Cambridge Assessment International Education

Example Responses – Paper 2

Cambridge International AS & A Level Chemistry 9701

For examination from 2022

Cambridge Pathway

Contents

Introduction

The main aim of this booklet is to exemplify standards for those teaching Cambridge International AS & A Level Chemistry 9701.

This booklet contains responses to all questions from June 2022 Paper 22, which have been written by a Cambridge examiner. Responses are accompanied by a brief commentary highlighting common errors and misconceptions where they are relevant.

The question papers and mark schemes are available to download from the School Support Hub.

9701 June 2022 Question Paper 22

9701 June 2022 Mark Scheme 22

Past exam resources and other teaching and learning resources are available from the School Support Hub.

Question 1

1 (a) Magnesium has a melting point of 650 °C and high electrical conductivity.

Explain these properties of magnesium by referring to its structure and bonding.

High melting point – many strong metallic bonds. Good conductor – movement of delocalised electrons through the lattice. [2]

Examiner comment

- Some answers stated the structure and bonding in magnesium, but did not attempt to answer the question and explain the properties in terms of the structure and bonding.
- Candidates needed to refer to movement of 'delocalised' electrons through the structure. It is not enough to just state 'sea of electrons move' or 'electrons in the metal lattice are free'.

(b) When magnesium is heated in air, magnesium oxide, MgO, is the major product. Smaller amounts of magnesium nitride, Mg_3N_2, are also made.

(i) Calculate the oxidation number for magnesium and for the nitrogen species in Mg_3N_2 to complete Table 1.1.

Table 1.1

species	magnesium in Mg_3N_2	nitrogen in Mg_3N_2
oxidation number	2	3–

[1]

(ii) Identify the type of reaction which takes place between magnesium and nitrogen. Explain your answer.

Redox. The oxidation number of magnesium increases and nitrogen decreases. [1]

Examiner comment

- Incomplete responses sometimes identified the type of reaction but gave no explanation.
- Other incomplete answers referred to the reaction of one of the species rather than both.

(iii) Define enthalpy change of formation.

The enthalpy change which occurs when 1 mol of compound is made from its elements in their standard states. [2]

Examiner comment

A common misconception was that 'standard conditions' is equivalent to 'standard states'. This is not the case; an element like carbon exists as two types of crystalline solid at room temperature and pressure. The enthalpy change for a reaction involving the element carbon, under these conditions, will be slightly different depending on whether diamond or graphite. Because of this, a definition for standard enthalpy change of formation needed to specify that the elements used are in their 'standard states'.

(iv) When 3.645 g of Mg(s) burns in excess N_2(g) to form Mg_3N_2(s), 23.05 kJ of energy is released.

Calculate the enthalpy change of formation, ΔH_f, of Mg_3N_2. Show your working.

	3Mg	+	N_2	→	Mg_3N_2
amount / mol	3.645 ÷ 24.3 = 0.15				0.15 ÷ 3 = 0.05

energy released = 23.05 ÷ 0.05 = 461

ΔH_f (Mg_3N_2) = −461 kJ mol^{-1} [3]

Examiner comment

- The amount of energy released from 3.645 g of magnesium to find the amount of energy released per mol of magnesium was seen frequently.
- Inclusion of a negative sign with the value for the enthalpy change calculated was less common, even though the details of the question state that energy was released in the reaction.
- Few answers addressed the question and calculated the standard enthalpy change of formation of Mg_3N_2 with the help of a balanced equation for this reaction.
- The relative atomic masses used should be the ones given in the Periodic Table provided in the question paper; the amount of magnesium involved should be calculated using 24.3 and not 24.
- All the data given in this question uses 3 or 4 significant figures therefore the final answer should be given to either 3 or 4 significant figures.

Question 2

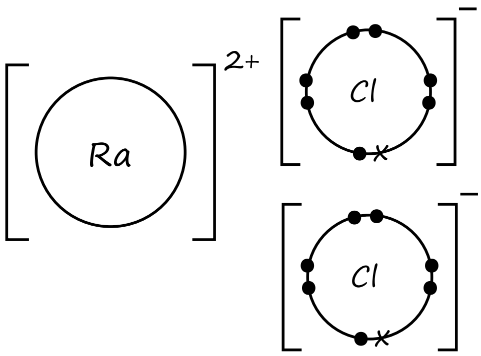
2 Radium, Ra, is an element found in Group 2 of the Periodic Table. It is a crystalline solid at room temperature and conducts electricity.

Radium chloride, $RaCl_2$, has a melting point of 900 °C and is soluble in water.

(a) Predict the lattice structure of $RaCl_2$(s) based on the properties described.

giant ionic .... [1]

(b) Draw a dot-and-cross diagram to show the arrangement of outer electrons in $RaCl_2$.



[1]

Examiner comment

- Many answers correctly identified the lattice structure of radium chloride as giant ionic in **2(a)**, but then went on to represent $RaCl_2$ as a covalent structure, with shared pairs of electrons rather than ionic bonds.
- Answers which involved ions sometimes described an incorrect 1+ charge on the radium ion.

(c) Solid Ra and Ca show similar reactions with H_2O, but the reactions occur at different rates.

Separate samples, each containing a single piece of solid Ra or Ca, are added to equal volumes of cold water.

Each sample contains equal numbers of moles of solid and the H_2O is in excess.

(i) Construct an equation for the reaction of Ra with H_2O.

$Ra + 2H_2O \rightarrow Ra(OH)_2 + H_2$ [1]

Examiner comment

Many candidates used the details given in the question to identify the production of radium hydroxide, but common errors included:

- the formula of radium hydroxide as RaOH rather than $Ra(OH)_2$
- no production of H_2
- equations that were not balanced.

(ii) Identify which element, Ra or Ca, reacts with H_2O at a faster rate. Suggest how the observations of each reaction would differ.

Radium. Solid radium disappears more quickly than calcium.

[1]

Examiner comment

- Many candidates identified Ra as the more reactive element with H_2O.
- Relevant observations should note how a specific event, common to each reaction, is identified and measured so that the element which reacted with H_2O at a faster rate could be determined.
- In the details provided in the question, both elements should produce the same final volume of gas. Observations that stated only ‘Ra produces more bubbles’ did not indicate how the rate of these reactions differed unless the statement was qualified by reference to time, for example ‘Ra produces more bubbles in the first minute’.
- Answers like ‘Ra involves a more vigorous reaction’ or ‘with Ra a gas is made more quickly’, did not describe an observation.

(iii) Suggest why these reactions occur at different rates.

The reaction with Ra has a lower activation energy so there is a greater frequency of effective collisions between water molecules and radium atoms. [2]

Examiner comment

- Candidates needed to use the details given in the question to realise that the only variable which had changed when the two samples were added to water was the Group 2 solid added.
- A common incomplete explanation described 'more effective collisions' with no reference to a unit of time during which these collisions occurred.
- Reacting particles identified should be appropriate. In this example, the radium species should not be described as 'radium molecules' or 'radium anions'.
- E_A is the abbreviation used for activation energy in the syllabus, so can be used here rather than the term 'activation energy'.

(iv) One of the solutions is cloudy when the reaction has finished.

At the end of each reaction, universal indicator is added to each reaction mixture.

Suggest pH values of the solutions made in both reactions. Explain your answer.

$Ra(OH)_2$ – pH 14. $Ca(OH)_2$ – pH 12

The solution made from Ra has a higher concentration of hydroxide ions as $Ra(OH)_2$ is more soluble. [2]

Examiner comment

The question asks candidates to 'Suggest pH values', but some answers did not refer to pH.

(d) A sample of aqueous calcium halide, $CaX_2(aq)$, contains either chloride, bromide or iodide ions.

Complete Table 2.1 to describe a two-step process that could be used to identify the halide ion present.

Table 2.1

step	method	observation with $CaCl_2$	observation with $CaBr_2$	observation with CaI_2
step **1**	add $AgNO_3(aq)$	white precipitate	cream precipitate	pale yellow precipitate
step **2**	followed by NH_3 (aq)	all the precipitate dissolves	some precipitate dissolves	no precipitate dissolves

[3]

[Total: 11]

Examiner comment

Inappropriate reagents included:

- addition of a silver halide in step 1 rather than aqueous silver nitrate
- addition of NaOH(aq) rather than ammonia solution in step 2
- addition of concentrated sulfuric acid in either step. This reagent could be used on solid samples of the calcium halide but is not appropriate here because the question states that the samples to be tested are all aqueous solutions.

Incorrect observations included:

- no reference to precipitates made in step 1
- mixing up the colour of the precipitates made in step 1 so that the precipitate made with calcium iodide was described as white and the precipitate made with calcium chloride was described as yellow
- incorrect pattern of solubility of the precipitates on addition of aqueous ammonia with the precipitate made using calcium iodide completely dissolving on addition of aqueous ammonia.

Question 3

3 **(a)** 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.

equation **1** $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

(i) Explain what is meant by dynamic equilibrium.

When the rate of the forward reaction equals the rate of the backward reaction in a closed system and the concentration of reactants and products remains constant. [2]

Examiner comment

A common error in this definition described equal concentrations of reactants and products at equilibrium when this statement is not always true. At equilibrium, the concentrations of reactants and products do not change, but they are not necessarily equal.

(ii) Describe **one** difference in the initial appearance of the reaction mixture compared to the mixture at equilibrium.

Initially it is colourless. At equilibrium it is purple. [1]

Examiner comment

- Some answers were incomplete. 'Purple gas' with no other details did not answer this question.
- Common errors included descriptions of brown gas made at equilibrium and purple vapour turning colourless at equilibrium.

(iii) Write an expression for K_p for the reaction described in equation **1**.

$$K_p = \frac{(pH_2)(pI_2)}{(pHI)^2}$$

[1]

Examiner comment

Use of square brackets in the expression was incorrect. Square brackets are used to represent concentrations but expressions of K_p only refer to partial pressure of the gases present in the sample.

(iv) At equilibrium the partial pressure of HI(g) is 86.4 kPa.

Calculate the amount of HI(g) present in the mixture at equilibrium. Show your working.

	2HI	→	H_2	+	I_2
initial mol	0.0250		0		0
mol at equilibria	0.025−2x		x		x

total number mol at equilibrium = 0.025 – 2x + x + x = 0.025

partial pressure of HI at equilibrium is 0.025 – 2x

$$86.4 = \frac{0.025 - 2x}{0.025} \times 100$$

$$0.025 - 2x = 0.0216$$

amount of HI(g) = ...0.0216........ mol [2]

Examiner comment

- Some answers calculated the amount of HI used up in the reaction but did not use this value to calculate the amount of HI at equilibrium as the question asked.
- Working must be shown clearly so that an examiner can decide if marks can be awarded for errors carried forward.
- If the candidate used and wrote down more than one method to produce an answer, the method and answer which is not to be marked must be crossed out.

(b) Use equation **1** and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH, for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
H–H	436
I–I	151
H–I	299

$$HI \rightarrow \tfrac{1}{2}H_2 + \tfrac{1}{2}I_2$$

$$\Delta H = 299 - (\tfrac{1}{2} \times 436 + \tfrac{1}{2} \times 151)$$

ΔH = ...+5.50........ kJ mol^{-1} [2]

Examiner comment

Many answers correctly calculated the enthalpy change for the decomposition of 2 mol HI but did not divide this value by 0.5 to calculate the enthalpy change for decomposition of 1 mol, as stated in the question.

(c) Describe the effect of increasing pressure on the value of K_p for the decomposition of HI(g).

No change .... [1]

(d) HC*l*(g) is prepared by adding NaC*l*(s) to concentrated H_2SO_4.

HI(g) is **not** prepared by adding NaI(s) to concentrated H_2SO_4 because the HI(g) produced also reacts with concentrated H_2SO_4.

(i) Identify the type of reaction that occurs when NaI(s) reacts with concentrated H_2SO_4 to form HI(g).

acid-base .... [1]

(ii) Write an equation for the reaction of HI(g) and concentrated H_2SO_4.

$8HI + H_2SO_4 \rightarrow 4I_2 + H_2S + 4H_2O$ .... [1]

Examiner comment

- A variety of balanced equations that showed production of I_2, H_2O with a combination of one or more of H_2S, SO_2 and S were also correct.
- Equations were not always balanced.

(iii) Explain why HI(g) reacts with concentrated H_2SO_4 whereas HC*l* does not.

HI is a stronger reducing agent, it reduces the sulfur in H_2SO_4. .... [1]

[Total: 12]

Examiner comment

- Use of appropriate terms is essential here.
- Confusion was seen in some answers in terms of identification of the species oxidised, species reduced and in the use of the terms oxidising agent and reducing agent.

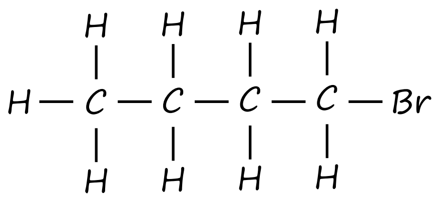
Question 4

4 **(a)** Bromine reacts with butane in the presence of ultraviolet light to form bromobutane.

Two structural isomers with the molecular formula C_4H_9Br are produced during this reaction.

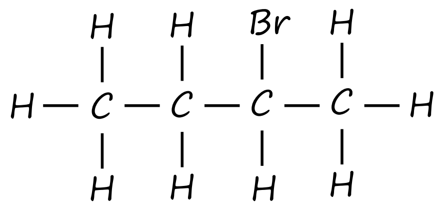
(i) Draw the two structural isomers and state the systematic name of each isomer.

structural isomer **1**



name 1–bromobutane

structural isomer **2**



name 2–bromobutane

Examiner comment

[2]

- The name of each isomer must include the number which refers to the carbon atom on the chain which is bonded to the bromine atom.
- Candidates needed to check that any structural formula drawn contained the correct number of hydrogen atoms attached to each 'C' shown.
- Candidates needed to check that the correct symbol for bromine is used. The symbol B represents boron, not bromine.

(ii) Identify the type of structural isomerism shown in **(a)(i)**.

positional [1]

(b) Halothane is an anaesthetic.

halothane

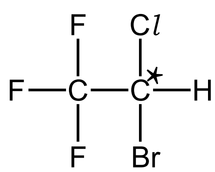


Fig. 4.1

(i) Identify the chiral centre in halothane and mark it with an asterisk (*). [1]

When halothane reacts in ultraviolet light, homolytic fission occurs and the C–Br bond is broken.

(ii) Construct an equation to show the homolytic fission of halothane, $CF_3CHBrCl$.

$CF_3CBrCl\,H \rightarrow CF_3CHCl\bullet + Br\bullet$ [1]

(iii) Complete Fig. 4.2 to show the arrangement of electrons in a bromine atom using the electrons in boxes notation.

	3d					4s	4p		
[Ar]	⥮	⥮	⥮	⥮	⥮	⥮	⥮	⥮	↿

Fig. 4.2

[1]

(c) **X** is an addition polymer.

X

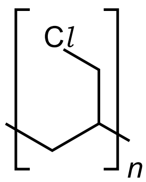
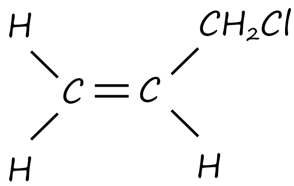


Fig. 4.3

(i) Draw the monomer of **X**.



[1]

Examiner comment

- The answer could be shown as a skeletal or structural or displayed formula because the question does not ask for a specific type of formula.
- Some candidates showed the carbon atoms of the double bond bonded to methyl groups rather than hydrogen atoms.

(ii) Suggest **one** reason why the disposal of items made from **X** is difficult.

X is non-biodegradable. [1]

[Total: 8]

Question 5

5 Fig. 5.1 shows three reactions of 2-bromopropane, $CH_3CH(Br)CH_3$.

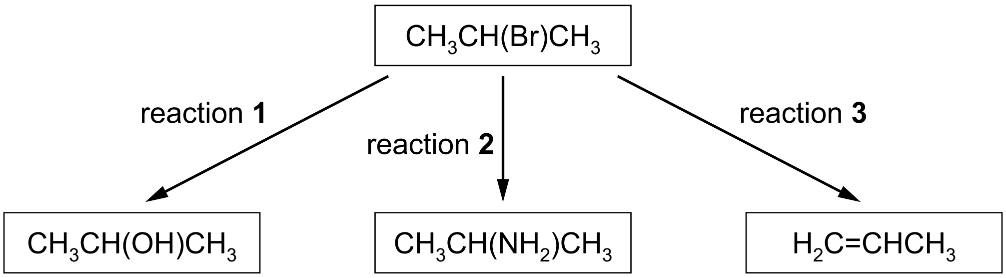


Fig. 5.1

(a) Complete Table 5.1 for each reaction, by:

- stating the reagent and conditions used
- identifying the type of reaction that occurs.

Table 5.1

reaction	reagent and conditions	type of reaction
1	+ NaOH(aq). Heat	substitution
2	+ NH_3 in ethanol heat under pressure	substitution
3	+ NaOH in ethanol. Heat.	elimination

[6]

Examiner comment

- In reaction 1, some answers identified H_2O as the reactant. However, this reaction is very slow, so it is more appropriate to use aqueous alkali.
- The term 'heat under pressure' is not equivalent to 'heat under reflux'.
- Candidates needed to take care when describing the reagent in reaction 3. Use of ethanal and ethanoic acid were stated instead of ethanol in some answers.

(b) A sample of 2-iodopropane, $CH_3CH(I)CH_3$, reacts under the same conditions as reaction **1** to produce $CH_3CH(OH)CH_3$.

Explain why 2-iodopropane reacts at a faster rate than 2-bromopropane.

Because the C–I bond is weaker than the C–Br bond, the activation energy for the reaction with 2-iodopropane is lower.

Examiner comment

- Some answers did not refer to the specific bonds broken in these reactions.
- Some answers referred to the strength of hydrogen-halogen bonds rather than carbon-halogen bonds.
- An attempt to link the difference in bond strength to the different rates of these reactions was often omitted.

(c) Fig. 5.2 shows how butan-1-ol can be made from 1-bromopropane in three steps.

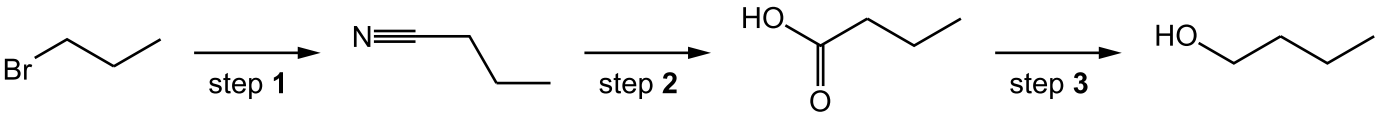


Fig. 5.2

(i) In step **1**, 1-bromopropane reacts with CN^- to form butanenitrile.

Complete Fig. 5.3 to show the mechanism for step **1**. Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate.

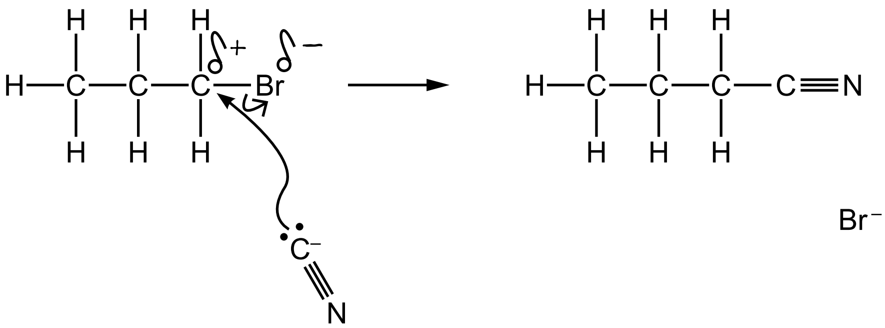


Fig. 5.3

[2]

Examiner comment

- In many answers, the lone pair of electrons used to make the new bond between the carbon atom of the cyanide ion and the carbon of the halogenoalkane was not shown.
- Curly arrows needed to be drawn carefully.
- An arrow with a full head (→) indicates the movement of a pair of electrons.
- The arrow begins at a bond or a lone pair of electrons.
- When a bond is broken, the arrowhead points to the atom which receives the shared pair of electrons from the bond. This atom becomes negatively charged.
- When a bond is made, the arrowhead points to where the new bond is made when a lone pair of electrons is shared between two atoms

(ii) In step **2**, butanenitrile is heated with HCl(aq). A hydrolysis reaction occurs.

Construct an equation for the reaction in step **2**.

$CH_3(CH_2)_2CN + 2H_2O + HCl \rightarrow CH_3(CH_2)_2CO_2H + NH_4Cl$ [1]

(iii) Step **3** is a reduction reaction.

Construct an equation for the reduction reaction in step **3**. Use [H] to represent one atom of hydrogen from the reducing agent.

$CH_3(CH_2)_2CO_2H + 4[H] \rightarrow CH_3(CH_2)_3OH + H_2O$ [1]

Examiner comment

Common incorrect answers included equations with correct species that were not balanced, and incomplete equations with the correct organic product as the only product.

(iv) State the identity of a suitable reducing agent in step **3**.

$LiAlH_4$ [1]

[Total: 13]

Examiner comment

- Either the name or the formula could be given here, because the question asks for the 'identity of' the species.
- $NaBH_4$ was a common incorrect answer. It is not a strong enough reducing agent to reduce carboxylic acids.

Question 6

6 **Z** is a molecule which contains the elements carbon, hydrogen and oxygen only.

Z contains only alkene and carboxyl functional groups.

(a) Complete Table 6.1 by describing the observations that occur when two different reagents are added to separate samples of **Z**(aq).

Table 6.1

reagent added to **Z**(aq)	observation
Br_2(aq)	orange Br_2 to colourless
Na_2CO_3(s)	fizzes

[2]

(b) Table 6.2 shows the percentage by mass of each element present in **Z**.

Table 6.2

element	percentage by mass / %
carbon	41.38
hydrogen	3.45
oxygen	55.17

Using the data in Table 6.2, demonstrate that the empirical formula of **Z** is CHO.
Show your working.

	C	:	H	:	O
% / A_r	41.38/12 = 3.448		3.45/1 = 3.45		55.17/16 = 3.448
÷ by smallest value % / A_r	1	:	1.0005	:	1
simplest whole number ratio	1	:	1	:	1

so empirical formula is CHO

[1]

(c) Fig. 6.1 shows the mass spectrum of **Z**.

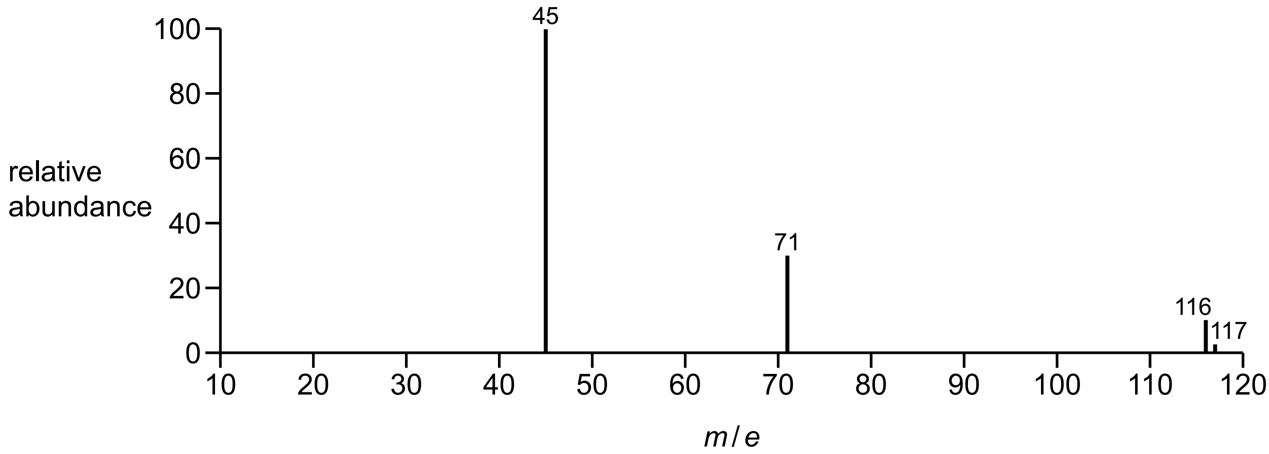


Fig. 6.1

(i) Deduce the molecular formula of **Z**. Explain your answer by referring to the molecular ion peak in Fig. 6.1 and the empirical formula of **Z**.

molecular ion peak – mass of 116

empirical formula CHO – mass of 12 + 1 + 16

116 ÷ 29 = 4

so molecular formula = $C_4H_4O_4$ [1]

Examiner comment

- Many answers stated the molecular formula, with no reference to the molecular ion peak or the empirical formula, as asked for in the question.
- Identification of the peak with the largest *m*/*e* as the molecular ion peak was common. The peak at 117 is caused by the presence of one ^{13}C isotope in a molecule of Z and is known as the M+1 peak.

(ii) Use Fig. 6.1 to suggest the formulae of the fragments with *m* / *e* peaks at 45 and at 71.

m / *e* 45 $^{+}COOH$

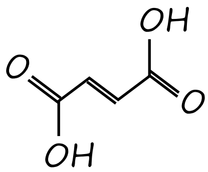
m / *e* 71 $C_3H_3O_2^{+}$

[2]

Examiner comment

The fragments identified in a mass spectrometer are always positively charged.

(iii) Suggest the structure of **Z** using relevant information from Table 6.1, **(b)** and **(c)**.



[1]

[Total: 7]

Examiner comment

- Incorrect structures did not use all the information given.
- Incorrect answers included those that:
  - did not have an empirical formula of CHO
  - did not have a molecular mass of 116
  - contained ester functional groups.

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