

- (a) Define the term *relative molecular mass*.

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

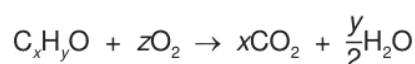
- (b) **T** is an alcohol, C_xH_yO . A gaseous sample of **T** occupied a volume of 20 cm^3 at 120°C and 100 kPa .

The sample was completely burned in 200 cm^3 of oxygen (an excess). The final volume, measured under the same conditions as the gaseous sample, was 250 cm^3 .

Under these conditions, all water present is vaporised. Removal of the water vapour from the gaseous mixture decreased the volume to 170 cm^3 .

Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to 110 cm^3 .

The equation for the complete combustion of **T** can be represented as shown.



- (i) Use the data given to calculate the value of x .

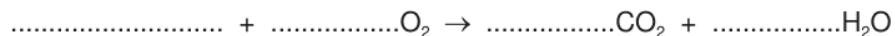
$x = \dots\dots\dots$ [1]

- (ii) Use the data given to calculate the value of y .

$y = \dots\dots\dots$ [1]

If you were unable to calculate values for x and y then use $x = 4$ and $y = 10$ for the remaining parts of this question. These are **not** the correct values.

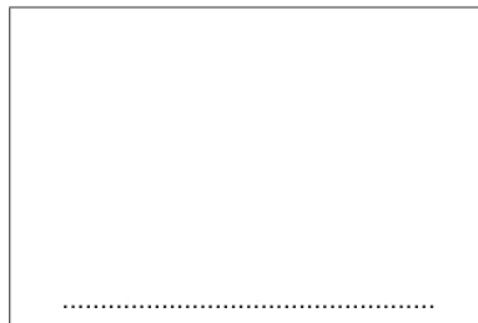
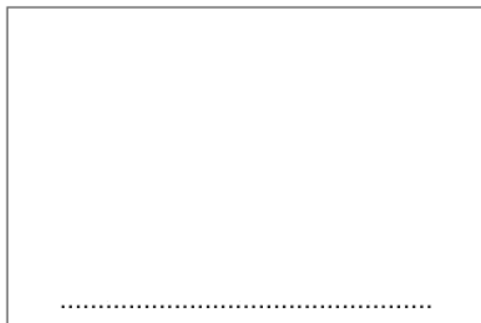
- (iii) Complete the equation for the complete combustion of the alcohol, **T**.



[1]

- (iv) Give the skeletal formulae for two possible structures of **T**.

Name each alcohol.



[2]

- (v) Use the general gas equation to calculate the mass of **T** present in the original 20 cm³ gaseous sample, which was measured at 120 °C and 100 kPa.

Give your answer to **three** significant figures. Show your working.

mass = g [3]

[Total: 10]

- (b) Boron occurs naturally as a mixture of two stable isotopes, ^{10}B and ^{11}B . The relative isotopic masses and percentage abundances are shown.

isotope	relative isotopic mass	abundance / %
^{10}B	10.0129	19.78
^{11}B	to be calculated	80.22

- (i) Define the term *relative isotopic mass*.

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

- (ii) Calculate the relative isotopic mass of ^{11}B .

Give your answer to **six** significant figures. Show your working.

[2]

[Total: 6]

- (iii) Give the molecular formula and the empirical formula of **P**.

molecular formula of **P**

empirical formula of **P**

[2]

- (ii) Calculate the amount, in moles, of C_{60} that reacted.

amount of C_{60} = mol [1]

- (iii) Calculate the amount, in moles, of hydrogen gas that reacted with the C_{60} .

amount of hydrogen gas = mol [2]

- (iv) Use your answers from (ii) and (iii) to deduce the molecular formula of the hydrocarbon, $C_{60}H_{2x}$.

If you were unable to calculate the amount of hydrogen gas, assume that 0.00240 mol of hydrogen gas reacted. This is **not** the correct value for the amount of hydrogen gas that reacted.

molecular formula = [2]

(iii) Calculate the amount, in moles, of manganate(VII) ions that reacted.

amount = mol [1]

(iv) Calculate the amount, in moles, of Fe^{2+} ions in the sample of the salt.

amount = mol [1]

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(v) Calculate the relative formula mass of $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$.

relative formula mass = [1]

May/June 2018 9701/22 · Q2 (d)(iii), (d)(iv), (d)(v)

(e) If **X** is treated with ammonia and the product hydrolysed, a compound, **Y**, is obtained that contains 51.3% C, 9.40% H, 12.0% N and 27.3% O by mass.

(i) Show that the empirical formula of **Y** is $\text{C}_5\text{H}_{11}\text{NO}_2$.

[2]

(ii) The empirical formula of **Y** is $\text{C}_5\text{H}_{11}\text{NO}_2$ and the M_r of **Y** is 117.

Deduce the molecular formula of **Y**. You **must** explain your reasoning.

molecular formula =

.....

.....

[1]

[Total: 16]

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- (d) Interhalogen compounds, such as BrCl or IF_5 , contain two or more different halogen atoms that are covalently bonded.

D is an interhalogen compound that contains only chlorine and fluorine.

At 0°C and $101\,325\text{ Pa}$, 1 dm^3 of **D** has a mass of 4.13 g .

- (i) Use the general gas equation to calculate the relative molecular mass, M_r , of **D**.

$M_r = \dots\dots\dots$
[3]

- (ii) Use your answer to (i) to determine the molecular formula of **D**.

If you were unable to calculate the M_r in (i), assume that the M_r is 130.5 . This is **not** the correct value.

molecular formula of **D** = $\dots\dots\dots$
[1]

[Total: 25]

Question 3 starts on the next page.

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March 2019 9701/22 · Q2 (d)(i), (d)(ii) (cont.)

(iv) The organic product of reaction 3 is **Y**.

Y can be hydrolysed using excess aqueous H_2SO_4 to form **Z**.

The molecular formula of **Z** is $\text{C}_4\text{H}_8\text{O}_4$.

Draw the structure of **Z**.

[2]

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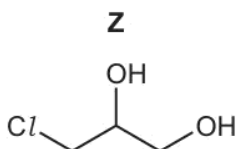
9701/22/F/M/19

[Turn over

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March 2019 9701/22 · Q4 (c)(iv)

(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.



(i) State the molecular formula of **Z**.

..... [1]

May/June 2019 9701/21 · Q4 (c)(i)

(ii) Use the graph to find the concentration of butane and methylpropane in the mixture at equilibrium.

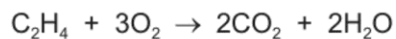
concentration of butane = mol dm^{-3}

concentration of methylpropane = mol dm^{-3}

[1]

May/June 2019 9701/22 · Q1 (c)(ii)

(c) The equation for the complete combustion of ethene is shown.



Calculate the volume, in dm^3 , of carbon dioxide formed in the complete combustion of 1.00 g of ethene at room temperature and pressure.

volume of CO_2 = dm^3 [3]

- (b) A sample of sulfur contains only two isotopes, ^{32}S and ^{34}S . The relative atomic mass of this sample is 32.09.

isotope	isotopic mass
^{32}S	32.0
^{34}S	34.0

Calculate the percentage abundance of the isotopes present in this sample.

% abundance ^{32}S =

% abundance ^{34}S =

[3]

6 (a) Three alkenes, **X**, **Y** and **Z**, have the same molecular formula.

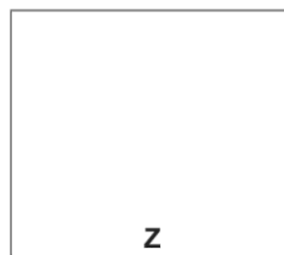
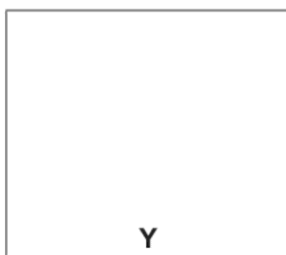
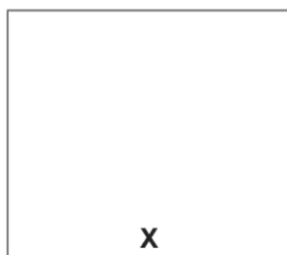
(i) Describe what is seen when aqueous bromine is added to **X**.

..... [1]

X, **Y** and **Z** are reacted separately with hot, concentrated, acidified manganate(VII) ions until no further reaction occurs. The carbon-containing products are shown in the table.

alkene	carbon-containing products
X	$\text{CO}_2 + (\text{CH}_3)_2\text{CO}$
Y	$\text{CO}_2 + \text{CH}_3\text{CH}_2\text{CO}_2\text{H}$
Z	$\text{CH}_3\text{CO}_2\text{H}$

(ii) Draw the structures of **X**, **Y** and **Z**.

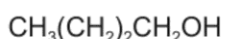


[3]

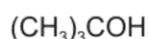
(iii) Deduce the molecular formula of **X**, **Y** and **Z**.

..... [1]

(b) The structures of **V** and **W** are shown.



V



W

(i) Name the class of compound that **V** and **W** each belong to.

V

W

[2]

(ii) **V** and **W** both react with sodium metal.

Write an equation for the reaction of **V** with sodium metal.

..... [1]

11

(iii) Name a reagent used to distinguish **V** from **W**. Describe any observations.

reagent

observations with **V**

observations with **W**

[3]

[Total: 11]

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- (a) Hydrocarbons with low relative molecular mass, M_r , are used as fuels in industry, in the home and for transport.

There is a high demand for the hydrocarbons with low M_r .

- (i) Name the process by which long-chain hydrocarbons are broken down into shorter-chain hydrocarbons.

..... [1]

- (ii) Give one reason why hydrocarbons with low M_r are suitable for use as fuels.

..... [1]

- (iv) Identify an analytical technique that can be used to monitor the levels of CO in the atmosphere.

Outline how this analytical technique may be used to monitor the levels of CO.

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

- (b) Thiophene, $C_4H_4S(l)$, is an organic compound that is found as a contaminant in crude oil.

- (i) Construct the equation for the complete combustion of thiophene, $C_4H_4S(l)$.

Include state symbols in your answer.

..... [2]

Oct/Nov 2019 9701/21 · Q3 (a)(i), (a)(ii), (a)(iv), (b)(i)

- (ii) State what further information is needed to calculate the relative atomic mass of gallium.

..... [1]

May/June 2020 9701/21 · Q1 (a)(ii)

- (d) But-1-ene reacts with steam in the presence of concentrated phosphoric acid to form two isomers of molecular formula $C_4H_{10}O$.

Each reaction occurs via a different intermediate ion.

- (i) Draw the structure of both intermediate ions.

[2]

May/June 2020 9701/21 · Q5 (d)(i)

- (a) Explain what is meant by the term *relative atomic mass*.

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

- (b) Calculate the relative atomic mass of gallium in this sample. Give your answer to 4 significant figures.

Show your working.

relative atomic mass = [2]

- (ii) Suggest an equation for the reaction between gallium oxide and NaOH(aq).

..... [2]

[Total: 12]

- 2 (a) Explain what is meant by the term *relative isotopic mass*.

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

- (b) A sample of copper contains two isotopes, ^{63}Cu and ^{65}Cu . The relative atomic mass of the copper in this sample is 63.55.

Calculate the percentage abundance of each of these isotopes. Show your working.

percentage abundance of ^{63}Cu = %

percentage abundance of ^{65}Cu = %
[2]

- (c) (i) Name the type of bonding within a sample of solid copper.

..... [1]

- (ii) Draw a labelled diagram to show the bonding within a sample of solid copper.

[2]

May/June 2020 9701/23 · Q2 (a), (b), (c)(i), (c)(ii), (d)(i), (d)(ii) (continued ·)

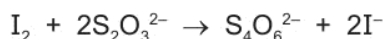
- (d) A student is provided with a sample of hydrated copper(II) sulfate, $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$, and is asked to determine the value of x .

The student dissolves a sample of the hydrated copper(II) sulfate in water and adds it to an excess of aqueous potassium iodide to make a total volume of 250.0 cm^3 of solution.



The amount of iodine produced during this reaction is found by titrating a sample of this solution with sodium thiosulfate solution.

25.0 cm^3 of the iodine-containing solution requires 20.0 cm^3 of 0.10 mol dm^{-3} sodium thiosulfate solution.



- (i) Calculate the amount, in mol, of copper(II) sulfate present in the original sample of hydrated copper(II) sulfate.

Show your working.

amount of copper(II) sulfate = mol [2]

- (ii) A total of 7.98 g of CuSO_4 is present in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$.

Complete each row of the table to calculate the value of x , where x is an integer.

$[M_r: \text{CuSO}_4, 159.6]$

amount of CuSO_4 in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$	 mol
amount of H_2O in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$	 mol
value of x	$x = \dots\dots\dots$

[3]

[Total: 13]

May/June 2020 9701/23 · Q2 (a), (b), (c)(i), (c)(ii), (d)(i), (d)(ii) (cont.)

(iii) Determine the empirical formula of fructose.

..... [1]

May/June 2020 9701/23 · Q3 (b)(iii)

(b) LiAlH_4 cannot be used in aqueous solution because it reacts with water to produce LiOH(aq) , $\text{H}_2(\text{g})$ and a white precipitate which is soluble in excess sodium hydroxide.

Identify the white precipitate.

..... [1]

Oct/Nov 2020 9701/21 · Q3 (b)

(iii) Use the information in (d) to deduce the molecular formula of L.

molecular formula of L = [1]

[Total: 17]

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- (a) (i) Explain what is meant by the term *relative molecular mass*.

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

- (ii) State the empirical formula of ethanedioic acid.

..... [1]

- (iii) Calculate how many atoms of carbon are present in 0.18 g of ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$.

Show your working.

atoms of carbon present = [3]

- (ii) Identify the type of reaction which occurs when CaC_2O_4 is heated.

..... [1]

May/June 2021 9701/21 · Q1 (a)(i), (a)(ii), (a)(iii), (b)(ii)

- (b) Compound **V** is found in naphtha. It has a molecular formula $\text{C}_{10}\text{H}_{22}$.

When **V** is heated at high pressure in the absence of air, an equal number of moles of ethene, propene and **W** are made. **W** is a compound made of straight chain, saturated molecules.

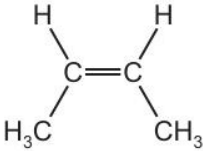
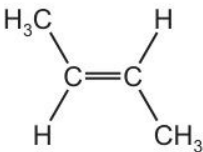
- (i) Name the process that describes this reaction.

..... [1]

May/June 2021 9701/21 · Q5 (b)(i)

- 4 (a) The table shows the structural formulae of four compounds, **A**, **B**, **C** and **D**, with molecular formula C_4H_8 .

(i) Complete the table by giving the systematic name of **A**, **B**, **C** and **D**.

	structural formula	name
A	$CH_3CH_2CH=CH_2$	
B		
C		
D	$CH_2=C(CH_3)_2$	

[4]

May/June 2021 9701/22 · Q4 (a)(i)

(c) Tungsten oxide, W_xO_y , is used to give colour to ceramic materials.

A sample of W_xO_y contains 79.29% tungsten by mass.

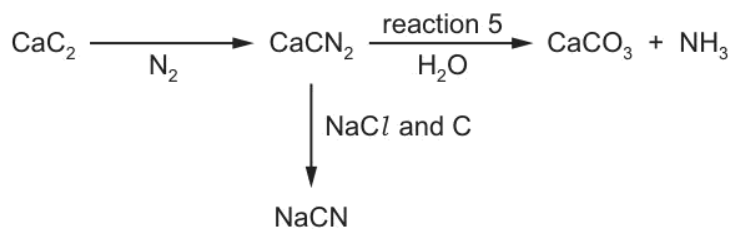
Calculate the empirical formula of W_xO_y .

Show your working.

empirical formula = [3]

[Total: 11]

May/June 2021 9701/23 · Q3 (c)

(d) The flowchart shows some reactions of CaC_2 .(i) Reaction 5 can be used to prepare NH_3 .

Calculate the minimum mass, in tonnes, of calcium cyanamide, CaCN_2 , that is required to produce 1.50×10^6 tonnes of NH_3 .

Show your working.

$$1 \text{ tonne} = 1.00 \times 10^6 \text{ g}$$

minimum mass of CaCN_2 = tonnes
[2]

Oct/Nov 2021 9701/21 · Q2 (d)(i)

(d) The hydrogen halides dissolve in water to form strong Brønsted–Lowry acids.

The concentration of a strong acid can be determined by titration.

(i) State what is meant by strong Brønsted–Lowry acid.

.....

 [2]

March 2022 9701/22 · Q3 (d)(i)

- (e) A sample of magnesium contains three isotopes, ^{25}Mg , ^{26}Mg and **X**.

The percentage abundance of the three isotopes is shown in Table 1.1.

Table 1.1

isotope of Mg	mass / a.m.u.	percentage abundance / %
X		78.99
^{25}Mg	24.99	10.00
^{26}Mg	25.98	11.01

- (i) The relative atomic mass, A_r , is calculated by comparing the average mass of the isotopes of an element to the unified atomic mass unit.

Define the unified atomic mass unit.

..... [1]

May/June 2022 9701/21 · Q1 (e)(i)

- (a) Calculate the molecular formula of **V**. Show your working.

molecular formula of **V** = [3]

- (ii) State the formula of the yellow precipitate produced when **X** is added to alkaline $\text{I}_2(\text{aq})$.

..... [1]

May/June 2022 9701/21 · Q4 (a), (c)(ii)

- (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 .

..... [1]

May/June 2022 9701/22 · Q2 (c)(i)

- (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

$\Delta H = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

May/June 2022 9701/22 · Q3 (b)

(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.

[1]

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May/June 2022 9701/22 · Q6 (b)

(iv) Deduce the molecular formula of **D1**.

..... [1]

Oct/Nov 2022 9701/22 · Q3 (a)(iv)

- (ii) Define relative atomic mass.

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

- (iii) The relative atomic mass of gallium, A_r , is 69.723.
The relative isotopic masses of ^{69}Ga and ^{71}Ga are:

^{69}Ga , 68.926; ^{71}Ga , 70.925.

Use this information to calculate the percentage abundance of ^{69}Ga in elemental gallium.
Show your working.

Assume that the element contains only the ^{69}Ga and ^{71}Ga isotopes.
Give your answer to **four** significant figures.

percentage abundance of ^{69}Ga = %
[2]

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

..... [1]

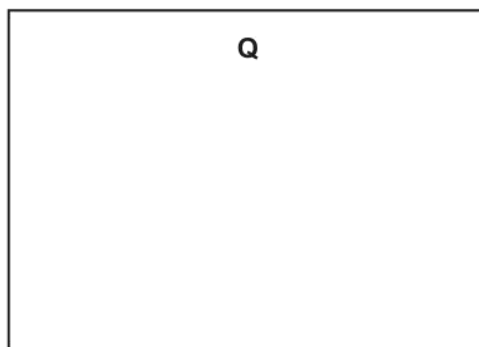
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- (c) **Q** contains the elements carbon, hydrogen and oxygen only. It is a saturated molecule with no branching in its carbon backbone.
Q contains only one functional group.
The relative molecular mass of **Q** is 88.
No effervescence is seen when Na_2CO_3 is added to **Q**.
Effervescence is seen when sodium is added to **Q**.
Q reacts with alkaline $\text{I}_2(\text{aq})$ to form a yellow precipitate.

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



[2]

[Total: 8]

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[Turn over

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May/June 2023 9701/21 · Q4 (b)(ii), (c) (cont.)

- (b) The relative isotopic masses and natural abundances of the two isotopes in a sample of copper are shown in Table 1.1.

Table 1.1

isotope	relative isotopic mass	% abundance
^{63}Cu	62.930	69.15
^{65}Cu	64.928	30.85

- (i) Define the unified atomic mass unit.

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

- (ii) Define relative atomic mass, A_r , in terms of the unified atomic mass unit.

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

- (iii) Calculate the relative atomic mass, A_r , of copper in this sample using the data in Table 1.1.

Show your working.

$A_r = \dots\dots\dots$ [1]

- (iii) Calculate the concentration of I_2 present in the reaction mixture at equilibrium.
Show your working.

concentration of I_2 = mol dm⁻³ [3]

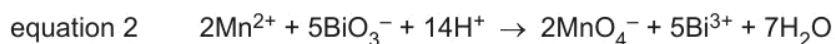
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9701/23/M/J/23

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May/June 2023 9701/23 · Q4 (b)(iii)

- (e) NaBiO_3 can be used to determine the concentration of $\text{Mn}^{2+}(\text{aq})$. The ionic equation for the reaction is shown in equation 2.



A student uses the following procedure in an experiment.

- Add 100.0 cm^3 of a saturated solution of $\text{Mn}^{2+}(\text{aq})$ to a volumetric flask.
- Add distilled water to the flask to make a 1.00 dm^3 diluted solution.
- Titrate a 25.00 cm^3 sample of the diluted solution with 0.100 mol dm^{-3} $\text{NaBiO}_3(\text{aq})$.

The 25.00 cm^3 sample of the diluted solution of $\text{Mn}^{2+}(\text{aq})$ reacts completely with exactly 21.50 cm^3 of 0.100 mol dm^{-3} $\text{NaBiO}_3(\text{aq})$.

Calculate the concentration, in mol dm^{-3} , of $\text{Mn}^{2+}(\text{aq})$ in the saturated solution.

Show your working.

concentration of $\text{Mn}^{2+}(\text{aq})$ in the saturated solution = mol dm^{-3} [3]

[Total: 16]

March 2024 9701/22 · Q1 (e)

- (ii) Deduce which sodium halide, NaCl, NaBr or NaI, produces the largest percentage yield of hydrogen halide when concentrated sulfuric acid is added. Explain your answer by considering the relative reactivity of the halide ions as reducing agents.

identity of sodium halide

explanation

.....

.....

[3]

[Total: 10]

(iii) Deduce the molecular formula of V.

..... [1]

May/June 2024 9701/21 · Q6 (a)(iii)

- (a) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **B** compared to **A**.

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

- (b) (i) Describe and explain the change, if any, to the percentage yield of $\text{NH}_3(\text{g})$ produced in **C** compared to **A**.

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

- (ii) Describe and explain the change to the rate of the forward reaction that occurs to establish the equilibrium in **C** compared to **A**.

You do **not** need to refer to the Boltzmann distribution in your answer.

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

- (ii) Outline how NO and NO₂ may contribute to the formation of photochemical smog.

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

[Total: 14]

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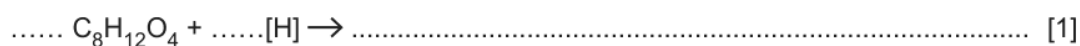
May/June 2024 9701/23 · Q2 (a), (b)(ii), (d)(ii) (cont.)

- (iii) In step 3, **X** reacts with reducing agent **Z** to produce **Y**.

Complete the equation for the reaction of **X** with **Z**.

Use a molecular formula to represent the organic product.

Use [H] to represent one atom of hydrogen from **Z**.



May/June 2024 9701/23 · Q5 (d)(iii)

(ii) Use Table 1.2 to calculate the relative atomic mass, A_r , of iridium in the alloy.

Give your answer to **two** decimal places.

relative atomic mass of iridium = [2]

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4

[Turn over]

Oct/Nov 2024 9701/21 · Q1 (c)(ii)

- (iii) A sample of pelopium contains 90.9% by mass $^{93}_{41}\text{Nb}$ and 9.1% by mass $^{181}_{73}\text{Ta}$.

Calculate the theoretical relative atomic mass of pelopium based on these data and Table 1.1.

Give your answer to two decimal places.

Show your working.

theoretical relative atomic mass of pelopium = [2]

[Total: 9]



Oct/Nov 2024 9701/22 · Q1 (b)(iii)

(ii) Suggest the role of reagent **G**.

[1]

[Total: 17]

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	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ 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 ⁻¹ K ⁻¹)

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Oct/Nov 2024 9701/22 · Q4 (e)(ii) (continued ·)



The Periodic Table of Elements

Group																						
1	2	Key												13	14	15	16	17	18			
		1 H hydrogen 1.0																				2 He helium 4.0
		atomic number atomic symbol name relative atomic mass																				
3 Li lithium 6.9	4 Be beryllium 9.0													5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0				
11	12													13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5				
Na sodium 23.0	Mg magnesium 24.3																			18 Ar argon 39.9		
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4							36 Kr krypton 83.8				
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3					
55	56	57–71 lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —				
87	88	89–103 actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganesson —				
Fr francium —	Ra radium —																					

- (ii) Use Table 1.2 to calculate the relative atomic mass, A_r , of iridium in the alloy.

Give your answer to **two** decimal places.

relative atomic mass of iridium = [2]

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[Turn over]

4

Oct/Nov 2024 9701/23 · Q1 (c)(ii)

- (iii) The third compound of phosphorus and chlorine, **W**, has a relative molecular mass, M_r , between that of PCl_3 and PCl_5 . The compound contains 69.6% by mass of chlorine.

Determine the molecular formula of **W**.

molecular formula of **W** = [2]

March 2025 9701/22 · Q1 (a)(iii)

(b) Fig. 2.1 shows the mass spectrum of the sample of iron.

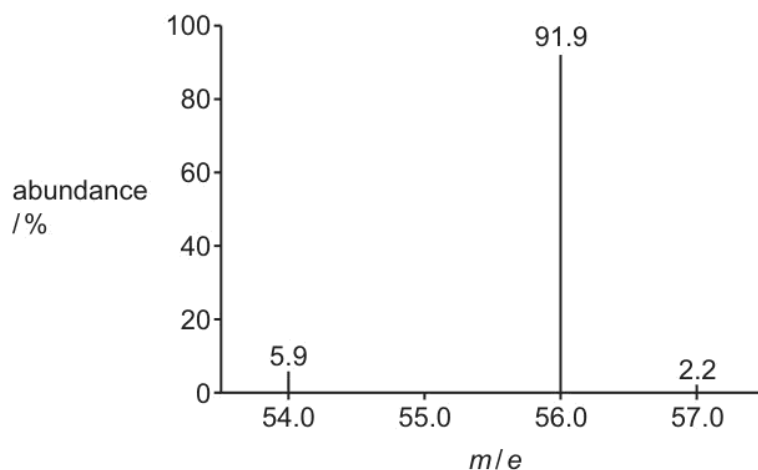


Fig. 2.1

(i) Use Fig. 2.1 to calculate the relative atomic mass, A_r , of iron to **one** decimal place.

Show your working.

A_r of iron = [2]

- (c) Reaction 2 shows the equilibrium reaction between X(g) and Y(g) to produce Z(g) in a sealed container.

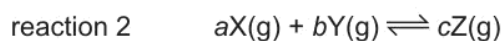


Fig. 3.3 shows the effect of changing pressure on the percentage yield of Z(g) at two different temperatures, 300 K and 350 K.

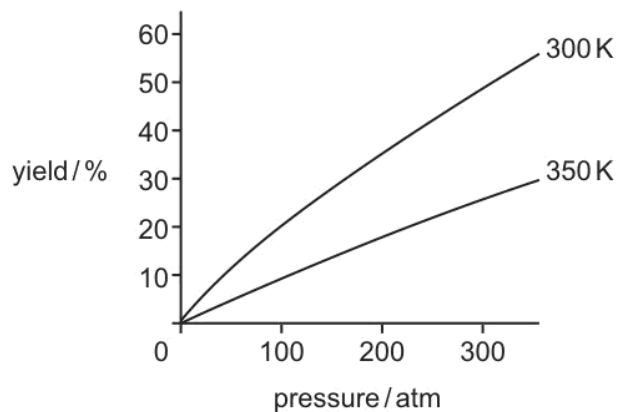


Fig. 3.3

Deduce **two** conclusions about reaction 2 using Fig 3.3.

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

[Total: 10]



- [1]

- $$\text{I}_2 + \text{vitamin C} \longrightarrow \text{Q} + 2\text{I}^- + 2\text{H}^+$$

A vitamin C tablet is dissolved in water to produce 200.0 cm³ of vitamin C solution. 5.00 cm³ of this vitamin C solution is added to a flask with approximately 150 cm³ of water and an indicator. Exactly 28.40 cm³ of 5.00 × 10⁻⁴ mol dm⁻³ I₂(aq) reacts with the sample of vitamin C solution in the flask.

(i) Calculate the amount, in mol, of $\text{I}_2(\text{aq})$ added to the flask in this titration.

amount of $I_2(aq)$ = mol [1]



- (ii) Use your answer to (b)(i) to calculate the mass, in g, of vitamin C in the tablet. Show your working.

(If you were unable to calculate a value for the amount of $I_2(aq)$ in (b)(i), use the value $2.64 \times 10^{-4} \text{ mol}$. This is **not** the correct value.)

mass of vitamin C in tablet =g [2]

- (iii) Deduce the role of $I_2(aq)$ in the reaction in Fig. 4.2.

..... [1]

May/June 2025 9701/21 · Q4 (a), (b)(i), (b)(ii), (b)(iii) (cont.)

- (a) (i) Define relative atomic mass.

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

- (ii) Table 2.1 shows the abundances of two of the isotopes present in the sample of iron.

Table 2.1

isotope	relative isotopic mass	abundance / %
^{54}Fe	53.9	6.0
^{56}Fe	55.9	91.9

Use Table 2.1 to calculate the relative isotopic mass of the third isotope of iron in the sample. Show your working.

relative isotopic mass = [2]

- (b) Deduce the number of pairs of electrons in the 3d sub-shell in an iron(II) ion.

..... [1]

- (c) Sketch the shape of the lowest energy orbital in the shell with principal quantum number $n = 2$.

[1]



(d) Complete Table 2.2 to show information about particles in one ion of $^{56}\text{Fe}^{3+}$.

Table 2.2

particle	number of particles present in one ion of $^{56}\text{Fe}^{3+}$
electrons	
	30

[2]

(e) The atomic radius of iron is $1.26 \times 10^{-10}\text{ m}$.

Suggest the change to the radius, if any, after an iron atom reacts to produce an Fe^{3+} ion.
Explain your answer.

.....

.....

.....

..... [2]

[Total: 10]

May/June 2025 9701/22 · Q2 (a)(ii), (b), (c), (d), (e) (cont.)

- (b) $\text{H}_2(\text{g})$ and nickel are added to alkene **X**. Fig. 3.2 shows how the concentration of **X** changes with time.

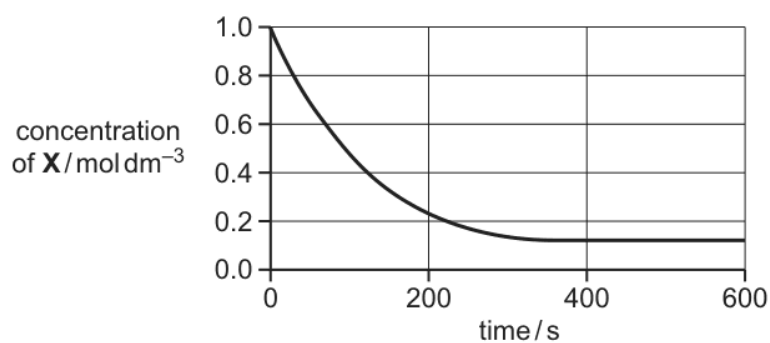


Fig. 3.2

- (i) Use Fig. 3.2 to identify the limiting reagent in this reaction. Explain your answer.

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

May/June 2025 9701/22 · Q3 (b)(i), (c) (continued ·)

(c) Hydrocarbon **Y** contains two C=C groups. There are no other functional groups present.

Y reacts with an excess of $\text{H}_2(\text{g})$ to produce hexane, C_6H_{14} .

Table 3.1

bond	energy / kJ mol^{-1}
C–C	350
C=C	610
$\text{C}\equiv\text{C}$	840
H–H	436
C–H	410

Use Table 3.1 to calculate the enthalpy change per mole of C_6H_{14} produced in this reaction.

enthalpy change = kJ mol^{-1} [2]



May/June 2025 9701/22 · Q3 (b)(i), (c) (cont.)

(b) The mass of vitamin C present in 150.0 g of lemon is found in an experiment.

stage 1 All the vitamin C in 150.0 g of lemon is extracted and dissolved in water to make 100.0 cm³ of solution L.

stage 2 A 25.0 cm³ sample of solution L is titrated with 5.00 × 10⁻³ mol dm⁻³ I₂(aq).

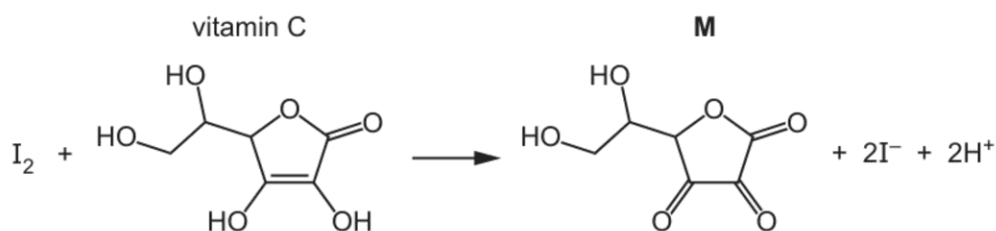


Fig. 5.2

Exactly 36.65 cm³ of I₂(aq) reacts with the 25.0 cm³ sample of solution L.

[*M_r*: vitamin C, 176]

(i) Calculate the amount, in mol, of I₂(aq) added in the titration.

amount of I₂(aq) = mol [1]

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(ii) Use your answer to (b)(i) to calculate the percentage by mass of vitamin C present in 150.0 g of lemon.

(If you were unable to calculate a value for the amount of I₂(aq) in (b)(i), use the value 7.65 × 10⁻⁴ mol. This is **not** the correct value.)

percentage by mass =% [2]

- (a) (i) Use Fig. 4.1 to find the average rate of change of concentration of HCl(aq) in this reaction between 0–100 seconds and between 400–500 seconds. Include units in your answers.

0–100 seconds units

400–500 seconds units

[2]

- (ii) Use Fig. 4.1 to identify the limiting reagent. Explain your answer.

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

- (ii) Use Table 4.1 to predict the strength of the dipole moment of SO_2 , if any, compared to that of H_2O . Explain your answer.

Table 4.1

	H	O	S
electronegativity	2.1	3.5	2.6

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

[Total: 11]

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[Turn over]

- 5 (a) **W** is a colourless liquid.

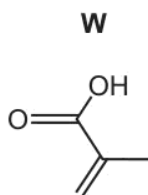


Fig. 5.1

- (i) Deduce the empirical formula of **W**.

..... [1]

- (ii) Two different reagents are each added to separate samples of **W** as shown in Table 5.1.

Complete Table 5.1.

Table 5.1

reagent and conditions	observation when reagent is added to W	structural formula of organic product when reagent is added to W
solid Na		
Br ₂ in absence of ultraviolet light		

[4]



(ii) **W** reacts with LiAlH_4 to produce **Y**.

Draw the structure of **Y**.

[1]

(iii) Identify the role of LiAlH_4 when it reacts with **W**.

[1]

(iv) Suggest the reagent and conditions required when **W** is converted into **Z**.

[1]

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9701/23/M/J/25

[Turn over]

10

Z

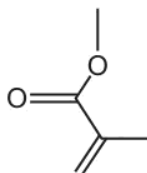


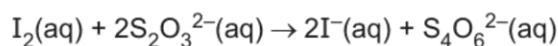
Fig. 5.3

- (a) In experiment 1, $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ are combined.

Water is then added to the equilibrium mixture to produce 1.00 dm^3 of solution **A**.

The amount of $\text{I}_2(\text{aq})$ present in 1.00 dm^3 of solution **A** is found by titration with $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.

Exactly 32.90 cm^3 of $0.200 \text{ mol dm}^{-3}$ $\text{Na}_2\text{S}_2\text{O}_3$ reacts with all of the I_2 in a 25.0 cm^3 sample of solution **A**.



- (i) Calculate the amount, in mol, of $\text{S}_2\text{O}_3^{2-}$ that reacts in the titration.

amount of $\text{S}_2\text{O}_3^{2-} = \dots\dots\dots \text{ mol}$ [1]

- (ii) Use your answer to (a)(i) to calculate the amount, in mol, of I_2 present in 1.00 dm^3 of solution **A**.

(If you were unable to obtain an answer in (a)(i), then use $9.42 \times 10^{-3} \text{ mol}$. This is **not** the correct answer.)

amount of I_2 in 1.00 dm^3 of solution **A** = $\dots\dots\dots \text{ mol}$ [2]

- (b) In experiment 2, 0.100 mol of $\text{H}_2(\text{g})$, 0.200 mol of $\text{I}_2(\text{g})$ and 0.300 mol of $\text{HI}(\text{g})$ are combined.

At equilibrium 0.154 mol of I_2 is present.

Calculate the amounts, in mol, of H_2 and HI in the equilibrium mixture produced in experiment 2.

amount of H_2 in equilibrium mixture = $\dots\dots\dots \text{ mol}$

amount of HI in equilibrium mixture = $\dots\dots\dots \text{ mol}$ [3]



(ii) Describe and explain the relative thermal stabilities of the hydrogen halides HCl and HI .

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

May/June 2025 9701/24 · Q3 (a)(i), (a)(ii), (b), (d)(ii) (cont.)

(a) State the molecular formula of **E**.

..... [1]

(b) Name **E**.

..... [1]

(iii) CH_3OH is used to make CH_3CN in a two-step process, as shown in Fig. 4.2.

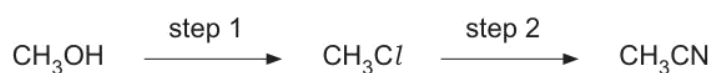


Fig. 4.2

State the reagents and conditions required for steps 1 and 2.

step 1

step 2

[3]

[Total: 11]



- (a) (i) Define empirical formula.

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

- (ii) Hydrocarbon **P** contains 85.7% by mass of carbon.

Calculate the empirical formula of **P**.

Show your working.

empirical formula of **P** = [2]

- (iii) Molecules of **P** have straight chains.

Name the homologous series to which **P** belongs.

..... [1]

- (ii) Use Fig. 6.1 and your answer to (c)(i) to deduce the molecular formula of **R**.

..... [1]

- (iii) Suggest the molecular formula of the fragment of **R** with $m/e = 57$.

..... [1]

[Total: 10]





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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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ($4.18 \text{ J g}^{-1} \text{ K}^{-1}$)





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							2 He helium 4.0						
3 Li lithium 6.9	4 Be beryllium 9.0																	5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2				
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12								13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9			
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8										
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3										
55 Cs caesium 132.9	56 Ba barium 137.3	lanthanoids		72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —									
87 Fr francium —	88 Ra radium —	actinoids		104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganesson —									
lanthanoids		57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 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		89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —											

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- (iv) Atoms of ^{52}Cr , ^{53}Cr and ^{54}Cr make up more than 95% of naturally occurring chromium atoms. The A_r of naturally occurring Cr is 51.996.

Suggest what these statements imply about the relative isotopic mass of the fourth stable isotope of chromium.

..... [1]

Oct/Nov 2025 9701/21 · Q1 (a)(iv)

(a) Define empirical formula.

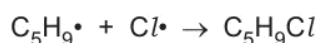
.....
..... [1]

(ii) Complete the equations to show the two propagation steps that follow the initiation step.

propagation 1 $\text{C}_5\text{H}_{10} + \dots \rightarrow \text{C}_5\text{H}_9\cdot + \dots$

propagation 2 $\text{C}_5\text{H}_9\cdot + \dots \rightarrow \dots$ [2]

(iii) The final step is shown.



Give the name for this step in the reaction.

..... [1]

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(d) Fig. 3.2 shows a reaction cycle involving cyclopentane, cyclopentene and $\text{C}_5\text{H}_9\text{Cl}$.

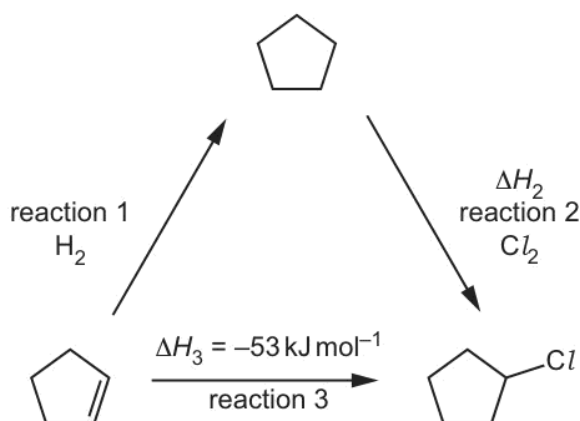


Fig. 3.2

(i) Identify a suitable reagent for reaction 3.

..... [1]

- (iii) A sample of manganese from the Moon is found to contain manganese-53 in addition to manganese-55.

State the two pieces of information needed to determine the relative atomic mass, A_r , of manganese in this sample.

1

2

[2]

Oct/Nov 2025 9701/22 · Q1 (a)(iii)

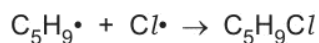
- (c) Alkanes with low relative molecular mass, M_r , are more useful than those found in heavier crude oil fractions.

Name the process that is used to obtain alkanes with low M_r from heavier crude oil fractions.

..... [1]

Oct/Nov 2025 9701/22 · Q3 (c)

- (iii) The final step is shown.



Give the name for this step in the reaction.

..... [1]

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Oct/Nov 2025 9701/23 · Q3 (c)(iii)

- (iii) **V** reacts with propan-2-ol in the presence of a catalytic amount of H_2SO_4 to form organic compound **W**.

Complete Table 4.1 to give details of this reaction.

Table 4.1

	reaction of V with propan-2-ol
type of reaction	
functional group formed	
molecular formula of organic product W	

[3]

[Total: 16]





13

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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	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ($4.18 \text{ J g}^{-1} \text{ K}^{-1}$)





1		2		Group										13		14		15		16		17		18	
3 Li lithium 6.9	4 Be beryllium 9.0	Key										1 H hydrogen 1.0													
		atomic number atomic symbol name relative atomic mass																							
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12	5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2								
17 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium —	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3								
55 Cs caesium 132.9	86 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium —	85 At astatine —	86 Rn radon —								
87 Fr francium —	88 Ra radium —	89–103 actinoids	104 Rf rutherfordium —	105 Db dubnium —	106 Sg seaborgium —	107 Bh bohrium —	108 Hs hassium —	109 Mt meitnerium —	110 Ds darmstadtium —	111 Rg roentgenium —	112 Cn copernicium —	113 Nh nihonium —	114 Fl flerovium —	115 Mc moscovium —	116 Lv livermorium —	117 Ts tennessine —	118 Og oganeson —								

lanthanoids															
57	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	lanthanum	cerium	praseodymium	neodymium	promethium	samarium	euroium	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium
	138.9	140.1	140.9	144.2	—	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0
actinoids															
89	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
	actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium	lawrencium



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