Victorian Certificate of Education

CHEMISTRY 2026 Unit 4

SAC 4 AOS 2 Outcome 2

Analysis and evaluation of primary and secondary data, including identified assumptions or data limitations, and conclusions

Reading time: 5 minutes

Writing time: 60 minutes

Directions to students

Student's Name: _____

Teacher: _____

Structure of booklet

Section	Question to be answered	Total marks
Short answer	4	62
	Total	62

Materials

- Students are permitted to bring into the examination room: pencils, highlighters, erasers, sharpeners, **rulers**, and an approved scientific calculator.
- Students are NOT permitted to bring into the examination room:
white out liquid/tape, phones or electronic devices, including smart watches.
- Students are provided with the following: Question and answer book of 13 pages and VCAA Data booklet.

The task

- Please ensure that you write your name and teacher's name on this booklet. This paper consists of short answer questions.

- There are a total of 62 marks available.

- Be sure to include states with all chemical equations.

- All numerical answers need to be quoted to the correct number of significant figures.

- All working out must be shown in the space provided.

1. Vitamin C (ascorbic acid) is a vital nutrient commonly found in fruits, where it contributes to their antioxidant properties and nutritional value. Quantitative analysis of vitamin C content in fruits is often performed using titration methods due to their accuracy and simplicity. Alongside vitamin C, fruits also contain various organic compounds responsible for their characteristic aromas and flavors. One such compound iscompound A, a molecule known for its distinctive fruity scent reminiscent of bananas and pears. Understanding the concentration of vitamin C and identifying flavor compounds likecompound A provides insights into fruit quality, ripeness, and nutritional value.

Figure 1 – the fruits shown have aa unique fruity smell due to a molecule calledcompound A.

1. A 25.00 mL sample of fresh apple juice was added to a 200 mL volumetric flask and filled to the mark with distilled water. Four 20.00 mL aliquots were then taken and pipetted into four separate 100 mL conical flasks with 2 drops of appropriate starch indicator. Each flask was titrated against a 0.00552 M I_2 solution. The results are shown in table 1 below. (20 marks)

Burette reading	1	2	3	4
Start	1.00	13.25	25.40	2.50
Final	13.25	25.40	37.75	14.70
Titre	12.25	12.15	12.35	12.20

Table 1 – the four titres for each trial of the titration with I_2 solution.

The reaction between vitamin C and I_2 is shown below.

$$\mathbf{C_6H_8O_6\ (ascorbic\ acid) + I_2 \rightarrow C_6H_6O_6\ (dehydroascorbic\ acid) + 2\ I^- + 2\ H^+}$$

a. Find the average titre of the titration. 2 marks

Only concordant data used
1----mark for concordant results
1-----mark for correct answer
Average titre = (12.25 + 12.15 + 12.20) ÷ 3 = 12.20 mL

b. Find the mol of I_2 in the average titre. 2 marks

1-----mark correct formula Mol => (n = C X V)

1-----mark correct answer => n = 0.00552 M X 0.01220 L = 6.73 X 10^{-5}

c. Find the concentration of Vitamin C in the volumetric flask in mol/Litre 2 marks

1-----mark => recognising 1:1 ratio of vitamin C and I_2

1----mark for correct answer => 6.73 X 10^{-5} X 0.0200 = 0.00336 M or 3.35 X 10^{-3}M

Concentration of [vit C] in the conical flask = [vit C] in the volumetric flask

d. Find the concentration of Vitamin C in the sample of apple juice in mol/Litre. 2 marks

1-----mark for application of $C_1V_1=C_2V_2$ => $C_1 = C_2V_2 / V_1$

1----mark for correct answer => C_1 = (0.00336 X 0.200) / 0.0250 = 0.0270 M

e. Express the concentration in Vitamin C (176 g/mol), in % m/m, given the density of the apple juice is 1.18 g/mL 3 marks

1-----mark for finding the mass of 1.00 L of apple juice . => 1.18g X 1000mL = 1180g

1-----mark for finding the mass of vit C in 1L of apple juice => 0.027 × 176 = 4.75 g
1-----mark for correct %m/m to right number of sig figs => (4.75 / 1180) X 100 = 0.400%m/m

f. The titration results show slight variation between trials (Table 1).
Explain how each of the following may impact the titre delivered.
- The burette was rinsed with the standard I_2 solution. 2 marks)

1-----mark => no impact to the average titre.
1-----mark => the burette should be washed with the standard solution used in the titration.

- The pipette used to deliver the 25.00 mL aliquot was washed with water but not dried. 2 marks)

1-----mark => possible dilution of original sample delivered to the volumetric flask.
1-----mark => Average titre would be underestimated.

g. A typical commercially available apple juice contains approximately 0.05% m/m Vitamin C.
i. Compare the concentration of vitamin C given as the answer to question e above and justify the discrepancy. 2 marks
1-----mark The value calculated and given in question e is higher than the commercial concentration.
1-----mark => Any valid explanation:
- other antioxidants were present not just vit C that reacted with the I_2.
- Commercial juices may lose some vit C in their production such as, fresh apples were not used and stored for a length of time that my have degraded the vit C content.

ii. State one assumption made during this titration and describe how it impacts both the accuracy and validity of the experimental results. (3 marks)

1-----mark => Assumption that vit C is the only antioxidant present that will react with I_2

1-----mark => Impact on accuracy => decreased accuracy due to over estimation of the amount of Vit C present

1-----mark => impact on validity => decreased validity as we are not measuring what we set out to measure. The assumption is false and hence we measure all antioxidant present.

2. Analysis ofcompound A was undertaken and several spectra of the compound are shown below. (26 marks)

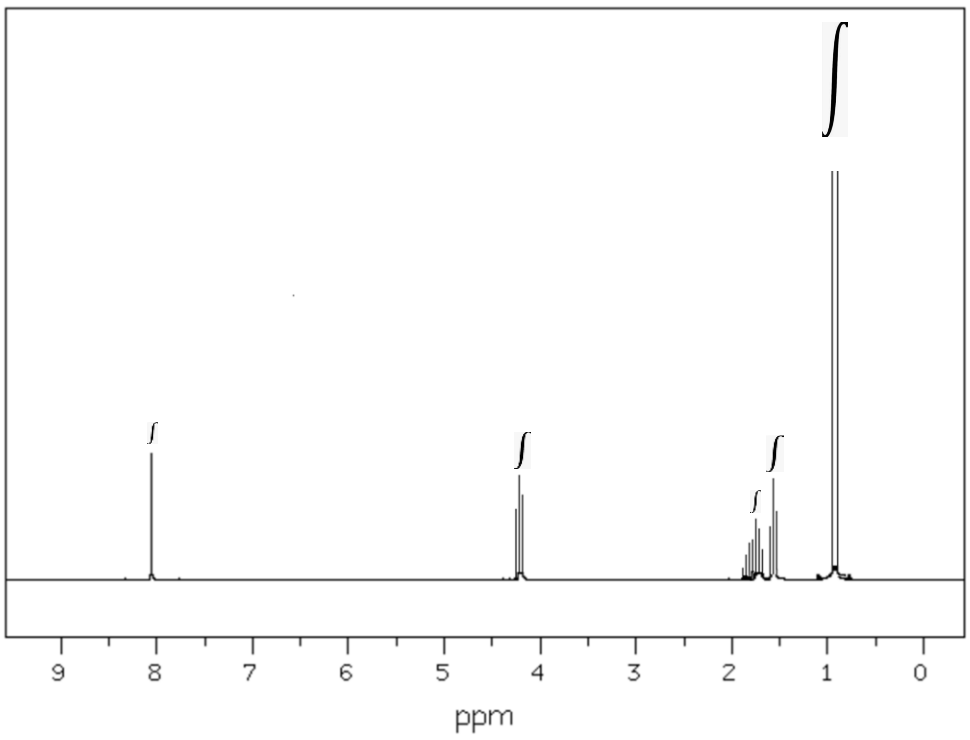


Figure 2 – ^{1}H-NMR ofcompound A ($C_6H_{12}O_2$) with integrations shown.

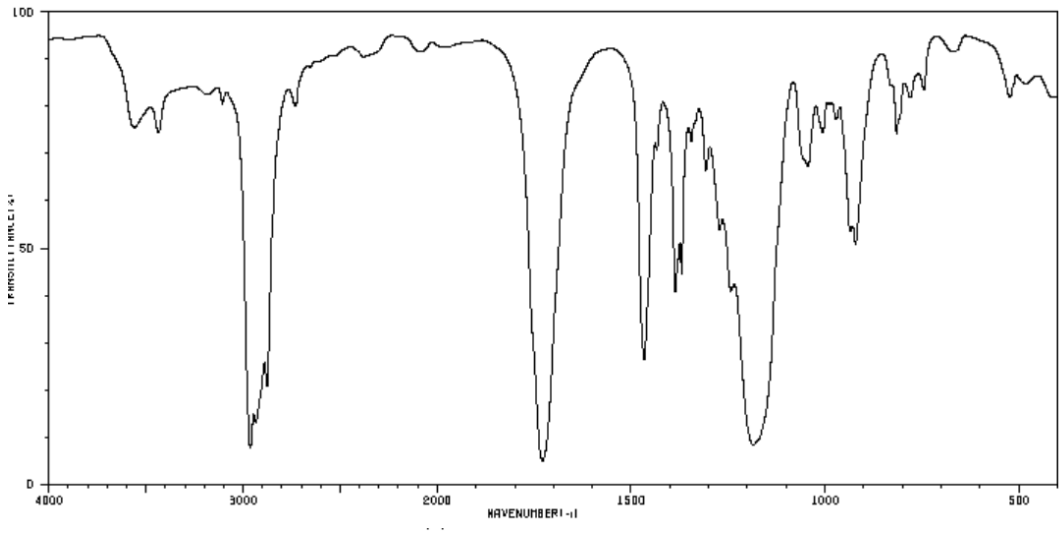


Figure 3 -IR spectrum ofcompound A ($C_6H_{12}O_2$)

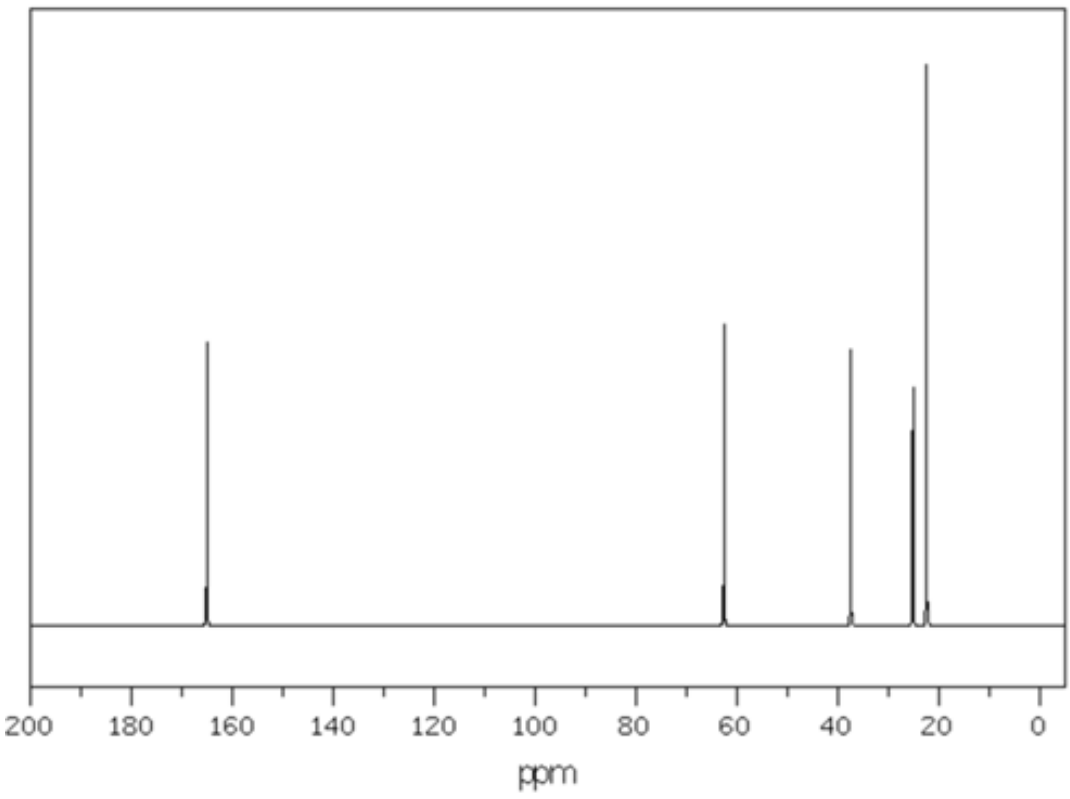


Figure 4 – ^{13}C-NMR of compound A ($C_6H_{12}O_2$)

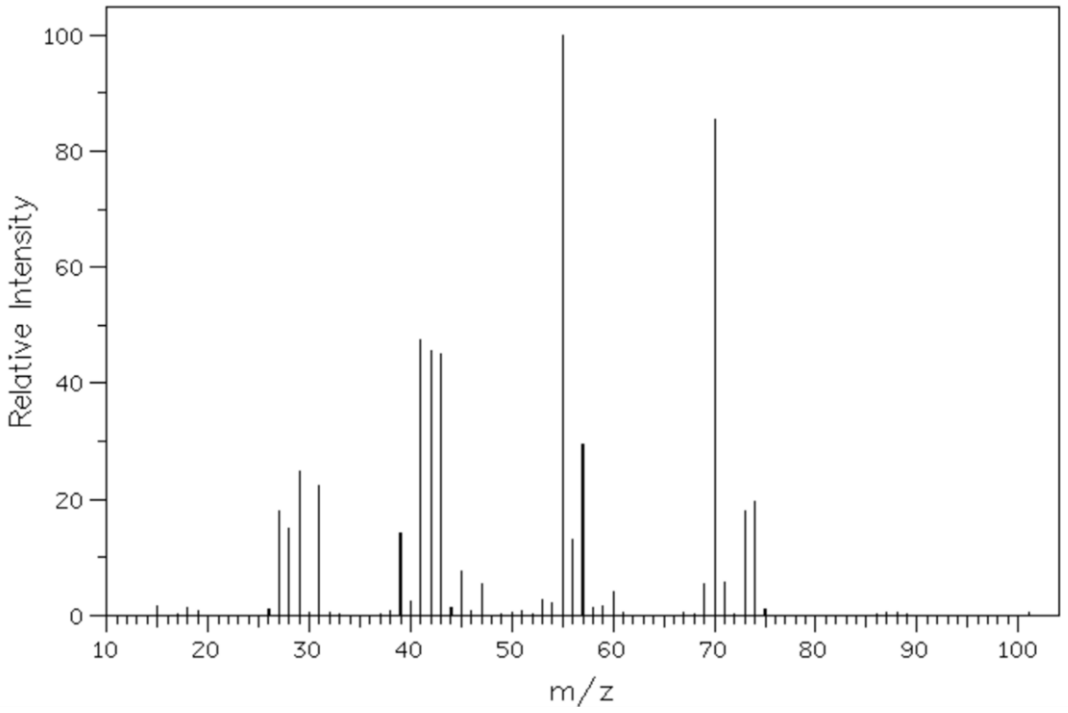


Figure 5 – Mass spectrum of compound A ($C_6H_{12}O_2$)

a. A student was unsure about which family of organic compoundscompound A belongs to. Upon analysing its IR spectrum, the student noticed a strong absorption at **1190 cm^{-1}**, indicative of a C–O bond.
Using **item 21** of the 2026 VCAA Data Booklet and the IR spectrum provided, complete the table below by:
   - Providing **two pieces of evidence** supporting the classification ofcompound A to the class of compounds you think it belongs to.
   - Providing **two pieces of evidence** that dismiss each of the other classes.
   Note: The "Acid" row is completed as an example. This shows that only one column needs to be filled per class (either support or dismiss), and in this example, the evidence dismissescompound A as an acid. (6 marks)

Class of compound	Evidence for choosing this class.	Evidence for dismissing this class
Alcohol		*- No strong absorption at 3200-3600 cm^{-} indicative of an alcohol O-H stretch* *- Any other reason to negate an alcohol eg presence of C=O stretch unlikely to indicate an alcohol.*
Ketone		*- No strong absorption between 1680-1700 cm^{-} indicating a ketone C=O* *- Strong absorption at 1190 cm^{-} indicative of a C-O stretch not present in ketones*
Acid		***- no broad absorption between 2500-3500 cm^{-} suggesting an acidic OH.*** ***- no absorption of an acidic C=O bond between 1680-1740.***
Ester	*- Strong absorption at 1190 cm^{-} indicative of a C-O stretch* *- Strong absorption at 1720 cm^{-} indicating an ester C=O*	

Marks awarded, for any unambiguous, valid reason for the above table.

b. Describe why different bonds in a molecule absorb infrared radiation at different wavenumbers (cm^{-1}). In your answer suggest what might cause variations in absorption frequencies.

1-----mark Different bonds absorb infrared radiation at specific wavenumbers due to their unique vibrational frequencies, which depend on the bond strength and the masses of the atoms involved.

1-----mark Stronger bonds and lighter atoms vibrate at higher frequencies, resulting in absorption at higher wavenumbers.

c. Explain why a molecule such as CO_2 can absorb infrared radiation, but Cl_2 cannot.

1-----mark CO_2 can absorb infrared radiation because it is a linear molecule with polar bonds and

1-----mark undergoes vibrational modes that result in a change in its dipole moment, which is necessary for IR absorption.

1-----mark In contrast, Cl_2 is a diatomic molecule made of two identical atoms with nonpolar bonds, so its vibrations do not produce a change in dipole moment, and hence it cannot absorb IR radiation.

d. Consider the ^{1}H-NMR and ^{13}C-NMR spectra of compound A ($C_6H_{12}O_2$), shown above.

i. Compound A contains six carbon atoms in its molecular structure. Based on the ^{13}C-NMR spectrum, how many chemically unique carbon environments are present in each molecule?

_____*5*_____ 1 mark

ii. Explain why the number of chemically unique carbons shown in the ^{13}C-NMR differs from the total number of carbon atoms in the molecule.

1-----mark Some carbon atoms are in identical chemical environments, due to some symmetry or branching.

1-----mark Making them chemically equivalent, so they produce the same signal in the ^{13}C-NMR spectrum. This reduces the number of distinct peaks compared to the total number of carbons.

iii. With reference to item 22 of the 2026 VCAA data booklet, suggest to what functional group the carbon that formed the peak at 165, of ^{13}C-NMR belongs to.

_____ *ester carbonyl group (C=O)*_____ 1 mark

iv. How many chemically unique hydrogen environments exist in the compound A?

_____*5*_____ 1 mark

v. Using the integration curves shown in Fig. 2, determine the simplest relative ratio of hydrogens in each environment. Show your working clearly. 2 marks

Each hydrogen environment has an integration length of each curve above each peak, the length of which is derived by measuring with a ruler of the following from left to right of the ^{1}H-NMR

1-----mark for correct measurement of integration curves

0.5 cm : 1 cm : 0.5 cm : 1 cm : 1.5 cm

1-----mark for simplest ratio

1:2:1:2:6

vi. What information can be extracted by analysing the peak at 0.98 ppm of the ^{1}H-NMR spectrum formed.

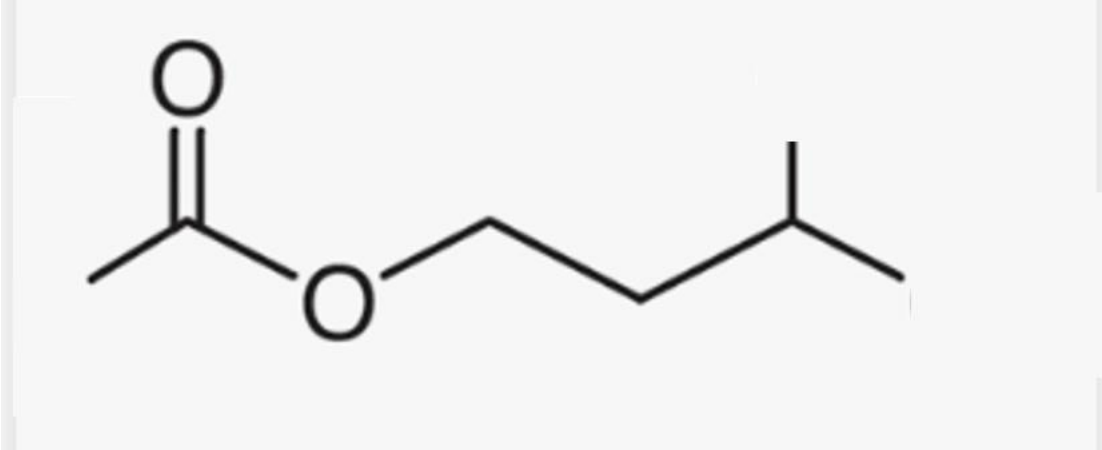
1-----mark => According to the 2026 VCAA data booklet it shows a CH_3 group.

1-----mark => Most likely judging by the integration curve it represents two CH_3 groups

1-----mark => Next to a neighbouring carbon with two different, chemically different hydrogens. Most likely a CH_2

vii. Draw the skeletal formula of compound A in the space provided below.

3 marks



1-----mark => correct ester functional group clearly shown

1-----mark => correct branching to show 5 different carbon chemical environments

1-----mark => correct overall correct skeletal structure.

e. The mass spectrum of compound A shows a peak at 57 m/z. With reference to the structure drawn in question d. vii above, give the fragment that produced this peak?

Consequential marks apply.

1-----mark => Any fragment related to the diagram given as the skeletal structure with a 55 m/z and positive charge clearly shown

3. A chromatogram of a mixture of unknown plant pigments, shown in fig 9, was developed using reversed phase HPLC. (8 marks)

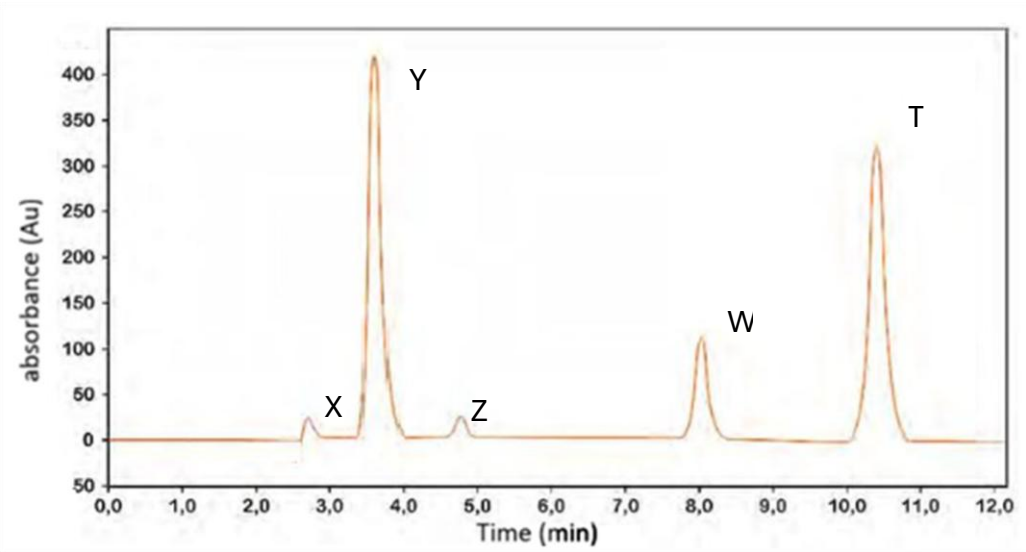


Figure 9 – A reversed phase HPLC chromatogram of a mixture of unknown plant pigments.

a. Explain how the chromatogram can be used to identify the presence of specific plant pigments in the mixture.

1-----mark => By running pure samples of each known component of the mixture and obtaining a retention time.

1-----mark => under identical conditions and using the same column as the unknown mixture will be subjected to.

1-----mark => The presence of known pigments is confirmed by matching retention times

b. Which compound is present in the highest concentration in the mixture? Justify your answer.

1-----mark => Compound Y

1-----mark => It has the greatest peak area.

c. Explain how the concentration of a component of the mixture can be accurately calculated?

1-----mark => Prepare a calibration curve by running known concentrations of the compound and measuring their peak areas under the exact conditions the unknown sample is subjected to.

1-----mark => a calibration curve is the established to accurately give a relationship between area under the peak vs concentration.

1-----mark => The peak area of the unknown sample is then compared to the calibration curve.

4. A sample of fruit juice was used to obtain pure samples of limolene, ethyl acetate and malic acid. Reversed phase HPLC uses a polar stationary phase with a non-polar mobile phase. The structure of each compound is shown below. (14 marks)

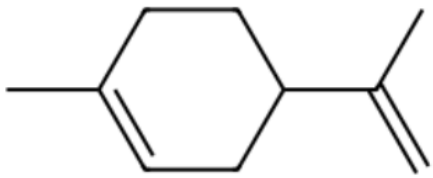


Figure 6 -Limolene

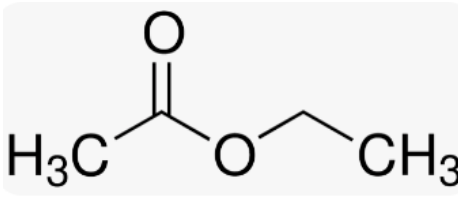


Figure 7 -Ethyl acetate

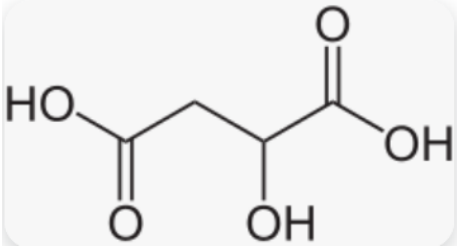


Figure 8 –Malic acid

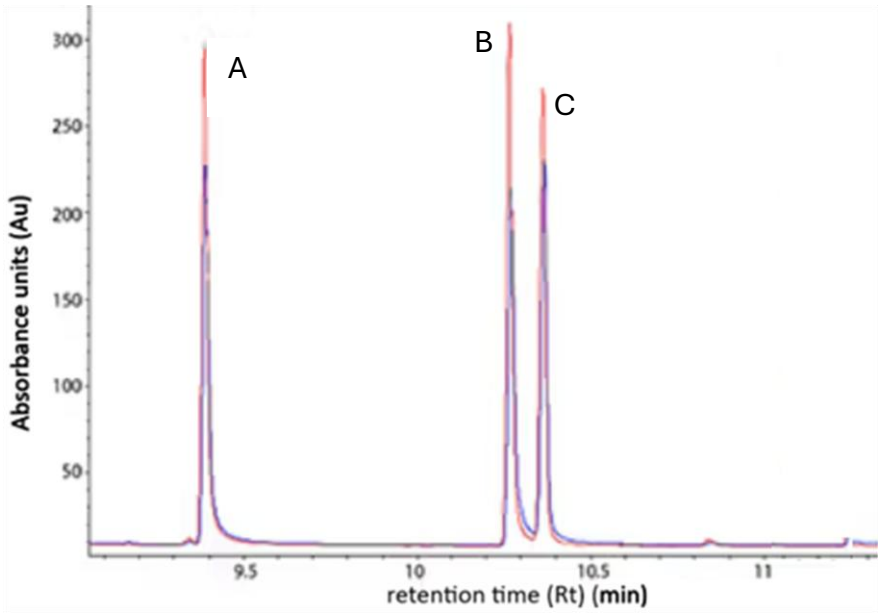


Figure 10 – Reversed phase HPLC chromatogram of a mixture of limolene, malic acid and ethyl acetate.

a. Identify the compound that produced each peak in the chromatogram in fig 10. Justify your answer.

*1-----mark => Peak A (shortest retention time) corresponds to **limonene**, the most nonpolar compound, which elutes first in reversed-phase HPLC.*

*1-----mark => Peak B corresponds to **ethyl acetate**, with moderate polarity and intermediate retention time.*

*1-----mark => Peak C (longest retention time) corresponds to **malic acid**, the most polar compound, retained longest on the polar stationary phase*

b. Peaks B and C in the chromatogram are very close to each other. Suggest two ways to increase the resolution between these peaks and explain how each method improves the separation.

Any valid change to the column that will result in a greater separation of the column by allowing either or both component to stay in the column longer. The suggestions below are not exhaustive.

Method 1

1-----mark => Change the mobile phase composition by increasing its polarity.
1-----mark => This will increase the interactions between the mobile phase and the polar molecules and increase separation between compounds with different polarities

Method 2

1-----mark => Lowering the temperature of the column
1-----mark => Lowering the temperature slows down the movement of compounds through the column, increasing interaction time with the stationary phase. This leads to better separation and therfore improved peak resolution.

c. A biochemical laboratory is investigating the enzyme-catalysed breakdown of malic acid and ascorbic acid in fruit extracts. Ethyl acetate is used as a solvent to extract potential enzyme inhibitors. The laboratory uses steam distillation to purify volatile compounds.

i. Describe the role of the **active site** in enzyme activity and explain how a competitive inhibitor could affect the enzyme's action on malic acid or ascorbic acid.

1-----mark => The active site of an enzyme is where the substrate binds and reacts. Such interaction occurs at a reduce activation energy.

*1-----mark => A competitive inhibitor can bind **temporarily** to the active site, preventing substrate binding, thus **reducing** not preventingthe breakdown of malic or ascorbic acid*

ii. Explain why ethyl acetate is a suitable solvent for extracting enzyme inhibitors, which may be polar or nonpolar, from fruit extracts. Refer to its chemical properties and the principle of solvent extraction.

1-----mark => Ethyl acetate is a moderately polar solvent that can dissolve both polar and nonpolar compounds to some extent.

1-----mark =>Ethyl acetate is immiscible with water, so it forms a separate layer during solvent extraction, making it easy to separate by decanting the inhibitors from the aqueous fruit extract.

iii. Volatile compounds in fruit often have high boiling points and subject to breakdown at these high temperatures. Explain why steam distillation is preferred over simple distillation for purifying these compounds during extraction. Include the advantages of steam distillation for heat-sensitive fruit-derived compounds.

1-----mark => Steam distillation allows these volatile compounds to boil at temperatures not exceeding 100°C by distilling with steam,

1-----mark => which prevents thermal decomposition.

1-----mark => Simple distillation requires heating to the compound's actual boiling point, often causing decomposition or damage to delicate compounds.