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Surname: StemUp Model Solution

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Centre Number | Candidate Number

Chemistry

Advanced Subsidiary

Paper 2: Core Organic and Physical Chemistry

Friday 10 June 2016 – Afternoon

Time: 1 hour 30 minutes

Paper Reference **8CH0/02**

You must have:
Data Booklet
Scientific calculator, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 80.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- For questions marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing the points that you make are related or follow on from each other where appropriate.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- Show all your working in calculations and include units where appropriate.

Turn over ▶

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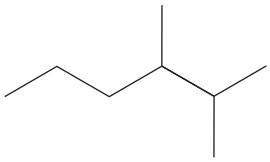
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Answer ALL questions.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Alkanes are a homologous series of hydrocarbons.

(a) What is the name of this compound?



(1)

☒ **A** 1,1,2-trimethylpentane

☒ **B** 2,3-dimethylhexane

☒ **C** 4,5-dimethylhexane

☒ **D** 4,5,5-trimethylpentane

(b) The number of structural isomers with the molecular formula C_5H_{12} is

(1)

☒ **A** 3

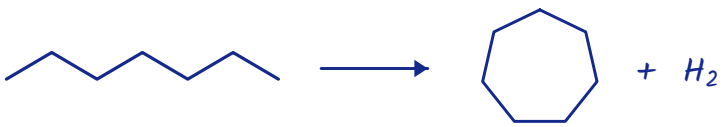
☒ **B** 4

☒ **C** 5

☒ **D** 6

(c) Write the equation for reforming heptane into cycloheptane, showing the **skeletal** formulae of the organic molecules.

(2)



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(d) Ethane reacts with chlorine in the presence of ultraviolet light to form a mixture of products.

(i) In the initiation step, chlorine molecules are converted into radicals.

$$Cl_2 \rightarrow 2Cl^{\bullet}$$

Identify the type of bond broken and the type of bond fission occurring in this step.

(1)

	Bond broken	Bond fission
☐ **A**	π	heterolytic
☐ **B**	σ	heterolytic
☐ **C**	π	homolytic
☒ **D**	σ	homolytic

(ii) Write the propagation steps to show the formation of C_2H_5Cl.

(2)

$C_2H_6 + Cl\cdot \rightarrow C_2H_5\cdot + HCl$

$C_2H_5\cdot + Cl_2 \rightarrow C_2H_5Cl + Cl\cdot$

(iii) State how some butane, C_4H_{10}, is formed in the reaction.

(1)

Two ethyl radicals react together: $C_2H_5\cdot + C_2H_5\cdot \rightarrow C_4H_{10}$

(Total for Question 1 = 8 marks)

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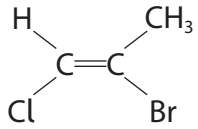
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2 Compounds with a carbon–carbon double bond are unsaturated.

(a) What is the name of the compound shown?



(1)

☒ **A** *cis*-2-bromo-1-chloroprop-1-ene

☒ **B** *E*-2-bromo-1-chloroprop-1-ene

☒ **C** *trans*-2-bromo-1-chloroprop-1-ene

☒ **D** *Z*-2-bromo-1-chloroprop-1-ene

(b) Ethene reacts with bromine in the dark.

(i) What is the classification of the mechanism for the reaction between ethene and bromine?

(1)

☒ **A** electrophilic addition

☒ **B** electrophilic substitution

☒ **C** nucleophilic addition

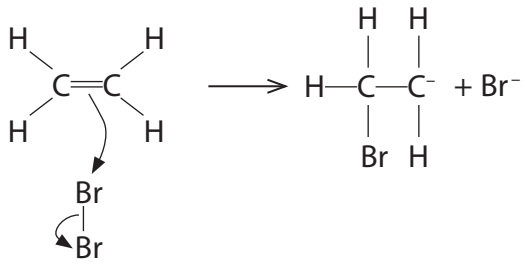
☒ **D** nucleophilic substitution

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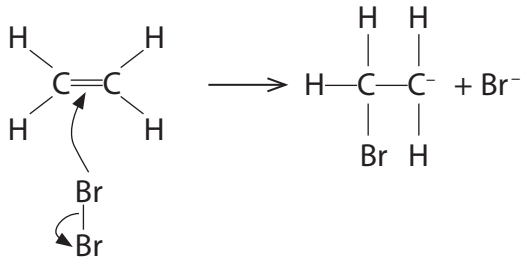
(ii) Which of the following shows the formation of the intermediate in the mechanism for the reaction between ethene and bromine?

(1)

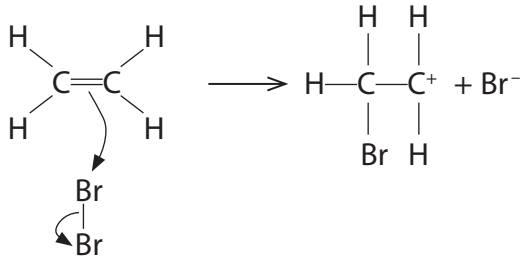
☒ **A**



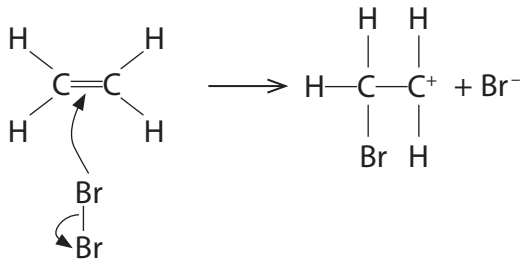
☒ **B**



☒ **C**



☒ **D**



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(c) Ethene reacts with steam to form ethanol in a reversible reaction.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \quad \Delta H = -45 \text{ kJ mol}^{-1}$$

At 300 °C and a pressure of 65 atm, the equilibrium yield of ethanol is 5%.

(i) State the effect, if any, on the yield of ethanol when the temperature is **increased**.

(1)

The yield of ethanol decreases (less ethanol is produced), as the endothermic backward reaction is favoured.

(ii) State the effect, if any, on the yield of ethanol when the pressure is **decreased**.

(1)

The yield of ethanol decreases, as there are more moles of gas on the left-hand side.

(iii) What is the expression for the equilibrium constant, K_c, for this reaction?

(1)

☒ **A** $\dfrac{[C_2H_4(g)]+[H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **B** $\dfrac{[C_2H_4(g)][H_2O(g)]}{[C_2H_5OH(g)]}$

☒ **C** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)]+[H_2O(g)]}$

☒ **D** $\dfrac{[C_2H_5OH(g)]}{[C_2H_4(g)][H_2O(g)]}$

(Total for Question 2 = 6 marks)

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3 This question is about halogenoalkanes and kinetics.

(a) Some halogenoalkanes are hydrolysed by aqueous potassium hydroxide.

(i) Write the **ionic** equation for the hydrolysis of 2-bromobutane showing the **structural** formulae for the organic molecules.

(1)

$CH_3CH_2CHBrCH_3 + OH^- \rightarrow CH_3CH_2CH(OH)CH_3 + Br^-$

*(ii) Devise an experiment to compare the rates of hydrolysis of 2-chlorobutane, 2-bromobutane and 2-iodobutane.

State the trend in the rates of reaction. Justify your answer.

(6)

Put equal volumes (e.g. 1 cm^3) of ethanol, as a solvent, into three test tubes and add the same number of drops (e.g. 5 drops) of 2-chlorobutane, 2-bromobutane and 2-iodobutane, one to each tube.

For a fair test, stand the tubes, and a tube of aqueous silver nitrate solution, in a water bath at the same temperature (e.g. 50 °C).

Add equal volumes (e.g. 1 cm^3) of the silver nitrate solution to each tube at the same time and start a stop clock.

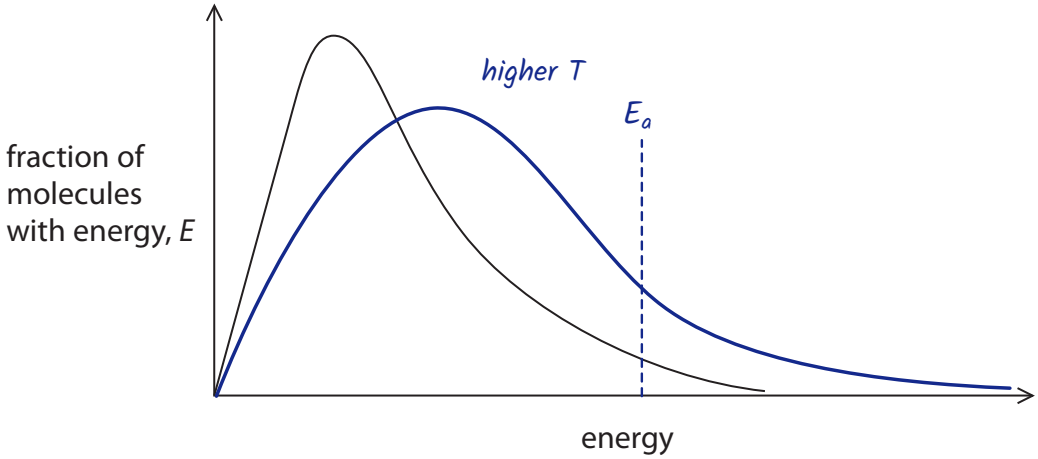
Water hydrolyses the halogenoalkane, and the halide ions released form a silver halide precipitate (AgCl white, AgBr cream, AgI yellow). Record the time taken for a precipitate to form in each tube.

Trend: 2-iodobutane is the fastest and 2-chlorobutane the slowest, so the rate is 2-iodobutane > 2-bromobutane > 2-chlorobutane.

This is because the C-X bond enthalpy decreases from C-Cl to C-Br to C-I, so the C-I bond is the weakest and breaks most easily.

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(b) The graph shows the Maxwell-Boltzmann distribution of molecular energies of a gaseous system.



(i) On the graph, draw the Maxwell-Boltzmann distribution for the same system at a higher temperature.

(1)

(ii) Use the graph to explain why a small increase in temperature results in a large increase in the rate of a gaseous reaction.

(3)

At the higher temperature the molecules have more kinetic energy, so they move faster and collide more frequently.

The activation energy, E_a, marked on the graph, stays the same, but the area under the curve to the right of E_a is much larger, so many more molecules have energy greater than or equal to E_a.

So a much greater proportion of the collisions are successful (result in a reaction), and the rate increases a lot.

(Total for Question 3 = 11 marks)

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4 Ethanol, C_2H_5OH, is a member of the homologous series of alcohols.

(a) Calculate the number of molecules in 55.2 kg of ethanol.

[Avogadro Constant = 6.02×10^{23} mol^{-1}]

(2)

$M_r(C_2H_5OH) = (2 \times 12.0) + (6 \times 1.0) + 16.0 = 46.0$

moles = 55 200 g ÷ 46.0 g mol^{-1} = 1200 mol

molecules = $1200 \times 6.02 \times 10^{23} = 7.22 \times 10^{26}$

(b) Write the equation to represent the standard enthalpy change of formation of ethanol. Include state symbols.

(2)

$2C(s, graphite) + 3H_2(g) + \frac{1}{2}O_2(g) \rightarrow C_2H_5OH(l)$

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(c) Ethanol burns completely in excess oxygen.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

(i) The table shows some mean bond enthalpy data.

Bond	C—C	C—H	C—O	O—H	O═O	C═O
Mean bond enthalpy / kJ mol^{-1}	347	413	358	464	498	805

Calculate the enthalpy change, in kJ mol^{-1}, for the complete combustion of 1 mol of ethanol.

(3)

Bonds broken: 1 C-C, 5 C-H, 1 C-O, 1 O-H and 3 O=O

= 347 + (5 × 413) + 358 + 464 + (3 × 498) = +4728 kJ

Bonds made: 4 C=O and 6 O-H

= (4 × 805) + (6 × 464) = 6004 kJ released

ΔH = 4728 − 6004

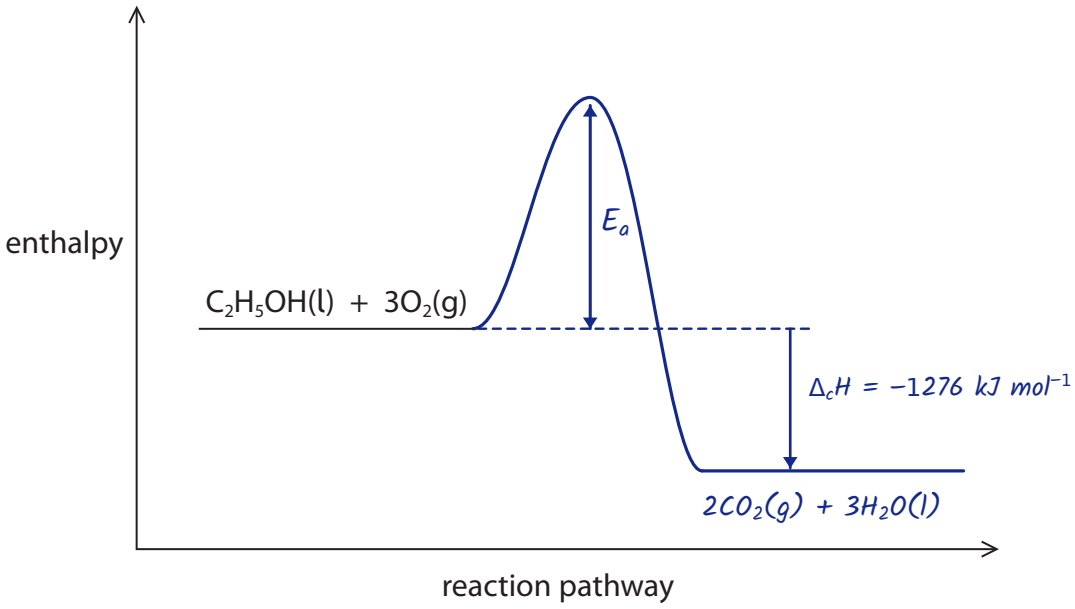
ΔH = −1276 kJ mol^{-1}

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(ii) Complete the reaction profile diagram for the combustion of ethanol and fully label the diagram.

(2)



(iii) A data book value for the standard enthalpy change of combustion of ethanol is $-1367.3\ kJ\ mol^{-1}$.

Give the **main** reason why the value you calculated in (b)(i) is different from this data book value.

(1)

Bond enthalpies are for gaseous molecules, but under standard conditions ethanol and water are liquids, so the enthalpy changes of state are not included.

(Total for Question 4 = 10 marks)

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5 The following procedure may be used to prepare 2-chloro-2-methylpropane.

Step 1 Place 15 cm^3 of 2-methylpropan-2-ol in a separating funnel and slowly add 30 cm^3 of concentrated hydrochloric acid (an excess), while swirling the funnel.

Step 2 When all the hydrochloric acid has been added, leave the mixture to stand for 20 minutes, shaking it gently at intervals.

Step 3 Once the organic and aqueous layers have completely separated, discard the aqueous layer.

Step 4 Add saturated sodium hydrogencarbonate solution, a little at a time, to the organic layer. After each addition, invert the separating funnel and open the tap.

Step 5 Discard the aqueous layer.

Step 6 Transfer the organic layer to a small flask, add a solid drying agent and swirl the flask.

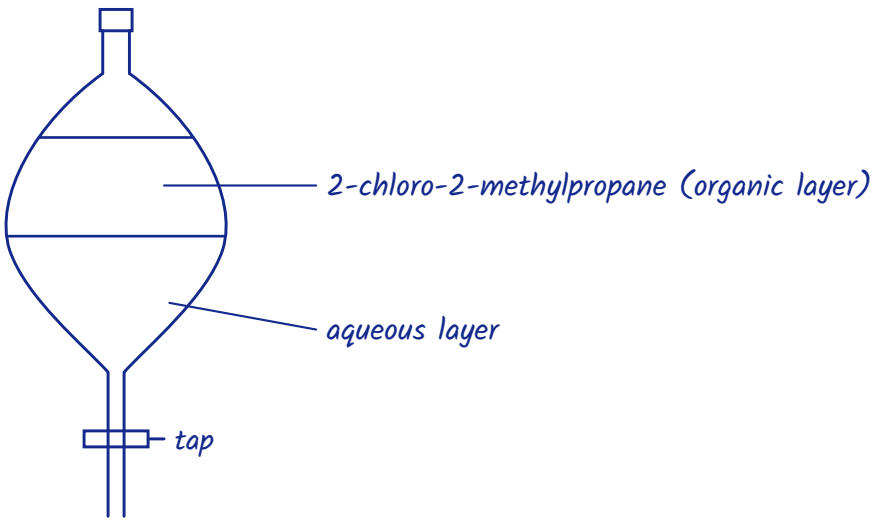
Step 7 Decant the liquid into a clean flask and distil it to collect pure 2-chloro-2-methylpropane.

Some data on the organic reactant and product are given in the table.

Data	2-methylpropan-2-ol	2-chloro-2-methylpropane
molar mass / g mol^{-1}	74.0	92.5
boiling temperature / °C	82	51
density / g cm^{-3}	0.79	0.84

(a) Draw a diagram of a separating funnel, labelling the aqueous layer and the layer of 2-chloro-2-methylpropane that would be observed at the end of **Step 2**.

(2)



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(b) Give the reason why sodium hydrogencarbonate solution is added to the organic layer in **Step 4** and why it is important to open the tap after adding this solution.

(2)

To neutralise (react with) the excess hydrochloric acid left in the organic layer.

The acid reacts with the hydrogencarbonate to produce carbon dioxide gas, so the tap is opened to release the CO_2 and relieve the build-up of pressure.

(c) Which one of these anhydrous compounds may be used as a drying agent in **Step 6**?

(1)

☒ **A** sodium chloride

☒ **B** sodium hydroxide

☒ **C** sodium nitrate

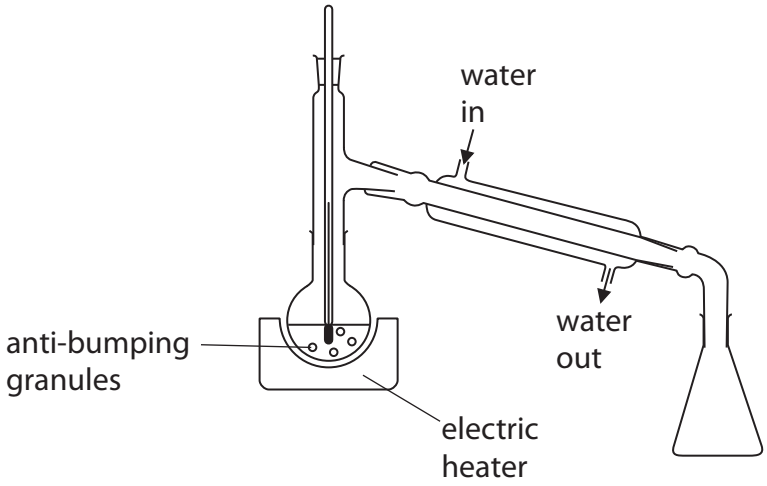
☒ **D** sodium sulfate

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(d) A student set up this apparatus for distillation in **Step 7** as shown.



(i) Describe **three** ways in which this apparatus must be modified for safe and efficient use. Assume the apparatus is suitably clamped.

(3)

The thermometer bulb must be raised so it is level with the opening to the condenser, to measure the temperature of the vapour, not the liquid.

The water flow must be reversed, so the water enters at the bottom of the condenser and leaves at the top, so the condenser stays full and cools efficiently.

The apparatus must not be sealed: leave a gap (vent) between the condenser and the conical flask, so that pressure cannot build up.

(ii) Give a suitable temperature range over which to collect the final product during the distillation.

(1)

50 °C to 52 °C

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(e) In the preparation, 15 cm^3 of 2-methylpropan-2-ol produced 6.9 cm^3 of 2-chloro-2-methylpropane.

The equation for the reaction is

$$(CH_3)_3COH + HCl \rightarrow (CH_3)_3CCl + H_2O$$

Calculate the percentage yield of 2-chloro-2-methylpropane, using data from the table.

Data	2-methylpropan-2-ol	2-chloro-2-methylpropane
molar mass / g mol^{-1}	74.0	92.5
boiling temperature / °C	82	51
density / g cm^{-3}	0.79	0.84

(3)

mass of alcohol = 15 × 0.79 = 11.85 g

moles of alcohol = 11.85 ÷ 74.0 = 0.1601 mol

1 : 1 ratio, so theoretical moles of product = 0.1601 mol

mass of product = 6.9 × 0.84 = 5.796 g

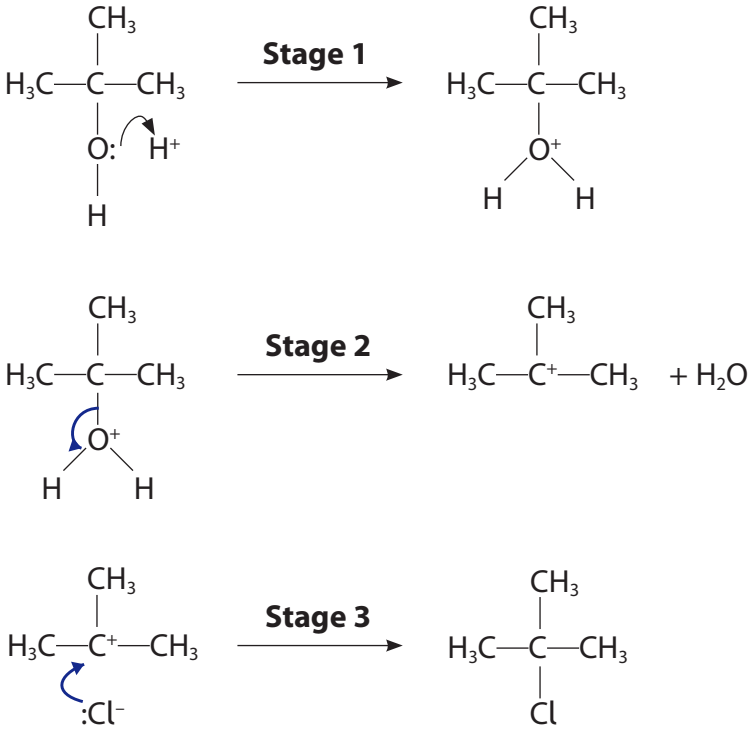
moles of product = 5.796 ÷ 92.5 = 0.06266 mol

% yield = (0.06266 ÷ 0.1601) × 100

% yield = 39.1 %

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(f) The mechanism for the reaction is in three stages.



Add curly arrows to the reactants in **Stages 2** and **3** to complete the mechanism.

(2)

(Total for Question 5 = 14 marks)

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6 A student carries out two experiments to determine the enthalpy change that occurs when anhydrous sodium carbonate reacts to form hydrated sodium carbonate.

$$Na_2CO_3(s) + 10H_2O(l) \rightarrow Na_2CO_3.10H_2O(s)$$

(a) In the first experiment, the student determines the enthalpy change of solution for anhydrous sodium carbonate.

50.0 g of distilled water is placed in a polystyrene cup and the temperature is recorded.

A sample of anhydrous sodium carbonate is added to the water, the mixture is stirred and the final temperature recorded.

The results for this experiment are shown in the table.

mass used / g	5.09
initial temperature / °C	27.0
final temperature / °C	32.4

Calculate the enthalpy change of solution, in kJ mol^{-1}, for anhydrous sodium carbonate.
Give your answer to an appropriate number of significant figures and include a sign.

[Use 4.18 J g^{-1} $°C^{-1}$ as the specific heat capacity of water]

$$Na_2CO_3(s) + aq \rightarrow Na_2CO_3(aq)$$

(4)

heat energy = mcΔT = 50.0 × 4.18 × 5.4 = 1128.6 J = 1.1286 kJ

$M_r(Na_2CO_3)$ = 106.0, moles = 5.09 ÷ 106.0 = 0.04802 mol

temperature rises, so the reaction is exothermic

ΔH = −1.1286 ÷ 0.04802 = −23.50

$\Delta H_{solution}$ = −23.5 kJ mol^{-1}

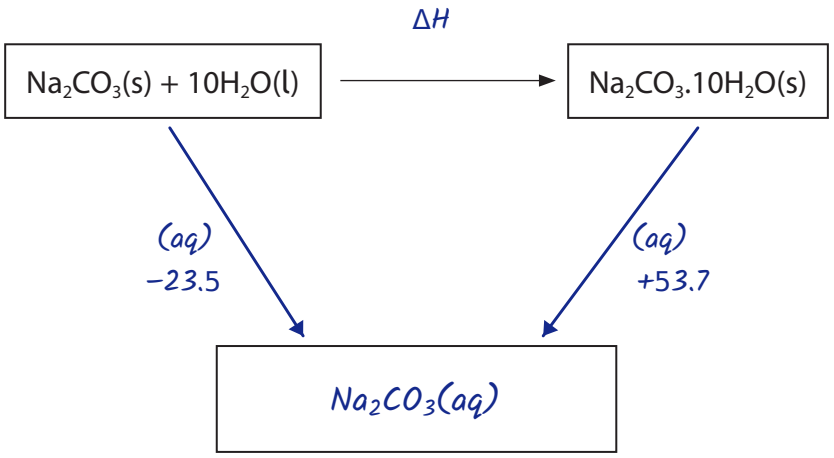
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(b) In the second experiment, the student determines the enthalpy change of solution for hydrated sodium carbonate.

$$Na_2CO_3.10H_2O(s) + aq \rightarrow Na_2CO_3(aq) \qquad \Delta H = +53.7\,kJ\,mol^{-1}$$

Complete the Hess cycle and, together with your answer to (a) calculate the enthalpy change when anhydrous sodium carbonate reacts to form hydrated sodium carbonate. Include a sign in your answer.

(2)



$\Delta H = -23.5 - (+53.7)$

$\Delta H = -77.2\ kJ\ mol^{-1}$

(c) Hydrated sodium carbonate slowly loses some water of crystallisation when left in air.

Explain how the enthalpy change in the second experiment would compare with the data book value if an old sample of hydrated sodium carbonate had been used.

(2)

The enthalpy change of solution would be lower (less endothermic, less positive) than the data book value.

This is because the old sample has lost some water, so it contains some anhydrous sodium carbonate, which reacts exothermically with water and releases energy; also less energy is needed to separate the fewer water molecules from the ions.

(Total for Question 6 = 8 marks)

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7 This question is about the identification of an alcohol, **X**.

(a) Alcohol **X** has the following percentage composition by mass:

carbon, C = 68.2%

hydrogen, H = 13.6%

oxygen, O = 18.2%

The molecular ion peak in the mass spectrum for alcohol **X** occurs at $m/z = 88$.

Use all of these data to show that the molecular formula for alcohol **X** is $C_5H_{12}O$. Include your working.

(2)

C : H : O = 68.2/12.0 : 13.6/1.0 : 18.2/16.0

= 5.68 : 13.6 : 1.14

÷ 1.14 gives 5 : 12 : 1, so empirical formula = $C_5H_{12}O$

M_r of $C_5H_{12}O$ = (5 × 12.0) + (12 × 1.0) + 16.0 = 88

this equals the molecular ion m/z = 88, so the molecular formula is $C_5H_{12}O$

(b) (i) When alcohol **X** is oxidised, a carboxylic acid is formed.

State what information this gives about alcohol **X**.

(1)

X is a primary alcohol.

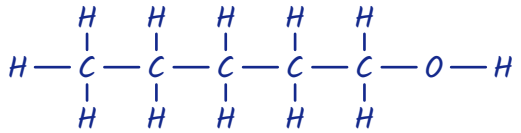
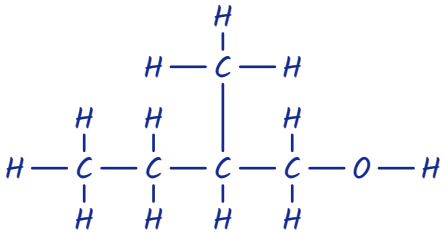
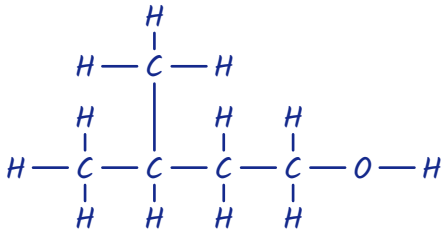
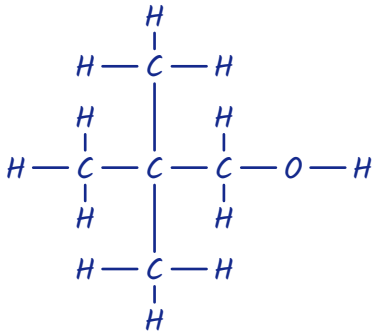
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(ii) Draw the **displayed** formulae of the four possible structural isomers that could be alcohol **X**.

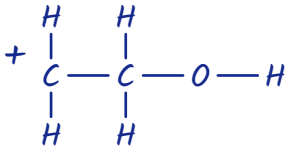
(3)

Alcohol 1	Alcohol 2
	
Alcohol 3	**Alcohol 4**
	

(iii) The mass spectrum of alcohol **X** has a major peak at $m/z = 45$.

Draw the structure of the species that could give this peak.

(1)



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(iv) Alcohol **X** has a branched chain.

Identify alcohol **X**, explaining your reasoning.

(2)

X is 3-methylbutan-1-ol, $(CH_3)_2CHCH_2CH_2OH$.

It is the only one of the branched isomers that can form the $CH_2CH_2OH^+$ fragment (m/z = 45); 2-methylbutan-1-ol and 2,2-dimethylpropan-1-ol cannot form it, and pentan-1-ol is not branched.

(Total for Question 7 = 9 marks)

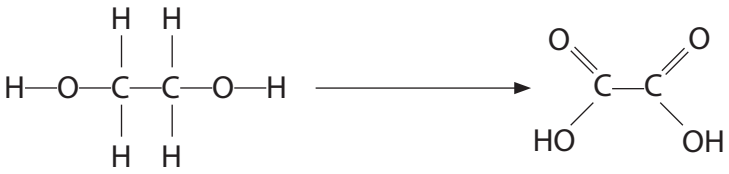
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8 Ethanedioic acid has two carboxylic acid groups.

(a) Ethanedioic acid, $H_2C_2O_4$, can be prepared from ethane-1,2-diol.



Give the reagents and condition required for this reaction.

(2)

Reagents *potassium dichromate(VI) and dilute sulfuric acid*

Condition *heat under reflux*

(b) The formula for ethanedioic acid crystals is $H_2C_2O_4.nH_2O$.

To determine the number of moles of water of crystallisation, n, in 1 mol of ethanedioic acid crystals, a student carried out the following procedure.

- Prepare 250.0 cm^3 of a solution containing a known mass of about 1 g of ethanedioic acid crystals.
- Titrate 25.0 cm^3 portions of the ethanedioic acid solution with 0.103 mol dm^{-3} sodium hydroxide solution, using phenolphthalein as indicator.

The student obtained these results:

mass of ethanedioic acid crystals = 1.09 g

mean titre = 16.20 cm^3

The equation for the reaction is

$$H_2C_2O_4 + 2NaOH \rightarrow Na_2C_2O_4 + 2H_2O$$

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(i) Describe how the student should prepare the 250.0 cm^3 of ethanedioic acid solution.

(4)

Weigh a weighing bottle containing about 1 g of the crystals, tip them into a beaker, reweigh the bottle and record the exact mass used.

Dissolve the crystals in a small volume of distilled water in the beaker, stirring with a glass rod.

Transfer the solution to a 250.0 cm^3 volumetric flask using a funnel, rinsing the beaker, rod and funnel with distilled water and adding the washings to the flask.

Make up to the mark with distilled water, adding the last drops dropwise, then stopper and invert the flask several times to mix.

(ii) Give the colour change at the end-point in this titration.

(1)

From *colourless* to *pink*

(iii) Calculate a value of n in the formula $H_2C_2O_4.nH_2O$ from these data.

(5)

moles NaOH = $16.20 \times 0.103 \div 1000 = 1.669 \times 10^{-3}$ mol

moles $H_2C_2O_4$ in 25.0 cm^3 = $1.669 \times 10^{-3} \div 2 = 8.343 \times 10^{-4}$ mol

moles $H_2C_2O_4$ in 250.0 cm^3 = $8.343 \times 10^{-4} \times 10 = 8.343 \times 10^{-3}$ mol

M_r of crystals = $1.09 \div 8.343 \times 10^{-3} = 130.6$

$M_r(H_2C_2O_4) = 2.0 + 24.0 + 64.0 = 90.0$

$18n = 130.6 - 90.0 = 40.6$

$n = 40.6 \div 18 = 2.26$, so $n = 2$

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(iv) The student thought that the ethanedioic acid crystals used may have been slightly damp.

Explain the effect of using damp crystals on the titre and on the value of n.

(2)

Damp crystals contain extra water, so the mass (and moles) of $H_2C_2O_4$ in the 1.09 g is lower and the solution is less concentrated.

So the titre will be lower, which gives fewer moles of acid and a larger M_r for the crystals, so the value of n will be higher.

(Total for Question 8 = 14 marks)

TOTAL FOR PAPER = 80 MARKS

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The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8) (18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

* Lanthanide series

* Actinide series

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