Cambridge Assessment
International Education

Cambridge International AS & A Level

1: Particles – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
1	2017	March	22
1	2017	June	21
1	2017	June	22

The mark scheme for each question is provided at the end of the document.

1 **(a)** The table shows information about some of the elements in the third period.

element	Na	Mg	A*l*	P	S	C*l*
atomic radius / nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion / nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(i) Complete the table to show the maximum oxidation number of each element in its compounds. [1]

(ii) Explain why the atomic radius of elements in the third period decreases from Na to C*l*.

....

....

....

....

.... [3]

(iii) The radius of the most common ion of Mg is much smaller than the radius of the most common ion of S.

Identify both ions and explain the difference in their radii.

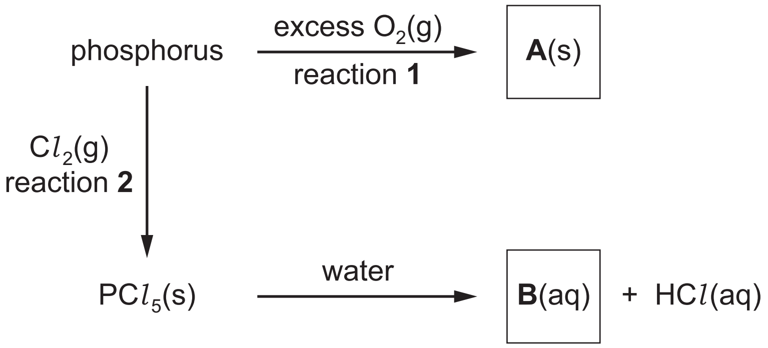
....

....

.... [2]

(b) Phosphorus is a non-metal in the third period. It reacts vigorously with excess oxygen but slowly with chlorine.

Some reactions of phosphorus are shown.



(i) Write an equation to represent reaction **1**, the formation of compound **A**.

.... [1]

(ii) Give **two** observations you could make in reaction **2**.

1. ....

2. ....

[2]

(iii) Name compound **B**.

.... [1]

(c) Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in the third period. Most of cerium's compounds contain Ce^{3+} or Ce^{4+} ions.

(i) Cerium shows the same structure and bonding as a typical metal.

Draw a labelled diagram to show the structure and bonding in cerium.

[2]

(ii) Cerium(IV) oxide, CeO_2, is a ceramic.

Suggest **two** physical properties of cerium(IV) oxide.

1. ....

2. ....
[2]

(iii) A naturally occurring sample of cerium contains only **four** isotopes. Data for **three** of the isotopes are shown in the table.

isotope	^{136}Ce	^{138}Ce	^{140}Ce	^{142}Ce
relative isotopic mass	135.907	137.906	139.905	to be calculated
percentage abundance	0.185	0.251	88.450	to be calculated

The A_r of the sample is 140.116.

Use these data to calculate the **relative isotopic mass** of the fourth isotope in this sample of cerium.

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

relative isotopic mass = ... [3]

[Total: 17]

1 Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds.

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

....

....

....

.... [2]

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

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

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

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

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

$$C_xH_yO + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

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

x = ... [1]

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

y = ... [1]

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

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

.... + ...O_2 → ....CO_2 + ...H_2O

[1]

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

Name each alcohol.

....

....

[2]

(v) Use the general gas equation to calculate the mass of **T** present in the original 20 cm^3 gaseous sample, which was measured at 120 °C and 100 kPa.

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

mass = ... g [3]

[Total: 10]

1 The composition of atoms and ions can be determined from knowledge of atomic number, nucleon number and charge.

(a) Complete the table.

atomic number	nucleon number	number of electrons	number of protons	number of neutrons	symbol
3		2			${}^{6}_{3}Li^{+}$
		23	26	32	

[2]

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

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

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

....

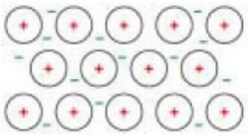
.... [2]

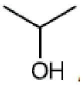
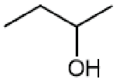
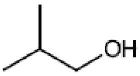
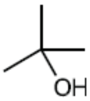
(ii) Calculate the relative isotopic mass of ${}^{11}B$.

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

[2]

[Total: 6]

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>1 (a) (i)</td><td><table><tr><td>max O.N.</td><td>+1</td><td>(+)2</td><td>(+)3</td><td>(+)5</td><td>(+)6</td><td>+7</td></tr></table></td><td>1</td></tr>
<tr><td rowspan="3">1 (a) (ii)</td><td>(from Na to C<i>l</i>) nuclear charge increases</td><td>1</td></tr>
<tr><td>electrons are in the same shell / have same shielding</td><td>1</td></tr>
<tr><td>greater / stronger attraction (of electrons to nucleus)</td><td>1</td></tr>
<tr><td rowspan="2">1 (a) (iii)</td><td>Mg^{2+} AND S^{2-}</td><td>1</td></tr>
<tr><td>ion of Mg / Mg^{2+} has one fewer shell (than ion of S / S^{2-})</td><td>1</td></tr>
<tr><td>1 (b) (i)</td><td>$P_4 + 5O_2 \rightarrow P_4O_{10}$ / $2P_2O_5$</td><td>1</td></tr>
<tr><td>1 (b) (ii)</td><td>any 2 from:
• yellow / green colour (of chlorine gas) disappears
• white flame
• white solid
• solid melts</td><td>2</td></tr>
<tr><td>1 (b) (iii)</td><td>Phosphoric(V) acid</td><td>1</td></tr>
<tr><td rowspan="3">1 (c) (i)</td><td></td><td>2</td></tr>
<tr><td><u>diagram</u> showing regular arrangement of (positive) ions</td><td>1</td></tr>
<tr><td>surrounded by / sea of (delocalised) electrons</td><td>1</td></tr>
<tr><td>1 (c) (ii)</td><td>any 2 from:
• high melting / boiling / sublimation point
• electrical / thermal insulator
• hard / rigid
• retains strength at high temperature / pressure</td><td>2</td></tr>
<tr><td rowspan="3">1 (c) (iii)</td><td>M1
% abundance of fourth isotope
$= 100 - (0.185 + 0.251 + 88.450) = 11.114$</td><td>1</td></tr>
<tr><td>M2
$\frac{(0.185 \times 135.907) + (0.251 \times 137.906) + (88.450 \times 139.905) + (11.114 \times RIM)}{100}$
$= 140.116$
$\therefore (140.116 \times 100) - 12434.35 = 1577.246 = 11.114 \times RIM$</td><td>1</td></tr>
<tr><td>M3
$RIM = \frac{1577.246}{11.114} = 141.915$</td><td>1</td></tr>
<tr><td></td><td></td><td>Total: 12</td></tr>
</table>

Question	Answer	Marks
1 (a)	The mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecules	**1**
	Relative / compared to $\frac{1}{12}$ (the mass) of an atom of carbon-12 OR on a scale in which a carbon-12 atom / isotope has a mass of (exactly) 12 (units)	**1**
1 (b) (i)	**3**	**1**
1 (b) (ii)	**8**	**1**
1 (b) (iii)	$C_3H_8O + 4\frac{1}{2}O_2 = 3CO_2 + 4H_2O$	**1**
1 (b) (iv)	 **AND** propan-2-ol / 2-propanol	**1**
	 **AND** propan-1-ol / 1-propanol	**1**
	Alternative answers (any two):  **AND** butan-1-ol / 1-butanol  **AND** butan-2-ol / 2-butanol  **AND** (2-)methylpropan-1-ol / (2-)methyl-1-propanol  **AND** (2-)methylpropan-2-ol / (2-)methyl-2-propanol	
1 (b) (iv)	correct conversions of data to SI / consistent units $p = 100\,000$; $V = 20 \times 10^{-6}$; $T = 393$	**1**
	calculation of n ($= pV/RT$) from M1 values $n = \frac{100 \times 10^{3} \times 20 \times 10^{-6}}{8.31 \times 393}$	**1**
	calculation of mass m ($= n \times Mr$) **AND** answer correct to **3sf** $m = 6.12 \times 10^{-4} \times 60 = 0.0367$ (g) alternative answer for using $C_4H_{10}O$: $m = 6.12 \times 10^{-4} \times 74 = 0.0453$ (g)	**1**
		Total: 10

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>1 (a)</td><td><table>
<tr><th>atomic number</th><th>nucleon number</th><th>number of electrons</th><th>number of protons</th><th>number of neutrons</th><th>symbol</th></tr>
<tr><td></td><td>6</td><td></td><td>3</td><td>3</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>$^{58}_{26}\text{Fe}^{3+}$</td></tr>
</table></td><td>2
1
1</td></tr>
<tr><td>1 (b) (i)</td><td>EITHER
mass of an atom / isotope
relative / compared to 1/12 (the mass) of (an atom of) C-12 OR
on a scale in which a C-12 (atom / isotope) has (a mass of exactly) 12 (units)
OR
mass of one mol (atoms) of an isotope
relative / compared to 1/12 (the mass) of 1 mol of C-12 OR
on a scale in which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g</td><td>2
1
1</td></tr>
<tr><td>1 (b) (ii)</td><td>$\frac{(10.0129 \times 19.78) + (80.22x)}{100} = 10.8$</td><td>1</td></tr>
<tr><td></td><td>x = 10.9941</td><td>1</td></tr>
<tr><td></td><td></td><td>Total: 6</td></tr>
</table>

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

2: Bonding and structure – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
2	2017	March	22
2	2017	June	21
2	2017	June	22

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

22 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HFF	$\mathrm{HC}l$	HBr	HI
boiling point / °C	19	–855	–67	–35
H–X bond energy / $\mathrm{KJ\,mol^{-1}}$	562	431	366	299

(a) **(i)** Explain the meaning of the term *bond polarity*.

....

....

.... [1]

(ii) Suggest why the boiling point of HF is **much** higher than the boiling points of the other hydrogen halides.

....

....

....

....

.... [2]

(iii) Describe and explain the relative thermal stabilities of the hydrogen halides.

....

....

....

....

....

.... [3]

(b) The equation for the preparation of hydrogen chloride using concentrated sulfuric acid is shown.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 ++ HCl$$

(i) Use the Brønsted-Lowry theory of acids and bases to identify the base and its conjugate acid in this reaction. Explain your answer.

Brønsted-Lowry base (base-I) = ...

conjugate acid (acid-II) = ...

....

....

....

[2]

(ii) Explain why the reaction of concentrated sulfuric acid and sodium iodide is **not** suitable for the preparation of hydrogen iodide.

....

....

....

.... [2]

(c) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(i) Use the data in the table to calculate the overall enthalpy change of reaction.

compound	enthalpy change of formation / $kJ\,mol^{-1}$
$HCl(g)$	–92
$H_2O(g)$	–242

enthalpy change of reaction = ... $kJ\,mol^{-1}$ [2]

(ii) State the **type** of catalyst used in this reaction. Explain how a catalyst is able to increase the rate of a chemical reaction.

....

....

....

.... [2]

(iii) The reaction exists in dynamic equilibrium.

The reaction was repeated at 1000 °C and the same pressure.

State and explain the effect on the composition of the equilibrium mixture of the change in temperature.

....

....

....

.... [2]

(iv) When 1.60 mol of HCl are mixed in a sealed container with 0.500 mol of O_2 at 400 °C, 0.600 mol of Cl_2 and 0.600 mol of H_2O are formed. The

total pressure inside the container is 1.50×10^5 Pa.

- Calculate the amounts, in mol, of HCl and O_2 in the equilibrium mixture.

HCl = ... mol

O_2 = ... mol

- Calculate the mole fraction of Cl_2 and hence the partial pressure of Cl_2 in the equilibrium mixture.

mole fraction of Cl_2 = ...

p_{Cl_2} = ... Pa

[3]

(v) In a separate experiment, an equilibrium reaction mixture was found to contain the four gases at the partial pressures shown in the table.

gas	HCl	O_2	Cl_2	H_2O
partial pressure / Pa	4.8×10^4	3.0×10^4	3.6×10^4	3.6×10^4

$$K_p = \frac{(p_{Cl_2})^2 \times (p_{H_2O})^2}{(p_{HCl})^4 \times p_{O_2}}$$

Use this information and the expression given for K_p to calculate a value for K_p. State the units of K_p.

K_p = ...

units = ...
[2]

(vi) The reaction is repeated without a catalyst.

State the effect of this on K_p.

.... [1]

[Total: 22]

2 Nitrogen gas, N_2, is very unreactive.

(a) Explain why nitrogen gas is so unreactive.

....

....

.... [2]

(b) Despite the low reactivity of N_2, oxides of nitrogen occur in the atmosphere through both natural and man-made processes.

(i) Explain why oxides of nitrogen can be produced by internal combustion engines.

....

....

.... [2]

(ii) State and explain, using a suitable equation, how oxides of nitrogen produced by internal combustion engines can be prevented from reaching the atmosphere.

....

.... [2]

(iii) State the role of nitrogen dioxide, NO_2, in the formation of acid rain by oxides of sulfur. Write suitable equations to explain this role.

role ....

equation 1 ....

equation 2 ....

[3]

(iv) Suggest an equation to show how NO_2 can contribute **directly** to acid rain.

.... [1]

(c) Explain how the uncontrolled use of nitrate fertilisers on land can lead to a severe reduction in water quality in rivers.

....

....

....

.... [3]

[Total: 13]

2 Structure and bonding can be used to explain many of the properties of substances.

(a) Copper, ice, silicon(IV) oxide, iodine and sodium chloride are all crystalline solids.

Complete the table with:

- the name of a type of bonding found in each crystalline solid,
- the type of lattice structure for each crystalline solid.

crystalline solid	type of bonding	type of lattice structure
copper		
ice		
silicon(IV) oxide		
iodine		
sodium chloride		

[5]

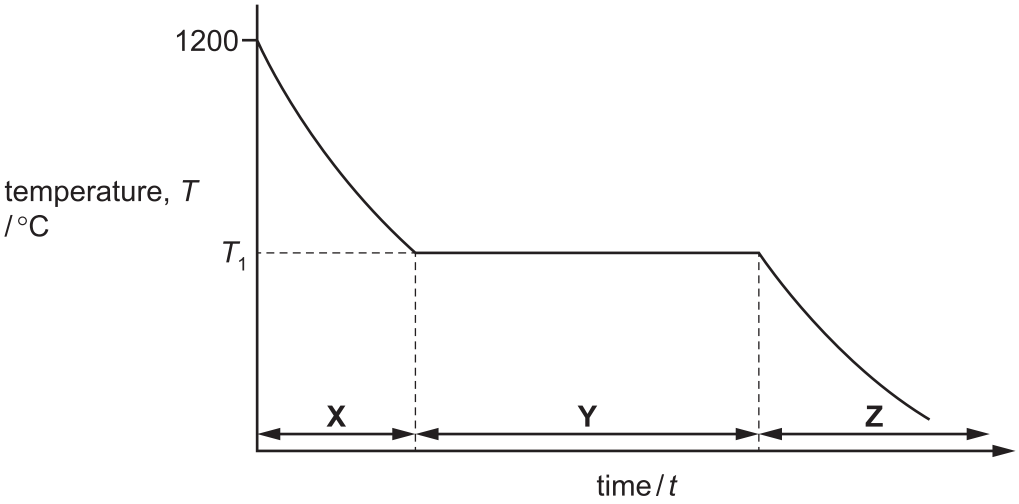
(b) **(i)** Name the strongest type of intermolecular force in ice.

.... [1]

(ii) Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

(c) The graph represents how the temperature of a sample of copper (melting point 1085 °C) changes as it is gradually cooled from 1200 °C.



(i) Identify the state(s) of matter present during each stage of the process shown in the graph.

X ....

Y ....

Z ....
[2]

(ii) State what is happening to the energy and movement of the particles in the copper during stage **X**.

....

....

.... [2]

(iii) Explain why the temperature stays constant at T_1 during stage **Y**.

....

....

....

.... [2]

[Total: 15]

Question	Answer	Marks
2 (a) (i)	bond in which the centres of positive and negative charges do not coincide **OR** electron distribution is asymmetric / unequal **OR** two (bonded) atoms are partially charged	**1**
2 (a) (ii)	HF has the strongest (permanent) dipole–dipole / van der Waals' (forces) / HF has hydrogen bonding	**1**
	requires more energy to overcome (than weaker (permanent) dipole–dipole / van der Waals' forces between other hydrogen halides)	**1**
2 (a) (iii)	thermal stability of the hydrogen halides decreases down group (17)	**1**
	larger (halogen) atoms / atomic radius (down group) / increased shielding	**1**
	bond energies decrease / less energy required to break H–X	**1**
2 (b) (i)	**M1** Base is Cl^- AND conjugate acid is HCl OR Base is HSO_4^- AND conjugate acid is H_2SO_4	**1**
	M2 Cl^- / HSO_4^- / base is a proton acceptor OR HCl / H_2SO_4 / (conjugate) acid has more H^+	**1**
2 (b) (ii)	H_2SO_4 is (too strong) an oxidising agent I_2 would be formed instead	**1** **1**
2 (c) (i)	$\Delta_rH = \Delta_rH$ {products} – Δ_rH {reactants} = 2 × (−242) − 4 × (−92)	**1**
	= −116 (sign **AND** answer)	**1**
2 (c) (ii)	heterogeneous (catalyst)	**1**
	provides an alternative pathway or lower activation energy	**1**
2 (c) (iii)	reaction is exothermic	**1**
	(increased temperature) shifts equilibrium to the left AND decreases yield of products (Cl_2 and / or H_2O) / less product formed	**1**

Continues on next page …

Question	Answer					Marks
2 (c) (iv)		HCl	O_2	Cl_2	H_2O	**3**
	Initial number of moles	1.60	0.500	0	0	
	M1 eqm number of moles	1.60 – 2 × 0.600 = 0.400	0.500 – ½ × 0.600 = 0.200	0.600	0.600	
	M2 mole fraction			0.600 / 1.80		
	M3 partial pressure			0.600 / 1.80 × p_{tot} = 5.00 × 10^4		
2 (c) (v)	$Kp = \frac{(3.6 \times 10^4)^2 \times (3.6 \times 10^4)^2}{(4.8 \times 10^4)^4 \times 3.0 \times 10^4} = 1.05 \times 10^{-5}$					**1**
	units = Pa^{-1}					**1**
2 (c) (vi)	*Kp* would not change					**1**
						Total: 22

Question	Answer			Marks
2 (a)	substance	type of bonding	type of lattice structure	**1** **1** **1** **1** **1**
	copper	metallic	giant / metallic	
	ice	covalent OR hydrogen(-bonding) / H(-bonding)	hydrogen-bonded / simple / molecular	
	silicon(IV) oxide	covalent	giant (molecular) / macromolecular	
	iodine	covalent	simple / molecular	
	sodium chloride	ionic	giant / ionic	
2 (b) (i)	hydrogen bonding			**1**
2 (b) (ii)	H-bond between O and H of different molecules			**1**
	minimum three partial charges (in a row) over two H_2O molecules, i.e.: either $^{\delta-}O—H^{\delta+}$ - - - - $^{\delta-}O$ or $H^{\delta+}$ - - - - $^{\delta-}O—H^{\delta+}$			**1**
	lone pair of electrons on O of H-bond, in line with H-bond			**1**

Continues on next page …

Question	Answer	Marks
2 (c) (i)	X = liquid AND Z = solid	**1**
	Y = liquid and solid OR ‘liquid / solid’ OR ‘liquid or solid’	**1**
2 (c) (ii)	(kinetic) energy reducing	**1**
	motion slowing *owtte*	**1**
2 (c) (iii)	energy given out / released forming bonds / forming bonds exothermic	**1**
	compensates for / counteracts heat loss / cooling *owtte*	**1**
		Total: 15

Question	Answer	Marks
2 (a)	strong triple bond	**1**
	non-polar / no dipole	**1**
2 (b) (i)	any 2 points covered correctly scores 2 marks; any 1 point covered correctly scores 1 mark • nitrogen (and oxygen) from the air / atmosphere (react): • high temperature (of internal combustion engine) / (engine) produces enough OR a lot of heat (energy); • (so) breaks (strong) bond(s) in nitrogen (and oxygen)	**2**
2 (b) (ii)	reduction / decomposition of NO_x using a catalyst / catalytic converter	**1**
	$2NO_2 + 4CO \rightarrow 4CO_2 + N_2$ OR $2NO + 2CO \rightarrow 2CO_2 + N_2$	**1**
2 (b) (iii)	(acts as a homogenous) catalyst OR oxidising agent	**1**
	$SO_2 + NO_2 \rightarrow SO_3 + NO$	**1**
	$NO + ½O_2 \rightarrow NO_2$ OR $SO_3 + H_2O \rightarrow H_2SO_4$	**1**
2 (b) (iv)	$2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ OR $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$	**1**

Continues on next page …

Question	Answer	Marks
2 (c)	fertiliser / nitrates dissolve in (river water) OR fertiliser / nitrates are washed / leached out / flows into (river water)	**1**
	algal bloom / promote algal growth / explosion of plant growth AND EITHER sunlight is blocked out (preventing photosynthesis) / plants can no longer carry out photosynthesis (and die) OR bacteria break down or decay dead organisms / plants / algae	**1**
	drop in oxygen (concentration)	**1**
		Total: 13

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

3: Controlling reactions 1 – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners’ understanding of this topic.

Question	Year	Series	Paper number
3	2017	June	22
3	2017	June	23
1	2017	November	21

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3 The hydrogen halides, HCl, HBr and HI, can undergo thermal decomposition.
In a sealed container an equilibrium is established according to the equation shown.

$$2HX(g) \rightleftharpoons H_2(g) + X_2(g) \qquad \text{(where X = C}l\text{, Br or I)}$$

(a) Some bond energies are shown in the table.

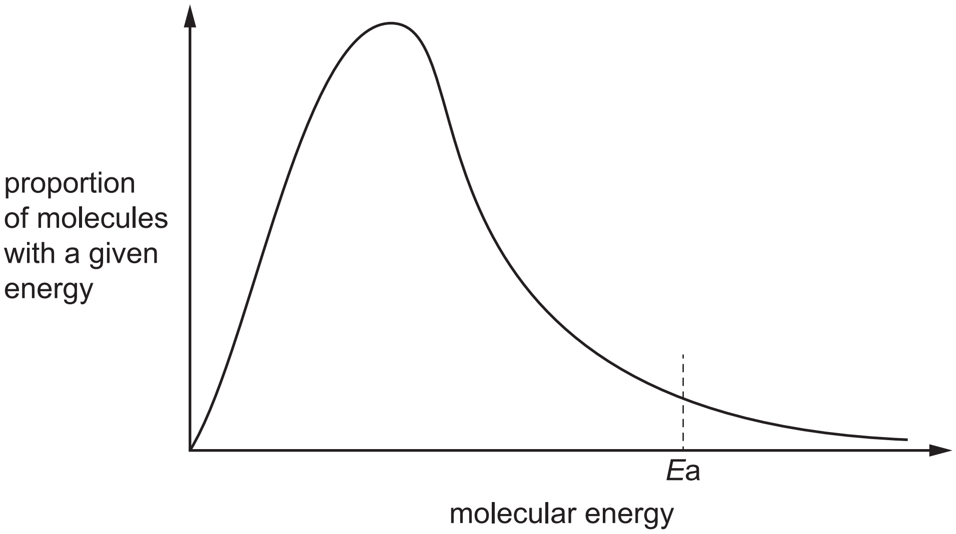
	bond energy / kJ mol^{-1}
H–Br	366
H–H	436
Br–Br	193

Use these data to calculate a value for the enthalpy change, Δ*H*, for the thermal decomposition of hydrogen bromide, HBr, according to the equation shown.

Δ*H* = ... kJ mol^{-1} [1]

(b) At a temperature of 700 K a sample of HBr is approximately 10% decomposed. Changing the temperature affects both the rate of decomposition of HBr and the percentage that decomposes.

The Boltzmann distribution for a sample of HBr at 700 K is shown. *E*a represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) With reference to the curves, state and explain the effect of increasing temperature on the rate of decomposition of HBr.

....

....

....

.... [3]

(iii) The decomposition of HBr is endothermic.

State the effect of increasing temperature on the percentage of HBr that decomposes. Use Le Chatelier's principle to explain your answer.

....

....

....

.... [3]

(iv) At 700 K HBr is approximately 10% decomposed but hydrogen iodide, HI, is approximately 20% decomposed.

Explain this difference with reference to bond strengths and the factors that affect them.

....

....

....

.... [3]

(c) At temperatures above 1500 K, HCl will decompose.

A sample of 0.300 mol of HCl decomposed in a sealed container.

The resulting equilibrium mixture was found to contain 1.50×10^{-2} mol of Cl_2.

(i) Calculate the amounts, in mol, of H_2 and HCl present in the equilibrium mixture.

H_2 = ... mol

HCl = ... mol

[2]

(ii) Calculate the mole fraction of each gas in the equilibrium mixture.

mole fraction of HCl = ...

mole fraction of H_2 = ...

mole fraction of Cl_2 = ...

[1]

(d) In another experiment under different conditions, an equilibrium mixture was produced with mole fractions for each species as shown.

species	mole fraction
HCl	0.88
H_2	0.06
Cl_2	0.06

(i) Write the expression for the equilibrium constant, K_p, for the decomposition of HCl.

$$2HCl(g) \rightleftharpoons H_2(g) + Cl_2(g)$$

K_p =

[1]

(ii) Explain why the total pressure of the system does **not** need to be known for K_p to be calculated for this experiment.

....

.... [1]

(iii) Calculate the value of K_p for this experiment.

K_p = ... [1]

[Total: 18]

3 Sulfur trioxide, SO_3, is manufactured from sulfur dioxide and oxygen by the Contact process.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196.0\,kJ\,mol^{-1}$$

(a) The enthalpy change of formation of SO_2, ΔH_f $SO_2(g)$, is $-296.8\,kJ\,mol^{-1}$.

(i) Define the term *enthalpy change of formation*.

....

....

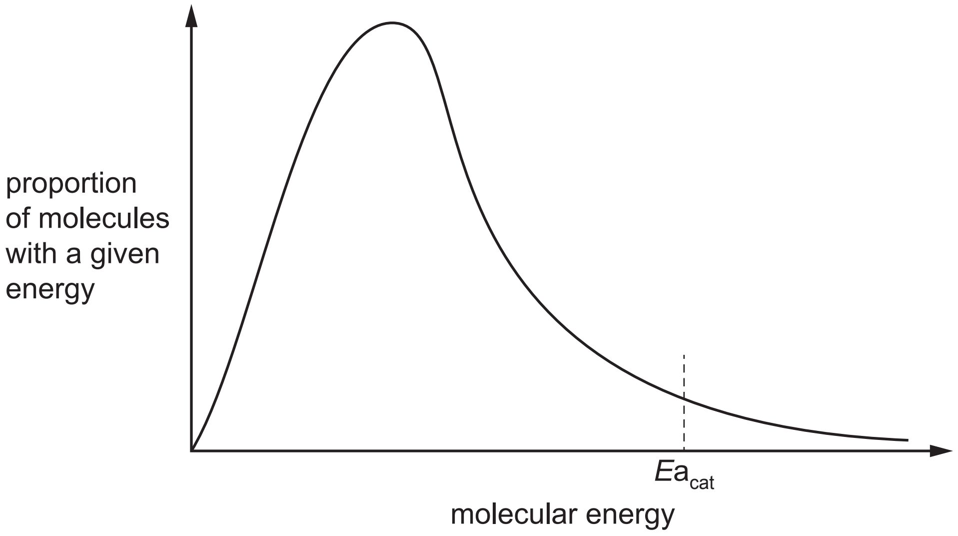
.... [2]

(ii) Use the data to calculate the enthalpy change of formation of $SO_3(g)$.

ΔH_f $SO_3(g)$ = ... $kJ\,mol^{-1}$ [2]

(b) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5.

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.
Ea_{cat} represents the activation energy for the reaction in the presence of the catalyst.



(i) Add a labelled mark, Ea_{uncat}, to the diagram to indicate the activation energy in the absence of the catalyst. [1]

(ii) State the benefit of using a catalyst in this reaction. Explain how it achieves this effect.

....

....

....

.... [2]

(iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate ....

....

....

....

yield ....

....

....

....
[4]

(c) At a pressure of 1.50×10^5 Pa, 1.00 mol of sulfur dioxide gas, SO_2, was mixed with 1.00 mol of oxygen gas, O_2. The final equilibrium mixture formed was found to contain 0.505 mol of O_2.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

(i) Calculate the amount, in mol, of SO_2 and SO_3 in the equilibrium mixture.

SO_2 = ... mol

SO_3 = ... mol

[1]

(ii) Calculate the partial pressure of oxygen gas, pO_2, in the equilibrium mixture.

pO_2 = ... Pa [2]

(d) In another equilibrium mixture formed from different starting amounts of SO_2 and O_2, the partial pressures of SO_2, O_2 and SO_3 were as shown.

$p\mathrm{SO_2} = 8.42 \times 10^2\,\mathrm{Pa}$

$p\mathrm{O_2} = 6.00 \times 10^4\,\mathrm{Pa}$

$p\mathrm{SO_3} = 9.10 \times 10^4\,\mathrm{Pa}$

(i) Write the expression for the equilibrium constant, K_p, for the production of SO_3 from SO_2 and O_2.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction and state the units.

K_p = ...

units = ...

[2]

[Total: 17]

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

$N\equiv N = 944\,kJ\,mol^{-1}$
$H–H = 436\,kJ\,mol^{-1}$

(i) Explain the meaning of the term *bond energy*.

....

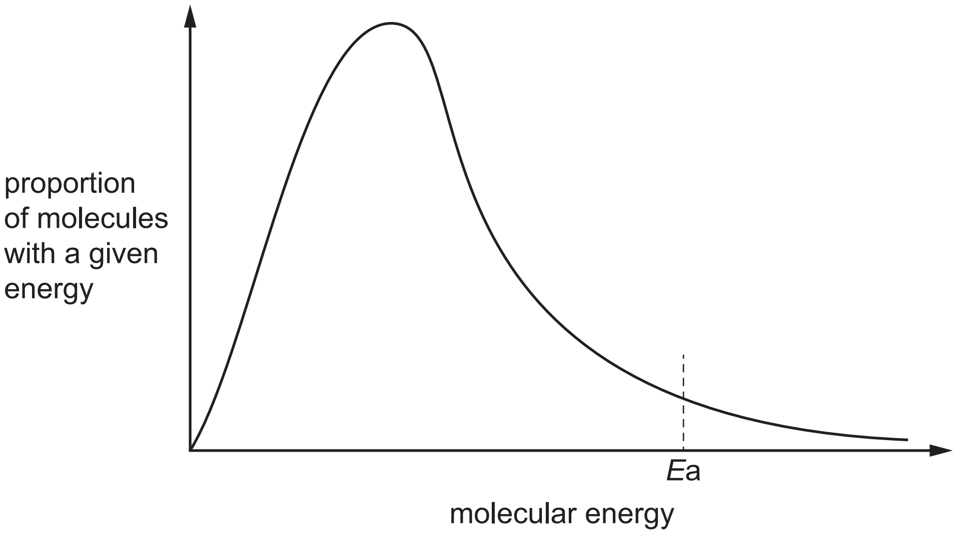
.... [2]

(ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... $kJ\,mol^{-1}$ [2]

(b) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
*E*a represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) **With reference to the Boltzmann distribution,** state and explain the effect of increasing temperature on the rate of production of ammonia.

....

....

....

.... [3]

(iii) State and explain the effect of increasing temperature on the yield of ammonia.
Use Le Chatelier's principle to explain your answer.

....

....

....

.... [3]

(c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $N_2(g)$, was mixed with 3.00 mol of hydrogen, $H_2(g)$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $NH_3(g)$.

(i) Calculate the amounts, in mol, of $N_2(g)$ and $H_2(g)$ in the equilibrium mixture.

$N_2(g)$ = ... mol

$H_2(g)$ = ... mol
[2]

(ii) Calculate the partial pressure of ammonia, pNH_3, in the equilibrium mixture.

Give your answer to three significant figures.

pNH_3 = ... Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure / Pa
$N_2(g)$	2.20×10^6
$H_2(g)$	9.62×10^5
$NH_3(g)$	1.40×10^4

(i) Write the expression for the equilibrium constant, K_p, for the production of ammonia from nitrogen and hydrogen.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction.

State the units.

K_p = ...

units = ...

[2]

(iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p.

effect on yield of ammonia ....

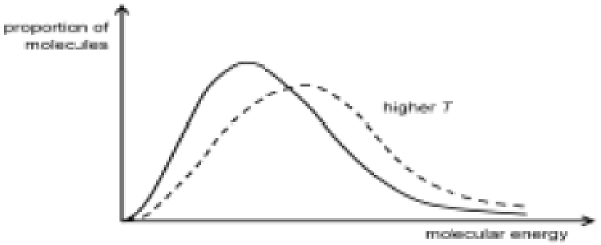
effect on value of K_p ....

[2]

[Total: 22]

Question	Answer	Marks
3 (a)	(+) 103	**1**
3 (b) (i)	general shape of the curve and peak are displaced to right of original and starts at origin	**1**
	the peak is lower and curve crosses once only finishing **above** original	**1**
3 (b) (ii)	rate increases AND correct explanation in terms of ‘more collisions’	**1**
	at higher T area above *E*a is greater / more molecules with $E \geqslant Ea$	**1**
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	**1**
3 (b) (iii)	increases (%) decomposition (of HBr)	**1**
	(increasing T) shifts equilibrium to the right / in the forward direction / endothermic direction / towards H_2 +Br_2	**1**
	to oppose the change or oppose the increase in temperature OR to absorb (additional) energy / heat OR to decrease the temperature	**1**
3 (b) (iv)	H–I bond strength less than H–Br OR Less energy needed to break H–I *ora*	**1**
	I (atom) is big(ger) (than Br) OR I (atom) has more shielding (than Br) *ora*	**1**
	Br (atom) has greater (%) orbital / outer shell overlap OR attraction (of nucleus in iodine) for shared (pair of) electrons is weak(er) OR attraction (of nucleus in iodine) for bonding pair (or electrons) is weak(er) *ora*	**1**
3 (c) (i)	H_2 = 0.015 (mol)	**1**
	HCl = 0.27 (mol)	**1**
3 (c) (ii)	HCl = 9 / 10 AND xH_2 = 1 / 20 AND Cl_2 = 1 / 20 OR HCl = 0.9(0) AND H_2 = 0.05 AND Cl_2 = 0.05	**1**
3 (d) (i)	$(K_p=)\dfrac{pH_2 \times pCl_2}{pHCl^2}$	**1**
3 (d) (ii)	equal number of moles (of gas) on either side (of equation) / (total) pressure cancels	**1**
3 (d) (iii)	4.649×10^{-3}	**1**
		Total: 18

Question	Answer	Marks
3 (a) (i)	(enthalpy / energy change) when one mole of a compound is formed	**1**
	from its elements in their standard states / standard conditions	**1**
3 (a) (ii)	($\Delta H_r = \sum \Delta H_f$ products – $\sum \Delta H_f$ reactants) $-196 = 2\Delta H_f\ SO_3 - (2 \times -296.8)$ $2\Delta H_f\ SO_3 = -196 + (2 \times -296.8) = -789.6$	**1**
	$\Delta H_f\ SO_3 = -394.8$ (kJ mol^{-1})	**1**
3 (b) (i)	Mark to right of original E_a	**1**
3 (b) (ii)	2 marks for any two points: - benefit of using a catalyst in terms of increasing rate or economic benefit i.e. (less heat required) - creates alternative pathway with lower E_a - more molecules with $E \geqslant E_a$	**2**
3 (b) (iii)	(rate) increases AND correct explanation in terms of ‘more collisions’	**1**
	more successful collisions per unit time / higher chance of successful per unit time / higher proportion of successful collisions per unit time	**1**
	(yield) increases and shifts equilibrium to the right / in the forward direction / towards SO_3 / towards the product / in exothermic direction	**1**
	to oppose the change or oppose the increase in pressure / fewer molecules on RHS so eqn moves to right (to oppose change)	**1**
3 (c) (i)	$SO_2 = 0.01$ (mol) AND $SO_3 = 0.99$ (mol)	**1**
3 (c) (ii)	$n_{TOT} = 1.505$	**1**
	$pO_2 = 1.50 \times 105 \times (0.505 / 1.505) = 5.03 \times 10^4$ (Pa)	**1**
3 (d) (i)	$(K_p =)\ \dfrac{pSO_3^{\,2}}{pO_2 \times pSO_2^{\,2}}$	**1**
3 (d) (ii)	0.1946737305	**1**
	Pa^{-1}	**1**
		Total: 17

Question	Answer	Marks
1 (a) (i)	Energy needed / required to break a mole of (covalent) bonds	**1**
	(All) in the gaseous state	**1**
1 (a) (ii)	−92 = {944 + 3(436)} = 6E(N–H)	**1**
	E(N–H) = (+)390.7 / 390.67 / 391	**1**
1 (b) (i)	general shape of the curve and peak are displaced to right of original line and starts at origin	**1**
	the peak is lower and curve crosses once only finishing **above** original line	**1**
		
1 (b) (ii)	rate increases AND explanation in terms of collisions	**1**
	(at higher T) area above E_a is greater OR (at higher T) more molecules with $E \geqslant E_a$	**1**
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	**1**
1 (b) (iii)	reduced yield (of ammonia)	**1**
	(increasing T) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants / in endothermic direction	**1**
	to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature	**1**
1 (c) (i)	N_2 = 0.850 (mol)	**1**
	H_2 = 2.55 (mol)	**1**
1 (c) (ii)	n_{TOTAL} = 3.7 mol	**1**
	mol fraction of NH_3 = 0.3 / 3.7	**1**
	$pNH_3 = 2 \times 10^7 \times (0.3 / 3.7) = 1.62 \times 10^6$	**1**

Continues on the next page …

Question	Answer	Marks
1 (d) (i)	$K_p = \dfrac{pNH_3^{\ 2}}{pN_2 \times pH_2^{\ 3}}$	**1**
1 (d) (ii)	K_p = 1.(00) × 10^{-16}	**1**
	Pa^{-2}	**1**
1 (d) (iii)	(yield of ammonia) increases	**1**
	(value of K_p) stays the same	**1**
		Total: 22

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

4: Organic chemistry 1 – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

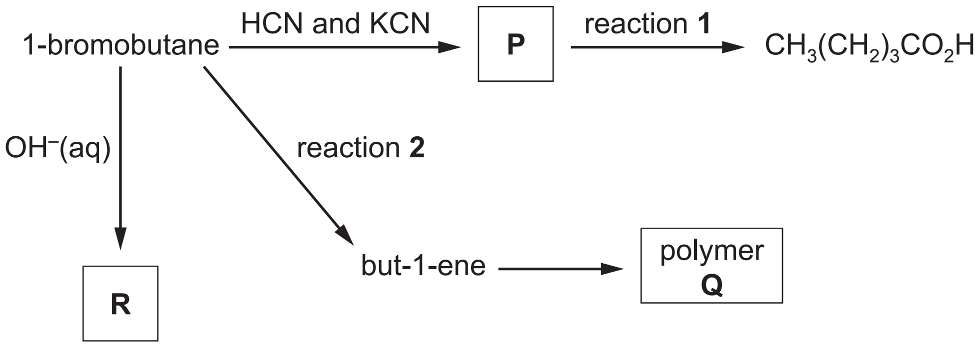
Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
3	2017	March	22
4	2017	June	21
4	2017	June	22

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

3 **(a)** A series of reactions starting from 1-bromobutane is shown.



(i) Draw the **displayed** formula of compound **P**.

[1]

(ii) Identify the reagent(s) and conditions for reactions **1** and **2**.

reaction **1** ....

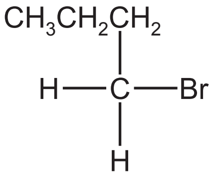
reaction **2** ....
[2]

(iii) Draw the structure of the repeat unit of polymer **Q**.

[2]

(b) Complete the reaction scheme to show the mechanism of the reaction of 1-bromobutane with $OH^-(aq)$ to produce **R**.

Include all necessary charges, dipoles, lone pairs and curly arrows and the structure of **R**.

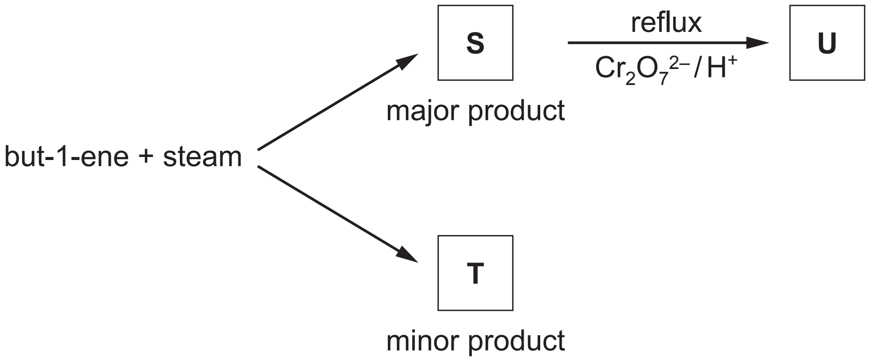


$$\begin{array}{ccc} & CH_3CH_2CH_2 & \\ & | & \\ H - & C & - Br \\ & | & \\ & H & \end{array}$$

^-OH

[3]

(c) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(i) Identify the *type of reaction* that occurs when but-1-ene reacts with steam.

.... [1]

(ii) State what can be deduced about the structure of **S** from its reaction with alkaline aqueous iodine.

.... [1]

(iii) Explain why **S** is the major product of the reaction of but-1-ene with steam.

....

....

....

....

.... [2]

(iv) Draw the **skeletal** formulae of **S**, **T** and **U**.

S

T

U

[3]

(v) Write an equation to represent the oxidation of **S** to **U** by acidified potassium dichromate(VI).

You should use [O] to represent the oxidising agent.

.... [1]

(d) $CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

It reacts with methanol in the presence of an acid catalyst to produce an organic product **V**, which has a pleasant fruity smell.

(i) Name **V**.

.... [1]

(ii) A student analysed $CH_3(CH_2)_3CO_2H$, methanol and **V** using infra-red spectroscopy. The spectra were returned to the student without labels.

Identify which of the infra-red spectra, X, Y or Z, corresponds to **V**.

compound	$CH_3(CH_2)_3CO_2H$	methanol	**V**
spectrum	▨	▨	

Explain your answer with reference to relevant features of the **three** spectra in the region above 1500 cm^{-1}.

....

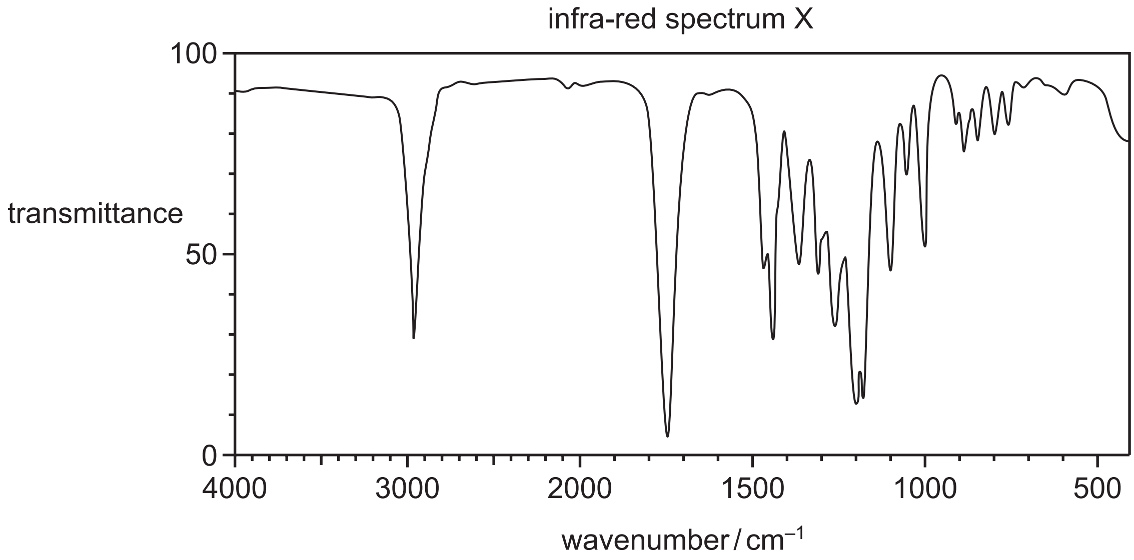
....

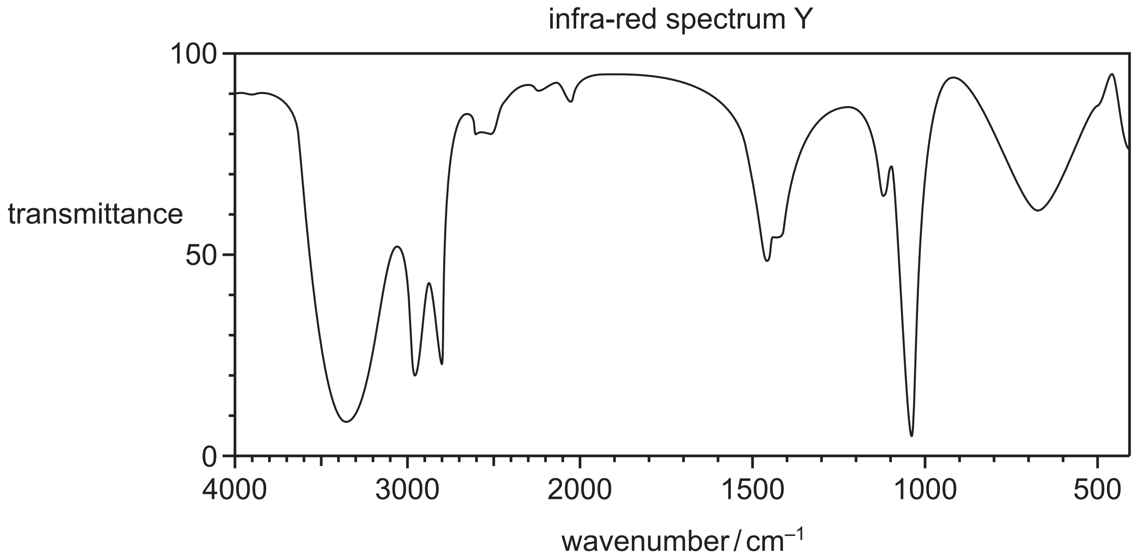
....

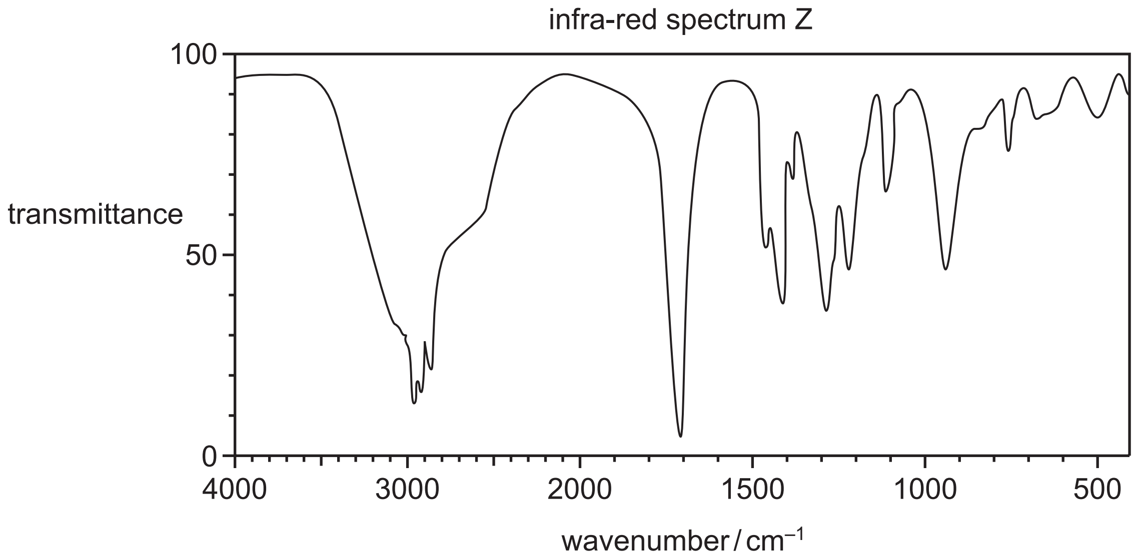
....

....

.... [4]


infra-red spectrum X
100
transmittance
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm^{-1}


infra-red spectrum Y
100
transmittance
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm^{-1}


infra-red spectrum Z
100
transmittance
50
0
4000
3000
2000
1500
1000
500
wavenumber / cm^{-1}

[Total: 21]

4 **(a)** The hydrocarbons **A**, C_4H_{10}, and **B**, C_4H_8, are both unbranched.

A does **not** decolourise bromine.

B decolourises bromine and shows geometrical isomerism.

(i) Draw the skeletal formula of **A**.

A

[1]

(ii) The hydrocarbon **A**, C_4H_{10}, has a branched isomer.

Suggest why unbranched **A** has a higher boiling point than its branched isomer.

....

....

....

....

.... [2]

(iii) Give the structural formula of **B**.

.... [1]

(iv) Explain why **B** shows geometrical isomerism.

....

....

....

.... [2]

(v) Draw the mechanism of the reaction of **B** with bromine, Br_2.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[4]

(vi) Explain the origin of the dipole on Br_2 in this mechanism.

....

....

.... [1]

(b) The alcohols **C** and **D** are isomers of each other with molecular formula $C_4H_{10}O$. Both isomers are branched.

When **C** is heated under reflux with acidified potassium dichromate(VI) no colour change is observed.

When **D** is heated under reflux with acidified potassium dichromate(VI) the colour of the mixture changes from orange to green and **E**, $C_4H_8O_2$, is produced.

E reacts with aqueous sodium carbonate to form carbon dioxide gas.

(i) Identify **C**, **D** and **E**.

C	**D**	**E**

[3]

(ii) Write the equation for the reaction between **E** and aqueous sodium carbonate.

.... [1]

(c) The isomers **F** and **G**, $C_5H_{10}O$, both form an orange precipitate when reacted with 2,4-DNPH.

F is unbranched and reacts with alkaline aqueous iodine to produce a yellow precipitate.

G does not react with alkaline aqueous iodine. It contains a chiral centre and produces a silver mirror when warmed with Tollens' reagent.

(i) Name the yellow precipitate produced by the reaction between **F** and alkaline aqueous iodine.

.... [1]

(ii) Give the structural formula of **F** and of **G**.

F ....

G ....
[2]

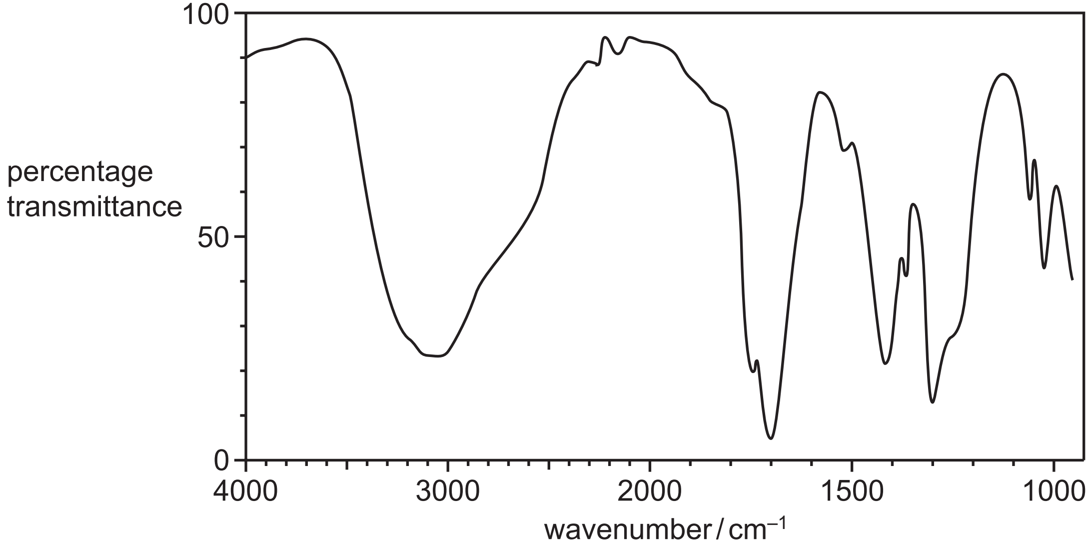
(iii) Explain the meaning of the term *chiral centre*.

....

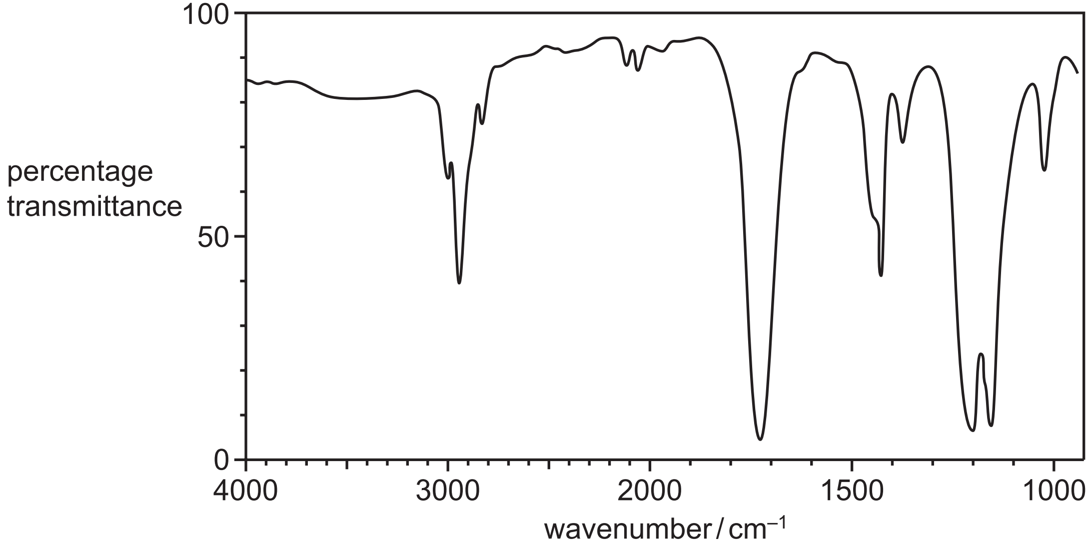
.... [1]

(d) **H** and **I** are isomers with molecular formula $C_2H_4O_2$. The infra-red spectra of isomers **H** and **I** are shown.

H



I



(i) Identify the bonds responsible for the principal peaks above 1500 cm^{-1} in each spectrum.

spectrum of **H** ....

....

spectrum of **I** ....

....

[2]

(ii) Name **H** and **I**.

H ....

I ....

[2]

[Total: 23]

4 **P**, **Q** and **R** all have the molecular formula C_3H_6O. They are all structural isomers of each other.

P and **Q** each contain an oxygen atom bonded directly to a carbon atom that is sp^2 hybridised. **R** contains an oxygen atom bonded directly to a carbon atom that is sp^3 hybridised.

(a) **(i)** Explain the meaning of the term *structural isomers*.

....

....

....

.... [2]

(ii) Explain how sp^2 and sp^3 hybridisation can occur in carbon atoms.

sp^2 hybridisation ....

....

sp^3 hybridisation ....

....

[2]

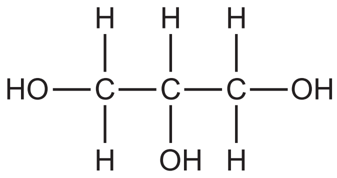
(iii) State the bond angles normally associated with each type of hybridisation in carbon atoms.

sp^2 ....

sp^3 ....

[2]

(b) **R** contains two different functional groups, one of which is an alkene group.
R reacts with cold, dilute, acidified manganate(VII) ions to form propane-1,2,3-triol.



propane-1,2,3-triol

(i) Give the displayed formula of **R**.

[1]

(ii) State the type of reaction and what you would observe when **R** reacts with bromine water.

....

.... [2]

(iii) Draw the structure of the product formed when **R** reacts with bromine water.

[1]

(iv) Identify the gaseous product formed when **R** reacts with hot, concentrated, acidified manganate(VII) ions.

.... [1]

(c) **P** and **Q** (C_3H_6O) both form an orange precipitate when reacted with 2,4-DNPH. Only **Q** produces a yellow precipitate when reacted with alkaline aqueous iodine.

(i) Name **P** and **Q**.

P ....

Q ....
[2]

(ii) Identify the yellow precipitate formed by the reaction of **Q** with alkaline aqueous iodine.

.... [1]

(d) **P** and **Q** each react with hydrogen cyanide to form a single product.
The product formed from **P** exists as a pair of optical isomers.
The product formed from **Q** does not exhibit optical isomerism.

(i) Explain the meaning of the term *optical isomers*.

....

....

....

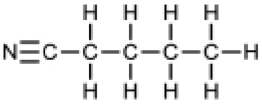
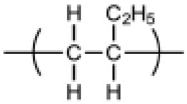
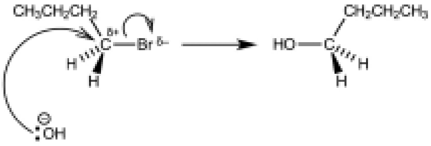
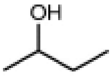
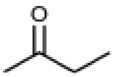
.... [2]

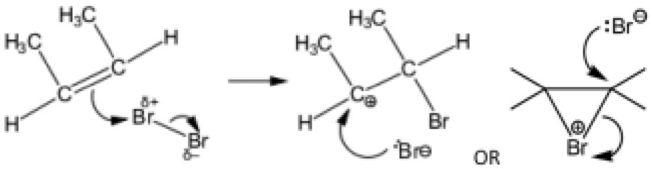
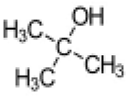
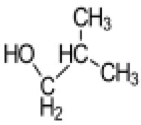
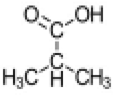
(ii) Ethanal, CH_3CHO, also reacts with hydrogen cyanide. The product of this reaction is $CH_3CH(OH)CN$.

Draw the mechanism of this reaction.
Include all necessary charges, dipoles, lone pairs and curly arrows.

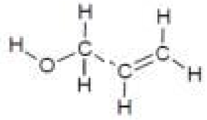
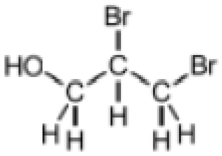
[3]

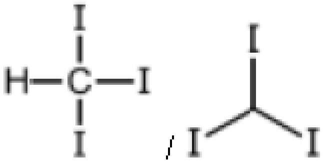
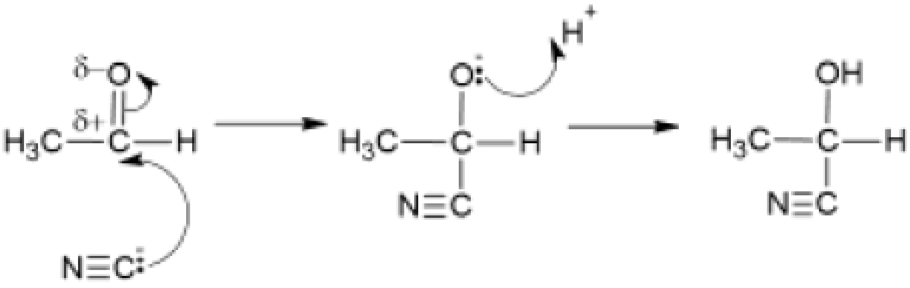
[Total: 19]

Question	Answer	Marks
3 (a) (i)	 $N\equiv C-CH_2-CH_2-CH_2-CH_3$	**1**
3 (a) (ii)	reaction **1** = HCl (aq)	**1**
	reaction **2** = (conc.) NaOH / KOH **AND** ethanol	**1**
3 (a) (iii)	 $-[CH_2-CH(C_2H_5)]-$	
	C–C backbone with dangling bonds	**1**
	rest of structure	**1**
3 (b)		
	lone pair on O **AND** curly arrow from O to C of C–Br	**1**
	dipole on C–Br **AND** curly arrow from C–Br to Br	**1**
	product (butan-1-ol)	**1**
3 (c) (i)	(electrophilic) addition	**1**
3 (c) (ii)	**S** has CH_3CHOH **OR** methyl / CH_3 group next to CHOH	**1**
3 (c) (iii)	positive inductive effect of more alkyl groups / more alkyl groups donate electron density	**1**
	secondary carbocation / secondary intermediate is more stable (than primary)	**1**
3 (c) (iv)	S= 	**1**
	T = 	**1**
	U = 	**1**
3 (c) (v)	$CH_3CHOHCH_2CH_3 + [O] \rightarrow CH_3COCH_2CH_3 + H_2O$	**1**
3 (d) (i)	methyl pentanoate	**1**
3 (d) (ii)	(compound **V** is) spectrum X	**1**
	spectra X and Z show a C=O (stretch) at 1730 (cm^{-1})	**1**
	spectra Y and Z show O–H (stretches) above 2500 (cm^{-1})	**1**
	V has a C=O (bond) and no O–H (bond)	**1**
		Total: 21

Question	Answer	Marks
4 (a) (i)	(A =) 	1
4 (a) (ii)	(**A** / straight chain) has strong(er) (temporary dipole-) induced dipole (attractions) *ora*	1
	(because **A** / straight chain has) bigger (surface) area / more (points of) contact (in unbranched isomer) *ora* OR (so) more energy required to break the intermolecular forces *ora*	1
4 (a) (iii)	$CH_3CHCHCH_3$ OR $CH_3CH{=}CHCH_3$	1
4 (a) (iv)	No rotation / restricted / limited rotation of C=C / (carbon) double bond	1
	One (of the two) methyl groups / one (of the two) H (atoms) is on each C (of C=C)	1
4 (a) (v)	 arrow from the C=C double bond drawn to the bromine	1
	dipole on Br_2 in correct orientation AND arrow from the Br-Br bond to the $Br^{\delta-}$	1
	correct carbocation / bromonium ion from the structure with C=C drawn	1
	Br^- with lone pair, negative charge AND arrow from lone pair to the carbon atom of intermediate OR using both arrows shown (in alternative diagram)	1
4 (a) (vi)	electrons in pi bond induce it (the dipole) OR (high) electron density in pi bond / double bond / C=C repels electrons (away from nearest Br) OR polarised by (high) electron density in pi bond / double bond / C=C	1
4 (b) (i)	**C** = (2-)methylpropan-2-ol / $(CH_3)_3COH$ / any unambiguous structure	1
	D = (2-)methylpropan-1-ol / $(CH_3)_2CHCH_2OH$ / any unambiguous structure	1
	E = (2-)methylpropanoic acid /$(CH_3)_2CHCO_2H$ / any unambiguous structure	1
	 **C**  **D**  **E**	
4 (b) (i)	$2C_4H_8O_2 + Na_2CO_3 \rightarrow 2C_4H_7O_2Na + H_2O + CO_2$	1
4 (c) (i)	triiodomethane	1

Question	Answer	Marks
4 (c) (ii)	**F** = $CH_3CH_2CH_2COCH_3$	1
	G = $C_2H_5CH(CH_3)CHO$	1
4 (c) (iii)	a (tetrahedral) atom with four different groups / atoms / substituents attached OR a carbon (atom) with four different groups / atoms / substituents attached	1
4 (d) (i)	**H** C=O (group / bond) AND O–H (group / bond)	1
	I C=O (group / bond) AND C–H (group / bond)	1
		Total: 21

Question	Answer	Marks
4 (a) (i)	(molecules / isomers with) the same molecular formula / same number of atoms of each element	1
	different structural / displayed formulae / arrangement of bonds	1
4 (a) (ii)	sp^2 overlap of (2)s with (2)p (atomic) orbitals	1
	sp^3 overlap of (2)s with all three (2)p (atomic) orbitals	1
4 (a) (iii)	sp^2 = 116° – 124°	1
	sp^3 = 106° – 112°	1
4 (b) (i)		1
4 (b) (ii)	(electrophilic) addition	1
	bromine decolourises / turns colourless / fades (from orange / brown)	1
4 (b) (iii)	$HOCH_2CHBrCH_2Br$ OR 	1
4 (b) (iv)	CO_2 / carbon dioxide	1
4 (c) (i)	**P** = propanal	1
	Q = propanone	1

Question	Answer	Marks
4 (c) (ii)	tr(i)iodomethane / CHI_3 	**1**
4 (d) (i)	(molecules / isomers with) the same (molecular and) structural formula	**1**
	Any two of: • Chiral centre / C attached to four different groups / atoms • Non-super(im)posable mirror images • Different spatial / 3D arrangement of atoms (owtte) • Different rotation of plane-polarised light	**1**
4 (d) (ii)		**1**
	curly arrow from lone pair on :C≡N to $C^{(\delta+)}$	**1**
	correct dipole on carbonyl $^{\delta+}C=O^{\delta-}$ AND curly arrow from bond to $O^{(\delta-)}$	**1**
	correct intermediate, including $C–O^-$ AND curly arrow from lone pair to H^+	**1**
		Total: 19

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

5: Chemical trends – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
2	2017	June	23
3	2017	June	21
2	2017	November	21

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

2 The halogens, chlorine, bromine and iodine, and their compounds, show a variety of similarities and trends in their physical and chemical properties.

(a) **(i)** Give the colours and states of chlorine, bromine and iodine at room temperature and pressure.

halogen	colour	state
chlorine		
bromine		
iodine		

[2]

(ii) The halogens become less volatile down the group.

Explain this trend in volatility.

....

....

.... [2]

(b) The halogens are oxidising agents.

State and explain the trend in oxidising power of the halogens.

....

....

....

.... [3]

(c) Concentrated sulfuric acid reacts with solid sodium halides.

(i) State any observations that would be made on addition of concentrated sulfuric acid to

- solid sodium chloride, ...

....

- solid sodium iodide. ....

....

[2]

(ii) Give reasons for the difference in the observations in **(i)**.

....

....

.... [2]

(iii) The addition of concentrated sulfuric acid to solid sodium bromide, NaBr, produces brown fumes and an acidic gas that decolourises acidified potassium manganate(VII) solution. This acidic gas is a significant contributor to acid rain.

Write the equation for the reaction of concentrated sulfuric acid with sodium bromide.

.... [2]

(d) An aqueous solution, **Z**, contains a mixture of sodium chloride and sodium iodide.

(i) Excess aqueous silver nitrate is added to **Z** in a test-tube. A yellow precipitate forms.

Explain the colour of this precipitate.

....

.... [1]

(ii) Aqueous ammonia is then added to the test-tube in **(i)**. The mass of precipitate decreases.

Explain this observation.

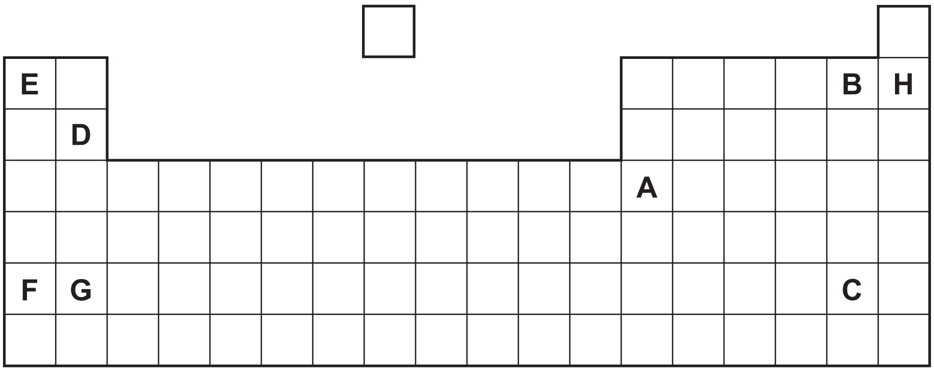
....

.... [1]

[Total: 15]

3 The properties of elements and their compounds show similarities, differences and trends depending on the positions of the elements in the Periodic Table.

(a) The positions of some elements are indicated. The letters used are **not** the symbols of the elements.



From the elements labelled, give the letter for;

(i) the element that forms an amphoteric oxide, ... [1]

(ii) the element with the highest first ionisation energy, ... [1]

(iii) the element that forms a soluble hydroxide and an insoluble sulfate, ... [1]

(iv) the most volatile element in a group that contains elements in all three states of matter at room temperature and pressure,

.... [1]

(v) the element that forms the largest cation. .... [1]

(b) The elements in Group 2 all react with oxygen and with water.

(i) State and explain the conditions needed for magnesium to react with oxygen.

....

.... [2]

(ii) State what would be seen during the reaction in **(b)(i)**.

....

.... [1]

(iii) Write an equation for the reaction of magnesium with cold water.
Include state symbols.

.... [2]

(c) The carbonates and nitrates of the elements in Group 2 can all be decomposed by heating.

(i) Write an equation for the thermal decomposition of magnesium nitrate.

.... [1]

(ii) The thermal decomposition of calcium carbonate forms a solid product that is industrially important. This solid product reacts with water to form a compound commonly known as slaked lime.

Write equations for the thermal decomposition of calcium carbonate and the reaction of the solid product to form slaked lime.

thermal decomposition ....

formation of slaked lime ....
[2]

(d) Calcium carbonate and calcium hydroxide both have an important use in agriculture.

(i) Describe this use and explain what makes these two compounds suitable for it.

....

....

.... [2]

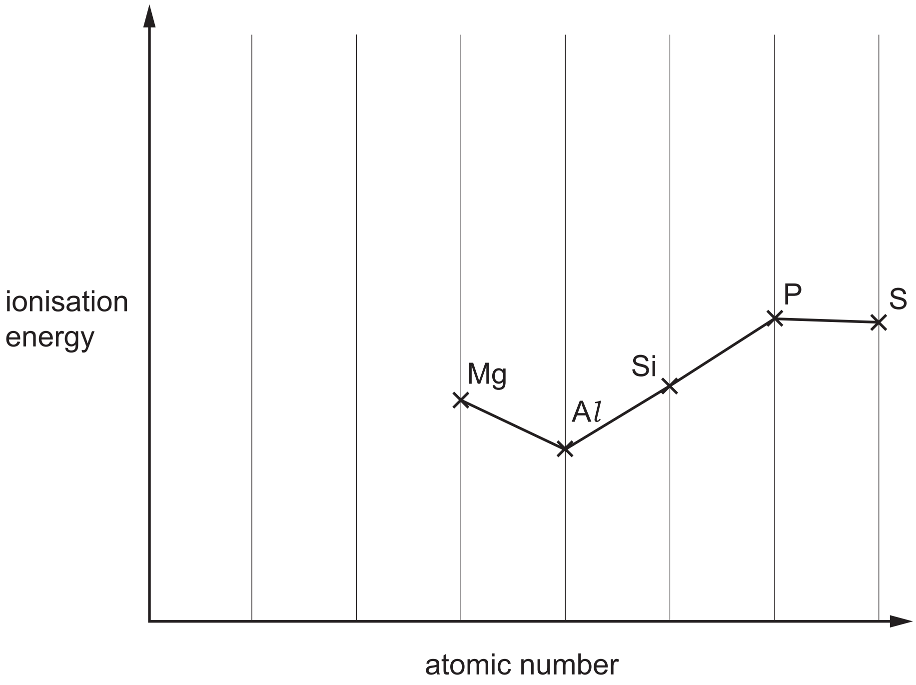
(ii) Write an ionic equation to illustrate this use of calcium carbonate.

.... [1]

[Total: 16]

2 The elements in the third period, and their compounds, show trends in their physical and chemical properties.

(a) A sketch graph of the first ionisation energies of five successive elements in the third period is shown.



(i) Explain why there is a general increase in the first ionisation energy across the third period.

....

....

.... [2]

(ii) Sketch, on the graph, the position of the ionisation energies of the two elements that come before Mg in this sequence. [2]

(iii) Explain, with reference to electron arrangements, the decreases in first ionisation energy between Mg and A*l* and between P and S.

Mg and A*l* ....

....

....

P and S ....

....

....

[4]

(b) The chlorides of the elements in the third period behave in different ways when added to water, depending on their structure and bonding.

L and **M** are each a chloride of an element in Period 3. A student investigated **L** and **M** and their results are given.

L is a white crystalline solid with a melting point of 987 K. **L** dissolves in water to form an approximately neutral solution. Addition of NaOH(aq) to an aqueous solution of **L** produces a white precipitate.

M is a liquid with a boiling point of 331 K. **M** is hydrolysed rapidly by cold water to form a strongly acidic solution, a white solid and white fumes.

Identify **L** and **M**.
Explain any properties and observations described.
Give equations where appropriate.

(i) **L** is ....

....

....

....

.... [3]

(ii) **M** is ....

....

....

....

.... [3]

[Total: 14]

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>2 (a) (i)</td><td><table>
<tr><td>halogen</td><td>colour</td><td>state</td></tr>
<tr><td>chlorine</td><td>yellow / green</td><td>gas</td></tr>
<tr><td>bromine</td><td>red / brown / orange</td><td>liquid</td></tr>
<tr><td>iodine</td><td>grey / black</td><td>solid</td></tr>
</table></td><td>2</td></tr>
<tr><td>2 (a) (ii)</td><td>increasing number of electrons</td><td>1</td></tr>
<tr><td></td><td>(gives) increasing strength of van der Waals’ / id-id forces / London / dispersion forces</td><td>1</td></tr>
<tr><td>2 (b)</td><td>oxidising power decreases down the group. *ora*</td><td>1</td></tr>
<tr><td></td><td>ability to accept electrons decreases (down the group) *ora*</td><td>1</td></tr>
<tr><td></td><td>because (outer shell experiences) more shielding
OR
increased distance from nucleus (to outer shell) (outweighs the increasing nuclear charge down the group) *ora*</td><td>1</td></tr>
<tr><td>2 (c) (i)</td><td>solid sodium chloride: steamy / misty / white fumes</td><td>1</td></tr>
<tr><td></td><td>solid sodium iodide: purple fumes</td><td>1</td></tr>
<tr><td>2 (c) (ii)</td><td>(conc sulfuric) not powerful enough oxidising agent (to oxidise chloride)
OR
chloride not powerful enough reducing agent (to reduce sulfuric acid)</td><td>1</td></tr>
<tr><td></td><td>iodide reduces sulfuric acid
OR
iodide / I^- is oxidised
OR
sulfuric acid oxidises iodide</td><td>1</td></tr>
<tr><td>2 (c) (iii)</td><td>$2NaBr + 2H_2SO_4 \rightarrow Br_2 + SO_2 + Na_2SO_4 + 2H_2O$
OR
$NaBr + H_2SO_4 \rightarrow NaHSO_4 + HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$
OR
$2NaBr + H_2SO_4 \rightarrow Na_2SO_4 + 2HBr$ AND $2HBr + H_2SO_4 \rightarrow Br_2 + SO_2 + 2H_2O$</td><td>2</td></tr>
<tr><td>2 (d) (i)</td><td>AgI (and AgCl solid) / silver ions reacting with iodide ions</td><td>1</td></tr>
<tr><td>2 (d) (ii)</td><td>AgCl (precipitate) dissolves (in ammonia) owtte</td><td>1</td></tr>
<tr><td></td><td></td><td>Total: 15</td></tr>
</table>

Question	Answer	Marks
3 (a) (i)	A	**1**
3 (a) (ii)	H	**1**
3 (a) (iii)	G	**1**
3 (a) (iv)	B	**1**
3 (a) (v)	F	**1**
3 (b) (i)	(strong) heating	**1**
	(to provide / overcome) high activation energy	**1**
3 (b) (ii)	**white** flame / **white** light / **white** smoke / **white solid**	**1**
3 (b) (iii)	$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$	**1**
3 (c) (i)	$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	**1**
3 (c) (ii)	$CaCO_3$ $CaO + CO_2$	**1**
	$CaO + H_2O$ $Ca(OH)_2$	**1**
3 (d) (i)	reduce acidity in soil / increase pH of soil	**1**
	(both) basic / base(s)	**1**
3 (d) (ii)	$CaCO_3 + 2H^+ \rightarrow Ca^{2+}$ $CO_2 + H_2O$ OR $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$	**1**
		Total: 16

Question	Answer	Marks
2 (a) (i)	due to increasing nuclear attraction (for electrons)	**1**
	due to increasing nuclear charge / atomic / proton number AND similar shielding / same (outer/number of) shell / energy level	**1**
2 (a) (ii)	Cross shown on first vertical line from the y-axis (Group 0 / Ne) is clearly higher than all shown	**1**
	Cross shown on second vertical line from the y-axis (Group 1 / Na) lower than all shown	**1**
2 (a) (iii)	A*l* (the outer / valence) electron (which is lost) is in (3)p sub-shell (Mg is in (3)s subshell) OR A*l* (the outer / valence) electron (which is lost) is in higher energy sub-shell	**1**
	(electron to be removed) is more shielded / experiences greater screening effect	**1**

Question	Answer	Marks
2 (b) (i)	(**L**=) $MgCl_2$ / magnesium chloride	**1**
4 (b) (ii)	Any two from: • (giant) ionic (with strong attractions) • $Mg^{2+}(aq)$ / $Mg(H_2O)_6^{2+}(aq)$ is neutral / undergoes (partial) hydrolysis • $Mg(OH)_2$ is the white precipitate / solid / insoluble / partially soluble • $MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$	**2**
2 (b) (iii)	(**M**=) $SiCl_4$ / silicon chloride	**1**
	Any two from: • (simple) molecular / simple covalent • hydrolysis possible due to available d orbitals • forms HCl (aq) / hydrochloric acid / solution and / or HCl gas / fumes • white solid is (hydrated) SiO_2 • $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	**2**
		Total: 12

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

6: Acids and bases – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
2	2017	June	41
2	2017	June	43
2	2017	November	41

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

2 **(a)** One atom of each of the four elements H, C, N and O can bond together in different ways. Two examples are molecules of cyanic acid, HOCN, and isocyanic acid, HNCO. The atoms are bonded in the order they are written.

(i) Draw 'dot-and-cross' diagrams of these two acids, showing outer shell electrons only.

HOCN, cyanic acid

HNCO, isocyanic acid

[3]

(ii) Suggest the values of the bond angles HNC and NCO in **isocyanic acid**.

HNC .... NCO .... [1]

(iii) Suggest which acid, cyanic or isocyanic, will have the **shorter** C–N bond length. Explain your answer.

....

.... [1]

(b) **(i)** Isocyanic acid is a weak acid.

$$HNCO \rightleftharpoons H^+ + NCO^- \qquad K_a = 1.2 \times 10^{-4}\,mol\,dm^{-3}$$

Calculate the pH of a 0.10 $mol\,dm^{-3}$ solution of isocyanic acid.

pH = ... [2]

(ii) Sodium cyanate, NaNCO, is used in the production of isocyanic acid.
Sodium cyanate is prepared commercially by reacting urea, $(NH_2)_2CO$, with sodium carbonate. Other products in this reaction are carbon dioxide, ammonia and steam.

Write an equation for the production of NaNCO by this method.

.... [1]

(c) Barium hydroxide, $Ba(OH)_2$, is completely ionised in aqueous solutions.
During the addition of 30.0 cm^3 of 0.100 mol dm^{-3} $Ba(OH)_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid, the pH was measured.

(i) Calculate the $[OH^-]$ at the end of the addition.

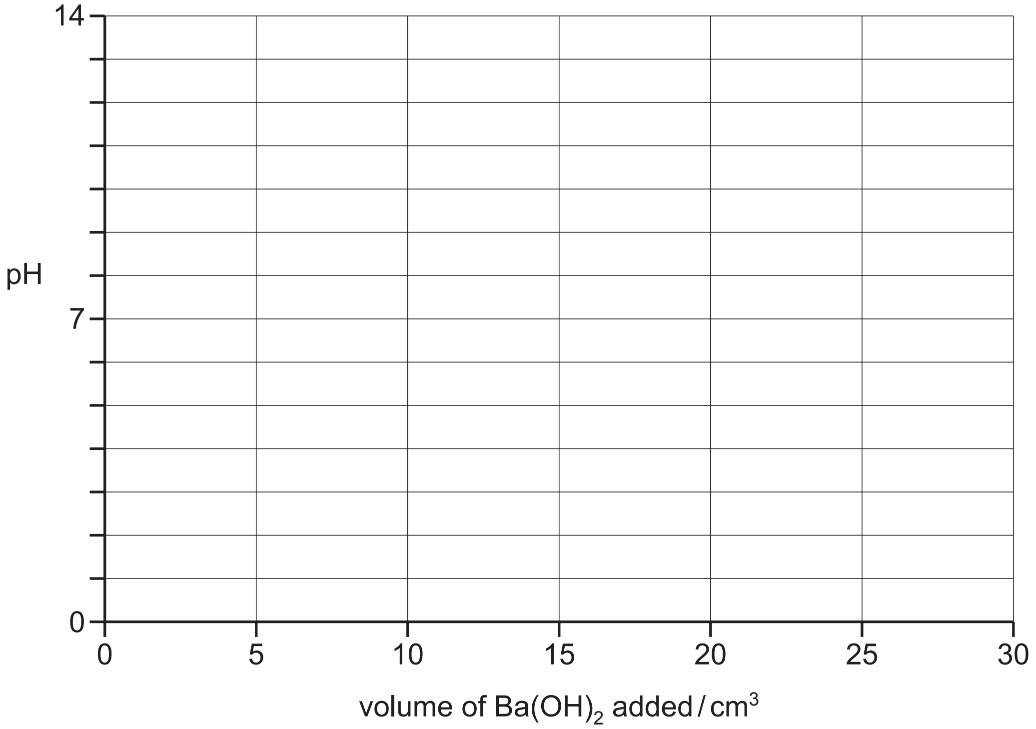
$[OH^-]$ = ... mol dm^{-3} [2]

(ii) Use your value in **(i)** to calculate $[H^+]$ and the pH of the solution at the end of the addition.

final [$^+$] = ... mol dm^{-3}

final pH = ...
[2]

(iii) On the following axes, sketch how the pH changes during the addition of a total of 30.0 cm^3 of 0.100 mol dm^{-3} $Ba(OH)_2$ to 20.0 cm^3 of 0.100 mol dm^{-3} isocyanic acid.



[3]

(d) The cyanate ion, NCO^-, can act as a *monodentate ligand*.

(i) State what is meant by the terms

monodentate, ...

....

ligand. ....

.... [2]

Silver ions, Ag^+, react with cyanate ions to form a linear complex.

(ii) Suggest the formula of this complex, including its charge.

.... [2]

(e) When heated with $HCl(aq)$, organic isocyanates, RNCO, are hydrolysed to the amine salt, RNH_3Cl, and CO_2.

$$RNCO + H_2O + HCl \rightarrow RNH_3Cl + CO_2$$

A 1.00 g sample of an organic isocyanate, RNCO, was treated in this way, and the CO_2 produced was absorbed in an excess of aqueous $Ba(OH)_2$ according to the equation shown. The solid $BaCO_3$ precipitated weighed 1.66 g.

$$Ba(OH)_2(aq) + CO_2(g) \rightarrow BaCO_3(s) + H_2O(l)$$

(i) Calculate the number of moles of $BaCO_3$ produced.

moles of $BaCO_3$ = ... [1]

(ii) Hence calculate the M_r of the organic isocyanate RNCO.

M_r of RNCO = ... [1]

The R group in RNCO and RNH_3Cl contains carbon and hydrogen only.

(iii) Use your M_r value calculated in **(ii)** to suggest the molecular formula of the organic isocyanate RNCO.

molecular formula of RNCO .... [1]

(iv) Suggest a possible structure of the amine RNH_2, which forms the amine salt, RNH_3Cl.

[1]

[Total: 23]

2 **(a)** The table lists values of solubility products, K_{sp}, of some Group 2 carbonates.

	solubility product in water at 298 K, K_{sp} / $mol^2\,dm^{-6}$
$MgCO_3$	1.0×10^{-5}
$CaCO_3$	5.0×10^{-9}
$SrCO_3$	1.1×10^{-10}

Use the data in the table to describe the trend in the solubility of the Group 2 carbonates down the group.

....

.... [1]

(b) **(i)** Write an equation to show the equilibrium for the solubility product for $MgCO_3$. Include state symbols.

$\rightleftharpoons$

.... [1]

(ii) With reference to your equation in **(i)**, suggest what is observed when a few cm^3 of concentrated $Na_2CO_3(aq)$ are added to a saturated solution of $MgCO_3$. Explain your answer.

....

....

.... [2]

(c) Use the data in the table to calculate the solubility of $MgCO_3$ in water at 298 K, in $g\,dm^{-3}$.

solubility of $MgCO_3$ = ... $g\,dm^{-3}$ [2]

(d) **(i)** Magnesium nitrate decomposes at a **lower** temperature than barium nitrate.

Explain why.

....

....

.... [2]

(ii) A sample of barium nitrate was heated strongly until no further change occurred. A white solid was formed.

Write an equation for the action of heat on barium nitrate.

.... [1]

(iii) When water was added to the white solid produced in **(d)(ii)**, an alkaline solution was produced. Adding sulfuric acid to this solution produced a white precipitate.

Write equations to explain these observations.

....

.... [2]

[Total: 11]

2 **(a)** When water is added to magnesium nitride, Mg_3N_2, the products are a white suspension of $Mg(OH)_2$ and an alkaline gas.

(i) Write an equation for this reaction.

.... [1]

(ii) A 2.52 g sample of Mg_3N_2 is added to an excess of water.

Calculate the mass of $Mg(OH)_2$ formed.

mass of $Mg(OH)_2$ = ... g [2]

(b) State and explain how the solubility of the Group 2 hydroxides varies down the group.

....

....

....

....

.... [4]

(c) Magnesium hydroxide is sparingly soluble in water. The concentration of its saturated solution at 298 K is 1.7×10^{-4} mol dm^{-3}.

(i) Write an expression for the solubility product, K_{sp}, of $Mg(OH)_2$.

K_{sp} =

[1]

(ii) Calculate the value of K_{sp} for $Mg(OH)_2$ at 298 K and state its units.

K_{sp} = ... units .... [2]

(d) The temperature at which the Group 2 hydroxides and carbonates start to decompose increases down the group.

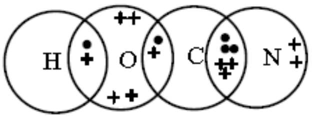
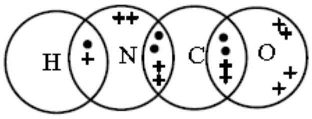
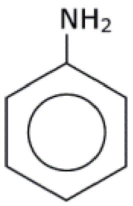
Suggest an explanation for this trend in the decomposition temperature of the Group 2 hydroxides.

....

....

.... [2]

[Total: 12]

Question	Answer	Marks
2 (a) (i)	 	**1+1**
	16 electrons on each diagram	**1**
2 (a) (ii)	HNC = 115–125° AND NCO = 180°	**1**
2 (a) (iii)	cyanic acid, because it's a stronger / higher bond enthalpy / triple / C≡N / more electrons involved bond	**1**
2 (b) (i)	$[H^+] = \sqrt{([HNCO]K_a)} = \sqrt{(0.1 \times 1.2 \times 10^{-4})}$ or 3.46×10^{-3}	**1**
	pH = log $[H^+]$ = **2.5** (2.46)	**1**
2 (b) (ii)	$Na_2CO_3 + 2(NH_2)_2CO \rightarrow 2NaNCO + CO_2 + 2NH_3 + H_2O$	**1**
2 (c) (i)	($n(OH^-)$ at start = $(2 \times 0.1 \times 30) / 1000 = 6 \times 10^{-3}$ mol) ($n(OH^-)$ reacted = $(0.1 \times 20) / 1000 = 2 \times 10^{-3}$ mol) $n(OH^-)$ remaining = $(6–2) \times 10^{-3} = 4 \times 10^{-3}$ mol, (in 50 cm^3)	**1**
	so $[OH^-]$end = $(4 \times 10^{-3} \times 1000) / 50$ = **0.08 mol dm^{-3}**	**1**
2 (c) (ii)	$[H^+] = K_w / [OH^-] = (1 \times 10^{-14}) / 0.08 = 1.25 \times 10^{-13}$ mol dm^{-3}	**1**
	so pH = $-\log(1.25 \times 10^{-13})$ = **12.9**	**1**
2 (c) (iii)	curve starts at 2.46 / 2.5	**1**
	vertical portion (end point) at vol added = 10.0 cm^3	**1**
	finishes at pH = 12.9	**1**
2 (d) (i)	*monodentate*: (a species that) forms **one** dative / coordinate bond	**1**
	ligand: a species that uses a lone pair of electrons to form a dative / coordinate bond to **a metal atom / metal ion**	**1**
2 (d) (ii)	$[Ag(NCO)_2]^-$ or $[Ag(OCN)_2]^-$ correct formula	**1**
	correct charge	**1**
2 (e) (i)	$n(BaCO_3)$ =1.66 / 197.3 = 8.4(1) × 10^{-3} mol	**1**
2 (e) (ii)	n(RNCO) = 8.41 × 10^{-3} mol, so Mr = 1 / (8.41 × 10^{-3}) = **119**	**1**
2 (e) (iii)	molecular formula = C7H5NO	**1**
2 (e) (iv)		**1**
		Total: 23

Question	Answer	Marks
2 (a)	it / solubility **decreases** down the group **and** K_{sp} decreases	**1**
2 (b) (i)	$MgCO_3$**(s)** ⇌ Mg^{2+}**(aq)** + CO_3^{2-}**(aq)**	**1**
2 (b) (ii)	(white) solid appears / precipitation (of $MgCO_3$)	**1**
	as $[CO_3^{2-}]$ increases shifting equilibrium to the LHS (precipitating out $MgCO_3$)	**1**
2 (c)	solubility = $\sqrt{1.0 \times 10^{-5}} = 3.16 \times 10^{-3}$ mol dm^{-3}	**1**
	solubility= $3.2 \times 10^{-3} \times 84.3 =$ **0.27** g dm^{-3}	**1**
2 (d) (i)	Mg^{2+} ion is smaller than Ba^{2+} ion **or** ionic radii increase down group ora	**1**
	(Mg^{2+}) distorts / polarises / the anion / nitrate group / nitrate **ion** / $NO_3^{(1)-}$ / NO_3ion more easily (than Ba^{2+}) ora	**1**
2 (d) (ii)	$Ba(NO_3)_2 \rightarrow BaO + 2NO_2 + ½O_2$	**1**
2 (d) (iii)	$BaO + H_2O \rightarrow Ba(OH)_2$	**1**
		Total: 11

Question	Answer	Marks
2 (a) (i)	$Mg_3N_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2NH_3$	**1**
2 (a) (ii)	moles of Mg_3N_2 = 2.52 / 100.9 = 0.025 (0.0249)	**1**
	(moles of $Mg(OH)_2$ = 0.075 (0.0749)) mass of $Mg(OH)_2$ = (0.075 × 58.3) = 4.37 g or 4.4 g	**1**
2 (b)	solubility increases (down the group)	**1**
	ΔH_{latt} and ΔH_{hyd} both decrease / less exothermic / more endothermic	**1**
	but ΔH_{latt} decreases more (than ΔH_{hyd} decreases)	**1**
	ΔH_{sol} becomes more negative / more exothermic / less endothermic	**1**
2(c) (i)	$K_{sp} = [Mg^{2+}] [OH^-]^2$	**1**
2 (c) (ii)	$K_{sp} = (1.7 \text{ x } 10^{-4}) \times (2 \times 1.7 \times 10^{-4})2 = 2.0 \times 10^{-11}$ (1.97×10^{-11})	**1**
	mol^3 dm^{-9}	**1**
2 (d)	cations become bigger / ionic radius increases	**1**
	polarisation/distortion of anion / hydroxide ion decreases	**1**
		Total: 12

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

7: Electricity and metals – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
6	2017	March	42
3	2017	June	41
5	2017	June	42

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

6 **(a)** **(i)** Draw the shape of one of the d orbitals.

[1]

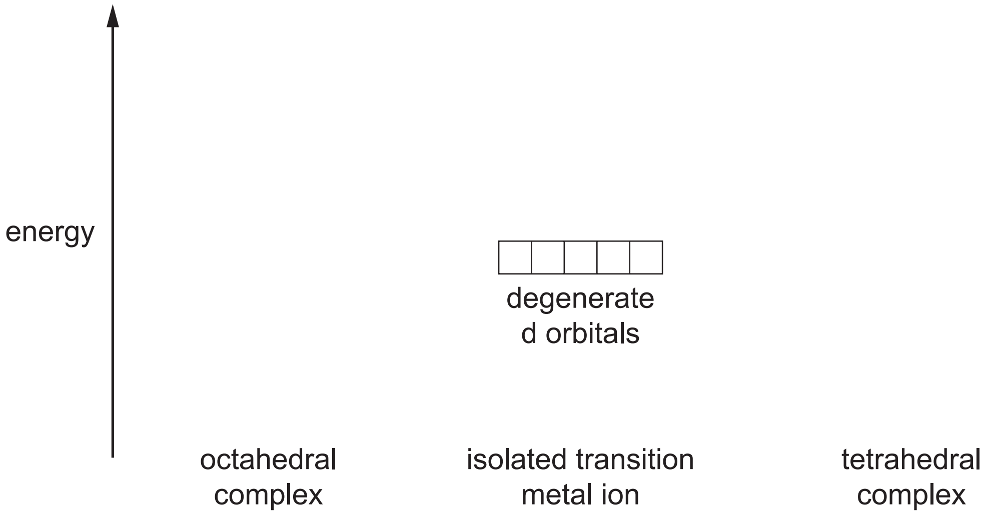
(ii) Complete the following electronic configurations.

Ni $1s^2 2s^2 2p^6 3s^2 3p^6$ ....

Ni^{3+} $1s^2 2s^2 2p^6 3s^2 3p^6$ ....

[1]

(b) **(i)** Complete the diagram to show how the presence of ligands around an isolated transition metal ion affects the **energy** of the d orbitals.



[1]

(ii) Explain why transition metal complexes are coloured.

....

....

....

.... [2]

(iii) $[Cu(H_2O)_6]^{2+}$ is pale blue but $[Cu(NH_3)_4(H_2O)_2]^{2+}$ is deep purple-blue.

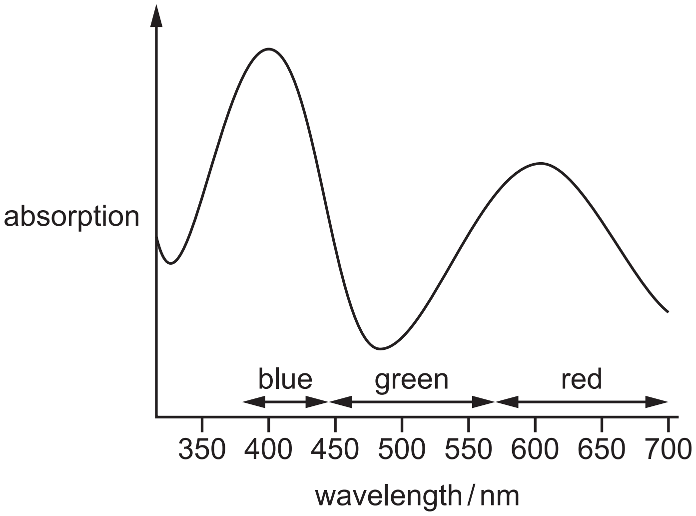
Suggest a reason for this.

....

....

.... [1]

(c) The diagram shows the visible spectrum of a solution of $[V(H_2O)_6]^{3+}$.



State and explain what colour the solution is.

colour of solution ....

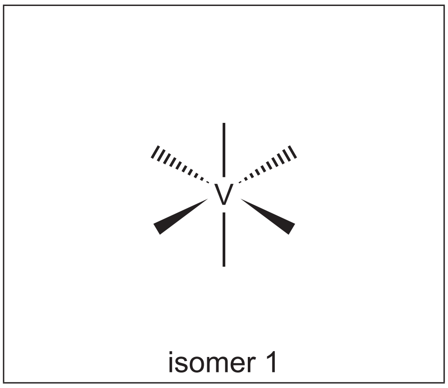
explanation ....

.... [2]

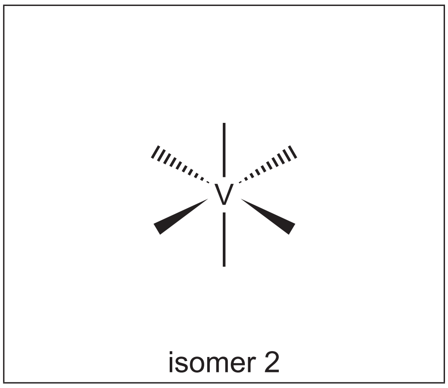
(d) **(i)** In the presence of chloride ions, $[V(H_2O)_6]^{3+}$ reacts to form a mixture of isomeric octahedral complexes.

$$[V(H_2O)_6]^{3+} + 2Cl^- \rightleftharpoons [V(H_2O)_4Cl_2]^+ + 2H_2O$$

Complete the three-dimensional diagrams to show the **two** isomers of $[V(H_2O)_4Cl_2]^+$.



isomer 1



isomer 2

[2]

(ii) State the type of isomerism shown by isomer 1 and isomer 2 in **(i)**.

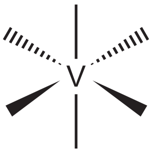
.... [1]

(e) **(i)** The complex $[V(H_2O)_6]^{3+}$ also reacts with ethane-1,2-diamine (*en*), $H_2NCH_2CH_2NH_2$, to form a mixture of isomeric octahedral complexes.

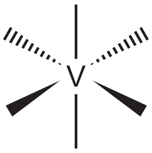
$$[V(H_2O)_6]^{3+} + 3en \rightleftharpoons [V(en)_3]^{3+} + 6H_2O$$

Complete the three-dimensional diagrams to show the **two** isomers of $[V(en)_3]^{3+}$.

You may use  to represent *en*.



isomer 1



isomer 2

[2]

(ii) State the type of isomerism shown by isomer 1 and isomer 2 in **(i)**.

.... [1]

(f) The reaction of $[Ni(H_2O)_6]^{2+}$ with aqueous ammonia produces the complex $[Ni(NH_3)_6]^{2+}$.

$$[Ni(H_2O)_6]^{2+}(aq) + 6NH_3(aq) \rightleftharpoons [Ni(NH_3)_6]^{2+}(aq) + 6H_2O(l)$$

(i) Write the expression for K_{stab} for $[Ni(NH_3)_6]^{2+}$.

K_{stab} =

[1]

(ii) $[Ni(H_2O)_6]^{2+}$ also reacts with *en* to form $[Ni(en)_3]^{2+}$.
The values of the stability constants for the two complexes are shown.

K_{stab} $[Ni(NH_3)_6]^{2+} = 4.8 \times 10^7\,mol^{-6}\,dm^{18}$

K_{stab} $[Ni(en)_3]^{2+} = 2.0 \times 10^{18}\,mol^{-3}\,dm^9$

A solution containing equal numbers of moles of ammonia and *en* is added to $[Ni(H_2O)_6]^{2+}$.

State which complex is produced in the larger amount. Explain your answer.

....

....

.... [1]

(iii) Adding a limited amount of *en* to $[Ni(H_2O)_6]^{2+}$ forms the complex $[Ni(H_2O)_2(en)_2]^{2+}$.

Suggest the number of possible stereoisomers of $[Ni(H_2O)_2(en)_2]^{2+}$. Explain your answer.
You are advised to include three-dimensional diagrams in your answer.

....

....

....

.... [2]

[Total: 18]

3 Bubbling air through different aqueous mixtures of $CoCl_2$, NH_4Cl and NH_3 produces various complex ions with the general formula $[Co(NH_3)_{6-n}Cl_n]^{3-n}$.

(a) (i) Determine the oxidation state of the cobalt in these complex ions.

.... [1]

(ii) Name the **two** types of reaction undergone by the cobalt ions during the formation of these complex ions.

....

.... [2]

(iii) The complex $[Co(NH_3)_4Cl_2]^+$ shows isomerism.

Draw three-dimensional structures of the two isomers, and suggest the type of isomerism shown here.

isomer 1

isomer 2

type of isomerism .... [3]

(b) (i) What is meant by the term *co-ordination number*?

....

.... [1]

(ii) Complete the table by predicting appropriate co-ordination numbers, formulae and charges for the complexes **C**, **D**, **E** and **F**.

complex	metal ion	ligand	co-ordination number	formula of complex	charge on complex
C	Cr^{3+}	CN^-			3–
D	Ni^{2+}	$H_2NCH_2CH_2NH_2$	6		
E	Pt^{2+}	Cl^-			2–
F	Fe^{3+}	$^-O_2C\text{–}CO_2^-$		$[Fe(O_2CCO_2)_3]$	

[6]

(c) Iron(III) forms complexes in separate reactions with both SCN^- ions and Cl^- ions.

$Fe^{3+}(aq) + SCN^-(aq) \rightleftharpoons [FeSCN]^{2+}(aq)$ equilibrium 1

$Fe^{3+}(aq) + 4Cl^-(aq) \rightleftharpoons [FeCl_4]^-(aq)$ equilibrium 2

(i) Write the expressions for the stability constants, K_{stab}, for these two equilibria. Include units in your answers.

K_{stab1} =

units = ...

K_{stab2} =

units = ...

[3]

(ii) An equilibrium can be set up between these two complexes as shown in equilibrium 3.

$[FeCl_4]^-(aq) + SCN^-(aq) \rightleftharpoons [FeSCN]^{2+}(aq) + 4Cl^-(aq)$ equilibrium 3

Write an expression for K_{eq3} in terms of K_{stab1} and K_{stab2}.

K_{eq3} = ... [1]

(iii) The numerical values for these stability constants are shown.

$K_{stab1} = 1.4 \times 10^2$ $K_{stab2} = 8.0 \times 10^{-2}$

Calculate the value of K_{eq3} stating its units.

K_{eq3} = ... units = ...

[2]

[Total: 19]

5 **(a)** 1,2-diaminoethane, *en*, $H_2NCH_2CH_2NH_2$, is a bidentate ligand.

(i) What is meant by the terms *bidentate* and *ligand*?

bidentate ....

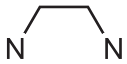
ligand ....

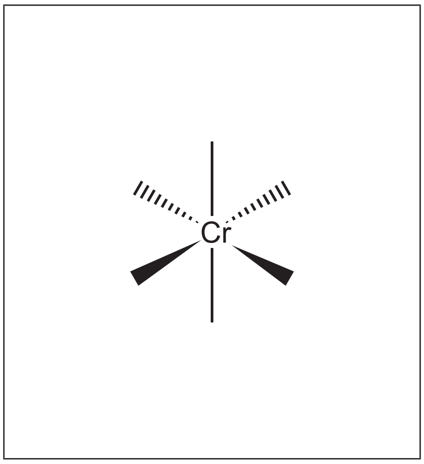
....

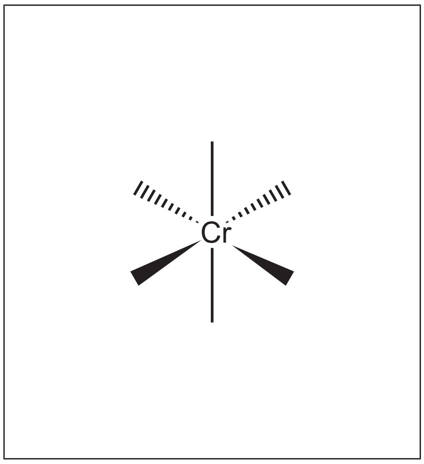
[2]

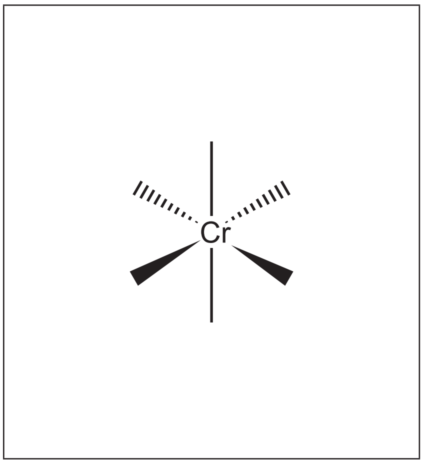
(ii) There are three isomeric complex ions with the formula $[\mathrm{Cr}(\mathit{en})_2\mathrm{C}l_2]^+$.

Complete the three-dimensional diagrams of the isomers in the boxes.

You may use  to represent *en*.







[3]

(b) Copper forms complexes with NH_3 and *en* according to equlibria 1 and 2.

equilibrium 1 $Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$

equilibrium 2 $Cu^{2+}(aq) + 2\mathit{en}(aq) \rightleftharpoons [Cu(\mathit{en})_2]^{2+}(aq)$

(i) Write the expressions for the stability constants, K_{stab1} and K_{stab2}, for equilibria 1 and 2. Include units in your answers.

K_{stab1} =

units = ...

K_{stab2} =

units = ...

[3]

(ii) An equilibrium is set up when both *en* and NH_3 ligands are added to a solution containing $Cu^{2+}(aq)$ as shown in equilibrium 3.

equilibrium 3 $[Cu(NH_3)_4]^{2+}(aq) + 2en(aq) \rightleftharpoons [Cu(en)_2]^{2+}(aq) + 4NH_3(aq)$

Write an expression for the equilibrium constant, K_{eq3}, in terms of K_{stab1} and K_{stab2}.

K_{eq3} = ... [1]

(iii) The numerical values for these stability constants are shown.

$$K_{stab1} = 1.2 \times 10^{13} \qquad K_{stab2} = 5.3 \times 10^{19}$$

Calculate the value of K_{eq3} stating its units.

K_{eq3} = ... unit = ...

[2]

(c) $\Delta S^{\ominus}$ values for equilibria 1 and 2 differ greatly, as can be seen in the table. All values are at a temperature of 298 K.

equilibrium	$\Delta H^{\ominus}$ / kJ mol^{-1}	$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta G^{\ominus}$ / kJ mol^{-1}
1	–92	–60	–74
2	–100	+40	

(i) Explain why $\Delta S^{\ominus}_{eq2}$ is so different from $\Delta S^{\ominus}_{eq1}$.

....

.... [1]

(ii) Calculate $\Delta G^{\ominus}_{eq2}$ at 298 K.

$\Delta G^{\ominus}_{eq2}$ = ... kJ mol^{-1}

[2]

(iii) What conclusion can be made about the relative feasibility of equilibria 1 and 2?

Explain your answer.

.... [1]

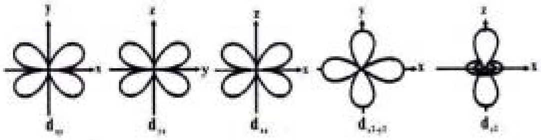
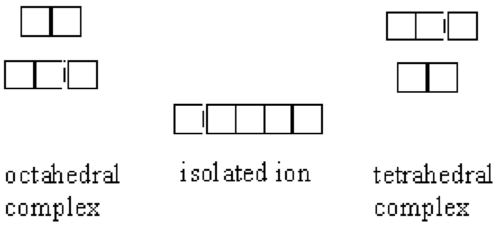
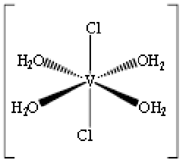
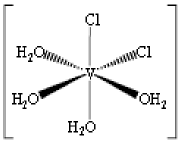
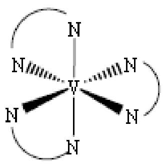
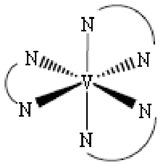
(iv) Using data from the table, suggest a value of $\Delta H^{\ominus}$ for equilibrium 3.

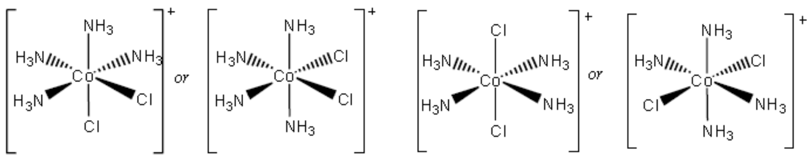
.... [1]

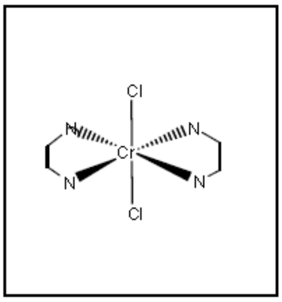
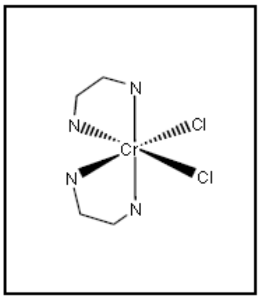
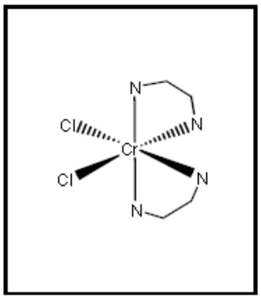
(v) State the *type of reaction* that is occurring in equilibrium 2.

.... [1]

[Total: 17]

Question	Answer	Marks
6 (a) (i)		**1+1**
6 (a) (ii)	Ni : $[1s^2 2s^2 2p^6 3s^2 3p^6]$ $\mathbf{3d^8 4s^2}$ Ni3+ : $[1s^2 2s^2 2p^6 3s^2 3p^6]$ $\mathbf{3d^7}$	**1**
6 (b) (i)		**1**
6 (b) (ii)	energy / photon is absorbed in the visible region / light	**1**
	electron jumps from the lower to the upper energy level / is excited	**1**
6 (b) (iii)	different frequency / wavelength of light are absorbed by the two complexes **OR** different size of energy gap	**1**
6 (c)	colour of solution: green	**1**
	explanation: because the solution absorbs most strongly in the blue **AND** red regions	**1**
6 (d) (i)	 	**1**
6 (d) (ii)	cis-trans / geometrical	**1**
6 (e) (i)	 	**1**
6 (e) (i)	optical	**1**
6 (f) (i)	$K_{stab} = [Ni(NH_3)_6{}^{2+}] / ([Ni(H_2O)_6{}^{2+}][NH_3]^6)$	**1**
6 (f) (ii)	$[Ni(en)_3]^{2+}$ would be formed because it is much more stable / K_{stab} is much greater **OR** in the presence of both ligands the overall equilibrium $[Ni(NH_3)_6]^{2+} \rightleftharpoons [Ni(H_2O)_6]^{2+} \rightleftharpoons [Ni(en)_3]^{2+}$ would shift right	**1**
6 (f) (iii)	cis-trans isomers identified	**1**
	two cis isomers identified	**1**
		Total: 17

Question	Answer	Marks
3 (a) (i)	+3 or Co^{3+}	**1**
3 (a) (ii)	oxidation	**1**
	ligand displacement / replacement / exchange / substitution	**1**
3 (a) (iii)	 cis trans	**1**
	geometrical or cis-trans	**1**
3 (b) (i)	The number of bonds / atoms bonded to **an atom / ion / species / metal**	**1**
3 (b) (ii)	**C** 6 $[Cr(CN)_6]$ – **D** – $[Ni(NH_2CH_2CH_2NH_2)_3]$ 2+/+2 **E** 4 $[PtCl_4]$ – **F** 6 – 3–/–3	**6**
3 (c) (i)	$K_{stab(1)} = [FeSCN^{2+}]/([Fe^{3+}][SCN^-])\ mol^{-1}\ dm^3$ $K_{stab(2)} = [FeCl^{4-}]/([Fe^{3+}][Cl^-]^4)\ mol^{-4}\ dm^{12}$	**3**
3 (c) (ii)	$K_{eq(3)} = K_{stab(1)} / K_{stab(2)}$	**1**
3 (c) (iii)	$K_{eq(3)} = 1750$	**1**
	$mol^3\ dm^{-9}$	**1**
		Total: 19

Question	Answer	Marks
5 (a) (i)	*bidentate*: (a species that) forms **two** dative bonds / donates **two** lone pairs	**1**
	ligand: a species that uses a **lone pair** to form a **dative** bond to **a metal atom / metal ion**	**1**
5 (a) (ii)	   each structure [1] × 3	**3**
5 (b) (i)	$K_{stab1} = [Cu(NH_3)_4{}^{2+}]/[Cu^{2+}][NH_3]^4$	**1**
	$K_{stab2} = [Cu(en)_2{}^{2+}]/[Cu^{2+}][en]^2$	**1**
	$mol^{-4}\ dm^{12}$ AND $mol^{-2}\ dm^6$	**1**

Question	Answer	Marks
5 (b) (ii)	$K_{eq3} = K_{stab2} / K_{stab1}$	**1**
5 (b) (iii)	$K_{eq3} = K_{stab2} / K_{stab1} = 4.4(2) \times 10^6$	**1**
	$mol^2\ dm^{-6}$	**1**
5 (c) (i)	(ΔS_{eq1} is negative as) **more / 5** moles of reactants are forming (one mole of) the complex OR (ΔS_{eq2} is positive as) **fewer / 3** moles of reactants are forming (one mole of) the complex	**1**
5 (c) (ii)	ΔG_{eq2} = –100 – 298 × 40 / 1000 OR $\Delta G = \Delta H - T\Delta S$	**1**
	= –112 or –111.9 (kJ mol^{-1}) correct answer	**1**
		Total: 14

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

8: Controlling reactions 2 – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
2	2017	March	42
1	2017	June	41
1	2017	June	42

The mark scheme for each question is provided at the end of the document.

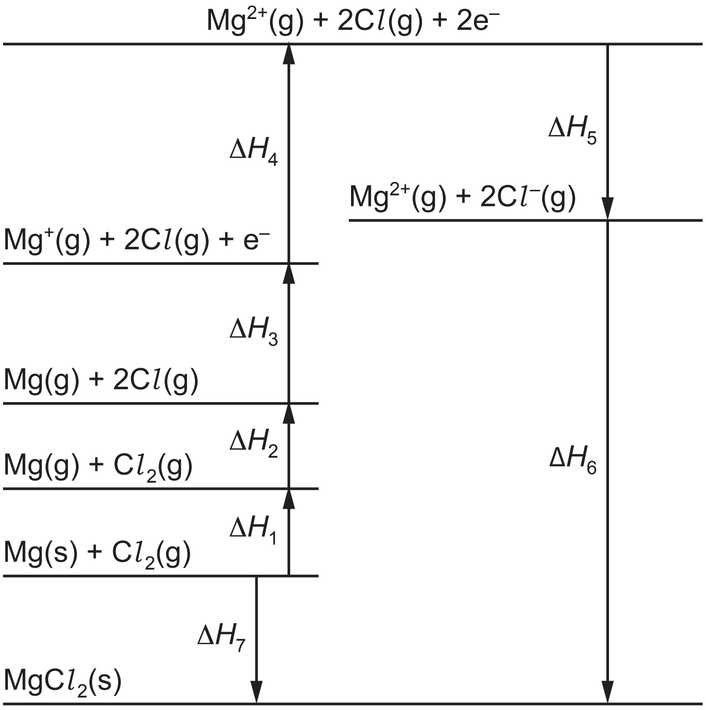
You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

2 **(a)** Complete the table using ticks (✓) to indicate whether the sign of each type of energy change, under standard conditions, is always positive, always negative or could be either positive or negative.

energy change	always positive	always negative	either positive or negative
electron affinity			
enthalpy change of atomisation			
ionisation energy			
lattice energy			

[2]

(b) The Born-Haber cycle for magnesium chloride is shown.



(i) Explain why ΔH_4 is greater than ΔH_3.

....

.... [1]

(ii) What names are given to the enthalpy changes ΔH_6 and ΔH_7?

ΔH_6 ....

ΔH_7 ....

[1]

(c) Chlorine is in Group 17.

Suggest the trend in the first electron affinity of the elements in Group 17. Explain your answer.

....

....

.... [2]

(d) The equation for the formation of magnesium oxide from its elements is shown.

$$\mathrm{Mg(s)} + \tfrac{1}{2}\mathrm{O_2(g)} \rightarrow \mathrm{MgO(s)} \qquad \Delta H^{\ominus} = -602\,\mathrm{kJ\,mol^{-1}}$$

substance	$S^{\ominus}$ / J K^{-1} mol^{-1}
Mg(s)	32.7
O_2(g)	205
MgO(s)	26.9

Use the equation and the data given in the table to calculate $\Delta G^{\ominus}$ for the reaction at 25 °C.

$\Delta G^{\ominus}$ = ... units ....

[4]

[Total: 10]

1 **(a)** Describe and explain the variation in the solubilities of the hydroxides of the Group 2 elements.

....

....

....

....

....

.... [4]

The table lists the standard enthalpy changes of formation, $\Delta H_f^\ominus$, for some compounds and aqueous ions.

species	$\Delta H_f^\ominus$ / kJ mol^{-1}
$Ba^{2+}(aq)$	–538
$OH^-(aq)$	–230
$CO_2(g)$	–394
$BaCO_3(s)$	–1216
$H_2O(l)$	–286

(b) **(i)** Reaction 1 occurs when $CO_2(g)$ is bubbled through an aqueous solution of $Ba(OH)_2$.

Use the data in the table to calculate the standard enthalpy change for reaction 1, $\Delta H_{r1}^\ominus$.

$$Ba(OH)_2(aq) + CO_2(g) \rightarrow BaCO_3(s) + H_2O(l) \qquad \text{reaction 1}$$

$\Delta H_{r1}^\ominus$ = ... kJ mol^{-1} [2]

If CO_2(g) is bubbled through an aqueous solution of $Ba(OH)_2$ for a long time, the precipitated $BaCO_3$(s) dissolves, as shown in reaction 2.

$$BaCO_3(s) + CO_2(g) + H_2O(l) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 2}$$

The standard enthalpy change for reaction 2, $\Delta H^{\ominus}_{r2}$, = –26 kJ mol^{-1}.

(ii) Use this information and the data in the table to calculate the standard enthalpy change of formation of the HCO_3^-(aq) ion.

$\Delta H^{\ominus}_{f}$ HCO_3^-(aq) = ... kJ mol^{-1} [2]

(iii) The overall process is shown by reaction 3.

Use your answer to **(ii)**, and the data given in the table, to calculate the standard enthalpy change for reaction 3, $\Delta H^{\ominus}_{r3}$.

$$Ba(OH)_2(aq) + 2CO_2(g) \rightarrow Ba(HCO_3)_2(aq) \qquad \text{reaction 3}$$

$\Delta H^{\ominus}_{r3}$ = ... kJ mol^{-1} [1]

(iv) How would the value of $\Delta H^{\ominus}_{r3}$ compare with the value of $\Delta H^{\ominus}_{r4}$ for the similar reaction with $Ca(OH)_2$(aq) as shown in reaction 4?
Explain your answer.

$$Ca(OH)_2(aq) + 2CO_2(g) \rightarrow Ca(HCO_3)_2(aq) \qquad \text{reaction 4}$$

....

....

.... [2]

(c) The standard entropy change for reaction 1 is $\Delta S^{\ominus}_{r1}$.

Suggest, with a reason, how the standard entropy change for reaction 3 might compare with $\Delta S^{\ominus}_{r1}$.

....

....

.... [2]

[Total: 13]

1 **(a)** **(i)** Describe and explain the variation in the thermal stabilities of the carbonates of the Group 2 elements.

....

....

....

....

.... [3]

(ii) Suggest and explain a reason why sodium carbonate is more stable to heat than magnesium carbonate.

....

....

.... [1]

(b) Sodium hydrogencarbonate, $NaHCO_3$, and potassium hydrogencarbonate, $KHCO_3$, decompose on heating to produce gases and the solid metal carbonate.

(i) Write an equation for the decomposition of $KHCO_3$.

.... [1]

(ii) Predict which of $NaHCO_3$ or $KHCO_3$ will decompose at the **lower** temperature. Explain your answer.

....

.... [1]

(c) **(i)** Use the data in the table below, and relevant data from the *Data Booklet*, to calculate the lattice energy, $\Delta H^{\ominus}_{latt}$, of potassium oxide, $K_2O(s)$.

energy change	value / $kJ\,mol^{-1}$
enthalpy change of atomisation of potassium, $\Delta H^{\ominus}_{at}$ K(s)	+89
electron affinity of O(g)	–141
electron affinity of O^-(g)	+798
enthalpy change of formation of potassium oxide, $\Delta H^{\ominus}_{f}$ $K_2O(s)$	–361

$\Delta H^{\ominus}_{latt}$ = ... $kJ\,mol^{-1}$ [3]

(ii) State whether the lattice energy of Na_2O would be more negative, less negative or the same as that of K_2O. Give reasons for your answer.

....

.... [1]

[Total: 10]

5 **(a)** 1,2-diaminoethane, *en*, $H_2NCH_2CH_2NH_2$, is a bidentate ligand.

(i) What is meant by the terms *bidentate* and *ligand*?

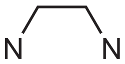
bidentate ....

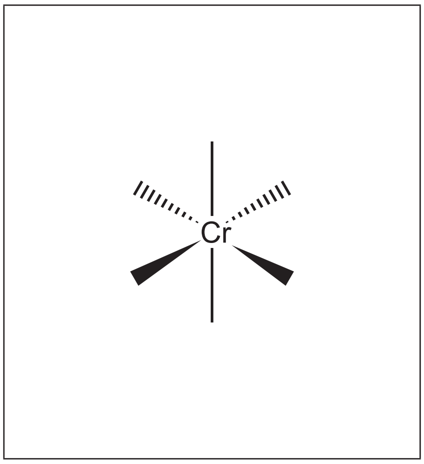
ligand ....

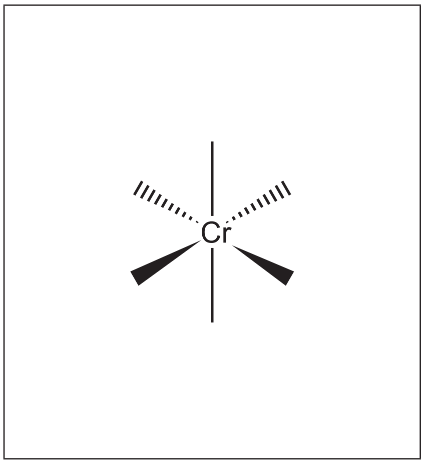
....
[2]

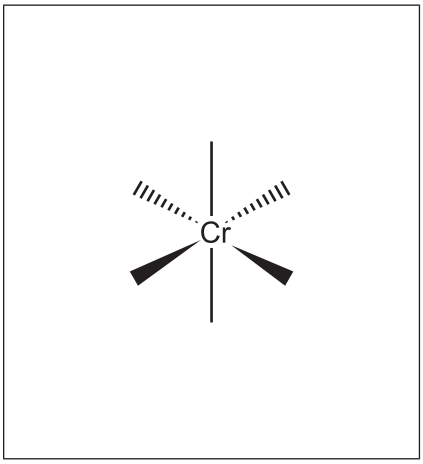
(ii) There are three isomeric complex ions with the formula $[Cr(en)_2Cl_2]^+$.

Complete the three-dimensional diagrams of the isomers in the boxes.

You may use  to represent *en*.







[3]

(b) Copper forms complexes with NH_3 and *en* according to equlibria 1 and 2.

equilibrium 1 $Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$

equilibrium 2 $Cu^{2+}(aq) + 2en(aq) \rightleftharpoons [Cu(en)_2]^{2+}(aq)$

(i) Write the expressions for the stability constants, K_{stab1} and K_{stab2}, for equilibria 1 and 2.
Include units in your answers.

K_{stab1} =

units = ...

K_{stab2} =

units = ...
[3]

(ii) An equilibrium is set up when both *en* and NH_3 ligands are added to a solution containing $Cu^{2+}(aq)$ as shown in equilibrium 3.

equilibrium 3 $[Cu(NH_3)_4]^{2+}(aq) + 2en(aq) \rightleftharpoons [Cu(en)_2]^{2+}(aq) + 4NH_3(aq)$

Write an expression for the equilibrium constant, K_{eq3}, in terms of K_{stab1} and K_{stab2}.

K_{eq3} = ... [1]

(iii) The numerical values for these stability constants are shown.

$$K_{stab1} = 1.2 \times 10^{13} \qquad K_{stab2} = 5.3 \times 10^{19}$$

Calculate the value of K_{eq3} stating its units.

K_{eq3} = ... unit = ...
[2]

(c) $\Delta S^{\ominus}$ values for equilibria 1 and 2 differ greatly, as can be seen in the table. All values are at a temperature of 298 K.

equilibrium	$\Delta H^{\ominus}$ / kJ mol^{-1}	$\Delta S^{\ominus}$ / J K^{-1} mol^{-1}	$\Delta G^{\ominus}$ / kJ mol^{-1}
1	–92	–60	–74
2	–100	+40	

(i) Explain why $\Delta S^{\ominus}_{eq2}$ is so different from $\Delta S^{\ominus}_{eq1}$.

....

.... [1]

(ii) Calculate $\Delta G^{\ominus}_{eq2}$ at 298 K.

$\Delta G^{\ominus}_{eq2}$ = ... kJ mol^{-1}
[2]

(iii) What conclusion can be made about the relative feasibility of equilibria 1 and 2?

Explain your answer.

.... [1]

(iv) Using data from the table, suggest a value of $\Delta H^{\ominus}$ for equilibrium 3.

.... [1]

(v) State the *type of reaction* that is occurring in equilibrium 2.

.... [1]

[Total: 17]

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>2 (a)</td><td>
<table>
<tr><td>Enthalpy change</td><td>positive</td><td>negative</td><td>either positive or negative</td></tr>
<tr><td>electron affinity</td><td></td><td></td><td>✓</td></tr>
<tr><td>enthalpy chare of atomisation</td><td>✓</td><td></td><td></td></tr>
<tr><td>enthalpy charge of ionisation</td><td>✓</td><td></td><td></td></tr>
<tr><td>lattice enthalpy</td><td></td><td>✓</td><td></td></tr>
</table>
</td><td>2</td></tr>
<tr><td>2 (b) (i)</td><td>the second electron is removed from a (more) positively charged ion</td><td>1</td></tr>
<tr><td>2 (b) (ii)</td><td>ΔH_6 is lattice (energy / enthalpy) AND ΔH_7 is (energy / enthalpy of) formation</td><td>1</td></tr>
<tr><td rowspan="2">2 (c)</td><td>the electron affinity becomes less exothermic / negative down the Group 17</td><td>1</td></tr>
<tr><td>electron affinity depends (mainly) on the electron-nucleus distance which increases down Group 17</td><td>1</td></tr>
<tr><td rowspan="4">2 (d)</td><td>M1 correct use of $\Delta G = \Delta H - T\Delta S$</td><td>1</td></tr>
<tr><td>M2 $\Delta S = 26.9 - (32.7 + 102.5) = -108.3$ J K^{-1} mol^{-1} OR -0.1083 kJ K^{-1} mol^{-1}</td><td>1</td></tr>
<tr><td>M3 $\Delta G = -602 - (298 \times (-0.1083)) = -570$</td><td>1</td></tr>
<tr><td>M4 units: kJ mol^{-1}</td><td>1</td></tr>
<tr><td colspan="3">Total: 10</td></tr>
</table>

Question	Answer	Marks
1 (a)	solubility increases down the group	**1**
	ΔH_{latt} and ΔH_{hyd} both **decrease** **or** ΔH_{latt} and ΔH_{hyd} both become less exothermic / more endothermic	**1**
	ΔH_{latt} decreases / changes more (than ΔH_{hyd} as OH^- being smaller than M^{2+})	**1**
	ΔHsol becomes more exothermic / more negative / less endothermic / less positive	**1**
1 (b) (i)	$\Delta H_{r1} - (538 + 2x230 + 394) = -(1216 + 286)$ $\Delta H_{r1} - 1392 = -1502$	**1**
	ΔH_{r1} = **–110**	**1**

Question	Answer	Marks
1 (b) (ii)	let $\Delta H_f(HCO_3^-(aq))$ = y 2y – 538 = –1216 – 394 – 286 – 26	**1**
	y = **–692**	**1**
1 (b) (iii)	ΔH_{r3} –538 – 2(230 + 394) = –538 – 2(692) ΔH_{r3} = **–136**	**1**
1 (b) (iv)	ΔH_{r3} will be identical to ΔH_{r4}, / unchanged	**1**
	as the reaction is the same, or: $2OH^-(aq) + 2CO_2(g) \rightarrow 2HCO_3^-(aq)$ or metal ions stay in solution/metal ions are unchanged / are spectators	**1**
1 (c)	more **gaseous moles** are being consumed (in reaction 3) **or** more **CO_2 moles** are being consumed (in reaction 3)	**1**
	ΔS is therefore expected to be **more negative/less positive** for reaction 3.	**1**
		Total: 13

Question	Answer	Marks
1 (a) (i)	increases down the group	**1**
	radius / size of (cat)ion/M^{2+} increases	**1**
	less polarisation / distortion of anion / carbonate **ion** / CO_3^{2-}	**1**
1 (a) (i)	Na^+ has smaller ionic charge **and** larger ionic radii OR the **charge density** of the **Na^+** is **lower**	**1**
1 (b) (ii)	$2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$	**1**
1 (b) (ii)	$NaHCO_3$ because Na^+ is **smaller** OR charge density Na^+ is **larger**	**1**
1 (c) (i)	LE = ΔH_f – 2(ΔH_{at} + IE) – ½(O=O) – (EA_1 + EA_2)	**1**
	= –361 – 2(89) **–** 2(418) – 496/2 – (–141+798)	**1**
	= **–2280** (kJ mol^{-1})	**1**
1 (c) (ii)	LE of Na_2O will be **more negative** AND as $Na^{(+)}$ is smaller / larger charge density / smaller radii AND so greater attraction (between the ions) OR (ionic) bonds will be stronger	**1**
		Total: 10

Notes about the mark scheme are available separately.

Cambridge Assessment
International Education

Cambridge International AS & A Level

9: Organic chemistry 2 – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners' understanding of this topic.

Question	Year	Series	Paper number
8	2017	March	42
4	2017	June	41
7	2017	June	42

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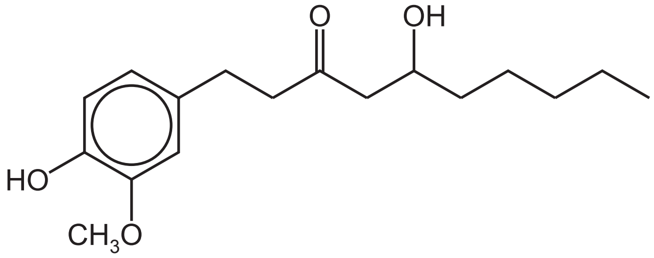
8 The root of the ginger plant contains compounds with medicinal and flavouring properties. Three of the more important compounds are gingerol, shogaol and zingerone.

(a) The structure of gingerol is shown. The $CH_3O–$ group in gingerol is unreactive.



gingerol

Gingerol reacts with acidified potassium dichromate(VI).

State the *type of reaction* and the functional group change which occurs during this reaction.

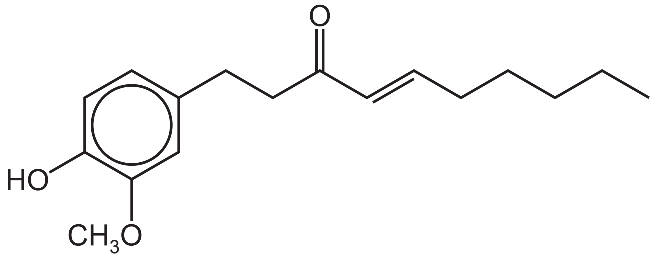
type of reaction ....

functional group change

from .... to ....

[1]

(b) The structure of shogaol is shown.



shogaol

(i) State the *type of reaction* needed to convert gingerol into shogaol.

.... [1]

(ii) State the reagents and conditions needed to convert gingerol into shogaol.

reagents ....

conditions ....

[1]

(iii) Shogaol reacts with hot, concentrated acidified manganate(VII) ions to form two organic products, **Q** and **R**.

Draw the structures of **Q** and **R**.

Q

R

[2]

(c) Zingerone is formed from gingerol.

Some reactions of zingerone are shown.

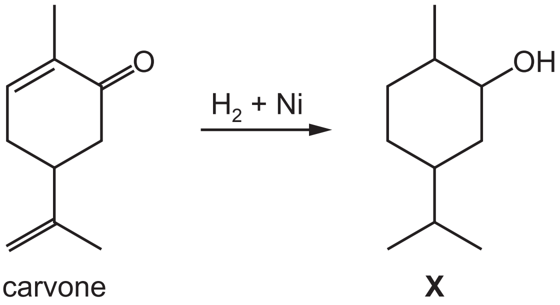
Complete the table to identify the functional groups in zingerone.

reagent and conditions	observation	functional group in zingerone indicated by the observation
benzenediazonium chloride, 5 °C, alkaline solution	red ppt.	
2,4-dinitrophenylhydrazine	orange ppt.	
warm with Tollens’ reagent	no change	

[2]

[Total: 7]

4 Carvone occurs in spearmint and a stereoisomer of carvone occurs in caraway seeds. Treating either isomer with hydrogen over a nickel catalyst produces a mixture of isomers with the structural formula **X**.



(a) **(i)** State the type of stereoisomerism carvone can show. Explain your answer.

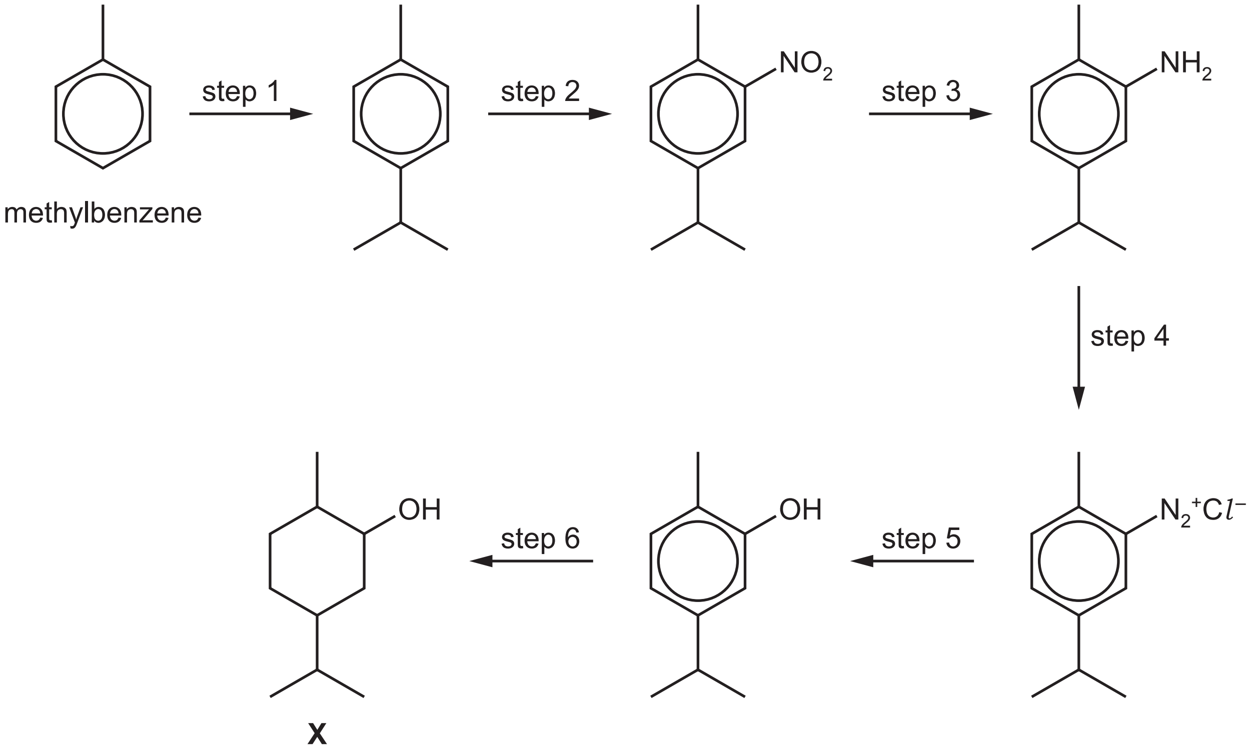
....

.... [1]

(ii) Write an equation, using molecular formulae, for this conversion of carvone to **X**.

.... [2]

X can be synthesised from methylbenzene by the following route.



(b) **(i)** Name the mechanism in step 1.

.... [1]

(ii) What type of reaction is occuring in the following steps?

step 3 ....

step 5 ....
[2]

(iii) Suggest reagents and conditions for each of the following steps.

step 1 ....

step 2 ....

step 3 ....

step 4 ....
[6]

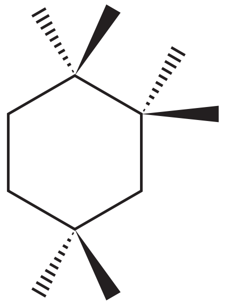
(c) During step 6, hydrogen is added to the benzene ring to produce the cyclohexane ring in **X**. The six hydrogen atoms are all added to the **same side** of the benzene ring.

(i) State the reagents and conditions needed for this reaction.

.... [1]

(ii) Complete the part structure to show the structure of the isomer of **X** that would most likely be obtained during this reaction.

X



[2]

[Total: 15]

7 Compounds **W**, **X**, **Y** and **Z** are isomers of each other with the molecular formula C_8H_7ClO.
All four isomers contain a benzene ring.
Only **one** of the isomers contains a chiral centre.
The results of six tests carried out on **W**, **X**, **Y** and **Z** are shown in the table.

test		observations with each isomer			
		W	**X**	**Y**	**Z**
1	add cold $AgNO_3$(aq)	white ppt. forms immediately	none	white ppt. forms very slowly	none
2	heat with NaOH(aq), then add dilute HNO_3 + $AgNO_3$(aq)	white ppt.	none	white ppt.	none
3	add NaOH(aq) + I_2(aq)	none	pale yellow ppt.	none	none
4	warm with Fehling's solution	none	none	red ppt.	none
5	add cold, dilute, acidified KMn $_4$(aq)	no change	no change	no change	decolourises
6	add Br_2(aq)	no change	no change	no change	decolourises and forms white ppt.

(a) Use the experimental results in the table above to determine the group(s), in addition to the benzene ring, present in the four isomers **W**, **X**, **Y** and **Z**.

Complete the table below, identifying the group(s) present in each isomer.

group(s) in compound			
W	**X**	**Y**	**Z**
....	....	....	....
....	....	....	....
....	....	....	....

[5]

(b) Isomers **W**, **X**, **Y** and **Z** all have the molecular formula C_8H_7ClO.

(i) Use the information in **(a)** to suggest a structure for each of these isomers and draw these in the boxes.

W

X

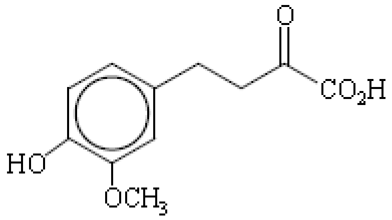
Y

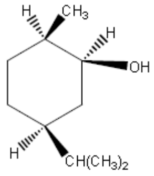
Z

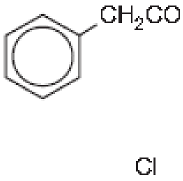
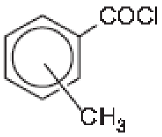
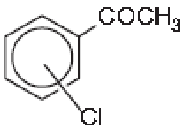
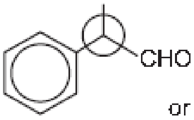
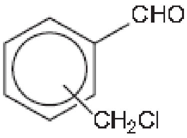
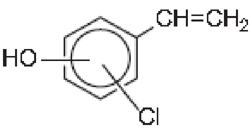
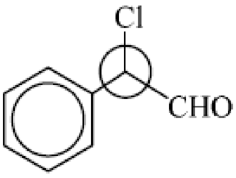
[4]

(ii) Draw a **circle** around the chiral centre in **one** of the above structures. [1]

[Total: 10]

Question	Answer	Marks
8 (a)	oxidation of –OH / alcohol to C=O / ketone / carbonyl	**1**
8 (b) (i)	dehydration / elimination	**1**
8 (b) (ii)	heat with Al_2O_3 **OR** heat with H_3PO_4 / H_2SO_4	**1**
8 (b) (iii)	 **Q**  **R**	**2**
8 (c)	phenol	**1**
	ketone	**1**
		Total: 7

Question	Answer	Marks
4 (a) (i)	optical, because it contains a / one chiral C-atom or chiral C-atoms or chiral atom / centre or C* indicated or C with 4 **different** groups	**1**
4 (a) (ii)	$C_{10}H_{14}O + 3H_2$ ||□ $C_{10}H_{20}O$ correct formulae	**1**
	balancing	**1**
4 (b) (i)	electrophilic substitution	**1**
4 (b) (ii)	step 3 reduction	**1**
	step 5 substitution / hydrolysis	**1**
4 (b) (iii)	step 1 $(CH_3)_2CHCl$ + $AlCl_3$ / $AlBr_3$ / $FeCl_3$ / $FeBr_3$	**1 + 1**
	step 2 HNO_3 + H_2SO_4 conc (T < 55 °C)	**1**
	step 3 Sn + HCl	**1**
	step 4 HNO_2 (*or* $NaNO_2$ + HCl) (at T < 10 °C)	**1**
	the two temperatures for steps 2 and 4	**1**
4 (c) (i)	$\mathbf{H_2}$ + Pt or $\mathbf{H_2}$ + Ni + heat or pressure	**1**
4 (c) (ii)	 $(CH_3)_2CH$, CH_3 and OH on the correct ring atoms i.e. structure is correct	**1**
	all Hs on the same side of the ring	**1**
		Total: 15

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>7 (a)</td><td>
<table>
<tr><th>W</th><th>X</th><th>Y</th><th>Z</th></tr>
<tr><td>acyl chloride / COCl</td><td>methyl ketone / CH_3CO group
aryl chloride</td><td>aldehyde / CHO
chloro(alkane) RCl</td><td>Alkene / C=C
Phenol / C_6H_5OH
aryl chloride</td></tr>
</table>
0–1 [0]; 2 [1]; 3 [2]; 4 [3]; 5 [4]; 6–8 [5]</td><td>5</td></tr>
<tr><td>7 (b) (i)</td><td>W  or  X  </td><td>1 + 1</td></tr>
<tr><td></td><td>Y  or  Z  </td><td>1 + 1</td></tr>
<tr><td>7 (b) (ii)</td><td>Y 
OR any chiral atom correctly labelled</td><td>1</td></tr>
<tr><td></td><td></td><td>Total: 10</td></tr>
</table>

Notes about the mark scheme are available separately.

Cambridge Assessment International Education

Cambridge International AS & A Level

10: Analysis – Topic questions

The questions in this document have been compiled from a number of past papers, as indicated in the table below.

Use these questions to formatively assess your learners’ understanding of this topic.

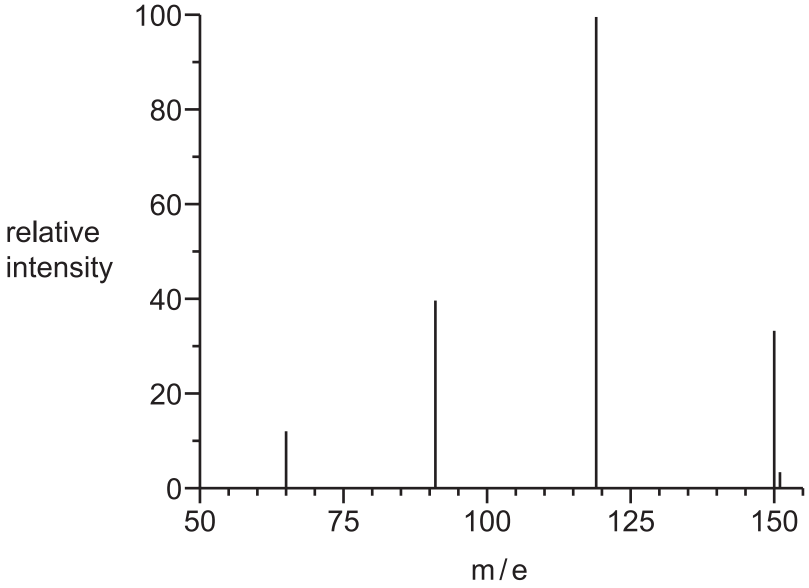
Question	Year	Series	Paper number
9	2017	March	42
6	2017	November	43
8	2017	November	42

The mark scheme for each question is provided at the end of the document.

You can find the complete question papers and the complete mark schemes (with additional notes where available) on the School Support Hub at www.cambridgeinternational.org/support

9 This question is about compound **T**, $C_xH_yO_z$.

(a) Part of the mass spectrum of **T** is shown.
The peak heights of the M and M+1 peaks are 33.9 and 3.4 respectively.



(i) Calculate x, the number of carbon atoms present in **T**.

x = ... [2]

(ii) Deduce the molecular formula of **T**.

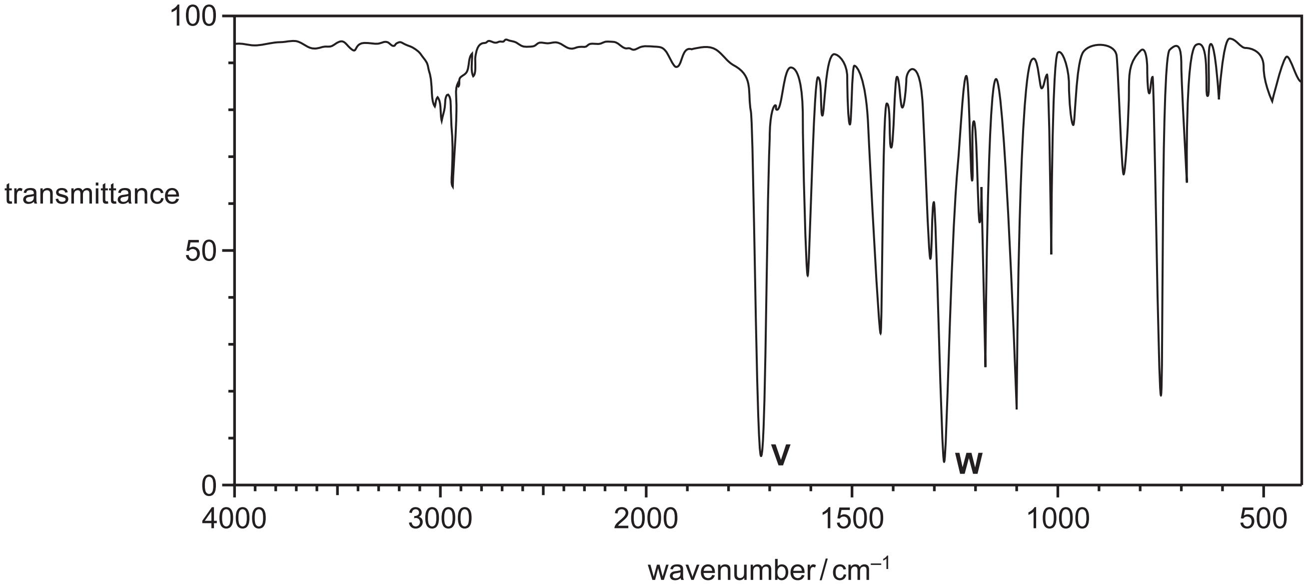
.... [1]

(iii) The mass spectrum has a peak at m / e = 119.

Identify the fragment lost from **T** to produce this peak.

.... [1]

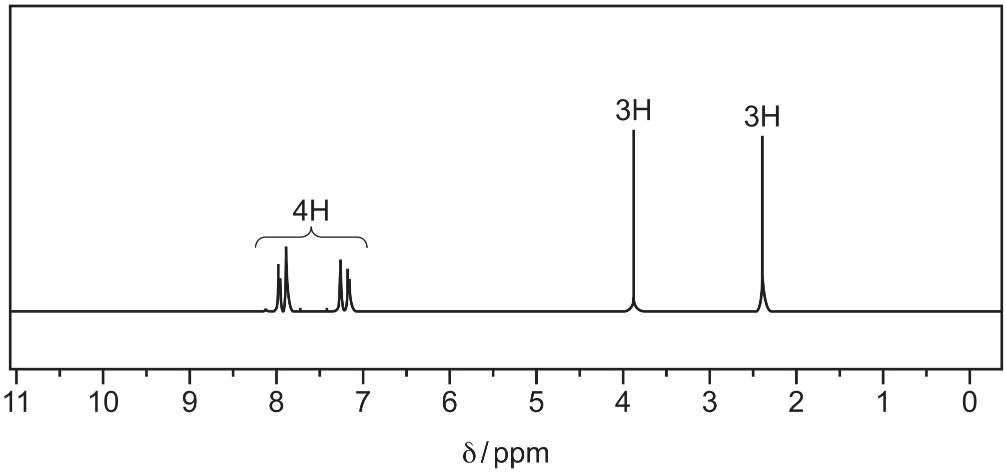
(b) The infra-red spectrum of **T** is shown.



Identify the type of bond responsible for each of the peaks **V** and **W**.
Use the *Data Booklet* to help you.

V .... **W** .... [1]

(c) The proton NMR spectrum of **T** in $CDCl_3$ is shown.



(i) Complete the table for the proton NMR spectrum of **T**.
Use the *Data Booklet* to help you.

δ / ppm	type of proton
3.9	
7.2–7.9	

[1]

(ii) The peak at $\delta = 2.4$ ppm is due to a proton attached to a saturated carbon atom.

State the **two** possible types of proton.

1. ....

2. ....
[1]

(iii) Adding D_2O to **T** does **not** change its proton NMR spectrum.

What does this tell you about the functional groups present in **T**?

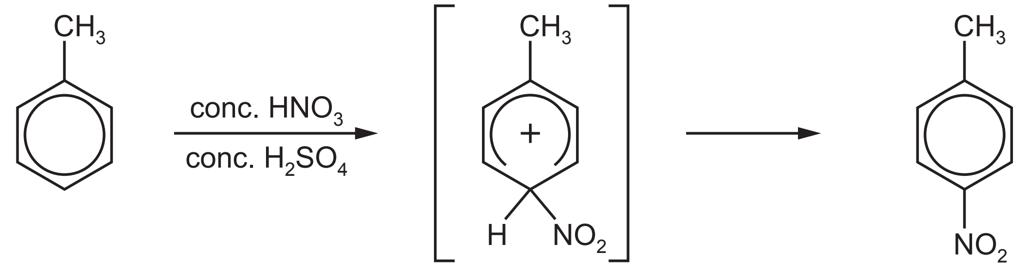
.... [1]

(d) Use the information to draw **two** possible structures of **T** which are functional group isomers of each other.

[2]

[Total: 10]

6 **(a)** 4-nitromethylbenzene can be prepared via an electrophilic substitution reaction as shown.



methylbenzene intermediate **T** 4-nitromethylbenzene

(i) This reaction also forms an isomer of 4-nitromethylbenzene as a by-product.

Draw the structure of this by-product.

[1]

(ii) Write an equation for the reaction between HNO_3 and H_2SO_4 that forms the electrophile for this reaction.

.... [1]

(iii) Describe how the **structure and bonding** of the six-membered ring in intermediate **T** differs from that in methylbenzene.

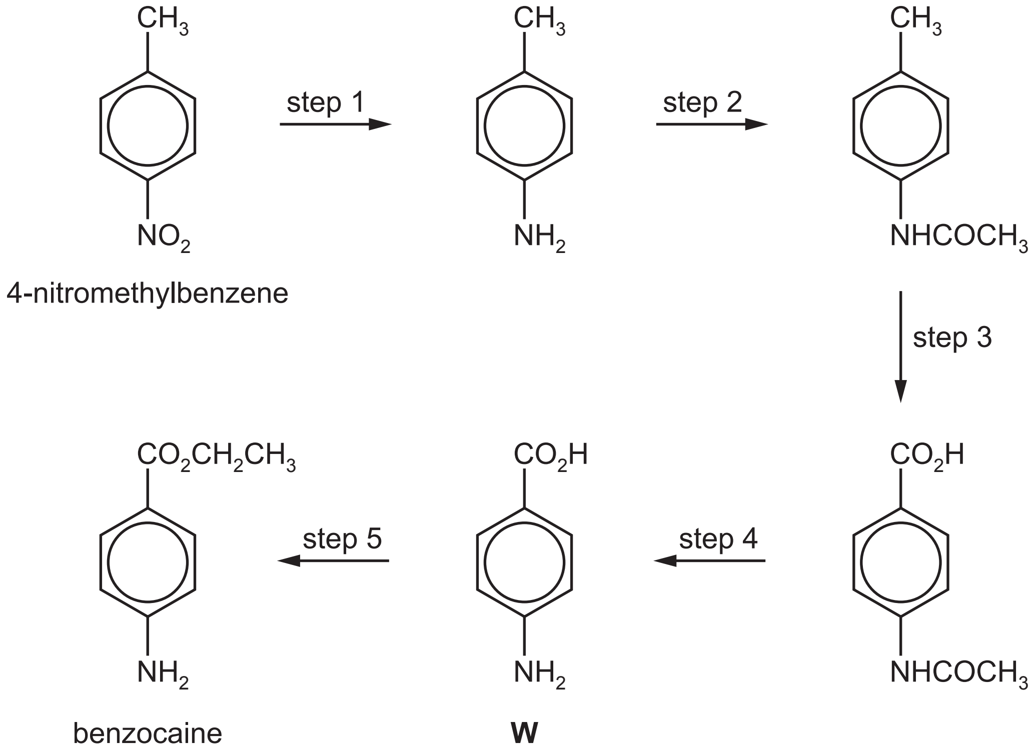
....

....

....

.... [3]

(b) Benzocaine is used as a local anaesthetic. It can be synthesised from 4-nitromethylbenzene by the route shown.



(i) Give the systematic name of compound **W**.

.... [1]

(ii) Suggest the reagents and conditions for steps 1–5.

step 1 ....

step 2 ....

step 3 ....

step 4 ....

step 5 ....
[6]

(c) Suggest how the basicity of benzocaine would compare to that of ethylamine.
Explain your answer.

....

....

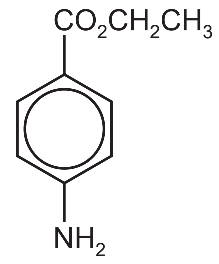
.... [2]

(d) A sample of benzocaine, shown below, was analysed by proton NMR and carbon-13 NMR spectroscopy.

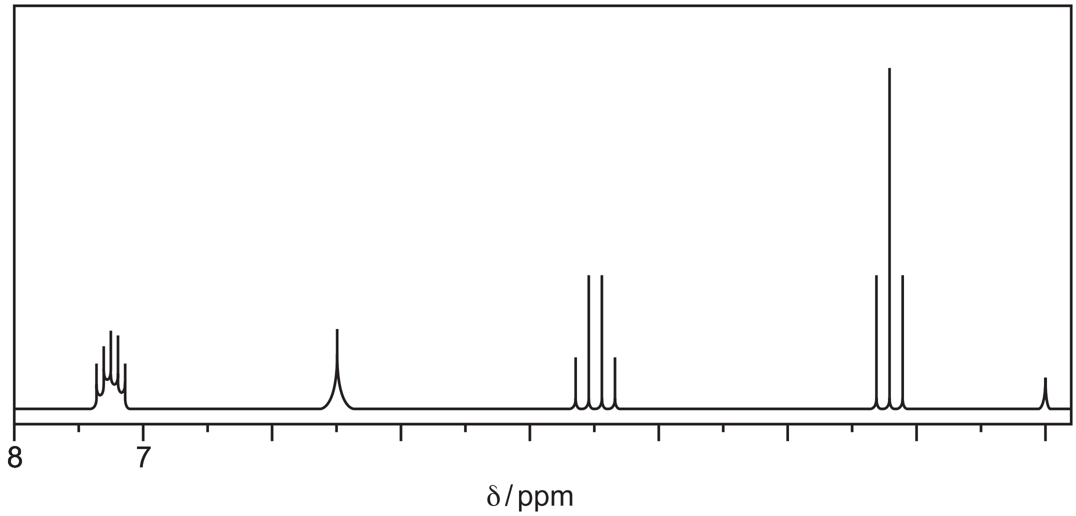
(i) Predict the number of peaks that would be seen in the carbon-13 NMR spectrum.

.... [1]

(ii) Benzocaine was dissolved in $CDCl_3$ and the proton NMR spectrum of this solution was recorded.



benzocaine



Suggest why $CDCl_3$ and not $CHCl_3$ is used as the solvent when obtaining a proton NMR spectrum.

....

.... [1]

(iii) Use the *Data Booklet* and the spectrum in **(d)(ii)** to complete the table for the proton NMR spectrum of benzocaine. The actual chemical shifts, δ, for the four absorptions have been added.

δ / ppm	group responsible for the peak	number of ^1H atoms responsible for the peak	splitting pattern
1.2			
3.5			
5.5			
7.1–7.4			multiplet

[4]

(iv) Explain the splitting pattern for the absorption at δ1.2 ppm.

....

.... [1]

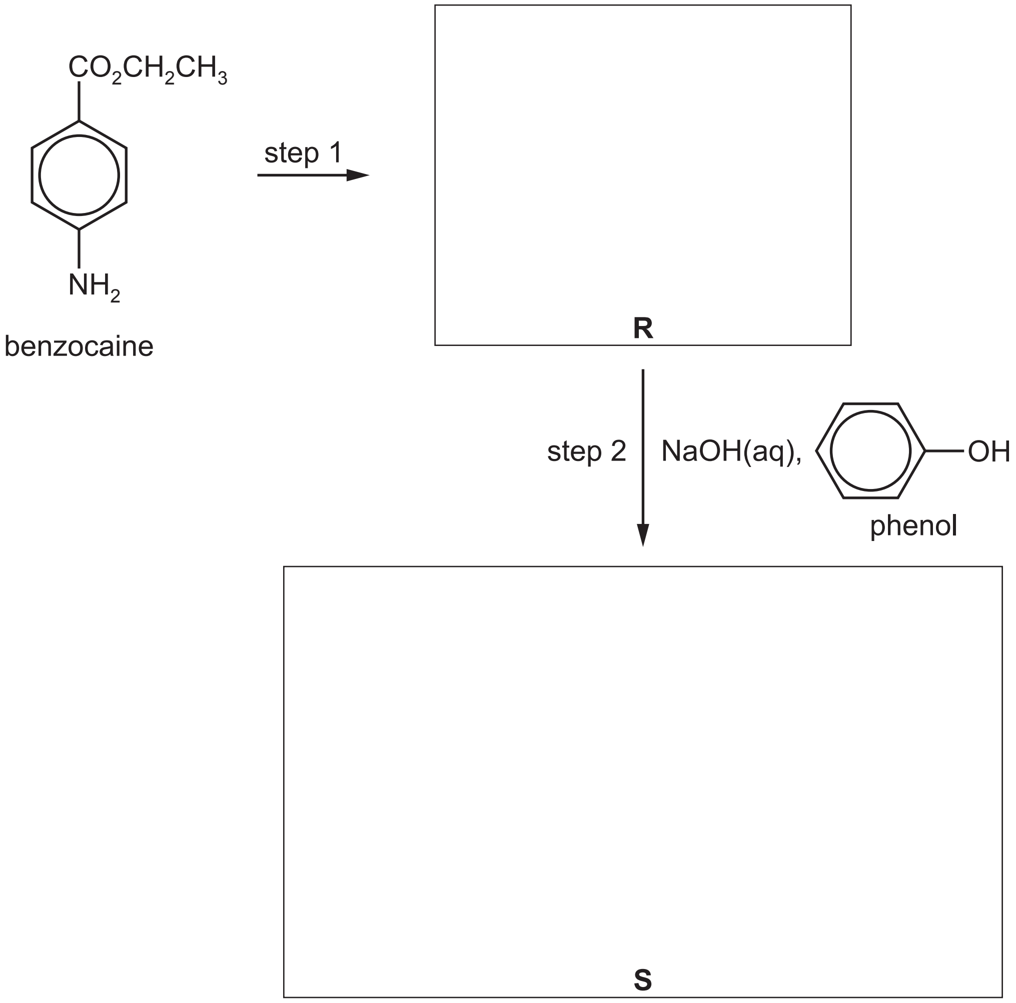
(v) The proton NMR spectrum of benzocaine dissolved in D_2O was recorded.

Suggest how this spectrum would differ from the spectrum in **(d)(ii)**.
Explain your answer.

....

.... [1]

(e) Benzocaine can also be used to synthesise the dyestuff **S** by the following route.



(i) Suggest the reagents used for step 1.

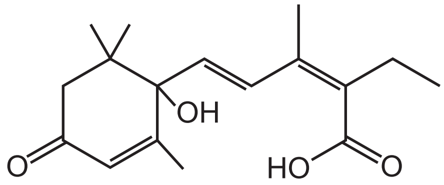
.... [1]

(ii) Suggest structures for compounds **R** and **S** and draw them in the boxes. [2]

[Total: 25]

8 **(a)** Compound **A** can be produced from a plant hormone.

A



(i) Compound **A** shows optical and geometrical isomerism.

On the structure of **A** above,

- draw a **line** through the bond(s) that give rise to geometrical isomerism,
- **circle** all chiral carbon atoms.

[2]

(ii) Give the **names** of four functional groups present in **A**.

....

.... [2]

(iii) A molecule of **A** has 17 carbon atoms.

State the number of carbon atoms that are sp, sp^2 and sp^3 hybridised in **A**.

sp carbons = ... sp^2 carbons = ... sp^3 carbons = ...

[1]

(iv) When **A** is reacted with an excess of hot, concentrated manganate(VII) ions, a mixture of three organic compounds is formed.

$$\textbf{A} \rightarrow \textbf{X} \text{ and } \textbf{Y} \text{ and } \textbf{Z}$$

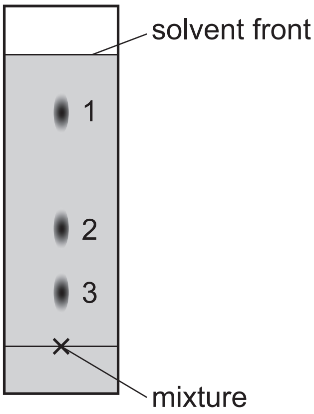
$(C_{10}H_{14}O_7)$ $(C_3H_4O_3)$ $(C_4H_6O_3)$

Suggest the structures of **Y** and **Z**.

Y $(C_3H_4O_3)$	**Z** $(C_4H_6O_3)$

[2]

(b) A mixture of three different compounds, **J**, **K** and **L**, was analysed by thin layer chromatography using a polar stationary phase and a non-polar mobile phase. The three compounds all have similar molecular masses. The resulting chromatogram is shown.



(i) Identify which spot corresponds to each compound.

compound	spot
J CH_3COCO_2H	
K HO_2CCO_2H	
L $CH_3CH_2COCH_2CH_3$	

[1]

(ii) Explain your answers to **(b)(i)**.

....

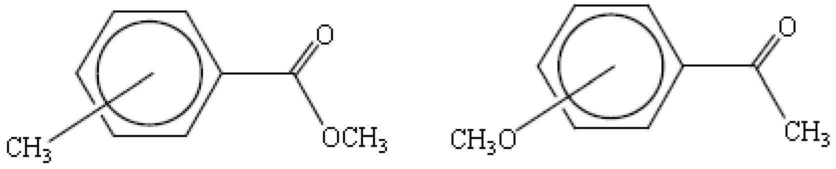
.... [1]

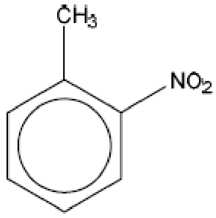
(iii) What is meant by the term R_f *value*?

....

.... [1]

[Total: 10]

Question	Answer	Marks
9 (a) (i)	n = 100 × (M+1)/(1.1 × M) = 100 × 3.4/(1.1 × 33.9) = 9.1	**1**
	hence **9** carbons atoms	**1**
9 (a) (ii)	$C_9H_{10}O_2$	**1**
9 (a) (iii)	(150 – 119 = 31), hence fragment is CH_3O	**1**
9 (b)	**V** is C=O **AND W** is C–O	**1**
9 (c) (i)	δ 3.9 is CH or alkyl / CH_3 next to oxygen **AND** δ 7.2–7.9 is CH / aryl hydrogens	**1**
9 (c) (ii)	alkyl H next to C=O **AND** alkyl H next to aryl ring	**1**
9 (c) (iii)	none of the functional groups in **T** contains a labile proton / **T** does not contain –OH or –NH groups.	**1**
9 (d)		**2**
		Total: 10

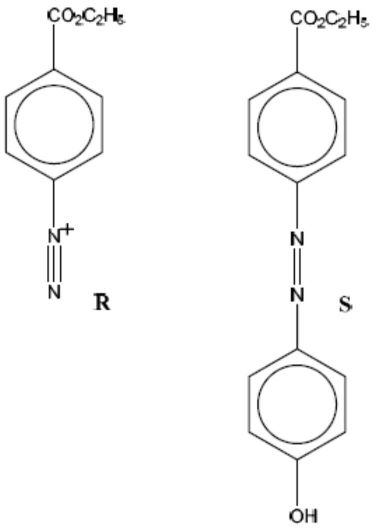
Question	Answer	Marks
6 (a) (i)		**1**
6 (a) (ii)	$HNO_3 + 2H_2SO^4 \rightarrow H_3O^+ + NO_2^+ + 2HSO_4^-$	**1**
6 (a) (iii)	**any three** from: Point 1: bonds / electrons are **partially** delocalised in **T** **or** delocalised / π system / π bonding extends over only five carbons Point 2: four π-electrons in the (delocalised system of **T**) **or** methylbenzene has (two) more π-electrons / (two) more delocalised electrons Point 3: contains a carbon that is sp^3 hybridised in **T** ***or*** (all the) carbons are sp^2 hybridised in methylbenzene Point 4**:** one carbon has a bond angle of 109.5° / tetrahedral (in **T)** ***or*** (C-C) bond strengths / lengths are not all the same **or** not all the bond angles are 120° (in **T**)	**3**
6 (b) (i)	4-aminobenzoic acid	**1**
	step 5 substitution / hydrolysis	**1**

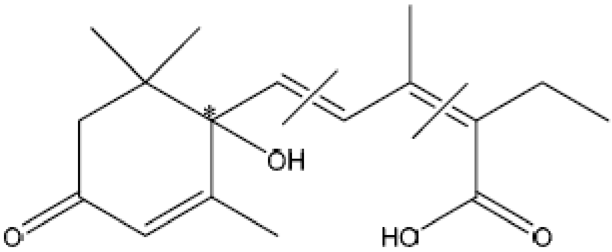
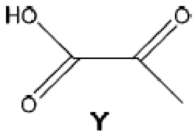
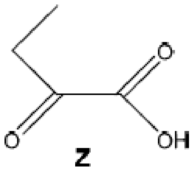
<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>4 (b) (iii)</td><td>step 1 Sn + HCl</td><td>1</td></tr>
<tr><td></td><td>concentrated / reflux / heat</td><td>1</td></tr>
<tr><td></td><td>step 2 CH_3COCl</td><td>1</td></tr>
<tr><td></td><td>step 3 $KMnO_4$ / manganate(VII) / MnO_4^- (acidified / alkaline) **and** heat</td><td>1</td></tr>
<tr><td></td><td>step 4 aqueous HCl **and** heat</td><td>1</td></tr>
<tr><td></td><td>step 5 ethanol, H_2SO_4, concentrated / reflux / heat</td><td>1</td></tr>
<tr><td>6 (c)</td><td>(benzocaine) is less (basic than ethylamine) **AND**
lone pair (on N) is less available to **accept** a proton / H^+

since (lone pair on N) is delocalised over the ring
or phenyl ring is electron withdrawing group

OR
ethylamine is more basic (than benzocaine) **AND**
lone pair (on N) is more available to **accept** a proton / H^+

since ethyl / alkyl group is electron-donating group</td><td>2</td></tr>
<tr><td>6 (d) (i)</td><td>7 peaks</td><td>1</td></tr>
<tr><td>6 (d) (ii)</td><td>$CDCl_3$ will produce no signal in the spectrum
or $CHCl_3$ would produce a signal / would be detected</td><td>1</td></tr>
<tr><td>6 (d) (iii)</td><td>
<table>
<tr><th>δ/ppm</th><th>group responsible for the peak</th><th>number of H atoms responsible for the peak</th><th>splitting pattern</th></tr>
<tr><td>*1.2*</td><td>CH(3)</td><td>3</td><td>triplet</td></tr>
<tr><td>*3.5*</td><td>CH(2)O</td><td>2</td><td>quartet</td></tr>
<tr><td>*5.5*</td><td>NH2</td><td>2</td><td>singlet (broad)</td></tr>
<tr><td>*7.1–7.4*</td><td>H attached to aromatic / benzene ring</td><td>4</td><td>*multiplet*</td></tr>
</table>
</td><td>4</td></tr>
<tr><td>6 (d) (iv)</td><td>neighbouring / adjacent carbon **atom** has two protons / H (attached to it)
or there is an adjacent CH_2(O) group</td><td>1</td></tr>
<tr><td>6 (d) (v)</td><td>peak at 5.5 / NH_2 peak will disappear
and
NH_2 / protons exchange / swap with deuterium</td><td>1</td></tr>
<tr><td>6 (e) (i)</td><td>$NaNO_2$ + HCl ***or*** HNO_2</td><td>1</td></tr>
</table>

Question	Answer	Marks
6 (e) (i)	 structure of diazonium salt **R**	1
	structure of azo dye **S**	1
		Total: 25

Question	Answer	Marks
8 (a) (i)	 circle or asterisk on correct C atom only [1] lines through the two correct bonds only [1]	2
8 (a) (ii)	ketone, (tertiary) alcohol, alkene, carboxylic acid two for each mark	2
8 (a) (iii)	sp carbons = 0 sp^2 carbons = 8 sp^3 carbons = 9	1
8 (a) (iv)	 **Y**  **Z**	2

<table>
<tr><th>Question</th><th>Answer</th><th>Marks</th></tr>
<tr><td>8 (b) (i)</td><td><table><tr><td>compound</td><td>spot</td></tr><tr><td>J</td><td>2</td></tr><tr><td>K</td><td>3</td></tr><tr><td>L</td><td>1</td></tr></table></td><td>1</td></tr>
<tr><td>8 (b) (ii)</td><td>The more polar the compound and stronger attractive forces to the (polar) stationary phase
ora: less polar compound and weaker attractive forces to the (polar) stationary phase</td><td>1</td></tr>
<tr><td>8 (b) (iii)</td><td>R_f = retardation factor or retention factor or
R_f =distance moved by compound from baseline over distance travelled by solvent front</td><td>1</td></tr>
<tr><td></td><td></td><td>Total: 10</td></tr>
</table>

Notes about the mark scheme are available separately.