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SECTION A

Answer **all** questions in the spaces provided.

1 This question is about the use of transition metals as catalysts.

1 (a) State how a catalyst speeds up a chemical reaction.

.....
.....

(2 marks)

1 (b) State the characteristic property of transition metals that enables them to act as catalysts in redox reactions.

.....

(1 mark)

1 (c) In the Contact Process for the conversion of sulfur dioxide into sulfur trioxide, vanadium(V) oxide acts as a heterogeneous catalyst.

1 (c) (i) Write **two** equations to show how the catalyst is involved in this reaction.

Equation 1

Equation 2

(2 marks)

1 (c) (ii) Suggest **one** reason why poisoning reduces the effectiveness of a heterogeneous catalyst.

.....

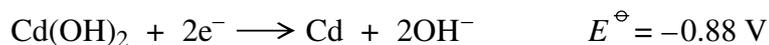
(1 mark)

1 (c) (iii) Suggest how poisoning of a catalyst, used in an industrial process, can be minimised.

.....

(1 mark)

- 2 Nickel–cadmium cells are used to power electrical equipment such as drills and shavers. The electrode reactions are shown below.



- 2 (a) Calculate the e.m.f. of a nickel–cadmium cell.

.....
(1 mark)

- 2 (b) Deduce an overall equation for the reaction that occurs in the cell when it is used.

.....
.....
.....
(2 marks)

- 2 (c) Identify the oxidising agent in the overall cell reaction and give the oxidation state of the metal in this oxidising agent.

Oxidising agent

Oxidation state

(2 marks)

5

Turn over for the next question

Turn over ►

- 3 (e) Give **one** reason, other than cost, why the platinum electrodes are made by coating a porous ceramic material with platinum rather than by using platinum rods.

.....
.....
(1 mark)

- 3 (f) Suggest why the e.m.f. of a hydrogen–oxygen fuel cell, operating in acidic conditions, is exactly the same as that of an alkaline fuel cell.

.....
(1 mark)

- 3 (g) Other than its lack of pollution, state briefly the main advantage of a fuel cell over a re-chargeable cell such as the nickel–cadmium cell when used to provide power for an electric motor that propels a vehicle.

.....
.....
(1 mark)

- 3 (h) Hydrogen–oxygen fuel cells are sometimes regarded as a source of energy that is carbon neutral. Give **one** reason why this may **not** be true.

.....
(1 mark)

10

Turn over for the next question

Turn over ►

- 4 The table below gives some values of standard enthalpy changes. Use these values to answer the questions.

Name of enthalpy change	$\Delta H^\ominus/\text{kJ mol}^{-1}$
Enthalpy of atomisation of chlorine	+121
Electron affinity of chlorine	-364
Enthalpy of atomisation of silver	+289
First ionisation enthalpy of silver	+732
Enthalpy of formation of silver chloride	-127

- 4 (a) Calculate the bond enthalpy of a Cl–Cl bond.

.....
(1 mark)

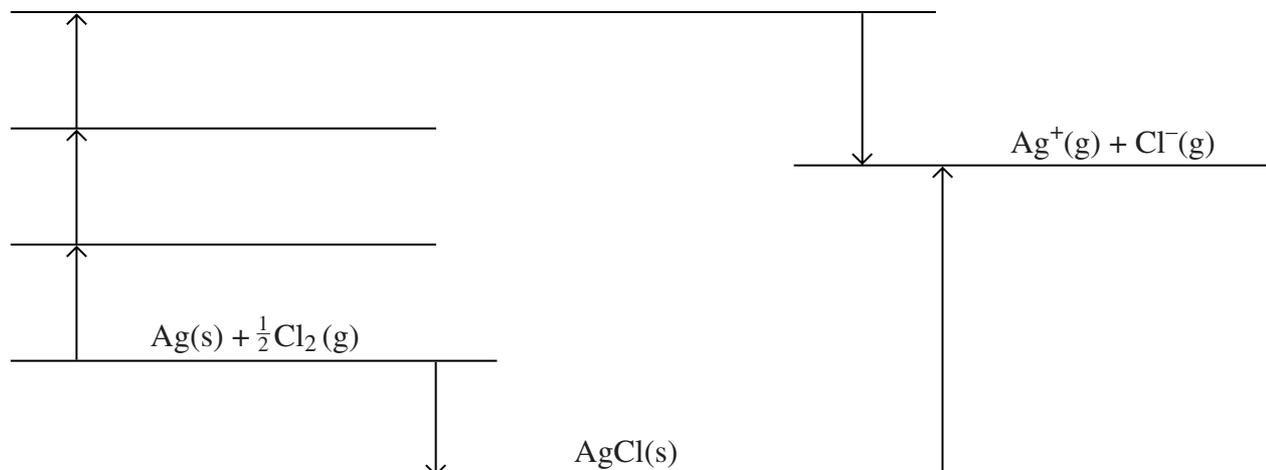
- 4 (b) Explain why the bond enthalpy of a Cl–Cl bond is greater than that of a Br–Br bond.

.....
.....
.....
.....
(2 marks)

- 4 (c) Suggest why the electron affinity of chlorine is an exothermic change.

.....
.....
(1 mark)

- 4 (d) The diagram below is an incomplete Born–Haber cycle for the formation of silver chloride. The diagram is not to scale.



- 4 (d) (i) Complete the diagram by writing the appropriate chemical symbols, with state symbols, on each of the three blank lines. (3 marks)
- 4 (d) (ii) Calculate a value for the enthalpy of lattice dissociation for silver chloride.

.....

.....

.....

.....

(2 marks)

Question 4 continues on the next page

Turn over ►

4 (e) The enthalpy of lattice dissociation for silver chloride can also be calculated theoretically assuming a perfect ionic model.

4 (e) (i) Explain the meaning of the term *perfect ionic model*.

.....
.....
(1 mark)

4 (e) (ii) State whether you would expect the value of the theoretical enthalpy of lattice dissociation for silver chloride to be greater than, equal to or less than that for silver bromide. Explain your answer.

Theoretical lattice enthalpy for silver chloride

Explanation

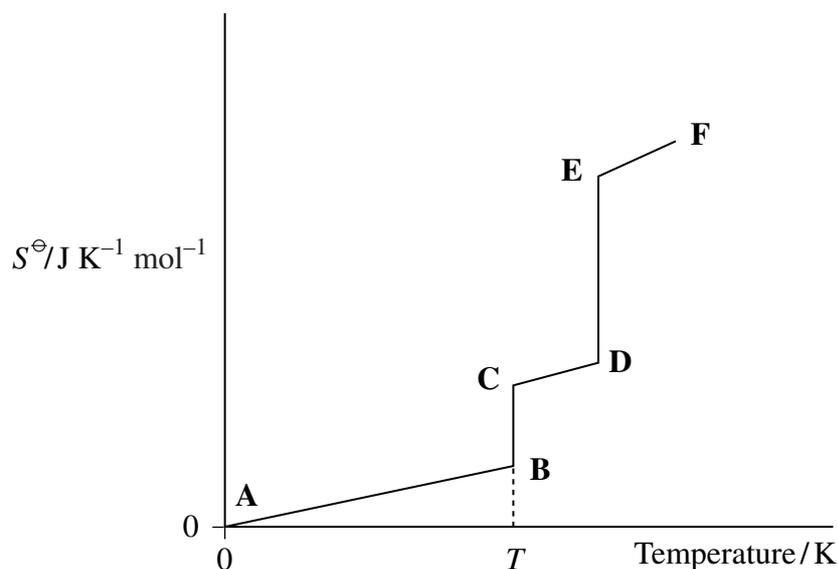
.....
.....
(3 marks)

(Extra space)

4 (e) (iii) Suggest why your answer to part (d) (ii) is greater than the theoretical value for the enthalpy of lattice dissociation for silver chloride.

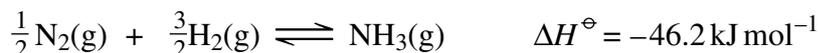
.....
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(2 marks)

- 5 The simplified diagram below shows how the entropy of ammonia varies with temperature at a pressure of 100 kPa. In this diagram, ammonia is a solid at point **A** and a gas at point **F**.



- 5 (a) State why the entropy value for ammonia is equal to zero at 0 K.
-
- (1 mark)
- 5 (b) Explain, in terms of the movement of particles, why the entropy value increases between points **A** and **B** on the diagram.
-
-
- (1 mark)
- 5 (c) Temperature T is marked on the diagram. What does the value of this temperature represent?
-
- (1 mark)
- 5 (d) Explain why there is a large entropy change between points **D** and **E** on the diagram.
-
-
- (2 marks)

- 5 (e) An equation for the reaction in the Haber Process is shown below, together with some entropy data.



	N ₂ (g)	H ₂ (g)	NH ₃ (g)
S [⊖] / J K ⁻¹ mol ⁻¹	192	131	193

- 5 (e) (i) Calculate a value for the entropy change, ΔS^\ominus , for the formation of one mole of ammonia.

.....

.....

.....

.....

(2 marks)

- 5 (e) (ii) Give the equation that relates free-energy change, ΔG^\ominus , to enthalpy change, ΔH^\ominus , and entropy change, ΔS^\ominus .

Use this equation to calculate the temperature at which the value of $\Delta G^\ominus = 0$ for the formation of ammonia in the Haber Process.

(If you have been unable to calculate an answer to part (e) (i), you may assume that $\Delta S^\ominus = -81.4 \text{ J K mol}^{-1}$ but this is not the correct value.)

Equation

Calculation

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.....

(4 marks)

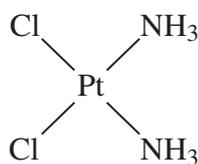
(Extra space)

- 5 (e) (iii) What can you deduce about the formation of ammonia if the reaction mixture is heated to a temperature above the value that you have calculated in part (e) (ii)?

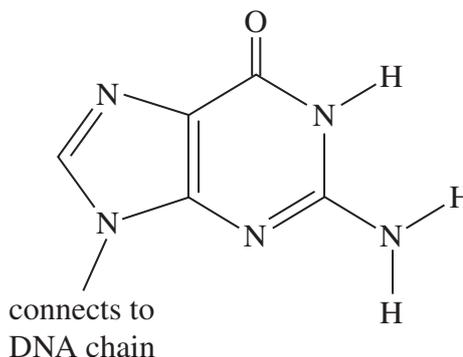
.....

(1 mark)

- 6 The complex cisplatin acts as an anticancer drug by changing the properties of DNA when it reacts with guanine, a component of DNA.



cisplatin



guanine

When cisplatin is absorbed into the human body, it undergoes a ligand substitution reaction and one chloride ligand is replaced by a water molecule forming a complex ion **Q**.

- 6 (a) Write an equation for this substitution reaction to form the complex ion **Q**.

.....
(2 marks)

- 6 (b) The complex ion **Q** can bond to guanine in two different ways.

- 6 (b) (i) The first way involves a hydrogen atom, from one of the ammonia ligands on **Q**, bonding to an atom in a guanine molecule. State the type of bond formed to guanine and identify an atom in guanine that could form a bond to this hydrogen atom.

Type of bond

Atom in guanine

(2 marks)

- 6 (b) (ii) The second way involves a ligand substitution reaction in which an atom in a guanine molecule bonds to platinum by displacing the water molecule from **Q**. State the type of bond formed between guanine and platinum when a water molecule is displaced and identify an atom in guanine that could bond to platinum in this way.

Type of bond

Atom in guanine

(2 marks)

- 6** (c) State and explain **one** risk associated with the use of cisplatin as an anticancer drug.

Risk

Explanation

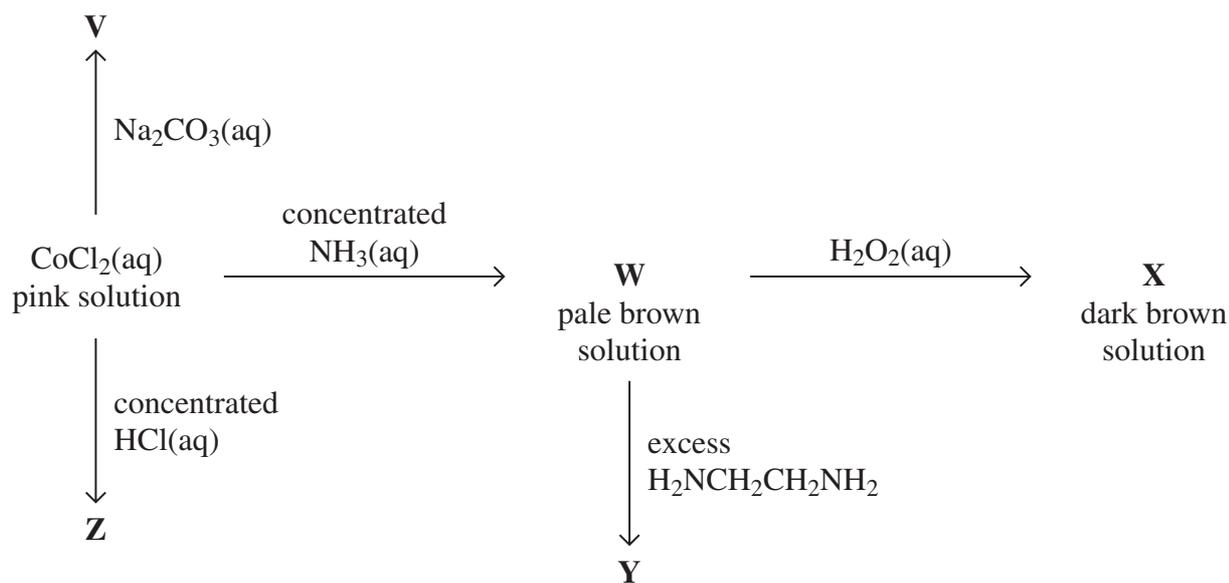
(2 marks)

8

Turn over for the next question

Turn over ►

7 This question is about some reactions of cobalt compounds.



7 (a) Give the formula of the complex responsible for the pink colour in aqueous CoCl_2 and name its shape.

Formula

Name of shape

(2 marks)

7 (b) Give the formula of the cobalt-containing compound **V** and describe its appearance.

Formula

Appearance

(2 marks)

7 (c) Write an equation for the reaction that occurs when the pink solution is converted into **W**.

.....

(2 marks)

- 7 (d) Give the formula of the cobalt-containing complex in **X** and state the role of the H_2O_2 in this reaction.

Formula

Role of H_2O_2

(2 marks)

- 7 (e) Give the formula of the cobalt-containing complex in **Y** and explain why this complex is more stable than the cobalt-containing complex in **W**.

Formula

Explanation

.....

.....

(3 marks)

- 7 (f) Identify the cobalt-containing complex in solution **Z** and explain why its co-ordination number is different from that in the pink solution of CoCl_2

Complex

Explanation

.....

(2 marks)

Turn over for the next question

Turn over ►

Answer **all** questions in the spaces provided.

- 8** (a) State and explain the trend in electronegativities across Period 3 from sodium to sulfur.

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(4 marks)

(Extra space)
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.....

9 (a) State the electron configuration of a Ti(III) ion and that of a Ti(IV) ion. Explain, in terms of electron configurations and electron transitions, why Ti(III) compounds are usually coloured but Ti(IV) compounds are colourless.

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(5 marks)

(Extra space)

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Question 9 continues on the next page

Turn over ►

- 9 (b) Transition metal ions and their complexes can often be identified from their colours. For each of the following, identify a complex ion responsible for the colour of the aqueous solution. Restrict your answers to complexes formed from the elements Cr, Fe, Co and Cu.

A deep blue solution formed in an excess of concentrated aqueous ammonia.

A green solution formed in an excess of aqueous sodium hydroxide.

A yellow–green solution formed in an excess of concentrated hydrochloric acid.

.....
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.....

(3 marks)

- 9 (c) An experiment is carried out to investigate the rate of the autocatalysed reaction between aqueous potassium manganate(VII) and ethanedioate ions in an excess of dilute sulfuric acid. When these reagents are mixed together, the colour of the reaction mixture gradually fades. The concentration of the manganate(VII) ions is recorded at different times using a spectrometer. The temperature of the reaction mixture is constant.

- 9 (c) (i) Give **two** reasons why the use of a spectrometer is the most appropriate method for measuring the concentration of the coloured ions in this experiment.

.....
.....
.....
.....

(2 marks)

(Extra space)
.....

GCE Chemistry Data Sheet

Table 1

Infrared absorption data

Bond	Wavenumber /cm ⁻¹
N-H (amines)	3300 – 3500
O-H (alcohols)	3230 – 3550
C-H	2850 – 3300
O-H (acids)	2500 – 3000
C≡N	2220 – 2260
C=O	1680 – 1750
C=C	1620 – 1680
C-O	1000 – 1300
C-C	750 – 1100

Table 2¹H n.m.r. chemical shift data

Type of proton	δ/ppm
ROH	0.5 – 5.0
RCH ₃	0.7 – 1.2
RNH ₂	1.0 – 4.5
R ₂ CH ₂	1.2 – 1.4
R ₃ CH	1.4 – 1.6
$\begin{array}{c} \\ \text{R}-\text{C}-\text{C}- \\ \quad \\ \text{O} \quad \text{H} \end{array}$	2.1 – 2.6
$\begin{array}{c} \\ \text{R}-\text{O}-\text{C}- \\ \\ \text{H} \end{array}$	3.1 – 3.9
RCH ₂ Cl or Br	3.1 – 4.2
$\begin{array}{c} \\ \text{R}-\text{C}-\text{O}-\text{C}- \\ \quad \\ \text{O} \quad \text{H} \end{array}$	3.7 – 4.1
$\begin{array}{c} \text{H} \\ \\ \text{R}-\text{C}=\text{C}- \\ \end{array}$	4.5 – 6.0
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{H} \end{array}$	9.0 – 10.0
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}-\text{O}-\text{H} \end{array}$	10.0 – 12.0

Table 3¹³C n.m.r. chemical shift data

Type of carbon	δ/ppm
$\begin{array}{c} \\ -\text{C}-\text{C}- \\ \end{array}$	5 – 40
$\begin{array}{c} \\ \text{R}-\text{C}-\text{Cl} \text{ or } \text{Br} \\ \end{array}$	10 – 70
$\begin{array}{c} \\ \text{R}-\text{C}-\text{C}- \\ \quad \\ \text{O} \end{array}$	20 – 50
$\begin{array}{c} / \\ \\ \text{R}-\text{C}-\text{N} \\ \end{array}$	25 – 60
$\begin{array}{c} \\ -\text{C}-\text{O}- \\ \end{array}$ alcohols, ethers or esters	50 – 90
$\begin{array}{c} / \\ \text{C}=\text{C} \\ \backslash \end{array}$	90 – 150
R-C≡N	110 – 125
	110 – 160
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}- \end{array}$ esters or acids	160 – 185
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}- \end{array}$ aldehydes or ketones	190 – 220

The Periodic Table of the Elements

1	2	3	4	5	6	7	0																																						
(1) 6.9 Li lithium 3	(2) 9.0 Be beryllium 4	(3) 45.0 Sc scandium 21	(4) 47.9 Ti titanium 22	(5) 50.9 V vanadium 23	(6) 52.0 Cr chromium 24	(7) 54.9 Mn manganese 25	(8) 55.8 Fe iron 26	(9) 58.9 Co cobalt 27	(10) 58.7 Ni nickel 28	(11) 63.5 Cu copper 29	(12) 65.4 Zn zinc 30	(13) 10.8 B boron 5	(14) 12.0 C carbon 6	(15) 14.0 N nitrogen 7	(16) 16.0 O oxygen 8	(17) 19.0 F fluorine 9	(18) 4.0 He helium 2																												
23.0 Na sodium 11	24.3 Mg magnesium 12	40.1 Ca calcium 20	88.9 Y yttrium 39	87.6 Rb rubidium 37	91.2 Zr zirconium 40	92.9 Nb niobium 41	92.9 Mo molybdenum 42	96.0 Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54																												
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La * lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86																												
[223] Fr francium 87	[226] Ra radium 88	[227] Ac † actinium 89	[267] Rf rutherfordium 104	[268] Db dubnium 105	[271] Sg seaborgium 106	[272] Bh bohrium 107	[270] Hs hassium 108	[276] Mt meitnerium 109	[281] Ds darmstadtium 110	[280] Rg roentgenium 111	Elements with atomic numbers 112-116 have been reported but not fully authenticated																																		
* 58 – 71 Lanthanides																																													
† 90 – 103 Actinides																																													
<table border="1"> <tbody> <tr> <td>140.1 Ce cerium 58</td> <td>140.9 Pr praseodymium 59</td> <td>144.2 Nd neodymium 60</td> <td>150.4 Sm samarium 62</td> <td>[145] Pm promethium 61</td> <td>152.0 Eu europium 63</td> <td>157.3 Gd gadolinium 64</td> <td>158.9 Tb terbium 65</td> <td>162.5 Dy dysprosium 66</td> <td>164.9 Ho holmium 67</td> <td>167.3 Er erbium 68</td> <td>168.9 Tm thulium 69</td> <td>173.1 Yb ytterbium 70</td> <td>175.0 Lu lutetium 71</td> </tr> <tr> <td>232.0 Th thorium 90</td> <td>231.0 Pa protactinium 91</td> <td>238.0 U uranium 92</td> <td>[244] Pu plutonium 94</td> <td>[237] Np neptunium 93</td> <td>[243] Am americium 95</td> <td>[247] Cm curium 96</td> <td>[247] Bk berkelium 97</td> <td>[251] Cf californium 98</td> <td>[252] Es einsteinium 99</td> <td>[257] Fm fermium 100</td> <td>[258] Md mendelevium 101</td> <td>[259] No nobelium 102</td> <td>[262] Lr lawrencium 103</td> </tr> </tbody> </table>																		140.1 Ce cerium 58	140.9 Pr praseodymium 59	144.2 Nd neodymium 60	150.4 Sm samarium 62	[145] Pm promethium 61	152.0 Eu europium 63	157.3 Gd gadolinium 64	158.9 Tb terbium 65	162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.1 Yb ytterbium 70	175.0 Lu lutetium 71	232.0 Th thorium 90	231.0 Pa protactinium 91	238.0 U uranium 92	[244] Pu plutonium 94	[237] Np neptunium 93	[243] Am americium 95	[247] Cm curium 96	[247] Bk berkelium 97	[251] Cf californium 98	[252] Es einsteinium 99	[257] Fm fermium 100	[258] Md mendelevium 101	[259] No nobelium 102	[262] Lr lawrencium 103
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Answer **all** questions in the spaces provided.

1 Comparisons of lattice enthalpies from Born–Haber cycles with lattice enthalpies from calculations based on a perfect ionic model are used to provide information about bonding in crystals.

1 (a) Define the terms *enthalpy of atomisation* and *lattice dissociation enthalpy*.

Enthalpy of atomisation

.....

.....

Lattice dissociation enthalpy

.....

.....

(4 marks)

1 (b) Use the following data to calculate a value for the lattice dissociation enthalpy of sodium chloride.

	$\Delta H^\ominus / \text{kJ mol}^{-1}$
Na(s) \longrightarrow Na(g)	+109
Na(g) \longrightarrow Na ⁺ (g) + e ⁻	+494
Cl ₂ (g) \longrightarrow 2Cl(g)	+242
Cl(g) + e ⁻ \longrightarrow Cl ⁻ (g)	-364
Na(s) + $\frac{1}{2}$ Cl ₂ (g) \longrightarrow NaCl(s)	-411

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(3 marks)

1 (c) Consider the following lattice dissociation enthalpy (ΔH_L^\ominus) data.

	NaBr	AgBr
$\Delta H_L^\ominus(\text{experimental}) / \text{kJ mol}^{-1}$	+733	+890
$\Delta H_L^\ominus(\text{theoretical}) / \text{kJ mol}^{-1}$	+732	+758

The values of ΔH_L^\ominus (experimental) have been determined from Born–Haber cycles.

The values of ΔH_L^\ominus (theoretical) have been determined by calculation using a perfect ionic model.

1 (c) (i) Explain the meaning of the term *perfect ionic model*.

.....

.....

.....

.....

(2 marks)

1 (c) (ii) State what you can deduce about the bonding in NaBr from the data in the table.

.....

.....

(1 mark)

1 (c) (iii) State what you can deduce about the bonding in AgBr from the data in the table.

.....

.....

(1 mark)

- 2** The balance between enthalpy change and entropy change determines the feasibility of a reaction. The table below contains enthalpy of formation and entropy data for some elements and compounds.

	N ₂ (g)	O ₂ (g)	NO(g)	C(graphite)	C(diamond)
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	0	0	+90.4	0	+1.9
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	192.2	205.3	211.1	5.7	2.4

- 2 (a)** Explain why the entropy value for the element nitrogen is much greater than the entropy value for the element carbon (graphite).

.....

 (2 marks)

- 2 (b)** Suggest the condition under which the element carbon (diamond) would have an entropy value of zero.

.....
 (1 mark)

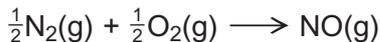
- 2 (c)** Write the equation that shows the relationship between ΔG , ΔH and ΔS for a reaction.

.....
 (1 mark)

- 2 (d)** State the requirement for a reaction to be feasible.

.....
 (1 mark)

2 (e) Consider the following reaction that can lead to the release of the pollutant NO into the atmosphere.



Use data from the table on page 3 to calculate the minimum temperature above which this reaction is feasible.

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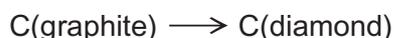
(5 marks)

2 (f) At temperatures below the value calculated in part 2(e), decomposition of NO into its elements should be spontaneous. However, in car exhausts this decomposition reaction does **not** take place in the absence of a catalyst. Suggest why this spontaneous decomposition does **not** take place.

.....
.....

(1 mark)

2 (g) A student had an idea to earn money by carrying out the following reaction.



Use data from the table on page 3 to calculate values for ΔH^\ominus and ΔS^\ominus for this reaction. Use these values to explain why this reaction is **not** feasible under standard pressure at any temperature.

ΔH^\ominus

ΔS^\ominus

Explanation

.....

(3 marks)

Turn over ►

3 There is a link between the properties of the oxides of the Period 3 elements and their structure and bonding. The table below shows the melting points of the oxides of some Period 3 elements.

	Na ₂ O	SiO ₂	P ₄ O ₁₀
<i>T_m/K</i>	1548	1883	573

3 (a) In terms of crystal structure and bonding, explain in each case why the melting points of sodium oxide and silicon dioxide are high.

Na₂O

.....

.....

SiO₂

.....

.....

(4 marks)

3 (b) Predict whether the melting point of lithium oxide is higher than, the same as, or lower than the melting point of sodium oxide and explain your prediction.

Prediction.....

Explanation.....

.....

.....

(3 marks)

3 (c) Phosphorus(V) oxide has a lower melting point than sodium oxide.

3 (c) (i) State the structure of and bonding in phosphorus(V) oxide.

.....

.....

.....

(2 marks)

3 (c) (ii) Explain why the melting point of phosphorus(V) oxide is low.

.....
.....

(1 mark)

3 (d) Separate samples of phosphorus(V) oxide and sodium oxide were reacted with water. In each case, predict the pH of the solution formed and write an equation for the reaction.

pH with P_4O_{10}

Equation

pH with Na_2O

Equation

(4 marks)

3 (e) Write an equation for the reaction between Na_2O and P_4O_{10} . State the general type of reaction illustrated by this example.

Equation

Reaction type

(2 marks)

Turn over for the next question

4 Three characteristic properties of transition metals are complex formation, coloured ions and catalytic activity.

4 (a) State the feature of transition metals that gives rise to these characteristic properties.

.....
(1 mark)

4 (b) State a fourth characteristic property of transition metals.

.....
(1 mark)

4 (c) For each of the following shapes of complex, identify an appropriate example by drawing its structure.

4 (c) (i) a linear complex

(1 mark)

4 (c) (ii) a square planar complex

(1 mark)

4 (c) (iii) a tetrahedral complex

(1 mark)

Question 4 continues on the next page

Turn over ►

4 (d) The chemical industry makes use of the catalytic activity of transition metal compounds. For example, vanadium(V) oxide is used as a heterogeneous catalyst in the Contact Process.

4 (d) (i) Write an equation for the overall reaction in the Contact Process.

.....
(1 mark)

4 (d) (ii) Explain the meaning of the term *heterogeneous* as applied to a catalyst.

.....
(1 mark)

4 (d) (iii) Write two equations to illustrate how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1

Equation 2
(2 marks)

4 (d) (iv) Suggest what is done to a heterogeneous catalyst such as vanadium(V) oxide to maximise its efficiency and how this is achieved.

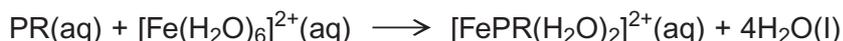
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.....
(2 marks)

4 (e) The porphyrin ring is a multidentate ligand that is found in living systems complexed with iron(II) ions in haemoglobin and with cobalt(II) ions in vitamin B₁₂

4 (e) (i) Give the meaning of the term *multidentate*.

.....
.....
(1 mark)

4 (e) (ii) A porphyrin ring can be represented by the symbol PR. It reacts with aqueous iron(II) ions as shown in the equation below.
The enthalpy change for this reaction is approximately zero.



Explain why the free-energy change for this reaction is negative.

.....
.....
.....
.....
(2 marks)

4 (e) (iii) In vitamin B₁₂ the cobalt(II) ion is co-ordinated to a porphyrin ring, a cyanide (CN⁻) ion and an additional unidentate ligand. The cyanide ion is very toxic.

Predict the co-ordination number of the cobalt ion in vitamin B₁₂
Suggest why vitamin B₁₂ is **not** toxic.

Co-ordination number

Reason why vitamin B₁₂ is **not** toxic

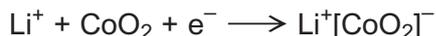
.....
.....
(2 marks)

- 5 (a) Lithium ion cells are used to power cameras and mobile phones. A simplified representation of a cell is shown below.



The reagents in the cell are absorbed onto powdered graphite that acts as a support medium. The support medium allows the ions to react in the absence of a solvent such as water.

The half-equation for the reaction at the positive electrode can be represented as follows.



- 5 (a) (i) Identify the element that undergoes a change in oxidation state at the positive electrode and deduce these oxidation states of the element.

Element

Oxidation state 1

Oxidation state 2

(3 marks)

- 5 (a) (ii) Write a half-equation for the reaction at the negative electrode during operation of the lithium ion cell.

.....

(1 mark)

- 5 (a) (iii) Suggest two properties of platinum that make it suitable for use as an external electrical contact in the cell.

Property 1

Property 2

(2 marks)

- 5 (a) (iv) Suggest **one** reason why water is **not** used as a solvent in this cell.

.....

.....

(1 mark)

- 5 (b)** The half-equations for two electrodes used to make an electrochemical cell are shown below.



- 5 (b) (i)** Write the conventional representation for the cell using platinum contacts.

.....
(2 marks)

- 5 (b) (ii)** Write an overall equation for the cell reaction and identify the oxidising and reducing agents.

Overall equation

.....

.....

Oxidising agent

Reducing agent

(3 marks)

12

Turn over for the next question

Turn over ►

Answer **all** questions in the spaces provided.

6 Aqueous metal ions can be identified by test-tube reactions.

For each of the following, describe what you would observe.

Write an equation or equations for any reactions that occur.

6 (a) The addition of aqueous sodium carbonate to a solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ ions.

.....

.....

.....

.....

.....

.....

(4 marks)

6 (b) The addition of aqueous sodium hydroxide, dropwise until in excess, to a solution containing $[\text{Al}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ ions.

.....

.....

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.....

(4 marks)

- 6 (c)** The addition of dilute aqueous ammonia, dropwise until in excess, to a solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ ions.

.....

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.....

.....

(4 marks)

- 6 (d)** The addition of concentrated hydrochloric acid, dropwise until in excess, to a solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ ions.

.....

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(2 marks)

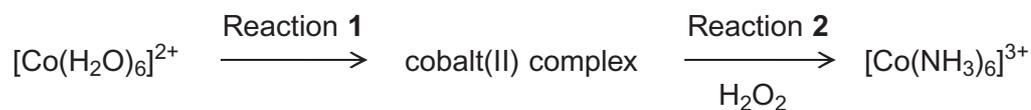
14

Turn over for the next question

Turn over ►

7 Hydrogen peroxide is used as an oxidising agent in the preparation of transition metal complexes.

7 (a) Consider the following reaction scheme. All the complexes are in aqueous solution.



7 (a) (i) Identify a reagent for Reaction 1 and describe the colour change that occurs.

.....
.....
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.....

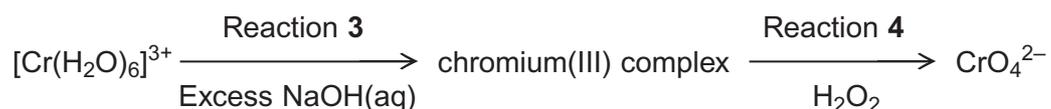
(3 marks)

7 (a) (ii) State the colour of the final solution formed in Reaction 2.

.....

(1 mark)

7 (b) Consider the following reaction scheme. All the complexes are in aqueous solution.



7 (b) (i) For Reaction 3, state the colour of the initial and of the final solution and write an equation for the reaction.

.....

.....

.....

.....

(4 marks)

7 (b) (ii) Write a half-equation for the reduction of hydrogen peroxide to hydroxide ions.

Deduce an overall equation for Reaction 4 and state the colour of the final solution.

.....

.....

.....

.....

.....

.....

(4 marks)

Question 7 continues on the next page

Turn over ►

GCE Chemistry Data Sheet

Table 1

Infrared absorption data

Bond	Wavenumber /cm ⁻¹
N-H (amines)	3300-3500
O-H (alcohols)	3230-3550
C-H	2850-3300
O-H (acids)	2500-3000
C≡N	2220-2260
C=O	1680-1750
C=C	1620-1680
C-O	1000-1300
C-C	750-1100

Table 2

¹H n.m.r. chemical shift data

Type of proton	δ/ppm
ROH	0.5-5.0
RCH ₃	0.7-1.2
RNH ₂	1.0-4.5
R ₂ CH ₂	1.2-1.4
R ₃ CH	1.4-1.6
$\begin{array}{c} \\ \text{R}-\text{C}-\text{C}- \\ \quad \\ \text{O} \quad \text{H} \end{array}$	2.1-2.6
$\begin{array}{c} \\ \text{R}-\text{O}-\text{C}- \\ \\ \text{H} \end{array}$	3.1-3.9
RCH ₂ Cl or Br	3.1-4.2
$\begin{array}{c} \\ \text{R}-\text{C}-\text{O}-\text{C}- \\ \quad \\ \text{O} \quad \text{H} \end{array}$	3.7-4.1
$\begin{array}{c} \text{R} \quad \text{H} \\ \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \diagdown \end{array}$	4.5-6.0
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\ \\ \text{H} \end{array}$	9.0-10.0
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\ \\ \text{O}-\text{H} \end{array}$	10.0-12.0

Table 3

¹³C n.m.r. chemical shift data

Type of carbon	δ/ppm
$\begin{array}{c} \quad \\ -\text{C}-\text{C}- \\ \quad \end{array}$	5-40
$\begin{array}{c} \\ \text{R}-\text{C}-\text{Cl or Br} \\ \end{array}$	10-70
$\begin{array}{c} \\ \text{R}-\text{C}-\text{C}- \\ \quad \\ \text{O} \end{array}$	20-50
$\begin{array}{c} \\ \text{R}-\text{C}-\text{N} \\ \quad \diagdown \end{array}$	25-60
$\begin{array}{c} \\ -\text{C}-\text{O}- \\ \end{array}$ alcohols, ethers or esters	50-90
$\begin{array}{c} \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \diagdown \end{array}$	90-150
R-C≡N	110-125
	110-160
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}- \\ \end{array}$ esters or acids	160-185
$\begin{array}{c} \text{O} \\ \\ \text{R}-\text{C}- \\ \end{array}$ aldehydes or ketones	190-220

Answer **all** the questions.

- 1 Methylbenzene, $C_6H_5CH_3$, is an aromatic hydrocarbon and is used widely as a solvent. It is readily nitrated and it can form mono-, di-, or tri-nitromethylbenzenes.

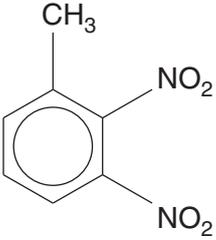
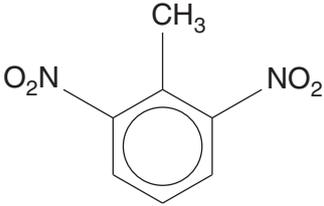
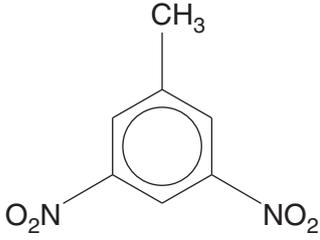
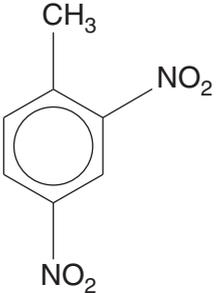
(a) 4-Nitromethylbenzene can be formed by the nitration of methylbenzene.

Outline the mechanism for the formation of 4-nitromethylbenzene from methylbenzene using NO_2^+ as the electrophile.

[4]

- (b) There are six possible structural isomers of $CH_3C_6H_3(NO_2)_2$ that are dinitromethylbenzenes. Four of the isomers are shown below.

Draw the structures of the other two isomers in the boxes provided.

 <p style="text-align: center;">isomer 1</p>	 <p style="text-align: center;">isomer 2</p>	 <p style="text-align: center;">isomer 3</p>
 <p style="text-align: center;">isomer 4</p>	<p style="text-align: center;">isomer 5</p>	<p style="text-align: center;">isomer 6</p>

[2]

(c) Esters can also be made by reacting an alcohol with either a carboxylic acid or with an acid anhydride.

Write equations for the formation of ethyl propanoate, $\text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3$, starting from:

- a carboxylic acid and an alcohol,

- an acid anhydride and an alcohol.

[2]

(d) Compound **A**, $\text{C}_4\text{H}_8\text{O}_3$, can lose water to form either:

compound **B**, a cyclic ester

OR

compound **C**, a polyester.

Identify compounds **A**, **B** and **C**.

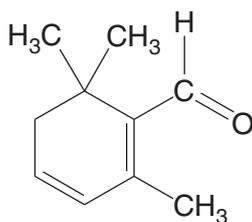
compound A	compound B
compound C	

[3]

[Total: 8]

Turn over

3 Safranal, shown below, is an aldehyde which contributes to the aroma of saffron.



safranal

An undergraduate chemist investigated some reactions of safranal.

(a) She prepared a solution of Tollens' reagent and added a few drops of safranal. She then warmed the mixture for about 5 minutes in a water bath.

Describe what you would expect the chemist to see.

State the type of reaction that the safranal undergoes.

Draw the structure of the organic product formed in this reaction.

.....

.....

.....

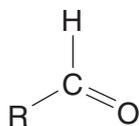
[3]

6

(b) The chemist then reduced safranal using an aqueous solution of NaBH_4 .

Outline the mechanism for this reaction.

Use curly arrows and show any relevant dipoles.



can be used to represent safranal.

[4]

(c) Suggest one reaction of safranal that does **not** involve the aldehyde group.

State the reagent, observation (if any) and draw the organic product.

reagent

observation

organic product

[3]

[Total: 10]

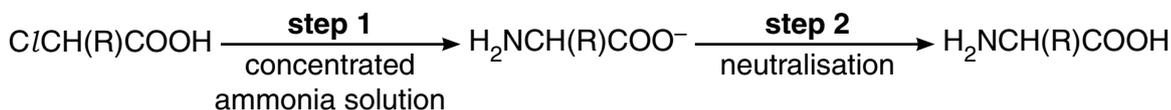
Turn over

4 Read the passage below and answer the questions that follow.

α -Amino acids can be synthesised in the laboratory by the two synthetic routes below.

Synthesis 1

An α -chlorocarboxylic acid is reacted with an excess of concentrated ammonia solution. The resulting solution is neutralised to produce an α -amino acid.



Synthesis 2

An aldehyde is reacted with an aqueous solution of potassium cyanide and ammonium chloride. The resulting product is hydrolysed with aqueous acid and then neutralised to produce an α -amino acid.



- (a) A chemist attempted the synthesis of the α -amino acid alanine (where R is CH_3) using **synthesis 1**.
- (i) Write the equation for the reaction of $\text{ClCH}(\text{CH}_3)\text{COOH}$ with excess concentrated ammonia solution, $\text{NH}_3(\text{aq})$, in **step 1** of **synthesis 1**.

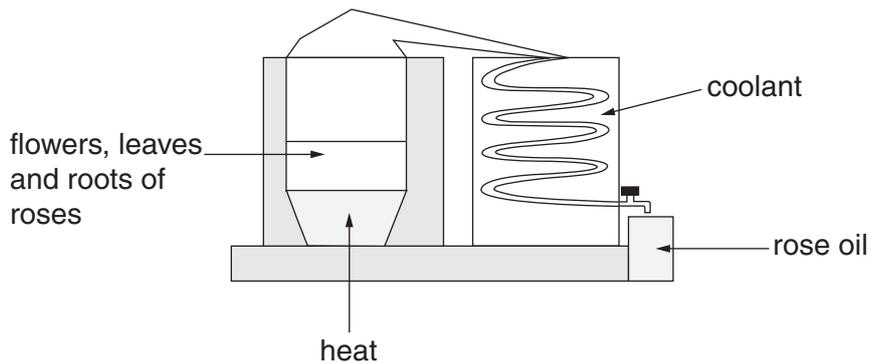
[1]

- (ii) A disadvantage of **synthesis 1** is that the α -amino acid can react further. For example, in the synthesis of alanine, an impurity with molecular formula $\text{C}_6\text{H}_{11}\text{NO}_4$ is also formed.

Draw the structure of this impurity.

[1]

5 Rose oil can be extracted from the flowers, leaves and roots of roses using the apparatus below.



(a) The rose oil contains a mixture of compounds, some of which can be separated by using thin-layer chromatography (TLC). The chromatogram obtained is shown below.

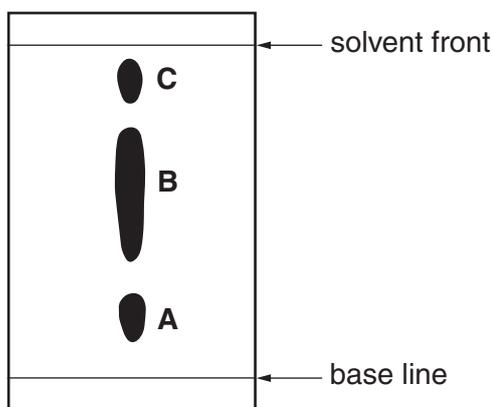


Fig. 5.1

(i) Explain how TLC separates compounds in the mixture.



In your answer, you should use appropriate technical terms, spelled correctly.

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

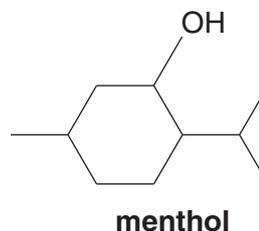
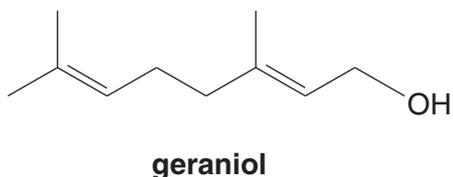
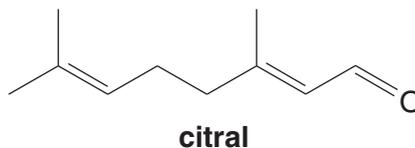
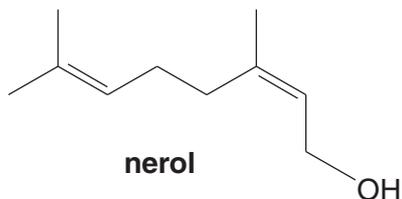
(ii) Estimate the R_f value of **A**.

[1]

(iii) Using the chromatogram in **Fig. 5.1**, suggest why it is **not** possible to conclude that the rose oil contains **only** three different compounds.

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

(b) GC–MS was used to identify the compounds present in the rose oil as nerol, geraniol, citral and menthol, shown below. These compounds all have stereoisomers.



(i) Explain how GC–MS can be used to identify these compounds in the rose oil.

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

(ii) Suggest, with a reason, which two compounds might be present in **B** in **Fig. 5.1**.

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

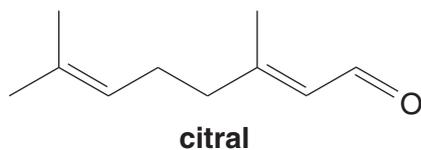
(iii) Explain what is meant by the term *stereoisomers*.

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

Turn over

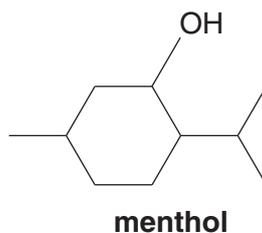
11

(iv) Draw a circle around the feature in citral that causes the stereoisomerism.



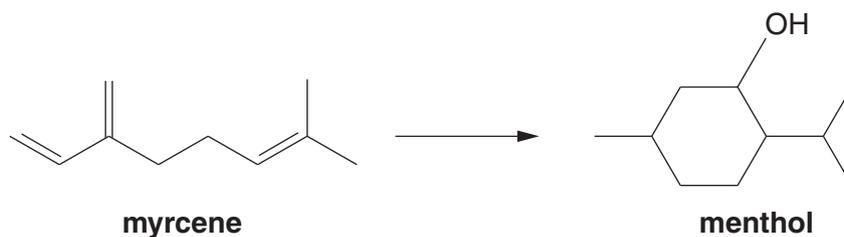
[1]

(v) Identify with asterisks (*) **all** the chiral centres in menthol that cause the stereoisomerism.



[2]

(c) Menthol is used in a wide range of products including lip balms, cough medicines and perfumery. The demand for menthol exceeds the supply from natural sources. Menthol is manufactured, using a chiral synthesis, from myrcene, a readily available starting material.



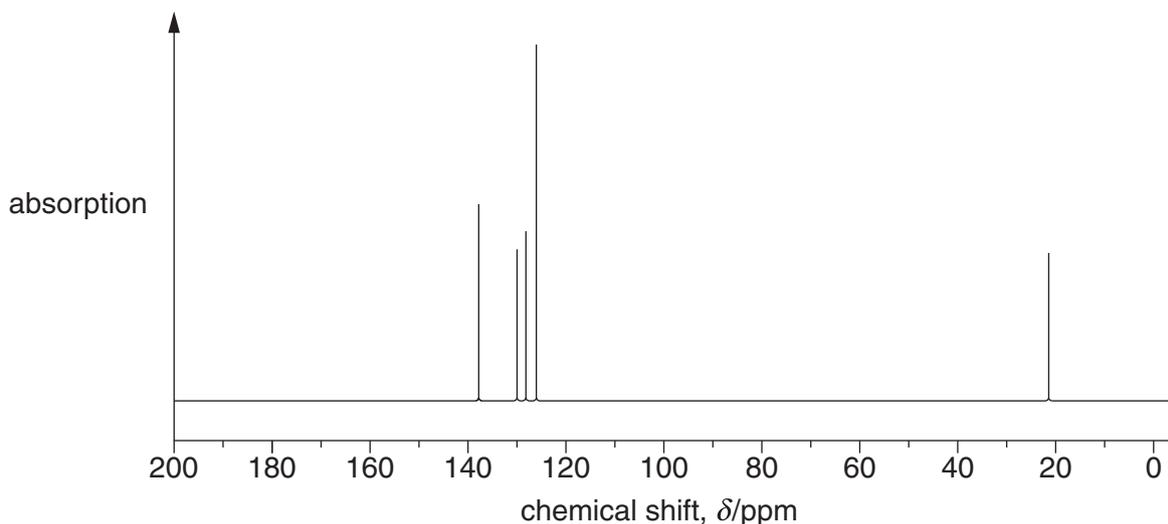
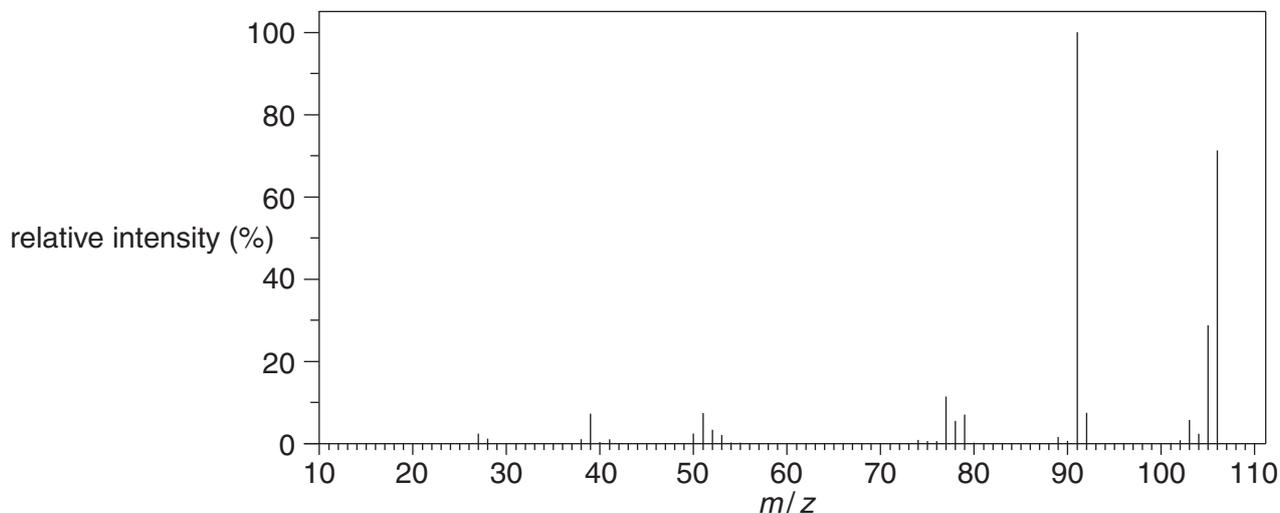
Calculate the mass of menthol that can be synthesised from 34.0 g of myrcene.
The percentage yield is 60%. M_r (Myrcene) = 136.

mass of menthol = g [3]

[Total: 12]

13

(b) The independent chemical engineer investigated an unknown aromatic hydrocarbon. He obtained the mass spectrum and the ^{13}C NMR spectrum of the aromatic hydrocarbon, which are shown below.



The aromatic hydrocarbon is one of **four** possible isomers.

Use the spectra to identify the aromatic hydrocarbon.

Show **all** of your working and explain how you ruled out the other three isomers.

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Answer **all** the questions.

1 This question looks at the properties and chemistry of some α -amino acids. The general formula of an α -amino acid is $RCH(NH_2)COOH$.

(a) In the α -amino acid alanine, $CH_3CH(NH_2)COOH$, R is CH_3 .
The isoelectric point of alanine is at pH 6.0.

(i) What is meant by the term *isoelectric point*?

.....

 [1]

(ii) Draw the structures of the ions formed by alanine at pH 6.0 and at pH 1.5.

ion formed at pH 6.0	ion formed at pH 1.5

[2]

(iii) Different R groups in α -amino acids result in different isoelectric points.

Suggest the functional group, in the R group, that results in the isoelectric point being lower than pH 3 and higher than pH 10.

functional group resulting in isoelectric point lower than pH 3:

functional group resulting in isoelectric point higher than pH 10: [2]

(b) The α -amino acid serine, where R is CH_2OH , readily forms a condensation polymer containing peptide links.

Draw a section of poly(serine), showing **two** repeat units.

Display the peptide linkage.

[2]

(c) Apart from glycine, where R is H, all α -amino acids show optical isomerism.

(i) Why does glycine **not** show optical isomerism?

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

(ii) Draw 3-D diagrams for the two optical isomers of the α -amino acid cysteine, where R is CH_2SH .

[2]

(iii) α -Amino acids are being used in the development of peptide-based pharmaceuticals. Optical isomerism has been found to be significant in the action of some pharmaceuticals.

- State **two** possible disadvantages of synthesising a peptide-based pharmaceutical that contains a mixture of optical isomers.
- State **two** methods that are used by manufacturers to synthesise pharmaceuticals containing just the required optical isomer.



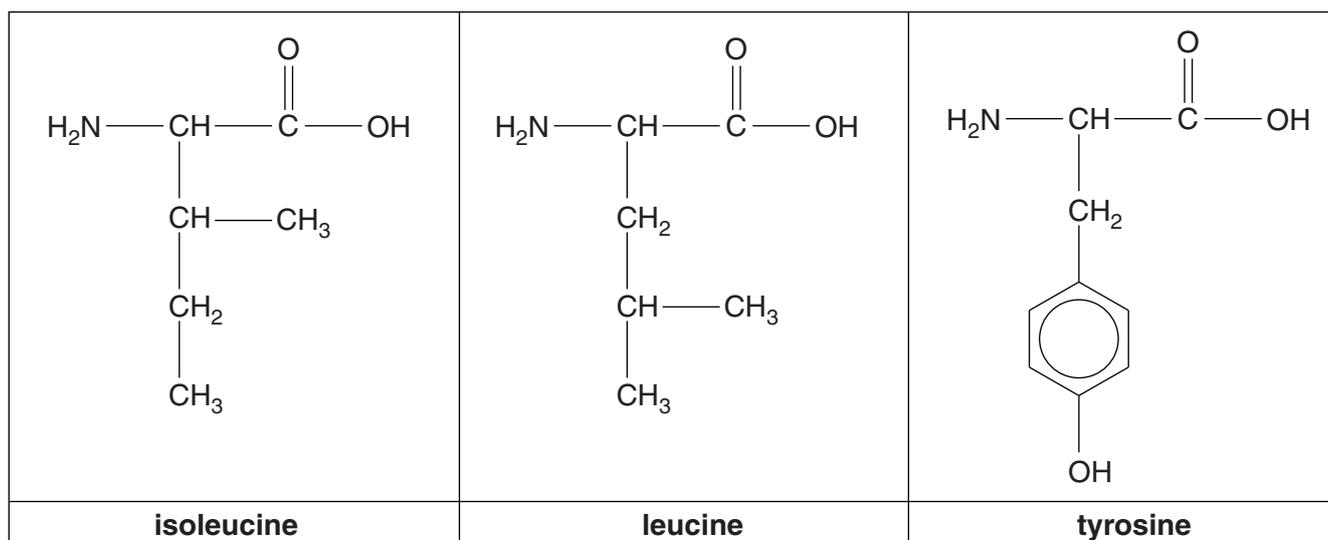
In your answer, you should use appropriate technical terms, spelled correctly.

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..... [4]

Turn over

3

(d) The structures of the α -amino acids isoleucine, leucine and tyrosine are shown below.



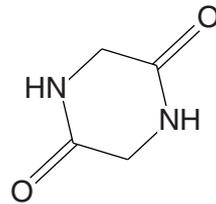
Predict the number of peaks in the carbon-13 spectrum of each of these α -amino acids.

α -amino acid	isoleucine	leucine	tyrosine
number of peaks			

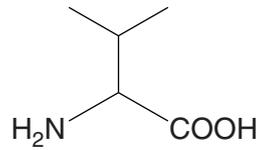
[3]

(e) When strongly heated, an α -amino acid can form a cyclic 'dimer' in a condensation reaction.

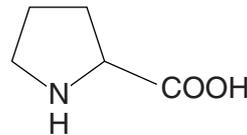
For example, glycine, where R is H, forms the cyclic dimer shown below.



Draw the structures of the cyclic dimers that could be formed from the α -amino acids valine and proline, shown below.



valine



proline

<p>cyclic dimer formed from valine</p>	<p>cyclic dimer formed from proline</p>
--	---

[2]

[Total: 19]

Turn over

2 Benzene is an important starting material in the production of dyes, detergents and medicines.

(a) Aromatic amines, such as 4-chlorophenylamine, are intermediates in the manufacture of azo dyes.

(i) Benzene can be converted into 4-chlorophenylamine in the three stages shown below.

In the boxes

- show the structures of the organic products
- state the chemicals used.



stage 1



chemicals:

.....

organic product

stage 2



chemicals:

.....

organic product

stage 3



chemicals:

.....

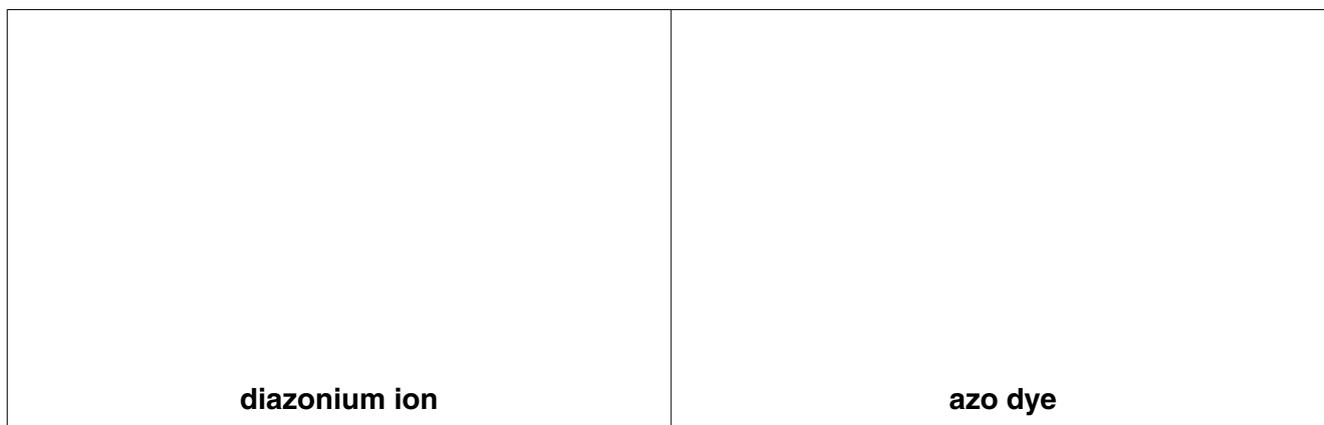


4-chlorophenylamine

[5]

- (ii) 4-Chlorophenylamine can be converted into a diazonium ion.
The diazonium ion can then be reacted with phenol in aqueous alkali to form an azo dye.

Draw the structures of the diazonium ion and the azo dye.

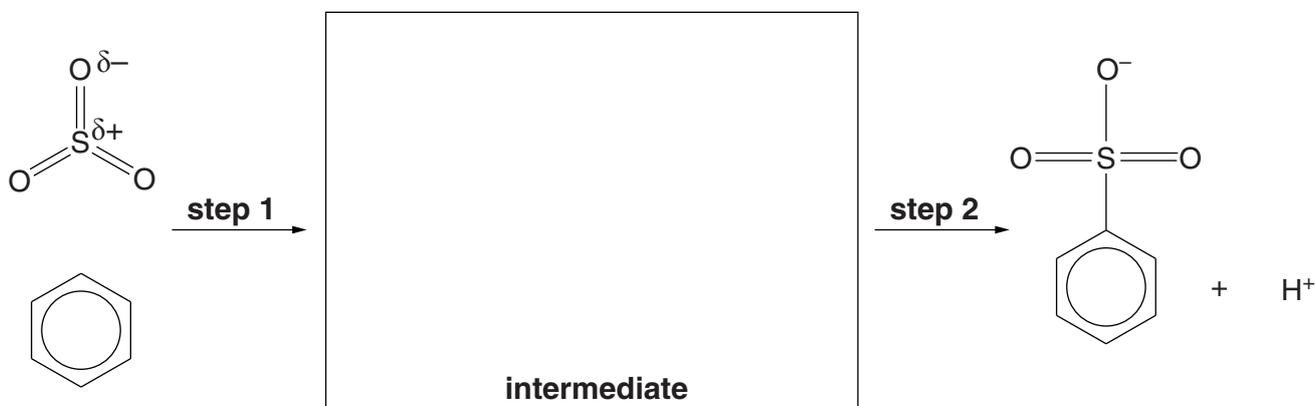


[2]

- (b) Benzene can be converted into benzenesulfonic acid, $C_6H_5SO_3H$, which is used in the manufacture of many detergents.

The reaction between benzene and sulfuric acid is an electrophilic substitution reaction.
Sulfur trioxide, SO_3 , is the electrophile.

Part of the mechanism for this reaction is shown below.

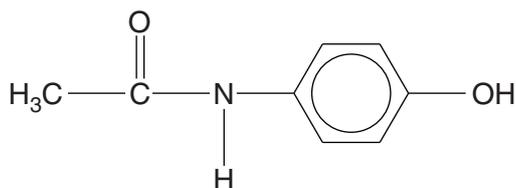


Complete the mechanism by drawing the intermediate and by adding curly arrows to show the movement of electron pairs in **steps 1** and **2**.

[4]

Turn over

(c) The painkiller paracetamol has the structure shown below.



(i) Separate samples of paracetamol are reacted with bromine, Br₂, and with sodium, Na.

Draw the structures of possible organic products formed in each reaction.

reaction with Br₂	reaction with Na

[2]

(ii) Another sample of paracetamol is hydrolysed by heating under reflux with hot aqueous sodium hydroxide, NaOH(aq).

Draw the structures of the two organic products formed in this hydrolysis.

--	--

[2]

[Total: 15]

3 This question is about different organic compounds containing C, H and O.

(a) A technician found an unlabelled bottle in a chemical store cupboard. The technician thinks that the bottle contains pentan-2-one, pentan-3-one or pentanal.

(i) Describe a series of chemical tests that the technician could use to confirm that the compound in the bottle is a ketone. Include appropriate reagents and any relevant observations.

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

(ii) Describe how the technician could use the product of one of the tests in (i) to show whether the bottle contains pentan-2-one or pentan-3-one.

The method used should **not** involve spectroscopy.

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

Turn over

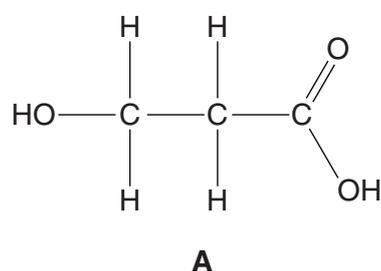
- (b) 3-Hydroxypropanoic acid, $\text{HOCH}_2\text{CH}_2\text{COOH}$, can be produced microbologically from sugars in corn. $\text{HOCH}_2\text{CH}_2\text{COOH}$ can be used as a 'green' starting material for the synthesis of many organic compounds including some important polymers.

Three synthetic routes are shown below for converting $\text{HOCH}_2\text{CH}_2\text{COOH}$, **A**, into different polymers.

The names of the processes for each synthetic step are given.

- (i) In the boxes below, give the structures of the organic compounds formed.

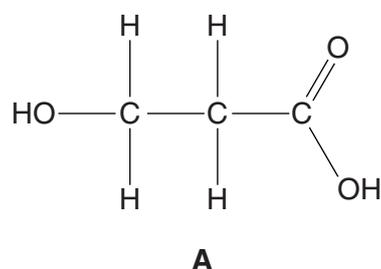
Synthesis 1



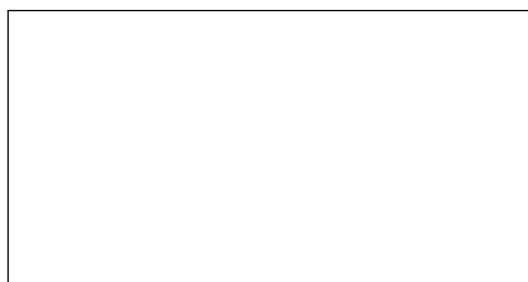
polymerisation



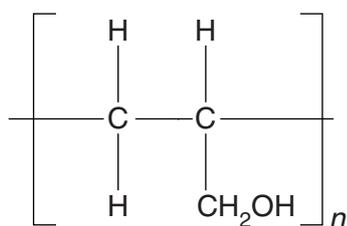
Synthesis 2



elimination
of H_2O



reduction



PVA, used in adhesives

polymerisation



4 A chemist prepares and analyses some esters.

- (a) The chemist prepares an ester of propan-2-ol, $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$, by reacting $\text{CH}_3\text{CH}(\text{OH})\text{CH}_3$ with ethanoic anhydride, $(\text{CH}_3\text{CO})_2\text{O}$.

Using structural formulae, write an equation for the reaction of propan-2-ol and ethanoic anhydride.

[2]

- (b) A sample contains a mixture of two esters contaminated with an alkane and an alcohol.

The chemist attempts to separate the four organic compounds in the mixture using gas chromatography, GC.

The column in the gas chromatograph contains a liquid alkane which acts as the stationary phase.

- (i) How does a liquid stationary phase separate the organic compounds in a mixture?

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

- (ii) Suggest how well these four compounds would be separated using the alkane stationary phase. In your answer, include some indication of the length of the retention times.

Explain your answer.

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

Turn over

- (c) GC is often used together with other techniques, such as mass spectrometry, MS, and NMR spectroscopy, to provide a far more powerful analytical tool than GC alone.

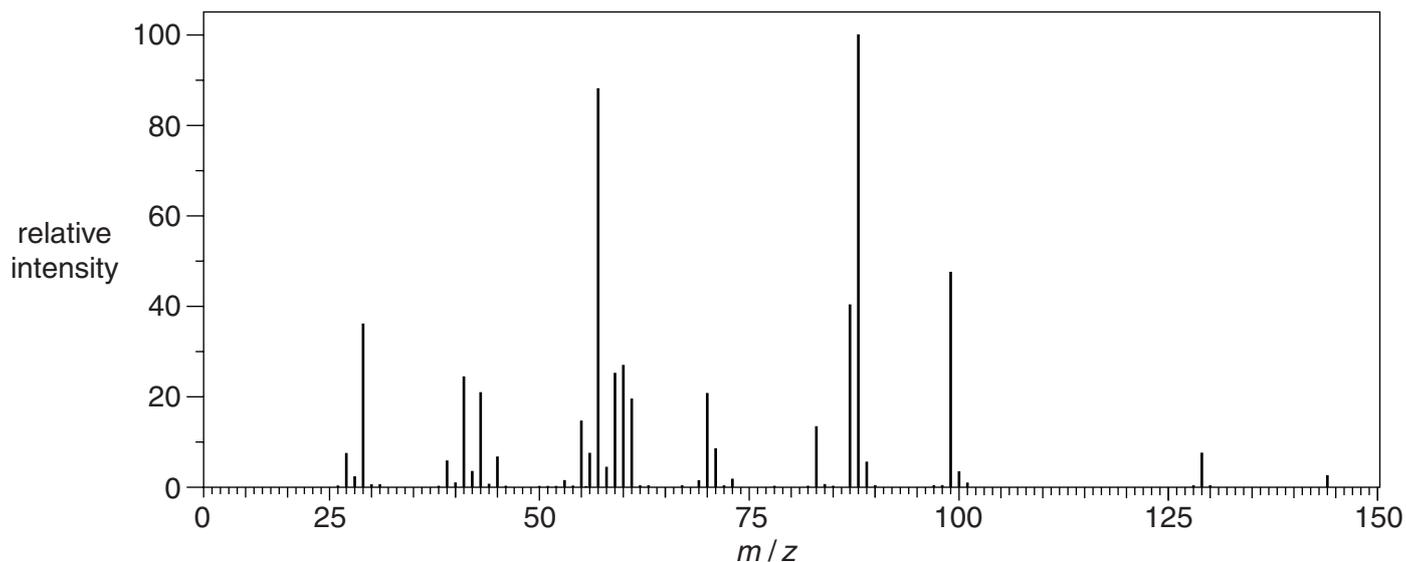
One of the esters in a perfume is separated by GC and then analysed.

The results are shown below.

Elemental analysis by mass

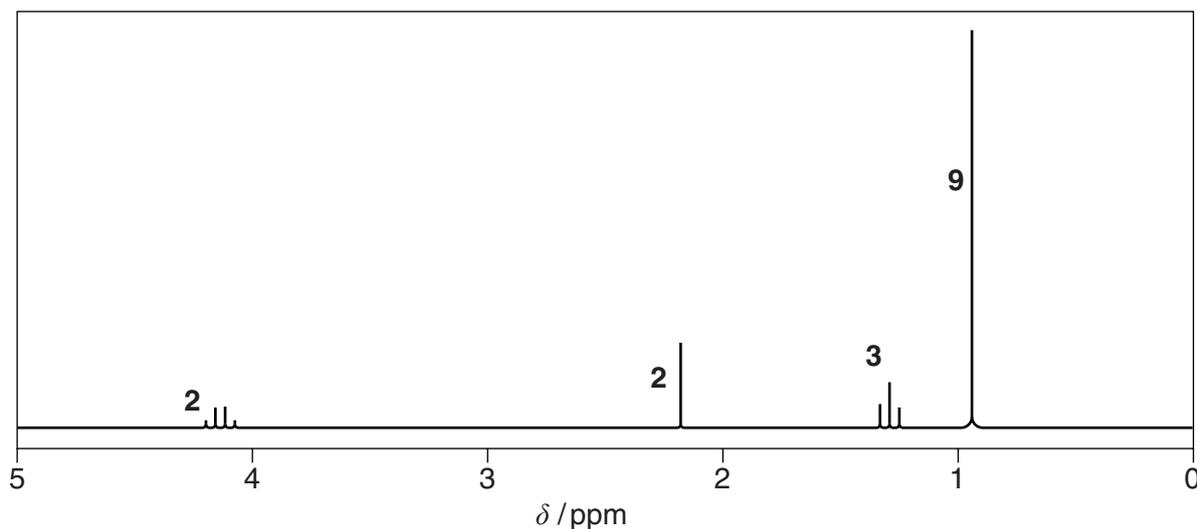
C, 66.63%; H, 11.18%; O, 22.19%

Mass spectrum



Proton NMR spectrum

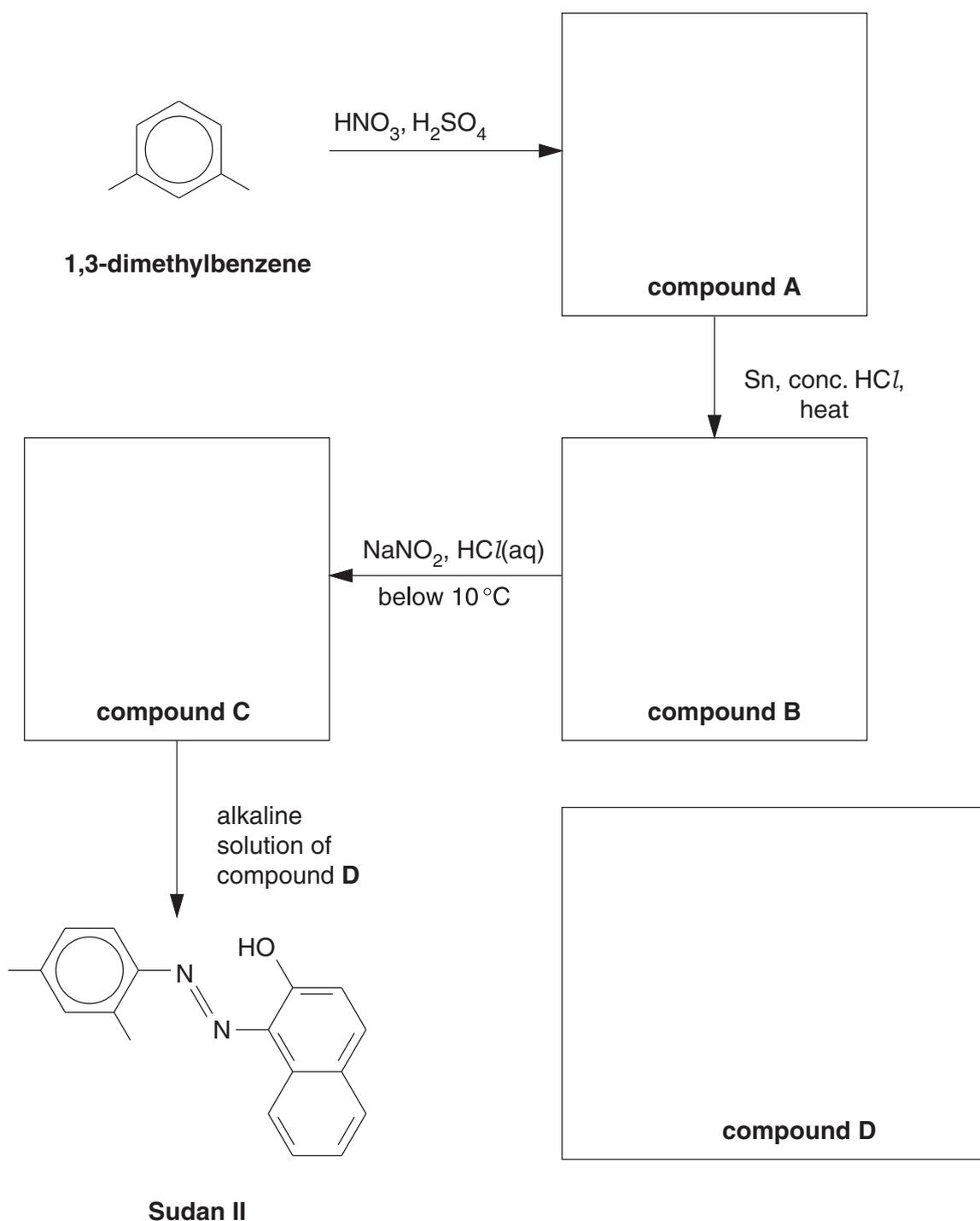
The numbers by each peak are the relative peak areas.



- (b) Sudan II is an azo dye which was used as a colourant in chilli powder. However, scientists advised the Food Standards Agency that Sudan II was linked to an increased risk of cancer and it is now no longer used as a food colourant.

The flowchart below shows how Sudan II could be prepared in the laboratory from 1,3-dimethylbenzene.

- (i) Draw the structures of the organic compounds **A**, **B**, **C** and **D** in the boxes below. Display the functional group in compound **C**.



[4]

3

(ii) Compound **A** is formed by reacting 1,3-dimethylbenzene with HNO_3 and H_2SO_4 .

Explain, with the aid of curly arrows, the mechanism for the formation of compound **A**.

Your answer should clearly show the role of H_2SO_4 as a catalyst.

[5]

(iii) Deduce how many **other** structural isomers of compound **A** could have been formed from the mononitration of 1,3-dimethylbenzene.

..... [1]

[Total: 13]

Turn over

2 A student was researching the development of polymers and discovered three polyesters, PET, PEN and PGA, that are used in the manufacture of plastic bottles.

(a) The student discovered that the first polyester developed was Terylene which is also known as poly(ethylene terephthalate) or PET.

PET can be made by reacting benzene-1,4-dicarboxylic acid with ethane-1,2-diol.

(i) Draw the **displayed** formula of the repeat unit in PET.

[2]

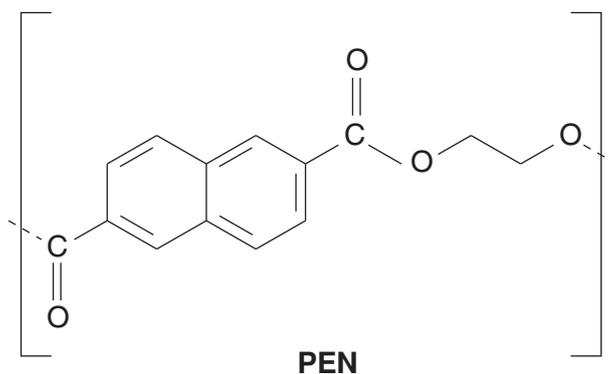
(ii) The industrial manufacture of PET involves two main stages. The first stage, known as 'pre-polymerisation', forms compound **F** with molecular formula $C_{12}H_{14}O_6$.

Draw the structure of compound **F**.

[1]

(b) PEN is a new kind of polyester. PEN is rigid at high temperature whereas PET readily softens.

The repeat unit of PEN is shown below.



(i) What is the empirical formula of the repeat unit in PEN?

..... [1]

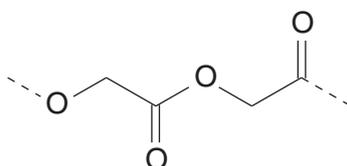
(ii) Draw the structures of **two** monomers that could be used to make PEN.

--	--

[2]

(c) Polyglycolic acid, PGA, is a polymer that is being developed as an inner coating for PET bottles.

A short section of PGA is shown below.



PGA

(i) Compared with other synthetic polymers, PGA can be easily hydrolysed.

Draw the skeletal formula of the organic product formed from the complete hydrolysis of PGA by NaOH(aq).

[2]

(ii) Explain why scientists now think that polymers such as PGA are better for the environment than hydrocarbon-based polymers.



In your answer, you should use appropriate technical terms, spelt correctly.

.....

.....

.....

.....

.....

..... [1]

[Total: 9]
Turn over

3 A student was given three compounds, an aldehyde, a ketone, and a carboxylic acid.

(a) The student carried out the same two chemical tests on each compound. This allowed her to distinguish between all three compounds.

- Describe two suitable tests that the student could have used.
- Show how the observations would allow her to distinguish between the compounds.

.....
.....
.....
.....
.....
.....
.....
..... [4]

(b) Explain how the student could use infrared spectroscopy to confirm which compound is a carboxylic acid.

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

(c) The aldehyde has the molecular formula $C_5H_{10}O$.

The 1H NMR spectrum of the aldehyde contains a doublet at $\delta = 0.9$ ppm with a relative peak area of six compared with the aldehyde proton.

Analyse this information to deduce the structure of the aldehyde. Explain your reasoning.

.....
.....
.....
.....
.....
..... [3]

4 Two esters, $\text{CH}_3(\text{CH}_2)_2\text{COO}(\text{CH}_2)_3\text{CH}_3$ and $\text{CH}_3(\text{CH}_2)_2\text{COOCH}_2\text{CH}_3$, contribute to the odour of pineapple. A food scientist analysed a sample of pineapple essence by separating the two esters using gas chromatography, GC, and measuring their retention times.

(a) (i) State what is meant by *retention time*.

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

(ii) Explain the possible limitations of GC in separating the two esters.

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

(iii) Give the systematic name for the ester $\text{CH}_3(\text{CH}_2)_2\text{COO}(\text{CH}_2)_3\text{CH}_3$.

..... [1]

(b) The unsaturated ester, ethyl deca-2,4-dienoate contributes to the flavour of pears.

(i) Draw the structure of this ester.

[2]

(ii) When pears ripen, ethyl deca-2,4-dienoate is formed following the breakdown of triglycerides.

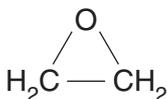
Draw the general structure of a triglyceride with any functional groups fully displayed.

You can use 'R' to represent the carbon chains.

[1]

- (b) Monoethanolamine, MEA, $\text{H}_2\text{NCH}_2\text{CH}_2\text{OH}$, is a hydroxyamine that is used in aqueous solution as a gas scrubber to remove acidic gases from emissions in incinerators.

MEA is prepared industrially by reacting ammonia with epoxyethane.



epoxyethane

- (i) Write an equation for the industrial preparation of MEA.

[1]

- (ii) During the manufacture of MEA, a compound with molecular formula $\text{C}_4\text{H}_{11}\text{NO}_2$ is also formed.

Draw the structure of the compound with molecular formula $\text{C}_4\text{H}_{11}\text{NO}_2$.

[1]

- (c) The combustion of some polymers produces emissions containing toxic acidic gases such as HCl and H_2S . MEA can remove HCl and H_2S from the emissions.

Give the formula of the organic salts formed when MEA removes:

- (i) HCl ,

[1]

- (ii) H_2S .

[1]

TURN OVER FOR QUESTION 5 PARTS (d) AND (e)

Turn over

(d) MEA, $\text{H}_2\text{NCH}_2\text{CH}_2\text{OH}$, can be oxidised to form an α -amino acid.

(i) Explain what is meant by an α -amino acid.

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

(ii) Write an equation for the oxidation of MEA to form an α -amino acid.

Use [O] to represent the oxidising agent.

..... [1]

(e) Isomers **F** and **G** are hydroxyamines each with the molecular formula $\text{C}_4\text{H}_{11}\text{NO}$.

- Isomer **F** can be dehydrated to form the cyclic compound 
- Isomer **G** has two chiral centres.

Identify and draw the structural isomers **F** and **G**.

isomer F	isomer G
-----------------	-----------------

[2]

[Total: 13]

END OF QUESTION PAPER