



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/21

October/November 2023

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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 **20** pages. Any blank pages are indicated.

- 1 The elements phosphorus, sulfur and chlorine are in Period 3 of the Periodic Table.

Table 1.1 shows some properties of the elements P to Cl.

The first ionisation energy of S is **not** shown.

Table 1.1

property	P	S	Cl
number of electrons in 3p subshell			
total number of unpaired electrons			
first ionisation energy /kJ mol ⁻¹	1060		1260
formula of most common anion	P ³⁻	S ²⁻	Cl ⁻

- (a) (i) Complete Table 1.1 to show the number of electrons in the 3p subshell and the total number of unpaired electrons in an atom of P, S and Cl. [2]

- (ii) Construct an equation to represent the first ionisation energy of P.

..... [1]

- (iii) Three possible values for the first ionisation energy of S are given.

1000 kJ mol⁻¹

1160 kJ mol⁻¹

1320 kJ mol⁻¹

Circle the correct value.

Explain your choice by comparing your chosen value to those of P and Cl.

.....

.....

.....

.....

.....

..... [4]

(b) P^{3-} , S^{2-} and Cl^{-} have the same number of electrons.

(i) Give the full electronic configuration of P^{3-} .

..... [1]

(ii) State the trend in ionic radius shown by P^{3-} , S^{2-} and Cl^{-} .

Explain your answer.

.....

 [2]

(c) A student does three tests on separate samples of $\text{NaCl}(\text{aq})$.

Complete Table 1.2 with the observations the student makes in each test.

Table 1.2

test	test	observations
1	addition of a few drops of $\text{Br}_2(\text{aq})$	
2	addition of a few drops of concentrated H_2SO_4	
3	addition of a few drops of dilute $\text{AgNO}_3(\text{aq})$	

[3]

- (d) POCl_3 shows similar chemical properties to PCl_5 .

POCl_3 has a melting point of 1°C and a boiling point of 106°C .

POCl_3 reacts vigorously with water, forming misty fumes and an acidic solution.

- (i) Explain how the information in (d) suggests the structure and bonding of POCl_3 is simple covalent.

.....

 [2]

- (ii) Construct an equation for the reaction of POCl_3 with water.

$\text{POCl}_3 + \dots \rightarrow \dots$ [1]

- (iii) POCl_3 contains a double covalent bond between P and O.

Complete the dot-and-cross diagram, in Fig. 1.1, to show the bonding in POCl_3 .

Show outer shell electrons only.

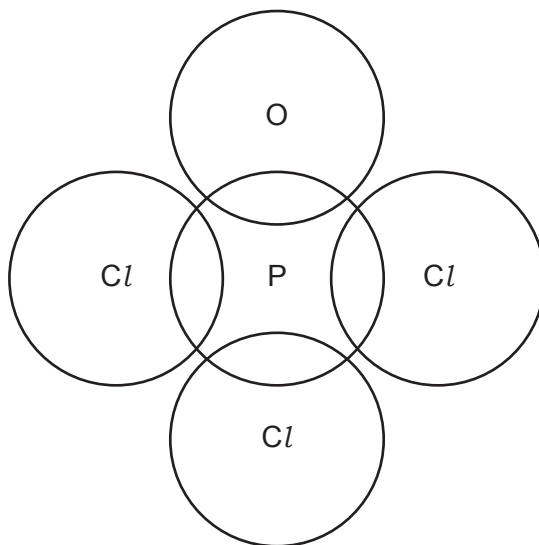


Fig. 1.1

[2]

- (e) $\text{POCl}_3(\text{g})$ forms when $\text{PCl}_3(\text{g})$ reacts with $\text{O}_2(\text{g})$.

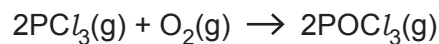


Table 1.3 gives some relevant data.

Table 1.3

process	value / kJ mol^{-1}
enthalpy change of formation of $\text{PCl}_3(\text{g})$	–289
enthalpy change of formation of $\text{POCl}_3(\text{g})$	–592
$\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$	+496

- (i) Define enthalpy change of formation, ΔH_f .

.....

 [2]

- (ii) Calculate the bond energy of $\text{P}=\text{O}$ in POCl_3 using the data in Table 1.3.

Show your working.

bond energy of $\text{P}=\text{O}$ = ... kJ mol^{-1}
 [2]

[Total: 22]

- 2 Barium hydroxide, $\text{Ba}(\text{OH})_2$, is a strong base used in inorganic and organic reactions.

Fig. 2.1 shows a reaction scheme involving $\text{Ba}(\text{OH})_2$.

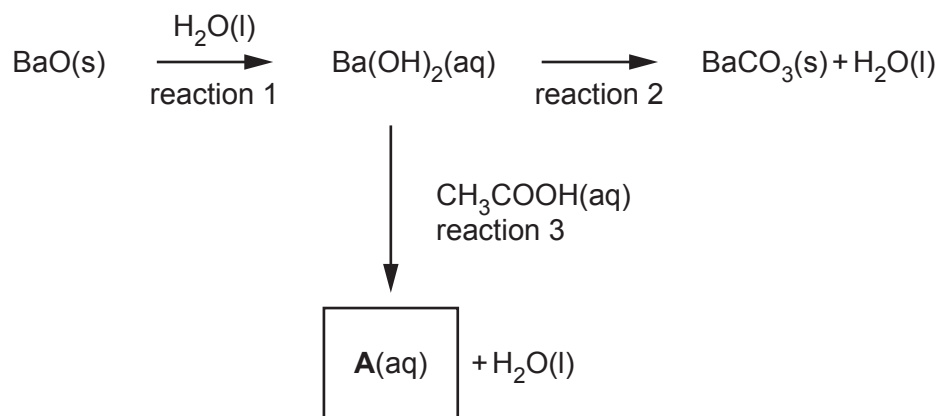


Fig. 2.1

- (a) (i) State the variation in solubilities of group 2 hydroxides.

..... [1]

- (ii) State what is observed in reaction 1.

..... [1]

- (iii) Suggest a reactant for reaction 2.

..... [1]

- (iv) Identify **A**.

..... [1]

- (v) $\text{Ba}(\text{OH})_2$ is made by the reaction of Ba with water.

Write an equation for this reaction.

..... [1]

(b) The mineral barytocalcite contains both BaCO_3 and CaCO_3 . Both compounds decompose on heating.

(i) State which compound decomposes first when barytocalcite is heated.

Explain your answer.

.....
 [1]

(ii) Construct an equation for the complete thermal decomposition of barytocalcite.

The formula of barytocalcite is $\text{BaCa}(\text{CO}_3)_2$.

$\text{BaCa}(\text{CO}_3)_2$ [1]

(c) $\text{Ba}(\text{OH})_2$ is used to hydrolyse organic compounds.

Fig. 2.2 shows the reaction of **B** with $\text{Ba}(\text{OH})_2$, followed by acidification.

Draw the structures of the organic products of the process shown in Fig. 2.2.

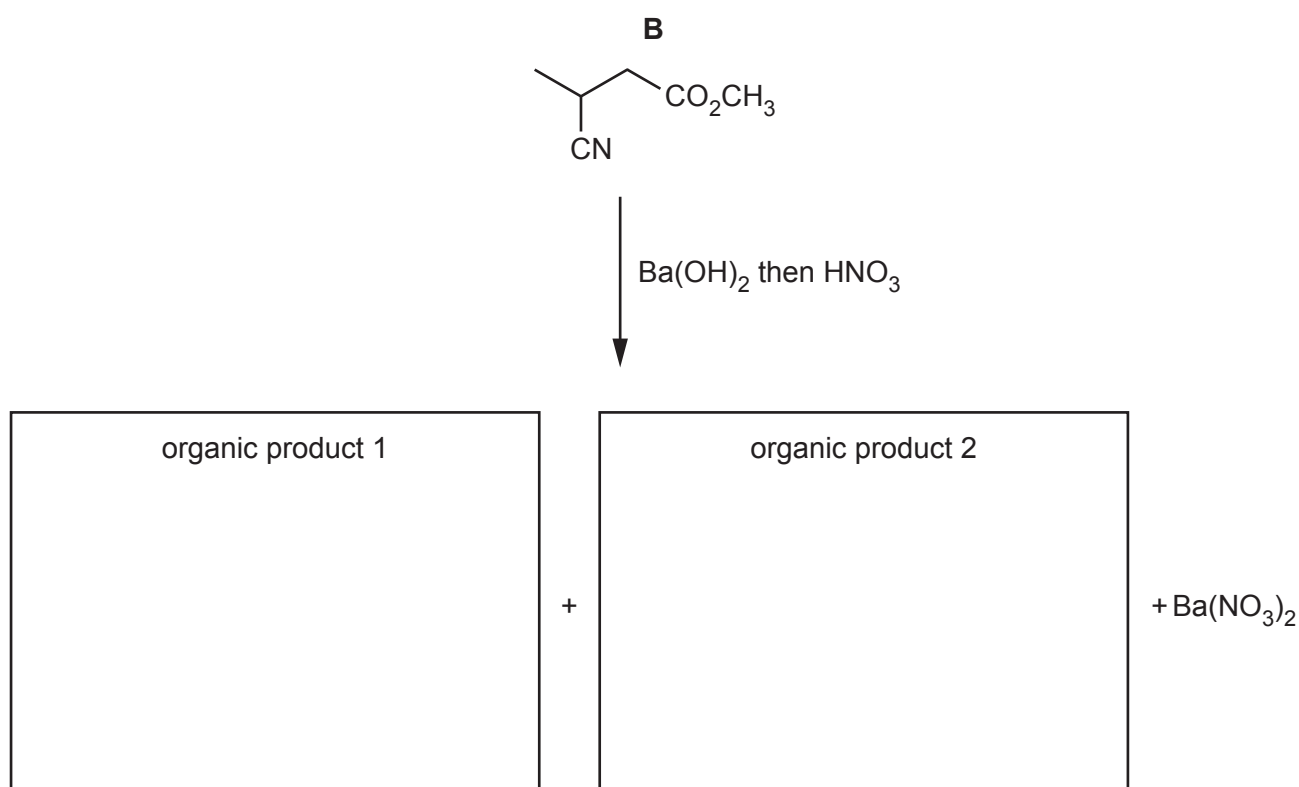


Fig. 2.2

[3]

[Total: 10]

3 Potassium chlorate, KClO_3 , is widely used as an oxidising agent and to make $\text{O}_2(\text{g})$.

(a) Define oxidising agent.

.....
 [1]

(b) $\text{KClO}_3(\text{s})$ decomposes when heated.

$\text{MnO}_2(\text{s})$ catalyses the exothermic decomposition reaction.

Complete and label the diagram in Fig. 3.1 to show the effect of $\text{MnO}_2(\text{s})$ on the decomposition of $\text{KClO}_3(\text{s})$.

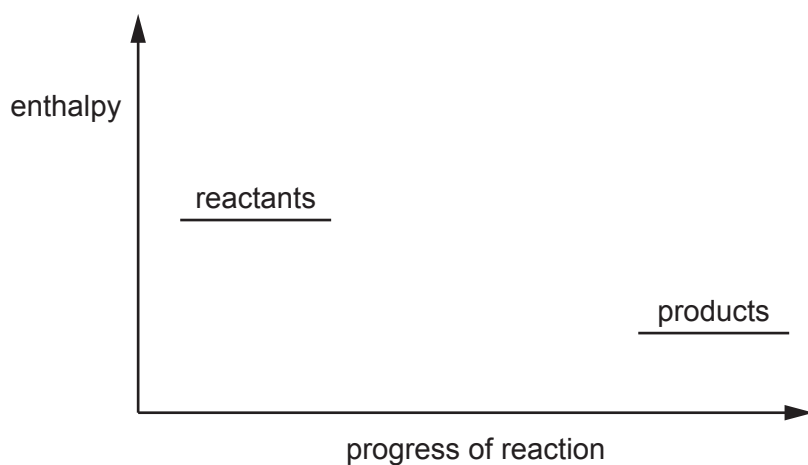


Fig. 3.1

[2]

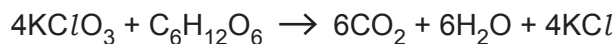
(c) When KClO_3 is heated without a catalyst, KClO_4 and KCl form.



Explain why this reaction is described as a disproportionation reaction.

.....
 [1]

(d) Molten KClO_3 reacts with glucose, $\text{C}_6\text{H}_{12}\text{O}_6$.



KClO_3 melts at 630 K. At this temperature, both CO_2 and H_2O are gases.

- (i) Use the ideal gas equation to calculate the volume, in m^3 , of one mole of gas at 630 K and $1.00 \times 10^5 \text{ Pa}$.

Show your working. Give your answer to 3 significant figures.

volume of 1 mol of gas = ... m^3
[1]

- (ii) 5.00 g of $\text{C}_6\text{H}_{12}\text{O}_6$ reacts completely with molten KClO_3 .

Use your answer to (d)(i) to calculate the total volume of gas released at 630 K and $1.00 \times 10^5 \text{ Pa}$ in this reaction.

(If you were unable to answer (d)(i), use 0.0463 m^3 in this question. This is **not** the correct answer to (d)(i).)

total volume of gas released = ... m^3
[2]

- (e) The structure of glucose, $C_6H_{12}O_6$, is shown in Fig. 3.2.

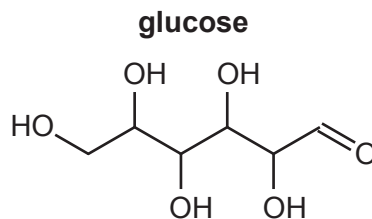


Fig. 3.2

- (i) Complete Table 3.1 to identify the number of primary, secondary and tertiary alcohol groups present in the structure shown in Fig. 3.2.

Table 3.1

type of alcohol group	primary	secondary	tertiary
number of groups			

[1]

- (ii) Separate samples of aqueous glucose are tested with the reagents shown in Table 3.2.

Complete Table 3.2 with the observation for each reaction.

Write “no reaction” if applicable.

Table 3.2

reagent and conditions	observation with glucose
acidified $KMnO_4(aq)$ and warm	
Fehling’s reagent and warm	
alkaline $I_2(aq)$ and warm	

[3]

- (iii) There are many structural isomers of $C_6H_{12}O_6$.

Define structural isomers.

.....
 [1]

[Total: 12]

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- 4 Compounds **C** and **D** are alkenes with the same molecular formula, C_5H_{10} .



Fig. 4.1

- (a) (i) Give the systematic name of **D**.

..... [1]

- (ii) Explain why **C** and **D** do not show geometrical (*cis/trans*) isomerism.

.....

..... [1]

- (iii) Draw the structure of a molecule that is a positional isomer of **C** and **D**.

[1]

- (iv) Give the structural formula of the compound formed when **D** reacts with $H_2(g)$ in the presence of a Pt catalyst.

..... [1]

- (v) **C** can form an addition polymer.

Draw the structure of **one** repeat unit of this addition polymer.

[1]

- (b) The mass spectrum of **C** shows a molecular ion peak at $m/e = 70$. This peak has a relative intensity of 48.7.

The relative intensity of the $[M+1]$ peak is 2.7.

Show that this information is consistent with the molecular formula of **C**.

[2]

- (c) **C** and **D** both react with HBr.

- (i) **C** reacts with HBr to form **E**.

Complete the diagram in Fig. 4.2 to show the mechanism for this reaction.

Draw the structure of the organic intermediate.

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

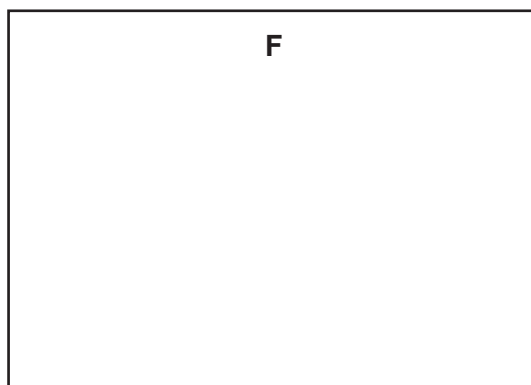


Fig. 4.2

[3]

- (ii) **D** reacts with HBr to produce **F**, a chiral bromoalkane.

Draw the structure of **F**.



[1]

(iii) Explain why the reaction of HBr with **C** and **D** produces different major products.



Fig. 4.3

.....

.....

.....

..... [2]

(d) **C** can be used to form **H**.

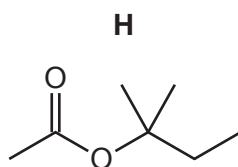


Fig. 4.4

One possible synthesis of **H** is shown in Fig. 4.5. Different portions of **C** are used in reactions 1 and 3. Some of the products are then combined to produce **H**.

Fig. 4.5 does not show any of the inorganic products of the reactions.

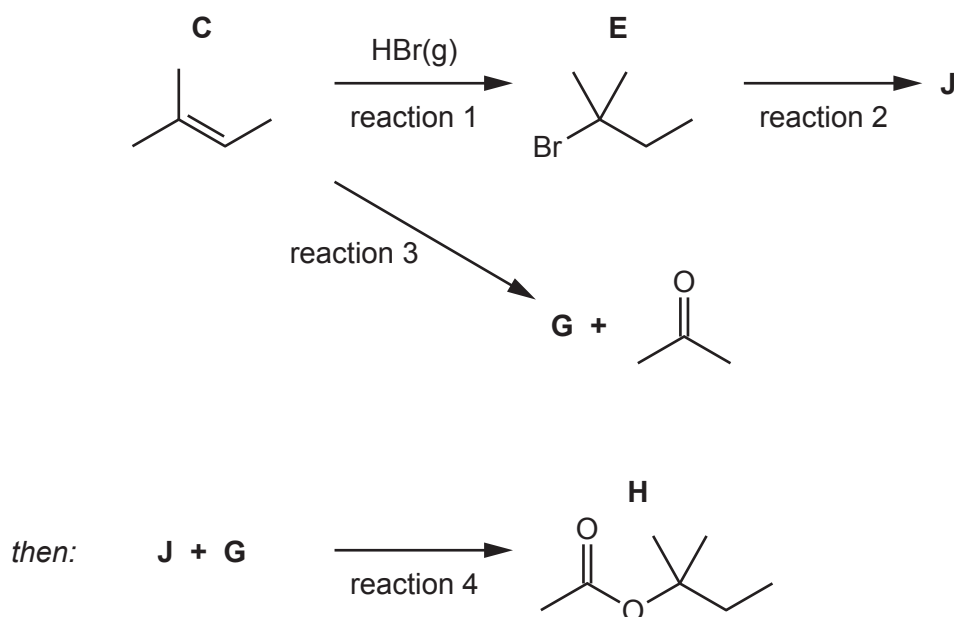


Fig. 4.5

Complete Table 4.1 with the reagents and conditions required for each of the reactions shown in Fig. 4.5.

Table 4.1

	reagent and conditions
reaction 1 C → E	HBr(g)
reaction 2 E → J	
reaction 3 C → G + 	
reaction 4 J + G → H	

[3]

[Total: 16]

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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 ⁻¹ 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																	
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											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	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 —	
												2							He helium 4.0

lanthanoids

actinoids

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
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	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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9701/22

October/November 2023

1 hour 15 minutes

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- Important values, constants and standards are printed in the question paper.

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[Turn over

1 The elements silicon, phosphorus and sulfur are in Period 3 of the Periodic Table.

(a) (i) Describe the variation in atomic radius from silicon to sulfur.

..... [1]

(ii) The melting point of silicon is 1410 °C. The melting point of sulfur is 113 °C.

Explain this difference.

.....

 [3]

(b) Table 1.1 shows some properties of the elements Si to S.

The first ionisation energy of P is **not** shown.

Table 1.1

property	Si	P	S
total number of electrons in s subshells			
total number of electrons in p subshells			
first ionisation energy/kJ mol ⁻¹	786		1000
formula of most common chloride	SiCl ₄	PCl ₅	SCl ₂

(i) Complete Table 1.1 to show the total number of s and p electrons in an atom of Si, P and S.

[2]

(ii) Construct an equation to represent the first ionisation energy of Si.

..... [1]

- (iii) Three possible values for the first ionisation energy of P are given.

619 kJ mol⁻¹

893 kJ mol⁻¹

1060 kJ mol⁻¹

Circle the correct value.

Explain your choice, including a comparison of your chosen value to those of Si and S.

.....

.....

.....

.....

.....

..... [4]

- (iv) SiCl_4 and PCl_5 each react with water, forming misty fumes.

Identify the chemical responsible for the misty fumes.

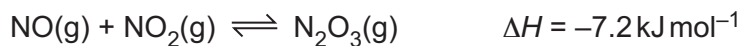
..... [1]

- (v) Predict the shape of the SCl_2 molecule.

..... [1]

[Total: 13]

- 2 NO and NO₂ react at 25 °C to give N₂O₃ as shown in the equation.



The reaction is reversible and reaches equilibrium in a closed system.

- (a) Fig. 2.1 shows how the rate of the forward reaction changes with time.

Initially, the rate of the reverse reaction is zero.

Complete Fig. 2.1 to sketch how the rate of the **reverse** reaction changes with time.

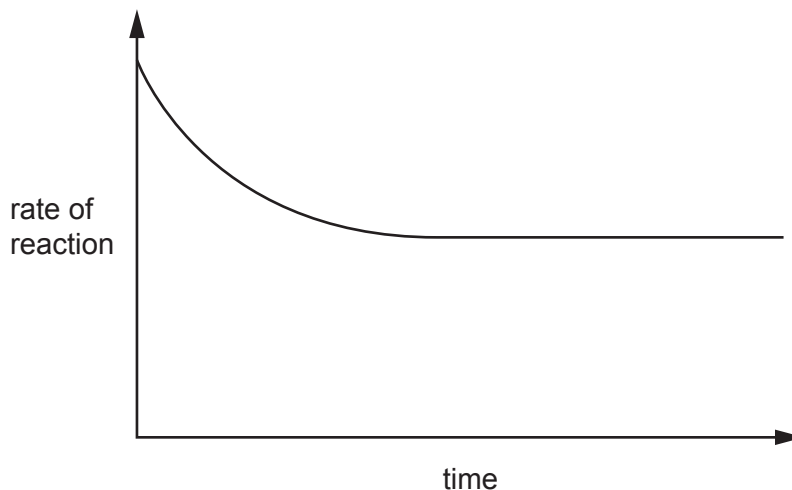


Fig. 2.1

[1]

- (b) State how the position of equilibrium changes, if at all, when the reaction takes place at 100 °C.

Explain your answer.

Assume the pressure remains constant.

.....

.....

.....

..... [2]

- (c) Table 2.1 shows the composition of an equilibrium mixture of $\text{NO}(\text{g})$, $\text{NO}_2(\text{g})$ and $\text{N}_2\text{O}_3(\text{g})$ at 101 kPa.

Table 2.1

gas	number of moles at equilibrium/mol
NO	0.605
NO_2	0.605
N_2O_3	0.390

Calculate K_p , the equilibrium constant with respect to partial pressures.

Deduce the units of K_p .

$K_p = \dots\dots\dots$ units $\dots\dots\dots$ [3]

- (d) Identify one natural process and one man-made process that cause the formation of atmospheric NO and NO_2 .

natural process $\dots\dots\dots$

man-made process $\dots\dots\dots$

[2]

(e) NO_2 is a brown gas that can be used to form nitric acid.

(i) NO_2 is a free radical.

Define free radical.

..... [1]

(ii) NO_2 has a catalytic role in the oxidation of atmospheric sulfur dioxide.

Write equations to show the catalytic role of NO_2 in this oxidation.

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

(iii) State **one** environmental consequence of the oxidation of atmospheric sulfur dioxide.

..... [1]

(f) A student titrates nitric acid with a base to form a solution containing aqueous magnesium nitrate.

(i) Identify a base that the student could use.

..... [1]

(ii) The student evaporates the water to obtain magnesium nitrate solid. When this solid is heated it decomposes.

Write an equation for the decomposition of magnesium nitrate.

..... [1]

(iii) State how the thermal stability of Group 2 nitrates changes down the group.

..... [1]

[Total: 15]

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3 Phosphoric(V) acid, H_3PO_4 , is used in both inorganic and organic reactions.

(a) H_3PO_4 is made in a two-step process from phosphorus.

step 1 Phosphorus reacts with an excess of oxygen to form a white solid.

step 2 The white solid then reacts with water to form H_3PO_4 .

(i) Write an equation for each step.

step 1

step 2

[2]

(ii) H_3PO_4 is a weak Brønsted–Lowry acid.

Define weak Brønsted–Lowry acid.

.....

 [2]

(b) H_3PO_4 is also formed in the process shown in reaction 1.

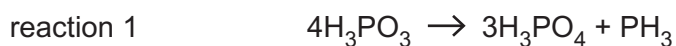


Table 3.1 shows some relevant thermodynamic data.

Table 3.1

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
H_3PO_3	−972
H_3PO_4	−1281
PH_3	+9

(i) Define enthalpy change of formation.

.....

 [2]

- (ii) Use the data in Table 3.1 to calculate the enthalpy change, ΔH_r , of reaction 1.

$$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$$

[2]

- (iii) Explain why reaction 1 is a disproportionation reaction.

Explain your reasoning with reference to relevant oxidation numbers.

.....

.....

..... [2]

(c) Fig. 3.1 shows a reaction scheme that involves H_3PO_4 in several reactions.

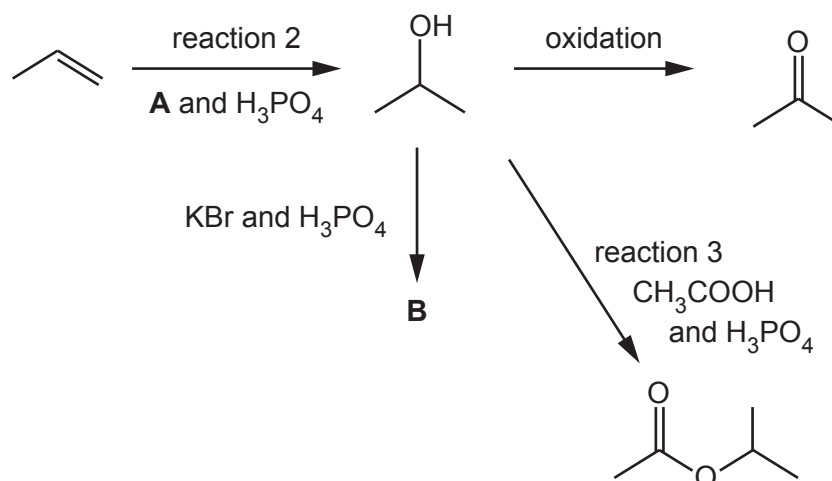


Fig. 3.1

(i) Identify **A**, which reacts with propene in the presence of H_3PO_4 in reaction 2.

..... [1]

(ii) Draw the structure of **B**.

[1]

(iii) Name the type of reaction that occurs in reaction 3.

..... [1]

- (iv) Reaction 3 is monitored using infrared spectroscopy. It is not possible to use the O—H absorption frequency to monitor the reaction.

Use Table 3.2 to identify a suitable bond whose absorption frequency can be used to monitor the progress of reaction 3.

State the change you would see in the infrared spectrum during reaction 3.

bond

change in infrared spectrum

.....

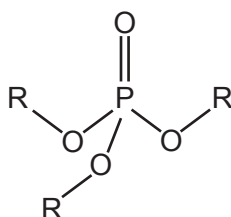
[2]

Table 3.2

bond	functional groups containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C—O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C—H	alkane	2850–2950

- (d) H_3PO_4 also reacts with alcohols to form organophosphates.

Organophosphates are compounds similar to esters. They have the general structure shown in Fig. 3.2.



R = alkyl group

Fig. 3.2

- (i) Complete the equation to suggest the products of the reaction of H_3PO_4 with methanol, CH_3OH .



- (ii) Compound **T** is a simple organophosphate.

The mass spectrum of **T** shows a molecular ion peak at $m/e = 182$. This peak has a relative intensity of 12.7.

The relative intensity of the $M+1$ peak is 0.84.

Deduce the number of carbon atoms in **T**.
Hence suggest the molecular formula of **T**.

Assume that phosphorus and oxygen exist as single isotopes.

Show your working.

number of carbon atoms in **T** = ...

molecular formula of **T** = ...

[3]

[Total: 19]

- 4 Lactic acid, $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$, and pyruvic acid, CH_3COCOOH , both contain two functional groups.

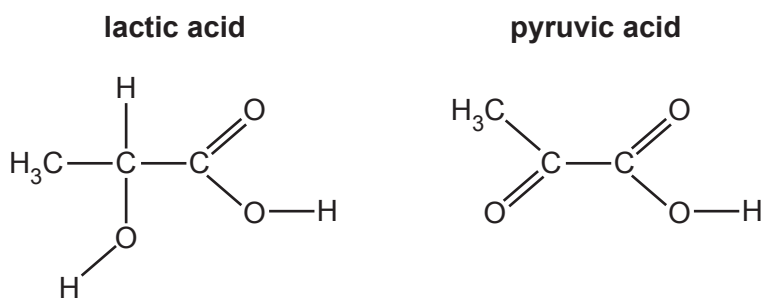


Fig. 4.1

- (a) (i) Explain why lactic acid exists as optical isomers.

.....

 [1]

- (ii) Give the systematic name of lactic acid.

..... [1]

- (iii) Lactic acid forms hydrogen bonds with water.

Complete Fig. 4.2 to show the formation of a hydrogen bond between one molecule of lactic acid and one molecule of water.

Label the hydrogen bond. Show any relevant dipoles and lone pairs of electrons.

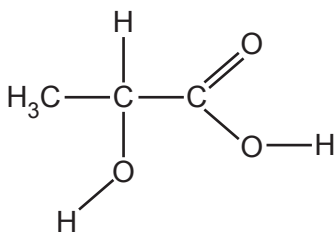


Fig. 4.2

[3]

(b) Two possible syntheses of pyruvic acid are shown in Fig. 4.3 and Fig. 4.4.

Each synthesis has a total of three steps.

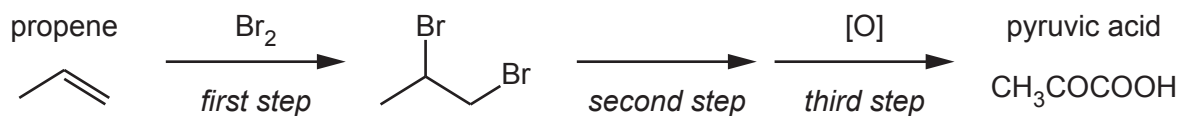


Fig. 4.3

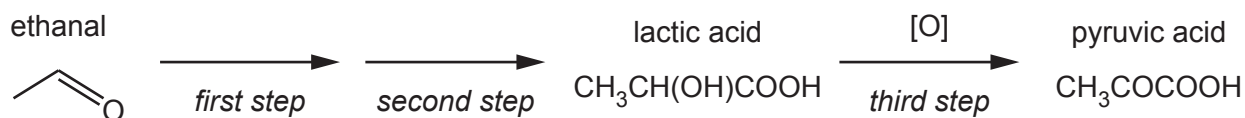


Fig. 4.4

- (i) Complete the diagram in Fig. 4.5 to show the mechanism for the reaction of propene with Br_2 .

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

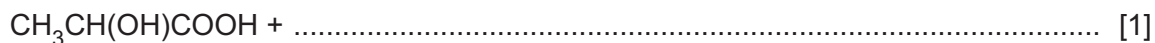


Fig. 4.5

[3]

- (ii) Write an equation for the oxidation of lactic acid to pyruvic acid, the third step of Fig. 4.4.

Use [O] to represent one atom of oxygen from an oxidising agent.



- (iii) Complete Table 4.1 to give details of the reagents and conditions used in each of the two syntheses shown in Fig. 4.3 and Fig. 4.4.

Table 4.1

		synthesis from propene (shown in Fig. 4.3)	synthesis from ethanal (shown in Fig. 4.4)
reagents and conditions used	<i>first step</i>	Br ₂	
	<i>second step</i>		
	<i>third step</i>		

[4]

[Total: 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	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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)

The Periodic Table of Elements

Group																				
1	2	Key												13	14	15	16	17	18	
		1 H hydrogen 1.0																		
		atomic number atomic symbol name relative atomic mass																		
3 Li lithium 6.9	4 Be beryllium 9.0																			
11 Na sodium 23.0	12 Mg magnesium 24.3																			
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	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 —		



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9701/23

October/November 2023

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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 **20** pages. Any blank pages are indicated.

- 1 The elements phosphorus, sulfur and chlorine are in Period 3 of the Periodic Table.

Table 1.1 shows some properties of the elements P to Cl.

The first ionisation energy of S is **not** shown.

Table 1.1

property	P	S	Cl
number of electrons in 3p subshell			
total number of unpaired electrons			
first ionisation energy /kJ mol ⁻¹	1060		1260
formula of most common anion	P ³⁻	S ²⁻	Cl ⁻

- (a) (i) Complete Table 1.1 to show the number of electrons in the 3p subshell and the total number of unpaired electrons in an atom of P, S and Cl. [2]

- (ii) Construct an equation to represent the first ionisation energy of P.

..... [1]

- (iii) Three possible values for the first ionisation energy of S are given.

1000 kJ mol⁻¹

1160 kJ mol⁻¹

1320 kJ mol⁻¹

Circle the correct value.

Explain your choice by comparing your chosen value to those of P and Cl.

.....

.....

.....

.....

.....

..... [4]

(b) P^{3-} , S^{2-} and Cl^{-} have the same number of electrons.

(i) Give the full electronic configuration of P^{3-} .

..... [1]

(ii) State the trend in ionic radius shown by P^{3-} , S^{2-} and Cl^{-} .

Explain your answer.

.....

 [2]

(c) A student does three tests on separate samples of $NaCl(aq)$.

Complete Table 1.2 with the observations the student makes in each test.

Table 1.2

test	test	observations
1	addition of a few drops of $Br_2(aq)$	
2	addition of a few drops of concentrated H_2SO_4	
3	addition of a few drops of dilute $AgNO_3(aq)$	

[3]

- (d) POCl_3 shows similar chemical properties to PCl_5 .

POCl_3 has a melting point of 1°C and a boiling point of 106°C .

POCl_3 reacts vigorously with water, forming misty fumes and an acidic solution.

- (i) Explain how the information in (d) suggests the structure and bonding of POCl_3 is simple covalent.

.....

 [2]

- (ii) Construct an equation for the reaction of POCl_3 with water.

$\text{POCl}_3 + \dots \rightarrow \dots$ [1]

- (iii) POCl_3 contains a double covalent bond between P and O.

Complete the dot-and-cross diagram, in Fig. 1.1, to show the bonding in POCl_3 .

Show outer shell electrons only.

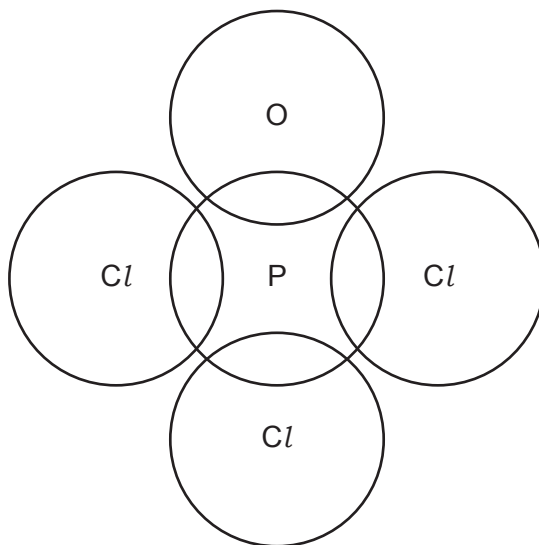


Fig. 1.1

[2]

- (e) $\text{POCl}_3(\text{g})$ forms when $\text{PCl}_3(\text{g})$ reacts with $\text{O}_2(\text{g})$.

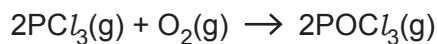


Table 1.3 gives some relevant data.

Table 1.3

process	value / kJ mol^{-1}
enthalpy change of formation of $\text{PCl}_3(\text{g})$	–289
enthalpy change of formation of $\text{POCl}_3(\text{g})$	–592
$\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$	+496

- (i) Define enthalpy change of formation, ΔH_f .

.....

 [2]

- (ii) Calculate the bond energy of $\text{P}=\text{O}$ in POCl_3 using the data in Table 1.3.

Show your working.

bond energy of $\text{P}=\text{O}$ = ... kJ mol^{-1}
 [2]

[Total: 22]

- 2 Barium hydroxide, $\text{Ba}(\text{OH})_2$, is a strong base used in inorganic and organic reactions.

Fig. 2.1 shows a reaction scheme involving $\text{Ba}(\text{OH})_2$.

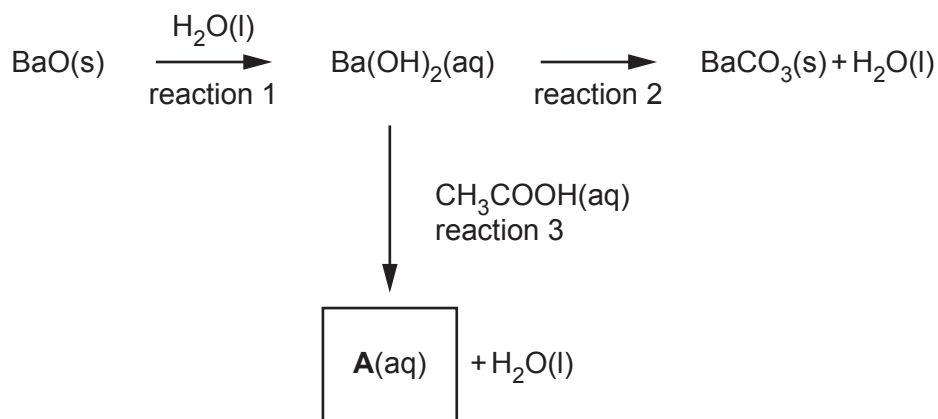


Fig. 2.1

- (a) (i) State the variation in solubilities of group 2 hydroxides.

..... [1]

- (ii) State what is observed in reaction 1.

..... [1]

- (iii) Suggest a reactant for reaction 2.

..... [1]

- (iv) Identify **A**.

..... [1]

- (v) $\text{Ba}(\text{OH})_2$ is made by the reaction of Ba with water.

Write an equation for this reaction.

..... [1]

(b) The mineral barytocalcite contains both BaCO_3 and CaCO_3 . Both compounds decompose on heating.

(i) State which compound decomposes first when barytocalcite is heated.

Explain your answer.

.....
 [1]

(ii) Construct an equation for the complete thermal decomposition of barytocalcite.

The formula of barytocalcite is $\text{BaCa}(\text{CO}_3)_2$.

$\text{BaCa}(\text{CO}_3)_2$ [1]

(c) $\text{Ba}(\text{OH})_2$ is used to hydrolyse organic compounds.

Fig. 2.2 shows the reaction of **B** with $\text{Ba}(\text{OH})_2$, followed by acidification.

Draw the structures of the organic products of the process shown in Fig. 2.2.

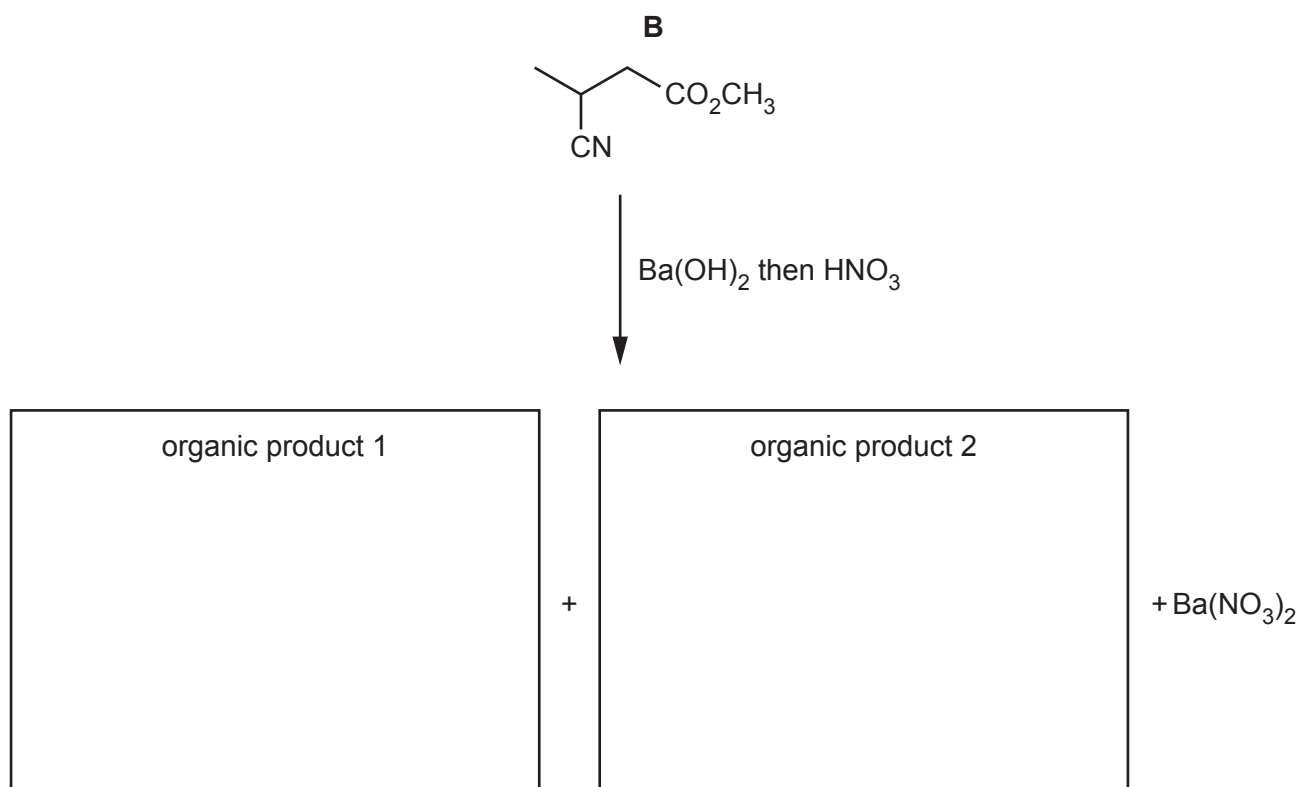


Fig. 2.2

[3]

[Total: 10]

3 Potassium chlorate, KClO_3 , is widely used as an oxidising agent and to make $\text{O}_2(\text{g})$.

(a) Define oxidising agent.

.....
 [1]

(b) $\text{KClO}_3(\text{s})$ decomposes when heated.

$\text{MnO}_2(\text{s})$ catalyses the exothermic decomposition reaction.

Complete and label the diagram in Fig. 3.1 to show the effect of $\text{MnO}_2(\text{s})$ on the decomposition of $\text{KClO}_3(\text{s})$.

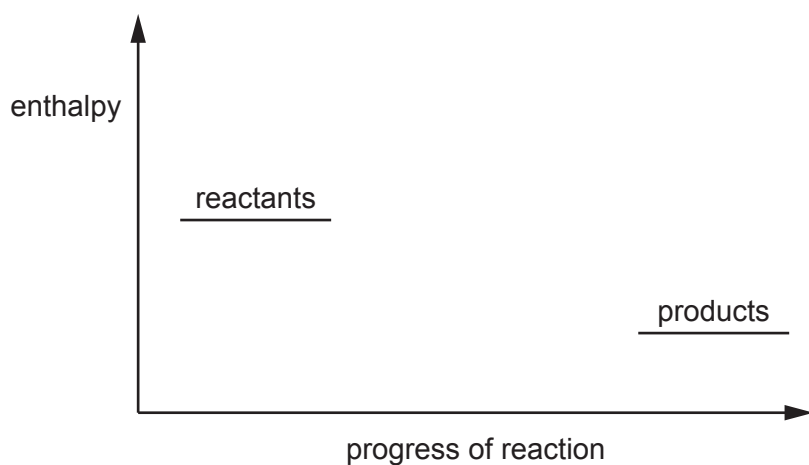


Fig. 3.1

[2]

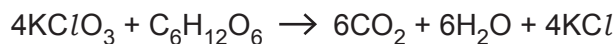
(c) When KClO_3 is heated without a catalyst, KClO_4 and KCl form.



Explain why this reaction is described as a disproportionation reaction.

.....
 [1]

(d) Molten KClO_3 reacts with glucose, $\text{C}_6\text{H}_{12}\text{O}_6$.



KClO_3 melts at 630 K. At this temperature, both CO_2 and H_2O are gases.

- (i) Use the ideal gas equation to calculate the volume, in m^3 , of one mole of gas at 630 K and $1.00 \times 10^5 \text{ Pa}$.

Show your working. Give your answer to 3 significant figures.

volume of 1 mol of gas = ... m^3
[1]

- (ii) 5.00 g of $\text{C}_6\text{H}_{12}\text{O}_6$ reacts completely with molten KClO_3 .

Use your answer to (d)(i) to calculate the total volume of gas released at 630 K and $1.00 \times 10^5 \text{ Pa}$ in this reaction.

(If you were unable to answer (d)(i), use 0.0463 m^3 in this question. This is **not** the correct answer to (d)(i).)

total volume of gas released = ... m^3
[2]

- (e) The structure of glucose, $C_6H_{12}O_6$, is shown in Fig. 3.2.

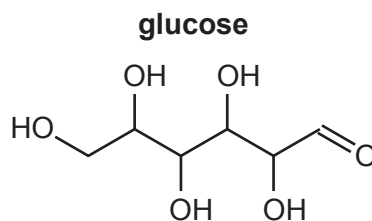


Fig. 3.2

- (i) Complete Table 3.1 to identify the number of primary, secondary and tertiary alcohol groups present in the structure shown in Fig. 3.2.

Table 3.1

type of alcohol group	primary	secondary	tertiary
number of groups			

[1]

- (ii) Separate samples of aqueous glucose are tested with the reagents shown in Table 3.2.

Complete Table 3.2 with the observation for each reaction.

Write “no reaction” if applicable.

Table 3.2

reagent and conditions	observation with glucose
acidified $KMnO_4(aq)$ and warm	
Fehling’s reagent and warm	
alkaline $I_2(aq)$ and warm	

[3]

- (iii) There are many structural isomers of $C_6H_{12}O_6$.

Define structural isomers.

.....

..... [1]

[Total: 12]

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- 4 Compounds **C** and **D** are alkenes with the same molecular formula, C_5H_{10} .



Fig. 4.1

- (a) (i) Give the systematic name of **D**.

..... [1]

- (ii) Explain why **C** and **D** do not show geometrical (*cis/trans*) isomerism.

.....

..... [1]

- (iii) Draw the structure of a molecule that is a positional isomer of **C** and **D**.

[1]

- (iv) Give the structural formula of the compound formed when **D** reacts with $H_2(g)$ in the presence of a Pt catalyst.

..... [1]

- (v) **C** can form an addition polymer.

Draw the structure of **one** repeat unit of this addition polymer.

[1]

- (b) The mass spectrum of **C** shows a molecular ion peak at $m/e = 70$. This peak has a relative intensity of 48.7.

The relative intensity of the $[M+1]$ peak is 2.7.

Show that this information is consistent with the molecular formula of **C**.

[2]

- (c) **C** and **D** both react with HBr.

- (i) **C** reacts with HBr to form **E**.

Complete the diagram in Fig. 4.2 to show the mechanism for this reaction.

Draw the structure of the organic intermediate.

Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

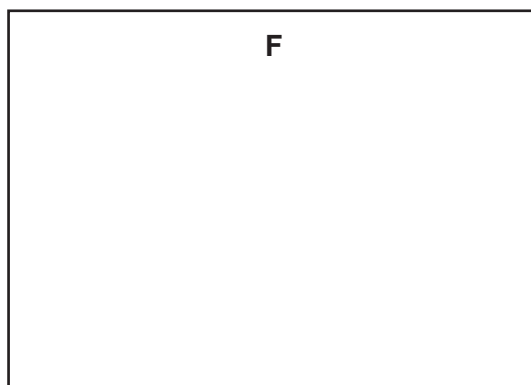


Fig. 4.2

[3]

- (ii) **D** reacts with HBr to produce **F**, a chiral bromoalkane.

Draw the structure of **F**.



[1]

(iii) Explain why the reaction of HBr with **C** and **D** produces different major products.



Fig. 4.3

.....

.....

.....

..... [2]

(d) **C** can be used to form **H**.

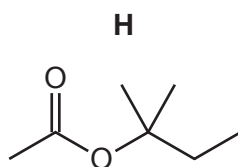


Fig. 4.4

One possible synthesis of **H** is shown in Fig. 4.5. Different portions of **C** are used in reactions 1 and 3. Some of the products are then combined to produce **H**.

Fig. 4.5 does not show any of the inorganic products of the reactions.

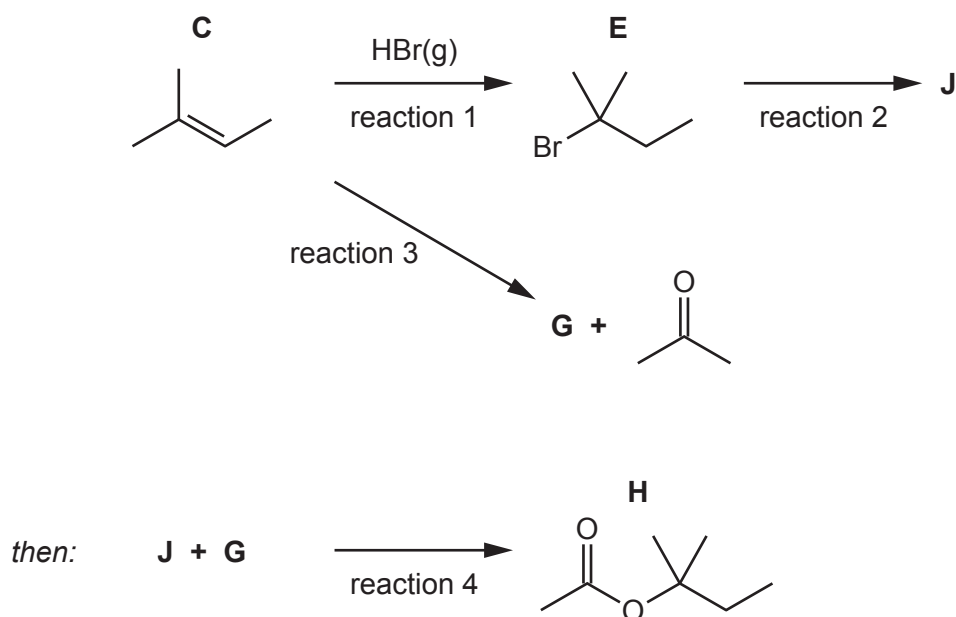


Fig. 4.5

Complete Table 4.1 with the reagents and conditions required for each of the reactions shown in Fig. 4.5.

Table 4.1

	reagent and conditions
reaction 1 C → E	HBr(g)
reaction 2 E → J	
reaction 3 C → G + 	
reaction 4 J + G → H	

[3]

[Total: 16]

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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 ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																		
1	2	Key										1						
		atomic number atomic symbol name relative atomic mass										1 H hydrogen 1.0	13	14	15	16	17	18
3 Li lithium 6.9	4 Be beryllium 9.0																	
11 Na sodium 23.0	12 Mg magnesium 24.3	3 Sc scandium 45.0	4 Ti titanium 47.9	5 V vanadium 50.9	6 Cr chromium 52.0	7 Mn manganese 54.9	8 Fe iron 55.8	9 Co cobalt 58.9	10 Ni nickel 58.7	11 Cu copper 63.5	12 Zn zinc 65.4	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	2 He helium 4.0	
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	13 Al aluminum 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	
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	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 —	
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 —	

lanthanoids

actinoids

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	euroium	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	yterbium	173.1	71	Lu	lutetium	175.0
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	—