BENCHMARK

VCE Chemistry Assessments

Student name _____

Chemistry

Question and Answer Book

Benchmark Open SAC 4.2: Identifying an unknown compound

- Writing time is **55 minutes**

Approved materials
- One scientific calculator

Materials supplied
- Question and Answer Book of 12 pages
- Data Book

Instructions
- Answer all questions in the spaces provided.
- Write using blue or black pen.

Students are **not** permitted to bring mobile phones or other electronic devices into the room.

Contents pages

Questions (3 questions, 40 marks) _____ 2–11

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Questions

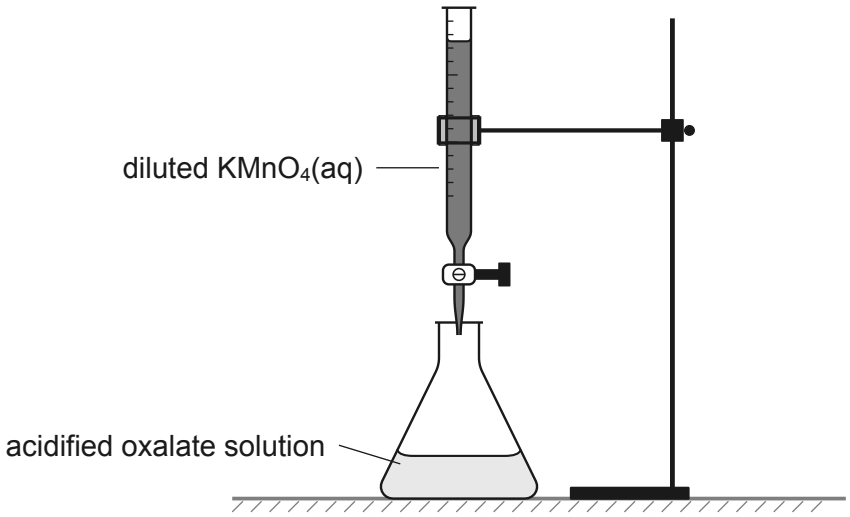
Instructions

- Answer **all** questions in the spaces provided.
- Write your responses in English.
- Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.
- Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.
- Ensure that chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g)$, NaCl(s).
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Question 1 (15 marks)

A researcher in a flavour laboratory plans to oxidise an unknown organic compound with acidified potassium permanganate. Solid potassium permanganate is not a primary standard, and the concentration of a stored permanganate solution slowly decreases. Before she uses her stock solution, the researcher therefore determines the concentration of permanganate ions in it by titration against sodium oxalate, which is a primary standard.

She dilutes 10.00 mL of the stock solution to 100.0 mL with water. She also dissolves 2.104 g of sodium oxalate, $Na_2C_2O_4$, in water and makes this solution up to 250.0 mL. Each 20.00 mL aliquot of the oxalate solution is acidified, warmed and titrated with the diluted permanganate solution, as shown.



The equation for the reaction is:

$$2MnO_4^-(aq) + 5C_2O_4^{2-}(aq) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 10CO_2(g) + 8H_2O(l)$$

The researcher records the burette readings for four trials, as shown in the table below.

	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
Initial reading (mL)	0.50	1.20	0.85	2.10
Final reading (mL)	21.15	21.55	21.24	22.46

a. Using the results in the table, calculate the mean concordant titre, in mL. 2 marks

b. Calculate the amount, in mol, of oxalate ions in each 20.00 mL aliquot. 2 marks

c. Calculate the concentration, in mol L^{-1}, of permanganate ions in the stock solution. 3 marks

The researcher has a bottle of a colourless liquid, Compound Y, which has the molecular formula $C_5H_{12}O$. Many different compounds have this molecular formula, so the label alone does not tell her which one is in the bottle.

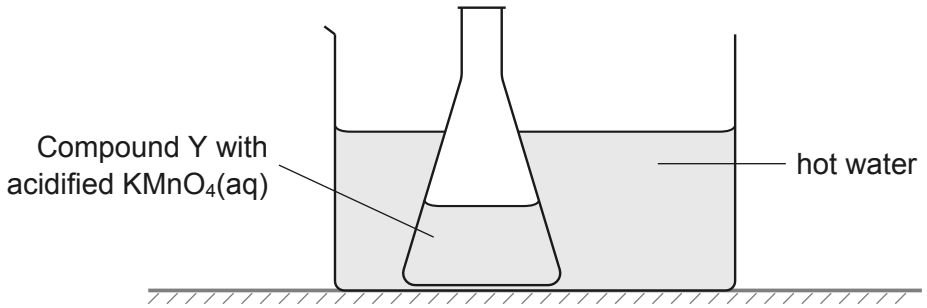
First, to find out which functional groups are present in Compound Y, she carries out three tests. Each test uses a separate sample of the liquid, and her observations are recorded in the table below.

Test	Reagent added	Observation
1	sodium carbonate solution	no bubbles form
2	bromine water	the orange colour remains
3	acidified potassium permanganate solution, then warmed	the purple colour fades to colourless

d. Explain how the molecular formula of Compound Y shows that the results of Tests 1 and 2 could have been predicted without doing them. 2 marks

e. State what the result of Test 3 indicates about Compound Y. 1 mark

The researcher then adds 1.85 g of Compound Y to 30.00 mL of the stock permanganate solution, together with an excess of acid. She heats the mixture in a beaker of hot water, as shown in the diagram below, until no further change is seen, and Compound X forms.



The equation for the reaction is:

$$5C_5H_{12}O(l) + 2MnO_4^-(aq) + 6H^+(aq) \rightarrow 5C_5H_{10}O(l) + 2Mn^{2+}(aq) + 8H_2O(l)$$

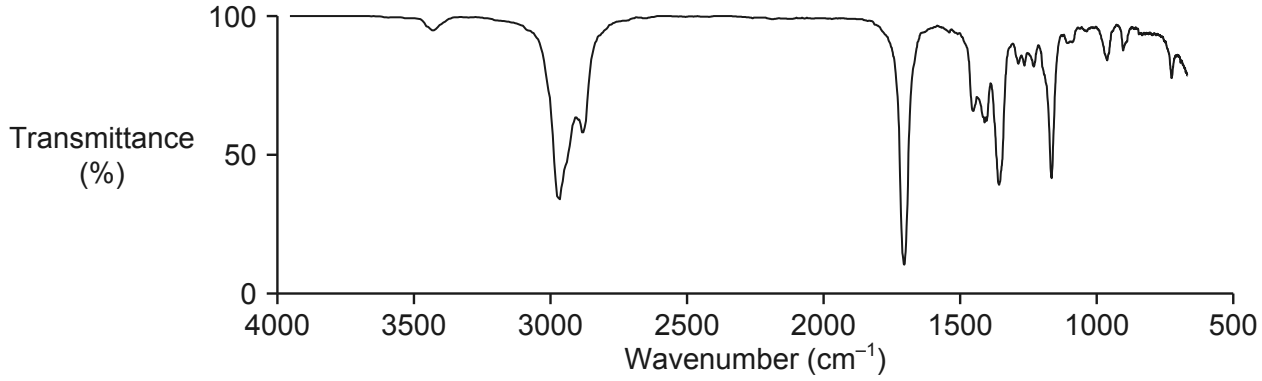
f. Using your answer to part **c.**, show by calculation that the permanganate ions are the limiting reactant. 3 marks

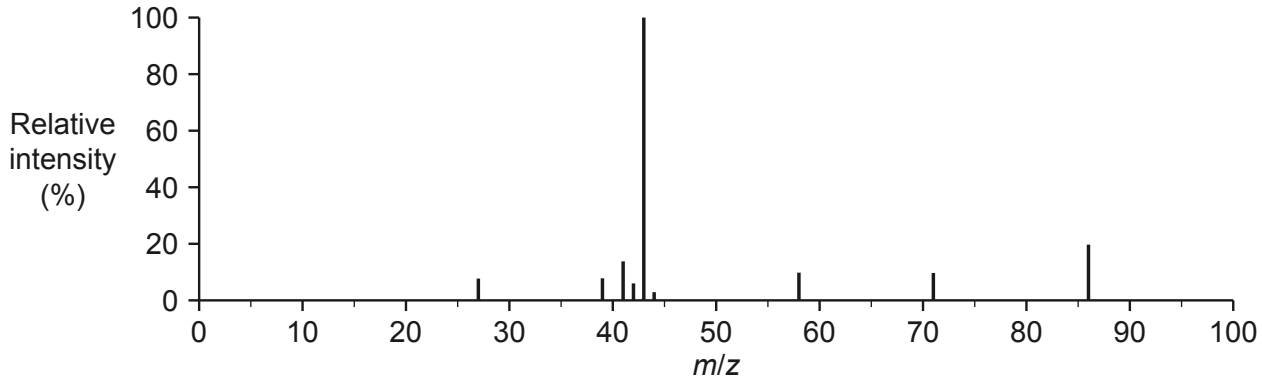
g. Calculate the maximum mass, in g, of Compound X that can form. 2 marks

Question 2 (15 marks)

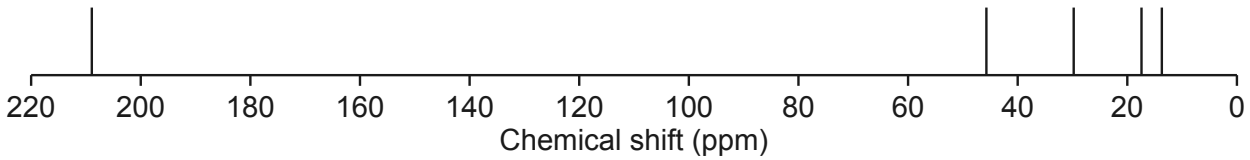
The researcher separates Compound X from the reaction mixture and purifies a sample of it. To identify Compound X, she records four spectra of the purified sample, because each kind of spectrum gives different information about the structure of a compound.

The infrared spectrum, mass spectrum, ^{13}C NMR spectrum and ^{1}H NMR spectrum of Compound X are shown below.

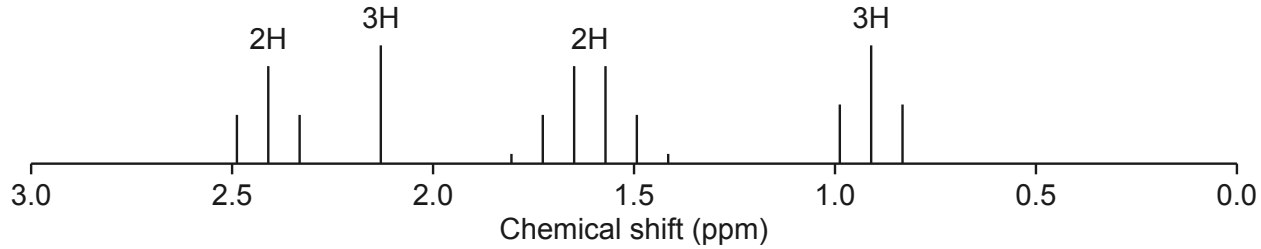




^{13}C NMR spectrum



^{1}H NMR spectrum



a. Refer to the infrared spectrum of Compound X shown at the start of this question.

i. Identify the bond responsible for the strong absorption near 1700 cm^{-1}. 1 mark

ii. Explain how the infrared spectrum indicates that the purification has removed Compound Y from this sample. 2 marks

b. Refer to the mass spectrum of Compound X.

i. State the *m/z* value of the molecular ion peak in the mass spectrum. 1 mark

ii. Write the formula of the ion responsible for the peak at *m/z* = 71. Include its charge. 1 mark

c. Identify the type of carbon atom responsible for the signal at 209 ppm in the ^{13}C NMR spectrum. 1 mark

d. Refer to the ^{1}H NMR spectrum, in which the label above each signal gives the relative number of hydrogen atoms.

i. Explain the splitting pattern of the signal at 2.4 ppm in terms of the structure of Compound X. 2 marks

ii. Deduce the group responsible for the signal at 2.1 ppm. Justify your answer. 2 marks

e. Draw the structural formula of Compound X. Show all atoms and bonds. 2 marks

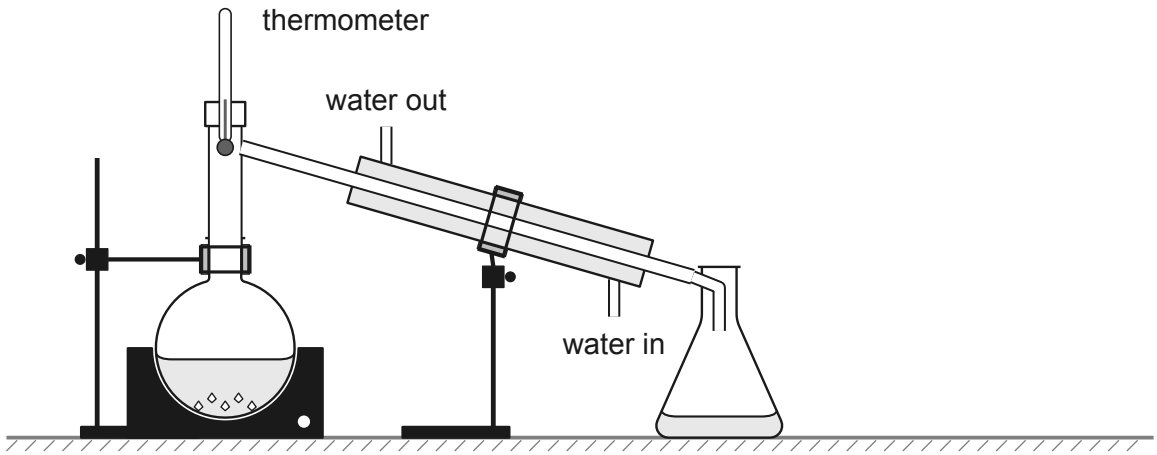
f. Give the IUPAC name of Compound X. 1 mark

g. Pentanal has the same molecular formula as Compound X and also has five carbon environments. Explain how the ^{1}H NMR spectrum shows that Compound X is not pentanal. 2 marks

Question 3 (10 marks)

The researcher now repeats the reaction on a larger scale, so that she has enough of Compound X to use in further work. Before it can be used, she needs to know how pure the product is.

She extracts Compound X and the unreacted Compound Y from the reaction mixture with a solvent. She then removes the solvent and distils the remaining liquid using simple distillation, as shown in the diagram below.

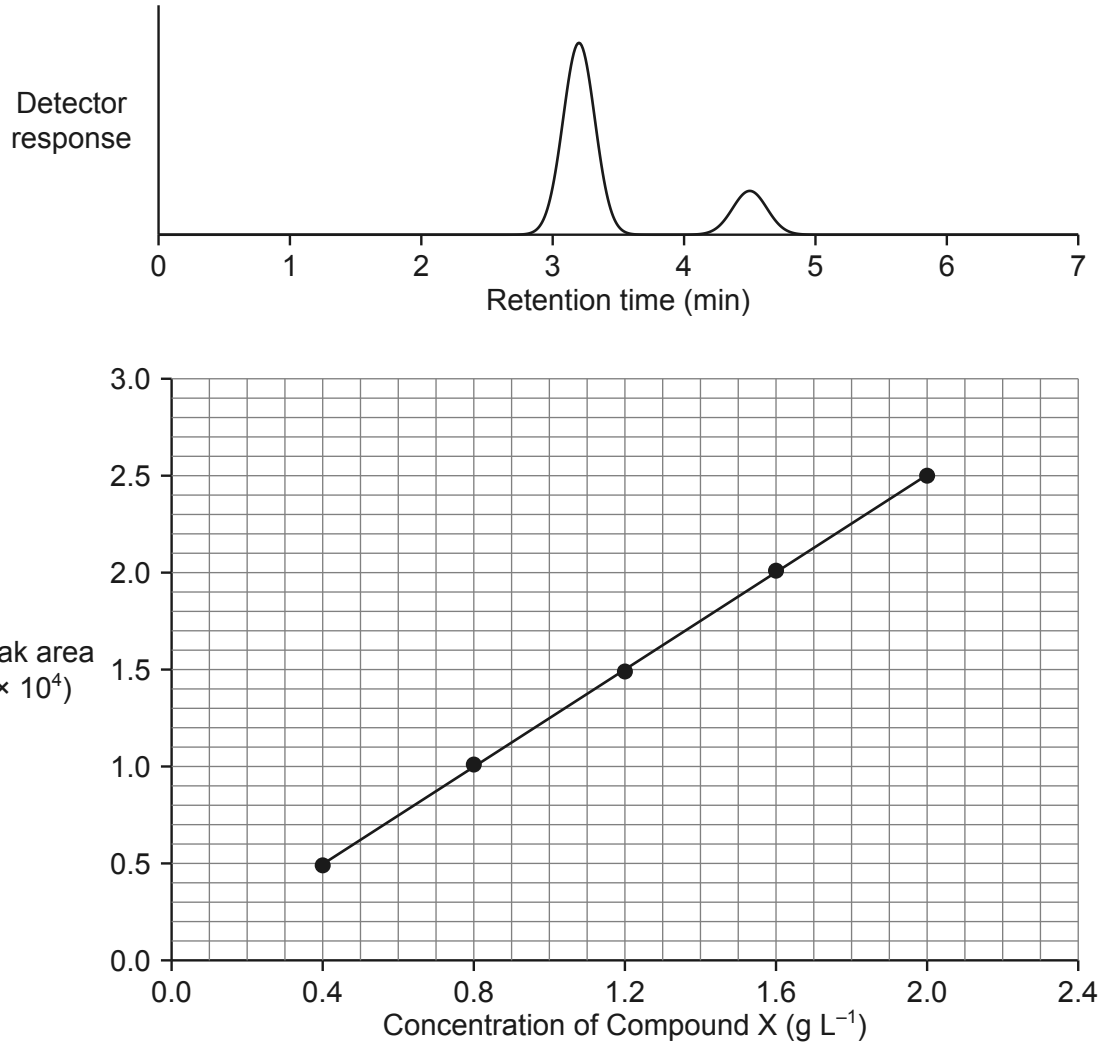


At normal atmospheric pressure, Compound X boils at 102 °C and Compound Y boils at 119 °C.

a. The distillate collected is mostly Compound X. Explain why the distillate still contains some Compound Y. 2 marks

The researcher dissolves 0.1527 g of the distillate in a solvent and makes the solution up to 100.0 mL. She analyses this solution by HPLC under the same conditions as standard solutions of Compound X.

Five standard solutions of Compound X, each of known concentration, were analysed first to construct a calibration curve. The column has a polar stationary phase. Under these conditions, Compound X has a retention time of 3.2 min and Compound Y has a retention time of 4.5 min. The peak area for Compound X in the sample is 1.64×10^4. The chromatogram of the sample and the calibration curve for Compound X are shown.



b. Refer to the chromatogram and the calibration curve.

i. State the evidence in the chromatogram that indicates the distillate still contains some Compound Y. 1 mark

ii. Use the calibration curve to determine the concentration, in g L^{-1}, of Compound X in the sample solution. 1 mark

iii. Calculate the percentage by mass of Compound X in the distillate. 2 marks

c. A colleague claims: “A sample is pure Compound X if its chromatogram shows only one peak, at the retention time of Compound X.” Evaluate this claim. In your answer, refer to the principles of chromatography and to the information provided by other analytical techniques. 4 marks

End of questions

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