

Trial Examination 2021

VCE Chemistry Units 3&4

Written Examination

Question and Answer Booklet

Reading time: 15 minutes

Writing time: 2 hours 30 minutes

Student's Name: _____

Teacher's Name: _____

Structure of booklet

<i>Section</i>	<i>Number of questions</i>	<i>Number of questions to be answered</i>	<i>Number of marks</i>
A	30	30	30
B	9	9	90
			Total 120

Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.

Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied

Question and answer booklet of 25 pages

Data booklet

Answer sheet for multiple-choice questions

Instructions

Write your **name** and your **teacher's name** in the space provided above on this page, and on the answer sheet for multiple-choice questions.

Unless otherwise indicated, the diagrams in this booklet are **not** drawn to scale.

All written responses must be in English.

At the end of the examination

Place the answer sheet for multiple-choice questions inside the front cover of this booklet.

You may keep the data booklet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

Students are advised that this is a trial examination only and cannot in any way guarantee the content or the format of the 2021 VCE Chemistry Units 3&4 Written Examination.

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SECTION A – MULTIPLE-CHOICE QUESTIONS**Instructions for Section A**

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1; an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Unless otherwise indicated, the diagrams in this booklet are **not** drawn to scale.

Question 1

Carboxylic acids are isomers of

- A. alcohols.
- B. esters.
- C. aldehydes.
- D. ketones.

Use the following information to answer Questions 2 and 3.

Both petrodiesel and biodiesel are suitable for use as transport fuels under certain conditions.

Question 2

Which one of the following is **most** similar for petrodiesel and biodiesel?

- A. chemical structure
- B. viscosity in cold weather
- C. products of complete combustion
- D. functional groups in each fuel

Question 3

Which one of the following statements is correct?

- A. Petrodiesel has approximately five times more energy per gram than biodiesel.
- B. Biodiesel absorbs more moisture from the atmosphere than petrodiesel.
- C. Biodiesel has no environmental impact in its production.
- D. Petrodiesel is produced in a process using no net energy.

Question 4

The volume of hydrogen gas required at standard laboratory conditions (SLC) to react completely with 56.0 g of ethene gas to form ethane is

- A. 1.23 L
- B. 24.8 L
- C. 49.6 L
- D. 61.2 L

Use the following information to answer Questions 5 and 6.

Information about liquid hexane is shown in the table below.

Molar mass	Density	Energy released on complete combustion
86 g mol^{-1}	0.66 g mL^{-1}	4163 kJ per mole

Question 5

How many kilojoules of energy are released when 2.0 L of liquid hexane is burnt in excess oxygen?

- A. 64
- B. 1.0×10^3
- C. 6.4×10^4
- D. 4.7×10^8

Question 6

If the 2.0 L of liquid hexane was vaporised before combustion, the energy released when the gaseous hexane is burnt in excess oxygen would be

- A. greater than the amount of energy released when liquid hexane is burnt.
- B. identical to the amount of energy released when liquid hexane is burnt.
- C. lower than the amount of energy released when liquid hexane is burnt.
- D. impossible to predict without knowing the temperature of the gaseous hexane.

Question 7

A mixture of Cr_2O_3 and ZnO is used as a catalyst in the industrial production of methanol, by the following reaction.



The catalyst

- A. increases the proportion of CH_3OH in the equilibrium mixture.
- B. decreases the enthalpy change for the forward reaction.
- C. decreases the rate of the formation of CO and H_2 .
- D. increases the amount of CH_3OH formed in a given time.

Question 8

One mole of which amino acid would react with exactly 572 mL of 3.50 M NaOH solution?

- A. glutamic acid
- B. glutamine
- C. glycine
- D. threonine

Question 9

Y is a metal that forms the oxide Y_2O according to the following equation.



When a sample of Y_2O decomposes to form 0.20 mol of $Y(s)$, then

- A. 4.0 kJ of energy will be released.
- B. 4.0 kJ of energy will be absorbed.
- C. 16.0 kJ of energy will be released.
- D. 16.0 kJ of energy will be absorbed.

Question 10

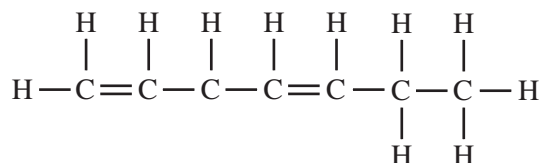
Many protein chains adopt a spiral shape.

This shape is mainly due to

- A. the formation of disulfide links between amino acids that contain sulfur atoms.
- B. ionic bonds that form between COO^- and NH_3^+ side groups of different amino acids.
- C. hydrogen bonds that develop between N–H groups of amino acid side groups.
- D. interaction between N–H and C=O groups on non-adjacent amino acid residues.

Use the following information to answer Questions 11 and 12.

The structure of 1,4-heptadiene is shown in the diagram below.

**Question 11**

This molecule can show *cis-trans* isomerism.

How many *cis-trans* isomers are possible for this molecule (including the isomer shown)?

- A. 1
- B. 2
- C. 3
- D. 4

Question 12

1,4-heptadiene can react with hydrogen gas to form a saturated product.

What volume of hydrogen gas measured at 50°C and 150 kPa will react completely with 5.0 mol of 1,4-heptadiene?

- A. 27 L
- B. 89 L
- C. 1.8×10^2 L
- D. 2.7×10^4 L

Use the following information to answer Questions 13 and 14.

To check the reliability of a 25.00 mL pipette at 25°C, aliquots of pure water were taken using the pipette and weighed. The results are shown in the table below.

Aliquot	1	2	3	4	5
Mass (g)	24.58	24.55	24.54	24.56	24.59

Question 13

The results show

- A. high accuracy and high precision.
- B. high accuracy and low precision.
- C. low accuracy and high precision.
- D. low accuracy and low precision.

Question 14

The results also show evidence of

- A. random error, which is removed by repeated measurements and taking an average.
- B. random error, which is not reduced by repeated measurements and taking an average.
- C. systematic error, which is remedied by repeated measurements and taking an average.
- D. systematic error, which is not remedied by repeated measurements and taking an average.

Question 15

Coenzymes

- A. act in combination with enzymes to enable a reaction to operate at a functional rate.
- B. make a reaction occur at a faster rate when acting alone as a catalyst.
- C. prevent the denaturation of proteins by preserving the primary structure.
- D. are usually proteins that combine with substrate molecules.

Question 16

An omega-3 fatty acid has

- A. only one double bond in the molecule.
- B. a double bond on the third carbon atom near the carboxyl end of the molecule.
- C. a set of three carboxyl functional groups in the molecule.
- D. a C=C bond on the third carbon atom at the methyl end of the molecule.

Question 17

How many chiral carbon atoms are in 2-chlorobutane?

- A. 0
- B. 1
- C. 2
- D. 3

Question 18

During an experimental procedure, a student obtained the following results.

Value obtained by experiment: 7.911

Theoretical/expected value: 7.932

The percentage error in the result obtained, expressed to the correct number of significant figures, is

- A. 0.26
- B. 0.2648
- C. 0.2654
- D. 0.27

Question 19

When 0.662 g of sucrose ($M = 342 \text{ g mol}^{-1}$) underwent combustion in a bomb calorimeter with a calibration factor of $3.90 \text{ kJ } ^\circ\text{C}^{-1}$, the temperature rose by 2.80°C .

Based on these results, the energy content of sucrose, in kJ mol^{-1} , is

- A. 16.5
- B. 5.64×10^3
- C. 16.5×10^3
- D. 5.64×10^6

Question 20

The following information is relevant to a particular chemical reaction with no catalyst and to the same reaction when it is catalysed.

Activation energy of uncatalysed reaction	Activation energy of uncatalysed reverse reaction	Activation energy of catalysed reaction
90 kJ mol^{-1}	140 kJ mol^{-1}	40 kJ mol^{-1}

What is the activation energy, in kJ mol^{-1} , of the catalysed reverse reaction?

- A. 40
- B. 50
- C. 90
- D. 140

Question 21

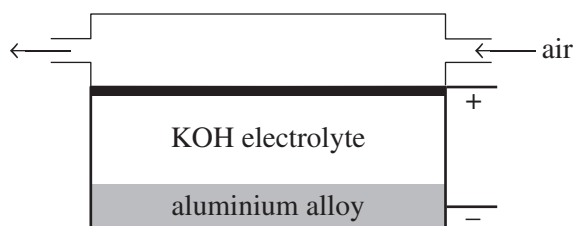
The concentration of an organic compound, Y, in a mixture is determined using high-performance liquid chromatography (HPLC).

Which one of the following steps is **not** required to complete this analysis?

- A. Measure the retention time of compound Y using mobile phases of various polarities.
- B. Determine the area under the peaks for solutions of compound Y of known concentrations.
- C. Find the area under the peak for compound Y in the HPLC analysis.
- D. Construct a calibration curve of peak area of standard solutions against concentration.

Use the following information to answer Questions 22–24.

The diagram below shows an aluminium–air cell, which produces electrical energy.



Question 22

Which one of the following statements is correct?

- A. Aluminium is reduced and oxygen is oxidised when the cell operates.
- B. The cell is usually recharged by using electrical energy to reverse the cell reaction.
- C. The positive electrode is likely to be made from an inert and porous material.
- D. Only non-spontaneous redox reactions will occur to produce electrical energy.

Question 23

The cell has been described as part galvanic cell and part fuel cell.

This is because

- A. both of these types of cells contain an electrolyte.
- B. electrons flow when the electrodes are connected to each other.
- C. the oxidising agent and reducing agent react to generate electricity.
- D. only one reactant is continuously supplied to the cell.

Question 24

The overall reaction when the cell generates electrical energy is

- A. $4\text{Al(s)} + 3\text{O}_2\text{(g)} + 6\text{H}_2\text{O(l)} \rightarrow 4\text{Al}^{3+}\text{(aq)} + 12\text{OH}^-\text{(aq)}$
- B. $4\text{Al(s)} + 3\text{O}_2\text{(g)} + 12\text{H}^+\text{(aq)} \rightarrow 4\text{Al}^{3+}\text{(aq)} + 6\text{H}_2\text{O(l)}$
- C. $4\text{Al}^{3+}\text{(aq)} + 12\text{OH}^-\text{(aq)} \rightarrow 4\text{Al(s)} + 3\text{O}_2\text{(g)} + 6\text{H}_2\text{O(l)}$
- D. $4\text{Al}^{3+}\text{(aq)} + 6\text{H}_2\text{O(l)} \rightarrow 4\text{Al(s)} + 3\text{O}_2\text{(g)} + 12\text{H}^+\text{(aq)}$

Question 25

Foods that have a high amylopectin content

- A. are hydrolysed more quickly than foods with a high amylose content.
- B. have a much lower glycaemic index value than foods with a high amylose content.
- C. produce very low quantities of glucose quite slowly during digestion.
- D. are digested at the same rate as cellulose is hydrolysed in the digestive system.

Question 26

Vitamin D is best described as

- A. an essential dietary requirement.
- B. having many polar groups in its structure.
- C. being soluble in oils and non-polar solvents.
- D. a protein that catalyses a metabolic reaction.

Question 27

The percentage composition by mass of two foods is shown in the table below.

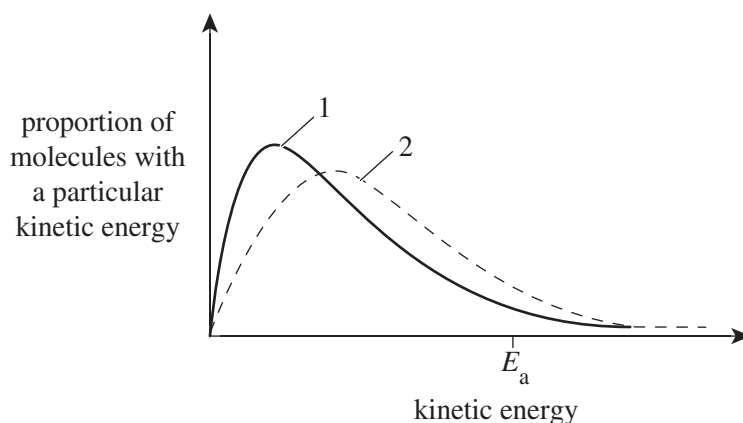
Food	Carbohydrate	Fats and oils	Protein
bread	45	5	10
cheese	3	29	21

How many grams of cheese has the same energy content as 100 g of bread?

- A. 14.3
- B. 72.7
- C. 75.9
- D. 137

Question 28

Two Maxwell–Boltzmann distribution curves for the same gas under different conditions are shown below.



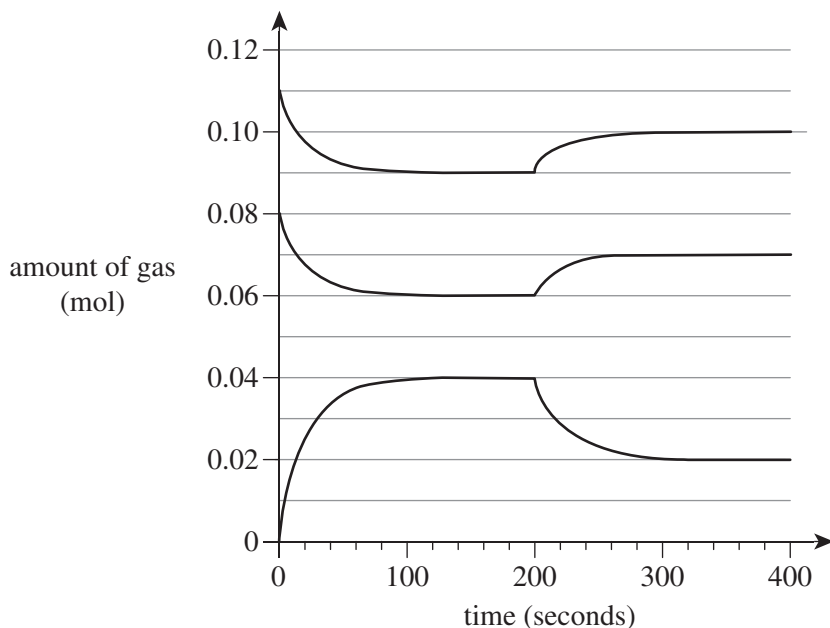
The curves show the energies of reactant particles for a particular reaction.

Which one of the following statements about these curves is correct?

- A. Curve 1 is at a higher temperature than curve 2.
- B. The number of reactant particles is higher in curve 1 than in curve 2.
- C. Curve 1 has a catalyst present, whereas curve 2 does not.
- D. Curve 2 results in a greater rate of reaction than curve 1.

Use the following information to answer Questions 29 and 30.

The results of an experiment on a gaseous equilibrium reaction were used to plot the graphs below. Initially, two gases were injected into an empty sealed vessel to begin the experiment.



Question 29

What are the units of the equilibrium constant (K_c) for the reaction?

- A. no units
- B. M^{-2}
- C. M^{-1}
- D. M^2

Question 30

Which one of the following actions was taken to cause a change during the experiment?

- A. An inert gas was added.
- B. A catalyst was introduced.
- C. The volume of the vessel was changed.
- D. The temperature of the gases was altered.

END OF SECTION A

SECTION B**Instructions for Section B**

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

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 chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $\text{H}_2(\text{g})$, $\text{NaCl}(\text{s})$.

Unless otherwise indicated, the diagrams in this booklet are **not** drawn to scale.

Question 1 (11 marks)

Nitric acid is manufactured in a three-stage process using the sequence of exothermic chemical reactions shown in the table below.

Reaction	Chemical equation	Reaction conditions
I	$4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightleftharpoons 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$	moderate pressure; moderate temperature; Pt/Rh catalyst
II	$2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$	high pressure; low temperature
III	$4\text{NO}_2(\text{g}) + \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightleftharpoons 4\text{HNO}_3(\text{aq})$	high pressure

- a. Oxygen is a reactant in all three reactions of the manufacturing process.

Explain the likely source of the oxygen and why this source is used.

2 marks

- b. i.** Referring to collision theory and Le Chatelier's principle, explain the effect of high pressure on the rate and yield of reaction I, and account for the use of a moderate pressure to conduct the reaction during the production of nitric acid. 5 marks

- ii.** The equilibrium constant for reaction II at various temperatures is shown in the following table.

Temperature (K)	298	500	900	1100
Equilibrium constant (M^{-1})	3.9×10^{13}	6.6×10^5	4.4	0.30

Explain how these values indicate that reaction II is exothermic. 2 marks

- c.** Use oxidation numbers to determine the reducing agent in reaction III. 2 marks

Question 2 (11 marks)

Sucrose is one of the most widely-used compounds in the world.

a. During digestion, sucrose is initially broken down into two smaller products.

- i.** Write a balanced equation using molecular formulas for this reaction.
(State symbols are **not** required.)

1 mark

- ii.** Name the type of linkage broken during the digestion of sucrose.

1 mark

b. Aspartame is an artificial sweetener used in place of sucrose. Its structure is shown in the Data Booklet.

- i.** What is the main advantage in using aspartame as a sweetener to replace sucrose?

2 marks

- ii.** The structure of aspartame is described as a methyl ester of a dipeptide that is synthesised using two naturally occurring amino acids.

Draw the structure, as a zwitterion, of the amino acid with the higher molar mass used to synthesise aspartame.

2 marks

- iii.** Aspartame is formed using naturally occurring amino acids. If optical isomers of these amino acids are used in the structure, the compound is bitter and not sweet.

What are optical isomers?

2 marks

- c.** Sucrose is used in the industrial production of ethanol by fermentation using yeast.

- i.** Why is ethanol produced using this method classed as a biofuel?

1 mark

- ii.** Ethanol can also be produced industrially using ethene gas derived from crude oil. Temperatures around 300°C and a H_3PO_4 catalyst are used in the production process.

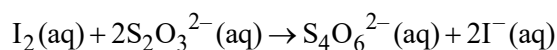
Write a balanced equation (including states) for this reaction.

2 marks

Question 3 (9 marks)

A 500 mL aqueous solution of KI was electrolysed using graphite electrodes for a short time with a current of 2.5 amperes.

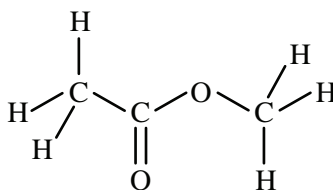
- a.** At one electrode, $I_2(aq)$ was formed.
- i.** Identify the name of this electrode (anode or cathode) and its polarity (positive or negative). 1 mark
- _____
- ii.** Write the half-equation for the reaction at this electrode. 1 mark
- _____
- b. i.** Write the half-equation for the reaction at the other electrode. 1 mark
- _____
- ii.** Explain any pH changes that are likely to occur near this electrode as the electrolysis proceeds. 1 mark
- _____
- _____
- _____
- c.** After a short time in the electrolysis, 20.00 mL of the electrolyte was removed and titrated with 0.065 M sodium thiosulfate solution using the following chemical reaction.



- i.** A titre of 28.50 mL was recorded.
Calculate the number of mole of I_2 that reacted with the thiosulfate ion. 2 marks
- _____
- _____
- _____
- ii.** Calculate the amount of charge transferred during the electrolysis of the KI solution. 2 marks
- _____
- _____
- _____
- iii.** Calculate the duration of the electrolysis. 1 mark
- _____
- _____

Question 4 (9 marks)

- a.** Compound X and compound Y react to form compound Z. Compound Z has the following structure.



- i.** Give the systematic name of compound Z. 1 mark
- _____
- ii.** To what family of organic compounds does compound Z belong? 1 mark
- _____
- iii.** Outline the reactants and conditions needed to produce compound Z. 2 marks
- _____
- _____
- iv.** Calculate the atom economy of producing compound Z from compounds X and Y. 2 marks
- _____
- _____
- _____
- b.** Show how ethanamine can be produced from an alkane in a series of reactions. Include reagents and any intermediate products in the reaction pathway. Use structural formulas for all organic compounds involved. 3 marks

Question 5 (5 marks)

Carbon oxyfluoride decomposes according to the following equation.



1.00 mole of COF_2 gas was placed in a 5.0 L sealed container and allowed to reach equilibrium at 200°C . At equilibrium, 0.40 mole of CF_4 gas was present.

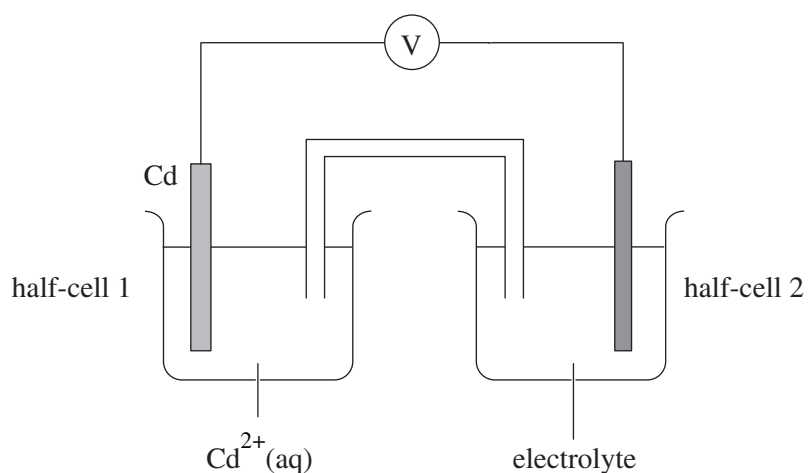
- a.** Write an expression for the equilibrium constant (K_c) for the reaction. 1 mark

- b.** Calculate the value of the equilibrium constant for the reaction at 200°C . 4 marks

Question 6 (11 marks)

- a.** When zinc metal is extracted from its ores, it is common to dissolve the ores in acid and remove any impurities from the solution of zinc ions. One method to remove any small amounts of silver ions is to add zinc dust.
- i.** Write an overall redox ionic equation for the reaction to remove the silver ion using zinc dust. 2 marks
- _____
- ii.** Using the electrochemical series, explain why this method is effective. 1 mark
- _____
- _____
- _____
- iii.** Identify a metal that could **not** be removed by adding zinc dust. 1 mark
- _____
- iv.** Explain why zinc dust is used rather than granules of zinc of 5 mm diameter. 2 marks
- _____
- _____
- _____
- v.** Why is it reasonable to assume that the activation energy for this reaction has a low value? 1 mark
- _____
- _____

- b. A galvanic cell was set up as follows under standard conditions using the cell reaction shown.



- i. Calculate the voltage of the cell. 1 mark
-
- ii. State a suitable electrode material for half-cell 2. 1 mark
-
- iii. On the diagram above, draw an arrow immediately above the voltmeter to show the direction of movement of electrons, and write 'electrons' above this arrow. 1 mark
- iv. On the diagram above, draw an arrow immediately above the salt bridge to show the direction of movement of anions, and write 'anions' above this arrow. 1 mark

Question 7 (12 marks)

One gram of each of the hydrocarbons shown in the table below releases 48 kJ of energy on complete combustion.

Hydrocarbon	Molecular formula	Boiling point (°C)
2,2,4-trimethylpentane	C ₈ H ₁₈	99
nonane	C ₉ H ₂₀	151
hexadecane	C ₁₆ H ₃₄	287

- a. i.** Give the molecular formula of the compound that has 20 carbon atoms per molecule and is in the same group of hydrocarbons as those shown in the table above. 1 mark

- ii.** Draw the skeletal structure of 2,2,4-trimethylpentane. 1 mark

- b.** Write a balanced thermochemical equation for the complete combustion of nonane. 3 marks

- c.** Using structure and bonding, explain the trend in boiling points for the three hydrocarbons listed in the table above. 2 marks

d. If a small sample of another hydrocarbon liquid, hexane (C_6H_{14}), is brought close to a lit match, it ignites immediately and burns with a sooty, yellow flame with black smoke.

i. Write a balanced chemical equation that is consistent with the information about the combustion of hexane. 2 marks

ii. Explain the observations for the burning of hexane after ignition. 2 marks

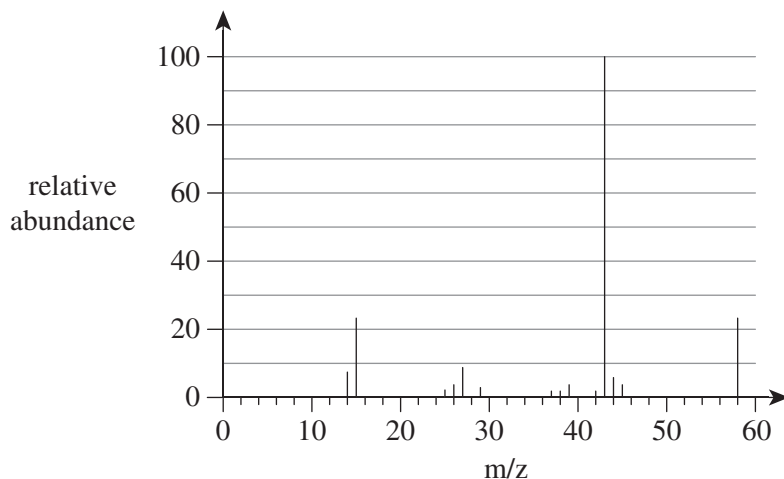
iii. All hydrocarbons will burn in air under suitable conditions. If a small sample of hexadecane is brought close to a lit match, no ignition will occur.

Explain why no ignition will occur under these conditions. 1 mark

Question 8 (12 marks)

Chemists use data from a range of instrumental analyses of organic compounds to confirm or deduce organic structures. Each of the organic compounds P, Q, R and S was analysed using a different analytical instrument.

- a. Compound P has the empirical formula C_3H_6O . The mass spectrum of compound P is shown below.



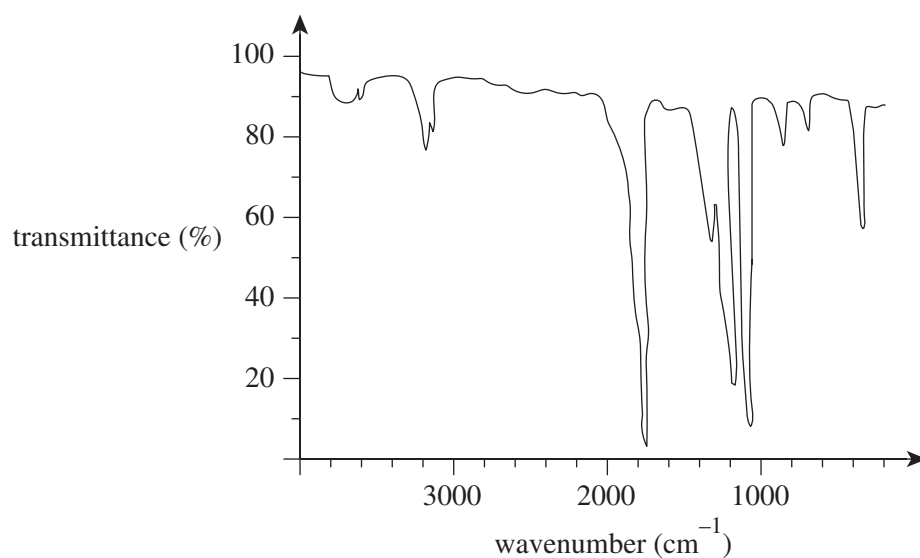
- i. Complete the following table by providing the relevant m/z values. 2 marks

Signal	base peak	molecular ion peak
m/z value		

- ii. State the molecular formula of compound P. 1 mark

- iii. Identify a possible fragment that produced the signal at m/z 15. 1 mark

- b. The infrared spectrum of compound Q is shown below.



Compound Q was produced by oxidation of a secondary alcohol.

- i. Explain the meaning of the term 'secondary alcohol'. 1 mark

- ii. Which functional group is present in compound Q? 1 mark

- iii. Explain how the infrared spectrum above can be used to derive information about the functional group in compound Q. 1 mark

- c. The proton NMR spectrum data of compound R are summarised in the table below.

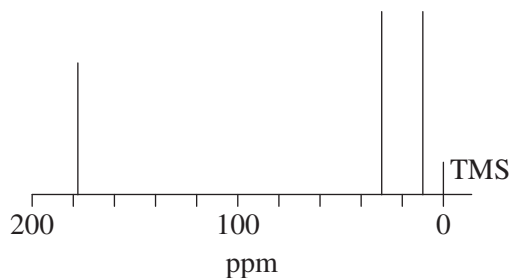
Chemical shift (ppm)	Relative peak area	Peak splitting
1.2	3	triplet
2.4	2	quadruplet
11.8	1	singlet

Compound R is a carboxylic acid with three carbon atoms per molecule.

Explain how the information in the table is consistent with the information provided about the structure of compound R.

3 marks

- d. The carbon-13 NMR of compound S is shown below.



- i. Even without the label, it is clear that this is **not** a proton NMR spectrum. Explain why.

1 mark

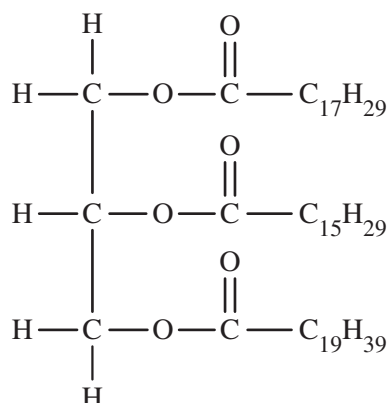
- ii. What information about compound S is revealed by this carbon-13 NMR spectrum?

1 mark

Question 9 (10 marks)

The enzyme lipase catalyses the breakdown of triglycerides.

- a. The following triglyceride was hydrolysed using lipase.



- i. Write the formula of the saturated fatty acid produced by the hydrolysis. 1 mark

 - ii. Give the name of the fatty acid produced that has the higher number of carbon-carbon double bonds per molecule. 1 mark

- b. An experiment was conducted to investigate the effect of temperature on the activity of lipase in breaking down the fats in milk. The experiment used a series of test tubes, each with the following contents.
- 5.0 mL of milk
 - 7.0 mL of sodium carbonate solution
 - 0.25 mL of phenolphthalein indicator

Phenolphthalein indicator is coloured pink in alkaline solutions of pH 10, but below pH 8.3 it changes to colourless. Therefore, as the triglycerides are broken down, the pH decreases and the pink colour changes. The activity of the enzyme can be determined by how long it takes for the colour to change.

Each test tube and its contents was heated or cooled to a set temperature and the reaction was initiated by adding 1.0 mL of lipase solution at the appropriate temperature. The length of time it took for the indicator to change colour in each test tube was measured after the lipase was added. These results were recorded in the table below.

Temperature of contents (°C)	5	15	25	35	45	55
Time it took for colour to change (s)	450	360	240	180	320	430

- i. Give the approximate temperature at which the enzyme has maximum activity. 1 mark

- ii. Explain, at a molecular level, why the enzyme has lower activity at temperatures that are higher or lower than the temperature of maximum enzyme activity. 3 marks

- iii. Why is it important that the temperature of the lipase solution that was added to initiate the reaction should match the temperature of the contents of each test tube? 2 marks

- iv. Explain why the effect of pH on lipase activity could **not** be investigated using this type of experiment. 2 marks

END OF QUESTION AND ANSWER BOOKLET

Trial Examination 2021

VCE Chemistry Units 3&4

Written Examination

Data Booklet

Instructions

This data booklet is provided for your reference.

A question and answer booklet is provided with this data booklet.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

1. Periodic table of the elements

1 H hydrogen 1.0		atomic number																2 He helium 4.0	
3 Li lithium 6.9		relative atomic mass																10 Ne neon 20.2	
11 Na sodium 23.0		symbol of element																9 F fluorine 19.0	
12 Mg magnesium 24.3		name of element																8 O oxygen 16.0	
19 K potassium 39.1		79 Au gold																7 N nitrogen 14.0	
20 Ca calcium 40.1		26 Fe iron																6 C carbon 12.0	
21 Sc scandium 45.0		25 Mn manganese																5 B boron 10.8	
22 Ti titanium 47.9		24 Cr chromium																13 Al aluminium 27.0	
23 V vanadium 50.9		23 V vanadium																14 Si silicon 28.1	
24 Cr chromium 52.0		22 Ti titanium																15 P phosphorus 30.1	
25 Mn manganese 54.9		21 Sc scandium																16 S sulfur 32.1	
26 Fe iron 55.8		20 Ca calcium																17 Cl chlorine 35.5	
27 Co cobalt 58.9		19 K potassium																36 Kr krypton 83.8	
28 Ni nickel 58.7		18 Ar argon 39.9																35 Br bromine 79.9	
29 Cu copper 63.5		17 Cl chlorine																54 Xe xenon 131.3	
30 Zn zinc 65.4		16 S sulfur																86 Rn radon (222)	
31 Ga gallium 69.7		15 P phosphorus																118 Og oganesson (294)	
32 Ge germanium 72.6		14 Si silicon																108 Ug unbinoidium (296)	
33 As arsenic 74.9		13 Al aluminium																117 Ts tennessine (294)	
34 Se selenium 79.0		12 Mg magnesium																116 Lv livermorium (292)	
35 Br bromine 79.9		11 Na sodium																115 Mc moscovium (289)	
36 Kr krypton 83.8		10 Ne neon 20.2																114 Fl flerovium (289)	
37 Rb rubidium 85.5		9 F fluorine 19.0																113 Nh nihonium (280)	
38 Sr strontium 87.6		8 O oxygen 16.0																112 Cn copernicium (285)	
39 Y yttrium 88.9		7 N nitrogen 14.0																111 Rg roentgenium (272)	
40 Zr zirconium 91.2		6 C carbon 12.0																110 Ds darmstadtium (271)	
41 Nb niobium 92.9		5 B boron 10.8																109 Mt meitnerium (268)	
42 Mo molybdenum 96.0		4 Be beryllium 9.0																108 Hs hassium (267)	
43 Tc technetium (98)		3 Li lithium 6.9																107 Bh bohrium (264)	
44 Ru ruthenium 101.1		2 He helium 4.0																106 Sg seaborgium (266)	
45 Rh rhodium 102.9		1 H hydrogen 1.0																105 Db dubnium (262)	
46 Pd palladium 106.4		0 0 unilithium (0)																104 Rf rutherfordium (261)	
47 Ag silver 107.9		-1 -1 unelithium (-1)																103 Lr lawrencium (262)	
48 Cd cadmium 112.4		-2 -2 unelithium (-2)																102 No nobelium (259)	
49 In indium 114.8		-3 -3 unelithium (-3)																101 Md mendelevium (258)	
50 Sn tin 118.7		-4 -4 unelithium (-4)																100 Fm fermium (257)	
51 Sb antimony 121.8		-5 -5 unelithium (-5)																99 Es einsteinium (252)	
52 Te tellurium 127.6		-6 -6 unelithium (-6)																98 Cf californium (251)	
53 I iodine 126.9		-7 -7 unelithium (-7)																97 Bk berkelium (247)	
54 Xe xenon 131.3		-8 -8 unelithium (-8)																96 Cm curium (247)	
55 Cs caesium 132.9		-9 -9 unelithium (-9)																95 Am americium (243)	
56 Ba barium 137.3		-10 -10 unelithium (-10)																94 Pu plutonium (244)	
57-71 lanthanoids		-11 -11 unelithium (-11)																93 Np neptunium (237)	
72 Hf hafnium 178.5		-12 -12 unelithium (-12)																92 U uranium 238.0	
73 Ta tantalum 180.9		-13 -13 unelithium (-13)																91 Pa protactinium 231.0	
74 W tungsten 183.8		-14 -14 unelithium (-14)																90 Th thorium 232.0	
75 Re rhenium 186.2		-15 -15 unelithium (-15)																89 Ac actinium (227)	
76 Os osmium 190.2		-16 -16 unelithium (-16)																88 Ra radium (226)	
77 Ir iridium 192.2		-17 -17 unelithium (-17)																87 Fr francium (223)	
78 Pt platinum 195.1		-18 -18 unelithium (-18)																86 Rn radon (222)	
79 Au gold 197.0		-19 -19 unelithium (-19)																85 At astatine (210)	
80 Hg mercury 200.6		-20 -20 unelithium (-20)																84 Po polonium (210)	
81 Tl thallium 204.4		-21 -21 unelithium (-21)																83 Bi bismuth (209)	
82 Pb lead 207.2		-22 -22 unelithium (-22)																82 Pb lead (208)	
83 Bi bismuth 209.0		-23 -23 unelithium (-23)																81 Th thorium (232)	
84 Po polonium (210)		-24 -24 unelithium (-24)																80 Ra radium (226)	
85 At astatine (210)		-25 -25 unelithium (-25)																79 Ac actinium (227)	
86 Rn radon (222)		-26 -26 unelithium (-26)																78 Fr francium (223)	
87 Fr francium (223)		-27 -27 unelithium (-27)																77 Rf rutherfordium (261)	
88 Ra radium (226)		-28 -28 unelithium (-28)																76 Hf hafnium (178)	
89-103 actinoids		-29 -29 unelithium (-29)																75 Re rhenium (186)	
104 Rf rutherfordium (261)		-30 -30 unelithium (-30)																74 W tungsten (183)	
105 Db dubnium (262)		-31 -31 unelithium (-31)																73 Ta tantalum (180)	
106 Sg seaborgium (266)		-32 -32 unelithium (-32)																72 Hf hafnium (178)	
107 Bh bohrium (264)		-33 -33 unelithium (-33)																71 La lanthanum (138)	
108 Hs hassium (267)		-34 -34 unelithium (-34)																70 Yb ytterbium (173)	
109 Mt meitnerium (268)		-35 -35 unelithium (-35)																69 Tm thulium (168)	
110 Ds darmstadtium (271)		-36 -36 unelithium (-36)																68 Er erbium (167)	
111 Rg roentgenium (272)		-37 -37 unelithium (-37)																67 Ho holmium (164)	
112 Cn copernicium (285)		-38 -38 unelithium (-38)																66 Dy dysprosium (162)	
113 Nh nihonium (280)		-39 -39 unelithium (-39)																65 Tb terbium (158)	
114 Fl flerovium (289)		-40 -40 unelithium (-40)																64 Gd gadolinium (157)	
115 Mc moscovium (289)		-41 -41 unelithium (-41)																63 Eu europium (152)	
116 Lv livermorium (292)		-42 -42 unelithium (-42)																62 Sm samarium (150)	
117 Ts tennessine (294)		-43 -43 unelithium (-43)																61 Pm promethium (145)	
118 Og oganesson (294)		-44 -44 unelithium (-44)																60 Nd neodymium (144)	
119 Ug unbinoidium (296)		-45 -45 unelithium (-45)																59 Pr praseodymium (140)	
120 Uu unbinoidium (298)		-46 -46 unelithium (-46)																58 Ce cerium (140)	
121 Uu unbinoidium (300)		-47 -47 unelithium (-47)																57 La lanthanum (138)	
122 Uu unbinoidium (302)		-48 -48 unelithium (-48)																56 Ba barium (137)	
123 Uu unbinoidium (304)		-49 -49 unelithium (-49)																55 Cs caesium (132)	
124 Uu unbinoidium (306)		-50 -50 unelithium (-50)																54 Xe xenon (131)	
125 Uu unbinoidium (308)		-51 -51 unelithium (-51)																53 I iodine (126)	
126 Uu unbinoidium (310)		-52 -52 unelithium (-52)																52 Te tellurium (127)	
127 Uu unbinoidium (312)		-53 -53 unelithium (-53)																51 Sb antimony (121)	
128 Uu unbinoidium (314)		-54 -54 unelithium (-54)																50 Sn tin (118)	
129 Uu unbinoidium (316)		-55 -55 unelithium (-55)																49 In indium (114)	
130 Uu unbinoidium (318)		-56 -56 unelithium (-56)																48 Cd cadmium (112)	
131 Uu unbinoidium (320)		-57 -57 unelithium (-57)																47 Ag silver (107)	
132 Uu unbinoidium (322)		-58 -58 unelithium (-58)																46 Pd palladium (106)	
133 Uu unbinoidium (324)		-59 -59 unelithium (-59)																45 Rh rhodium (102)	
134 Uu unbinoidium (326)		-60 -60 unelithium (-60)																44 Ru ruthenium (101)	
135 Uu unbinoidium (328)		-61 -61 unelithium (-61)																43 Tc technetium (98)	
136 Uu unbinoidium (330)		-62 -62 unelithium (-62)																42 Mo molybdenum (96)	
137 Uu unbinoidium (332)		-63 -63 unelithium (-63)																41 Nb niobium (92)	
138 Uu unbinoidium (334)		-64 -64 unelithium (-64)																40 Zr zirconium (91)	
139 Uu unbinoidium (336)		-65 -65 unelithium (-65)																39 Y yttrium (88)	
140 Uu unbinoidium (338)		-66 -66 unelithium (-66)																38 Sr strontium (87)	
141 Uu unbinoidium (340)		-67 -67 unelithium (-67)																37 Rb rubidium (85)	
142 Uu unbinoidium (342)		-68 -68 unelithium (-68)																36 Kr krypton (83)	
143 Uu unbinoidium (344)		-69 -69 unelithium (-69)																35 Br bromine (79)	
144 Uu unbinoidium (346)		-70 -70 unelithium (-70)																34 Se selenium (79)	
145 Uu unbinoidium (348)		-71 -71 unelithium (-71)																33 As arsenic (74)	
146 Uu unbinoidium (350)		-72 -72 unelithium (-72)																32 Ge germanium (72)	
147 Uu unbinoidium (352)		-73 -73 unelithium (-73)																31 Ga gallium (69)	
148 Uu unbinoidium (354)		-74 -74 unelithium (-74)																30 Zn zinc (65)	
149 Uu unbinoidium (356)		-75 -75 unelithium (-75)																29 Cu copper (63)	
150 Uu unbinoidium (358)		-76 -76 unelithium (-76)																28 Ni nickel (58)	
151 Uu unbinoidium (360)		-77 -77 unelithium (-77)																27 Co cobalt (58)	
152 Uu unbinoidium (362)		-78 -78 unelithium (-78)																26 Fe iron (55)	
153 Uu unbinoidium (364)		-79 -79 unelithium (-79)																25 Mn manganese (54)	
154 Uu unbinoidium (366)		-80 -80 unelithium (-80)																24 Cr chromium (52)	
155 Uu unbinoidium (368)		-81 -81 unelithium (-81)																23 V vanadium (50)	
156 Uu unbinoidium (370)		-82 -82 unelithium (-82)																22 Ti titanium (47)	
157 Uu unbinoidium (372)		-83 -83 unelithium (-83)																21 Sc scandium (45)	
158 Uu unbinoidium (374)		-84 -84 unelithium (-84)																20 Ca calcium (40)	
159 Uu unbinoidium (376)		-85 -85 unelithium (-85)																19 K potassium (39)	
160 Uu unbinoidium (378)		-86 -86 unelithium (-86)																18 Ar argon (39)	
161 Uu unbinoidium (380)		-87 -87 unelithium (-87)																17 Cl chlorine (35)	
162 Uu unbinoidium (382)		-88 -88 unelithium (-88)																16 S sulfur (32)	
163 Uu unbinoidium (384)		-89 -89 unelithium (-89)																15 P phosphorus (30)	
164 Uu unbinoidium (386)		-90 -90 unelithium (-90)																14 Si silicon (28)	
165 Uu unbinoidium (388)		-91 -91 unelithium (-91)																13 Al aluminium (27)	
166 Uu unbinoidium (390)		-92 -92 unelithium (-92)																12 Mg magnesium (24)	
167 Uu unbinoidium (392)		-93 -93 unelithium (-93)																11 Na sodium (23)	
168 Uu unbinoidium (394)		-94 -94 unelithium (-94)																10 Ne neon (20)	
169 Uu unbinoidium (396)		-95 -95 unelithium (-95)																9 F fluorine (19)	
170 Uu unbinoidium (398)		-96 -96 unelithium (-96)																8 O oxygen (16)	
171 Uu unbinoidium (400)		-97 -97 unelithium (-97)																7 N nitrogen (14)	
172 Uu unbinoidium (402)		-98 -98 unelithium (-98)																6 C carbon (12)	
173 Uu unbinoidium (404)		-99 -99 unelithium (-99)																5 B boron (10)	
174 Uu unbinoidium (406)		-100 -100 unelithium (-100)																4 Be beryllium (9)	
175 Uu unbinoidium (408)		-101 -101 unelithium (-101)																3 Li lithium (6)	
176 Uu unbinoidium (410)		-102 <																	

The value in the brackets indicates the mass number of the longest-lived isotope.

2. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25°C
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.87
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.77
$\text{Au}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Au}(\text{s})$	+1.68
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq})$	+1.36
$\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.09
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.68
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}(\text{aq})$	+0.15
$\text{S}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{S}(\text{g})$	+0.14
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
$\text{Cd}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cd}(\text{s})$	-0.40
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.83
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.66
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.37
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.93
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.04

3. Chemical relationships

Name	Formula
number of moles of a substance	$n = \frac{m}{M}; \quad n = cV; \quad n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$
calibration factor (CF) for bomb calorimetry	$CF = \frac{VIt}{\Delta T}$
heat energy released in the combustion of a fuel	$q = mc\Delta T$
enthalpy of combustion	$\Delta H = \frac{q}{n}$
electric charge	$Q = It$
number of moles of electrons	$n(e^-) = \frac{Q}{F}$
% atom economy	$\frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times \frac{100}{1}$
% yield	$\frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$

4. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A or L	$6.02 \times 10^{23} \text{ mol}^{-1}$
charge on one electron (elementary charge)	e	$-1.60 \times 10^{-19} \text{ C}$
Faraday constant	F	$96\,500 \text{ C mol}^{-1}$
molar gas constant	R	$8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
molar volume of an ideal gas at SLC (25°C and 100 kPa)	V_m	24.8 L mol^{-1}
specific heat capacity of water	c	$4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ or $4.18 \text{ J g}^{-1} \text{ K}^{-1}$
density of water at 25°C	d	997 kg m^{-3} or 0.997 g mL^{-1}

5. Unit conversions

Measured value	Conversion
0°C	273 K
100 kPa	750 mm Hg or 0.987 atm
1 litre (L)	1 dm ³ or 1 × 10 ⁻³ m ³ or 1 × 10 ³ cm ³ or 1 × 10 ³ mL

6. Metric (including SI) prefixes

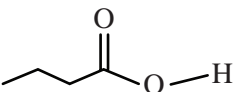
Metric (including SI) prefixes	Scientific notation	Multiplying factor
giga (G)	10 ⁹	1 000 000 000
mega (M)	10 ⁶	1 000 000
kilo (k)	10 ³	1000
deci (d)	10 ⁻¹	0.1
centi (c)	10 ⁻²	0.01
milli (m)	10 ⁻³	0.001
micro (μ)	10 ⁻⁶	0.000001
nano (n)	10 ⁻⁹	0.000000001
pico (p)	10 ⁻¹²	0.000000000001

7. Acid–base indicators

Name	pH range	Colour change from lower pH to higher pH in range
thymol blue (1st change)	1.2–2.8	red → yellow
methyl orange	3.1–4.4	red → yellow
bromophenol blue	3.0–4.6	yellow → blue
methyl red	4.4–6.2	red → yellow
bromothymol blue	6.0–7.6	yellow → blue
phenol red	6.8–8.4	yellow → red
thymol blue (2nd change)	8.0–9.6	yellow → blue
phenolphthalein	8.3–10.0	colourless → pink

8. Representations of organic molecules

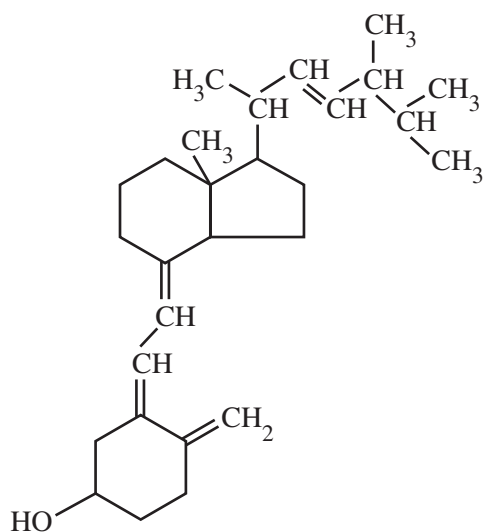
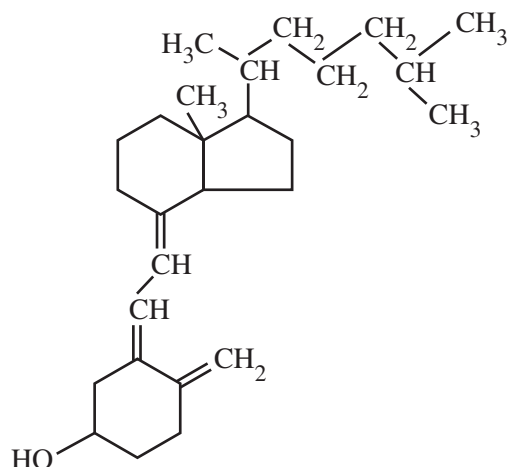
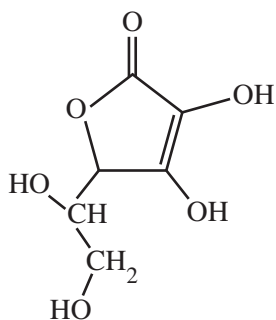
The following table shows different representations of organic molecules, using butanoic acid as an example.

Formula	Representation
molecular formula	$C_4H_8O_2$
structural formula	$ \begin{array}{ccccccc} & H & & H & & H & \\ & & & & & & \\ H & - C & - & C & - & C & - C \\ & & & & & & // \\ & H & & H & & H & O \\ & & & & & & \backslash \\ & & & & & & O-H \end{array} $
semi-structural (condensed) formula	$CH_3CH_2CH_2COOH$ or $CH_3(CH_2)_2COOH$
skeletal structure	

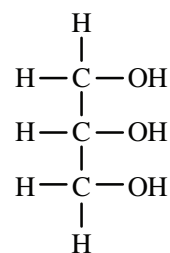
9. Formulas of some fatty acids

Name	Formula	Semi-structural formula
lauric	$C_{11}H_{23}COOH$	$CH_3(CH_2)_{10}COOH$
myristic	$C_{13}H_{27}COOH$	$CH_3(CH_2)_{12}COOH$
palmitic	$C_{15}H_{31}COOH$	$CH_3(CH_2)_{14}COOH$
palmitoleic	$C_{15}H_{29}COOH$	$CH_3(CH_2)_4CH_2CH=CHCH_2(CH_2)_5CH_2COOH$
stearic	$C_{17}H_{35}COOH$	$CH_3(CH_2)_{16}COOH$
oleic	$C_{17}H_{33}COOH$	$CH_3(CH_2)_7CH=CH(CH_2)_7COOH$
linoleic	$C_{17}H_{31}COOH$	$CH_3(CH_2)_4(CH=CHCH_2)_2(CH_2)_6COOH$
linolenic	$C_{17}H_{29}COOH$	$CH_3CH_2(CH=CHCH_2)_3(CH_2)_6COOH$
arachidic	$C_{19}H_{39}COOH$	$CH_3(CH_2)_{17}CH_2COOH$
arachidonic	$C_{19}H_{31}COOH$	$CH_3(CH_2)_4(CH=CHCH_2)_3CH=CH(CH_2)_3COOH$

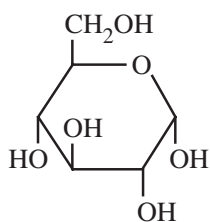
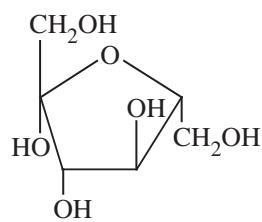
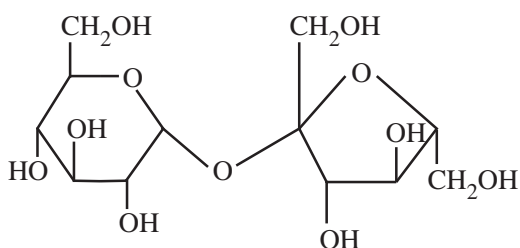
10. Formulas of some biomolecules

vitamin D₂ (ergocalciferol)vitamin D₃ (cholecalciferol)

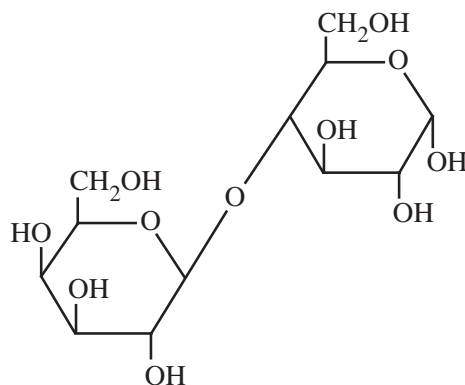
vitamin C (ascorbic acid)

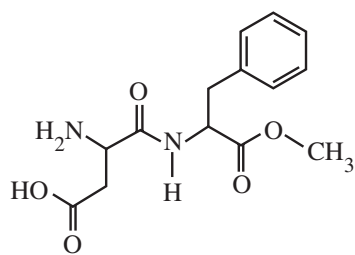


glycerol

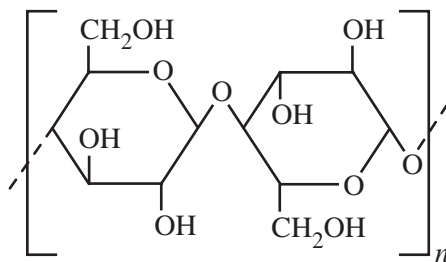
 α -glucose β -fructose

sucrose

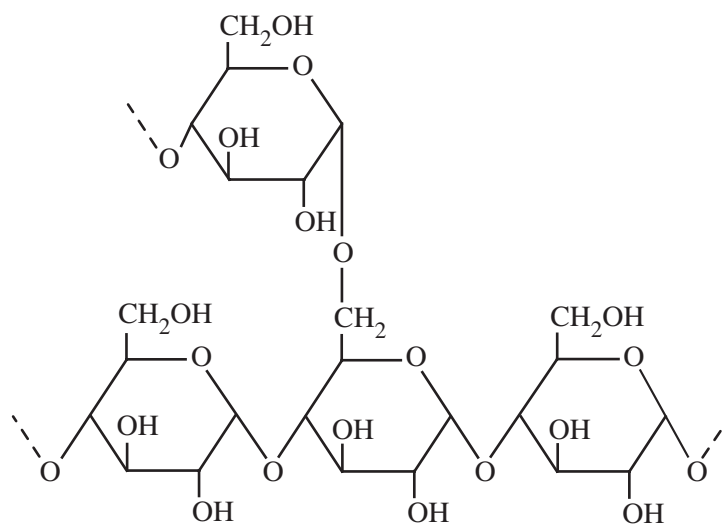
 α -lactose



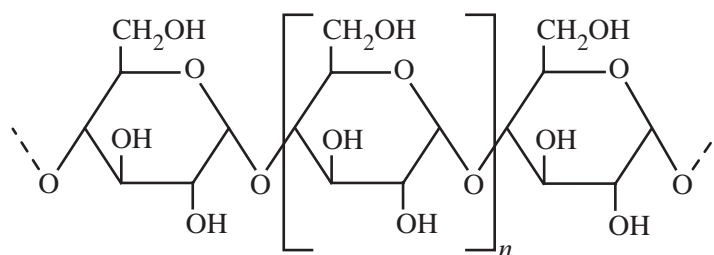
aspartame



cellulose



amylopectin (starch)



amylose (starch)

11. Heats of combustion of common fuels

The heats of combustion in the following table are calculated at SLC (25°C and 100 kPa) with combustion products being CO₂ and H₂O. Heat of combustion may be defined as the heat energy released when a specified amount of a substance burns completely in oxygen and is, therefore, reported as a positive value, indicating a magnitude. Enthalpy of combustion, ΔH , for the substances in this table would be reported as negative values, indicating the exothermic nature of the combustion reaction.

Fuel	Formula	State	Heat of combustion (kJ g ⁻¹)	Molar heat of combustion (kJ mol ⁻¹)
hydrogen	H ₂	gas	141	282
methane	CH ₄	gas	55.6	890
ethane	C ₂ H ₆	gas	51.9	1560
propane	C ₃ H ₈	gas	50.5	2220
butane	C ₄ H ₁₀	gas	49.7	2880
octane	C ₈ H ₁₈	liquid	47.9	5460
ethyne (acetylene)	C ₂ H ₂	gas	49.9	1300
methanol	CH ₃ OH	liquid	22.7	726
ethanol	C ₂ H ₅ OH	liquid	29.6	1360

12. Heats of combustion of common blended fuels

Blended fuels are mixtures of compounds with different mixture ratios and, hence, determination of a generic molar enthalpy of combustion is not realistic. The values provided in the following table are typical values for heats of combustion at SLC (25°C and 100 kPa) with combustion products being CO₂ and H₂O. Values for heats of combustion will vary depending on the source and composition of the fuel.

Fuel	State	Heat of combustion (kJ g ⁻¹)
kerosene	liquid	46.2
diesel	liquid	45.0
natural gas	gas	54.0

13. Energy content of food groups

Food	Heat of combustion (kJ g ⁻¹)
fats and oils	37
protein	17
carbohydrate	16

14. Characteristic ranges for infra-red absorption

Bond	Wave number (cm ⁻¹)	Bond	Wave number (cm ⁻¹)
C–Cl (chloroalkanes)	600–800	C=O (ketones)	1680–1850
C–O (alcohols, esters, ethers)	1050–1410	C=O (esters)	1720–1840
C=C (alkenes)	1620–1680	C–H (alkanes, alkenes, arenes)	2850–3090
C=O (amides)	1630–1680	O–H (acids)	2500–3500
C=O (aldehydes)	1660–1745	O–H (alcohols)	3200–3600
C=O (acids)	1680–1740	N–H (amines and amides)	3300–3500

15. ¹³C NMR data

Typical ¹³C shift values relative to TMS = 0

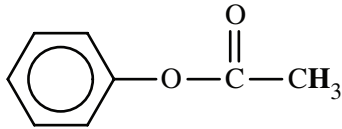
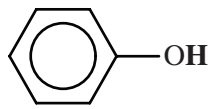
These can differ slightly in different solvents.

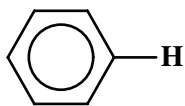
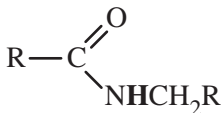
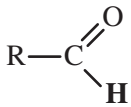
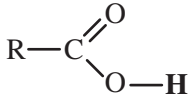
Type of carbon	Chemical shift (ppm)
R–CH ₃	8–25
R–CH ₂ –R	20–45
R ₃ –CH	40–60
R ₄ –C	36–45
R–CH ₂ –X	15–80
R ₃ C–NH ₂ , R ₃ C–NR	35–70
R–CH ₂ –OH	50–90
RC≡CR	75–95
R ₂ C=CR ₂	110–150
RCOOH	160–185
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C}=\text{O} \\ \diagup \\ \text{RO} \end{array}$	165–175
$\begin{array}{c} \text{R} \\ \diagdown \\ \text{C}=\text{O} \\ \diagup \\ \text{H} \end{array}$	190–200
R ₂ C=O	205–220

16. ^1H NMR data

Typical proton shift values relative to TMS = 0

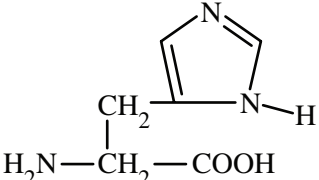
These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

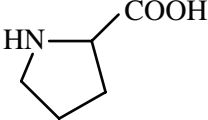
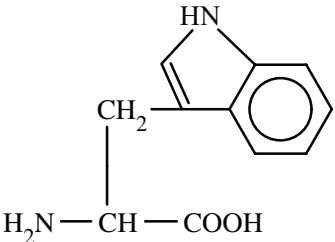
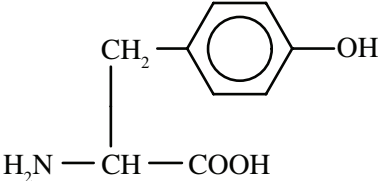
Type of proton	Chemical shift (ppm)
$\text{R}-\text{CH}_3$	0.9–1.0
$\text{R}-\text{CH}_2-\text{R}$	1.3–1.4
$\text{RCH}=\text{CH}-\text{CH}_3$	1.6–1.9
R_3-CH	1.5
$\text{CH}_3-\text{C}(=\text{O})\text{OR}$ or $\text{CH}_3-\text{C}(=\text{O})\text{NHR}$	2.0
$\text{R}-\text{C}(=\text{O})\text{CH}_3$	2.1–2.7
$\text{R}-\text{CH}_2-\text{X}$ (X = F, Cl, Br or I)	3.0–4.5
$\text{R}-\text{CH}_2-\text{OH}$, $\text{R}_2-\text{CH}-\text{OH}$	3.3–4.5
$\text{R}-\text{C}(=\text{O})\text{NHCH}_2\text{R}$	3.2
$\text{R}-\text{O}-\text{CH}_3$ or $\text{R}-\text{O}-\text{CH}_2\text{R}$	3.3–3.7
	2.3
$\text{R}-\text{C}(=\text{O})\text{OCH}_2\text{R}$	3.7–4.8
$\text{R}-\text{O}-\text{H}$	1–6 (varies considerably under different conditions)
$\text{R}-\text{NH}_2$	1–5
$\text{RHC}=\text{CHR}$	4.5–7.0
	4.0–12.0

Type of proton	Chemical shift (ppm)
	6.9–9.0
	8.1
	9.4–10.0
	9.0–13.0

17. 2-amino acids (α -amino acids)

The table below provides simplified structures to enable the drawing of zwitterions, the identification of products of protein hydrolysis and the drawing of structures involving condensation polymerisation of amino acid monomers.

Name	Symbol	Structure
alanine	Ala	$\begin{array}{c} \text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
arginine	Arg	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}-\text{C}(=\text{NH})-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
asparagine	Asn	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
aspartic acid	Asp	$\begin{array}{c} \text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
cysteine	Cys	$\begin{array}{c} \text{CH}_2-\text{SH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamic acid	Glu	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamine	Gln	$\begin{array}{c} \text{O} \\ \\ \text{CH}_2-\text{CH}_2-\text{C}-\text{NH}_2 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glycine	Gly	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$
histidine	His	 $\begin{array}{c} \text{CH}_2-\text{COOH} \\ \\ \text{H}_2\text{N}-\text{CH}_2-\text{COOH} \end{array}$
isoleucine	Ile	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_3 \\ \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$

Name	Symbol	Structure
leucine	Leu	$ \begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\ \\ \text{CH}_2 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
lysine	Lys	$ \begin{array}{c} \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{NH}_2 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
methionine	Met	$ \begin{array}{c} \text{CH}_2 - \text{CH}_2 - \text{S} - \text{CH}_3 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
phenylalanine	Phe	$ \begin{array}{c} \text{CH}_2 - \text{C}_6\text{H}_5 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
proline	Pro	
serine	Ser	$ \begin{array}{c} \text{CH}_2 - \text{OH} \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
threonine	Thr	$ \begin{array}{c} \text{CH}_3 - \text{CH} - \text{OH} \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	$ \begin{array}{c} \text{CH}_3 - \text{CH} - \text{CH}_3 \\ \\ \text{H}_2\text{N} - \text{CH} - \text{COOH} \end{array} $

END OF DATA BOOKLET

VCE Chemistry Units 3&4

Written Examination

Multiple-choice Answer Sheet

Student's Name: _____

Teacher's Name: _____

Instructions

Use a **pencil** for **all** entries. If you make a mistake, **erase** the incorrect answer – **do not** cross it out. Marks will **not** be deducted for incorrect answers.

No mark will be given if more than **one** answer is completed for any question.

All answers must be completed like this example:

A	B	C	D
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Use pencil only

1	A	B	C	D
2	A	B	C	D
3	A	B	C	D
4	A	B	C	D
5	A	B	C	D
6	A	B	C	D
7	A	B	C	D
8	A	B	C	D
9	A	B	C	D
10	A	B	C	D

11	A	B	C	D
12	A	B	C	D
13	A	B	C	D
14	A	B	C	D
15	A	B	C	D
16	A	B	C	D
17	A	B	C	D
18	A	B	C	D
19	A	B	C	D
20	A	B	C	D

21	A	B	C	D
22	A	B	C	D
23	A	B	C	D
24	A	B	C	D
25	A	B	C	D
26	A	B	C	D
27	A	B	C	D
28	A	B	C	D
29	A	B	C	D
30	A	B	C	D