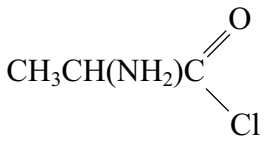
☒ **C** 2-chlorobutane forms a carbocation intermediate.

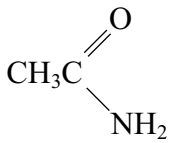
☒ **D** 2-chlorobutane forms a five-bonded transition state.

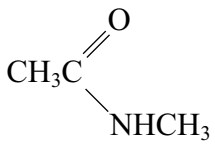
(Total for Question 10 = 1 mark)

11 The organic product of the reaction between ethanoyl chloride and methylamine has the formula

☒ **A** 

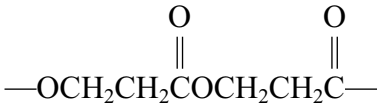
☒ **B** 

☒ **C** 

☒ **D** 

(Total for Question 11 = 1 mark)

12 A section of a polymer is shown below. Which of the following monomers would form this polymer?



☒ **A** $HOCH_2CH_2OH$ and $ClCOCH_2CH_2COCl$

☒ **B** $HOCH_2CH_2OH$ and $HOOCCH_2CH_2COOH$

☒ **C** $ClCH_2CH_2COCl$ alone

☒ **D** $HOCH_2CH_2COOH$ alone

(Total for Question 12 = 1 mark)

13 Which of the following is **not** a reaction of a Brønsted-Lowry acid and base?

☒ **A** $CH_3Cl + OH^- \rightarrow CH_3OH + Cl^-$

☒ **B** $NH_3 + HCl \rightarrow NH_4^+ + Cl^-$

☒ **C** $H_2O + HSO_4^- \rightarrow H_2SO_4 + OH^-$

☒ **D** $HCO_3^- + H_2O \rightarrow CO_3^{2-} + H_3O^+$

(Total for Question 13 = 1 mark)

14 A buffer solution is made from ammonia and ammonium chloride. When a small amount of acid is added to this buffer

☒ **A** hydrogen ions in the acid combine with chloride ions to make HCl.

☒ **B** hydrogen ions in the acid combine with NH_3 to make NH_4^+.

☒ **C** NH_4^+ ions dissociate to make more NH_3.

☒ **D** the hydrogen ions in the acid prevent dissociation of the NH_4Cl.

(Total for Question 14 = 1 mark)

15 Information about four samples of acid is shown below.

Sample 1: 1.0 mol dm^{-3} HCl

Sample 2: 1.0 mol dm^{-3} H_2SO_4

Sample 3: 0.1 mol dm^{-3} HCl

Sample 4: 0.1 mol dm^{-3} CH_3COOH

Which of the following lists shows the samples in order of increasing pH?

☒ **A** 1, 2, 3, 4

☒ **B** 4, 3, 2, 1

☒ **C** 2, 1, 3, 4

☒ **D** 4, 3, 1, 2

(Total for Question 15 = 1 mark)

16 Which reaction has an enthalpy change equal to the enthalpy of hydration of the sodium ion?

☒ **A** $Na^+(g)$ + excess $H_2O(l)$ → $Na^+(aq)$

☒ **B** $Na^+(g)$ + 1 mol of $H_2O(l)$ → $Na^+(aq)$

☒ **C** $Na^+(s)$ + excess $H_2O(l)$ → $Na^+(aq)$

☒ **D** $Na^+(s)$ + 1 mol of $H_2O(l)$ → $Na^+(aq)$

(Total for Question 16 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

17 Hydrogen can be manufactured by reacting methane with steam, as shown in the equation below.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus}_{298} = +206.1\,\text{kJ mol}^{-1}$$

Use these values:

the standard entropy of 1 mol of $H_2(g)$ is $(2 \times 65.3) = 130.6\,\text{J mol}^{-1}\,\text{K}^{-1}$
the standard entropy of 1 mol of $H_2O(g)$ is $188.7\,\text{J mol}^{-1}\,\text{K}^{-1}$

You will also need to refer to the data booklet in the calculations which follow.

(a) Calculate the standard entropy change of the system, $\Delta S^{\ominus}_{\text{system}}$, for this reaction at 298 K.

(2)

(b) Calculate the standard entropy change of the surroundings, $\Delta S^{\ominus}_{\text{surroundings}}$, for this reaction at 298 K. Include a sign and units in your answer.

(2)

(c) Calculate the total entropy change, $\Delta S^{\ominus}_{\text{total}}$, for this reaction at 298 K.

Explain why this value shows that the reaction is not spontaneous at this temperature.

(2)

.....

.....

(d) The composition of an equilibrium mixture produced at 2.0 atmospheres pressure and at a much higher temperature is shown below.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

Amount in equilibrium mixture / mol	0.80	0.80	1.20	3.60

*(i) Write the expression for the equilibrium constant, K_p, of the reaction and calculate its value. Include units in your answer.

(6)

(ii) The total entropy change in J mol^{-1} K^{-1} is related to the equilibrium constant by the equation

$$\Delta S^{\ominus}_{total} = R \ln K_p \quad \text{or} \quad \Delta S^{\ominus}_{total} = 2.3R \log K_p$$

Calculate the total entropy change at the temperature of the reaction.

[R = 8.31 J mol^{-1} K^{-1}]

(1)

(iii) Calculate the temperature at which this equilibrium is reached using your answer to (ii) for $\Delta S^{\ominus}_{total}$. Assume that ΔH is still +206.1 kJ mol^{-1} and that $\Delta S^{\ominus}_{system}$ = +225 J K^{-1} mol^{-1}. (This is not the same as the value for $\Delta S^{\ominus}_{system}$ calculated in (a) which is at 298 K.)

(2)

*(e) Use the magnitude and signs of the entropy changes to explain the effect of a temperature increase on the equilibrium constant of this endothermic reaction.

(2)

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(Total for Question 17 = 17 marks)

18 (a) Calculate the pH of 0.25 mol dm^{-3} hydrochloric acid.

(1)

(b) Propanoic acid, CH_3CH_2COOH, is a weak acid with $K_a = 1.3 \times 10^{-5}$ mol dm^{-3} at 25 °C.

(i) Write the expression for K_a for propanoic acid.

(1)

(ii) Calculate the pH of 0.25 mol dm^{-3} propanoic acid at 25 °C.

(2)

(c) During a titration, 10 cm^3 0.10 mol dm^{-3} sodium hydroxide was added to 10 cm^3 of 0.25 mol dm^{-3} propanoic acid.

(i) Write an equation for the reaction which occurs. State symbols are **not** required.

(1)

(ii) At this point the titration mixture contains 1.5×10^{-3} moles of propanoic acid and 1.0×10^{-3} moles of propanoate ion.

Use your expression for K_a for propanoic acid to calculate the pH of the mixture.

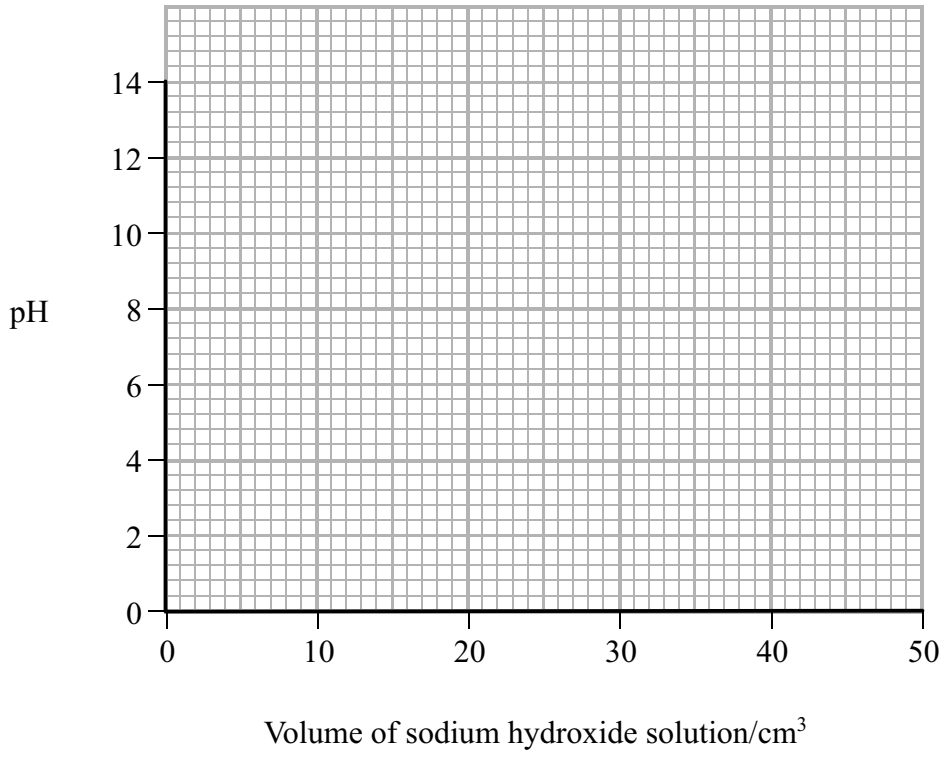
(2)

*(iii) When a further small amount of 0.10 mol dm^{-3} sodium hydroxide is added in the titration, the pH changes very little. Explain why the pH change is small.

(3)

(iv) Draw the titration curve showing the change in pH when 0.10 mol dm^{-3} sodium hydroxide is added to 10 cm^3 of 0.25 mol dm^{-3} propanoic acid until present in excess. The equivalence point is 25 cm^3.

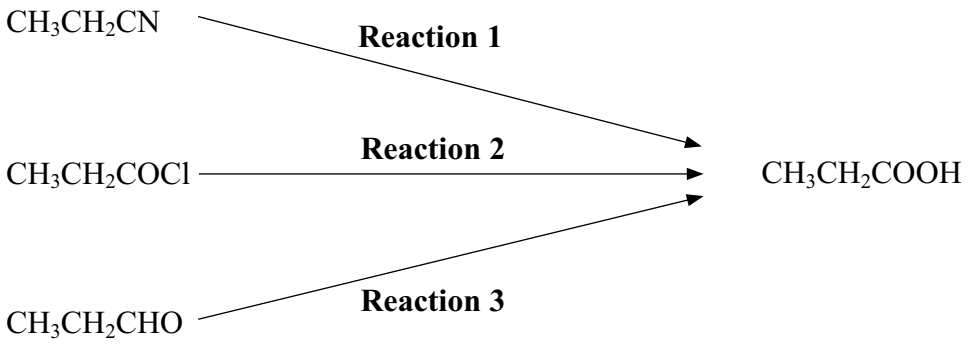
(3)



(v) Explain, referring to your data booklet, whether bromocresol green would be a suitable indicator for this titration.

(2)

(d) Propanoic acid is produced in the reactions shown below.



(i) Suggest a reagent which could be used to carry out **reaction 1**.

(1)

(ii) Write an equation for **reaction 2**. State symbols are **not** required.

(1)

(iii) What would be observed if **reaction 3** was carried out using potassium dichromate(VI) and sulfuric acid?

(1)

(e) What type of reagent would be used to convert propanoic acid to propan-1-ol? Identify a suitable reagent for this reaction.

(2)

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(Total for Question 18 = 20 marks)

19 A student investigated the reaction between iodine and propanone in acidic conditions.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

- 50 cm^3 of 0.020 mol dm^{-3} iodine solution was measured into a flask.
- 25 cm^3 of propanone and 25 cm^3 of 1.0 mol dm^{-3} sulfuric acid were measured into a second flask.
- Several 10 cm^3 samples of 0.5 mol dm^{-3} sodium hydrogencarbonate solution were placed in separate conical flasks.
- The mixture of propanone and sulfuric acid was added to the iodine, and a clock started.
- At two minute intervals, 10 cm^3 of the reaction mixture was removed and added to one of the flasks containing sodium hydrogencarbonate solution.
- The contents of this flask were then titrated with 0.01 mol dm^{-3} sodium thiosulfate.

(a) Explain the purpose of adding the reaction mixture to the sodium hydrogencarbonate.

(2)

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(b) What indicator should be used in the titration?

(1)

.....

*(c) In this experiment the concentration of the iodine was 0.020 mol dm^{-3} and the concentrations of propanone and sulfuric acid were both 1.00 mol dm^{-3}. Why was the iodine solution used much less concentrated than the propanone and sulfuric acid?

(2)

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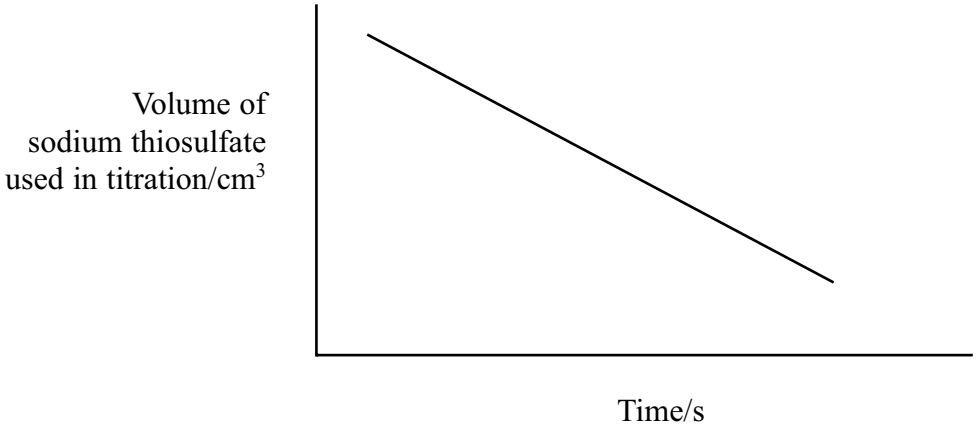
(d) The shape of the graph obtained from the results of the experiment is shown below.



Use the graph to deduce the order of reaction with respect to iodine, explaining your reasoning.

(2)

(e) The solutions used in this experiment could be measured using either measuring cylinders or pipettes.

Give **one** advantage of using a measuring cylinder and **one** advantage of using a pipette.

(2)

(f) In a further investigation, different volumes of sulfuric acid, propanone, iodine and water were mixed. The time taken for the mixture to go colourless was measured.

The experiments were repeated and the results below show average values for the rate of the reaction.

Expt	2 mol dm^{-3} H_2SO_4 /cm^3	2 mol dm^{-3} propanone /cm^3	Water /cm^3	0.01 mol dm^{-3} iodine /cm^3	Rate /mol dm^{-3} s^{-1}
1	20.0	8.0	0	4.0	8×10^{-5}
2	10.0	8.0	10.0	4.0	4×10^{-5}
3	20.0	4.0	4.0	4.0	4×10^{-5}

(i) Explain why water is added in experiments 2 and 3.

(1)

(ii) Show how you would use the data in the table to deduce the order of reaction with respect to propanone and hydrogen ions. Write the rate equation for the reaction.

(3)

(Total for Question 19 = 13 marks)

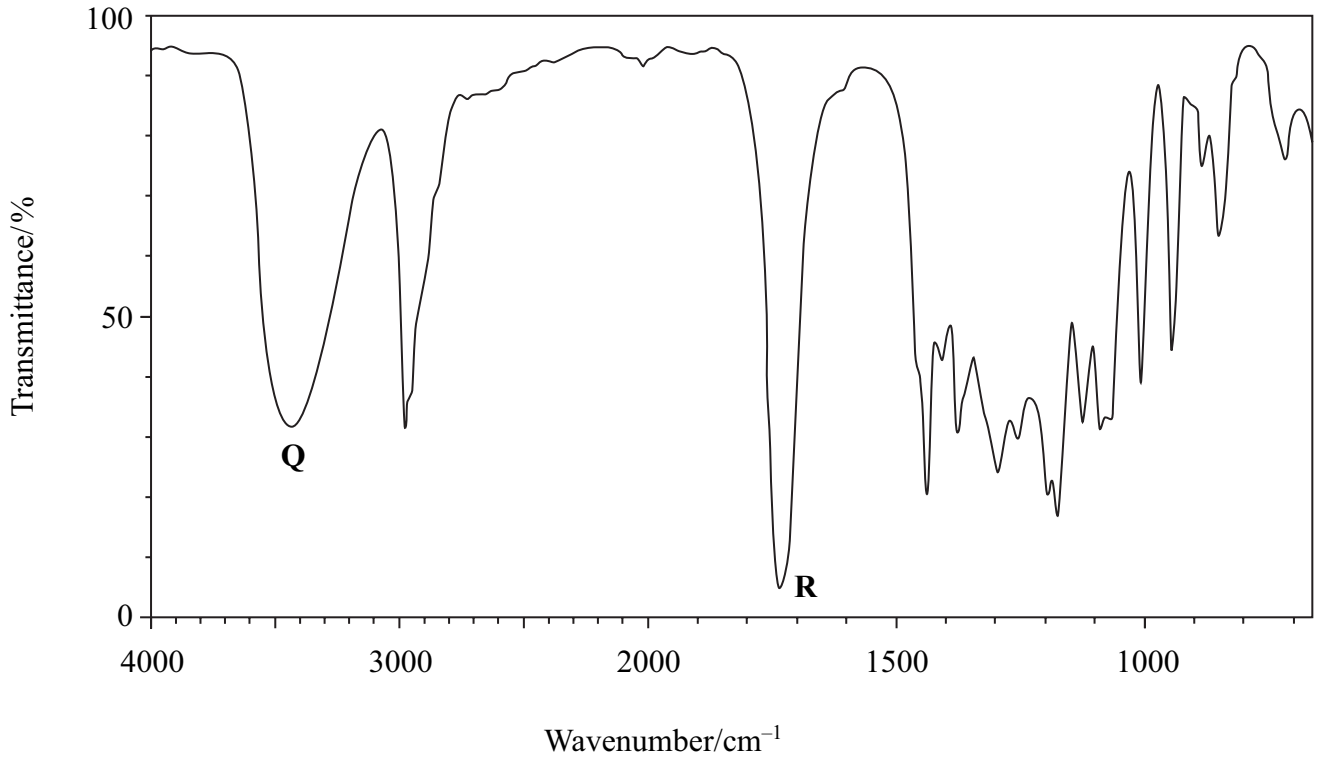
TOTAL FOR SECTION B = 50 MARKS

SECTION C

20 An organic compound **X** is an ester found in orange peel and has the molecular formula $C_5H_{10}O_3$.

(a) Identify the bonds responsible for the peaks labelled **Q** and **R** in the infrared spectrum of **X** shown below, referring to your data booklet.

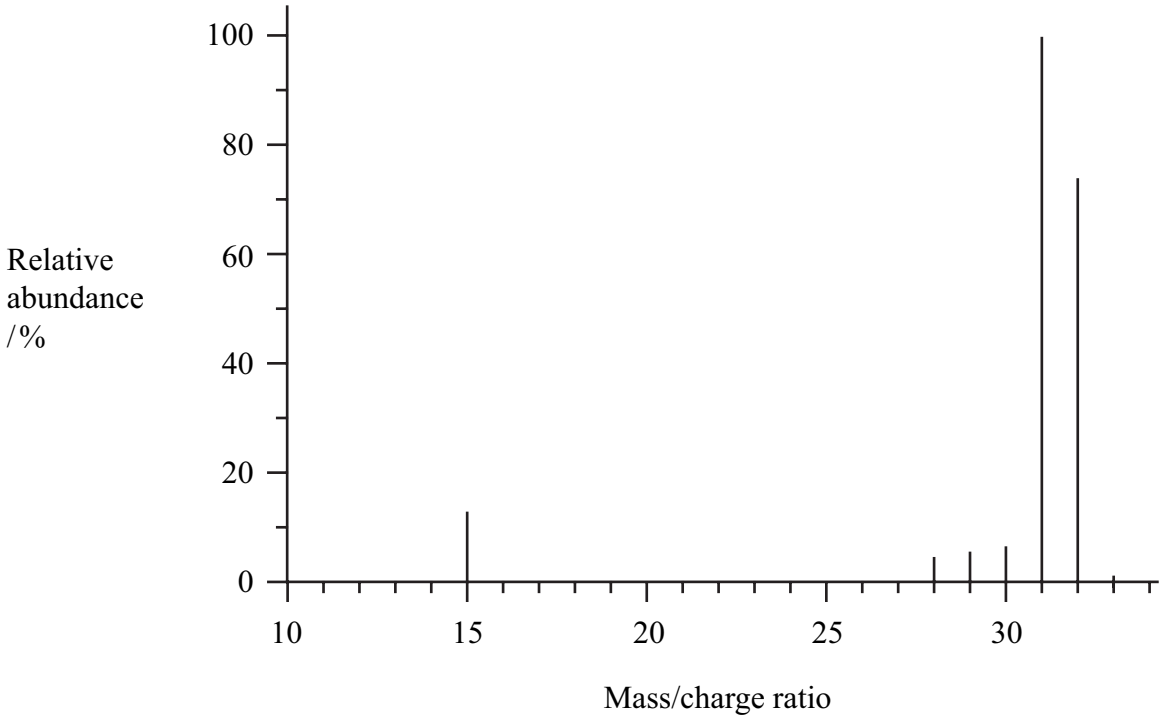
(2)



Q .....

R .....

(b) **X** was heated under reflux with dilute sulfuric acid. The resulting mixture was distilled and a liquid **Y** was collected. The mass spectrum of **Y** is shown below.



(i) Identify **Y**, by name or formula, using the information available. Use **two** pieces of data from the mass spectrum to support your answer.

(2)

(ii) The identity of **Y** could be confirmed using nmr spectroscopy. Predict the number of peaks in the low resolution proton nmr spectrum of **Y**. Give the chemical shift range for each peak, referring to your data booklet.

(2)

(c) A second product from the reaction of **X** with hydrochloric acid is **Z**, which has the molecular formula $C_4H_8O_3$.

What can you deduce about **Z** from the results of the following tests?

(i) One mole of **Z** reacts with two moles of phosphorus(V) chloride, PCl_5.

(1)

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.....

(ii) When sodium carbonate solution is added to **Z**, effervescence is seen.

(1)

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(iii) **Z** is warmed gently with potassium dichromate(VI) and sulfuric acid. The organic product of the reaction gives a yellow precipitate with 2,4-dinitrophenylhydrazine (Brady's reagent) but does not react with Tollens' reagent.

(1)

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(iv) **Z** reacts with a solution of iodine in sodium hydroxide to produce a yellow precipitate with an antiseptic smell.

(1)

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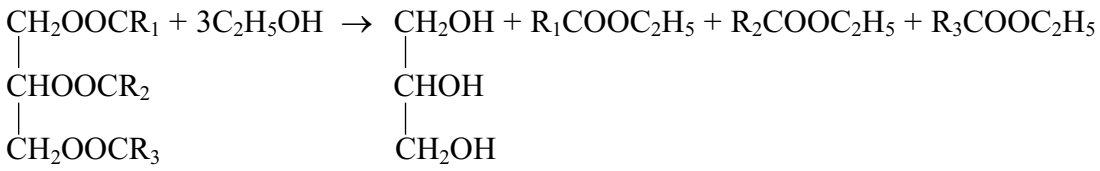
.....

(d) Use the results of these tests to deduce the structural formula of **Z** and hence the structural formula of **X**.

(2)

(Total for Question 20 = 12 marks)

21 The equation below shows the type of reaction which can be used in the production of biodiesel from vegetable oils.



(a) (i) Name this type of reaction.

(1)

.....

(ii) Suggest why water must not be present when this reaction with ethanol is carried out.

(1)

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(b) Give **one** reason why biodiesel is considered a "greener" fuel than diesel produced from crude oil.

(1)

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*(c) The products of the type of reaction shown with ethanol can be separated and identified using gas chromatography (GC).

In chromatography, compounds are separated because of the difference in distribution between a mobile phase and a stationary phase.

Explain why this difference in distribution occurs, and contrast the phases used in gas chromatography (GC) and high performance liquid chromatography (HPLC).

(5)

(Total for Question 21 = 8 marks)

TOTAL FOR SECTION C = 20 MARKS
TOTAL FOR PAPER = 90 MARKS

mock papers 4

SECTION A

1 Which of the following methods would **not** be suitable for measuring the rate of the reaction between methanoic acid and bromine?

$$HCOOH(aq) + Br_2(aq) \rightarrow 2H^+(aq) + 2Br^-(aq) + CO_2(g)$$

☒ **A** Colorimetry

☒ **B** Measuring change in electrical conductivity

☒ **C** Quenching samples and titrating with acid

☒ **D** Measuring change in pressure

(Total for Question 1 = 1 mark)

---

2 The equation below shows the hydrolysis of a bromoalkane.

$$RBr + OH^- \rightarrow ROH + Br^-$$

For a particular bromoalkane, the rate equation is

$$rate = k[RBr]$$

The bromoalkane, RBr, is most likely to be

☒ **A** CH_3Br

☒ **B** CH_3CH_2Br

☒ **C** $(CH_3)_3CCH_2Br$

☒ **D** $(CH_3)_3CBr$

(Total for Question 2 = 1 mark)

---

3 A decrease in the entropy of the system, ΔS_{system}, occurs when

☒ **A** water freezes.

☒ **B** water boils.

☒ **C** water reacts with sodium.

☒ **D** water reacts with ethanoyl chloride.

(Total for Question 3 = 1 mark)

---

4 Methanol is produced in the equilibrium reaction

$$2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -18.3 \text{ kJ mol}^{-1}$$

Addition of more hydrogen to the equilibrium mixture at constant temperature

☒ **A** increases the equilibrium yield of methanol.

☒ **B** decreases the equilibrium yield of methanol.

☒ **C** increases the value of K_p.

☒ **D** decreases the value of K_p.

(Total for Question 4 = 1 mark)

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5 The equation for the equilibrium between $NO_2(g)$ and $N_2O_4(g)$ can be written in two ways.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \text{Equilibrium constant} = K_c$$

or

$$NO_2(g) \rightleftharpoons \tfrac{1}{2}N_2O_4(g) \quad \text{Equilibrium constant} = K'_c$$

Which expression is correct?

☒ **A** $K_c = K'_c$

☒ **B** $K_c = (K'_c)^2$

☒ **C** $K_c = 2(K'_c)$

☒ **D** $K_c = \tfrac{1}{2}K'_c$

(Total for Question 5 = 1 mark)

---

6 4.0 mol of methanoic acid are reacted with 6.0 mol of ethanol.

$$HCOOH(l) + C_2H_5OH(l) \rightleftharpoons HCOOC_2H_5(l) + H_2O(l)$$

The equilibrium mixture contains 3.0 mol of $HCOOC_2H_5$.

The equilibrium constant, K_c, for the reaction is

☒ **A** 0.33

☒ **B** 1.0

☒ **C** 3.0

☒ **D** 4.0

(Total for Question 6 = 1 mark)

---

7 A solution of hydrochloric acid has pH 3.0. When it is made 10 times more dilute, the pH is

☒ **A** 0.3

☒ **B** 2.0

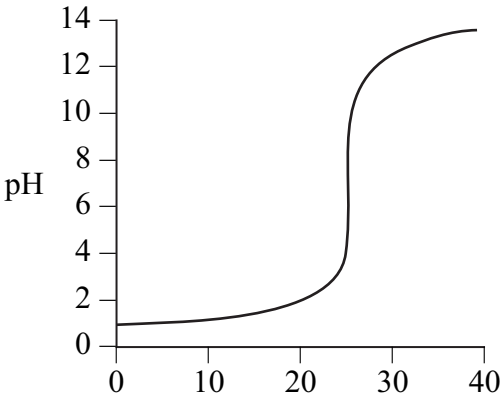
☒ **C** 4.0

☒ **D** 13.0

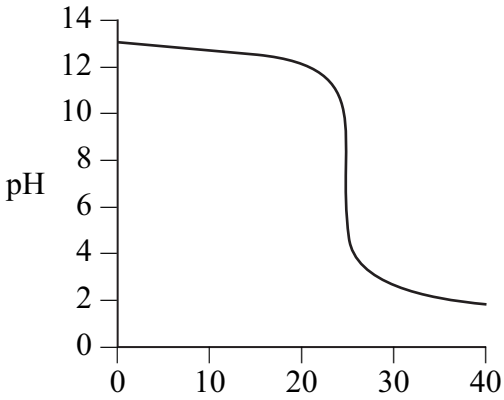
(Total for Question 7 = 1 mark)

8 The titration curves below were obtained using different acids and bases, each with concentration 0.1 mol dm^{-3}.

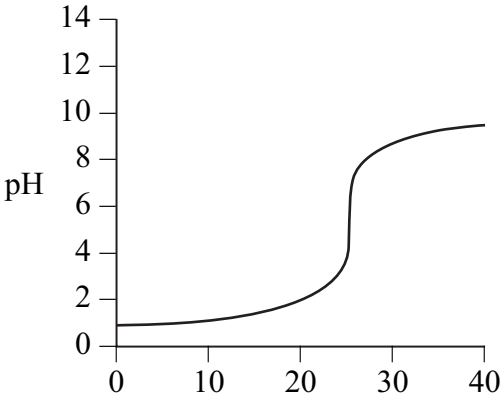
A



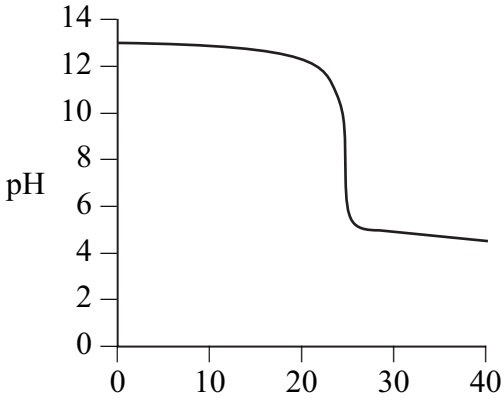
B



C



D



(a) Which curve is produced by adding ammonia to 25 cm^3 of hydrochloric acid?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(b) Which curve is produced by adding ethanoic acid to 25 cm^3 of sodium hydroxide?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(c) An indicator with pK_{In} 8.5 is suitable for the following titrations.

(1)

☒ **A** Titrations **A** and **B** only.

☒ **B** Titrations **A**, **B** and **D** only.

☒ **C** Titration **C** only.

☒ **D** Titrations **A**, **B**, **C** and **D**.

(Total for Question 8 = 3 marks)

9 Ethanoic acid is **not** a product in the reaction of

☒ **A** ethanal with lithium tetrahydridoaluminate.

☒ **B** ethanoyl chloride with water.

☒ **C** ethyl ethanoate with dilute sulfuric acid.

☒ **D** ethanol refluxed with potassium dichromate(VI) and sulfuric acid.

(Total for Question 9 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

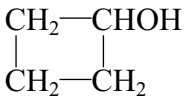
10 This question is about four compounds with molecular formula C_4H_8O.

A $CH_3COCH_2CH_3$

B $CH_3CH_2CH_2CHO$

C $CH_3CH{=}CHCH_2OH$

D



(a) The compounds which react when heated with a mixture of potassium dichromate(VI) and sulfuric acid are

(1)

☒ **A** compounds **A**, **B** and **C**.

☒ **B** compounds **A**, **B** and **D**.

☒ **C** compounds **A**, **C** and **D**.

☒ **D** compounds **B**, **C** and **D**.

(b) The compound which produces a yellow precipitate when heated with a mixture of iodine and sodium hydroxide is

(1)

☒ **A** compound **A**.

☒ **B** compound **B**.

☒ **C** compound **C**.

☒ **D** compound **D**.

(c) There would **not** be a significant peak at mass/charge ratio of 15 in the mass spectrum of

(1)

☒ **A** compound **A**.

☒ **B** compound **B**.

☒ **C** compound **C**.

☒ **D** compound **D**.

(Total for Question 10 = 3 marks)

11 The following tests can be carried out on organic compounds.

A Warm with 2,4-dinitrophenylhydrazine.

B Warm with Fehling's or Benedict's solution.

C Add solid sodium carbonate.

D Add phosphorus(V) chloride, PCl_5.

(a) Which test would give a positive result with propanoic acid but not with propan-1-ol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(b) Which test would give a positive result with propanoic acid **and** with propan-1-ol?

(1)

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(c) Which test would give a positive result with propanal but not with propanone?

(1)

☒ **A**

☒ **B**

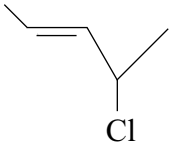
☒ **C**

☒ **D**

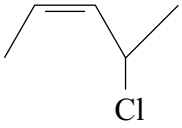
(Total for Question 11 = 3 marks)

12 Which of the following compounds is a *Z* isomer **and** contains a chiral carbon atom?

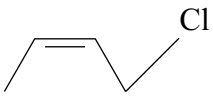
☒ **A**



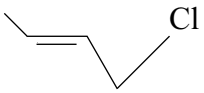
☒ **B**



☒ **C**



☒ **D**



(Total for Question 12 = 1 mark)

13 Which of the following statements about ethanoyl chloride is **not** correct?

☒ **A** It reacts with ammonia to make an amine.

☒ **B** It reacts with an amine to make an amide.

☒ **C** It reacts with an alcohol to make an ester.

☒ **D** It reacts with water to make an organic acid.

(Total for Question 13 = 1 mark)

14 In gas chromatography, mixtures are passed through a long tube containing a liquid as the stationary phase. The mixtures are separated into their components because the components differ in

☒ **A** relative molecular mass.

☒ **B** melting temperature.

☒ **C** volatility.

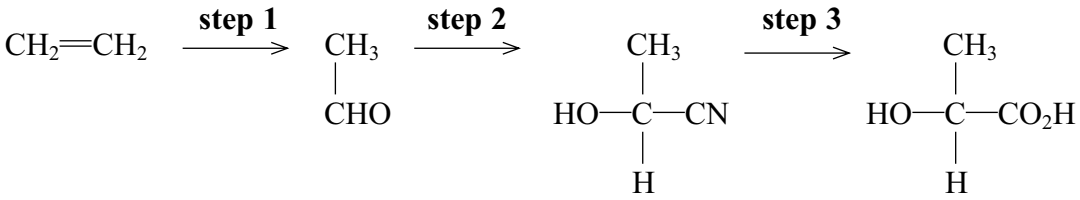
☒ **D** force of attraction to the liquid.

(Total for Question 14 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

15 A sequence of reactions for the production of lactic acid is shown below.



lactic acid

(a) (i) Name the type and mechanism of the reaction in **step 2**.

(2)

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(ii) Which **two** substances need to be added to ethanal to carry out the reaction in **step 2**?

(2)

.....

.....

(iii) Give the mechanism for the reaction in **step 2**, using curly arrows to show movements of electron pairs.

(3)

*(iv) The product of **step 2** is not optically active even though it has a chiral carbon atom in its formula. Explain, by reference to the mechanism, the reason for the lack of optical activity.

(2)

(b) What reactant, or combination of reactants, is needed to carry out **step 3**?

(1)

(c) (i) What is the systematic name of lactic acid?

(1)

(ii) Lactic acid molecules can combine to form a biodegradable polymer, poly(lactic acid) or PLA. Draw a section of the polymer with **two** units of the polymer chain and showing all bonds.

(1)

(iii) Suggest why PLA is biodegradable.

(1)

(iv) Lactic acid can be prepared from ethene as shown in the scheme. Lactic acid also forms when milk turns sour.

Suggest **one** reason why it would be advantageous to make lactic acid from milk rather than from ethene.

(1)

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(Total for Question 15 = 14 marks)

16 Nitrogen(IV) oxide, NO_2, is a brown gas which is a pollutant in air. It is produced in the reaction below.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

(a) The table below shows the results of a series of experiments to measure the rate of this reaction at 298 K.

Experiment number	Initial concentration / mol dm^{-3}		Initial rate / mol dm^{-3} s^{-1}
	$[O_2(g)]$	$[NO(g)]$	
1	0.0050	0.0125	5.10×10^{-4}
2	0.0100	0.0125	10.2×10^{-4}
3	0.0100	0.0250	40.8×10^{-4}

(i) State, with reasons, the order of reaction with respect to oxygen and the order of reaction with respect to nitrogen(II) oxide, NO.

(2)

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(ii) Write the rate equation for the reaction.

(1)

(iii) Calculate the value of the rate constant. Include units in your answer.

(2)

(b) Nitrogen(IV) oxide in air reacts with carbon monoxide in car exhausts. The following two-step reaction mechanism has been suggested.

Step 1: $2NO_2(g) \rightarrow NO(g) + NO_3(g)$ Slow

Step 2: $NO_3(g) + 2CO(g) \rightarrow NO(g) + 2CO_2(g)$ Fast

(i) Write the equation for the overall reaction which takes place.

(1)

(ii) The overall reaction is second order. Suggest a rate equation for this reaction, justifying your answer.

(2)

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(Total for Question 16 = 8 marks)

17 Ammonia is manufactured using the reaction

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

(a) (i) Calculate $\Delta S^{\ominus}_{system}$ for this reaction at 298 K. Give your answer in J mol^{-1} K^{-1} and include a sign. You will need to refer to your data booklet.

[Note that the standard molar entropy values for gaseous diatomic elements are given for half a mole of molecules, and not per mole of molecules
eg entropy for 1 mol of N_2 is 2 × 95.8 J mol^{-1} K^{-1}.]

(2)

(ii) Using ideas about disorder, explain whether the sign of your answer to (a)(i) is as expected.

(2)

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(b) At 700 K, the enthalpy change for this reaction, $\Delta H = -110.2$ kJ mol^{-1}.

(i) Calculate the entropy change of the surroundings, $\Delta S_{surroundings}$, at 700 K. Include a sign and units in your answer.

(2)

(ii) Calculate ΔS_{system} for this reaction at 700 K. At this temperature the total entropy change, $\Delta S_{total} = -78.7$ J K^{-1} mol^{-1}. Include a sign and units in your answer.

(1)

(iii) What does the value of ΔS_{total}, which is -78.7 J K^{-1} mol^{-1} at 700 K, indicate about the relative proportions of nitrogen, hydrogen and ammonia at equilibrium?

(1)

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(c) A mixture of nitrogen, hydrogen and ammonia is at equilibrium at 150 atm. The partial pressures of nitrogen and ammonia in the mixture are 21 atm and 36 atm respectively.

(i) Write an expression for the equilibrium constant, K_p, for the formation of ammonia, in terms of partial pressures for this reaction, and calculate its value at 700 K. Include units in your answer.

(4)

(ii) In the manufacture of ammonia, pressures of between 100 and 250 atm are used. State and explain **one** advantage, in terms of the yield of ammonia, of using a pressure above 100 atm.

(1)

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*(iii) In the manufacture of ammonia, a temperature of about 700 K is used.

For this exothermic reaction how does $\Delta S_{surroundings}$ change as temperature increases?

Explain how this change affects the value of ΔS_{total} and the equilibrium constant as temperature increases.

Hence explain the disadvantage of using a temperature higher than 700 K.

(4)

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(iv) Suggest **one** advantage of using a temperature higher than 700 K.

(1)

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(Total for Question 17 = 18 marks)

18 Methanoic acid, ethanoic acid and iodic(I) acid, HIO, are all weak acids.

(a) The values of the acid dissociation constant, K_a, for methanoic and ethanoic acid at 298 K are given below. Iodic(I) acid has a pK_a of 10.64. Complete the table by calculating the value of K_a for iodic(I) acid.

(1)

Acid	K_a / mol dm^{-3}
methanoic acid	1.6×10^{-4}
ethanoic acid	1.7×10^{-5}
iodic(I) acid	

(b) (i) Write the expression for K_a for methanoic acid, HCOOH.

(1)

(ii) Calculate the pH of a solution of methanoic acid with concentration 0.50 mol dm^{-3} at 298 K.

(3)

(iii) State **one** of the assumptions you have made when calculating the pH in (ii).

(1)

.....

.....

.....

.....

.....

(c) The following equilibrium occurs in a mixture of pure methanoic and ethanoic acids.

$$HCOOH + CH_3COOH \rightleftharpoons HCOO^- + CH_3COOH_2^+$$

(i) Give the formulae of the two Brønsted-Lowry acids in this equilibrium.

(1)

.....

.....

(ii) Write an equation showing the products of the equilibrium which is set up when iodic(I) acid is mixed with ethanoic acid.

(1)

$HIO + CH_3COOH \rightleftharpoons$ ..... + ...

(d) A shampoo is buffered by the addition of a mixture of methanoic acid and sodium methanoate.

The pH of this shampoo is 4.9. Calculate the hydrogen ion concentration in the shampoo, and hence the ratio of methanoate ions to methanoic acid.

(2)

(Total for Question 18 = 10 marks)

TOTAL FOR SECTION B = 50 MARKS

SECTION C

19 The chemical **X** is an ester with formula $CH_3COOC(CH_3)_3$ which occurs in raspberries and pears. It can be prepared in the laboratory by refluxing ethanoic acid with an alcohol in the presence of a catalyst.

(a) **Name** the alcohol and catalyst which would be used to make **X**.

(2)

Alcohol .....

Catalyst .....

(b) After refluxing, the resulting mixture is distilled to give an impure product containing **X**. The impure product is washed several times with sodium carbonate solution and then dried.

(i) Name the piece of equipment in which the impure product would be washed.

(1)

.....

(ii) What is the purpose of washing the impure product with sodium carbonate solution?

(1)

.....

(iii) Name a suitable drying agent.

(1)

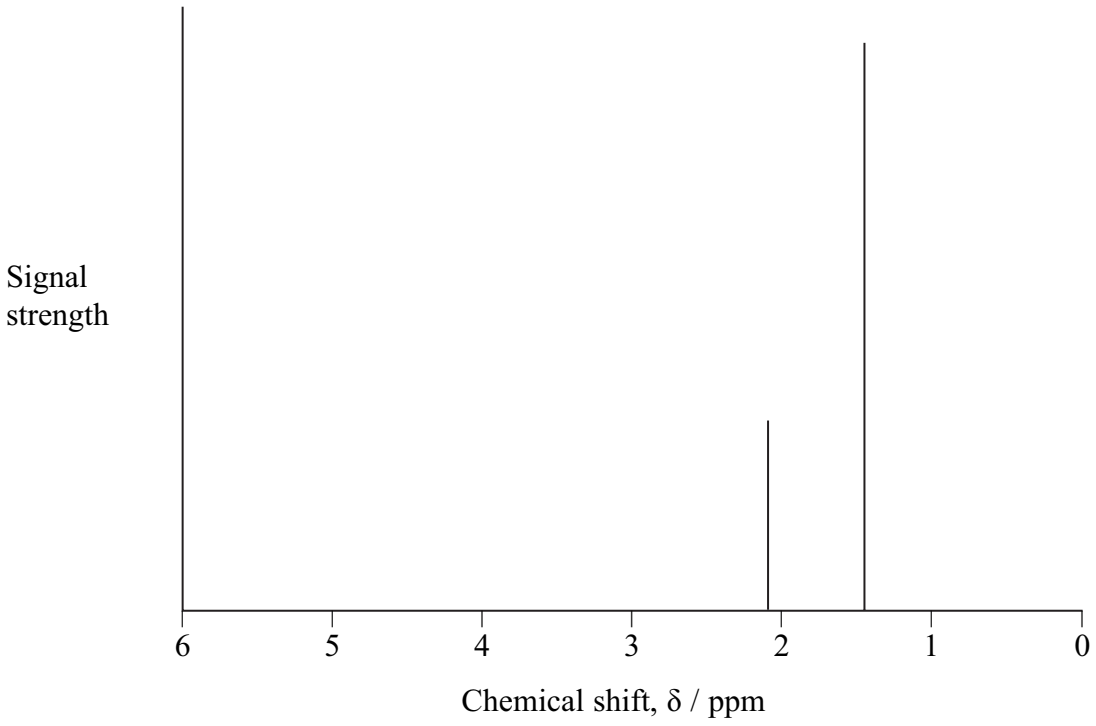
.....

(iv) The impure product is then redistilled and **X**, which has a boiling temperature of 97 °C, is collected. Draw a labelled diagram of the apparatus you would use.

(3)

*(c) **Spectrum 1** is the high resolution proton nmr spectrum of **X**, $CH_3COOC(CH_3)_3$.

Spectrum 1



Explain how **spectrum 1** is consistent with the structure of **X**. You should refer to the number and height of the peaks, the atoms which produce them and their splitting patterns.

(4)

(d) **X** has an isomer, **Y**. **Y** is an ester which can be made from ethanoic acid and 2-methylpropan-1-ol.

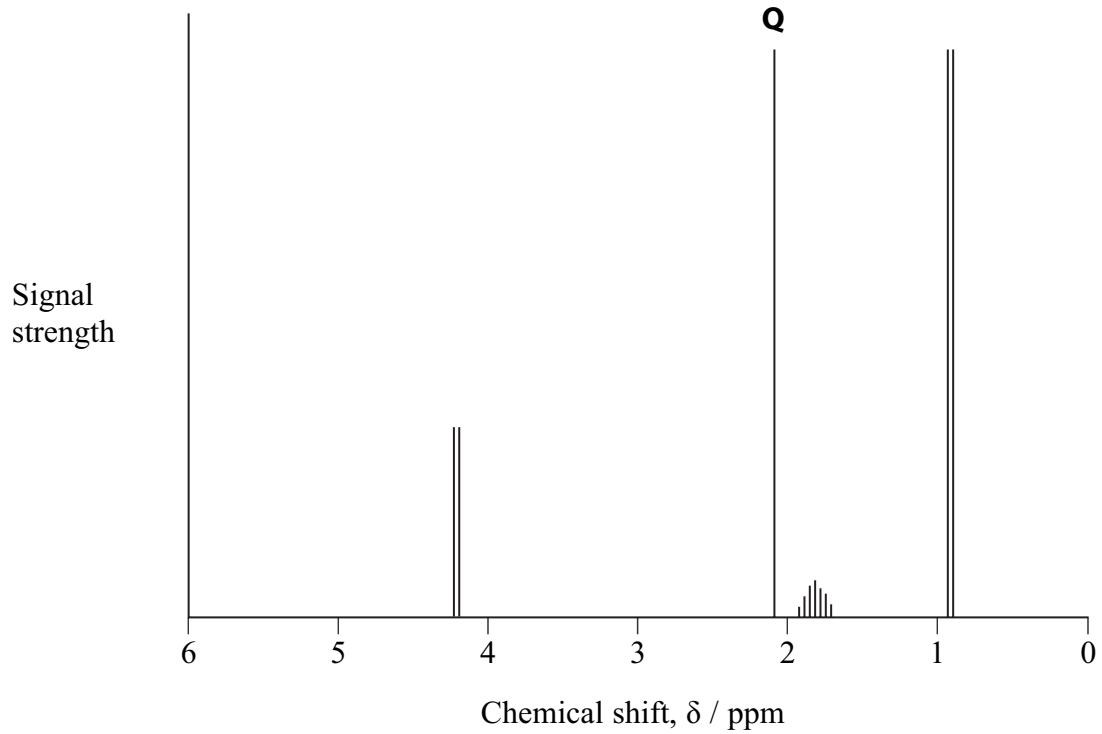
(i) Draw the structural formula of **Y**.

(1)

(ii) **Spectrum 2** is the high resolution proton nmr spectrum of **Y**. On your structural formula in (i), circle the atom or atoms causing the peak labelled **Q** on **spectrum 2**.

(1)

Spectrum 2



(e) **X** has several other structural isomers which have a broad peak at approximately 2960 cm^{-1} in their infrared spectra. Some of the isomers have a chiral carbon atom and all have a higher boiling temperature than **X**. None of them reacts with 2,4-dinitrophenylhydrazine.

*(i) Draw the structure of **one** of the isomers which is optically active, explaining how you use **all** the information in the question.

(5)

(ii) Could the compound you have drawn in (e)(i) be distinguished by infrared spectroscopy from its other isomers with the properties listed above? Explain your answer.

(1)

(Total for Question 19 = 20 marks)

TOTAL FOR SECTION C = 20 MARKS
TOTAL FOR PAPER = 90 MARKS