

Surname <i>StemUp Model Solution</i>	Centre Number	Candidate Number
First name(s)		2



GCE AS/A LEVEL

2410U20-1



FRIDAY, 27 MAY 2022 – AFTERNOON

CHEMISTRY – AS unit 2

Energy, Rate and Chemistry of Carbon Compounds

1 hour 30 minutes

Section A

Section B

ADDITIONAL MATERIALS

In addition to this examination paper, you will need a:

- calculator;
- **Data Booklet** supplied by WJEC.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid. You may use a pencil for graphs and diagrams only.

Write your name, centre number and candidate number in the spaces at the top of this page.

Section A Answer **all** questions.

Section B Answer **all** questions.

Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

Candidates are advised to allocate their time appropriately between **Section A (10 marks)** and **Section B (70 marks)**.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.

The maximum mark for this paper is 80.

Your answers must be relevant and must make full use of the information given to be awarded full marks for a question.

The assessment of the quality of extended response (QER) will take place in **Q9(c)**.

For Examiner's use only		
Question	Maximum Mark	Mark Awarded
1. to 5.	10	
6.	15	
7.	17	
8.	10	
9.	12	
10.	16	
Total	80	

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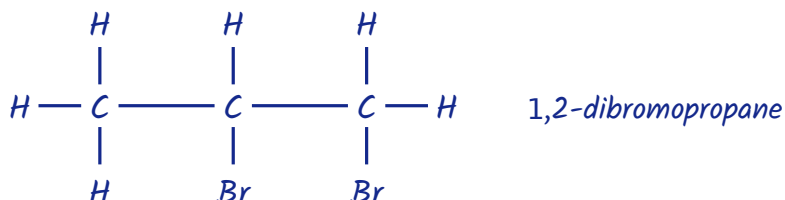
SECTION AAnswer **all** questions.

1. Bromine water can be used to test for alkenes.

- (a) (i) State the expected colour change for a positive test for alkenes. [1]

orange to colourless

- (ii) Draw the structure of the product formed when propene reacts with bromine water. [1]

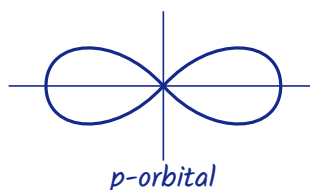


- (b) Identify another reagent that can be used to test for the presence of alkenes. [1]

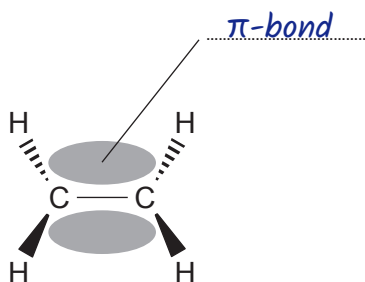
alkaline potassium manganate(VII) (purple to colourless)

2. Bonds in hydrocarbons are formed by the overlap of orbitals between each atom.

- (a) Draw an s-orbital and a p-orbital in the space below. [1]



- (b) Name the type of bond shown in the diagram below. [1]

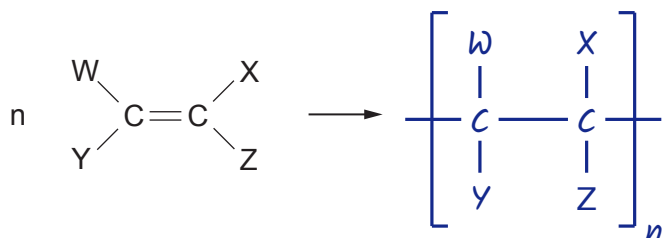


3. A student suspects an unlabelled organic liquid is a carboxylic acid. Name the reagent(s) that must be added to the unknown organic liquid to test for the presence of a carboxylic acid. Give the expected observations for a positive result. [2]

Add sodium carbonate (or sodium hydrogencarbonate) solution.

Positive result: fizzing / effervescence is observed (the CO₂ gas turns limewater milky).

4. Complete the equation below to show the product of addition polymerisation. [1]



5. State the meaning of the term 'standard enthalpy change of formation'. [2]

The enthalpy change when 1 mol of a compound is formed from its constituent elements in their standard states, under standard conditions of 1 atm and 298 K.



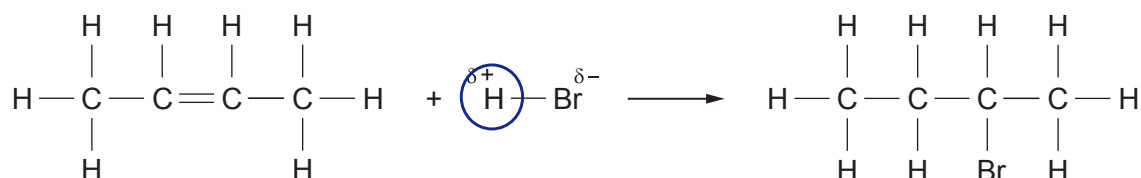
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Answer **all** questions.

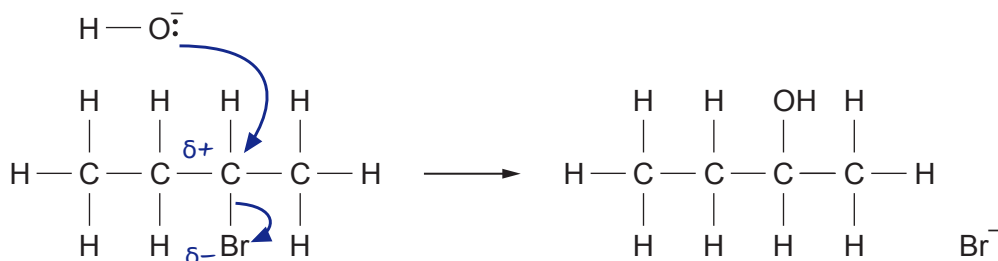
(a) In the first step, but-2-ene is reacted with HBr to form 2-bromobutane.



- (i) Circle the species that represents the electrophile. [1]
- (ii) Name the type of bond fission that takes place in the H — Br bond in the first step of the mechanism. [1]

heterolytic (fission)

- (b) In the second step, 2-bromobutane undergoes nucleophilic substitution to form butan-2-ol.



- (i) Use curly arrows to complete the equation to show the mechanism of the nucleophilic substitution. Include any relevant partial charges. [2]
- (ii) Give the reagents and conditions required for this nucleophilic substitution. [2]
- aqueous sodium hydroxide, NaOH(aq)*
- heat under reflux*
- (iii) State the classification of alcohol to which butan-2-ol belongs. [1]

secondary (2°) alcohol



- (c) In the final step, butan-2-ol is heated with acidified potassium manganate(VII) to produce butanone.

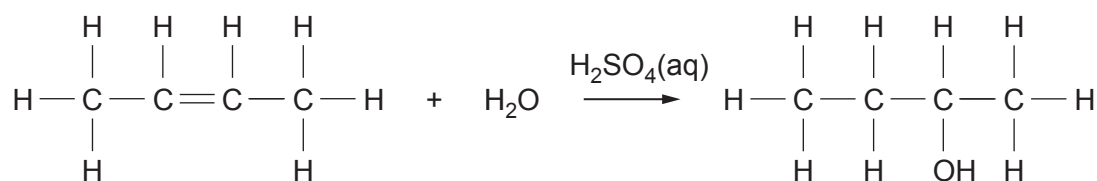
(i) State the role of the acidified potassium manganate(VII) in this reaction. [1]

oxidising agent

(ii) Explain why butanone can be removed from the reaction as it is formed using distillation, leaving unreacted butan-2-ol in the reaction mixture. [2]

Butan-2-ol molecules form hydrogen bonds with each other but butanone molecules do not, so butanone has a lower boiling temperature than butan-2-ol and distils off first.

- (d) Butan-2-ol can also be made directly by hydration of but-2-ene in the presence of dilute sulfuric acid, which acts as a catalyst.



(i) Suggest why the overall yield of the two-step synthesis is likely to be lower than the yield of the direct hydration. [1]

Some product is lost at the end of each step, so with two steps the losses multiply and the overall percentage yield is lower.

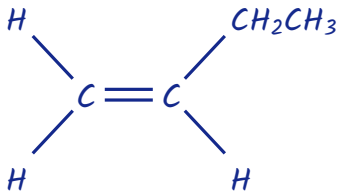
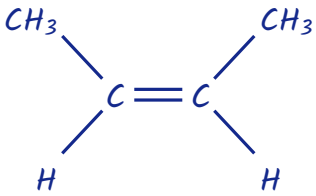
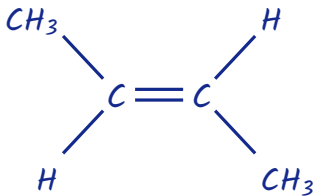


- (ii) Reaction of butan-2-ol with **concentrated** sulfuric acid results in the formation of three isomers with the formula C_4H_8 .

I. Name the type of reaction used to form alkenes from alcohols. [1]

dehydration (elimination)

II. Give the structure and **name** of the three isomers formed. [3]

Structure	Structure	Structure
		
Name: <i>but-1-ene</i>	Name: <i>(Z)-but-2-ene</i>	Name: <i>(E)-but-2-ene</i>

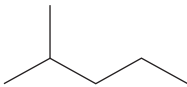
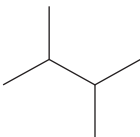
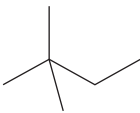


7. Petroleum ether (50–70) is a mixture of different alkanes extracted from crude oil which is commonly used as an organic solvent. The major components of petroleum ether (50–70) are the structural isomers of C_6H_{14} .

- (a) (i) Give the meaning of the term 'structural isomer'. [1]

Compounds with the same molecular formula but a different structural formula.

- (ii) Complete the table below showing important information about the isomers of C_6H_{14} . [3]

Name	Shortened structural formula	Skeletal formula	Boiling temperature / °C
hexane	$CH_3CH_2CH_2CH_2CH_2CH_3$		69
2-methylpentane	<i>$CH_3CH(CH_3)CH_2CH_2CH_3$</i>		62
3-methylpentane	$CH_3CH_2CH(CH_3)CH_2CH_3$		63
<i>2,3-dimethylbutane</i>	$(CH_3)_2CHCH(CH_3)_2$		58
2,2-dimethylbutane	$CH_3C(CH_3)_2CH_2CH_3$		50



- (iii) State the relationship between the boiling temperature and the carbon chain length. Explain this relationship in terms of intermolecular forces. [2]

As the main carbon chain length increases, the boiling temperature increases.

Longer chains have more contact, so stronger van der Waals forces between molecules, needing more heat energy to overcome.

- (b) Hexane can be used as a fuel in a combustion reaction.

- (i) Write an equation for the complete combustion of hexane in excess oxygen. [2]



- (ii) The enthalpy change of combustion ($\Delta_c H^\theta$) for hexane is approximately $-4160 \text{ kJ mol}^{-1}$. Explain why the enthalpy change of combustion for the isomers of hexane should be similar. [2]

The isomers have the same number and types of bonds (5 C-C and 14 C-H) and form the same products.

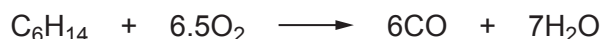
So the energy absorbed breaking bonds and the energy released forming bonds are similar.

- (iii) 2,2-dimethylbutane is the isomer of C_6H_{14} which ignites most readily. Suggest a reason for this. [1]

It has the lowest boiling temperature (it is the most volatile), so it vaporises most readily, as its branched molecules have the weakest van der Waals forces.



- (iv) When hexane burns in a limited supply of oxygen it undergoes a different reaction known as incomplete combustion:



The bond enthalpy values for the bonds present in these molecules are given below:

Bond	Average bond enthalpy / kJ mol^{-1}
C — C	348
C — H	413
O = O	495
C $\equiv$ O (in CO)	1072
O — H	464

- I. Using a Hess cycle or otherwise, calculate the enthalpy change of this reaction.

[3]

bonds broken: $(5 \times 348) + (14 \times 413) + (6.5 \times 495) = 10739.5$

bonds formed: $(6 \times 1072) + (14 \times 464) = 12928$

$\Delta H = 10739.5 - 12928 = -2188.5 \text{ kJ mol}^{-1}$

enthalpy change = *-2188.5* kJ mol^{-1}

- II. **Use the enthalpy values** from parts (b)(ii) and (b)(iv) I. to explain quantitatively why it is important to maintain an excess of oxygen while burning hexane as a fuel.

[2]

Complete combustion releases 4160 kJ mol^{-1} but incomplete

combustion only $2188.5 \text{ kJ mol}^{-1}$, so excess oxygen releases about

twice as much energy (an extra $1971.5 \text{ kJ mol}^{-1}$).



III. State a health hazard associated with the incomplete combustion of hexane. [1]

*Carbon monoxide is produced, which is toxic; it binds to
haemoglobin and stops the blood carrying oxygen.*

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8. Compound **A** contains only carbon, hydrogen and an unknown halogen.

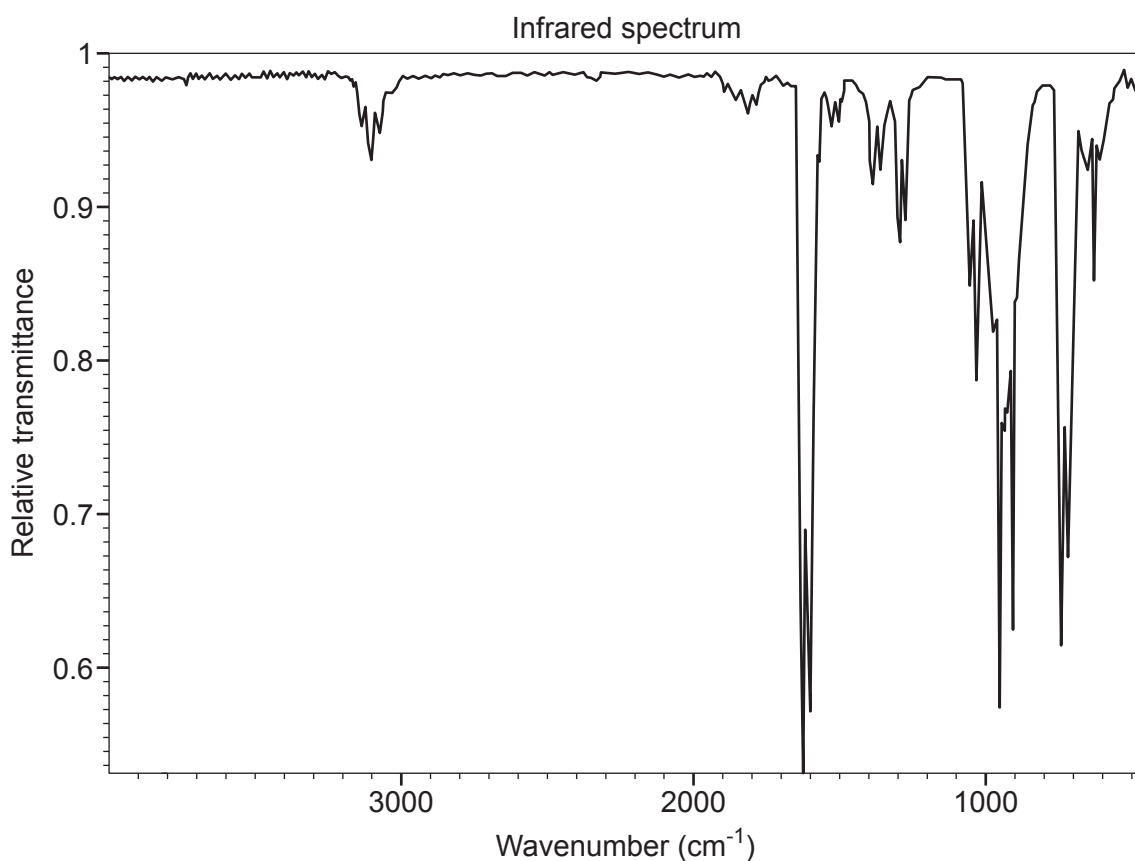
Refluxing compound **A** in aqueous sodium hydroxide followed by the addition of nitric acid and aqueous silver nitrate produces a white precipitate.

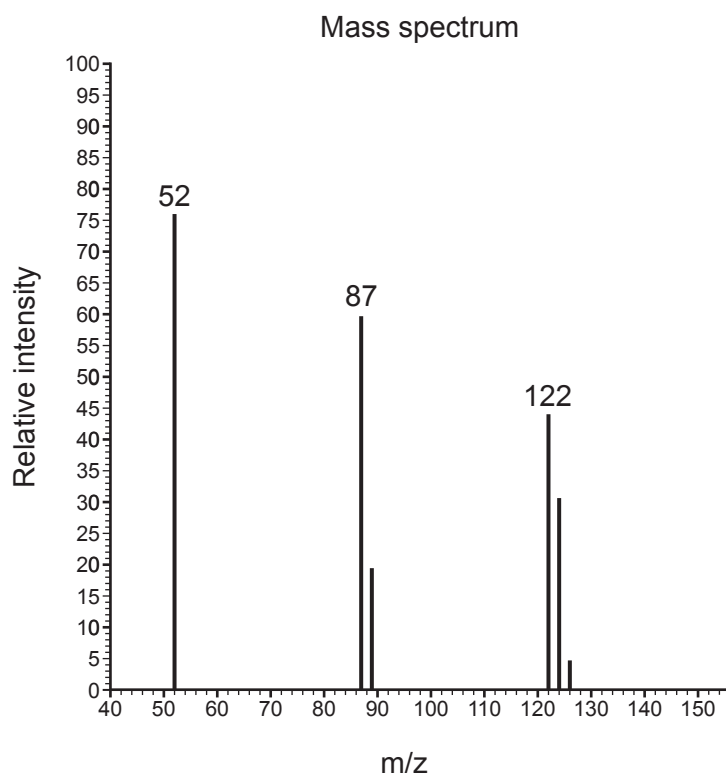
Elemental analysis of compound **A** indicates it contains 39.02% carbon and 3.25% hydrogen by mass.

When bromine is added to compound **A**, 123 g of compound **A** reacts with 320 g of bromine.

The ^1H NMR spectrum of compound **A** consists of only one peak. The ^{13}C NMR spectrum of compound **A** consists of two peaks.

The infrared spectrum and simplified mass spectrum are shown below and overpage.





Use **all** of the data provided to determine the identity of compound **A**. Explain your answer using information from all of the data sources provided. [10]

White precipitate with silver nitrate: the halogen is chlorine.

$Cl = 100 - 39.02 - 3.25 = 57.73\%$. $C: 39.02/12.0 = 3.25$; $H: 3.25/1.01 =$

3.22 ; $Cl: 57.73/35.5 = 1.63$. Ratio $C:H:Cl = 2:2:1$, so the empirical formula is

C_2H_2Cl .

Molecular ion peak at m/z 122 ($C_2H_2Cl = 61$), so the molecular formula is

$C_4H_4Cl_2$.

Peaks at 122, 124 and 126 in the ratio 9:6:1 show two Cl atoms (^{35}Cl and ^{37}Cl). The peak at 87 is $C_4H_4Cl^+$ (loss of Cl) and 52 is $C_4H_4^+$ (loss of both Cl).

$n(Br_2) = 320/159.8 = 2$ mol and $n(A) = 123/123 = 1$ mol. Bromine reacts, so A has $C=C$ bonds; 1 mol of A reacts with 2 mol of Br_2 , so A has two $C=C$ double bonds.

IR: absorption at about 1650 cm^{-1} is $C=C$ and at about 650 to 800 cm^{-1} is

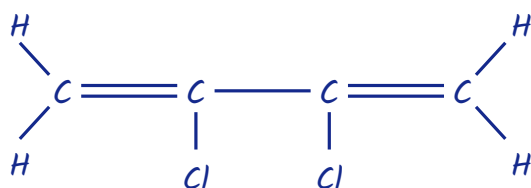


C-Cl. No broad O-H or C=O absorption.

^1H NMR: one peak, so all four H atoms are in one environment (two identical $=\text{CH}_2$ groups).

^{13}C NMR: two peaks, so two carbon environments ($=\text{CH}_2$ and $=\text{CCl}-$), so the molecule is symmetrical.

Compound A is 2,3-dichlorobuta-1,3-diene, $\text{CH}_2=\text{CCl}-\text{CCl}=\text{CH}_2$.



2,3-dichlorobuta-1,3-diene

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9. Chloe was investigating the effect of using catalysts on the rate of reaction.

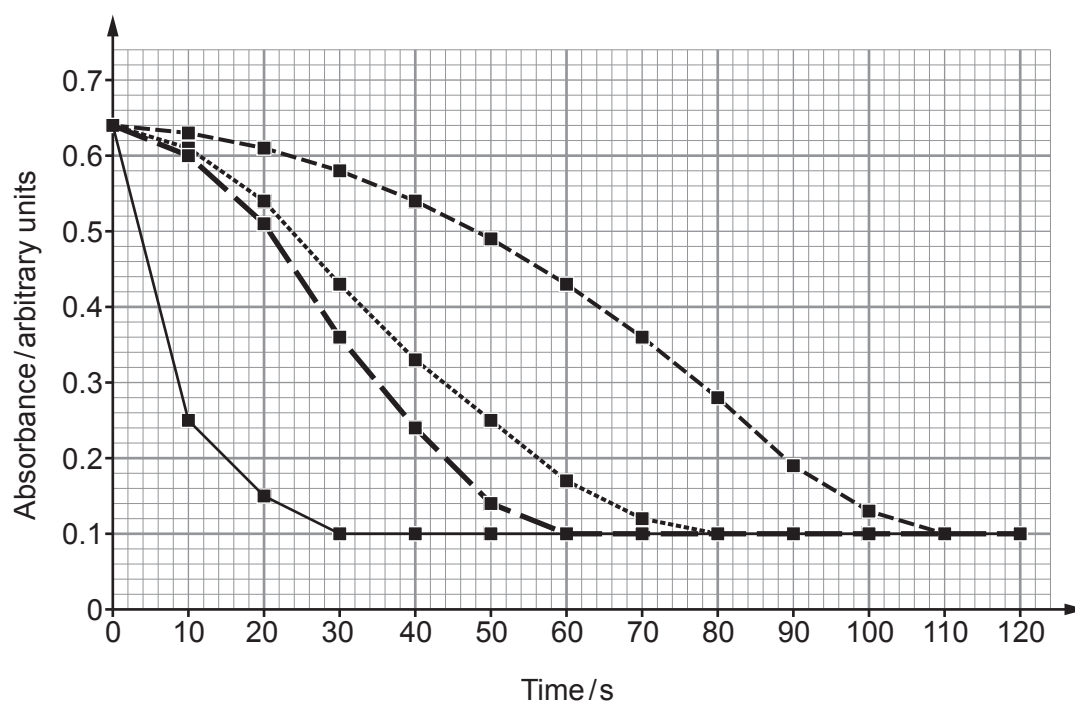
She added 50 cm^3 of 0.1 mol dm^{-3} iron(III) nitrate solution to 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulfate solution. The reaction forms a deep violet iron(III) complex which is unstable and is gradually reduced to form a light green iron(II) complex.

Chloe monitored the rate of reaction by measuring the absorption of light at a wavelength of 500 nm every 10 seconds for two minutes using a data logger.

- (a) The violet complex appears black at the beginning of the reaction. State the name of the technique used to monitor the rate of reaction by measuring the absorption of light. [1]

colorimetry

- (b) Chloe repeated the experiment three times adding 1 cm^3 of a different catalyst each time at a concentration 0.10 mol dm^{-3} . Below is a graph showing her results:



Key: - - - - - ■ - - - - - No catalyst - - - - - ■ - - - - - Fe^{2+}
 ······ ■ ······ Co^{2+} ——— ■ ——— Cu^{2+}

- (i) State which catalyst is the most effective. Explain your answer. [2]

Cu^{2+} , because the absorbance falls to 0.1 (the reaction is complete) in the shortest time; its curve has the steepest initial gradient.



- (ii) Calculate the initial rate of reaction for the reaction catalysed by the copper(II) ions. [2]

$$\text{change in absorbance in first } 10 \text{ s} = 0.64 - 0.25 = 0.39$$

$$\text{initial rate} = 0.39 / 10 = 0.039 \text{ s}^{-1}$$

$$\text{rate} = \dots\dots\dots 0.039 \dots\dots\dots \text{ s}^{-1}$$

- (iii) Each catalysed reaction contained the same number of moles of catalyst at the beginning of the reaction. Calculate the moles of catalyst left at the end of the reaction. [1]

$$\text{catalyst is not used up: } 1 \times 0.10 / 1000$$

$$\text{moles} = \dots\dots\dots 1.0 \times 10^{-4} \dots\dots\dots \text{ mol}$$

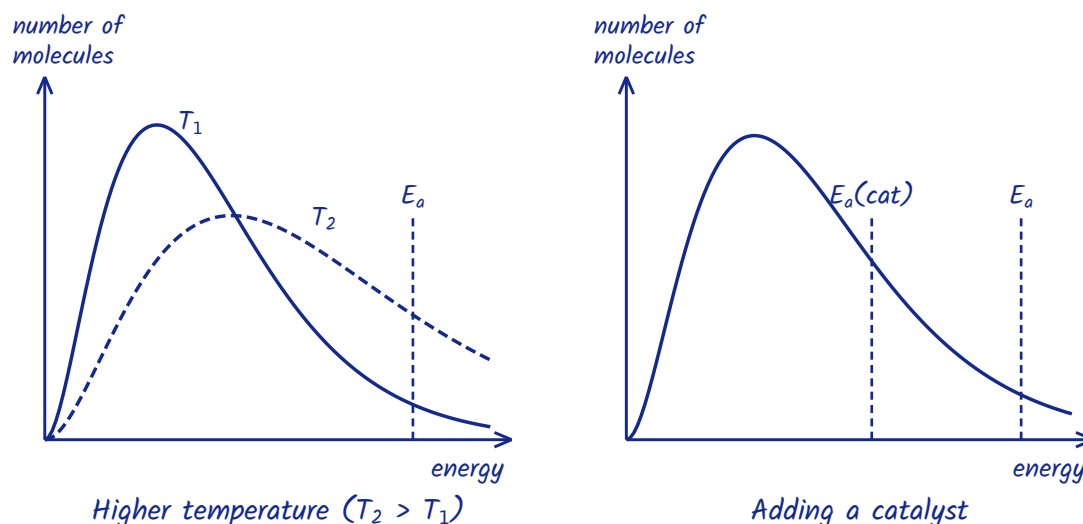


- (c) Increasing temperature and the addition of a catalyst are two ways of increasing the rate of a reaction.

Using your knowledge of the Boltzmann distribution and particle theory, explain how the rate of reaction is increased using these two different methods.

You may use a diagram(s) to support your answer.

[6 QER]



Temperature: at the higher temperature T_2 the particles have more kinetic energy, so the curve flattens and its peak moves to the right (the area under the curve stays the same).

Many more particles now have energy greater than or equal to the activation energy E_a , and the particles also move faster and collide more often, so there are more successful collisions per second and the rate increases.

Catalyst: a catalyst provides an alternative reaction pathway (or a surface for the particles to adsorb to) with a lower activation energy, $E_a(\text{cat})$, to the left of E_a on the same distribution curve.

The energy distribution of the particles does not change, but more particles now have energy greater than or equal to the lower activation energy, so a greater proportion of collisions are successful, giving more successful collisions per second and a faster rate.



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10. The crystallisation of sodium ethanoate from a super-saturated solution is used to release heat in reusable hand warmers.

- (a) A super-saturated solution of sodium ethanoate was made by dissolving 320 g of hydrated sodium ethanoate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$) in 60 cm^3 of hot water. It was then allowed to cool to room temperature, which was measured as 17°C .

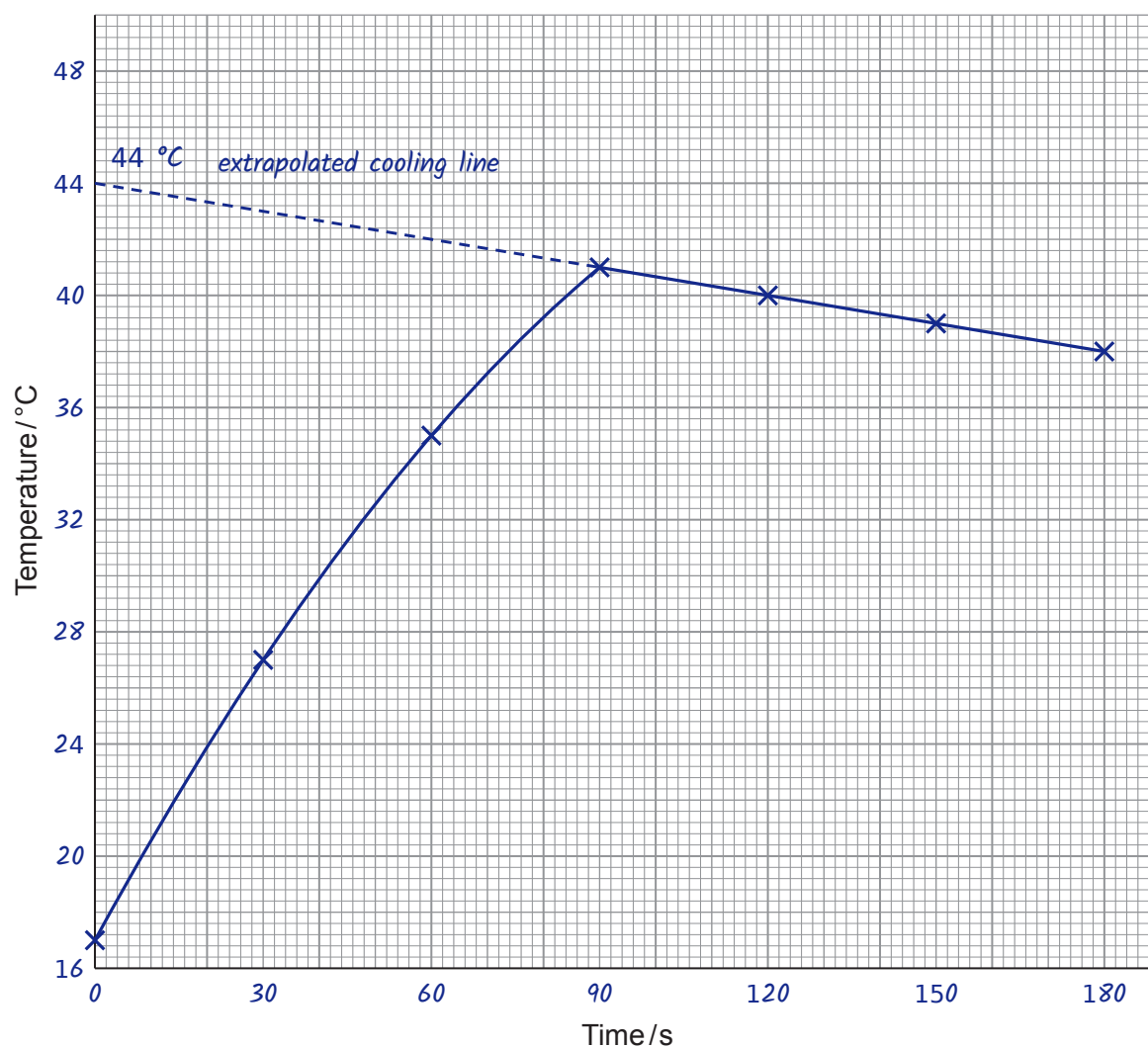
A thermometer was added to the solution, which caused the sodium ethanoate to start crystallising. The temperature of the process was recorded every 30 seconds for 3 minutes. The results are shown below:

Time/s	Temperature/ $^\circ\text{C}$
0	17
30	27
60	35
90	41
120	40
150	39
180	38



(i) Plot the results on the graph paper below.

[2]



(ii) Use your graph to calculate the maximum temperature change for this crystallisation.

[2]

extrapolate the cooling line back to $t = 0$: $T_{max} = 44\text{ }^{\circ}\text{C}$

$$\Delta T = 44 - 17 = 27\text{ }^{\circ}\text{C}$$

maximum temperature change = ... 27 $^{\circ}\text{C}$



- (iii) Use the **total mass** of the sodium ethanoate solution and the temperature change from the graph to calculate the enthalpy change of crystallisation per mole of sodium ethanoate. Assume the density of water is 1.00 g cm^{-3} and the specific heat capacity of sodium ethanoate solution is $4.18 \text{ J K}^{-1} \text{ g}^{-1}$.

$$M_r(\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}) = 136$$

[4]

$$\text{mass of solution} = 320 + 60 = 380 \text{ g}$$

$$q = mc\Delta T = 380 \times 4.18 \times 27 = 42\,886.8 \text{ J} = 42.9 \text{ kJ}$$

$$n(\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}) = 320 / 136 = 2.35 \text{ mol}$$

$$\Delta H = -42.9 / 2.35 = -18.26 \text{ kJ mol}^{-1} \text{ (heat released, exothermic)}$$

$$\text{enthalpy change} = \dots\dots\dots -18.26 \dots\dots\dots \text{ kJ mol}^{-1}$$

- (iv) Suggest a reason why the experimental enthalpy change is often lower than the theoretical enthalpy change. [1]

Heat is lost to the surroundings (or not all the sodium ethanoate crystallises).

- (b) Sodium ethanoate can be made in a neutralisation reaction. Complete the following equation: [2]



- (c) The carboxylic acid used to produce sodium ethanoate can be produced using an oxidation reaction.

- (i) Name the reagents and give the expected observations. [2]

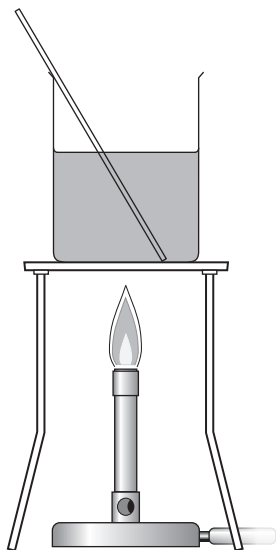
Ethanol heated under reflux with acidified potassium dichromate(VI)

(K₂Cr₂O₇/H₂SO₄).

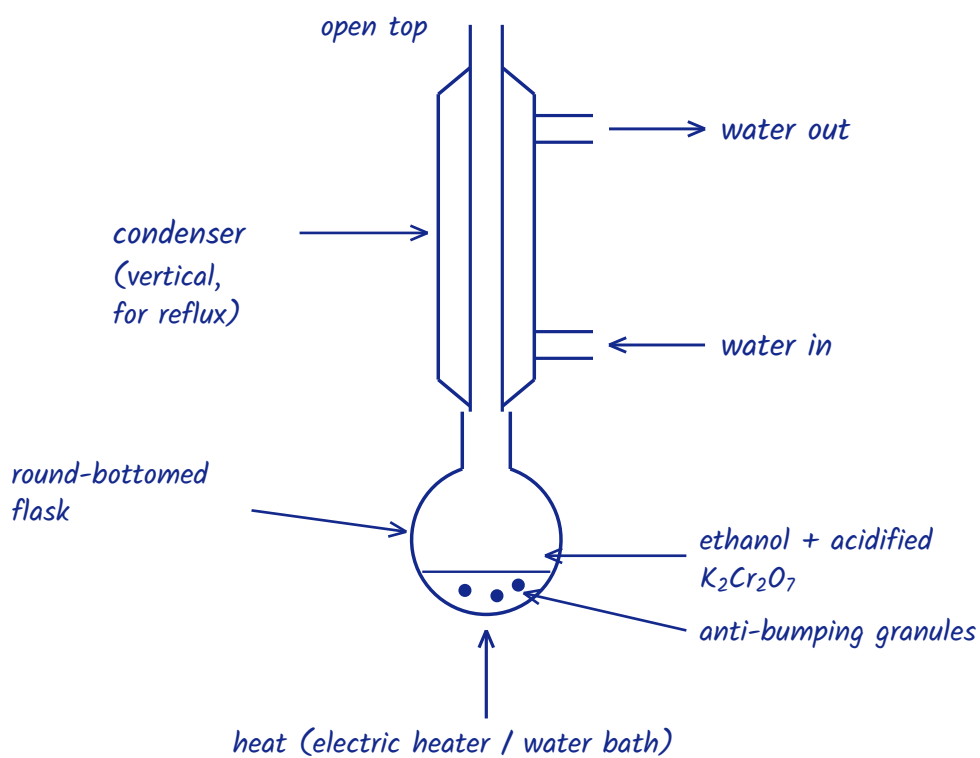
Observation: the colour changes from orange to green.



- (ii) A student proposed that the apparatus below should be used to perform this oxidation reduction experiment.



The teacher said that this would not work and would be unsafe. Draw a labelled diagram of the apparatus that should be used in this experiment. [3]



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[illegible]

[illegible]

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GCE AS/A LEVEL

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FRIDAY, 27 MAY 2022 – AFTERNOON

CHEMISTRY – AS unit 2

Data Booklet

Avogadro constant
molar gas constant
molar gas volume at 273 K and 1 atm
molar gas volume at 298 K and 1 atm
Planck constant
speed of light
density of water
specific heat capacity of water
ionic product of water at 298 K
fundamental electronic charge

$$\begin{aligned}N_A &= 6.02 \times 10^{23} \text{ mol}^{-1} \\R &= 8.31 \text{ J mol}^{-1} \text{ K}^{-1} \\V_m &= 22.4 \text{ dm}^3 \text{ mol}^{-1} \\V_m &= 24.5 \text{ dm}^3 \text{ mol}^{-1} \\h &= 6.63 \times 10^{-34} \text{ Js} \\c &= 3.00 \times 10^8 \text{ ms}^{-1} \\d &= 1.00 \text{ g cm}^{-3} \\c &= 4.18 \text{ J g}^{-1} \text{ K}^{-1} \\K_w &= 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \\e &= 1.60 \times 10^{-19} \text{ C}\end{aligned}$$

temperature (K) = temperature (°C) + 273

$1 \text{ dm}^3 = 1000 \text{ cm}^3$
 $1 \text{ m}^3 = 1000 \text{ dm}^3$
1 tonne = 1000 kg
 $1 \text{ atm} = 1.01 \times 10^5 \text{ Pa}$

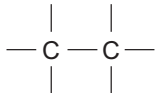
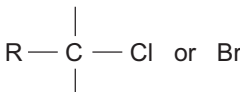
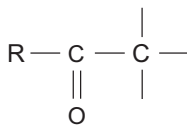
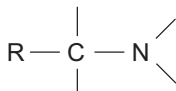
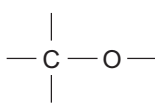
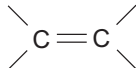
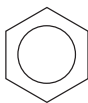
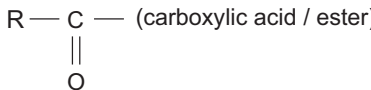
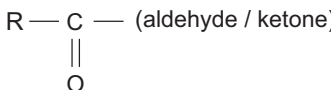
Multiple	Prefix	Symbol
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m

Multiple	Prefix	Symbol
10^3	kilo	k
10^6	mega	M
10^9	giga	G

Infrared absorption values

Bond	Wavenumber / cm^{-1}
C — Br	500 to 600
C — Cl	650 to 800
C — O	1000 to 1300
C = C	1620 to 1670
C = O	1650 to 1750
C $\equiv$ N	2100 to 2250
C — H	2800 to 3100
O — H (carboxylic acid)	2500 to 3200 (very broad)
O — H (alcohol / phenol)	3200 to 3550 (broad)
N — H	3300 to 3500

 ^{13}C NMR chemical shifts relative to TMS = 0

Type of carbon	Chemical shift, δ (ppm)
	5 to 40
	10 to 70
	20 to 50
	25 to 60
	50 to 90
	90 to 150
	110 to 125
	110 to 160
	160 to 185
	190 to 220

^1H NMR chemical shifts relative to TMS = 0

Type of proton	Chemical shift, δ (ppm)
$-\text{CH}_3$	0.1 to 2.0
$\text{R}-\text{CH}_3$	0.9
$\text{R}-\text{CH}_2-\text{R}$	1.3
$\text{CH}_3-\text{C}\equiv\text{N}$	2.0
$\text{CH}_3-\text{C}(=\text{O})$	2.0 to 2.5
$-\text{CH}_2-\text{C}(=\text{O})$	2.0 to 3.0
 - CH_3	2.2 to 2.3
$\text{HC}-\text{Cl}$ or $\text{HC}-\text{Br}$	3.1 to 4.3
$\text{HC}-\text{O}$	3.3 to 4.3
$\text{R}-\text{OH}$	4.5 *
$-\text{C}=\text{CH}$	4.5 to 6.3
$-\text{C}=\text{CH}-\text{CO}$	5.8 to 6.5
 - $\text{CH}=\text{C}$	6.5 to 7.5
 - H	6.5 to 8.0
 - OH	7.0 *
$\text{R}-\text{C}(=\text{O})\text{H}$	9.8 *
$\text{R}-\text{C}(=\text{O})\text{OH}$	11.0 *

*variable figure dependent on concentration and solvent

THE PERIODIC TABLE

Group 1 2 3 4 5 6 7 0

Period 1 2 3 4 5 6 7

1	1.01 H Hydrogen 1							4.00 He Helium 2
2	6.94 Li Lithium 3	9.01 Be Beryllium 4						
3	23.0 Na Sodium 11	24.3 Mg Magnesium 12						
4	39.1 K Potassium 19	40.1 Ca Calcium 20						
5	85.5 Rb Rubidium 37	87.6 Sr Strontium 38						
6	133 Cs Caesium 55	137 Ba Barium 56						
7	(223) Fr Francium 87	(226) Ra Radium 88	(227) Ac Actinium 89	f block				
s block				p block				
d block				p block				
f block				p block				
Lanthanoid elements				p block				
Actinoid elements				p block				

Ar	Symbol	Name	Z
relative atomic mass			atomic number