



# Cambridge International AS & A Level

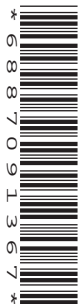
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## CHEMISTRY

9701/21

Paper 2 AS Level Structured Questions

May/June 2023

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

## INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

## INFORMATION

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **16** pages. Any blank pages are indicated.

## 2

- 1 Tellurium is an element in Group 16. The most common isotope of tellurium is  $^{130}\text{Te}$ . Its electronic configuration is  $[\text{Kr}] 4d^{10} 5s^2 5p^4$ .

(a) Complete Table 1.1.

Table 1.1

	nucleon number	number of neutrons	number of electrons
$^{130}\text{Te}$			

[3]

(b) Identify the sub-shell in an atom of Te that contains electrons with the lowest energy.

..... [1]

(c) Construct an equation to represent the first ionisation energy of Te.

..... [1]

(d) (i) The radius of Te ions decreases after each successive ionisation.

State **two** factors that are responsible for the increase in the first six ionisation energies of Te.

.....  
 .....  
 ..... [2]

(ii) Sketch a graph in Fig. 1.1 to show the trend in the first **seven** ionisation energies of Te.

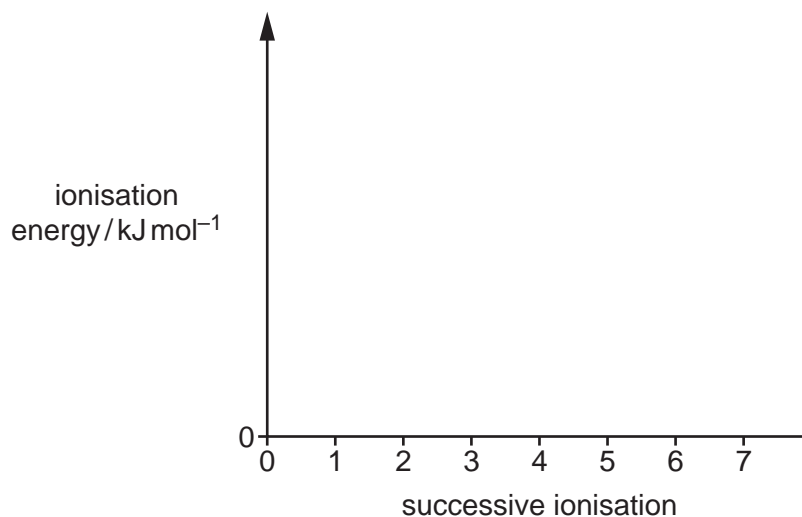


Fig. 1.1

[2]

3

- (e) Te reacts with  $F_2$  at  $150^\circ C$  to form  $TeF_x$ . Molecules of  $TeF_x$  are octahedral with bond angles of  $90^\circ$ .

Explain why  $TeF_x$  is octahedral with bond angles of  $90^\circ$ .

.....  
.....  
..... [2]

- (f)  $TeF_x$  reacts with water to form tellurium hydroxide and HF. The oxidation number of tellurium does **not** change during this reaction.

- (i) Construct an equation for the reaction of  $TeF_x$  with water.

..... [1]

- (ii) Name the type of reaction that occurs when  $TeF_x$  reacts with water.

..... [1]

[Total: 13]

- 2 A neutralisation reaction occurs when NaOH(aq) is added to H<sub>2</sub>SO<sub>4</sub>(aq).



- (a) Define enthalpy change of neutralisation,  $\Delta H_{\text{neut}}$ .

.....  
 .....  
 ..... [2]

- (b) An experiment is carried out to calculate  $\Delta H_{\text{neut}}$  for the reaction between NaOH(aq) and H<sub>2</sub>SO<sub>4</sub>(aq).

100 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> NaOH(aq) is added to 75 cm<sup>3</sup> of 1.00 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub>(aq) in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

**Table 2.1**

initial temperature of NaOH(aq) / °C	20.0
initial temperature of H <sub>2</sub> SO <sub>4</sub> (aq) / °C	20.0
maximum temperature of mixture / °C	27.8

- (i) Use equation 1 to calculate the amount, in mol, of H<sub>2</sub>SO<sub>4</sub>(aq) that is neutralised in the experiment.

amount of H<sub>2</sub>SO<sub>4</sub>(aq) neutralised = ..... mol [1]

- (ii) Calculate  $\Delta H_{\text{neut}}$  using the results in Table 2.1. Include units in your answer.

Assume that:

- the specific heat capacity of the final solution is 4.18 J g<sup>-1</sup> K<sup>-1</sup>
- 1.00 cm<sup>3</sup> of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- full dissociation of H<sub>2</sub>SO<sub>4</sub>(aq) occurs
- the experiment takes place at constant pressure.

Show your working.

$\Delta H_{\text{neut}} = \dots\dots\dots$  units ..... [3]

5

- (c) (i) Complete the equation for the reaction that occurs when a solution of  $\text{Ba(OH)}_2$  is added to aqueous sulfuric acid. Include state symbols.

..... $\text{H}_2\text{SO}_4(\text{aq})$  + ..... $\text{Ba(OH)}_2(\text{aq}) \rightarrow$  ..... [2]

- (ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

.....  
..... [1]

[Total: 9]

**3** Chlorine is a very reactive element.

**(a)** Chlorine reacts with silicon to form silicon(IV) chloride.

Describe the appearance of silicon(IV) chloride at room temperature and pressure. State its structure and bonding.

appearance .....

structure and bonding .....

[2]

**(b)** Samples of magnesium chloride and phosphorus(V) chloride are added to separate beakers of cold water.

Complete Table 3.1. Ignore temperature changes when considering observations for these reactions.

**Table 3.1**

	magnesium chloride	phosphorus(V) chloride
appearance at room temperature		
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		
pH of final solution		

[4]

**(c) (i)** State the reagent and conditions required for the formation of sodium chlorate(V) from  $\text{Cl}_2(\text{g})$ .

..... [1]

**(ii)** Explain why the reaction in **(c)(i)** is described as a disproportionation reaction. Your answer should refer to relevant species and their oxidation numbers.

.....

..... [1]

(d) Chlorine reacts with methane in a series of reactions to produce chloroalkanes.

(i) State the conditions required for chlorine to react with methane.

..... [1]

(ii) One of the products of the reaction is  $\text{CH}_2\text{Cl}_2$  which reacts further to produce  $\text{CHCl}_3$ .

Complete Table 3.2 to show details of the mechanism that forms  $\text{CHCl}_3$  from  $\text{CH}_2\text{Cl}_2$ .

**Table 3.2**

name of step	equation
initiation	.....
propagation	$\text{CH}_2\text{Cl}_2 + \text{Cl}^\bullet \rightarrow$ .....
termination	..... $\rightarrow \text{CHCl}_3$

[3]

(e)  $\text{CHCl}_3$  and HF are used to form  $\text{CHClF}_2$  in a substitution reaction.

Construct an equation for this reaction.

..... [1]

(f) **X** is a product of the substitution reaction that occurs when  $\text{CHClF}_2$  reacts with  $\text{Br}_2$ .

There is only one naturally occurring isotope of fluorine,  $^{19}\text{F}$ .

The mass spectrum of **X** shows molecular ion peaks at  $m/e = 164, 166$  and  $168$ .

Complete Table 3.3 to show **all** the molecular ions responsible for each peak.

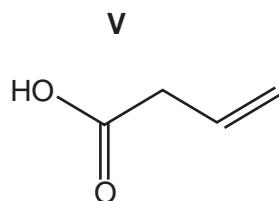
**Table 3.3**

$m/e$	formulae of molecular ions
164	
166	
168	$(\text{CF}_2^{37}\text{Cl}^{81}\text{Br})^+$

[2]

[Total: 15]

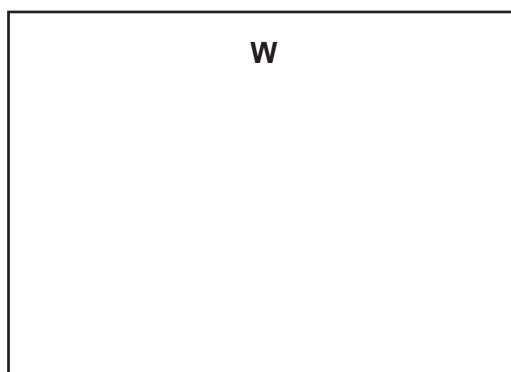
- 4 **V** is a colourless liquid.



**Fig. 4.1**

- (a) **V** reacts with an excess of  $\text{LiAlH}_4$  to form **W**.

- (i) Draw the structure of **W** in the box.

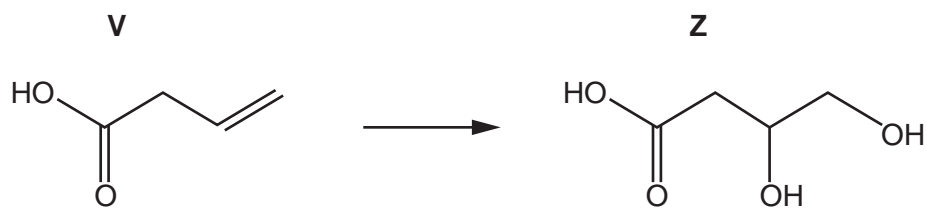


[1]

- (ii) Identify the role of  $\text{LiAlH}_4$  in the reaction with **V**.

..... [1]

- (b) **V** reacts to form **Z** in a single reaction, as shown in Fig. 4.2.



**Fig. 4.2**

- (i) Suggest the reagent and conditions needed to form **Z** from **V**.

..... [1]

- (ii) Deduce the empirical formula of **Z**.

..... [1]



- (iii) Complete Table 4.1 to show the number of  $sp^2$  and  $sp^3$  hybridised carbon atoms that are present in a molecule of **V**.

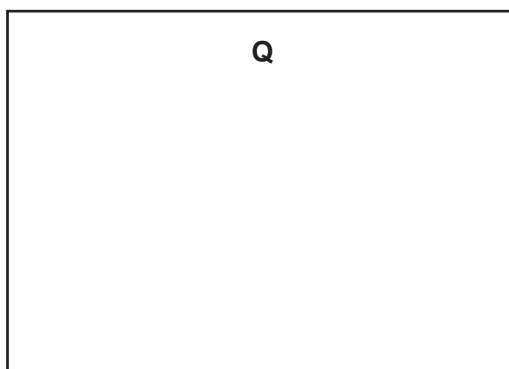
Table 4.1

type of hybridisation	$sp^2$	$sp^3$
number of carbon atoms in <b>V</b>		

[2]

- (c) **Q** contains the elements carbon, hydrogen and oxygen only. It is a saturated molecule with no branching in its carbon backbone.  
**Q** contains only one functional group.  
 The relative molecular mass of **Q** is 88.  
 No effervescence is seen when  $Na_2CO_3$  is added to **Q**.  
 Effervescence is seen when sodium is added to **Q**.  
**Q** reacts with alkaline  $I_2(aq)$  to form a yellow precipitate.

Draw the structure of **Q** in the box.



[2]

[Total: 8]

- 5 (a) Molecule **M** is present in petrol, a fuel used in cars. **M** is a saturated, non-cyclic hydrocarbon. **M** contains eight carbon atoms.

(i) Construct an equation for the complete combustion of **M**.

..... [2]

(ii) Describe how the composition of products differs when incomplete combustion of **M** occurs.

.....

..... [2]

(b) When petrol is burned in an internal combustion engine, oxides of nitrogen are released into the atmosphere. Oxides of nitrogen are responsible for the formation of acid rain.

(i) Suggest the conditions required for the production of oxides of nitrogen during combustion of **M** in an internal combustion engine. Use an appropriate equation in your answer.

.....

.....

.....

..... [2]

(ii) Describe how acid rain is formed in the atmosphere in the presence of oxides of nitrogen and  $\text{SO}_2$ . Identify the role of the oxides of nitrogen in this process. Include **all** relevant equations.

.....

.....

.....

..... [3]

(iii) State **one** other type of air pollution that is caused by the production of oxides of nitrogen in an internal combustion engine.

..... [1]

- (c) Biodiesel **T** is a fuel made from vegetable oil **R**. Fig. 5.1 shows the production of **T** from **R** in a two-step process.

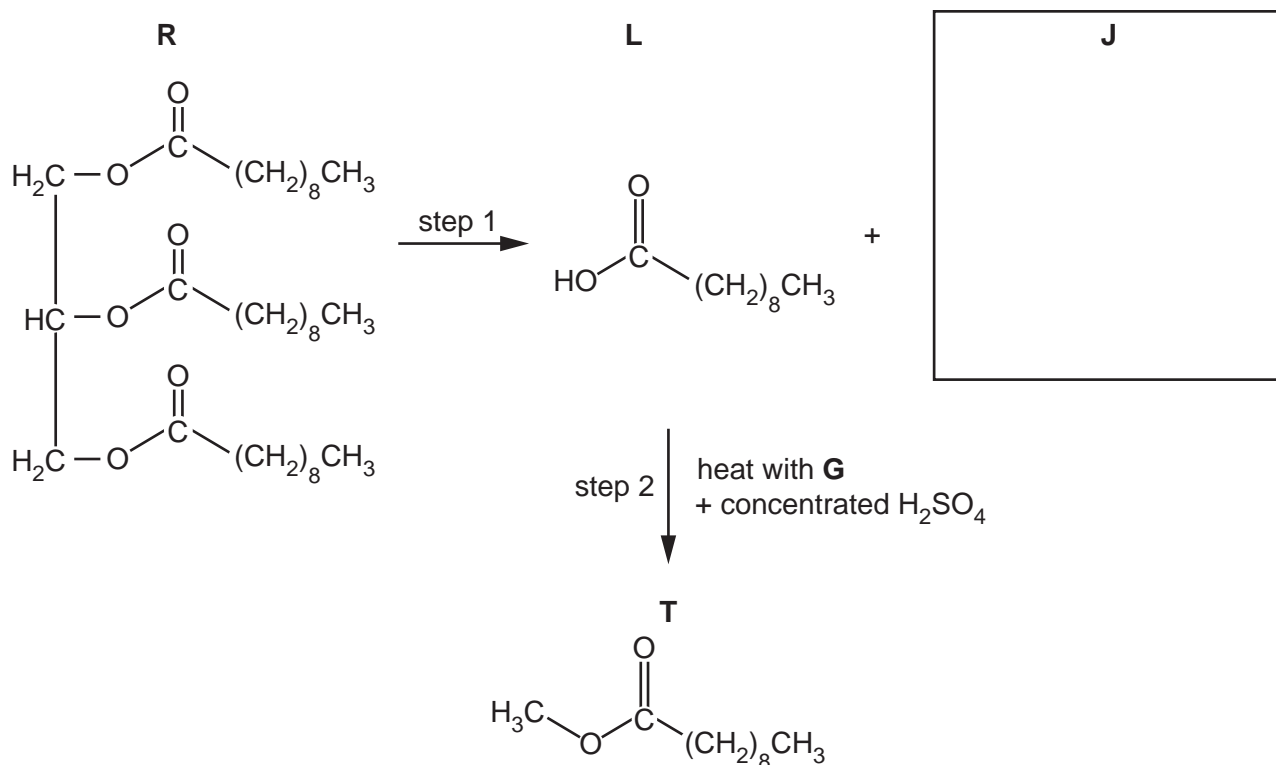


Fig. 5.1

- (i) In step 1 all three ester groups in **R** react. Suggest a suitable reagent and conditions for step 1.  
 ..... [1]
- (ii) Draw the structural formula of **J** in the box in Fig. 5.1. [1]
- (iii) Name the type of reaction that occurs in step 2.  
 ..... [1]
- (iv) Name organic reagent **G** used in step 2.  
 ..... [1]
- (v) **L** is called decanoic acid. Use systematic nomenclature to deduce the name of **T**.  
 ..... [1]

[Total: 15]



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**Important values, constants and standards**

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g <sup>-1</sup> K <sup>-1</sup> )

## The Periodic Table of Elements

Group																		
1	2	Key										13	14	15	16	17	18	
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0						
3	4																	2
Li lithium 6.9	Be beryllium 9.0																	He helium 4.0
11	12																	10
Na sodium 23.0	Mg magnesium 24.3																	Ne neon 20.2
19	20																	18
K potassium 39.1	Ca calcium 40.1																	Ar argon 39.9
37	38																	36
Rb rubidium 85.5	Sr strontium 87.6																	Kr krypton 83.8
55	56																	54
Cs caesium 132.9	Ba barium 137.3																	Xe xenon 131.3
87	88																	86
Fr francium —	Ra radium —																	Rn radon —
89–103 actinoids	89–103 actinoids																	118
Fr francium —	Ra radium —																	Og oganesson —
																		17
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																		8
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																		6
																		5
																		4
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																		2
																		1

lanthanoids

57	La	lanthanum	138.9
58	Ce	cerium	140.1
59	Pr	praseodymium	140.9
60	Nd	neodymium	144.4
61	Pm	promethium	—
62	Sm	samarium	150.4
63	Eu	euporium	152.0
64	Gd	gadolinium	157.3
65	Tb	terbium	158.9
66	Dy	dysprosium	162.5
67	Ho	holmium	164.9
68	Er	erbium	167.3
69	Tm	thulium	168.9
70	Yb	ytterbium	173.1
71	Lu	lutetium	175.0

actinoids