



Oxford Cambridge and RSA

Tuesday 12 October 2021 – Morning

A Level Chemistry B (Salters)

H433/02 Scientific literacy in chemistry

Time allowed: 2 hours 15 minutes



You must have:

- a clean copy of the Advance Notice Article (inside this document)
- the Data Sheet for Chemistry B

You can use:

- a scientific or graphical calculator
- an HB pencil



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

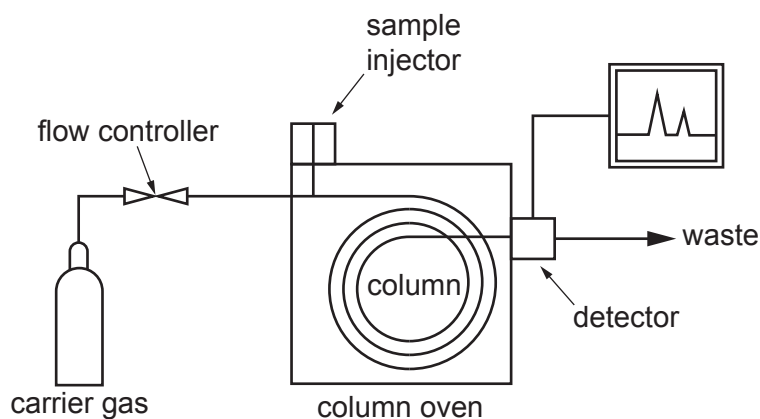
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

ADVICE

- Read each question carefully before you start your answer.

Answer **all** the questions.

- 1 Gas-liquid chromatography can be used to analyse the components of car petrol.



A gas chromatograph

- (a) (i) State an important property of the carrier gas.

It is inert (unreactive). [1]

- (ii) What does the column consist of?

A high-boiling liquid (the stationary phase) coated on a porous solid support, packed in a long thin tube. [2]

- (b) The first four components of a sample of petrol to emerge from the column are shown in **Table 1.1** in the order they come out.

1	methylbenzene
2	2-methylheptane
3	3-methylheptane
4	octane

Table 1.1

- (i) Suggest the method used to identify these compounds as they emerge from the column.

Mass spectrometry (the mass spectrum of each compound). [1]

- (ii) Which of the compounds in **Table 1.1** has the shortest retention time?

Compound 1, methylbenzene ($C_6H_5CH_3$). [1]

- (c) Suggest, with reasons, which of compounds 2, 3 and 4 from **Table 1.1** has the highest boiling point.

Compound 4, octane. It is unbranched, so its straight chains can get closer together, with more surface contact than branched compounds 2 and 3. So octane has the most (strongest) instantaneous dipole to induced dipole (London) forces between molecules, needing the most energy to overcome.

[3]

- (d) Octane can be cracked.

Write an equation for the cracking of octane into but-2-ene, $\text{CH}_3\text{CH}=\text{CHCH}_3$, and one other compound.

Use **molecular** formulae.



[1]

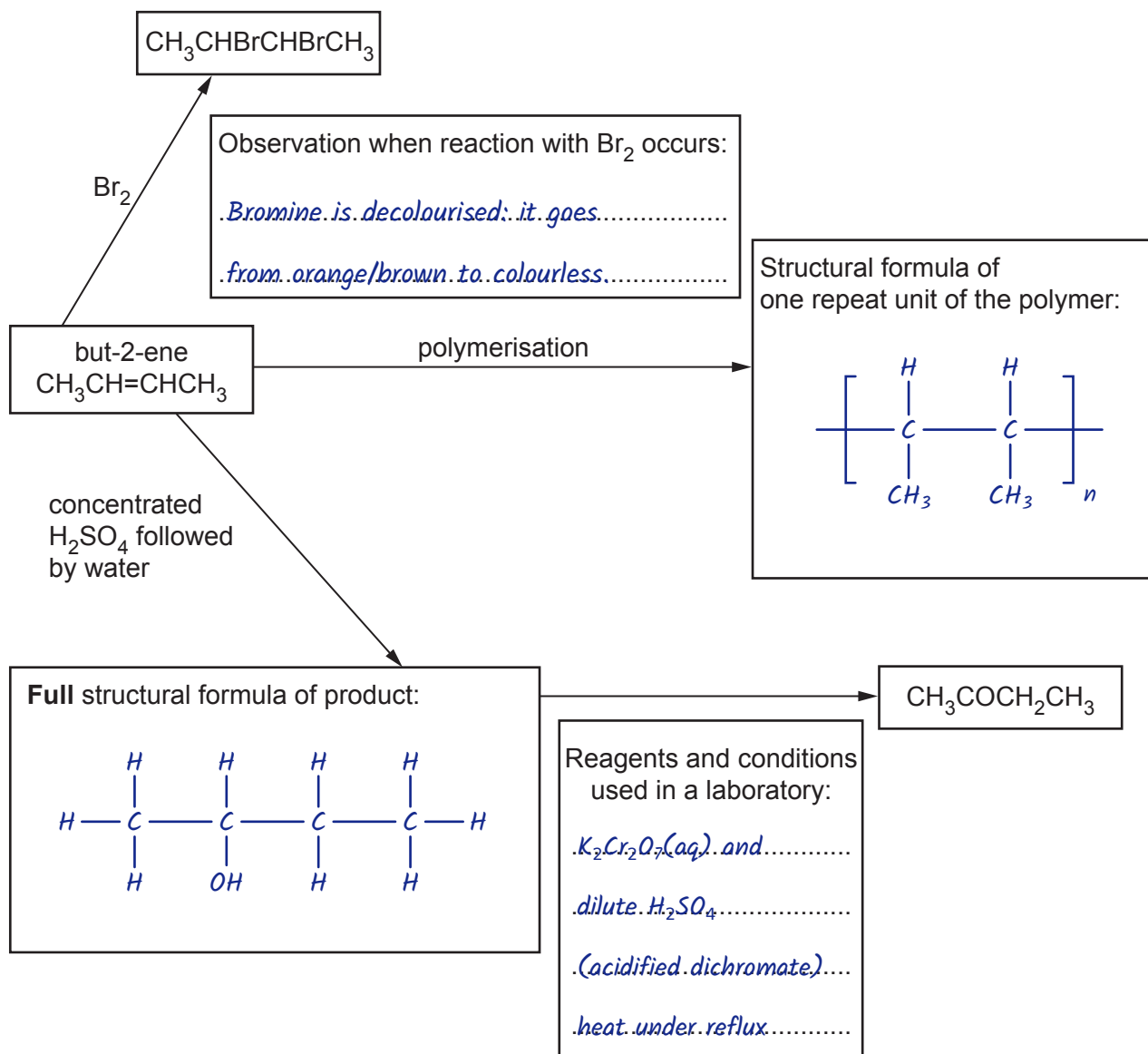
- (e) Explain why but-2-ene has two stereoisomers.

There is no (restricted) rotation about the $\text{C}=\text{C}$ double bond, and each carbon of the $\text{C}=\text{C}$ has two different groups attached (CH_3 and H), so E and Z isomers exist.

[2]

(f) Some reactions of but-2-ene are shown in the diagram below.

Complete the diagram by filling in the incomplete boxes.



[5]

- (g) A hydrocarbon is completely burned.
11 g of carbon dioxide and 6.0 g of water are formed.

Calculate the empirical formula of the hydrocarbon.

$$n(\text{CO}_2) = 11 \div 44.0 = 0.25 \text{ mol, so } n(\text{C}) = 0.25 \text{ mol}$$

$$n(\text{H}_2\text{O}) = 6.0 \div 18.0 = 0.333 \text{ mol, so } n(\text{H}) = 0.667 \text{ mol}$$

$$\text{C} : \text{H} = 0.25 : 0.667 = 1 : 2.67 = 3 : 8$$

formula C_3H_8 [3]

- 2 Some students are investigating the rusting of iron.

They use the electrode potentials in **Table 2.1**.

	Half equation	$E^\ominus/\text{V}$
1	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	- 0.76
2	$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	- 0.44
3	$\dots\frac{1}{2}\dots\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + \dots 2\dots\text{e}^- \rightleftharpoons 2\text{OH}^-(\text{aq})$	+ 0.40

Table 2.1

- (a) (i) Complete half-equation 3 in **Table 2.1** by writing numbers on the dotted lines. [2]

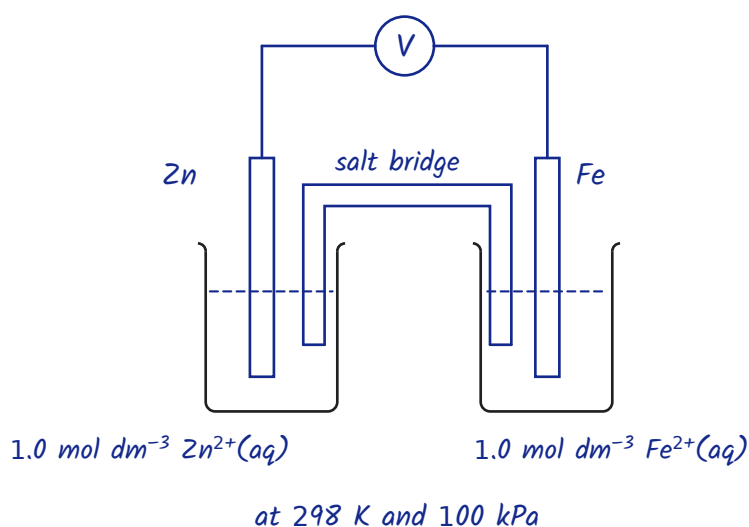
- (ii) Use oxidation states to state and explain what is being reduced in half-equation 3 in **Table 2.1**.

Oxygen (O_2) is reduced: the oxidation state of O goes from 0 in O_2 to -2 in OH^- , a decrease in oxidation state (gain of electrons).

..... [2]

- (b) The students set up a cell under standard conditions using half-equations 1 and 2 in **Table 2.1**. They aim to measure $E^\ominus_{\text{cell}}$.

- (i) Complete the diagram of their apparatus. Indicate how standard conditions are obtained.



[3]

(ii) Use the data in **Table 2.1** to calculate the $E^\ominus_{\text{cell}}$ value for the cell in **(b)(i)**.

$$-0.44 - (-0.76) \quad E^\ominus_{\text{cell}} = \dots\dots\dots +0.32 \dots\dots\dots \text{V} \quad [1]$$

(c) Zinc blocks are often fixed to the bottom of steel ships to stop the ships rusting in sea water.

A student compares this process with the cell in part **(b)(i)**.

The student makes the following statements:

- Electrons flow from the iron (steel) to the zinc.
- This stops the rusting by reversing half-equation 2.
- The process is limited as there is no salt bridge.

Comment, with reasons, on the student's statements.

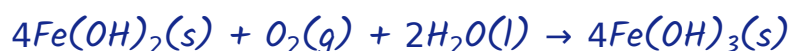
Statement 1 is incorrect: electrons flow from zinc to iron, because E_{Zn} (-0.76 V) is more negative than E_{Fe} (-0.44 V), so zinc is oxidised.

Statement 2 is incorrect: half-equation 2 is not reversed; it goes in the forward direction as E_{Fe} is more positive than E_{Zn} . Half-equation 1 is reversed.

Statement 3 is incorrect: the sea water (ions in solution) acts as the salt bridge. [4]

(d) The students add aqueous sodium hydroxide to a fresh aqueous solution of an iron(II) salt. A precipitate of iron(II) hydroxide forms that gradually turns to iron(III) hydroxide.

Write a full equation with state symbols for the formation of iron(III) hydroxide from iron(II) hydroxide.



[3]

- (e) The students are given a sample of 5.0 g of rust with the formula $\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$.

The students heat the rust and find that it loses 1.0 g.

Show by calculation whether the students have the correct result.

$$M(\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}) = (2 \times 55.8) + (3 \times 16.0) + (2 \times 18.0) = 195.6 \text{ g mol}^{-1}$$

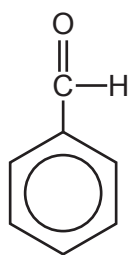
$$n(\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}) = 5.0 \div 195.6 = 0.0256 \text{ mol}$$

$$\text{mass of water lost} = 0.0256 \times 2 \times 18.0 = 0.92 \text{ g}$$

0.92 g is less than 1.0 g, so the students' result is incorrect.

[2]

- 3 Benzaldehyde gives the smell and taste of almonds to almond oil.



benzaldehyde

- (a) The mass spectrum of benzaldehyde has many peaks. Two of the peaks have m/z values of 107 and 77.

Suggest explanations for these values.

107 *M+1 peak: the molecular ion containing one ^{13}C atom, $(\text{C}_6^{13}\text{H}_5\text{O})^+$*

77 *C_6H_5^+ (phenyl cation, loss of CHO from the molecular ion)*

[2]

- (b) Benzaldehyde has a benzene ring. The benzene ring has delocalised electrons.

Describe how the delocalised electrons are arranged in the benzene structure.

The delocalised electrons form two rings (doughnuts) of electron density, one above and one below the plane of the ring of carbon atoms (from overlap of p-orbitals).

[2]

- (c) Benzene and ethene each undergo electrophilic reactions.

State how these reactions differ.

Benzene undergoes electrophilic substitution, whereas ethene undergoes electrophilic addition.

[1]

(d) Benzaldehyde can be nitrated to give nitrobenzaldehyde, which is yellow.

- (i) A student says the colour occurs because nitrobenzaldehyde absorbs the complementary colour to yellow and emits yellow light.

Comment on the student's statement.

The student is partly incorrect. The complementary colour (blue-violet) is absorbed from white light, which is correct. But the molecule does not emit yellow light: yellow is the colour that is left (transmitted/reflected) after the blue-violet light has been absorbed.

[3]

- (ii) Calculate the wavelength (in cm) of the light associated with an electron energy change of 3.5×10^{-19} J.

$$\lambda = hc \div E$$

$$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) \div 3.5 \times 10^{-19}$$

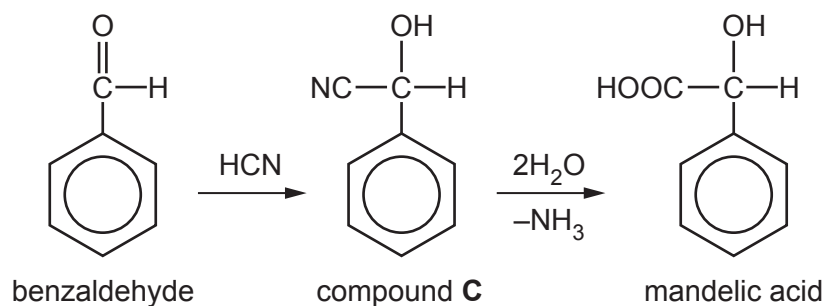
$$\lambda = 5.7 \times 10^{-7} \text{ m}$$

$$= 5.7 \times 10^{-7} \times 100 = 5.7 \times 10^{-5} \text{ cm}$$

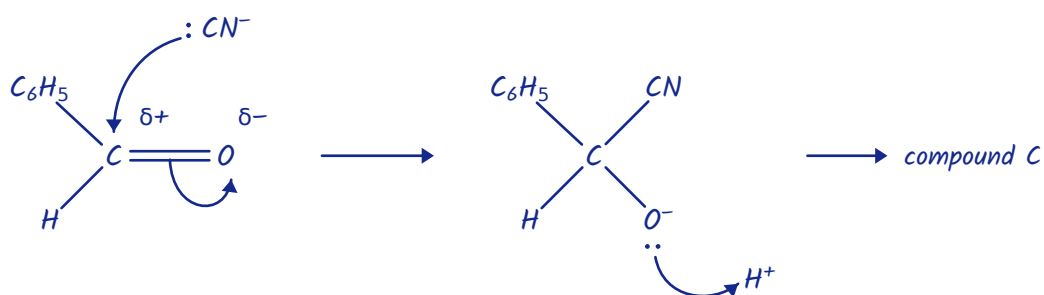
wavelength = 5.7×10^{-5} cm [3]

- (e) Mandelic acid, an antibiotic, can be made from benzaldehyde.

The reaction scheme below shows a synthesis of mandelic acid.



- (i) Draw the mechanism for the attack of a cyanide ion on benzaldehyde, followed by attack by H^+ to give compound **C**.



[2]

- (ii) Name the functional group attached to the benzene ring in compound **C**.

Hydroxynitrile (cyanohydrin) [1]

- (iii) In an experiment, 5.0 g of benzaldehyde gives 6.3 g of mandelic acid.

Calculate the percentage yield.

$$M(C_6H_5CHO) = 106.0; \quad M(\text{mandelic acid}, C_8H_8O_3) = 152.0$$

$$n(\text{benzaldehyde}) = 5.0 \div 106.0 = 0.0472 \text{ mol}$$

$$n(\text{mandelic acid}) = 6.3 \div 152.0 = 0.0414 \text{ mol}$$

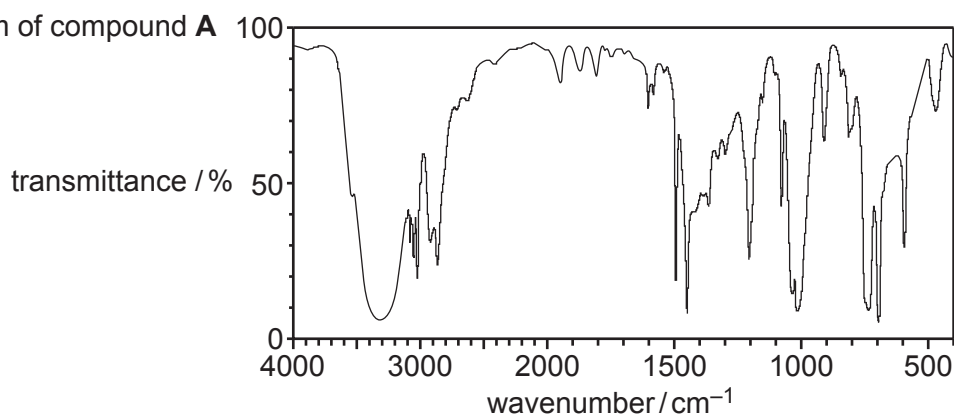
$$\text{yield} = 0.0414 \div 0.0472 \times 100 = 88\%$$

yield = ... 88 % [3]

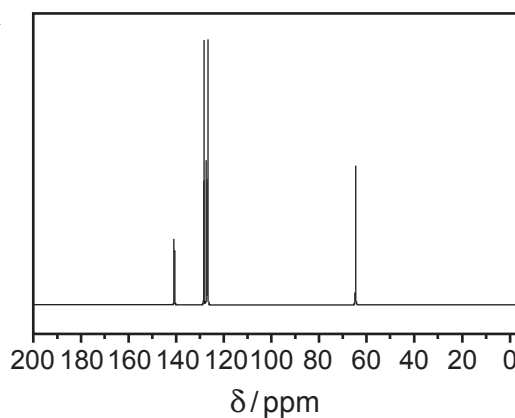
- (f)* When benzaldehyde is reacted with alkali, and then neutralised, it forms two compounds, **A** and **B**.

Working may be done on this page but it will not be marked.

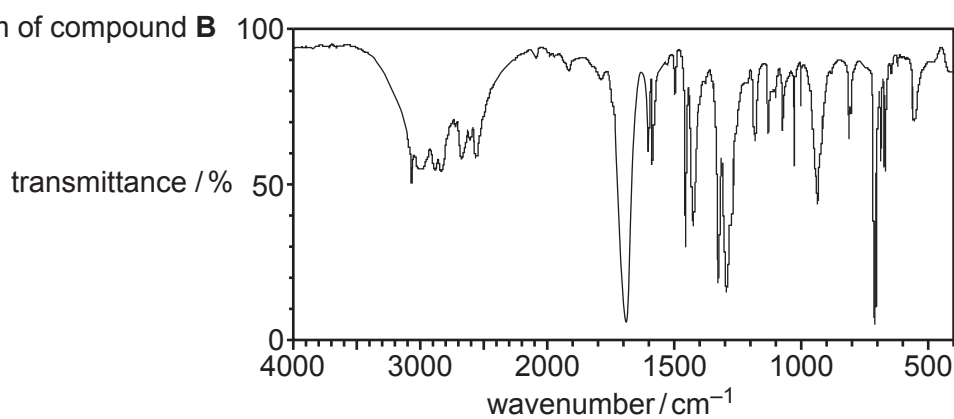
Infrared spectrum of compound **A**



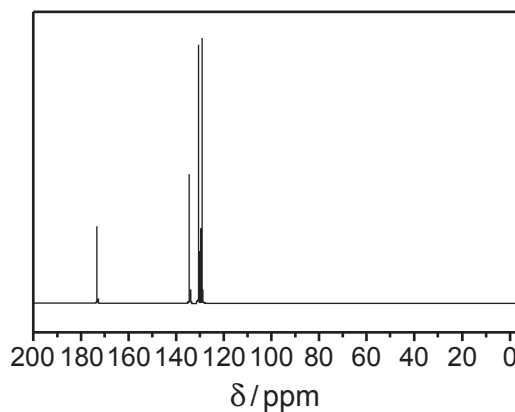
^{13}C – NMR spectrum of compound **A**



Infrared spectrum of compound **B**



^{13}C – NMR spectrum of compound **B**



Use the spectra on page 12 to identify compounds **A** and **B**. Each one has seven carbon atoms.

Give full evidence from **all** the spectra, including relevant wavenumbers and chemical shifts.

Compound A is phenylmethanol, $C_6H_5CH_2OH$. Compound B is benzoic acid, C_6H_5COOH .

IR of A: a strong broad absorption at about 3300 cm^{-1} (range 3200 to 3600 cm^{-1}) shows an O-H in an alcohol. There is no $C=O$ absorption around 1700 cm^{-1} , so A is not a carbonyl compound or acid. Peaks between 1450 and 1650 cm^{-1} are aromatic $C=C$.

^{13}C NMR of A: peaks between 120 and 140 ppm are the aromatic ring carbons, and the peak at about 65 ppm is a C-O carbon (the CH_2 bonded to OH). So A is $C_6H_5CH_2OH$.

IR of B: a strong sharp absorption at about 1700 cm^{-1} shows $C=O$, and the very broad absorption from 2500 to 3300 cm^{-1} shows the O-H of a carboxylic acid. Aromatic $C=C$ peaks appear between 1450 and 1650 cm^{-1} . [6]

Additional answer space if required.

^{13}C NMR of B: peaks around 130 ppm (128 to 135 ppm) are the aromatic carbons and the peak at about 175 ppm is the $C=O$ carbon of a carboxylic acid ($COOH$). There is no peak near 65 ppm , so no C-O single-bonded CH_2 . So B is C_6H_5COOH .

4 Some students investigate the dissolving of potassium salts.

- (a) The students are given 10.1 g of potassium nitrate, KNO_3 .
They dissolve this in 150 cm^3 of water.

The temperature goes down by 5.3°C .

- (i) Give practical details of how they would carry out the experiment.

Include the apparatus required and the measurements to be made.

*Measure 150 cm^3 of water using a measuring cylinder and pour it into
an insulated polystyrene cup (in a beaker for support).
Measure the initial temperature of the water with a thermometer
before adding the solid, and weigh the 10.1 g of KNO_3 on a balance.
Add the solid, stir, and measure the final (lowest) temperature when
all the solid has dissolved and the temperature has become constant.*

..... [4]

- (ii) Use the students' result to calculate a value for $\Delta_{\text{solution}}H$ in kJ mol^{-1} .

Give your answer to an **appropriate** number of significant figures.

Assume the solution has the same specific heat capacity and density as water.

$$q = mc\Delta T = 150 \times 4.18 \times 5.3 = 3323 \text{ J} = 3.323 \text{ kJ}$$

$$M(\text{KNO}_3) = 101.1, \text{ so } n(\text{KNO}_3) = 10.1 \div 101.1 = 0.100 \text{ mol}$$

$$\Delta H = 3.323 \div 0.100 = 33 \text{ kJ mol}^{-1}$$

temperature fell, so endothermic: ΔH is positive, 2 s.f.

$$\Delta_{\text{solution}}H = \dots\dots\dots +33 \dots\dots\dots \text{ kJ mol}^{-1} \text{ [4]}$$

- (b) The students find the data below for dissolving another salt, KIO_3 , in water.

$$\Delta_{\text{solution}} H = +17.8 \text{ kJ mol}^{-1}$$

$$\Delta_{\text{sys}} S = +41 \text{ J K}^{-1} \text{ mol}^{-1}$$

- (i) Explain the sign of $\Delta_{\text{sys}} S$ in terms of the particles involved in the process.

*Entropy is a measure of the number of ways of arranging the particles
(and their energy quanta). The ions in the solid lattice are ordered
(fewer ways); dissolved ions in solution are more random, so entropy
increases and ΔS_{sys} is positive.* [2]

- (ii) A student says that the dissolving of KIO_3 is not feasible below 434 K.

Carry out suitable calculations and comment on the student's statement.

$$\Delta S_{\text{tot}} = \Delta S_{\text{sys}} - \Delta H/T \quad \text{with } \Delta H = +17\,800 \text{ J mol}^{-1}$$

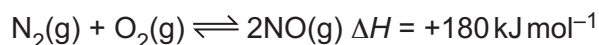
$$\text{At } 434 \text{ K: } \Delta S_{\text{tot}} = 41 - (17\,800 \div 434) = 41 - 41.0 = 0 \text{ J K}^{-1} \text{ mol}^{-1}$$

$$\text{At } 298 \text{ K: } \Delta S_{\text{tot}} = 41 - (17\,800 \div 298) = 41 - 59.7 = -18.7 \text{ J K}^{-1} \text{ mol}^{-1}$$

Below 434 K, $\Delta H/T$ is larger than 41, so ΔS_{tot} is negative.

*The student is correct: below 434 K ΔS_{tot} is negative, so dissolving is
not feasible; above 434 K ΔS_{tot} is positive.* [4]

- (c) The students then discuss the enthalpy and entropy data for the industrial process shown in **Equation 4.1**.



Equation 4.1

- (i) $\Delta_{\text{sys}} S$ is very small for the forward reaction.

Explain why, in terms of **Equation 4.1**.

*There are the same number of moles of gas (2) on each side of the
equation.* [1]

- (ii)* A chemical company considers the conditions for making NO by the process shown in Equation 4.1.

Suggest and explain the conditions of temperature and pressure that you would recommend to the company for this process.

Temperature: the forward reaction is endothermic ($\Delta H = +180 \text{ kJ mol}^{-1}$), so by Le Chatelier's principle a higher temperature shifts the equilibrium to the right to absorb the heat, giving a greater yield of NO. A higher temperature also increases the rate, because a greater proportion (frequency) of collisions have energy greater than or equal to the activation energy.

Pressure: there are 2 moles of gas on each side, so changing the pressure has no effect on the position of equilibrium; yield does not depend on pressure. A higher pressure would increase the rate, as gas molecules are closer together so collisions are more frequent.

Recommendation: use a high temperature (such as about 500 K or higher) to maximise yield and rate, limited by the energy cost and [6]

Additional answer space if required.

safety of very high temperatures. Use a low pressure of about 1 to 2 atm, since high pressure does not improve yield and is expensive and unsafe to maintain.

- 5 This question refers to the Advanced Notice Article 'Smartphones: Smart Chemistry' that is included as an insert with this paper.

(a) Lanthanide elements are important in smartphones.

The lanthanides can be described as being in a 'block' of the Periodic Table.

Use the electronic configurations of the lanthanides shown in the article to suggest the name of the block.

f-block (the 4f subshell is being filled) [1]

(b) The lanthanides were discovered using atomic emission spectroscopy.

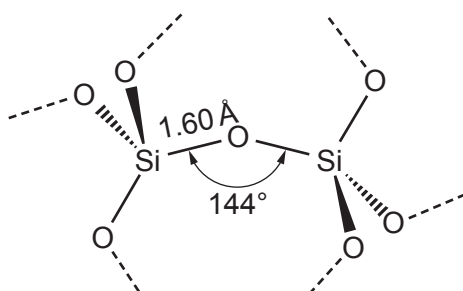
(i) Describe the appearance of an atomic emission spectrum.

Bright coloured lines on a black background (lines converge at higher frequency) [1]

(ii) Describe how emission spectra are formed and explain how they allow different elements to be distinguished.

Electrons are excited to higher energy levels, then fall back to lower energy levels, releasing energy as light.
The energy given out is $\Delta E = h\nu$, so each line has a frequency proportional to the energy gap.
Each element has different (unique) energy levels, so it gives a different pattern of lines in its spectrum. [3]

- (c) The Article shows that the three-dimensional structure of silicon dioxide can be represented as shown below.



The Si-O-Si bonds have a larger angle than the H-O-H bond angle of water.

- (i) State the H-O-H bond angle in a water molecule.

104.5° [1]

- (ii) Explain the bond angle in water.

The O atom has four areas of electron density (electron pairs) around it: two bonding pairs and two lone pairs. These repel each other as far apart as possible to minimise repulsion (tetrahedral arrangement). Lone pairs repel more than bonding pairs, so the H-O-H angle is reduced from 109.5° to 104.5°. [3]

- (d) Ceramics and 'gorilla glass' are both strong in resisting compression.

Which features of their chemical structures do they share and what does gorilla glass have in addition?

Both are giant structures with covalent Si-O bonds (both based on silicon dioxide, containing silicon and oxygen). Gorilla glass has, in addition, Al-O bonds (aluminosilicate anions) and ionic bonds, with sodium/potassium ions held between the aluminosilicate anions. [3]

- (e) Explain why potassium ions can replace sodium ions in the structure of 'gorilla glass' and why potassium ions are larger.

Both form 1+ ions (same charge, both Group 1), so K^+ can replace Na^+ . K^+ has more electrons and one more shell than Na^+ , so it is larger.

[2]

- (f) An aluminosilicate ion has the formula $Al_2Si_{14}O_{32}^{x-}$.

State and explain the value of x using oxidation states.

Al is +3 and Si is +4: $(2 \times +3) + (14 \times +4) = +62$. O is -2: $32 \times -2 = -64$.
Overall charge = $+62 - 64 = -2$, so $x = 2$.

[2]

- (g) Indium tin oxide consists of indium oxide and tin oxide and is used in capacitive touchscreens. Indium forms the oxide In_2O_3 .

- (i) Predict the charge on the indium ion from its position in the Periodic Table.

Use this to explain the formula In_2O_3 .

Indium is in Group 13 (3), so it loses 3 electrons and forms In^{3+} .
Oxide ions are O^{2-} , so 2 In^{3+} (+6) balance 3 O^{2-} (-6), giving In_2O_3 .

[2]

- (ii) The Article says that one form of indium tin oxide has percentages by mass: 53% In, 28% Sn and 19% O.

Show how the percentages by mass are related to the formulae of the oxides from which the indium tin oxide is made.

$$\begin{aligned} In : Sn : O &= 53 \div 114.8 : 28 \div 118.7 : 19 \div 16.0 \\ &= 0.462 : 0.236 : 1.19 \quad (\text{divide by } 0.236) \\ &= 2 : 1 : 5, \text{ so } In_2SnO_5 = In_2O_3 + SnO_2 \end{aligned}$$

The oxides are indium oxide In_2O_3 and tin oxide SnO_2 (1 : 1 ratio).

[2]

END OF QUESTION PAPER

[illegible]

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