Please check the examination details below before entering your candidate information

Candidate surname	Other names
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Centre Number | Candidate Number

Pearson Edexcel Level 3 GCE

Friday 20 June 2025

Morning (Time: 2 hours 30 minutes)

Paper reference **9CH0/03**

Chemistry

Advanced

PAPER 3: General and Practical Principles in Chemistry

You must have:
Scientific calculator, Data Booklet, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 120.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk (*)**, marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

Turn over ▶

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Answer ALL questions.

Write your answers in the spaces provided.

1 This question is about ionisation energies.

The table shows the first four ionisation energies of three elements in the same group of the Periodic Table.
The letters used are not the symbols of the elements.

Element	First ionisation energy / kJ mol^{-1}	Second ionisation energy / kJ mol^{-1}	Third ionisation energy / kJ mol^{-1}	Fourth ionisation energy / kJ mol^{-1}
X	403	2632	3900	5080
Y	419	3051	4412	5877
Z	496	4563	6913	9544

(a) State what is meant by the term '**first** ionisation energy'.

(2)

The energy required to remove one electron from each atom in one mole of gaseous atoms (to form one mole of gaseous 1+ ions).

e.g. $X(g) \rightarrow X^{+}(g) + e^{-}$

(b) Explain to which group the elements **X**, **Y** and **Z** belong.

(2)

There is a very large jump (increase) in ionisation energy between the first and the second ionisation energy, so there is only one electron in the outer shell.

So X, Y and Z are in Group 1 (the alkali metals).

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(c) Explain which of the elements **X**, **Y** and **Z** has the highest atomic number.

(3)

Element X, because it has the lowest first ionisation energy (first ionisation energy decreases down the group).

In X the outer electron removed is furthest from the nucleus (X has the largest atomic radius),

and there is more shielding by the inner electron shells, which outweighs the increase in the number of protons, so there is less attraction between the nucleus and the outer electron.

(Total for Question 1 = 7 marks)

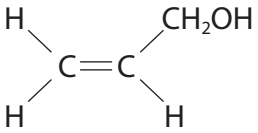
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2 This question is about compounds that contain both an alkene and an alcohol functional group.

(a) Prop-2-en-1-ol, present in garlic, has the structure shown.



(i) Describe a test, and the positive result, that confirms the presence of a C=C group.

(2)

Test

Add bromine water and shake.

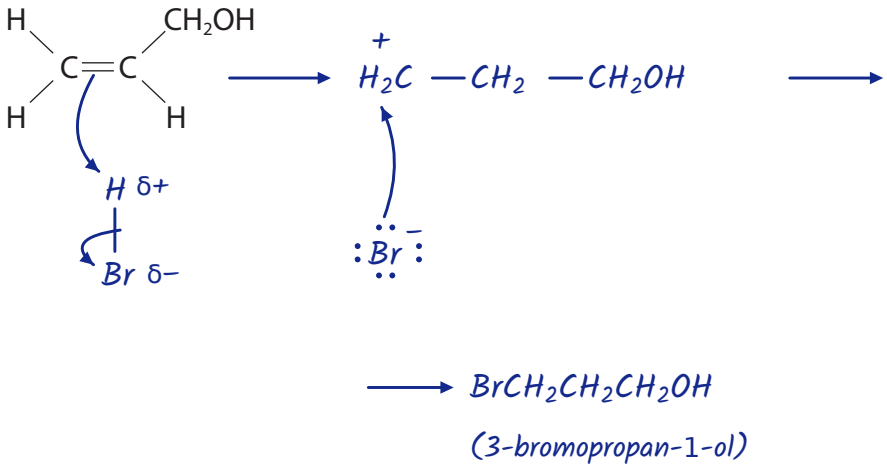
Result

The bromine water decolourises: orange to colourless.

(ii) Prop-2-en-1-ol reacts with hydrogen bromide to form 3-bromopropan-1-ol as one of the products.

Draw a mechanism for this reaction.
Include curly arrows, and relevant lone pairs and dipoles.

(3)



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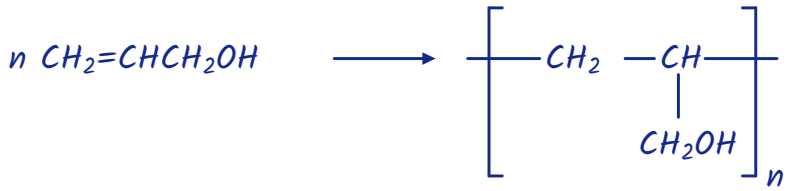
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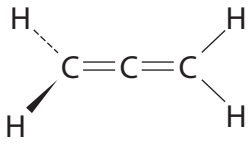
(b) Prop-2-en-1-ol can polymerise to form an addition polymer.

Write a balanced equation for this polymerisation.

(2)



(c) Prop-2-en-1-ol can form the alkene propadiene, which has two adjacent C═C bonds, as shown.



propadiene

Explain why the CH_2 groups at each end of the molecule are at right angles to each other.
Use your knowledge of how orbitals overlap to form π-bonds.

(2)

π-bonds form by the sideways overlap of p orbitals (above and below the C–C axis).

The central carbon uses two different p orbitals for its two π-bonds, e.g. p_y and p_z,

which are at right angles (perpendicular) to each other, so the two π-bonds are

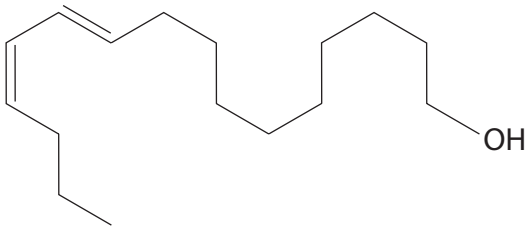
perpendicular and the CH_2 groups at each end lie in planes at right angles.

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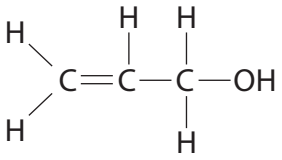
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(d) The compound bombykol is a pheromone secreted by female silk moths.
Like prop-2-en-1-ol, it can also be classified as both an alkene and an alcohol.



bombykol



prop-2-en-1-ol

Bombykol can exist as a number of geometric isomers.

(i) Give the number of different geometric isomers of bombykol.

(1)

4 (four)

(ii) Give the reason why prop-2-en-1-ol does **not** exhibit geometric isomerism.

(1)

Prop-2-en-1-ol has two hydrogen atoms (the same groups) on the first carbon atom of the C=C double bond.

(iii) Explain the expected solubilities in water of bombykol and prop-2-en-1-ol.

(3)

Prop-2-en-1-ol is much more soluble in water than bombykol (prop-2-en-1-ol is soluble and bombykol is insoluble).

Both have an OH (alcohol) group which can form hydrogen bonds with water molecules.

However, bombykol has a very long non-polar (hydrophobic) hydrocarbon chain, which cannot hydrogen bond with water and forms strong London forces between bombykol molecules, so bombykol does not dissolve.

(Total for Question 2 = 14 marks)

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***3** A student carries out a series of qualitative tests to identify the contents of three unlabelled bottles. The bottles are known to contain the following solutions.

- ammonium carbonate, $(NH_4)_2CO_3(aq)$
- potassium carbonate, $K_2CO_3(aq)$
- potassium sulfate, $K_2SO_4(aq)$

The student has access to just test tubes and a water bath, plus **only** the reagents shown.

$AgNO_3(aq)$	$BaCl_2(aq)$	$Ca(OH)_2(aq)$	$CuSO_4(aq)$
$HCl(aq)$	$HNO_3(aq)$	$MgCl_2(aq)$	$NaOH(aq)$
	red litmus paper	blue litmus paper	

The student carries out qualitative tests to **positively** identify either an anion or a cation in each compound and so identify the contents of each bottle.

Describe the qualitative tests carried out, the expected observations and appropriate deductions.

(6)

Test 1, carbonate ions: put a sample of each solution into a separate test tube and add dilute $HNO_3(aq)$ (or $HCl(aq)$) to each.

Two of the solutions effervesce (fizz) because carbonate ions react with the acid to give CO_2, which turns $Ca(OH)_2(aq)$ cloudy (milky). So these two are $(NH_4)_2CO_3$ and K_2CO_3, and the solution that does not fizz must be K_2SO_4.

Test 2, ammonium ions: to fresh samples of the two carbonate solutions add $NaOH(aq)$ and warm the test tubes gently in the water bath.

Hold damp red litmus paper at the mouth of each test tube. The solution that gives off a gas (ammonia, NH_3) which turns the damp red litmus paper blue contains NH_4^+ ions, so it is ammonium carbonate, $(NH_4)_2CO_3$. The other carbonate solution gives no change, so it is potassium carbonate, K_2CO_3.

Test 3, sulfate ions: to a fresh sample of the third solution add dilute $HCl(aq)$ (or $HNO_3(aq)$) and then $BaCl_2(aq)$.

A white precipitate of barium sulfate forms, which confirms that sulfate ions are

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present, so this bottle is potassium sulfate, K_2SO_4. The acid is added first to remove any carbonate ions, which would also give a white precipitate with $BaCl_2$.

(Total for Question 3 = 6 marks)

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4 This question is about the kinetics of the reaction between iodine and propanone under acidic conditions.
The equation for the reaction is shown.

$$CH_3COCH_3 + I_2 \xrightarrow{H^+} CH_3COCH_2I + HI$$

An experiment is carried out to determine the order of the reaction with respect to iodine.

Step **1** 50.0 cm^3 of 0.0200 mol dm^{-3} iodine solution, $I_2(aq)$, is added from a burette to a conical flask.

Step **2** 25.0 cm^3 of 2.00 mol dm^{-3} sulfuric acid, $H_2SO_4(aq)$, is added to the conical flask using a pipette.

Step **3** 25.0 cm^3 of 2.00 mol dm^{-3} propanone solution, $CH_3COCH_3(aq)$, is added to the conical flask using a pipette.
The flask is swirled and a timer is started.

Step **4** After 2 minutes, a 10.0 cm^3 sample of the reaction mixture is removed and quenched.

Step **5** The quenched sample is then titrated using 0.0100 mol dm^{-3} sodium thiosulfate solution, $Na_2S_2O_3(aq)$.

Step **6** Steps **4** and **5** are repeated every two minutes, until six titres have been determined.

(a) Before carrying out Step **2**, a student noticed droplets of an unknown colourless aqueous solution in the pipette.

Describe how the pipette should be treated before it is used in Step **2**.
Justify your answer.

(2)

Rinse the pipette with deionised water and then with the 2.00 mol dm^{-3} sulfuric acid, so that the acid is not diluted and its concentration stays the same.

(b) Samples from the reaction mixture are quenched in Step **4**.

(i) Explain why quenching is necessary.

(2)

Quenching stops (or greatly slows down) the reaction, so that the concentration of iodine does not change any further before the titration is carried out.

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(ii) State a compound which can be added to the reaction mixture to quench the reaction.
Include an equation for the reaction that takes place during the quenching process. State symbols are not required.

(2)

Compound

sodium hydrogencarbonate, $NaHCO_3$

Equation

$2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2CO_2 + 2H_2O$

(c) One of the products of the reaction, iodopropanone (CH_3COCH_2I) is corrosive, strongly irritating to the eyes and can cause breathing difficulties.

Explain why a risk assessment for this experiment says it does **not** have to be carried out in a fume cupboard.

(2)

The risk depends on both the hazard and the amount of a substance (exposure).

Only a very small amount of iodopropanone is formed, and it remains dissolved in the solution (it is not volatile), so very little can be breathed in.

(d) Show, by calculating the initial quantities of the reactants involved, that this experiment provides evidence for the order with respect to iodine **only**.

(4)

$n(I_2) = (50.0 \div 1000) \times 0.0200 = 1.00 \times 10^{-3}$ mol

n(propanone) $= (25.0 \div 1000) \times 2.00 = 0.0500$ mol

$0.0500 \text{ mol} \gg 1.00 \times 10^{-3}$ mol, so propanone is in large excess (50 times more moles than iodine).

So the concentration of propanone (and of the H^+ catalyst) stays effectively constant, so any change in rate is due only to the changing concentration of iodine, so the experiment gives the order with respect to iodine only.

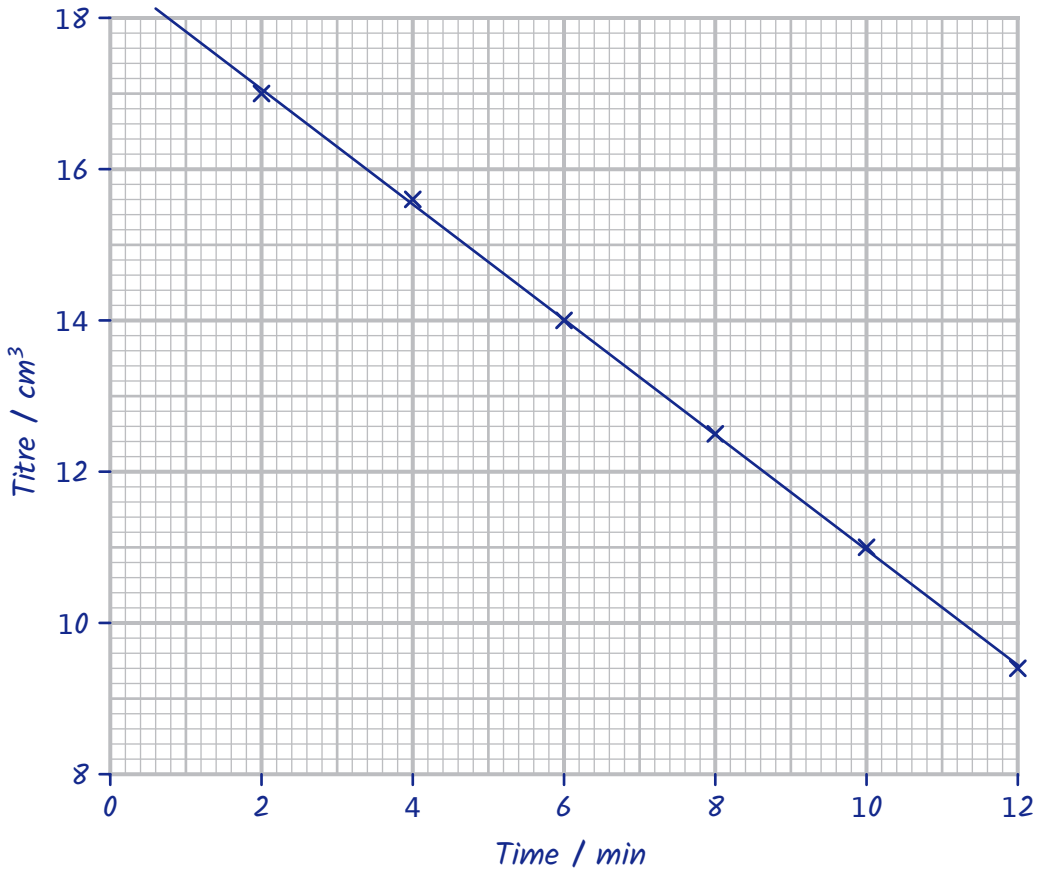
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(e) The results of the experiment are shown.

Time / min	Titre / cm^3
2	17.00
4	15.60
6	14.00
8	12.50
10	11.00
12	9.40

(i) Plot a graph of titre against time.

(2)



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(ii) Give the reason why it is not necessary to calculate the concentration of iodine so that the order can be deduced.

(1)

The titre (volume of sodium thiosulfate) is directly proportional to the concentration of iodine, so the titre can be used in place of the concentration.

(iii) Deduce the order with respect to iodine. Justify your answer.

(2)

The order with respect to iodine is zero.

The graph is a straight line, so the gradient (rate) stays constant as the concentration of iodine decreases.

(Total for Question 4 = 17 marks)

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5 This question is about cobalt complexes.

(a) A sample of cobalt(II) chloride was dissolved in aqueous ammonia, $NH_3(aq)$. During the process, a stream of oxygen was gently bubbled through the solution to oxidise the cobalt(II) ion.

A coloured solid, **R**, was extracted from the solution. A pure sample of this solid was found to contain the masses of the elements shown and had a molar mass of 233.4 g mol^{-1}.

Element	Mass / g
Co	1.26
N	1.20
H	0.257
Cl	2.28

(i) Show that the empirical formula **and** the molecular formula of **R** is $CoN_4H_{12}Cl_3$. You must show your working.

(2)

Co: 1.26 ÷ 58.9 = 0.0214 *N: 1.20 ÷ 14.0 = 0.0857*

H: 0.257 ÷ 1.0 = 0.257 *Cl: 2.28 ÷ 35.5 = 0.0642*

Divide by the smallest (0.0214):

Co = 1, N = 4.00, H = 12.0, Cl = 3.00

so the empirical formula is $CoN_4H_{12}Cl_3$

M_r = 58.9 + (4 × 14.0) + (12 × 1.0) + (3 × 35.5) = 233.4

This equals the molar mass of 233.4 g mol^{-1},

so the molecular formula is also $CoN_4H_{12}Cl_3$

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(ii) 1.00 g of **R** was dissolved in water forming a coloured solution of the complex ion, **Q**.

The solution was reacted with excess silver nitrate solution, forming 0.614 g of silver chloride, AgCl(s).

Calculate the number of moles of chloride ions released when 1 mol of **R** dissolves.

(2)

$n(AgCl) = 0.614 \div 143.4 = 4.28 \times 10^{-3}$ mol $= n(Cl^-)$ released

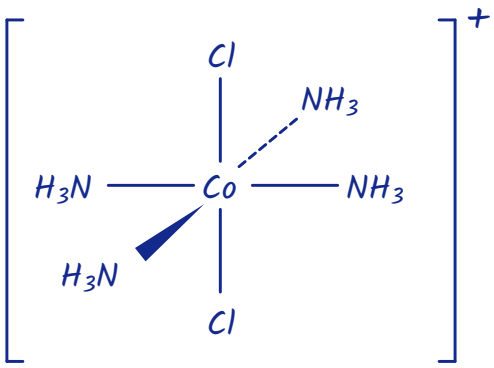
$n(R) = 1.00 \div 233.4 = 4.28 \times 10^{-3}$ mol

$R : Cl^- = 4.28 \times 10^{-3} : 4.28 \times 10^{-3} = 1 : 1$

so 1 mol of chloride ions is released per mole of R

(iii) Draw the three-dimensional shape of the complex ion, **Q**, using your answer to (a)(ii) to help deduce the formula and overall charge.

(3)



octahedral

$Q = [Co(NH_3)_4Cl_2]^+$

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(b) An aqueous solution of cobalt(II) chloride contains the complex ion $[Co(H_2O)_6]^{2+}$.

The dynamic equilibria shown occur when $NH_3(aq)$ and $EDTA^{4-}(aq)$ are each added to separate solutions of this complex ion.

$$[Co(H_2O)_6]^{2+}(aq) + 6NH_3(aq) \rightleftharpoons [Co(NH_3)_6]^{2+}(aq) + 6H_2O(l) \quad \log K_c = 4.39$$

$$[Co(H_2O)_6]^{2+}(aq) + EDTA^{4-}(aq) \rightleftharpoons [Co(EDTA)]^{2-}(aq) + 6H_2O(l) \quad \log K_c = 16.5$$

(i) State what is meant by the term 'dynamic equilibrium'.

(2)

The forward and backward reactions take place at the same rate, so the concentrations of the reactants and products remain constant (in a closed system).

(ii) Explain, in terms of equilibria and entropy, which of the three complex ions is the most stable.

(3)

$[Co(EDTA)]^{2-}$ is the most stable, because its equilibrium has the largest K_c (log K_c = 16.5), so the equilibrium lies furthest to the right.

In the EDTA reaction 2 moles of reactant species form 7 moles of product species (in the NH_3 reaction 7 moles form 7 moles),

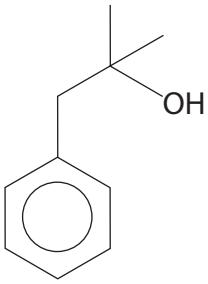
so there is a large increase in entropy of the system (ΔS_{system} is positive), making the formation of $[Co(EDTA)]^{2-}$ very favourable.

(Total for Question 5 = 12 marks)

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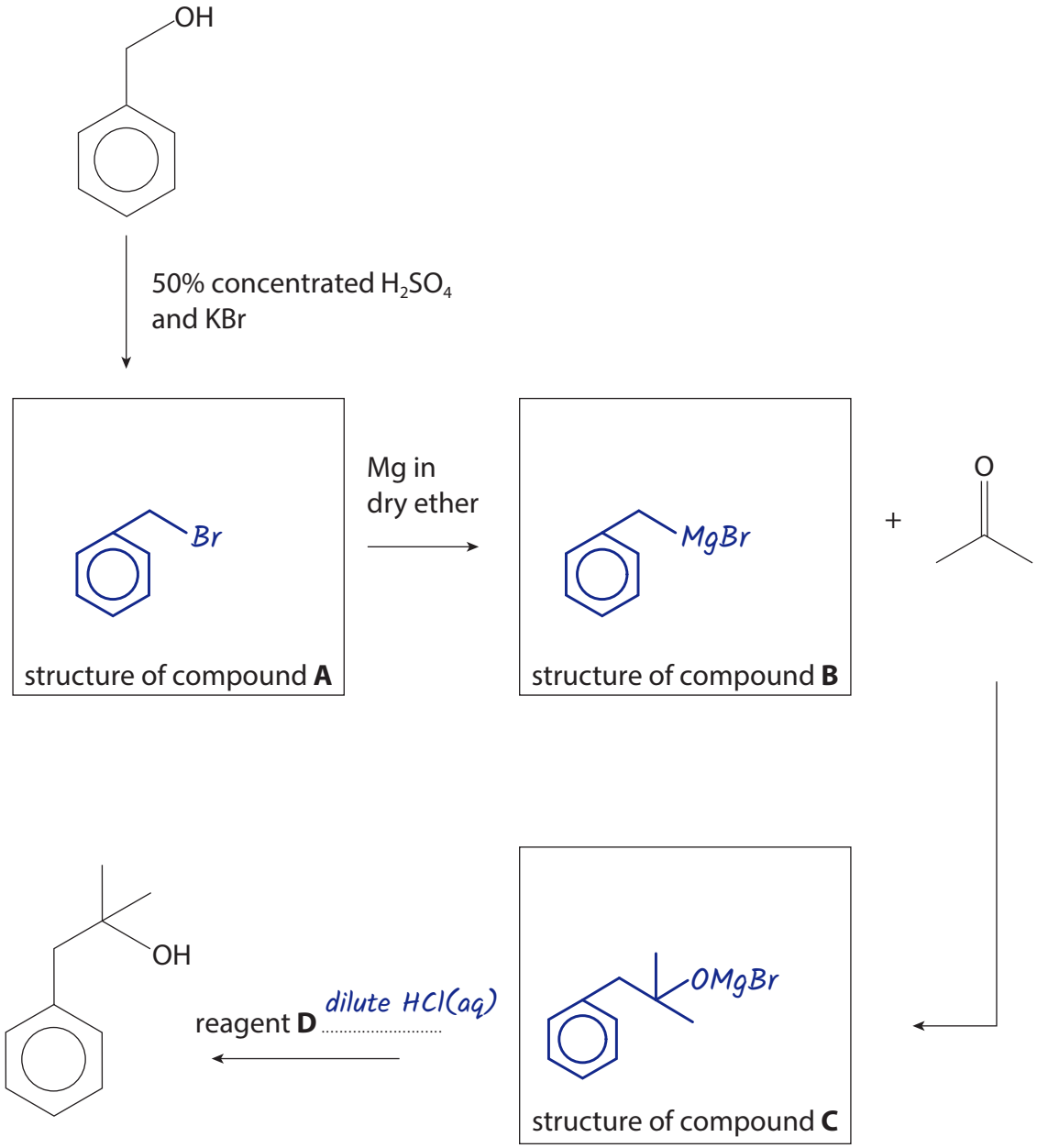
6 The compound 2-methyl-1-phenylpropan-2-ol is found in small amounts in cocoa beans and has the structure shown.



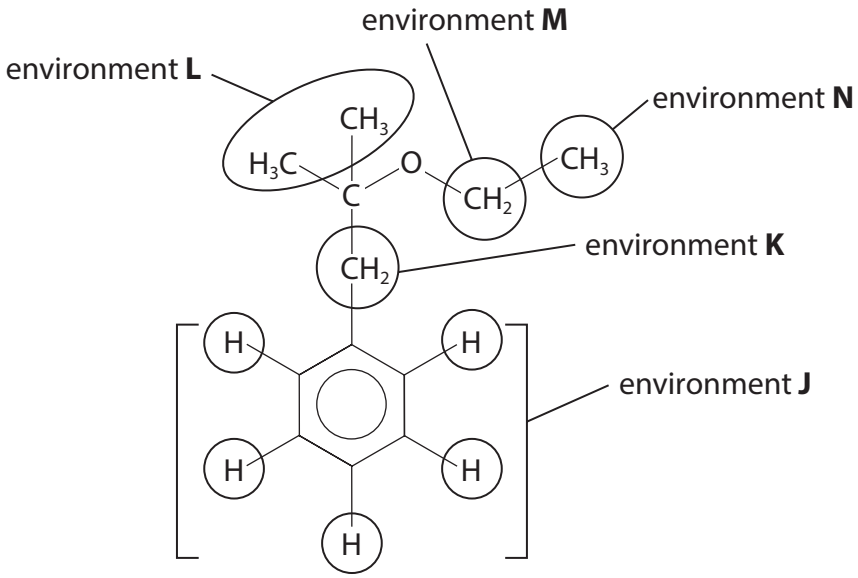
(a) A proposed synthesis of 2-methyl-1-phenylpropan-2-ol from phenylmethanol and propanone is shown.

Complete the diagram to show the structures of compounds **A**, **B** and **C** and the formula of reagent **D**.

(4)



(b) 2-Methyl-1-phenylpropan-2-ol can be converted to compound **S**.
When considering the ^{1}H NMR spectrum of **S**, the hydrogen atoms of the benzene have been assumed to be a single environment, labelled **J**.
The other hydrogen environments have been labelled **K**, **L**, **M** and **N**.



compound **S**

Complete the table for each of the environments **K** to **N** in the high resolution ^{1}H NMR spectrum of **S**.

(5)

	Chemical shift / ppm	Relative peak area	Splitting pattern
Environment **J**	1.6 to 3.8 (e.g. 2.2 or 7.7)	5	complex
Environment **K**	0.2 to 2.0 (e.g. 1.2)	6	singlet
Environment **L**	2.8 to 4.4 (e.g. 3.4)	2	quartet
Environment **M**	0.2 to 2.0 (e.g. 1.1)	3	triplet
Environment **N**			

(Total for Question 6 = 9 marks)

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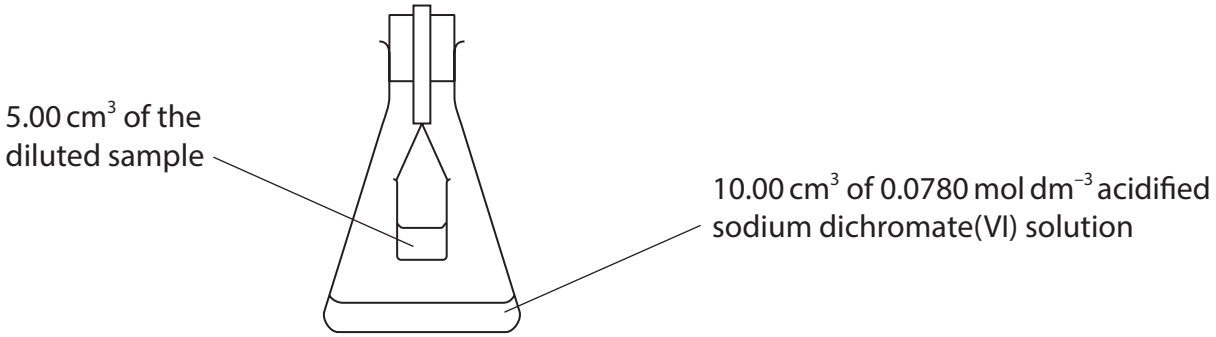
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7 A laboratory technician analysed a sample of an alcoholic drink to determine the concentration of ethanol, in g dm^{-3}.

20.00 cm^3 of the alcoholic drink was added to a 250 cm^3 volumetric flask and made up to the mark with deionised water.

The ethanol in 5.00 cm^3 of the diluted sample was oxidised in the equipment shown.

The sample was suspended in an open beaker in a sealed conical flask over 10.00 cm^3 of acidified sodium dichromate(VI), of concentration 0.0780 mol dm^{-3}.



The apparatus was left in a warm place for 24 hours for the acidified sodium dichromate(VI) to oxidise the ethanol.

Excess potassium iodide solution was then added to the **remaining** acidified sodium dichromate(VI) in the conical flask, forming iodine.

All of this iodine was then titrated using 0.0220 mol dm^{-3} sodium thiosulfate solution, $Na_2S_2O_3(aq)$.

The volume of $Na_2S_2O_3(aq)$ required in the titration was 32.70 cm^3.

The equations for the reactions that take place during the experiment are shown.

$$3CH_3CH_2OH(l) + 2Cr_2O_7^{2-}(aq) + 16H^+(aq) \rightarrow 3CH_3COOH(aq) + 4Cr^{3+}(aq) + 11H_2O(l)$$

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \rightarrow 2Cr^{3+}(aq) + 3I_2(aq) + 7H_2O(l)$$

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

(a) Explain why the apparatus was left in a **warm** room and for **24 hours**.

(2)

The warmth allows all of the ethanol to evaporate from the open beaker so that it reaches the acidified dichromate(VI).

24 hours allows time for all of the ethanol to react fully (be fully oxidised) to ethanoic acid.

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(b) (i) Calculate the number of moles of ethanol in 5 cm^3 of the **diluted** drink.

(5)

$n(S_2O_3^{2-}) = (32.70 \div 1000) \times 0.0220 = 7.194 \times 10^{-4}$ mol

$n(I_2) = 7.194 \times 10^{-4} \div 2 = 3.597 \times 10^{-4}$ mol

$n(Cr_2O_7^{2-})$ left over $= 3.597 \times 10^{-4} \div 3 = 1.199 \times 10^{-4}$ mol

$n(Cr_2O_7^{2-})$ at start $= (10.00 \div 1000) \times 0.0780 = 7.80 \times 10^{-4}$ mol

$n(Cr_2O_7^{2-})$ that reacted with ethanol

$= 7.80 \times 10^{-4} - 1.199 \times 10^{-4} = 6.601 \times 10^{-4}$ mol

n(ethanol) $= 6.601 \times 10^{-4} \times (3 \div 2)$

$= 9.90 \times 10^{-4}$ mol

(ii) Calculate the concentration of ethanol in the alcoholic drink in **g dm^{-3}**.

(3)

n(ethanol) in 250 $cm^3 = 9.9015 \times 10^{-4} \times (250 \div 5.00) = 0.049508$ mol

[ethanol] in drink $= 0.049508 \div (20.00 \div 1000) = 2.4754$ mol dm^{-3}

$M_r(C_2H_5OH) = 46.0$

concentration $= 2.4754 \times 46.0 = 114$ g dm^{-3}

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(c) It was suggested that the **titration** as described might lead to an unreliable result.

State **two** ways the procedure could be amended to counter this suggestion.

(2)

Repeat the whole experiment (or set up more than one flask and run them at the same time) and calculate a mean.

Take more than one smaller sample of the remaining dichromate(VI) solution, so that more than one titration can be carried out and concordant titres obtained.

(d) Another technician suggested that it was unnecessary to suspend the drink sample above the acidified sodium dichromate(VI) solution and proposed a change to the procedure.

The proposal was that the drink sample should be mixed with the acidified sodium dichromate(VI) solution and then heated under reflux to allow the ethanol to be oxidised.

Give **one** reason to support this change and **one** reason to leave the method unchanged. In each case justify your answer.

(2)

Reason to support this change

Heating under reflux speeds up the reaction, so there is less chance of incomplete oxidation of the ethanol.

Reason to leave the method unchanged

Other (less volatile) substances in the drink could also be oxidised by the dichromate(VI), giving a result that is too high.

(Total for Question 7 = 14 marks)

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8 This question is about weak acids.

(a) An aqueous solution of a weak acid, HA(aq), with a concentration of 0.0712 mol dm^{-3}, has a pH = 3.25 at room temperature.

Calculate the value of K_a for the weak acid HA(aq).

(2)

$[H^+] = 10^{-3.25} = 5.623 \times 10^{-4}$ mol dm^{-3}

$K_a = [H^+]^2 \div [HA] = (5.623 \times 10^{-4})^2 \div 0.0712$

$K_a = 4.44 \times 10^{-6}$ mol dm^{-3}

(b) The value of K_a may be determined from experimental data, using a titration curve.

Ethanoic acid, $CH_3COOH(aq)$, with a concentration of 0.0500 mol dm^{-3}, has a pH of 3.03 at room temperature.

A 20.0 cm^3 sample of the acid was titrated with sodium hydroxide solution, NaOH(aq), with a concentration of 0.0500 mol dm^{-3}.
During the experiment, 40.0 cm^3 of sodium hydroxide solution was slowly added to the ethanoic acid.

A pH probe connected to a data logger was used to monitor the pH throughout the experiment.

(i) Calculate the pH of the sodium hydroxide solution.
Give your answer to one decimal place.

[$K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6}]

(1)

$[H^+] = K_w \div [OH^-] = 1.00 \times 10^{-14} \div 0.0500$

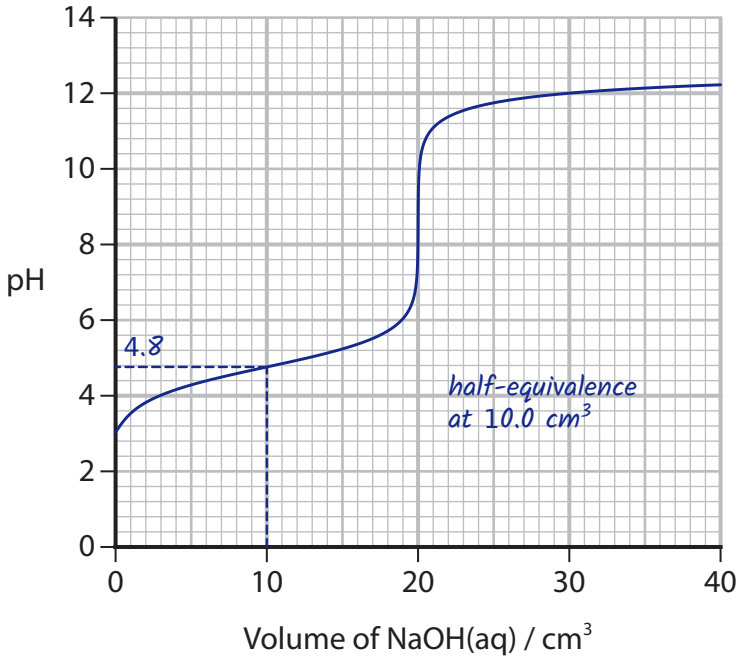
$= 2.00 \times 10^{-13}$ mol dm^{-3}

$pH = -\log(2.00 \times 10^{-13}) = 12.7$

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(ii) Draw a titration curve, on the axes shown, to show the change in pH throughout the experiment.

(3)



(iii) Give an estimate of the pH value at the half-equivalence point. Show your working on the titration curve.

(1)

pH = 4.8 (at 10.0 cm^3, half of the 20.0 cm^3 end-point volume)

(iv) Calculate a value for K_a of ethanoic acid using your answer to (b)(iii). You **must** show your working.

(3)

$K_a = [CH_3COO^-][H^+] \div [CH_3COOH]$

At half-equivalence $[CH_3COOH] = [CH_3COO^-]$,

so $K_a = [H^+]$ $(pK_a = pH)$

$K_a = 10^{-4.8} = 1.58 \times 10^{-5}$ mol dm^{-3}

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(c) Another method used to monitor the titration is to use a pH meter without a data logger. The pH is measured and recorded after the addition of each 1.00 cm^3 portion of NaOH(aq).

A student assessed the two methods and concluded that using the data logger was a more effective way to carry out the experiment.

Give **three** reasons that support this conclusion.

(3)

The data logger records readings far more frequently (continuously), so there are many more data points and the vertical section and end-point are found more precisely.

Data collection is automatic, so there is less chance of human error (e.g. misreading or recording the meter).

Data collection is faster, the graph can be seen in real time and the data can be stored and transferred to a spreadsheet.

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(d) A solution containing propanoic acid and sodium propanoate forms a buffer.

(i) 2.30 g of sodium propanoate is dissolved in propanoic acid solution.
This forms a buffer with pH = 4.2 and a volume of exactly 100 cm^3.

Calculate the concentration of the propanoic acid, in mol dm^{-3}, in this buffer.

[K_a (propanoic acid) = 1.34×10^{-5} mol dm^{-3} $M_r(CH_3CH_2CO_2Na)$ = 96.0]

(4)

$[H^+] = 10^{-4.2} = 6.310 \times 10^{-5}$ mol dm^{-3}

$n(CH_3CH_2CO_2Na) = 2.30 \div 96.0 = 0.023958$ mol

$[CH_3CH_2CO_2^-] = 0.023958 \div 0.100 = 0.23958$ mol dm^{-3}

$K_a = [H^+][CH_3CH_2CO_2^-] \div [CH_3CH_2COOH]$

$[CH_3CH_2COOH] = [H^+][CH_3CH_2CO_2^-] \div K_a$

$= (6.310 \times 10^{-5} \times 0.23958) \div 1.34 \times 10^{-5}$

$= 1.13$ mol dm^{-3}

(ii) Explain why there is no significant change in pH when a small amount of hydrochloric acid, HCl(aq), is added to this buffer.

(3)

The buffer contains a large reservoir (high concentration) of propanoate ions, from sodium propanoate, and of propanoic acid.

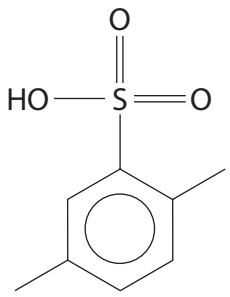
The added H^+ ions react with propanoate ions: $CH_3CH_2CO_2^- + H^+ \rightarrow CH_3CH_2COOH$, so the equilibrium moves to the left.

The changes in [acid] and [salt] are negligible, so the ratio [acid] : [salt] stays nearly constant, and so the pH hardly changes.

(Total for Question 8 = 20 marks)

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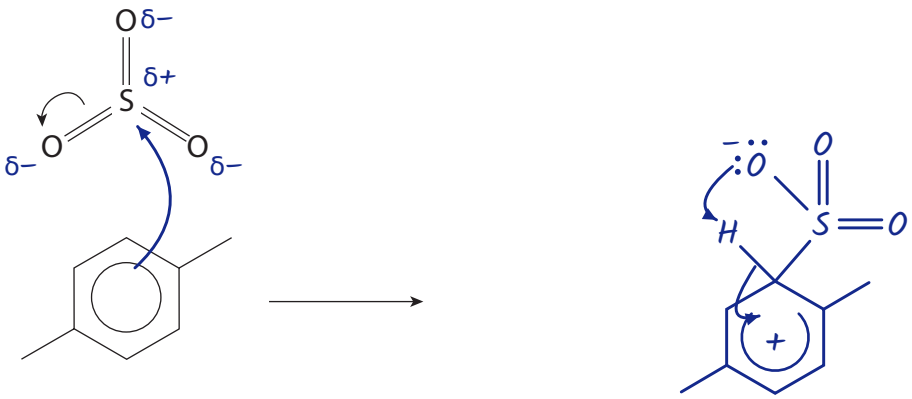
9 This question is about the compound 2,5-dimethylbenzenesulfonic acid, which has the structure shown.



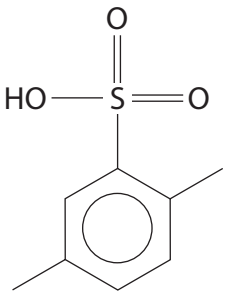
It is used to analyse levels of cholesterol in blood plasma. It can be synthesised by the reaction of 1,4-dimethylbenzene with concentrated sulfuric acid.
The electrophile in this reaction is sulfur trioxide.

(a) Complete a possible mechanism for this reaction by adding curly arrows, and any relevant dipoles, charges and lone pairs.

(3)



structure of intermediate



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(b) The 2,5-dimethylbenzenesulfonic acid formed can be purified by recrystallisation using hot water as a solvent.

Procedure

Step **1** Dissolve impure 2,5-dimethylbenzenesulfonic acid in the minimum volume of hot water.

Step **2** Allow the solution to cool until 2,5-dimethylbenzenesulfonic acid has crystallised.

Step **3** Separate the 2,5-dimethylbenzenesulfonic acid by filtering under reduced pressure.

Step **4** Rinse the 2,5-dimethylbenzenesulfonic acid using a small amount of ice-cold water.

Step **5** Dry the 2,5-dimethylbenzenesulfonic acid between two pieces of filter paper.

(i) Explain how recrystallisation reduces the amount of **soluble** impurities.

(3)

Both the 2,5-dimethylbenzenesulfonic acid and the soluble impurities dissolve in the minimum volume of hot water.

On cooling, the acid is much less soluble in cold water so it crystallises, but the impurities (present in small amounts) stay soluble in the cold solvent,

so the impurities remain in solution (in the filtrate) and the pure crystals remain on the filter paper.

(ii) A student carrying out this procedure noticed some **insoluble** impurities in their sample.

Describe how the procedure should be amended to remove these insoluble impurities.

(2)

After Step 1 (before Step 2), filter the hot solution using a pre-heated (hot) filter funnel and filter paper,

so the insoluble impurities stay on the filter paper while the product stays dissolved and does not crystallise in the funnel.

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(c) The hydrated form of the acid has the formula $C_6H_3(CH_3)_2SO_3H \cdot nH_2O$.
An experiment was carried out to determine the number of moles of water of crystallisation, n, in this formula.

The method involves adding excess sodium hydroxide to a known mass of the hydrated 2,5-dimethylbenzenesulfonic acid.
The amount of unreacted sodium hydroxide is then determined by titration.

Procedure

Step **1** 10.0 cm^3 of 1.00 mol dm^{-3} NaOH(aq) was added to 1.60 g of hydrated 2,5-dimethylbenzenesulfonic acid in a small conical flask.

Step **2** The solution formed was diluted to give a volume of exactly 100 cm^3.

Step **3** 20.0 cm^3 samples of the diluted solution required a mean titre of 22.40 cm^3 of 0.02500 mol dm^{-3} HCl(aq) to neutralise the unreacted sodium hydroxide present in the sample.

(i) Describe how to make the diluted solution, in Step **2**.

(4)

Transfer the solution from the small conical flask into a 100 cm^3 volumetric flask using a funnel.

Rinse the conical flask (and funnel) several times with deionised water and add all the washings to the volumetric flask.

Add more deionised water until the bottom of the meniscus is on the line (mark), adding the last drops with a dropping pipette.

Stopper the flask and invert it several times to mix, so that the solution is homogeneous.

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(ii) Calculate the relative formula mass of hydrated 2,5-dimethylbenzenesulfonic acid and hence deduce the value of n.

(5)

$n(HCl) = (22.40 \div 1000) \times 0.02500 = 5.60 \times 10^{-4}$ mol

$n(NaOH)$ left in 20.0 $cm^3 = 5.60 \times 10^{-4}$ mol

$n(NaOH)$ left in 100 $cm^3 = 5.60 \times 10^{-4} \times 5 = 2.80 \times 10^{-3}$ mol

$n(NaOH)$ added $= (10.0 \div 1000) \times 1.00 = 1.00 \times 10^{-2}$ mol

$n(acid) = 1.00 \times 10^{-2} - 2.80 \times 10^{-3} = 7.20 \times 10^{-3}$ mol

M_r of hydrated acid $= 1.60 \div 7.20 \times 10^{-3} = 222.2$

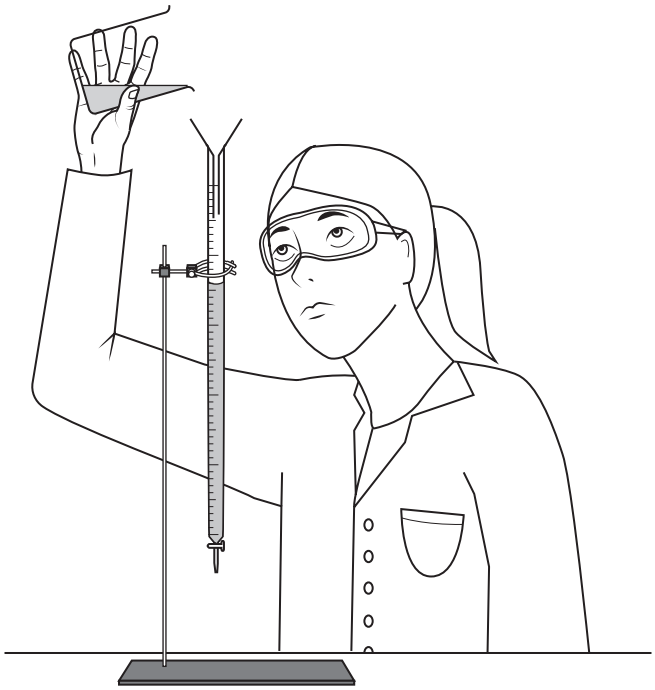
M_r of $C_6H_3(CH_3)_2SO_3H = 186.1$

mass of water $= 222.2 - 186.1 = 36.1$ and $36.1 \div 18.0 = 2.0$

so $n = 2$

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(d) A student carrying out this experiment used a funnel as shown to try to ensure the acid was added safely to the burette during the titration.



(i) Give **one** change to this technique that would reduce the risk to this student.

(1)

Lower the burette (e.g. stand it on the floor) so the acid is poured in below eye level.

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(ii) The student forgot to remove the funnel from the burette and during the titration five drops of acid from the funnel dripped into the burette.

Explain what effect, if any, this error will have on the final value for n.

(3)

The extra acid entering the burette makes the final burette reading lower, so the recorded titre is smaller than the volume of acid actually added.

So the calculated moles of unreacted (excess) NaOH are smaller, and the calculated moles of 2,5-dimethylbenzenesulfonic acid that reacted are greater,

so the calculated M_r of the hydrated acid is smaller, and so the calculated value of n is smaller.

(Total for Question 9 = 21 marks)

TOTAL FOR PAPER = 120 MARKS

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The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8)
																	(18)
							1.0 H hydrogen 1										4.0 He helium 2
(1)	(2)						(8)					(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4											10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)		(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	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	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

Elements with atomic numbers 112-116 have been reported but not fully authenticated

140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

* Lanthanide series

* Actinide series

P 7 7 8 3 4 A 0 3 6 3 6

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