



Cambridge International AS & A Level

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CHEMISTRY

9701/21

Paper 2 AS Level Structured Questions

May/June 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

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



- 1 (a) Solid sodium conducts electricity. Sodium oxide conducts electricity when molten but not when solid.

- (i) Name the type of bonding present in sodium and in sodium oxide.

bonding in sodium

bonding in sodium oxide

[1]

- (ii) Explain how solid sodium conducts electricity.

.....

..... [1]

- (iii) Explain why sodium oxide conducts electricity when molten.

.....

..... [1]

- (b) Separate samples of sodium and sodium oxide are each added to an excess of cold water.

- (i) Write an equation for the reaction of sodium with cold water.

..... [1]

- (ii) Write an equation for the reaction of sodium oxide with cold water.

..... [1]

- (iii) Complete Table 1.1.

Do **not** refer to temperature changes when considering observations for these reactions.

Table 1.1

	sodium	sodium oxide
one similarity in observation on addition to cold water		
one difference in observation on addition to cold water		

[2]



- (c) State the oxidation number of the Period 3 elements bonded to Cl in NaCl and PCl₅. Explain the difference in the oxidation number.

.....

.....

..... [2]

- (d) Table 1.2 shows melting points of some oxides.

Table 1.2

oxide	melting point/°C
SO ₂	−73
H ₂ O	0
SO ₃	17
SiO ₂	1610
MgO	2852
Al ₂ O ₃	2072

A student suggests the following hypothesis.

*The higher the oxidation number of the element combined with oxygen,
the higher the melting point of the oxide.*

Use Table 1.2 to deduce if this hypothesis is true or false or if there is **not** enough information to make a conclusion. Explain your answer.

.....

.....

..... [2]

[Total: 11]



- 2 A sample of iron is analysed using a mass spectrometer. The mass spectrum shows three isotopes of iron are present in the sample.

(a) Define isotopes.

.....

.....

..... [1]

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

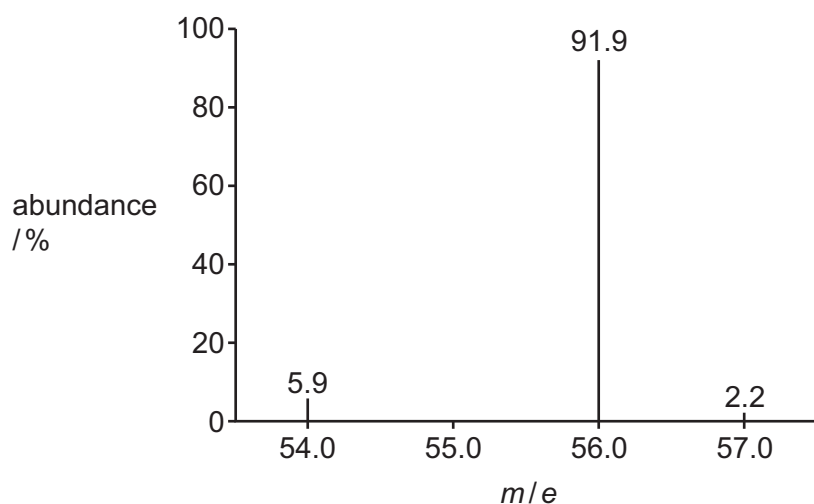


Fig. 2.1

- (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]



(ii) Complete Table 2.1 to show the number of protons and nucleons in one atom of ^{56}Fe .

Table 2.1

particle	number of particles in one atom of ^{56}Fe
protons	
nucleons	

[2]

(c) Deduce the number of pairs of electrons in the shell with principal quantum number $n = 3$ in an Fe atom.

number of pairs of electrons [1]

(d) Write an equation to represent the first ionisation energy of iron.

..... [1]

(e) Suggest how the value for the first ionisation energy of ^{54}Fe compares to the first ionisation energy of ^{56}Fe . Explain your answer in terms of the factors that affect ionisation energy.

.....

.....

.....

.....

..... [4]

[Total: 11]



- 3 (a) Hexene reacts with hydrogen gas to produce hexane.

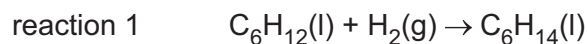


Fig. 3.1 shows the distribution of energies of $\text{H}_2(\text{g})$ molecules at temperature T .

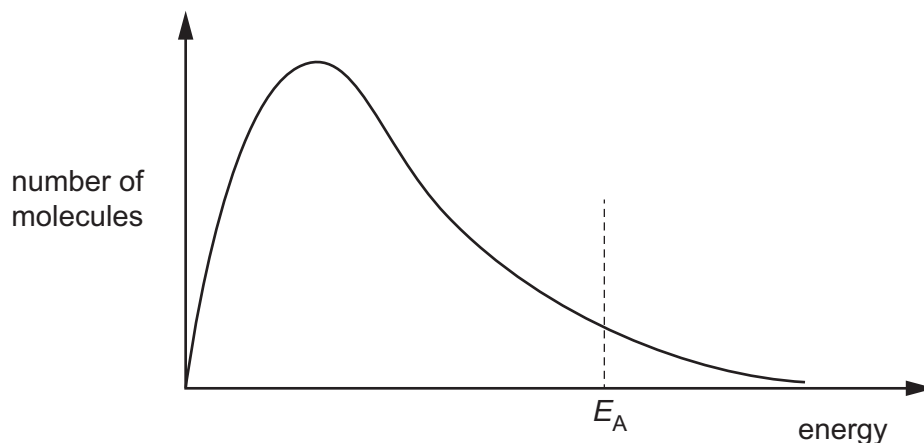


Fig. 3.1

- (i) Sketch on Fig. 3.1 the shape of the curve for the same sample of $\text{H}_2(\text{g})$ molecules when the temperature is increased. [2]
- (ii) Explain why increasing the temperature increases the rate of reaction 1. [2]
-
-
-
- (iii) State the role of nickel when it is added to reaction 1. [1]
-
- (iv) Annotate Fig. 3.2 to show the effect of adding nickel to reaction 1 at temperature T .

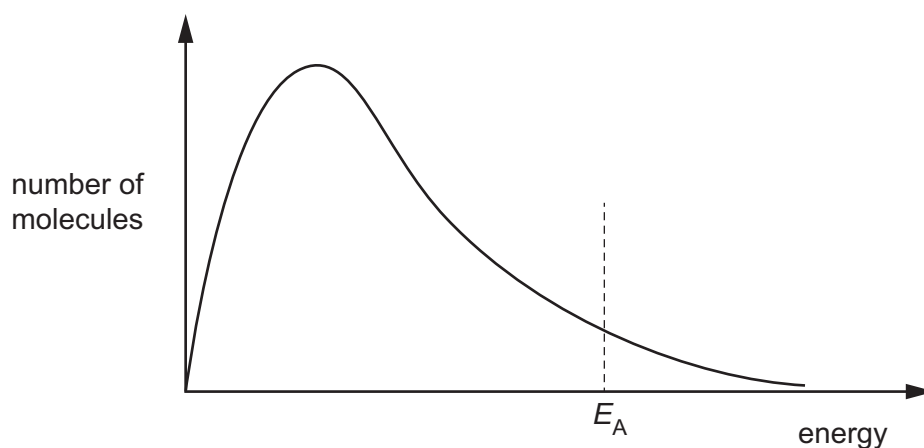


Fig. 3.2



(b) Define Le Chatelier's principle.

.....

.....

..... [2]

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

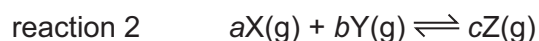


Fig. 3.3 shows the effect of changing pressure on the percentage yield of Z(g) at two different temperatures, 300 K and 350 K.

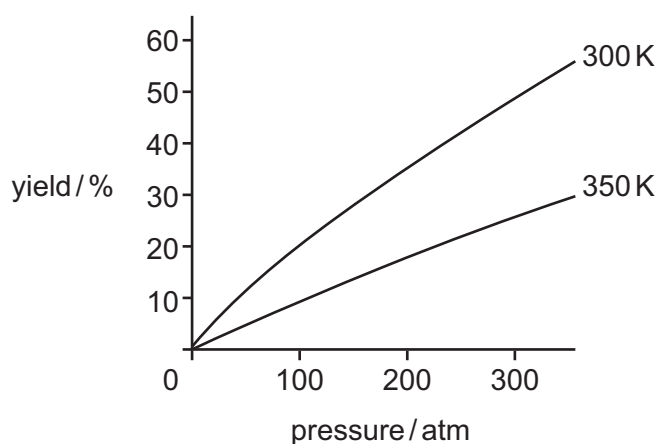


Fig. 3.3

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

.....

.....

..... [2]

[Total: 10]



vitamin C

The chemical structure of vitamin C (ascorbic acid) is shown. It consists of a five-membered lactone ring with a double bond between two carbons. One of these carbons is also bonded to a hydroxyl group. The other carbon in the ring is bonded to a hydroxyl group and a side chain. The side chain consists of a CH2 group bonded to a CH group, which is in turn bonded to a hydroxyl group.

OC1=CC(=O)O[C@H](O)[C@H](O)CO1

Fig. 4.1

- (a) Deduce the empirical formula of vitamin C.

..... [1]

- (b)** The concentration of vitamin C is found by titration with $\text{I}_2(\text{aq})$.

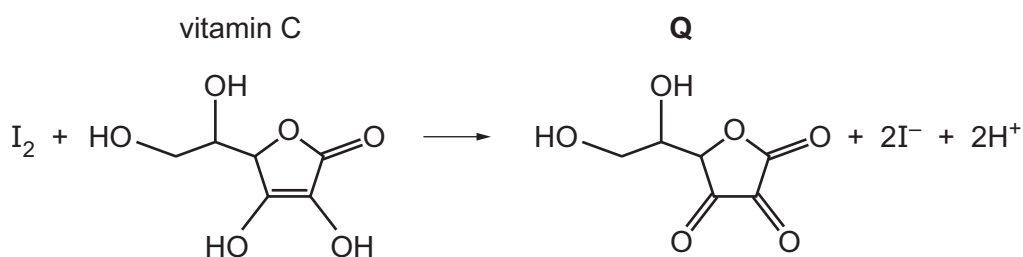


Fig. 4.2

A vitamin C tablet is dissolved in water to produce 200.0 cm^3 of vitamin C solution. 5.00 cm^3 of this vitamin C solution is added to a flask with approximately 150 cm^3 of water and an indicator. Exactly 28.40 cm^3 of $5.00 \times 10^{-4}\text{ mol dm}^{-3}$ $\text{I}_2(\text{aq})$ reacts with the sample of vitamin C solution in the flask.

[M_r : vitamin C, 176]

- (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]

- (iv) Suggest **two** reasons why hot concentrated acidified potassium manganate(VII) is **not** a suitable reagent for producing **Q** from vitamin C.

1

.....

2

.....

[2]





- (c) Predict **two** absorptions that will be seen in the infrared spectra of both vitamin C and **Q**. Describe the relevant bond and the specific functional group that is responsible for each absorption identified.

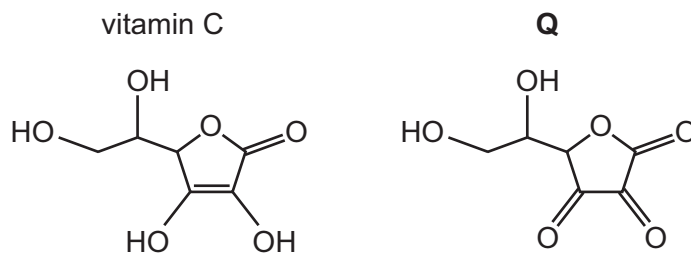


Fig. 4.3

.....

.....

..... [2]

[Total: 9]

Table 4.1

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≡N	nitrile	2200–2250
C-H	alkane	2850–2950
N-H	amine, amide	3300–3500
O-H	carboxyl hydroxy	2500–3000 3200–3650







- 5 Compound **A** contains the elements carbon, hydrogen and oxygen only.
When **A** is heated with $\text{H}_2\text{SO}_4(\text{aq})$, compounds **B** and **C** are produced, as shown in Fig. 5.1.

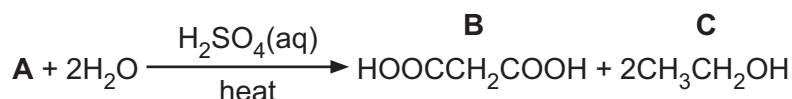


Fig. 5.1

- (a) Draw the structure of **A**.

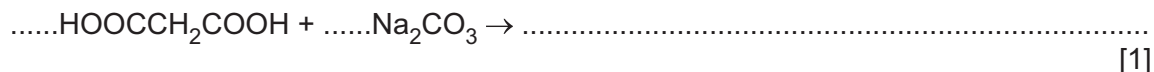
[2]

- (b) Name the type of reaction that occurs when **A** is heated with $\text{H}_2\text{SO}_4(\text{aq})$.

[1]

- (c) When aqueous Na_2CO_3 is added to separate samples of **B** and **C**, effervescence is observed with **B** only.

- (i) Complete the equation to describe the reaction between **B** and an excess of aqueous Na_2CO_3 .



- (ii) Suggest why **C** does **not** react with aqueous Na_2CO_3 in a similar type of reaction to **B**.

[1]

- (d) A student suggests a two-step synthesis to produce **B**, as shown in Fig. 5.2.

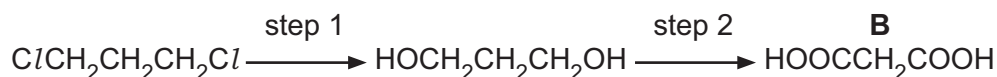


Fig. 5.2

- (i) Identify the reagents and conditions required in steps 1 and 2.

step 1

step 2 [2]

- (ii) Identify the type of reaction that $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{OH}$ undergoes in step 2.

[1]



(e) **B** reacts with an excess of reducing agent **R** to produce **D**.

An excess of PCl_5 is added to **D**.

- A vigorous reaction occurs.
- Misty fumes are seen.
- Organic compound **E** is produced.

(i) Identify the formula of the reducing agent **R**.

..... [1]

(ii) Complete the equation to describe the reaction of **B** with an excess of **R**.

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

..... $\text{HOOCCH}_2\text{COOH}$ + ...[H] $\rightarrow$ [2]

(iii) Name organic compound **E**.

..... [1]

[Total: 12]



- 6 Three bottles of colourless liquids labelled **F**, **G** and **H** contain separate pure samples of the compounds ethanal, propanal or propanone but **not** necessarily in that order.

(a) State the functional group in ethanal, propanal and propanone.

..... [1]

- (b) State a reagent and the relevant observation that confirm that **F**, **G** and **H** have the same functional group.

reagent

observation [2]

- (c) Separate samples of **F**, **G** and **H** are each tested with Tollens' reagent and with alkaline $I_2(aq)$. The observations are shown in Table 6.1.

Table 6.1

	Tollens' reagent	alkaline $I_2(aq)$
F	no observable change	pale yellow precipitate
G	silver mirror	pale yellow precipitate
H	silver mirror	no precipitate

- (i) Use Table 6.1 to name the organic compounds in bottles **F**, **G** and **H**.

F = ...

G = ...

H = ... [2]

- (ii) Identify the yellow precipitate produced when alkaline $I_2(aq)$ is added to separate samples of **F** and **G**.

..... [1]

- (iii) Compound **J** does **not** contain the same functional group as **F**, **G** and **H**. Compound **J** also reacts with alkaline $I_2(aq)$ to produce a pale yellow precipitate.

Suggest the structure of compound **J**.

[1]

[Total: 7]





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 J g ⁻¹ K ⁻¹)





The Periodic Table of Elements

Group																							
1	2													13	14	15	16	17	18				
		1 H hydrogen 1.0																					
		Key																					
		atomic number atomic symbol name relative atomic mass																					
3	4													5	6	7	8	9	10	11	12		
Li lithium 6.9	Be beryllium 9.0													B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0					
11	12													13	14	15	16	17	18				
Na sodium 23.0	Mg magnesium 24.3													Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9				
19	20													31	32	33	34	35	36				
K potassium 39.1	Ca calcium 40.1													Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8				
37	38													49	50	51	52	53	54				
Rb rubidium 85.5	Sr strontium 87.6													In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3				
55	56													81	82	83	84	85	86				
Cs caesium 132.9	Ba barium 137.3													Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —				
87	88													113	114	115	116	117	118				
Fr francium —	Ra radium —													Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —				

Key

atomic number
atomic symbol
name
relative atomic mass

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	europlum	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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- 1 (a) Diamond and graphite are both crystalline solids made from carbon atoms. Graphite conducts electricity. Diamond does **not** conduct electricity.

(i) Name the type of lattice structure present in the crystalline solids diamond and graphite.

..... [1]

(ii) Explain how graphite conducts electricity.

.....

..... [1]

(iii) Explain why diamond does **not** conduct electricity.

.....

..... [1]

- (b) Separate samples of phosphorus(V) chloride and silicon(IV) chloride are each added to an excess of cold water.

(i) Write an equation for each reaction.

.....

..... [2]

(ii) Describe the appearance of phosphorus(V) chloride and silicon(IV) chloride at room temperature.

phosphorus(V) chloride

silicon(IV) chloride

[2]

(iii) Compare the appearance of the mixtures produced when each reaction is complete.

.....

..... [2]

- (c) Some oxides are amphoteric.

(i) Describe what is meant by amphoteric.

.....

..... [1]

(ii) Identify the formula of a Period 3 oxide that is amphoteric.

..... [1]



(d) The melting points of different oxides are shown in Table 1.1.

Table 1.1

oxide	melting point / °C	force of attraction broken during melting
SO ₂	−73	
H ₂ O	0	
SiO ₂	1610	
Na ₂ O	1132	
MgO	2852	

- (i) Complete Table 1.1 by identifying the strongest force of attraction in each oxide that is broken during melting. Use the abbreviations below.

i.d. = instantaneous dipole–induced dipole

p.d. = permanent dipole–permanent dipole

H = hydrogen bond

C = covalent bond

I = ionic bond

[3]

- (ii) A student suggests the following hypothesis.

*The stronger the covalent bond between atoms in non-metal oxides,
the higher the melting point.*

Use Table 1.1 to deduce if this hypothesis is true or false or if there is **not** enough information to make a conclusion. Explain your answer.

.....

 [2]

[Total: 16]



- 2 A sample of iron contains three different isotopes and has a relative atomic mass, A_r , of 55.8.

(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]



3 (a) C_3H_6 reacts with HBr(g) in an addition reaction.

(i) Define addition reaction.

.....
 [1]

(ii) Complete Fig. 3.1 to show the mechanism for the addition reaction between C_3H_6 and HBr to produce 2-bromopropane. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.



Fig. 3.1

[4]

(iii) Explain why the major product of this reaction is 2-bromopropane rather than 1-bromopropane.

.....

 [2]



- (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.

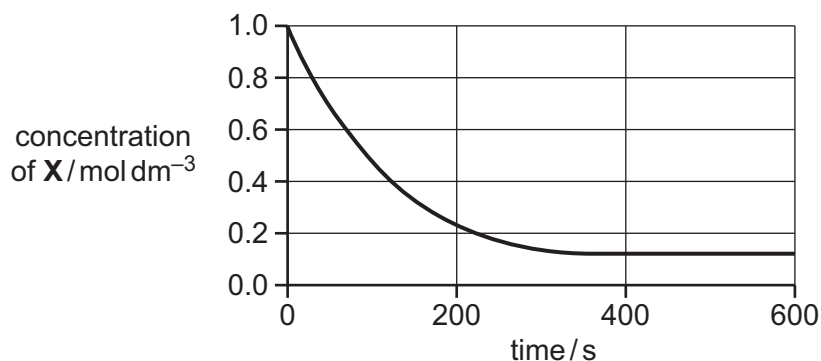


Fig. 3.2

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

.....
 [1]

- (ii) Use Fig. 3.2 to describe how the gradient changes as the reaction proceeds. State what this shows about the rate during this reaction.

.....

 [1]





(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]





(d) Hydrocarbon **Y** reacts with $\text{H}_2(\text{g})$.

Fig. 3.3 shows the distribution of energies of $\text{H}_2(\text{g})$ at temperature T .

Area **A** represents the number of molecules with energy greater than or equal to the activation energy, E_A , at temperature T .

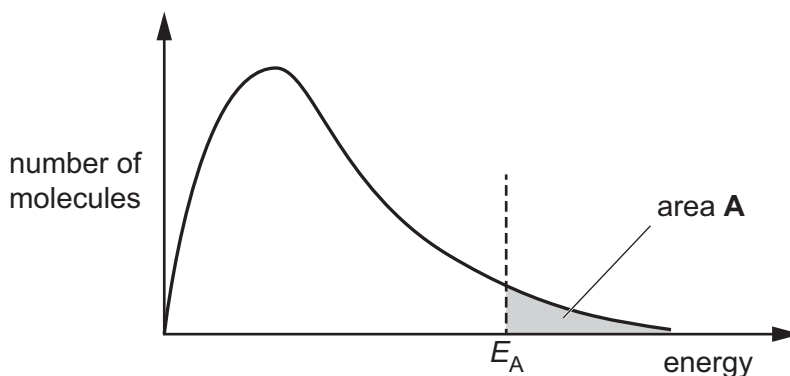


Fig. 3.3

- (i) Annotate Fig. 3.3 to show the effect of adding nickel to **Y** and $\text{H}_2(\text{g})$ at temperature T . [1]
- (ii) Area **B** (not labelled on Fig. 3.3) represents the number of molecules with energy greater than or equal to the activation energy when nickel is added at temperature T .

State the difference, if any, between areas **A** and **B**. Explain the significance of your answer on the rate of hydrogenation of **Y**. Give your answer in terms of collisions.

.....

.....

..... [2]

- (e) Alkene **Z** contains two $\text{C}=\text{C}$ bonds. **Z** reacts with an excess of hot concentrated acidified KMnO_4 to produce **only** CH_3COCH_3 , $\text{HOOCCH}_2\text{COOH}$, CO_2 and H_2O .

Suggest the structure of **Z**.

[2]

[Total: 16]



- 4 (a) Propanoic acid, $\text{CH}_3\text{CH}_2\text{COOH}$, reacts with reducing agent **Q** to produce propan-1-ol, $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$.

(i) Suggest the formula of reducing agent **Q**.

..... [1]

(ii) Complete the equation to show the reduction of propanoic acid to propan-1-ol. Use [H] to represent one atom of hydrogen from **Q**.

..... $\text{CH}_3\text{CH}_2\text{COOH}$ + ...[H] $\rightarrow$ [1]

(b) Propan-1-ol is converted to compound **T** in a three-step synthesis.

In step 1, SOCl_2 is added to propan-1-ol to produce compound **E**.

In step 2, **E** reacts with a suitable reagent to produce butanenitrile.

In step 3, butanenitrile is heated with NaOH(aq) .

(i) Name the type of reaction that occurs in step 1.

..... [1]

(ii) Identify the reagent and conditions required in step 2.

..... [1]

(iii) Construct an equation to describe the reaction of butanenitrile with NaOH(aq) in step 3.

..... [2]

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

..... [1]



(c) Compounds **A**, **B** and **C** belong to the alcohol homologous series. Each molecule of **A**, **B** and **C** contains four saturated carbon atoms.

(i) Identify the type of hybridisation shown in the saturated carbon atoms of all alcohols.

..... [1]

(ii) Identify the gas produced when Na(s) is added to separate samples of each alcohol.

..... [1]

(iii) Describe the role of Na(s) when it reacts with alcohols.

..... [1]

(d) Table 4.1 shows the results of two tests on separate samples of **A**, **B** and **C**.

Table 4.1

compound	heat under reflux with acidified $K_2Cr_2O_7$	warm with alkaline $I_2(aq)$
A	remains orange	no visible change
B	orange to green	no visible change
C	orange to green	pale yellow precipitate

(i) Deduce the structure of **A**.

[1]

(ii) Deduce a possible name for **B**.

..... [1]

(iii) Deduce the identity of **C**.

..... [1]

[Total: 13]



5 The structure of vitamin C is shown in Fig. 5.1.

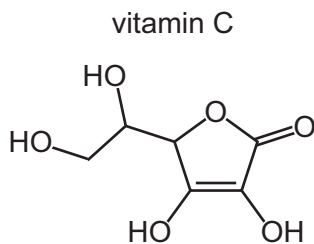


Fig. 5.1

- (a)** Deduce the empirical formula of vitamin C.

..... [1]

- (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).

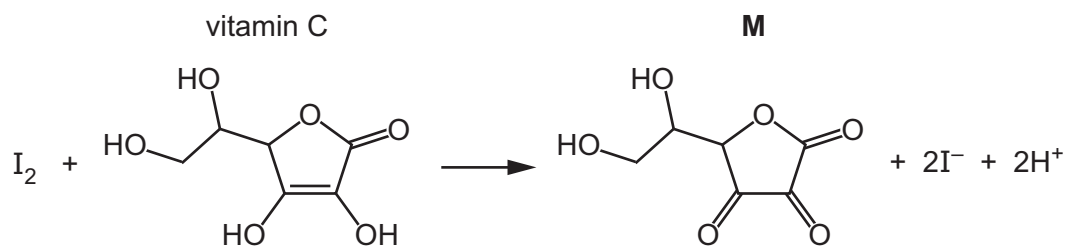


Fig. 5.2

Exactly 36.65 cm^3 of $\text{I}_2(\text{aq})$ reacts with the 25.0 cm^3 sample of solution L.

[M_r : vitamin C, 176]

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

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

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

(If you were unable to calculate a value for the amount of $I_2(aq)$ in (b)(i), use the value $7.65 \times 10^{-4} \text{ mol}$. This is **not** the correct value.)

percentage by mass = ...% [2]

- (iii) The progress of the reaction of vitamin C with $I_2(aq)$ to produce **M** is monitored using infrared spectroscopy.

Table 5.1 indicates the presence of some absorptions in the infrared spectrum of vitamin C. Complete Table 5.1 to predict which of these absorptions, if any, are present in the infrared spectrum of **M**.

Table 5.1

absorption / cm^{-1}	present in spectrum of vitamin C	present in spectrum of M
1500–1680	✓	
2850–2950	✓	
3200–3650	✓	

[1]

Table 5.2

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≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

[Total: 5]







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 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										1 H hydrogen 1.0								
3	4											5	6	7	8	9				
Li lithium 6.9	Be beryllium 9.0											B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	He helium 4.0			
11	12											13	14	15	16	17	18			
Na sodium 23.0	Mg magnesium 24.3											Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9			
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8			
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3			
55	56	57–71 lanthanoids		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86		
Cs caesium 132.9	Ba barium 137.3			Hf hafnium 178.5	Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —		
87	88	89–103 actinoids		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118		
Fr francium —	Ra radium —			Rf rutherfordium —	Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —		

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
lanthanum	cerium	praseodymium	neodymium	promethium	samarium	europlum	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
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
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	mendeleevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—





Cambridge International AS & A Level

CANDIDATE
NAME

CENTRE
NUMBER

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CANDIDATE
NUMBER

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CHEMISTRY

9701/23

Paper 2 AS Level Structured Questions

May/June 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

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



1 The chemical properties of an element are related to the electronic configuration of its atoms.

(a) (i) Give the full electronic configuration of a fluorine atom.

..... [1]

(ii) Deduce the number of pairs of electrons in the second energy shell, $n = 2$, of an oxygen atom.

..... [1]

(iii) Draw the shape of the highest energy orbital that contains electrons in an atom of calcium.

[1]

(b) (i) Write an equation to represent the first ionisation energy of sulfur.

..... [1]

(ii) Explain why the first ionisation energy of sulfur is less than the first ionisation energy of phosphorus.

.....

 [2]

(iii) Arrange the three species F^- , Ne and Na^+ in order of increasing radius.

Explain your answer.

..... < <
 smallest radius largest radius

.....

 [4]

[Total: 10]



2 The chemical properties of oxides are related to the chemical bonding present in these compounds.

- (a) A Period 3 oxide produces a solution with a pH greater than 10 when it is added to water.
State the formula of the oxide.

..... [1]

- (b) P_4O_{10} is added to an excess of aqueous NaOH.
Write an equation to describe the reaction.

..... [1]

- (c) Table 2.1 shows the melting points of some oxides.

Table 2.1

oxide	melting point/ $^{\circ}\text{C}$
SO_2	-73
H_2O	0
SO_3	17
SiO_2	1610
Na_2O	1132
MgO	2852
Al_2O_3	2072

- (i) Identify the oxide from Table 2.1 that contains the element with the highest oxidation number.

..... [1]

- (ii) A student suggests the following hypothesis.

The melting point of an ionically bonded oxide is only determined by the charge on the cation.

Use Table 2.1 to deduce if this hypothesis is true or false or if there is **not** enough information to make a conclusion. Explain your answer.

.....

 [2]





(d) State why ZnO is described as a Brønsted–Lowry base when it is added to $\text{H}_2\text{SO}_4(\text{aq})$.

..... [1]

(e) Al_2O_3 is a white amphoteric compound.

(i) State the formula of the aluminium-containing species produced when Al_2O_3 reacts with $\text{NaOH}(\text{aq})$.

..... [1]

(ii) State the formula of the aluminium-containing salt produced when Al_2O_3 reacts with $\text{H}_2\text{SO}_4(\text{aq})$.

..... [1]

[Total: 8]



3 (a) Different hydrocarbon mixtures produced from fractional distillation of crude oil have different uses.

- (i) State the compound that is heated with long-chain hydrocarbons to produce more useful smaller alkanes and alkenes.

..... [1]

- (ii) Describe how photochemical smog is produced during the combustion of petrol in an internal combustion engine.

.....

 [2]

(b) C_4H_8 reacts with an excess of H_2 to produce C_4H_{10} .



- (i) Name a catalyst for reaction 1.

..... [1]

- (ii) Define activation energy, E_A .

.....
 [1]

- (iii) The Boltzmann distribution for the reaction mixture in reaction 1 is shown in Fig. 3.1. Use the Boltzmann distribution to explain the effect of adding a catalyst on the rate of reaction.



Fig. 3.1

.....

 [2]



- 4 The reaction between $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ and $\text{HCl}(\text{aq})$ is monitored at constant temperature.

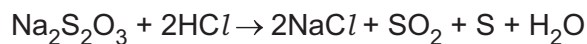


Fig. 4.1 shows how the concentration of $\text{HCl}(\text{aq})$ varies with time.

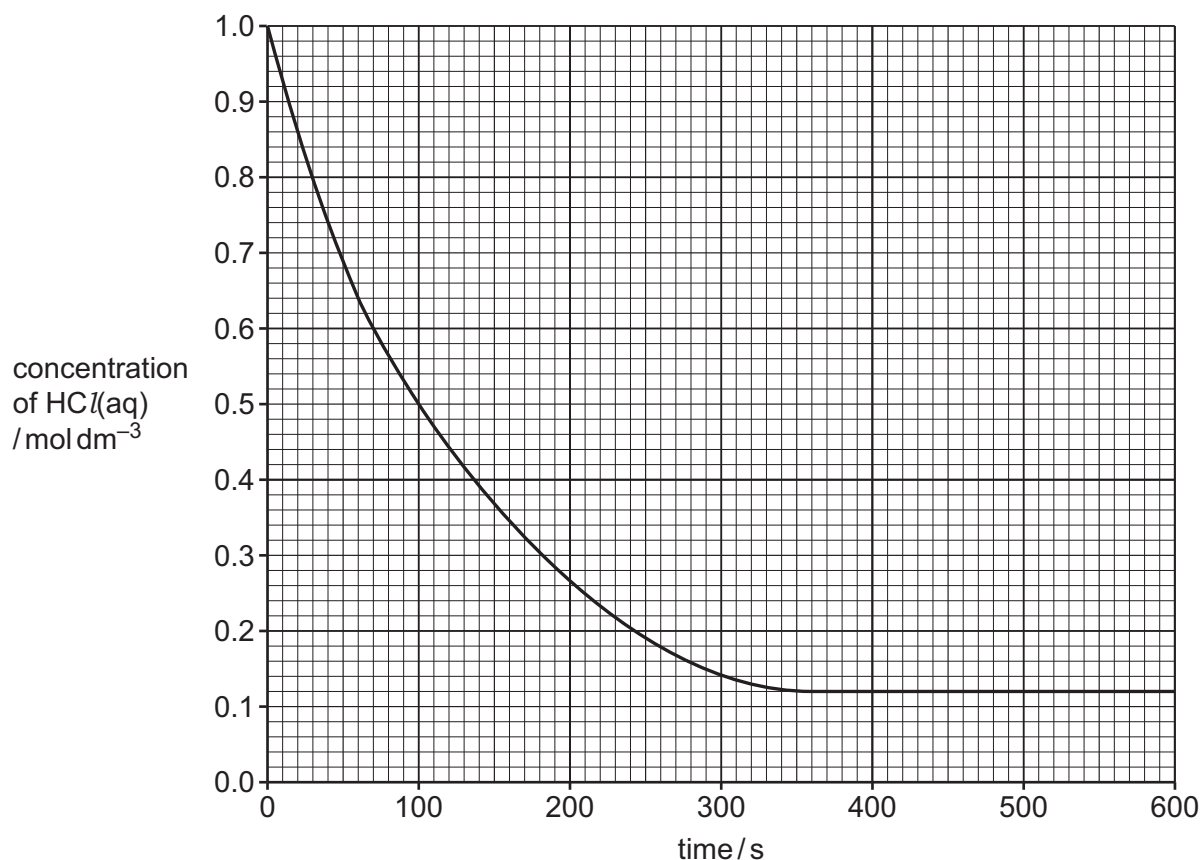


Fig. 4.1

- (a) (i) Use Fig. 4.1 to find the average rate of change of concentration of $\text{HCl}(\text{aq})$ 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]

- (iii) Explain why the rate of reaction changes with time.

.....

 [1]



- (iv) The reaction between $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ and $\text{HCl}(\text{aq})$ is repeated in a second experiment.

In this second experiment, 25.0 cm^3 of 0.050 mol dm^{-3} $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ reacts with 0.0020 mol of $\text{HCl}(\text{aq})$. Calculate the number of sulfur atoms produced.

number of sulfur atoms produced = ... [2]

- (v) Explain why the rate of reaction **cannot** be monitored accurately by measuring the volume of $\text{SO}_2(\text{g})$ produced in this reaction.

.....
 [1]

- (b) Fig. 4.2 shows a possible arrangement of outer-shell electrons in one SO_2 molecule.

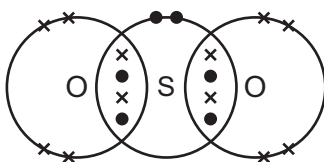


Fig. 4.2

- (i) Use Fig. 4.2 to predict the shape and bond angle of a molecule of SO_2 .

shape

bond angle $^{\circ}$

[2]

- (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]





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

W

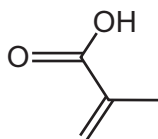


Fig. 5.1

(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]



(b) Fig. 5.2 shows two reactions of **W** to produce organic compounds **Y** and **Z**.

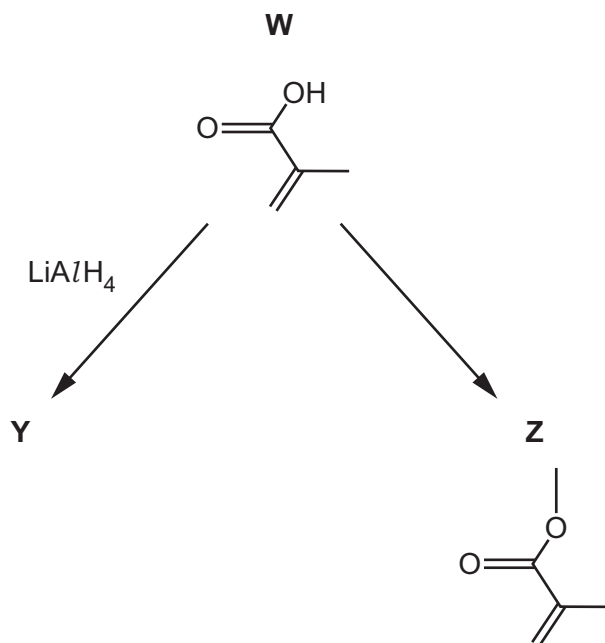


Fig. 5.2

- (i) Deduce the number of sigma (σ) bonds and pi (π) bonds present in **Z**.

number of σ bonds

number of π bonds

[2]

- (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]





10

Z

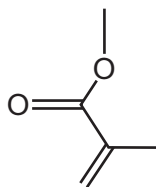


Fig. 5.3

- (v) Fig. 5.3 shows the structure of **Z**.
Fig. 5.4 is the infrared spectrum of **Z**.

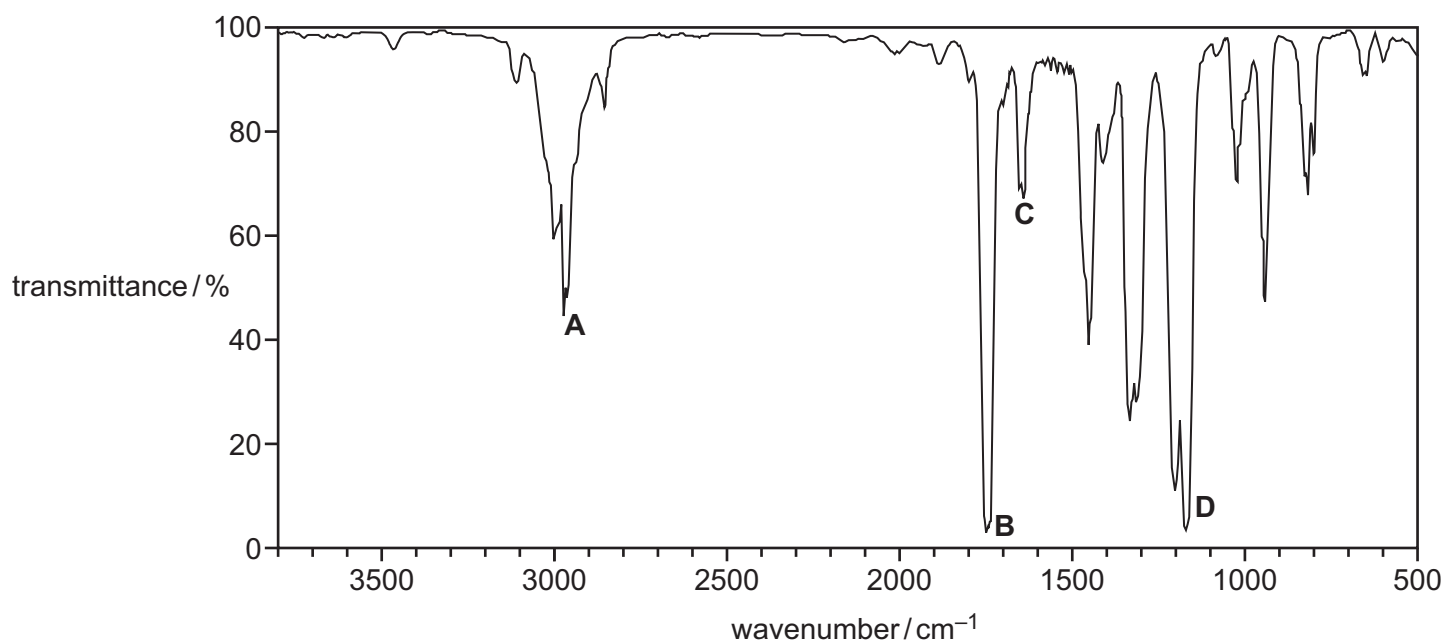


Fig. 5.4

Identify the bond and functional group responsible for each of the absorptions labelled **A**, **B**, **C** and **D** in Fig. 5.4.

A

B

C

D

[2]





Table 5.2

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≡N	nitrile	2200–2250
C–H	alkane	2850–2950
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

(vi) **Z** is used to produce addition polymer **Q**.

Draw the repeat unit of polymer **Q**.

[1]

(c) Poly(ethene) is an addition polymer made from ethene.

Explain why ethene reacts with electrophiles but poly(ethene) does **not**.

.....
 [1]

[Total: 14]



6 (a) HOCl reacts with $\text{CH}_2=\text{CH}_2$ to produce $\text{HOCH}_2\text{CH}_2\text{Cl}$ in an electrophilic addition reaction.

(i) Define addition reaction.

.....
 [1]

(ii) Describe how Cl_2 is used to produce HOCl .

.....
 [1]

(iii) State **one** use for HOCl .

.....
 [1]

(b) Complete Fig. 6.1 to show the mechanism for the reaction between HOCl and $\text{CH}_2=\text{CH}_2$ to produce $\text{HOCH}_2\text{CH}_2\text{Cl}$.

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

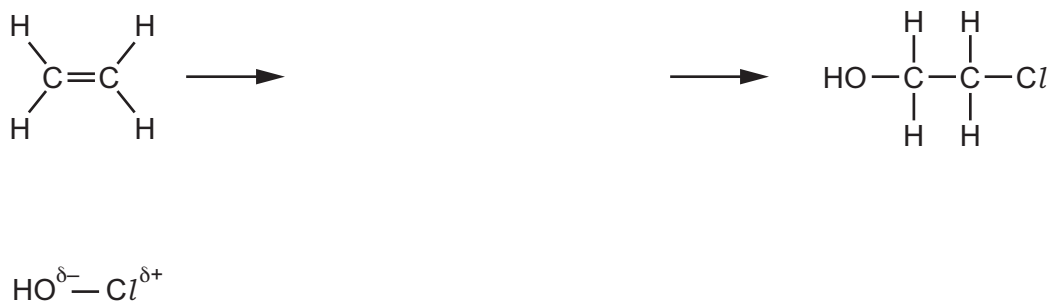


Fig. 6.1

[4]





- (c) $\text{HOCH}_2\text{CH}_2\text{Cl}$ reacts in a two-step synthesis to produce $\text{HOCH}_2\text{CH}_2\text{COOH}$, as shown in Fig. 6.2.

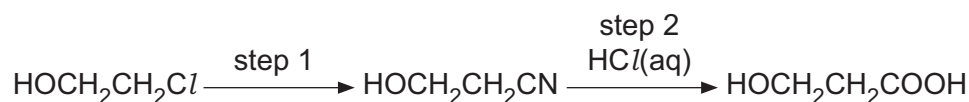


Fig. 6.2

- (i) State the reagent and conditions for step 1.

..... [1]

- (ii) Identify the type of reaction that occurs in step 2.

..... [1]

- (iii) Complete the equation to show the reaction in step 2.

$\text{HOCH}_2\text{CH}_2\text{CN} + \dots\dots\dots$ [1]

[Total: 10]





**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 J g ⁻¹ K ⁻¹)





The Periodic Table of Elements

Group																											
1	2	1												13	14	15	16	17	18								
		Key																									
		atomic number																									
		atomic symbol																									
		name																									
		relative atomic mass																									
3	4													5	6	7	8	9	10	11	12	13	14	15	16	17	18
Li lithium 6.9	Be beryllium 9.0													B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0							He helium 4.0		
11	12													13	14	15	16	17							10		
Na sodium 23.0	Mg magnesium 24.3													Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5							Ne neon 20.2		
19	20													31	32	33	34	35							36		
K potassium 39.1	Ca calcium 40.1													Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9							Kr krypton 83.8		
37	38													49	50	51	52	53							54		
Rb rubidium 85.5	Sr strontium 87.6													In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9							Xe xenon 131.3		
55	56													81	82	83	84	85							86		
Cs caesium 132.9	Ba barium 137.3													Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —							Rn radon —		
87	88													113	114	115	116	117							118		
Fr francium —	Ra radium —													Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —							Og oganesson —		

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids																			
57	La	lanthanum	138.9	58	Ce	cerium	140.1	59	Pr	praseodymium	140.9	60	Nd	neodymium	144.2	61	Pm	promethium	—
89	Ac	actinium	—	90	Th	thorium	232.0	91	Pa	protactinium	231.0	92	U	uranium	238.0	93	Np	neptunium	—
actinoids																			
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
71	Er	erbium	167.3	72	Tm	thulium	168.9	73	Yb	ytterbium	173.1	74	Lu	lutetium	175.0	75	Hf	hafnium	180.9
73	Ho	holmium	164.9	74	Er	erbium	167.3	75	Tm	thulium	168.9	76	Yb	ytterbium	173.1	77	Lu	lutetium	175.0
75	Gd	gadolinium	157.3	76	Tb	terbium	158.9	77	Dy	dysprosium	162.5	78	Ho	holmium	164.9	79	Er	erbium	167.3
77	Eu	europlum	152.0	78	Gd	gadolinium	157.3	79	Tb	terbium	158.9	80	Dy	dysprosium	162.5	81	Ho	holmium	164.9
79	Sm	samarium	150.4	80	Eu	europlum	152.0	81	Gd	gadolinium	157.3	82	Tb	terbium	158.9	83	Dy	dysprosium	162.5
81	Pu	plutonium	—	82	Am	americium	—	83	Cm	curium	—	84	Bk	berkelium	—	85	Cf	californium	—
83	Np	neptunium	—	84	Pu	plutonium	—	85	Am	americium	—	86	Cm	curium	—	87	Bk	berkelium	—
85	Pa	protactinium	231.0	86	U	uranium	238.0	87	Np	neptunium	—	88	Pu	plutonium	—	89	Am	americium	—
87	Th	thorium	232.0	88	Pa	protactinium	231.0	89	U	uranium	238.0	90	Np	neptunium	—	91	Pu	plutonium	—
91	Pr	praseodymium	140.9	92	Ce	cerium	140.1	93	Th	thorium	232.0	94	Pa	protactinium	231.0	95	U	uranium	238.0
93	Np	neptunium	—	94	Pu	plutonium	—	95	Am	americium	—	96	Cm	curium	—	97	Bk	berkelium	—
95	Eu	europlum	152.0	96	Gd	gadolinium	157.3	97	Tb	terbium	158.9	98	Dy	dysprosium	162.5	99	Ho	holmium	164.9
97	Tm	thulium	168.9	98	Yb	ytterbium	173.1	99	Lu	lutetium	175.0	100	Er	erbium	167.3	101	Tm	thulium	168.9
101	Lr	lawrencium	—	102	No	nobelium	—	103	Lr	lawrencium	—	104	Th	thorium	232.0	105	Pa	protactinium	231.0
103	Ac	actinium	—	104	Th	thorium	232.0	105	Pa	protactinium	231.0	106	U	uranium	238.0	107	Np	neptunium	—
105	Pr	praseodymium	140.9	106	Ce	cerium	140.1	107	Th	thorium	232.0	108	Pa	protactinium	231.0	109	U	uranium	238.0
107	Np	neptunium	—	108	Pu	plutonium	—	109	Am	americium	—	110	Cm	curium	—	111	Bk	berkelium	—
109	Eu	europlum	152.0	110	Gd	gadolinium	157.3	111	Tb	terbium	158.9	112	Dy	dysprosium	162.5	113	Ho	holmium	164.9
111	Tm	thulium	168.9	112	Yb	ytterbium	173.1	113	Lu	lutetium	175.0	114	Er	erbium	167.3	115	Tm	thulium	168.9
113	Lr	lawrencium	—	114	No	nobelium	—	115	Lr	lawrencium	—	116	Th	thorium	232.0	117	Pa	protactinium	231.0
115	Ac	actinium	—	116	Th	thorium	232.0	117	Pa	protactinium	231.0	118	U	uranium	238.0	119	Np	neptunium	—
117	Pr	praseodymium	140.9	118	Ce	cerium	140.1	119	Th	thorium	232.0	120	Pa	protactinium	231.0	121	U	uranium	238.0
119	Np	neptunium	—	120	Pu	plutonium	—	121	Am	americium	—	122	Cm	curium	—	123	Bk	berkelium	—
121	Eu	europlum	152.0	122	Gd	gadolinium	157.3	123	Tb	terbium	158.9	124	Dy	dysprosium	162.5	125	Ho	holmium	164.9
123	Tm	thulium	168.9	124	Yb	ytterbium	173.1	125	Lu	lutetium	175.0	126	Er	erbium	167.3	127	Tm	thulium	168.9
125	Lr	lawrencium	—	126	No	nobelium	—	127	Lr	lawrencium	—	128	Th	thorium	232.0	129	Pa	protactinium	231.0
127	Ac	actinium	—	128	Th	thorium	232.0	129	Pa	protactinium	231.0	130	U	uranium	238.0	131	Np	neptunium	—
129	Pr	praseodymium	140.9	130	Ce	cerium	140.1	131	Th	thorium	232.0	132	Pa	protactinium	231.0	133	U	uranium	238.0
131	Np	neptunium	—	132	Pu	plutonium	—	133	Am	americium	—	134	Cm	curium	—	135	Bk	berkelium	—
133	Eu	europlum	152.0	134	Gd	gadolinium	157.3	135	Tb	terbium	158.9	136	Dy	dysprosium	162.5	137	Ho	holmium	164.9
135	Tm	thulium	168.9	136	Yb	ytterbium	173.1	137	Lu	lutetium	175.0	138	Er	erbium	167.3	139	Tm	thulium	168.9
137	Lr	lawrencium	—	138	No	nobelium	—	139	Lr	lawrencium	—	140	Th	thorium	232.0	141	Pa	protactinium	231.0
139	Ac	actinium	—	140	Th	thorium	232.0	141	Pa	protactinium	231.0	142	U	uranium	238.0	143	Np	neptunium	—
141	Pr	praseodymium	140.9	142	Ce	cerium	140.1	143	Th	thorium	232.0	144	Pa	protactinium	231.0	145	U	uranium	238.0
143	Np	neptunium	—	144	Pu	plutonium	—	145	Am	americium	—	146	Cm	curium	—	147	Bk	berkelium	—
145	Eu	europlum	152.0	146	Gd	gadolinium	157.3	147	Tb	terbium	158.9	148	Dy	dysprosium	162.5	149	Ho	holmium	164.9
147	Tm	thulium	168.9	148	Yb	ytterbium	173.1	149	Lu	lutetium	175.0	150	Er	erbium	167.3	151	Tm	thulium	168.9
149	Lr	lawrencium	—	150	No	nobelium	—	151	Lr	lawrencium	—	152	Th	thorium	232.0	153	Pa	protactinium	231.0
151	Ac	actinium	—	152	Th	thorium	232.0	153	Pa	protactinium	231.0	154	U	uranium	238.0	155	Np	neptunium	—
153	Pr	praseodymium	140.9	154	Ce	cerium	140.1	155	Th	thorium	232.0	156	Pa	protactinium	231.0	157	U	uranium	238.0
155	Np	neptunium	—	156	Pu	plutonium	—	157	Am	americium	—	158	Cm	curium	—	159	Bk	berkelium	—
157	Eu	europlum	152.0	158	Gd	gadolinium	157.3	159	Tb	terbium	158.9	160	Dy	dysprosium	162.5	161	Ho	holmium	164.9
159	Tm	thulium	168.9	160	Yb	ytterbium	173.1	161	Lu	lutetium	175.0	162	Er	erbium	167.3	163	Tm	thulium	168.9
161	Lr	lawrencium	—	162	No	nobelium	—	163	Lr	lawrencium	—	164	Th	thorium	232.0	165	Pa	protactinium	231.0
163	Ac	actinium	—	164	Th	thorium	232.0	165	Pa	protactinium	231.0	166	U	uranium	238.0	167	Np	neptunium	—
165	Pr	praseodymium	140.9	166	Ce	cerium	140.1	167	Th	thorium	232.0	168	Pa	protactinium	231.0	169	U	uranium	238.0
167	Np	neptunium	—	168	Pu	plutonium	—	169	Am	americium	—	170	Cm	curium	—	171	Bk	berkelium	—
169	Eu	europlum	152.0	170	Gd	gadolinium	157.3	171	Tb	terbium	158.9	172	Dy	dysprosium	162.5	173	Ho	holmium	164.9
171	Tm	thulium	168.9	172	Yb	ytterbium	173.1	173	Lu	lutetium	175.0	174	Er	erbium	167.3	175	Tm	thulium	168.9
173	Lr	lawrencium	—	174	No	nobelium	—	175	Lr	lawrencium	—	176	Th	thorium	232.0	177	Pa	protactinium	231.0
175	Ac	actinium	—	176	Th	thorium	232.0	177	Pa	protactinium	231.0	178	U	uranium	238.0	179	Np	neptunium	—
177	Pr	praseodymium	140.9	178	Ce	cerium	140.1	179	Th	thorium	232.0	180	Pa	protactinium	231.0	181	U	uranium	238.0
179	Np	neptunium	—	180	Pu	plutonium	—	181	Am	americium	—	182	Cm	curium	—	183	Bk	berkelium	—
181	Eu	europlum	152.0	182	Gd	gadolinium	157.3	183	Tb	terbium	158.9	184	Dy	dysprosium	162.5	185	Ho	holmium	164.9
183	Tm	thulium	168.9	184	Yb	ytterbium	173.1	185	Lu	lutetium	175.0	186	Er	erbium	167.3	187	Tm	thulium	168.9
185	Lr	lawrencium	—	186	No	nobelium	—	187	Lr	lawrencium	—	188	Th	thorium	232.0	189	Pa	protactinium	231.0
187	Ac	actinium	—	188	Th	thorium	232.0	189	Pa	protactinium	231.0	190	U	uranium	238.0	191	Np	neptunium	—
189	Pr	praseodymium	140.9	190	Ce	cerium	140.1	191	Th	thorium	232.0	192	Pa	protactinium	231.0	193	U	uranium	238.0
191	Np	neptunium	—	192	Pu	plutonium	—	193	Am	americium	—	194	Cm	curium	—	195	Bk	berkelium	—
193	Eu	europlum	152.0	194	Gd	gadolinium	157.3	195	Tb	terbium	158.9	196	Dy	dysprosium	162.5	197	Ho	holmium	164.9
195	Tm	thulium	168.9	196	Yb	ytterbium	173.1	197	Lu	lutetium	175.0	198	Er	erbium	167.3	199	Tm	thulium	168.9
197	Lr	lawrencium	—	198	No	nobelium	—	199	Lr	lawrencium	—	200	Th	thorium	232.0	201	Pa	protactinium	231.0
199	Ac	actinium	—	200	Th	thorium	232.0	201	Pa	protactinium	231.0	202	U	uranium	238.0	203	Np	neptunium	—
201	Pr	praseodymium	140.9	202	Ce	cerium	140.1	203	Th	thorium	232.0	204	Pa	protactinium	231.0	205	U	uranium	238.0
203	Np	neptunium	—	204	Pu	plutonium	—	205	Am	americium	—	206	Cm	curium	—	207	Bk	berkelium	—
205	Eu	europlum	152.0	206	Gd	gadolinium	157.3	207	Tb	terbium	158.9	208	Dy	dysprosium	162.5	209	Ho	holmium	164.9
207	Tm	thulium	168.9	208	Yb	ytterbium	173.1	209	Lu	lutetium	175.0	210	Er	erbium	167.3	211	Tm	thulium	168.9
209	Lr	lawrencium	—	210	No	nobelium	—	211	Lr	lawrencium	—	212	Th	thorium	232.0	213	Pa	protactinium	231.0
211	Ac	actinium	—	212	Th	thorium	232.0	213	Pa	protactinium	231.0	214	U	uranium	238.0	215	Np	neptunium	—
213	Pr	praseodymium	140.9	214	Ce	cerium	140.1	215	Th	thorium	232.0	216	Pa	protactinium	231.0	217	U	uranium	238.0
215	Np	neptunium	—	216	Pu	plutonium	—	217	Am	americium	—	218	Cm	curium	—	219	Bk	berkelium	—
217	Eu	europlum	152.0	218	Gd	gadolinium	157.3	219	Tb	terbium	158.9	220	Dy	dysprosium	162.5	221	Ho	holmium	164.9
219	Tm	thulium	168.9	220	Yb	ytterbium	173.1	221	Lu	lutetium	175.0	222	Er	erbium	167.3	223	Tm	thulium	168.9
221	Lr	lawrencium	—	222	No	nobelium	—	223	Lr	lawrencium	—	224	Th	thorium	232.0	225	Pa	protactinium	231.0
223	Ac	actinium	—	224	Th	thorium	232.0	225	Pa	protactinium	231.0	226	U	uranium	238.0	227	Np	neptunium	—
225	Pr	praseodymium	140.9	226	Ce	cerium	140.1	227	Th	thorium	232.0	228	Pa	protactinium	231.0	229	U	uranium	238.0
227	Np	neptunium	—	228	Pu	plutonium	—	229	Am	americium	—	230	Cm						



Cambridge International AS & A Level

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CHEMISTRY

9701/24

Paper 2 AS Level Structured Questions

May/June 2025

1 hour 15 minutes

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

INFORMATION

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

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



1 Elements in Period 3 of the Periodic Table show trends in their properties.

(a) Complete Table 1.1 by identifying the lattice structures of the crystalline solids of Mg, Si and P.

Table 1.1

element	Mg	Si	P
lattice structure in crystalline solid			

[3]

(b) The relative electrical conductivities of the Period 3 elements are shown in Fig. 1.1.

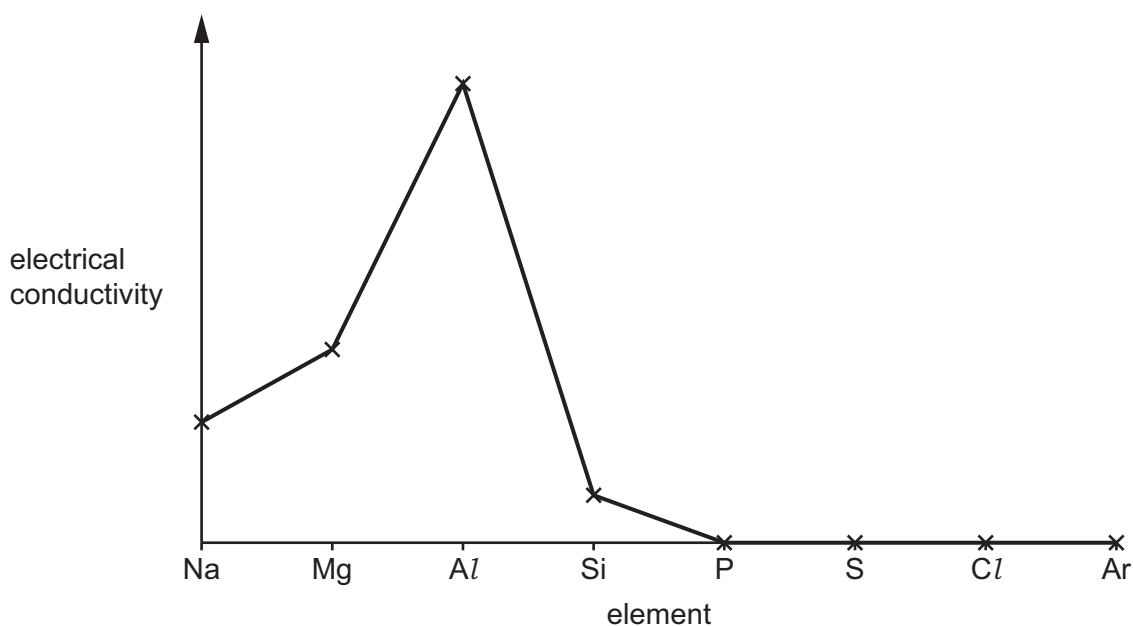


Fig. 1.1

Explain why there is an increase in conductivity from Na to Al and why P, S and Cl are non-conductors of electricity.

.....

.....

.....

.....

.....

[2]





(c) The **third** ionisation energies of the Period 3 elements are shown in Fig. 1.2.

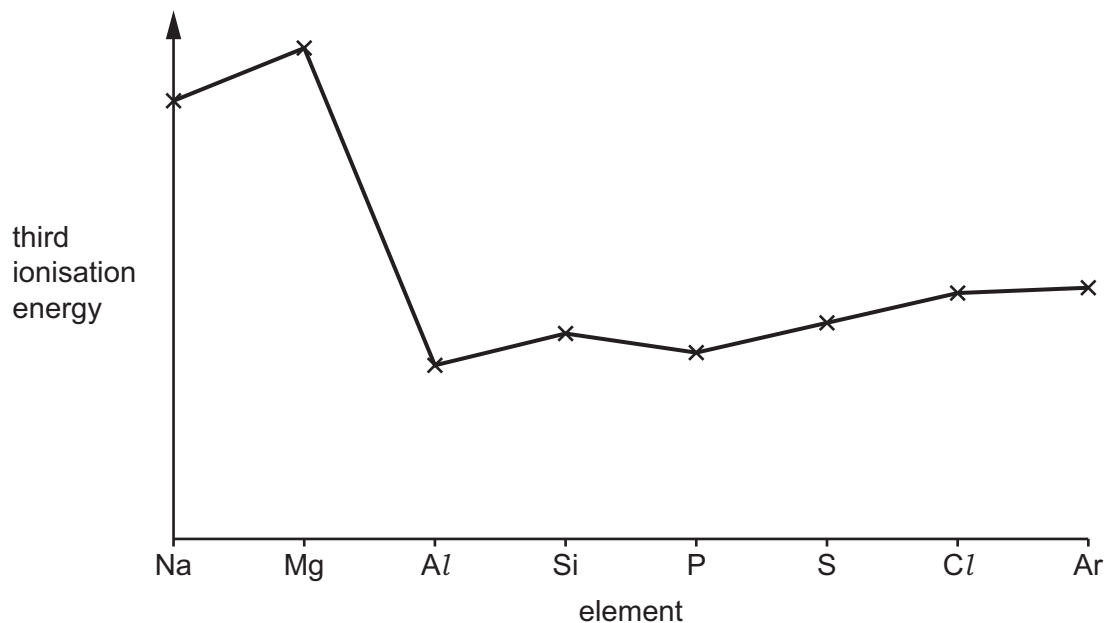


Fig. 1.2

- (i) Write an equation, including state symbols, to represent the **third** ionisation energy of argon.

..... [2]

- (ii) The differences in the values for third ionisation energy shown in Fig. 1.2 are due to differences in the strength of attraction between the nucleus and the outer electron of each ion.

State **two** factors that affect the strength of attraction between the nucleus and the outer electron.

1

2 [2]

- (iii) Use Fig. 1.2 to suggest the most significant factor that determines the size of attraction between the nucleus and the outer electron. Explain your answer.

.....

.....

..... [2]





- (iv) In the third ionisation energy of argon, the ion produced has the electronic configuration $1s^2 2s^2 2p^6 3s^2 3p^3$.

Complete Fig. 1.3 to show the arrangement of electrons in the orbitals of this ion.

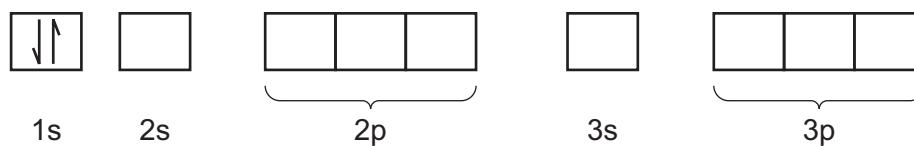


Fig. 1.3

[1]

- (d) Most Period 3 elements react with oxygen to form oxides.

- (i) Write an equation for the reaction of phosphorus with oxygen.

..... [1]

- (ii) Write an equation for the reaction of aluminium oxide with an excess of aqueous sodium hydroxide.

..... [1]

[Total: 14]





- 2 (a) Fig. 2.1 shows the covalent bonds and lone pairs of electrons in a molecule of SCl_2 .

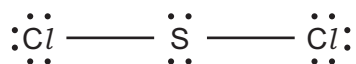


Fig. 2.1

- (i) Use VSEPR theory to predict the shape of a molecule of SCl_2 .

..... [1]

- (ii) Predict the bond angle in a molecule of SCl_2 .

..... ° [1]

- (b) SCl_2 is a red liquid that reacts with water.



- (i) Describe **two** observations, other than temperature change, that are made when an excess of water is added to SCl_2 .

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

- (ii) When SCl_2 reacts with water, the SCl_2 is broken down and a disproportionation reaction occurs.

State the oxidation numbers of sulfur in SCl_2 and H_2SO_3 .

oxidation number of S in SCl_2

oxidation number of S in H_2SO_3 [2]

- (iii) State the general name to describe the type of reaction that occurs when a substance is broken down by water.

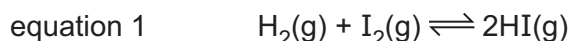
..... [1]

[Total: 7]





- 3 $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ react to form $\text{HI}(\text{g})$ in a reversible reaction, as shown in equation 1.



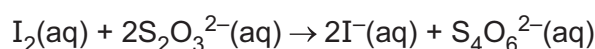
In three separate experiments, a student combines different amounts of two or more of the gases from equation 1. In each experiment, the gases are left to reach equilibrium at a given temperature.

- (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]





- (c) In experiment 3, 0.0772 mol of H_2 and 0.0986 mol of I_2 are present in an equilibrium mixture at 298 K.



Use the equilibrium constant, K_c , to calculate the amount, in mol, of HI present in the equilibrium mixture in experiment 3.

amount of HI in equilibrium mixture = ... mol [1]

- (d) The value of K_c for the dissociation of HCl at 298 K is 5.50×10^{-34} .



- (i) Define covalent bond.

.....
 [1]

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

.....

 [2]

- (iii) Use the data given in (c) and (d) to suggest a value for the equilibrium constant for the **dissociation** of $\text{HBr}(\text{g})$ at 298 K.

..... [1]

[Total: 11]





4 The skeletal formula of **E** is shown in Fig. 4.1.

E

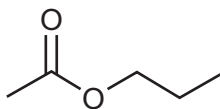


Fig. 4.1

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

..... [1]

(b) Name **E**.

..... [1]

(c) **E** is made when a carboxylic acid and an alcohol react together.

(i) Name the type of reaction that takes place during this esterification reaction.

..... [1]

(ii) Write an equation for the formation of **E** from a carboxylic acid and an alcohol. Use structural formulae to represent the organic species.

..... [1]

(iii) State the systematic name of the alcohol used to make **E**.

..... [1]





(d) **F** is an isomer of **E**.

F reacts with HCl(aq) to produce **G** and **H**.

G is a secondary alcohol.

H is also produced when HCl(aq) is added to CH_3CN .

(i) Construct an equation for the acid hydrolysis of CH_3CN with HCl(aq) .

..... [1]

(ii) Draw the displayed formula of **G**.

[2]

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

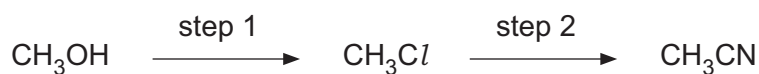


Fig. 4.2

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

step 1

step 2

[3]

[Total: 11]





5 The skeletal formula of **W** is shown in Fig. 5.1.

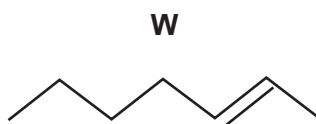


Fig. 5.1

(a) **W** has two positional isomers. Only one shows stereoisomerism.

Draw the structures of the **two** positional isomers of **W** in the boxes.



[2]

(b) (i) Describe the origin of stereoisomerism in **W**.

.....
 [1]

(ii) State why **W** shows stereoisomerism but one of the positional isomers in (a) does **not**.

.....

 [1]

(c) Draw the skeletal structure of the stereoisomer of **W**.

[1]



(d) **W** reacts with reagent **X** to produce ethanoic acid and pentanoic acid.

(i) State the role of **X** in this reaction.

..... [1]

(ii) Identify **X** and state the conditions used for this reaction.

.....

..... [1]

[Total: 7]





6 **P**, **Q** and **R** are three different hydrocarbon molecules.

(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]

(b) **Q** is a volatile hydrocarbon.

0.194 g of gaseous **Q** occupies a volume of 71.5 cm^3 at 100°C and 100 kPa.

Use the ideal gas equation to calculate the M_r of **Q**.

M_r of **Q** = ... [2]



- (c) The mass spectrum of hydrocarbon **R** is recorded.
Information about the two peaks with m/e greater than 135 is shown in Fig. 6.1.

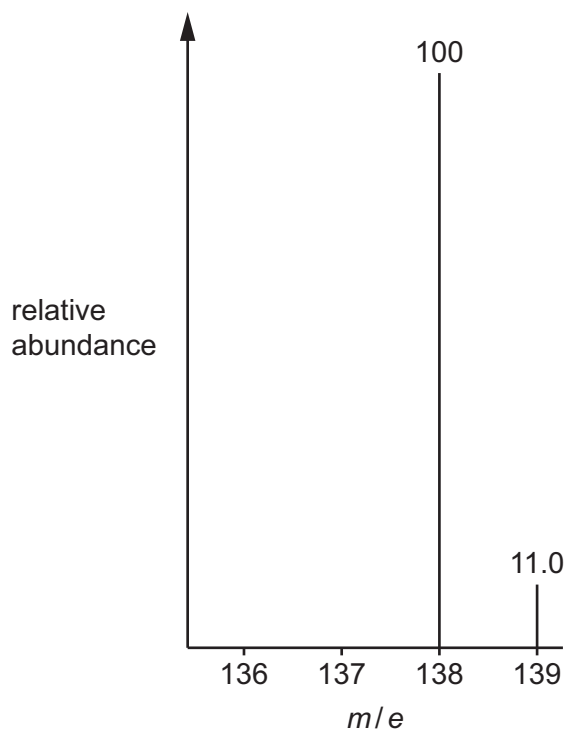


Fig. 6.1

- (i) Use Fig. 6.1 to deduce the number of carbon atoms in a molecule of **R**.

Show your working.

number of carbon atoms = ... [2]

- (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]





**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 J g ⁻¹ K ⁻¹)



Group																	
1	2		Group														
			1 H hydrogen 1.0														
			Key														
			atomic number atomic symbol name relative atomic mass														
3	4																
Li lithium 6.9	Be beryllium 9.0																
11	12																
Na sodium 23.0	Mg magnesium 24.3																
		3	4	5	6	7	8	9	10	11	12						
19	20	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4						
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3
55	56	57–71 lanthanoids	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Cs caesium 132.9	Ba barium 137.3	Hf hafnium 178.5		Ta tantalum 180.9	W tungsten 183.8	Re rhenium 186.2	Os osmium 190.2	Ir iridium 192.2	Pt platinum 195.1	Au gold 197.0	Hg mercury 200.6	Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —
87	88	89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
Fr francium —	Ra radium —	Rf rutherfordium —		Db dubnium —	Sg seaborgium —	Bh bohrium —	Hs hassium —	Mt meitnerium —	Ds darmstadtium —	Rg roentgenium —	Cn copernicium —	Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganesson —

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	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	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	209.0
85	At	astatine	210.0
86	Rn	radon	222.0
87	Fr	francium	223.0
88	Ra	radium	226.0
89	Ac	actinium	227.0
90	Th	thorium	232.0
91	Pa	protactinium	231.0
92	U	uranium	238.0
93	Np	neptunium	237.0
94	Pu	plutonium	244.0
95	Am	americium	243.0
96	Cm	curium	247.0
97	Bk	berkelium	247.0
98	Cf	californium	251.0
99	Es	einsteinium	252.0
100	Fm	fermium	257.0
101	Md	mendelevium	258.0
102	No	nobelium	259.0
103	Lr	lawrencium	262.0

89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
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