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SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The reaction between carbon monoxide and hydrogen reaches a dynamic equilibrium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) Which of these statements about a dynamic equilibrium is **not** true?

(1)

☒ **A** The forward rate of reaction is equal to the backward rate of reaction.

☒ **B** The concentrations of the products and reactants do not change.

☒ **C** The concentrations of the products and reactants are equal.

☒ **D** The equilibrium can be approached from either direction.

(b) The K_c expression for the above reaction is

(1)

☒ **A** $K_c = \dfrac{[CH_3OH]}{[CO] \times [H_2]^2}$

☒ **B** $K_c = \dfrac{[CO] \times 2[H_2]}{[CH_3OH]}$

☒ **C** $K_c = \dfrac{[CO] \times [H_2]^2}{[CH_3OH]}$

☒ **D** $K_c = \dfrac{[CH_3OH]}{[CO] \times 2[H_2]}$

(Total for Question 1 = 2 marks)

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

2 Hydrogen and iodine, both with an initial concentration of 0.010 mol dm^{-3}, were allowed to react. At equilibrium, the concentration of hydrogen iodide was 0.0030 mol dm^{-3}.

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

K_c is calculated using the values

		$H_2(g)$ / mol dm^{-3}	$I_2(g)$ / mol dm^{-3}	HI(g) / mol dm^{-3}
☒	**A**	0.0070	0.0070	0.0030
☒	**B**	0.0040	0.0040	0.0030
☒	**C**	0.0040	0.0040	0.0060
☒	**D**	0.0085	0.0085	0.0030

(Total for Question 2 = 1 mark)

3 The reaction below reached a dynamic equilibrium from an initial mixture of all four substances P, Q, R and S in aqueous solution.

$$P + Q \rightleftharpoons R + S$$

The following data were obtained.

Substance	Concentration at equilibrium / mol dm^{-3}
P	0.050
Q	0.040
R	0.020
S	0.010

K_c for the equilibrium is

☒ **A** 0.10

☒ **B** 0.33

☒ **C** 3.00

☒ **D** 10.0

(Total for Question 3 = 1 mark)

4 The Haber process is used to make ammonia from nitrogen and hydrogen at 450 °C.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92.0 \text{ kJ mol}^{-1}$$

(a) If the partial pressures of these gases were measured in atm, the units of the equilibrium constant K_p will be

(1)

☒ **A** atm

☒ **B** atm^2

☒ **C** atm^{-2}

☒ **D** atm^{-1}

(b) When the temperature of the system is increased

(1)

☒ **A** K_p decreases.

☒ **B** K_p increases.

☒ **C** K_p stays the same.

☒ **D** K_p first decreases and then increases.

(Total for Question 4 = 2 marks)

---

5 In high performance liquid chromatography, HPLC, which of these factors does **not** affect the time taken for a component to pass through the column?

☒ **A** Type of detector

☒ **B** Material of stationary phase

☒ **C** Particle size of stationary phase

☒ **D** Temperature of column

(Total for Question 5 = 1 mark)

---

6 When equimolar amounts of the solutions below are mixed, which forms a buffer solution with a pH less than 7?

☒ **A** Hydrochloric acid and sodium chloride

☒ **B** Ethanoic acid and sodium ethanoate

☒ **C** Sodium hydroxide and sodium chloride

☒ **D** Ammonia and ammonium chloride

(Total for Question 6 = 1 mark)

---

7 The pH of a 1.5 mol dm^{-3} solution of hydrochloric acid, HCl(aq), is

- ☒ **A** −1.50
- ☒ **B** −0.18
- ☒ **C** 0.18
- ☒ **D** 1.50

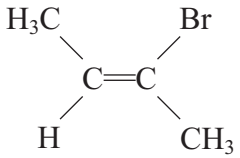
(Total for Question 7 = 1 mark)

8 Which of these solid substances is likely to have the greatest standard entropy? Use of the data booklet is not required.

- ☒ **A** SnO
- ☒ **B** SnO_2
- ☒ **C** $SnBr_2$
- ☒ **D** $SnBr_4$

(Total for Question 8 = 1 mark)

9 What is the correct name for the molecule shown below?



- ☒ **A** *Z*-2-bromobut-2-ene
- ☒ **B** *E*-2-bromobut-2-ene
- ☒ **C** *E*-3-bromobut-2-ene
- ☒ **D** *Z*-3-bromobut-2-ene

(Total for Question 9 = 1 mark)

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

10 Ketones react with hydrogen cyanide, HCN, in the presence of cyanide ions, CN^-.

(a) Which of these ketones does **not** form a racemic mixture in this reaction?

(1)

☒ **A** $CH_3CH_2CH_2COCH_3$

☒ **B** $CH_3CH_2COCH_2CH_3$

☒ **C** $CH_3CH_2CH_2CH_2COCH_3$

☒ **D** $CH_3CH_2CH_2COCH_2CH_3$

(b) This type of reaction is classified as

(1)

☒ **A** nucleophilic substitution.

☒ **B** nucleophilic addition.

☒ **C** electrophilic addition.

☒ **D** electrophilic substitution.

(Total for Question 10 = 2 marks)

---

11 Which of these is **not** observed when ethanoyl chloride reacts with water?

☒ **A** Misty fumes given off.

☒ **B** The gas given off turns damp blue litmus paper red.

☒ **C** The mixture gets hot.

☒ **D** A white precipitate forms.

(Total for Question 11 = 1 mark)

---

12 UV light is useful in initiating some reactions because it

☒ **A** lowers the activation energy of the reaction.

☒ **B** causes bonds in molecules to stretch and bend.

☒ **C** causes molecules to form ions.

☒ **D** causes molecules to form free radicals.

(Total for Question 12 = 1 mark)

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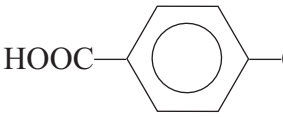
13 Butane-1,4-diol, $HO(CH_2)_4OH$, and benzene-1,4-dicarboxylic acid,

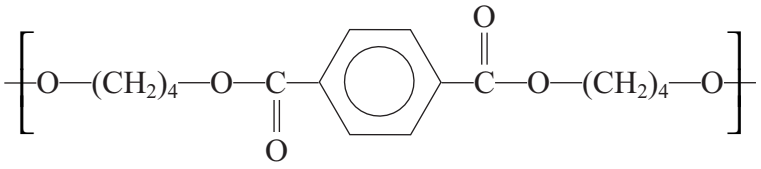


react to form a polyester.

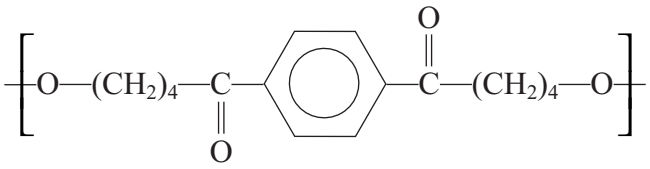
(a) The repeat unit of the polyester is

(1)

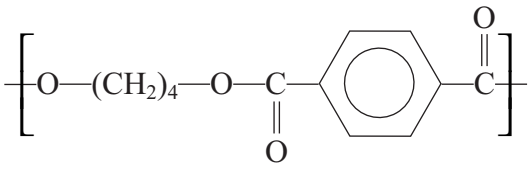
☒ **A**



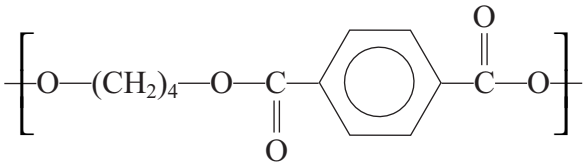
☒ **B**



☒ **C**



☒ **D**



(b) The type of reaction is

(1)

☒ **A** hydrolysis.

☒ **B** addition.

☒ **C** substitution.

☒ **D** condensation.

(Total for Question 13 = 2 marks)

14 The equation for the enthalpy of hydration for a magnesium ion is

☒ **A** $Mg^{2+}(s) + aq \rightarrow Mg^{2+}(aq)$

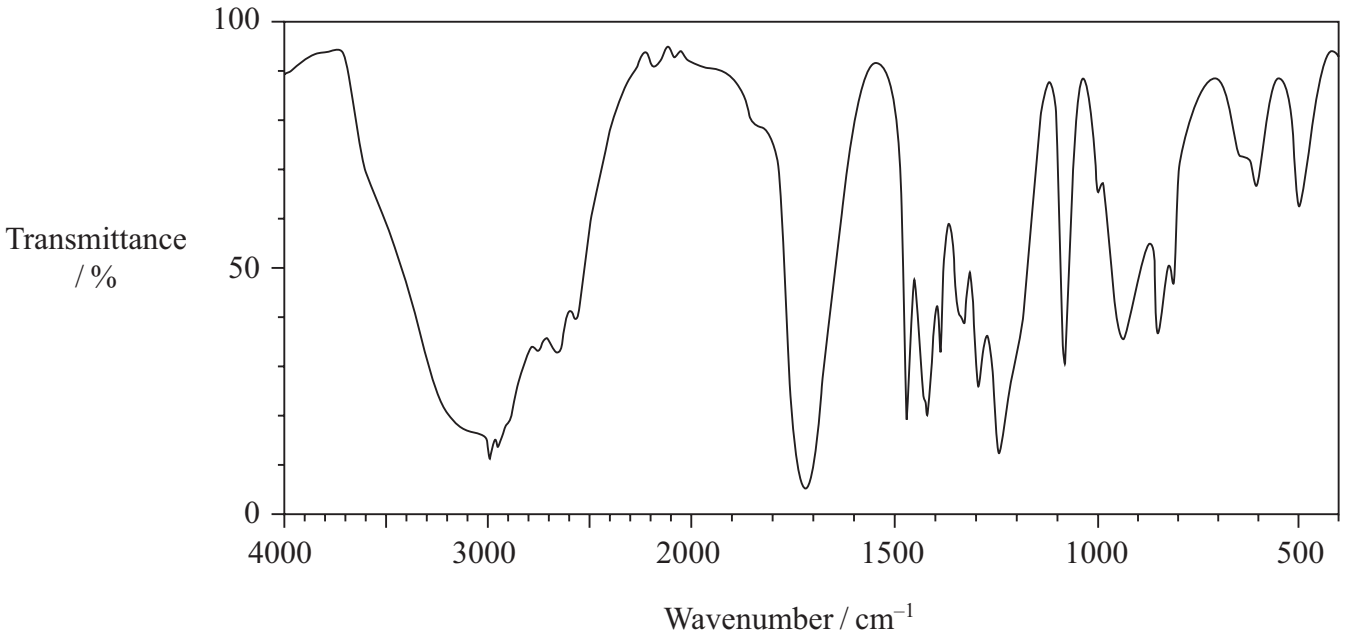
☒ **B** $Mg^{2+}(g) + aq \rightarrow Mg^{2+}(aq)$

☒ **C** $Mg^{2+}(aq) \rightarrow Mg^{2+}(g) + aq$

☒ **D** $Mg^{2+}(aq) \rightarrow Mg^{2+}(s) + aq$

(Total for Question 14 = 1 mark)

15 The IR spectrum of a substance is shown below.



Which of the following substances has this spectrum?

You may use the information on page 6 of the data booklet.

☒ **A** Propan-1-ol

☒ **B** Propanal

☒ **C** Propanone

☒ **D** Propanoic acid

(Total for Question 15 = 1 mark)

16 Two ketones, $CH_3COCH_2CH_2CH_3$ and $CH_3CH_2COCH_2CH_3$, both have $M_r = 86$. Which peak due to fragmentation into singly charged ions would you expect to be present in the mass spectrum of one but not the other?

☒ **A** 71

☒ **B** 57

☒ **C** 43

☒ **D** 29

(Total for Question 16 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

17 Two organic compounds, **X** and **Y**, both with the molecular formula C_4H_8O, contain a carbonyl group.

(a) Describe what you would see when 2,4-dinitrophenylhydrazine is added to either of these compounds.

(1)

.....

(b) It is suspected that **X** is a ketone and **Y** is an aldehyde. Outline a chemical test you could carry out to confirm this, describing the results in each case.

(3)

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(c) (i) Give the structural formulae of the two possible isomers of **Y** which are aldehydes.

(1)

(ii) Name the technique you would use to purify the product of the test with 2,4-dinitrophenylhydrazine.

(1)

.....

(iii) Other than by spectroscopic techniques, how would you use the purified product to identify compound **Y**? [Practical details are not required.]

(2)

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(Total for Question 17 = 8 marks)

18 Kits for manufacturing biodiesel from vegetable oils and methanol are sold for home use. The reaction which takes place may be represented by the following equation.

$$3CH_3OH + \begin{array}{l} CH_2OOCR \\ | \\ CHOOCR' \\ | \\ CH_2OOCR'' \end{array} \xrightarrow[50\,^{\circ}C,\ 98\%\ \text{yield}]{NaOH(s)} \begin{array}{l} CH_2OH \\ | \\ CHOH \\ | \\ CH_2OH \end{array} \begin{array}{l} + RCOOCH_3 \\ \\ + R'COOCH_3 \\ \\ + R''COOCH_3 \end{array}$$

*(a) Describe any two of the main hazards when carrying out this reaction. What precaution would you take to minimise the risk in each case?

(4)

Hazard .....

.....

Precaution .....

.....

Hazard .....

.....

Precaution .....

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(b) Suggest **two** environmental benefits of using these kits, despite the associated risks.

(2)

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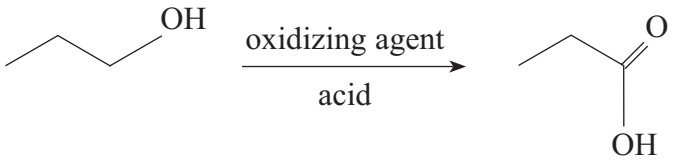
(Total for Question 18 = 6 marks)

19 The carboxylic acid, propanoic acid, can be prepared by oxidation of the alcohol, propan-1-ol.



propan-1-ol propanoic acid

(a) (i) Identify a suitable oxidizing agent you could use in this reaction.

(1)

.....

(ii) If you carried out this preparation in the laboratory, describe **two** measures you would take to ensure the maximum possible yield of propanoic acid is obtained.

(2)

.....

.....

.....

.....

(iii) Propanoic acid can be made by the hydrolysis of a nitrile. Give the structural formula of the nitrile and write an equation for this reaction.

(3)

Structural formula .....

Equation

*(b) Propanoic acid reacts with methanol, CH_3OH, to form the ester, methyl propanoate.

$$CH_3CH_2COOH + CH_3OH \rightleftharpoons CH_3CH_2COOCH_3 + H_2O$$

Even with the use of a catalyst, this reaction is quite slow and incomplete. Suggest a reagent, to replace the propanoic acid, which would form the ester at a faster rate. Suggest **two** reasons why your chosen reagent reacts faster.

(3)

(c) The structure of methyl propanoate can be investigated by using high resolution ^1H nuclear magnetic resonance (nmr) spectroscopy.

(i) What type of radiation interacts with ^1H nuclei in nmr spectroscopy?

(1)

(ii) Describe what happens to ^1H nuclei when they absorb this radiation.

(2)

(iii) Complete the table to show values for the chemical shift of the different ^1H nuclei in methyl propanoate and their splitting pattern. Page 7 of the data booklet gives information about chemical shifts.

(2)

^1H environment	Chemical shift, δ / ppm	Splitting pattern
CH_3O–	3.7	Singlet
–CH_2–	2.3	
–CH_3		Triplet

(Total for Question 19 = 14 marks)

20 The exothermic reaction between carbon monoxide and hydrogen can be used industrially to make methanol. The process is carried out at 250 °C and between 50 and 100 atm.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) Explain why increasing the pressure increases the yield of methanol. Give **one** disadvantage of increasing the pressure.

(2)

(b) The reaction gives a greater equilibrium yield at 100 °C than at 250 °C.

(i) Explain, in terms of the entropy change of the surroundings and the total entropy change of the reaction, why this is so.

A calculation is **not** required.

(2)

(ii) Explain why the reaction is, nevertheless, carried out at 250 °C.

(1)

(c) Given that the reaction is an equilibrium, suggest **two** ways in which the atom economy of this process could be maximised without changing the temperature or pressure.

(2)

(Total for Question 20 = 7 marks)

21 This question is about the kinetics of the reaction between bromoethane and aqueous hydroxide ions.

(a) The results of an experiment to find the initial rate of the reaction are shown in the table below.

$[CH_3CH_2Br]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
0.100	0.150	1.54×10^{-6}

The rate equation for the reaction is

$$\text{rate} = k[CH_3CH_2Br][OH^-]$$

(i) Calculate the value of k. Give your answer to three significant figures and include units.

(3)

(ii) Calculate the initial rate if the concentrations of both reactants were changed to 0.020 mol dm^{-3}.

(1)

(b) (i) State the order of the reaction.

(1)

.....

(ii) The mechanism for this reaction can be inferred from the rate equation. Draw the transition state formed in the reaction between bromoethane and hydroxide ions.

(2)

(c) The rate constant for the reaction between bromoethane and hydroxide ions was determined at five different temperatures. The results are shown in the table below.

Temperature (T) / K	1/Temperature (1/T) / K^{-1}	Rate constant, k	ln k
293	3.41×10^{-3}	5.83×10^{-5}	−9.75
303	3.30×10^{-3}	1.67×10^{-4}	−8.70
313	3.19×10^{-3}	5.26×10^{-4}	−7.55
323	3.10×10^{-3}	1.36×10^{-3}	−6.60
333		3.77×10^{-3}	

(i) Complete the missing values in the table.

(2)

(ii) Plot a graph of ln k against 1/T. Calculate the gradient of your graph and use this to calculate the activation energy, E_A. The Arrhenius equation can be expressed as

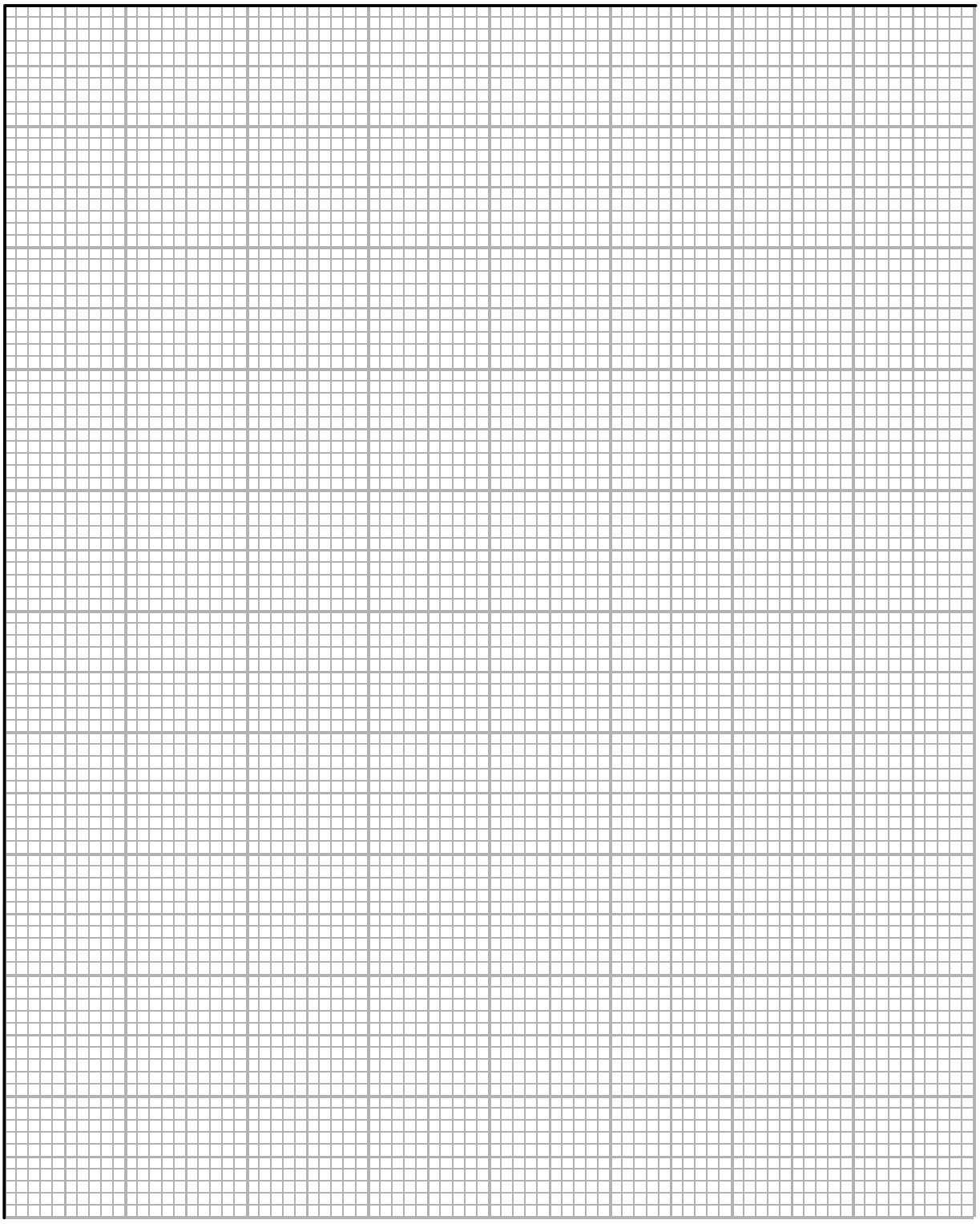
$$\ln k = \frac{-E_A}{R} \times \left(\frac{1}{T}\right) + \text{a constant}$$

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

(5)

$1/T/K^{-1}$

ln k



(Total for Question 21 = 14 marks)

TOTAL FOR SECTION B = 49 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

22 The hydrocarbon butane can be cracked to form propene and methane by passing it over a heated aluminium oxide catalyst at a temperature of 700 K. The equation for the reaction is

$$C_4H_{10}(g) \rightarrow C_3H_6(g) + CH_4(g) \qquad \Delta H = +71.9 \text{ kJ mol}^{-1}$$

(a) (i) Use page 20 of the data booklet to complete the table below.

(1)

Hydrocarbon	$S^{\ominus}$/ J mol^{-1} K^{-1}
$C_4H_{10}(g)$	+310.1
$C_3H_6(g)$	+266.9
$CH_4(g)$	

(ii) Calculate the standard entropy change of the system, $\Delta S^{\ominus}_{system}$, for this reaction. Include a sign in your answer.

(2)

(iii) Was the sign for your answer as you expected? Fully justify your answer.

(2)

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.....

(iv) Calculate the entropy change of the surroundings, $\Delta S_{surroundings}$, at 700 K.

Include a sign and units in your answer.

Use this value and your answer to (ii) to explain why butane cracks into propene and methane at this temperature.

(3)

(v) Calculate the minimum temperature needed for this reaction to be thermodynamically feasible.

(3)

(b) The aluminium oxide behaves as a heterogeneous catalyst. Explain both what is meant by the term **heterogeneous** and how, in terms of activation energy, the catalyst is able to speed up the reaction.

(3)

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(Total for Question 22 = 14 marks)

23 The bubble bath 'Colour Change Matey' has amongst its ingredients the weak acid benzoic acid, as well as the indicator bromocresol green. When it is added to bath water, its colour changes from yellow to blue.

(a) (i) Write the K_a expression for the dissociation of benzoic acid, C_6H_5COOH.

(1)

(ii) Use the data on page 18 of the data booklet to calculate the pH of a solution of benzoic acid, C_6H_5COOH, of concentration 0.0025 mol dm^{-3}.

(2)

*(b) Use the data on page 19 of the data booklet, and your answer to (a)(ii), to suggest why the bubble bath changes colour when it is diluted by being added to the bath water.

(4)

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(Total for Question 23 = 7 marks)

TOTAL FOR SECTION C = 21 MARKS
TOTAL FOR PAPER = 90 MARKS

SECTION A

Answer ALL the questions in this section. You should aim to spend no more than 20 minutes on this section. For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 An electrochemical cell consists of a standard hydrogen electrode and a $Cu^{2+}(aq)|Cu(s)$ electrode which uses copper(II) sulfate solution. Which one of the following does **not** affect the e.m.f. of the cell?

☒ **A** The volume of the copper(II) sulfate solution.

☒ **B** The temperature.

☒ **C** The pressure of the hydrogen.

☒ **D** The concentration of the copper(II) sulfate solution.

(Total for Question 1 = 1 mark)

---

2 Which answer corresponds to the correct value of $E^{\ominus}_{cell}$ for the oxidation of hydrogen peroxide by manganate(VII) ions? The half-reactions are

$$2H^+ + O_2 + 2e^- \rightleftharpoons H_2O_2 \qquad E^{\ominus} = +0.68\ V$$

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O \qquad E^{\ominus} = +1.51\ V$$

The overall equation is

$$2MnO_4^- + 6H^+ + 5H_2O_2 \rightleftharpoons 2Mn^{2+} + 8H_2O + 5O_2$$

☒ **A** $E^{\ominus}_{cell} = +2.19\ V$

☒ **B** $E^{\ominus}_{cell} = -0.83\ V$

☒ **C** $E^{\ominus}_{cell} = -0.38\ V$

☒ **D** $E^{\ominus}_{cell} = +0.83\ V$

(Total for Question 2 = 1 mark)

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

3 The transition metal complex $Pt(NH_3)_2Cl_2$ exists as two geometric isomers. This is because the complex

☒ **A** is square-planar.

☒ **B** is tetrahedral.

☒ **C** contains a double bond.

☒ **D** is octahedral.

(Total for Question 3 = 1 mark)

4 Hydrogen peroxide, H_2O_2, can be analysed by titration. The hydrogen peroxide solution is treated with acidified potassium iodide solution, and the liberated iodine is titrated with a standard solution of sodium thiosulfate, $Na_2S_2O_3$. The products are iodide ions and tetrathionate ions, $S_4O_6^{2-}$.

Which of the following applies to this reaction?

		Action of H_2O_2	Action of $S_2O_3^{2-}$
☒	**A**	oxidizing agent	oxidizing agent
☒	**B**	oxidizing agent	reducing agent
☒	**C**	reducing agent	oxidizing agent
☒	**D**	reducing agent	reducing agent

(Total for Question 4 = 1 mark)

5 A hydrated transition metal ion is colourless. Which of the following could be the electronic configuration of this ion?

☒ **A** [Ar] $3d^5 4s^2$

☒ **B** [Ar] $3d^8$

☒ **C** [Ar] $3d^{10} 4s^2$

☒ **D** [Ar] $3d^{10}$

(Total for Question 5 = 1 mark)

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

6 Which of the following reagents would enable you to separate iron(III) hydroxide from a mixture of iron(III) hydroxide and copper(II) hydroxide?

☒ **A** Dilute hydrochloric acid

☒ **B** Aqueous ammonia

☒ **C** Dilute nitric acid

☒ **D** Sodium hydroxide solution

(Total for Question 6 = 1 mark)

7 When a solution containing 0.10 mol of chromium(III) chloride, $CrCl_3.6H_2O$, is treated with excess silver nitrate solution, 0.20 mol of silver chloride, AgCl, is immediately precipitated. The formula of the complex ion in the solution is

☒ **A** $[Cr(OH)_6]^{3-}$

☒ **B** $[Cr(H_2O)_6]^{3+}$

☒ **C** $[CrCl(H_2O)_5]^{2+}$

☒ **D** $[CrCl_2(H_2O)_4]^{+}$

(Total for Question 7 = 1 mark)

8 Which of the following species is **not** able to act as a ligand in the formation of transition metal complexes?

☒ **A** $C_6H_5NH_2$

☒ **B** NH_3

☒ **C** $NH_2CH_2CH_2CH_2NH_2$

☒ **D** NH_4^+

(Total for Question 8 = 1 mark)

9 The element zinc, with electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2$, is **not** regarded as a transition element because

☒ **A** the oxide of zinc is amphoteric.

☒ **B** none of its ions has an unpaired electron in the *d*-subshell.

☒ **C** it does not readily form complex ions.

☒ **D** it has a boiling temperature low enough for it to be easily distilled.

(Total for Question 9 = 1 mark)

10 The compounds below were heated with aqueous sodium hydroxide solution. Which one of them did **not** give sodium ethanoate, CH_3COONa, as one of the products?

☒ **A** CH_3COOCH_3

☒ **B** CH_3COCH_3

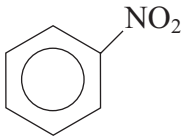
☒ **C** CH_3COOH

☒ **D** CH_3COCl

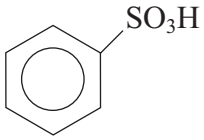
(Total for Question 10 = 1 mark)

11 Which of the following products is formed when phenylamine (aniline) is reacted with **dilute** sulfuric acid?

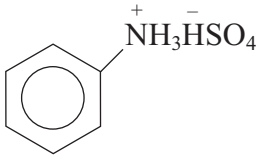
☒ **A**



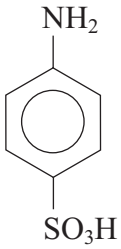
☒ **B**



☒ **C**



☒ **D**



(Total for Question 11 = 1 mark)

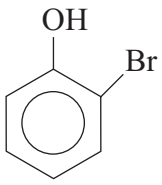
Use this space for any rough working. Anything you write in this space will gain no credit.

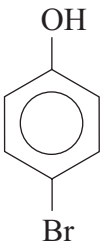
12 For the nitration of phenol, which is the most suitable set of conditions and the reason for its use?

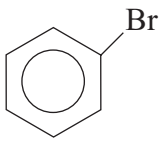
		Conditions	Reactivity of phenol to electrophiles compared with benzene
☒	**A**	dilute nitric acid at room temperature	more reactive
☒	**B**	concentrated nitric and sulfuric acid at room temperature	more reactive
☒	**C**	concentrated nitric and sulfuric acid at 55 °C	the same
☒	**D**	dilute nitric acid and dilute sulfuric acid at room temperature	less reactive

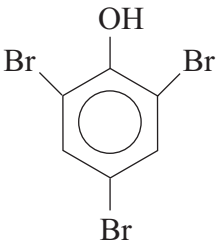
(Total for Question 12 = 1 mark)

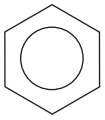
13 Phenol reacts with excess bromine water to give as the organic product(s)

☒ **A** 

and 

☒ **B** 

☒ **C** 

☒ **D** 

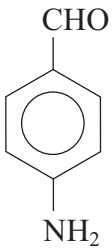
(Total for Question 13 = 1 mark)

14 An organic compound, **X**, shows the following properties:

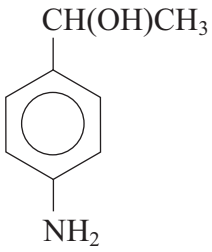
- Oxidation of compound **X** produces a substance that reacts with 2,4-dinitrophenylhydrazine to give a yellow precipitate but does **not** react with Fehling's or Benedict's solution.
- Compound **X** reacts with ice-cold nitrous acid to form a compound that gives a yellow precipitate with an alkaline solution of phenol.

What is the formula of compound **X**?

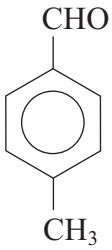
☒ **A**



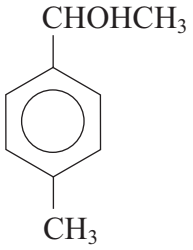
☒ **B**



☒ **C**



☒ **D**



(Total for Question 14 = 1 mark)

15 Which sequence shows the bases in order of decreasing strength?

☒ **A** $C_6H_5NH_2 > CH_3NH_2 > NH_3$

☒ **B** $NH_3 > CH_3NH_2 > C_6H_5NH_2$

☒ **C** $CH_3NH_2 > NH_3 > C_6H_5NH_2$

☒ **D** $NH_3 > C_6H_5NH_2 > CH_3NH_2$

(Total for Question 15 = 1 mark)

16 Bromoethane can be made by heating ethanol under reflux with 50% sulfuric acid and sodium bromide. When the mixture is distilled, the products include sulfur dioxide, bromine, hydrogen bromide and water as well as bromoethane.

The product mixture is shaken with sodium carbonate solution and later with anhydrous sodium sulfate before being re-distilled. Which of the following shows the correct list of impurities removed at each step?

		Aqueous sodium carbonate wash	Addition of sodium sulfate
☒	**A**	HBr	SO_2, Br_2, water
☒	**B**	SO_2, Br_2	HBr, water
☒	**C**	SO_2, HBr	Br_2, water
☒	**D**	SO_2, Br_2, HBr	water

(Total for Question 16 = 1 mark)

17 A compound is known to have either the structure $H_2NCH_2CH_2NH_2$ or H_2NCH_2COOH. Which of the following tests would best distinguish between the two compounds?

☒ **A** Reaction with concentrated aqueous sodium hydroxide.

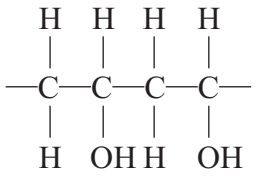
☒ **B** Reaction with nitrous acid.

☒ **C** Reaction with aqueous sodium hydrogencarbonate.

☒ **D** Reaction with ethanoyl chloride.

(Total for Question 17 = 1 mark)

18 Poly(ethenol) is a water-soluble polymer. A section of the chain has the structure shown below.



The polymer is used for making hospital laundry bags so that laundry can be loaded directly into washing machines without it having to be handled.

Poly(ethenol) is water soluble because the polymer

☒ **A** is broken down by the water into monomers.

☒ **B** is broken down by the washing detergent.

☒ **C** breaks into monomers at the temperature of the wash.

☒ **D** forms many strong hydrogen bonds with the water.

(Total for Question 18 = 1 mark)

19 Which of the following substances is capable of damaging the ozone layer?

☒ **A** NaCl

☒ **B** CO_2

☒ **C** C_2HF_5

☒ **D** $C_2F_3Cl_3$

(Total for Question 19 = 1 mark)

20 Analysis suggests that a particular organic synthesis produces a medicine that contains trace impurities that may be hazardous. What is the best way for this discovery to be reported and evaluated?

☒ **A** In a scientific journal which subjects its articles to peer review.

☒ **B** On the Internet in an article on a website.

☒ **C** In a newspaper article in several broadsheet newspapers.

☒ **D** In a widely circulated magazine.

(Total for Question 20 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

Answer ALL the questions. Write your answers in the spaces provided.

21 (a) Chromium is a typical transition metal, although its electronic configuration does **not** fit the general trend found in the first transition series.

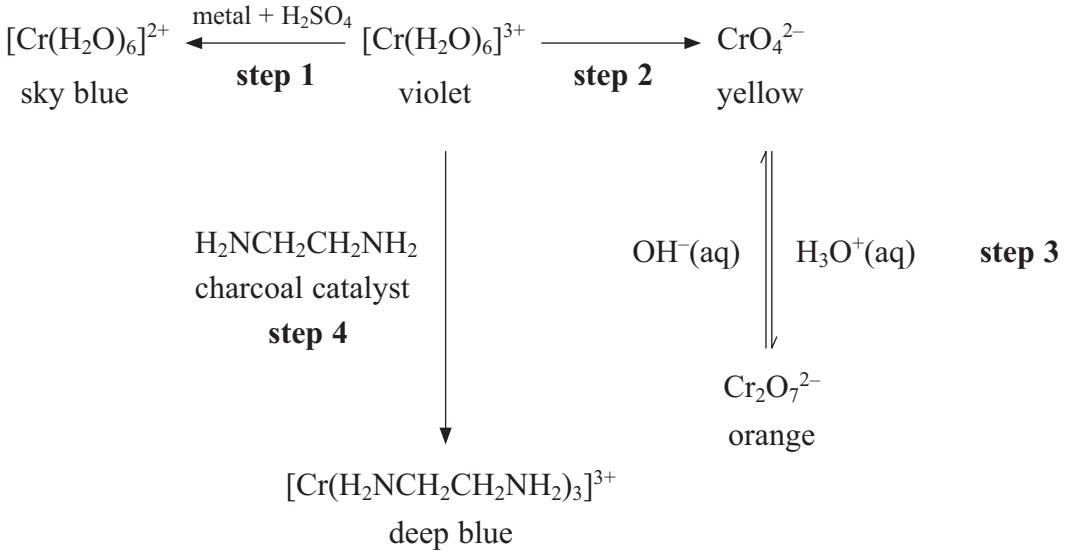
Complete the electronic configurations in *s,p,d* notation for vanadium and chromium.

(1)

Vanadium: [Ar] .....

Chromium: [Ar] .....

(b) Some interconversions found in the chemistry of chromium are shown below. Use this information to answer the questions that follow.



(i) State **two** typical properties of transition metals, other than the formation of coloured ions, which are shown in the diagram above.

(2)

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(ii) Use $E^{\ominus}$ values from your data booklet to suggest a metal that could be used for **step 1**. Justify your answer by calculating $E^{\ominus}$ for your cell.

(2)

(iii) Explain, using oxidation numbers, whether or not the conversion in **step 3** is a redox reaction.

(2)

(iv) The organic compound $H_2NCH_2CH_2NH_2$ that is used in **step 4** is 1,2-diaminoethane, often called ethylenediamine.
It is a **bidentate ligand**. Explain the meaning of this term.

(1)

(v) Explain, in terms of its structure, how $H_2NCH_2CH_2NH_2$ can act as a bidentate ligand whereas H_2NNH_2 cannot.

(2)

(c) The half-equations relating the interconversion of the species $Cr^{2+}(aq)$, $Cr^{3+}(aq)$ and $Cr_2O_7^{2-}(aq)$ are given below.

Half-equation I: $Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$

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

(i) Use your data booklet to find $E^{\ominus}$ for each of the above half-equations.

(1)

Half-equation I ..... Volts

Half-equation II ..... Volts

*(ii) Write the overall equation for the disproportionation of Cr^{3+} into Cr^{2+} and $Cr_2O_7^{2-}$.

Use the $E^{\ominus}$ values you have obtained in (c)(i) to show whether or not this disproportionation is feasible under standard conditions.

(4)

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(Total for Question 21 = 15 marks)

22 (a) Tiglic acid is a compound that is used as a defensive agent by some beetles.

(i) Tiglic acid contains, by mass, 60% carbon, 8% hydrogen, with the remainder being oxygen. Show that these data are consistent with the formula $C_5H_8O_2$.

(1)

(ii) Tiglic acid contains a carbon-carbon double bond and a carboxylic acid group.

Suggest **one** test for each of these groups in tiglic acid. State what you would do and what you would see as a positive result for the tests.

(4)

Test for C═C .....

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Test for —COOH .....

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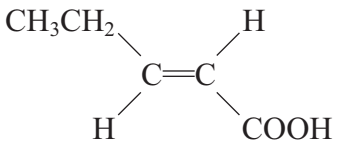
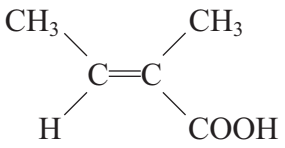
(b) It is suggested that the structure of tiglic acid is either that of **A** or **B**.



A



B

(i) State, with a reason, whether **B** is the *E*- or *Z*- isomer.

(2)

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.....

.....

(ii) The mass spectrum of tiglic acid shows two prominent peaks at mass/charge ratios 45 and 55. Write the formulae of the fragments giving rise to each of these peaks.

(2)

45 .....

55 .....

(iii) Does this data from the mass spectrum **alone** enable you to decide which of **A** or **B** is the structure of tiglic acid? Explain your answer.

(1)

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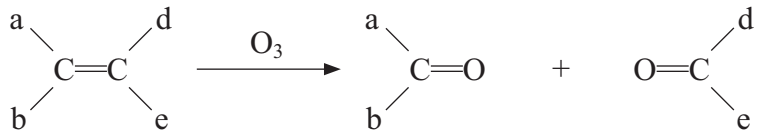
(c) The position of a C═C double bond in a molecule can be determined by ozonolysis. The compound is reacted with ozone and then dilute acid, two carbonyl compounds being produced as shown below.



Ozonolysis of tiglic acid gives two carbonyl compounds, **C** and **D**.

Compound **C** gives a silver mirror with Tollens' reagent and gives iodoform with iodine in alkali.

Compound **D** does **not** give a silver mirror with Tollens' reagent, but does give iodoform with iodine in alkali.

*(i) From the results of the experiments, deduce the functional groups present in **C** and **D**. By considering the two possible structures for tiglic acid, give the structural formulae of **C** and **D**.

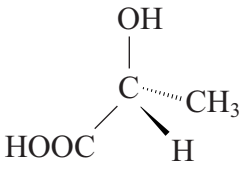
From the structures you have drawn, state which of the structures **A** or **B** could represent tiglic acid.

(6)

(ii) Explain whether or not these tests show definitely that your answer to (c)(i) represents tiglic acid.

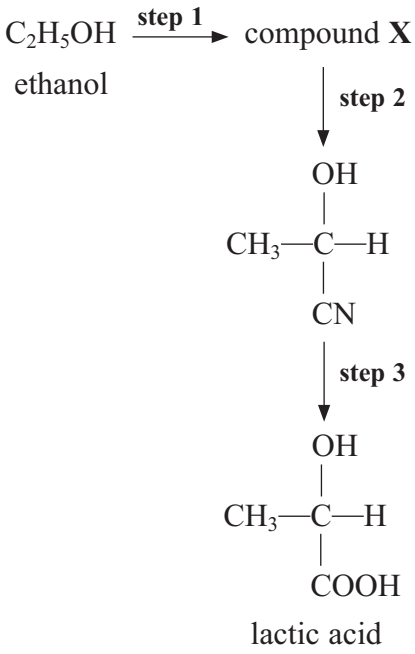
(1)

(d) Lactic acid is a chiral molecule that is found in sweat as the (–) isomer only. Its structural formula is



(–) - lactic acid

(i) Lactic acid can be made from ethanol in three steps.



lactic acid

Give the structural formula of the intermediate **X** and the reagents and conditions required for **steps 1** and **2**.

(4)

Step 1 .....

.....

Step 2 .....

.....

(ii) Classify the type and mechanism of the reaction that occurs in **step 2**.

(1)

.....

*(iii) By considering the stereochemistry of the mechanism in **step 2**, explain why this synthesis would **not** give a single optical isomer of lactic acid.

(2)

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(iv) Suggest why synthetic pathways for the manufacture of pharmaceuticals may require reactions that are highly stereospecific.

(1)

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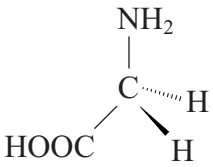
(Total for Question 22 = 25 marks)

23 Proteins are polymers of α-amino acids, the simplest of which is glycine.



(a) (i) Draw the **structural** formula for the zwitterion of glycine in the solid state.

(1)

(ii) Explain, on the basis of your answer to (a)(i), why glycine has a relatively high melting temperature for such a small molecule.

(2)

(iii) Draw the structure of the protein chain that would be formed if glycine alone were to be polymerized. Show part of the chain containing two glycine residues.

(2)

*(b) A solution of hydrolysed protein contains the individual amino acids that make up the protein. Briefly state how you would use chromatography, together with known samples of amino acids, to show which amino acids the protein contained. Do **not** give detailed experimental instructions.

(5)

(Total for Question 23 = 10 marks)

TOTAL FOR SECTION B = 50 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

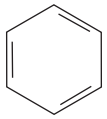
24 Read the passage below carefully and answer the questions which follow.

Molecular structure and colour chemistry

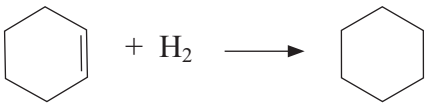
The sight of tubes of paint or of coloured pencils in an artists' supply shop is something that most people enjoy; we love colour.

The ability to synthesise brightly-coloured compounds coincides with the rapid growth of the organic chemicals industry. Synthetic organic dyes started to appear in the mid-19th century when William Perkin synthesised Mauve in 1856 at the age of 18. He was trying to synthesise quinine even though he did not know the structure of the molecule.

In the 19th century many chemists did not believe that molecules existed. The work of Butlerov, Couper, and notably Kekulé showed that molecules not only exist but have specific structures. In 1865 Kekulé suggested a ring structure for the aromatic compound benzene which he represented as



Kekulé knew that benzene does not react with bromine water. Later work showed that the enthalpy change of hydrogenation of the compound is $-205\ kJ\ mol^{-1}$, rather than the value of $-360\ kJ\ mol^{-1}$ that would be expected if the structure was exactly as shown above, given that the enthalpy change of hydrogenation for cyclohexene to cyclohexane



is $-120\ kJ\ mol^{-1}$.

When Greiss in 1856 discovered diazotisation and the azo dyes, he used a reaction characteristic of aromatic amines. Witt, in 1876, found the functional groups in the dye molecule that make it water-soluble and enable it to attach to the cloth fibres. Graebe, Liebermann and Perkin in 1869 patented the synthesis of alizarin, found in madder root grown in Holland and Von Baeyer synthesised indigo in 1880, until then grown in India. Synthetic dyes were made available in large quantities and were cheaper than the sources from plants.

Now the organic chemical industry produces a vast range of pigments and dyestuffs for use in paints and for fabrics, inks and other materials, making our world the most colourful that it has ever been.

(a) (i) Explain why Perkin's attempted synthesis of quinine was almost certain to fail.

(1)

(ii) Suggest the effect that the growth of the organic chemicals industry in the late 19th century had on Holland and India in particular.

(2)

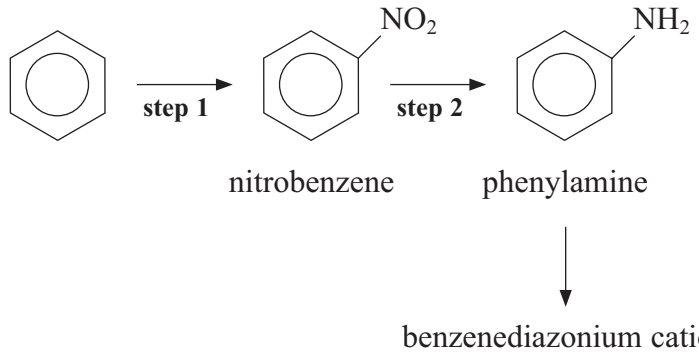
(b) (i) What observation did Kekulé make to show that benzene does **not** react with bromine water? Explain the significance of this with reference to his representation of the molecule.

(2)

(ii) Explain, in terms of the bonding in the benzene ring, why the enthalpy of hydrogenation is less exothermic than would be expected from a molecule with three double bonds.

(3)

(c) The first steps in the preparation of an azo dye from benzene are shown below.



Give the mechanism for the reaction in **step 1**, including the equation for the formation of the electrophile.

(4)

Equation for formation of electrophile

Mechanism

(d) (i) Phenylamine is converted into the benzenediazonium cation using sodium nitrite and hydrochloric acid at a temperature between 0 °C and 10 °C.

Explain why the temperature must **not** be lower or higher than these limits if a good yield is to be obtained.

(2)

.....

.....

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.....

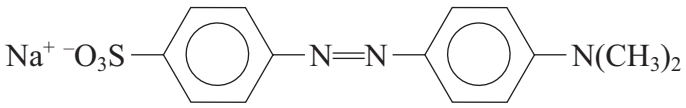
(ii) Draw the structural formula of the benzenediazonium cation showing all the bonds and the charge.

(1)

(iii) Suggest how you could convert a sample of the benzenediazonium cation into an azo dye. Give the name of the other compound you would use and the skeletal formula of the azo dye you would obtain.

(3)

(e) The structural formula of methyl orange is given below.



Suggest the main features of methyl orange which make it water-soluble, giving your reasons.

(2)

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(Total for Question 24 = 20 marks)

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

Do not write outside the box

Section A

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

1 (a) State the meaning of the term *mass number* of an isotope.

.....

.....

.....

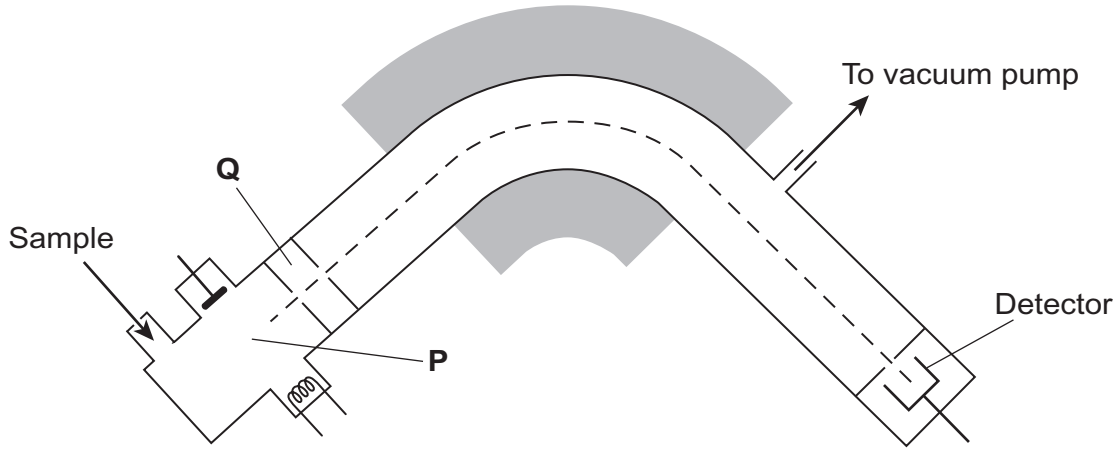
(1 mark)

1 (b) Give the symbol of the element that has an isotope with a mass number of 68 and has 38 neutrons in its nucleus.

.....

(1 mark)

1 (c) The following shows a simplified diagram of a mass spectrometer.



1 (c) (i) State what happens to the sample in the parts labelled **P** and **Q**.

P .....

Q .....

(2 marks)

1 (c) (ii) In a mass spectrometer, the isotopes of an element are separated.
Two measurements for each isotope are recorded on the mass spectrum.

State the **two** measurements that are recorded for each isotope.

Measurement 1 .....

Measurement 2 .....

(2 marks)

1 (d) A sample of element **R** contains isotopes with mass numbers of 206, 207 and 208 in a 1:1:2 ratio of abundance.

1 (d) (i) Calculate the relative atomic mass of **R**. Give your answer to one decimal place.

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(3 marks)

1 (d) (ii) Identify **R**.

.....

(1 mark)

1 (d) (iii) All the isotopes of **R** react in the same way with concentrated nitric acid.

State why isotopes of an element have the same chemical properties.

.....

.....

(1 mark)

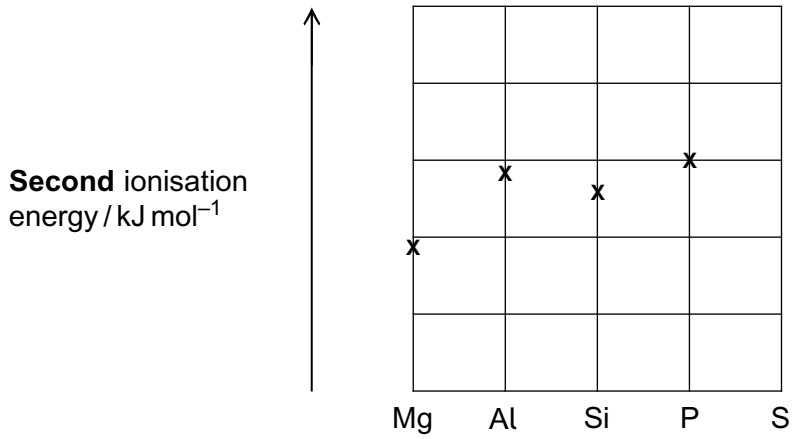
(Extra space) .....

.....

11

Do not write outside the box

2 (a) Use your knowledge of electron configuration and ionisation energies to answer this question.
The following diagram shows the **second** ionisation energies of some Period 3 elements.



2 (a) (i) Draw an '**X**' on the diagram to show the **second** ionisation energy of sulfur.

(1 mark)

2 (a) (ii) Write the full electron configuration of the Al^{2+} ion.

.....

(1 mark)

2 (a) (iii) Write an equation to show the process that occurs when the **second** ionisation energy of aluminium is measured.

.....

(1 mark)

2 (a) (iv) Give **one** reason why the **second** ionisation energy of silicon is lower than the **second** ionisation energy of aluminium.

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.....

.....

(1 mark)

2 (b) Predict the element in Period 3 that has the highest **second** ionisation energy. Give a reason for your answer.

Element .....

Reason .....

.....

.....

(2 marks)

2 (c) The following table gives the successive ionisation energies of an element in Period 3.

	First	Second	Third	Fourth	Fifth	Sixth
Ionisation energy / kJ mol^{-1}	786	1580	3230	4360	16 100	19 800

Identify this element.

.....

(1 mark)

2 (d) Explain why the ionisation energy of every element is endothermic.

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.....

(1 mark)

(Extra space) .....

.....

8

Do not write outside the box

3 The following table shows the electronegativity values of the elements from lithium to fluorine.

	Li	Be	B	C	N	O	F
Electronegativity	1.0	1.5	2.0	2.5	3.0	3.5	4.0

3 (a) (i) State the meaning of the term *electronegativity*.

.....

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.....

(2 marks)

(Extra space) .....

.....

3 (a) (ii) Suggest why the electronegativity of the elements increases from lithium to fluorine.

.....

.....

.....

(2 marks)

(Extra space) .....

.....

3 (b) State the type of bonding in lithium fluoride.
Explain why a lot of energy is needed to melt a sample of solid lithium fluoride.

Bonding .....

Explanation .....

.....

.....

(3 marks)

(Extra space) .....

.....

3 (c) Deduce why the bonding in nitrogen oxide is covalent rather than ionic.

.....

.....

(1 mark)

(Extra space) .....

.....

3 (d) Oxygen forms several different compounds with fluorine.

3 (d) (i) Suggest the type of crystal shown by OF_2

.....

(1 mark)

3 (d) (ii) Write an equation to show how OF_2 reacts with steam to form oxygen and hydrogen fluoride.

.....

(1 mark)

3 (d) (iii) One of these compounds of oxygen and fluorine has a relative molecular mass of 70.0 and contains 54.3% by mass of fluorine.

Calculate the empirical formula and the molecular formula of this compound. Show your working.

Empirical formula .....

.....

.....

.....

.....

.....

Molecular formula .....

.....

(4 marks)

14

4 The following table shows the boiling points of some straight-chain alkanes.

	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}
Boiling point / °C	–162	–88	–42	–1	36

4 (a) State a process used to separate an alkane from a mixture of these alkanes.

.....

(1 mark)

4 (b) Both C_3H_8 and C_4H_{10} can be liquefied and used as fuels for camping stoves.

Suggest, with a reason, which of these two fuels is liquefied more easily.

.....

.....

.....

(1 mark)

4 (c) Write an equation for the complete combustion of C_4H_{10}

.....

(1 mark)

4 (d) Explain why the complete combustion of C_4H_{10} may contribute to environmental problems.

.....

.....

.....

(1 mark)

4 (e) Balance the following equation that shows how butane is used to make the compound called maleic anhydride.

$$\text{.....}CH_3CH_2CH_2CH_3 + \text{.....}\ O_2 \longrightarrow \text{.....}C_2H_2(CO)_2O + \text{.....}\ H_2O$$

(1 mark)

Do not write outside the box

4 (f) Ethanethiol (C_2H_5SH), a compound with an unpleasant smell, is added to gas to enable leaks from gas pipes to be more easily detected.

4 (f) (i) Write an equation for the combustion of ethanethiol to form carbon dioxide, water and sulfur dioxide.

.....

(1 mark)

4 (f) (ii) Identify a compound that is used to react with the sulfur dioxide in the products of combustion before they enter the atmosphere.

Give **one** reason why this compound reacts with sulfur dioxide.

Substance .....

Reason .....

.....

(2 marks)

4 (f) (iii) Ethanethiol and ethanol molecules have similar shapes.

Explain why ethanol has the higher boiling point.

.....

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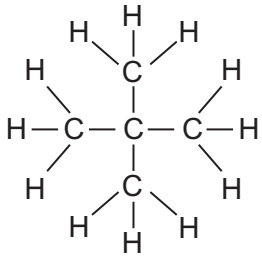
(2 marks)

Question 4 continues on the next page

Do not write outside the box

4 (g) The following compound **X** is an isomer of one of the alkanes in the table on page 8.



4 (g) (i) Give the IUPAC name of **X**.

.....

(1 mark)

4 (g) (ii) **X** has a boiling point of 9.5 ºC.

Explain why the boiling point of **X** is lower than that of its straight-chain isomer.

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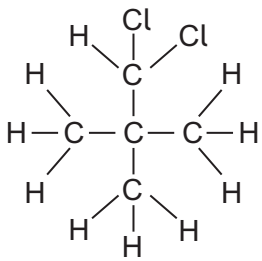
(2 marks)

4 (g) (iii) The following compound **Y** is produced when **X** reacts with chlorine.



Deduce how many **other** position isomers of **Y** can be formed.
Write the number of **other** position isomers in this box.

(1 mark)

4 (h) Cracking of one molecule of an alkane **Z** produces one molecule of ethane, one molecule of propene and two molecules of ethene.

4 (h) (i) Deduce the molecular formula of **Z**.

.....

(1 mark)

4 (h) (ii) State the type of cracking that produces a high proportion of ethene and propene. Give the **two** conditions for this cracking process.

Type of cracking .....

Conditions .....

.....

(2 marks)

17

Turn over for the next question

Do not write outside the box

Section B

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

5 Ammonia is used to make nitric acid (HNO_3) by the Ostwald Process.
Three reactions occur in this process.

Reaction **1** $4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$

Reaction **2** $2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$

Reaction **3** $3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$

5 (a) In one production run, the gases formed in Reaction **1** occupied a total volume of $4.31\,m^3$ at 25 °C and 100 kPa.

Calculate the amount, in moles, of NO produced.
Give your answer to 3 significant figures.
(The gas constant $R = 8.31\,J\,K^{-1}\,mol^{-1}$)

.....

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(4 marks)

(Extra space) .....

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Do not write outside the box

5 (b) In another production run, 3.00 kg of ammonia gas were used in Reaction **1** and all of the NO gas produced was used to make NO_2 gas in Reaction **2**.

5 (b) (i) Calculate the amount, in moles, of ammonia in 3.00 kg.

.....

.....

.....

.....

(2 marks)

5 (b) (ii) Calculate the mass of NO_2 formed from 3.00 kg of ammonia in Reaction **2** assuming an 80.0% yield.
Give your answer in kilograms.
(If you have been unable to calculate an answer for part **(b) (i)**, you may assume a value of 163 mol. This is **not** the correct answer.)

.....

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(3 marks)

(Extra space) .....

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Question 5 continues on the next page

Do not write outside the box

5 (c) Consider Reaction **3** in this process.

$$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + NO(g)$$

Calculate the concentration of nitric acid produced when 0.543 mol of NO_2 is reacted with water and the solution is made up to 250 cm^3.

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(2 marks)

(Extra space) .....

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5 (d) Suggest why a leak of NO_2 gas from the Ostwald Process will cause atmospheric pollution.

.....

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(1 mark)

5 (e) Give **one** reason why excess air is used in the Ostwald Process.

.....

.....

(1 mark)

5 (f) Ammonia reacts with nitric acid as shown in this equation.

$$NH_3 + HNO_3 \longrightarrow NH_4NO_3$$

Deduce the type of reaction occurring.

.....

(1 mark)

14

6 Chlorine can form molecules and ions that contain only chlorine, or that contain chlorine combined with another element.

6 (a) Use your understanding of the electron pair repulsion theory to draw the shape of the $AsCl_3$ molecule and the shape of the Cl_3^+ ion.
Include any lone pairs of electrons that influence the shape.

Name the shape made by the atoms in the $AsCl_3$ molecule and in the Cl_3^+ ion.

.....

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(4 marks)

(Extra space) .....

.....

6 (b) Explain why the $AsCl_4^+$ ion has a bond angle of 109.5º

.....

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.....

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(2 marks)

(Extra space) .....

.....

6

END OF QUESTIONS

Do not write outside the box

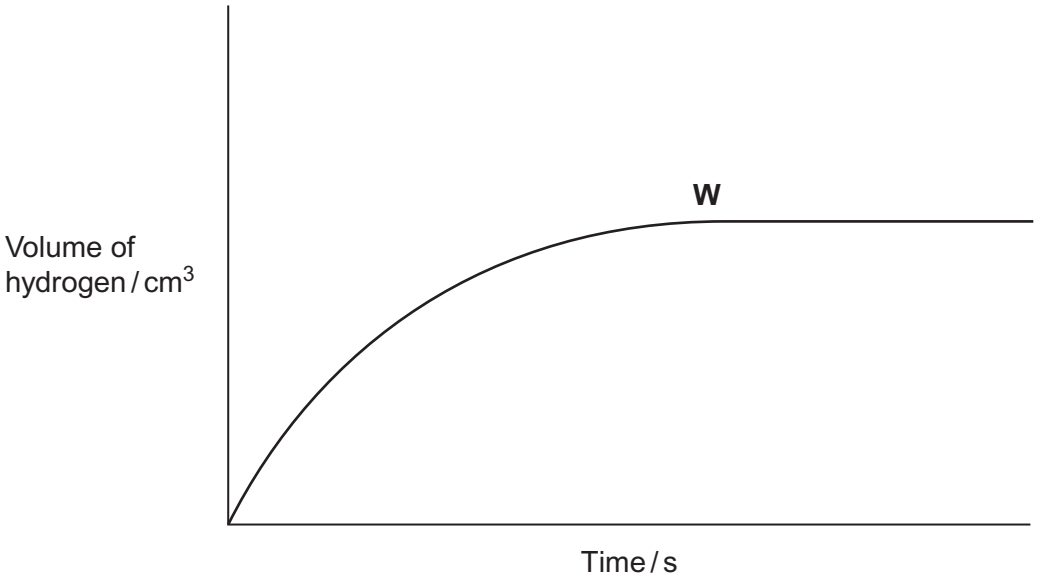
Section A

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

1 (a) **Figure 1** shows the volume of hydrogen gas collected when a sample of magnesium reacted with an excess of dilute hydrochloric acid.

The rate of this reaction can be studied by measuring the time it takes for a given volume of hydrogen to be collected.

Figure 1



1 (a) (i) State the meaning of the term *rate of reaction*.

.....

.....

.....

(1 mark)

1 (a) (ii) State and explain what has happened to the rate of this reaction at point **W** in **Figure 1**.

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(2 marks)

Do not write outside the box

1 (a) (iii) In terms of collision theory explain why, at a fixed temperature, the rate of this reaction doubles when the concentration of the hydrochloric acid doubles.

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(2 marks)

1 (b) In a study of the reaction in part **(a)**, a student referred to activation energy.

1 (b) (i) State the meaning of the term *activation energy*.

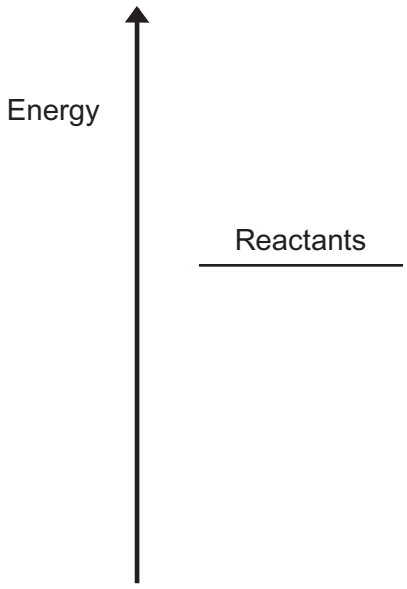
.....

.....

(1 mark)

1 (b) (ii) Complete **Figure 2** by drawing the shape of the reaction profile from reactants to products for an exothermic reaction.
Show the position of the products. Show and label the activation energy.

Figure 2



(2 marks)

Question 1 continues on the next page

1 (c) Barium metal reacts very quickly with dilute hydrochloric acid, but it reacts more slowly with water.

1 (c) (i) Write an equation for the reaction of barium with water.

.....

(1 mark)

1 (c) (ii) A solution containing barium ions can be used to show the presence of sulfate ions in an aqueous solution of sodium sulfate.

Write the **simplest ionic** equation for the reaction that occurs and state what is observed.

Simplest ionic equation

.....

Observation

.....

(2 marks)

1 (c) (iii) State **one** use of barium sulfate in medicine.
Explain why this use is possible, given that solutions containing barium ions are poisonous.

Use .....

.....

Explanation .....

.....

.....

(2 marks)

13

Turn over for the next question

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

2 A study of equilibrium is important for understanding chemical reactions.

2 (a) State Le Chatelier's principle.

.....

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.....

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(1 mark)

(Extra space) .....

.....

2 (b) Catalysts play an important role in many reactions.

2 (b) (i) State the meaning of the term *catalyst*.
Explain, in general terms, how catalysts work.

Meaning of the term *catalyst* .....

.....

.....

How catalysts work .....

.....

.....

.....

(3 marks)

(Extra space) .....

.....

2 (b) (ii) State the effect, if any, of a catalyst on the time taken to reach equilibrium.

.....

(1 mark)

2 (b) (iii) State the effect, if any, of a catalyst on the position of an equilibrium.

.....

(1 mark)

Do not write outside the box

2 (c) Consider the following equilibrium reactions.

		$\Delta H^{\ominus}$ / kJ mol^{-1}
P	$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$	–10
Q	$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$	–49
R	$N_2O_4(g) \rightleftharpoons 2NO_2(g)$	+58
S	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	–92
T	$C_2H_4(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$	–42

In each of parts **(c) (i)** to **(c) (v)**, you should record in the box **one** of the letters, **P**, **Q**, **R**, **S** or **T**, that corresponds to the equilibrium that best fits the information provided. You may use each letter once, more than once or not at all.

2 (c) (i) A decrease in temperature at constant pressure shifts the position of this equilibrium from right to left.

(1 mark)

2 (c) (ii) This equilibrium uses concentrated phosphoric acid as a catalyst in a hydration reaction.

(1 mark)

2 (c) (iii) A decrease in pressure at constant temperature shifts the position of this equilibrium from left to right.

(1 mark)

2 (c) (iv) There is no change in the position of this equilibrium when the pressure is increased at constant temperature.

(1 mark)

2 (c) (v) An increase in the concentration of steam at constant temperature and constant pressure shifts the position of this equilibrium from right to left.

(1 mark)

11

3 This question is about the extraction of metals.

3 (a) Manganese can be extracted from Mn_2O_3 by reduction with carbon monoxide at high temperature.

3 (a) (i) Use the standard enthalpy of formation data from the table and the equation for the extraction of manganese to calculate a value for the standard enthalpy change of this extraction.

	$Mn_2O_3(s)$	$CO(g)$	$Mn(s)$	$CO_2(g)$
$\Delta H_f^{\ominus}$ / kJ mol^{-1}	– 971	– 111	0	– 394

$$Mn_2O_3(s) + 3CO(g) \longrightarrow 2Mn(s) + 3CO_2(g)$$

.....

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(3 marks)

3 (a) (ii) State why the value for the standard enthalpy of formation of Mn(s) is zero.

.....

(1 mark)

Do not write outside the box

3 (b) Titanium is extracted in industry from titanium(IV) oxide in a two-stage process.

3 (b) (i) Write an equation for the first stage of this extraction in which titanium(IV) oxide is converted into titanium(IV) chloride.

.....

(2 marks)

3 (b) (ii) Write an equation for the second stage of this extraction in which titanium(IV) chloride is converted into titanium.

.....

(2 marks)

3 (c) Chromium is extracted in industry from chromite ($FeCr_2O_4$).

3 (c) (i) In the first stage of this extraction, the $FeCr_2O_4$ is converted into Na_2CrO_4

Balance the equation for this reaction.

..... $FeCr_2O_4$ + ... Na_2CO_3 + ... O_2 $\longrightarrow$ ..... Na_2CrO_4 + $2Fe_2O_3$ + $8CO_2$

(1 mark)

3 (c) (ii) In the final stage, chromium is extracted from Cr_2O_3 by reduction with aluminium.

Write an equation for this reaction.

.....

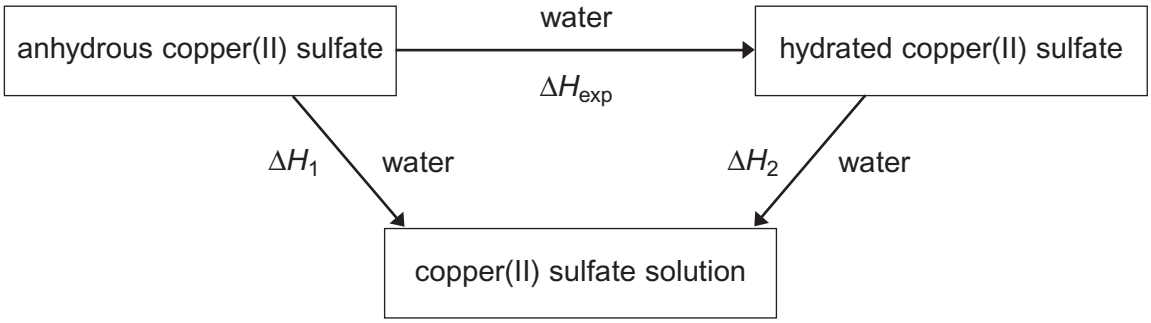
(1 mark)

10

Turn over for the next question

Do not write outside the box

4 A student used Hess's Law to determine a value for the enthalpy change that occurs when anhydrous copper(II) sulfate is hydrated.
This enthalpy change was labelled ΔH_{exp} by the student in a scheme of reactions.



4 (a) State Hess's Law.

.....

.....

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.....

(1 mark)

4 (b) Write a mathematical expression to show how ΔH_{exp}, ΔH_1 and ΔH_2 are related to each other by Hess's Law.

.....

(1 mark)

4 (c) Use the mathematical expression that you have written in part **(b)**, and the data book values for the two enthalpy changes ΔH_1 and ΔH_2 shown, to calculate a value for ΔH_{exp}

$\Delta H_1 = -156\,kJ\,mol^{-1}$
$\Delta H_2 = +12\,kJ\,mol^{-1}$

.....

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.....

(1 mark)

4 (d) The student added 0.0210 mol of pure anhydrous copper(II) sulfate to 25.0 cm^3 of deionised water in an open polystyrene cup. An exothermic reaction occurred and the temperature of the water increased by 14.0 °C.

4 (d) (i) Use these data to calculate the enthalpy change, in $kJ\,mol^{-1}$, for this reaction of copper(II) sulfate. This is the student value for ΔH_1

In this experiment, you should assume that all of the heat released is used to raise the temperature of the 25.0 g of water. The specific heat capacity of water is $4.18\,J\,K^{-1}\,g^{-1}$.

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(3 marks)

4 (d) (ii) Suggest **one** reason why the student value for ΔH_1 calculated in part **(d) (i)** is less accurate than the data book value given in part **(c)**.

.....

.....

(1 mark)

4 (e) Suggest **one** reason why the value for ΔH_{exp} **cannot** be measured directly.

.....

.....

(1 mark)

(Extra space) .....

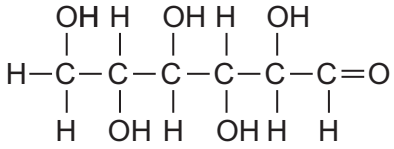
.....

8

Do not write outside the box

5 Glucose is an organic molecule. Glucose can exist in different forms in aqueous solution.

5 (a) In aqueous solution, some glucose molecules have the following structure.

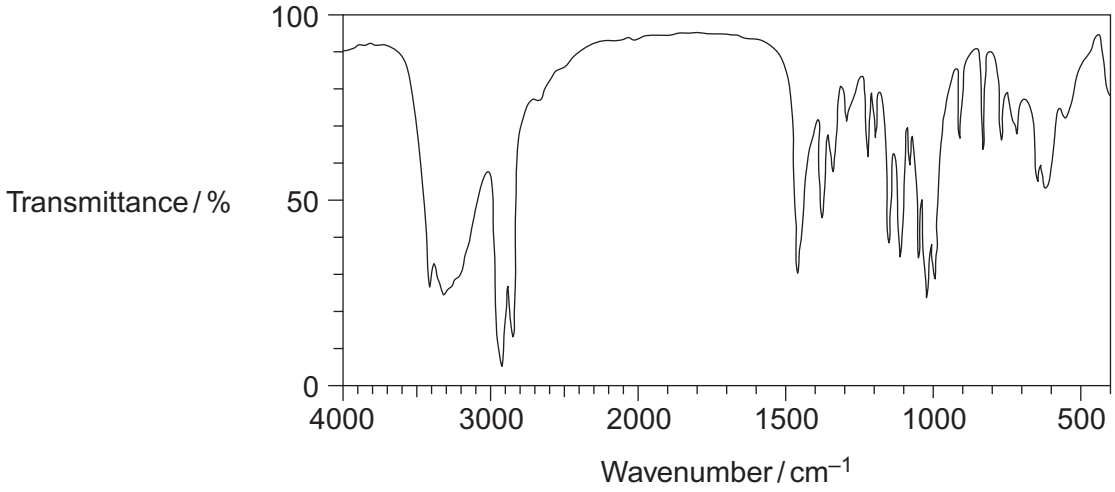


5 (a) (i) Deduce the empirical formula of glucose.

.....

(1 mark)

5 (a) (ii) Consider the infrared spectrum of solid glucose.



State why it is possible to suggest that in the solid state very few molecules have the structure shown.
You may find it helpful to refer to **Table 1** on the Data Sheet.

.....

.....

(1 mark)

Do not write outside the box

5 (b) In the absence of oxygen, an aqueous solution of glucose can be fermented to produce ethanol for use in alcoholic drinks.

Write an equation for this fermentation reaction.
Give **two** other essential conditions for the production of ethanol in this fermentation.

Equation

.....

Condition 1 .....

Condition 2 .....

(3 marks)

5 (c) Any ethanol present in the breath of a drinker can be detected by using a breathalyser. The ethanol is converted into ethanoic acid. The breathalyser has negative and positive electrodes. A current is measured and displayed in terms of alcohol content.

The overall redox equation is as follows

$$CH_3CH_2OH(l) + O_2(g) \longrightarrow CH_3COOH(l) + H_2O(l)$$

5 (c) (i) Draw the displayed formula for ethanoic acid.

(1 mark)

5 (c) (ii) Deduce a half-equation for the reduction of atmospheric oxygen to water in acidic solution at one electrode of the breathalyser.

.....

(1 mark)

5 (c) (iii) Deduce a half-equation for the oxidation of ethanol in water to ethanoic acid at the other electrode of the breathalyser.

.....

(1 mark)

Question 5 continues on the next page

5 (c) (iv) The earliest breathalysers used laboratory chemicals to oxidise the ethanol to ethanoic acid. Detection was by a colour change.

Identify a reagent or combination of reagents that you would use in the laboratory to oxidise ethanol to ethanoic acid.
State the colour **change** that you would expect to see.

Reagent or combination of reagents .....

Colour change .....

(2 marks)

5 (d) The fermentation of glucose from crops is the main method for the production of ethanol. The product is called bioethanol. The European Union has declared that bioethanol is carbon-neutral.

5 (d) (i) State the meaning of the term *carbon-neutral*.

.....

.....

.....

(1 mark)

(Extra space) .....

.....

5 (d) (ii) Other than carbon-neutrality, state the **main** advantage of the use of glucose from crops as the raw material for the production of ethanol.

.....

.....

(1 mark)

5 (d) (iii) Give **one** disadvantage of the use of crops for the production of ethanol.

.....

.....

(1 mark)

13

6 Hydrazine (N_2H_4) decomposes in an exothermic reaction. Hydrazine also reacts exothermically with hydrogen peroxide when used as a rocket fuel.

6 (a) Write an equation for the decomposition of hydrazine into ammonia and nitrogen only.

.....

(1 mark)

6 (b) State the meaning of the term *mean bond enthalpy*.

.....

.....

.....

.....

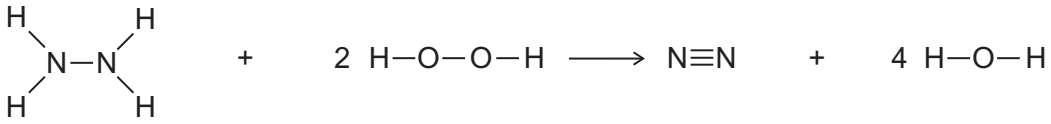
.....

(2 marks)

6 (c) Some mean bond enthalpies are given in the table.

	N—H	N—N	N≡N	O—H	O—O
Mean bond enthalpy / kJ mol^{-1}	388	163	944	463	146

Use these data to calculate the enthalpy change for the gas-phase reaction between hydrazine and hydrogen peroxide.



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(3 marks)

6

Do not write outside the box

7 The refrigerant R410A, used in air conditioners, is a mixture of two fluoroalkanes, pentafluoroethane and difluoromethane.

7 (a) (i) The mechanism for the reaction of fluorine with either an alkane or a fluoroalkane is similar to that for the reaction of chlorine with methane.

Name the type of mechanism for the reaction of chlorine with methane.

.....

(1 mark)

7 (a) (ii) Write equations for the following steps in the mechanism for the reaction of fluorine with fluoromethane (CH_3F) to form difluoromethane (CH_2F_2).

Initiation step

.....

First propagation step

.....

Second propagation step

.....

A termination step leading to the formation of 1,2-difluoroethane.

.....

(4 marks)

7 (a) (iii) Write an overall equation for the reaction of fluorine with ethane to form pentafluoroethane (CF_3CHF_2) by this mechanism.

.....

(1 mark)

7 (b) The refrigerant R112A (CCl_3CF_2Cl) has been banned because of concerns about ozone depletion.

Give the IUPAC name for CCl_3CF_2Cl

.....

(1 mark)

7 (c) Nitrogen monoxide (NO) catalyses the decomposition of ozone into oxygen.

7 (c) (i) Write the overall equation for this decomposition.

.....

(1 mark)

7 (c) (ii) Use the overall equation to deduce Step **3** in the following mechanism that shows how nitrogen monoxide catalyses this decomposition.

Step **1** $O_3 \longrightarrow O + O_2$

Step **2** $NO + O_3 \longrightarrow NO_2 + O_2$

Step **3** .....

(1 mark)

9

Turn over for the next question

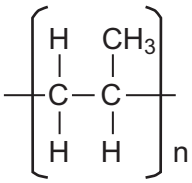
Section B

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

8 Consider the following reactions.

$$H_2C{=}CHCH_3 \xrightarrow[HBr]{\text{Reaction } \mathbf{1}} CH_3CHBrCH_3 \xrightarrow[NH_3]{\text{Reaction } \mathbf{2}} CH_3CH(NH_2)CH_3$$

Reaction **3** ↓



substance **X**

8 (a) Name and outline a mechanism for Reaction **1**.

Name of mechanism .....

Mechanism

(5 marks)

8 (b) Name and outline a mechanism for Reaction **2**.

Name of mechanism .....

Mechanism

(5 marks)

8 (c) State the type of reaction in Reaction **3**.
Give the name of substance **X**.

.....

.....

.....

(2 marks)

Question 8 continues on the next page

Do not write outside the box

8 (d) The haloalkane produced in Reaction **1** can be converted back into propene in an elimination reaction using ethanolic potassium hydroxide.

$$CH_3CHBrCH_3 \xrightarrow{KOH} H_2C{=}CHCH_3$$

Outline a mechanism for this conversion.

(3 marks)

15

Do not write outside the box

9 Concentrated sulfuric acid reacts with solid potassium iodide as shown in the equation.

$$8KI + 9H_2SO_4 \longrightarrow 4I_2 + 8KHSO_4 + H_2S + 4H_2O$$

Give **two** observations that you would make when this reaction occurs.

In terms of electrons, state what happens to the iodide ions in this reaction.

State the **change** in oxidation state of sulfur that occurs during this formation of H_2S and deduce the half-equation for the conversion of H_2SO_4 into H_2S

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(5 marks)

5

Turn over for the next question

Do not write outside the box

10 Chlorine is a powerful oxidising agent.

10 (a) Write the **simplest ionic** equation for the reaction between chlorine and aqueous potassium bromide.

State what is observed when this reaction occurs.

.....

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.....

.....

(2 marks)

(Extra space) .....

.....

10 (b) Write an equation for the reaction between chlorine and cold, dilute, aqueous sodium hydroxide.

Give a major use for the solution that is formed by this reaction.

Give the IUPAC name of the chlorine-containing compound formed in this reaction in which chlorine has an oxidation state of +1.

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(3 marks)

(Extra space) .....

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Do not write outside the box

10 (c) Write an equation for the equilibrium reaction that occurs when chlorine gas reacts with cold water.

Give **one** reason why chlorine is used for the treatment of drinking water even though the gas is very toxic.

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(2 marks)

(Extra space) .....

.....

10 (d) State how you could test a sample of water to show that it contains chloride ions.

In your answer, give a reagent, **one** observation and the **simplest ionic** equation for the reaction with the reagent.

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(3 marks)

(Extra space) .....

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10

END OF QUESTIONS

Do not write outside the box

Section A

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

1 (a) The data in the following table were obtained in two experiments about the rate of the reaction between substances **B** and **C** at a constant temperature.

Experiment	Initial concentration of **B** / mol dm^{-3}	Initial concentration of **C** / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	4.2×10^{-2}	2.6×10^{-2}	8.4×10^{-5}
2	6.3×10^{-2}	7.8×10^{-2}	To be calculated

The rate equation for this reaction is known to be

$$\text{rate} = k[\mathbf{B}]^2[\mathbf{C}]$$

1 (a) (i) Use the data from Experiment **1** to calculate a value for the rate constant k at this temperature and deduce its units.

Calculation .....

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Units .....

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(3 marks)

(Extra space) .....

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1 (a) (ii) Calculate a value for the initial rate in Experiment **2**.

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(1 mark)

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1 (b) The data in the following table were obtained in a series of experiments about the rate of the reaction between substances **D** and **E** at a constant temperature.

Experiment	Initial concentration of **D** / mol dm^{-3}	Initial concentration of **E** / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
3	0.13	0.23	0.26×10^{-3}
4	0.39	0.23	2.34×10^{-3}
5	0.78	0.46	9.36×10^{-3}

1 (b) (i) Deduce the order of reaction with respect to **D**.

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(1 mark)

1 (b) (ii) Deduce the order of reaction with respect to **E**.

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(1 mark)

Question 1 continues on the next page

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1 (c) The compound $(CH_3)_3CBr$ reacts with aqueous sodium hydroxide as shown in the following equation.

$$(CH_3)_3CBr + OH^- \longrightarrow (CH_3)_3COH + Br^-$$

This reaction was found to be first order with respect to $(CH_3)_3CBr$ but zero order with respect to hydroxide ions.

The following two-step process was suggested.

Step **1** $(CH_3)_3CBr \longrightarrow (CH_3)_3C^+ + Br^-$

Step **2** $(CH_3)_3C^+ + OH^- \longrightarrow (CH_3)_3COH$

1 (c) (i) Deduce the rate-determining step in this two-step process.

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(1 mark)

1 (c) (ii) Outline a mechanism for this step using a curly arrow.

(1 mark)

8

Do not write outside the box

2 In this question, give all values of pH to 2 decimal places.

2 (a) The ionic product of water has the symbol K_w

2 (a) (i) Write an expression for the ionic product of water.

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(1 mark)

2 (a) (ii) At 42 °C, the value of K_w is 3.46×10^{-14} mol^2 dm^{-6}.

Calculate the pH of pure water at this temperature.

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(2 marks)

2 (a) (iii) At 75 °C, a 0.0470 mol dm^{-3} solution of sodium hydroxide has a pH of 11.36

Calculate a value for K_w at this temperature.

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(2 marks)

Question 2 continues on the next page

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2 (b) Methanoic acid (HCOOH) dissociates slightly in aqueous solution.

2 (b) (i) Write an equation for this dissociation.

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(1 mark)

2 (b) (ii) Write an expression for the acid dissociation constant K_a for methanoic acid.

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(1 mark)

2 (b) (iii) The value of K_a for methanoic acid is 1.78×10^{-4} mol dm^{-3} at 25 °C.

Calculate the pH of a 0.0560 mol dm^{-3} solution of methanoic acid.

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(3 marks)

2 (b) (iv) The dissociation of methanoic acid in aqueous solution is endothermic.

Deduce whether the pH of a solution of methanoic acid will increase, decrease or stay the same if the solution is heated. Explain your answer.

Effect on pH .....

Explanation .....

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(3 marks)

(Extra space) .....

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2 (c) The value of K_a for methanoic acid is 1.78×10^{-4} mol dm^{-3} at 25 °C.
A buffer solution is prepared containing 2.35×10^{-2} mol of methanoic acid and 1.84×10^{-2} mol of sodium methanoate in 1.00 dm^3 of solution.

2 (c) (i) Calculate the pH of this buffer solution at 25 °C.

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(3 marks)

(Extra space) .....

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2 (c) (ii) A 5.00 cm^3 sample of 0.100 mol dm^{-3} hydrochloric acid is added to the buffer solution in part **(c) (i)**.

Calculate the pH of the buffer solution after this addition.

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(4 marks)

(Extra space) .....

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20

3 Esters are produced by the reaction of alcohols with other esters and by the reaction of alcohols with carboxylic acids.

3 (a) The esters which make up biodiesel are produced industrially from the esters in vegetable oils.

3 (a) (i) Complete the equation for this formation of biodiesel.

(2 marks)

3 (a) (ii) Write an equation for the complete combustion of $C_{17}H_{35}COOCH_3$

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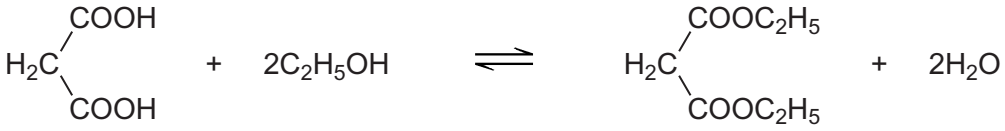
(2 marks)

3 (b) The ester commonly known as diethyl malonate (**DEM**) occurs in strawberries and grapes. It can be prepared from acid **A** according to the following equilibrium.



A **DEM**

3 (b) (i) A mixture of 2.50 mol of **A** and 10.0 mol of ethanol was left to reach equilibrium in an inert solvent in the presence of a small amount of concentrated sulfuric acid. The equilibrium mixture formed contained 1.80 mol of **DEM** in a total volume, V dm^3, of solution.

Calculate the amount (in moles) of **A**, of ethanol and of water in this equilibrium mixture.

Moles of **A** .....

Moles of ethanol .....

Moles of water.....

(3 marks)

3 (b) (ii) The total volume of the mixture in part **(b) (i)** was doubled by the addition of more of the inert solvent.

State and explain the effect of this addition on the equilibrium yield of **DEM**.

Effect .....

Explanation .....

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(2 marks)

3 (b) (iii) Using **A** to represent the acid and **DEM** to represent the ester, write an expression for the equilibrium constant K_c for the reaction.

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(1 mark)

3 (b) (iv) In a second experiment, the equilibrium mixture was found to contain 0.85 mol of **A**, 7.2 mol of ethanol, 2.1 mol of **DEM** and 3.4 mol of water.

Calculate a value of K_c for the reaction and deduce its units.

Calculation.....

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Units.....

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(3 marks)

13

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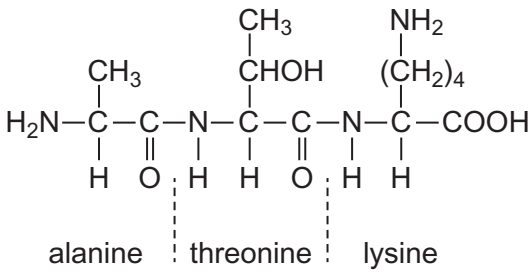
ANSWER IN THE SPACES PROVIDED

4 (a) The tripeptide shown is formed from the amino acids alanine, threonine and lysine.



4 (a) (i) Draw a separate circle around **each** of the asymmetric carbon atoms in the tripeptide.

(1 mark)

4 (a) (ii) Draw the zwitterion of alanine.

(1 mark)

4 (a) (iii) Give the IUPAC name of threonine.

.....

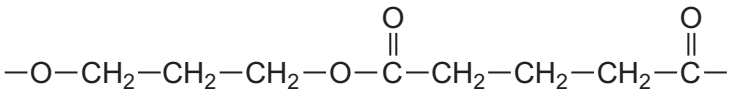
(1 mark)

4 (a) (iv) Draw the species formed by lysine at low pH.

(1 mark)

Question 4 continues on the next page

4 (b) The repeating unit shown represents a polyester.



4 (b) (i) Name this type of polymer.

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(1 mark)

4 (b) (ii) Give the IUPAC name for the alcohol used to prepare this polyester.

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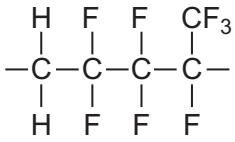
(1 mark)

4 (c) The repeating unit shown represents a polyalkene co-polymer. This co-polymer is made from two different alkene monomers.



4 (c) (i) Name the type of polymerisation occurring in the formation of this co-polymer.

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(1 mark)

4 (c) (ii) Draw the structure of each alkene monomer.

Alkene monomer 1 Alkene monomer 2

(2 marks)

4 (d) One of the three compounds shown in parts **(a)**, **(b)** and **(c)** **cannot** be broken down by hydrolysis.

Write the letter **(a)**, **(b)** or **(c)** to identify this compound and explain why hydrolysis of this compound does **not** occur.

Compound .....

Explanation .....

.....

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(2 marks)

11

Turn over for the next question

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5 This question concerns isomers of $C_6H_{12}O_2$ and how they can be distinguished using n.m.r. spectroscopy.

5 (a) The non-toxic, inert substance TMS is used as a standard in recording both ^1H and ^{13}C n.m.r. spectra.

5 (a) (i) Give **two** other reasons why TMS is used as a standard in recording n.m.r. spectra.

Reason 1 .....

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Reason 2 .....

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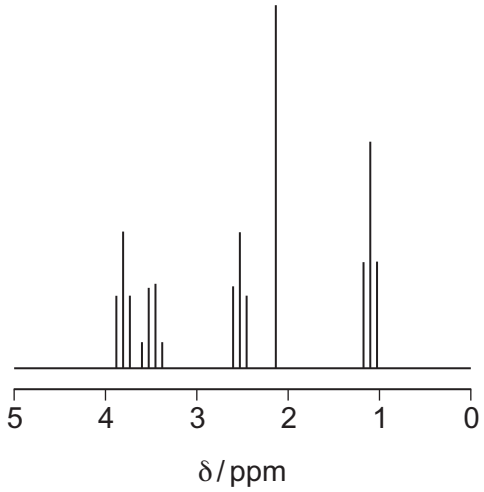
(2 marks)

5 (a) (ii) Give the structural formula of TMS.

(1 mark)

5 (b) The proton n.m.r. spectrum of compound **P** ($C_6H_{12}O_2$) is represented in **Figure 1**.

Figure 1



The integration trace gave information about the five peaks as shown in **Figure 2**.

Figure 2

δ / ppm	3.8	3.5	2.6	2.2	1.2
Integration ratio	2	2	2	3	3

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5 (b) (i) Use **Table 2** on the Data Sheet, **Figure 1** and **Figure 2** to deduce the structural fragment that leads to the peak at δ 2.2

(1 mark)

5 (b) (ii) Use **Table 2** on the Data Sheet, **Figure 1** and **Figure 2** to deduce the structural fragment that leads to the peaks at δ 3.5 and 1.2

(1 mark)

5 (b) (iii) Use **Table 2** on the Data Sheet, **Figure 1** and **Figure 2** to deduce the structural fragment that leads to the peaks at δ 3.8 and 2.6

(1 mark)

5 (b) (iv) Deduce the structure of **P**.

(1 mark)

Question 5 continues on the next page

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5 (c) These questions are about different isomers of **P** ($C_6H_{12}O_2$).

5 (c) (i) Draw the structures of the two esters that both have only two peaks in their proton n.m.r. spectra. These peaks both have an integration ratio of 3:1

Ester 1

Ester 2

(2 marks)

5 (c) (ii) Draw the structure of an optically active carboxylic acid with five peaks in its ^{13}C n.m.r. spectrum.

(1 mark)

5 (c) (iii) Draw the structure of a cyclic compound that has only two peaks in its ^{13}C n.m.r. spectrum and has no absorption for C = O in its infrared spectrum.

(1 mark)

11

Turn over for the next question

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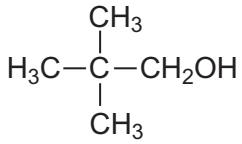
ANSWER IN THE SPACES PROVIDED

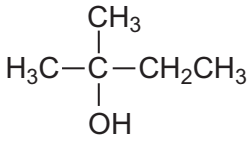
6 Describe how you could distinguish between the compounds in the following pairs using **one** simple test-tube reaction in each case.

For each pair, identify a reagent and state what you would observe when both compounds are tested separately with this reagent.

6 (a)



R



S

Reagent .....

Observation with **R** .....

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Observation with **S** .....

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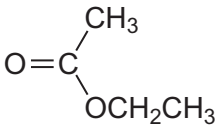
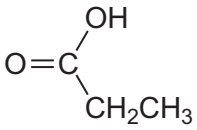
(3 marks)

6 (b)



T



U

Reagent .....

Observation with **T** .....

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Observation with **U** .....

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(3 marks)

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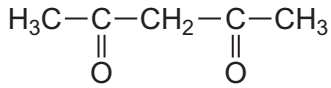
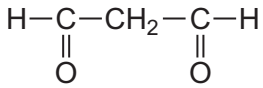
6 (c)



V



W

Reagent .....

Observation with **V** .....

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Observation with **W** .....

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(3 marks)

9

Turn over for the next question

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Section B

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

7 Each of the following conversions involves reduction of the starting material.

7 (a) Consider the following conversion.

Identify a reducing agent for this conversion.

Write a balanced equation for the reaction using molecular formulae for the nitrogen-containing compounds and [H] for the reducing agent.

Draw the repeating unit of the polymer formed by the product of this reaction with benzene-1,4-dicarboxylic acid.

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(5 marks)

(Extra space) .....

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7 (b) Consider the following conversion.

Identify a reducing agent for this conversion.

State the empirical formula of the product.

State the bond angle between the carbon atoms in the starting material and the bond angle between the carbon atoms in the product.

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(4 marks)

Question 7 continues on the next page

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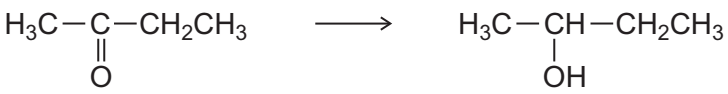
7 (c) The reducing agent in the following conversion is $NaBH_4$



7 (c) (i) Name and outline a mechanism for the reaction.

Name of mechanism .....

Mechanism

(5 marks)

7 (c) (ii) By considering the mechanism of this reaction, explain why the product formed is optically inactive.

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(3 marks)

17

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8 Acyl chlorides such as CH_3COCl are useful compounds in synthesis.

8 (a) The acyl chloride CH_3COCl reacts with benzene.

8 (a) (i) Write an equation for this reaction and name the organic product.

Identify a catalyst for the reaction.

Write an equation to show how this catalyst reacts with CH_3COCl to produce a reactive intermediate.

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(4 marks)

8 (a) (ii) Name and outline a mechanism for the reaction of benzene with the reactive intermediate in part **(a) (i)**.

Name of mechanism .....

Mechanism

(4 marks)

Question 8 continues on the next page

8 (b) Nucleophiles such as alcohols can react with CH_3COCl
The ion CH_3COO^- can act as a nucleophile in a similar way.

State the meaning of the term *nucleophile*.

Draw the structure of the organic product formed by the reaction of CH_3COO^- with CH_3COCl

Name the functional group produced in this reaction.

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(3 marks)

11

END OF QUESTIONS