2024 NHT

SUPERVISOR TO ATTACH
PROCESSING LABEL HERE

Write your **student number** in the boxes above. **Letter**

Chemistry

Question and Answer Book

VCE (NHT) Examination – Wednesday 22 May 2024

- Reading time is **15 minutes**: 2.00 pm to 2.15 pm
- Writing time is **2 hours 30 minutes**: 2.15 pm to 4.45 pm

Approved materials

- One scientific calculator

Materials supplied

- Question and Answer book of 36 pages
- Data Book
- Multiple-Choice Answer Sheet

Instructions

- Follow the instructions on your Multiple-Choice Answer Sheet.
- At the end of the examination, place your Multiple-Choice Answer Sheet inside the front cover of this book.

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

Contents

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

Section A – Multiple-choice questions

Instructions

- Answer **all** questions in pencil on your Multiple-Choice Answer Sheet.
- 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 book are **not** drawn to scale.

Question 1

Which one of the following correctly compares fuel cells and galvanic cells?

	Galvanic cells	Fuel cells
A.	use a stored supply of reactants	use a continuous supply of reactants
B.	use a continuous supply of reactants	use a stored supply of reactants
C.	convert electrical energy into chemical energy	convert chemical energy into electrical energy
D.	convert chemical energy into electrical energy	convert electrical energy into chemical energy

Question 2

Which value can be calculated with data from a calorimeter?

A. the standard electrode potential of a redox reaction

B. the equilibrium constant of a chemical reaction

C. the calibration factor of a chemical reaction

D. the enthalpy change of a chemical reaction

Question 3

Which one of the following statements is true of a scientific poster?

A. The discussion section should identify outliers in the results.

B. The introduction section should present the experimental procedures.

C. The conclusion section should explain background chemical concepts.

D. The results section should compare results with theoretical expectations.

Question 4

Catalysts

A. increase the potential energy of the reactants in a reaction.

B. shift the equilibrium position of the reaction.

C. change the activation energy of the reaction.

D. stabilise the products of the reaction.

Question 5

Collision theory

A. applies only to gases at standard temperature and pressure.

B. explains why particles with a smaller surface area have a greater rate of reaction.

C. asserts that a reaction only occurs if reactant molecules collide with kinetic energy at least equal to the activation energy.

D. predicts that increasing the temperature increases the proportion of reactant particles that collide in the correct orientation.

Question 6

Two substances are added to a test tube. When the reactants are mixed, the test tube becomes colder.

Which one of the following is the correct description of the chemical reaction that occurs in the test tube?

	Reaction type	Energy is converted to mass
A.	exothermic	yes
B.	exothermic	no
C.	endothermic	yes
D.	endothermic	no

Question 7

What is the pressure of 3.0 mol of a gas in a 60 L container at 127 °C?

A. 6.0×10^5 kPa

B. 1.9×10^5 kPa

C. 1.7×10^2 kPa

D. 5.3×10 kPa

Question 8

Faraday's first law of electrolysis states, 'the amount of substance produced at each electrode is directly proportional to the quantity of charge flowing through the cell'.

Source: <www.chem.libretexts.org>

Which one of the following variables should be measured in an electrolytic cell to test Faraday's first law of electrolysis?

A. current through the circuit

B. change in electrode volume

C. voltage across the electrodes

D. change in solution temperature

Question 9

When 5.0 g of ethanol, $C_2H_5OH(l)$, undergoes complete combustion in air, the mass of carbon dioxide, CO_2, gas produced is

A. 2.4 g

B. 4.8 g

C. 9.6 g

D. 19 g

Question 10

Consider the following statements.

1 An energy profile diagram represents the enthalpy changes of an exothermic and an endothermic reaction.

2 Exothermic reactions have a higher activation energy barrier than endothermic reactions.

Which of the statements is/are always true?

A. 1 only

B. 2 only

C. both 1 and 2

D. neither 1 nor 2

Question 11

A solution of 0.125 M methanamine, CH_5N, reacts with 50.0 mL of a 0.200 M hydrochloric acid, HCl, solution in a titration.

What volume of the CH_5N solution is required to fully react with the HCl solution?

A. 0.050 L

B. 0.080 L

C. 0.100 L

D. 0.125 L

Question 12

Which one of the following statements regarding fuel cells is correct?

A. The state of the electrolyte can be aqueous, liquid or solid.

B. The porous electrodes decrease the contact area for the reactants.

C. During operation, gases move through the membrane.

D. During operation, the cell voltage decreases because the reactants are used up.

Question 13

The three unknown organic substances, X, Y and Z, were tested for their flashpoints. X had the highest flashpoint and Z had the lowest flashpoint.

Consider the boiling points and viscosities of X, Y and Z.

Which one of the following would show the same trend as the flashpoint?

A. viscosity only

B. boiling point only

C. boiling point and viscosity

D. neither boiling point nor viscosity

Question 14

Which one of the following statements is correct for **both** electrolytic cells and galvanic cells?

A. The anode is negative.

B. The half-cells must be separated.

C. The overall chemical reaction is exothermic.

D. Electrons move from the anode to the cathode.

Question 15

A sample of gas occupies a volume of 10.0 L at 25 °C and a pressure of 2.0 atm. The temperature of the gas is increased to 50 °C at constant pressure.

Which one of the following is closest to the new gas volume after the temperature increase?

A. 5.0 L

B. 10 L

C. 20 L

D. 40 L

Question 16

When a fat molecule is hydrolysed, three

A. ester groups are formed.

B. carboxyl groups are formed.

C. water molecules are formed.

D. glycerol molecules are formed.

Question 17

The results below were recorded using a bomb calorimeter.

Voltage	4.50 V
Current	2.00 A
Time	2.00 min
Temperature change	1.50 °C

What is the value of the calibration factor for the bomb calorimeter in J °C^{-1}?

A. 12
B. 27
C. 720
D. 1080

Use the following information to answer Questions 18 and 19.

HPLC is used to separate a mixture containing methyl ethanoate, propanoic acid and butan-1-ol. This technique uses a polar stationary phase and a non-polar mobile phase to achieve separation.

Question 18

Which one of the following options describes the state of the mobile phase and lists the three molecules in order of retention time from shortest to longest?

	State of mobile phase	Order of retention time from shortest to longest
A.	gas	propanoic acid, methyl ethanoate, butan-1-ol
B.	gas	methyl ethanoate, butan-1-ol, propanoic acid
C.	liquid	propanoic acid, methyl ethanoate, butan-1-ol
D.	liquid	methyl ethanoate, butan-1-ol, propanoic acid

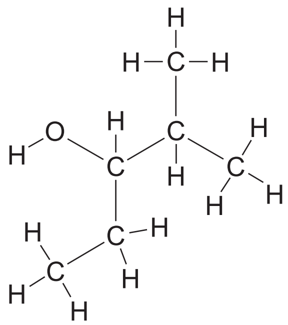
Question 19

Which one of the following options is correct?

A. The sample is vaporised before passing through the stationary phase.
B. A calibration curve can be used to identify each component of the mixture.
C. Pressure is applied to overcome resistance of the mobile phase in the column.
D. A high retention time indicates that a component is highly attracted to the mobile phase.

Do not write in this area.

Question 20



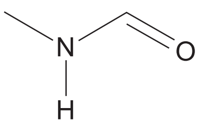
Which one of the following shows the correct IUPAC name and type of alcohol for the molecule above?

	Systematic IUPAC name	Type of alcohol
A.	2-methylpentan-3-ol	secondary
B.	4-methylpentan-3-ol	secondary
C.	2-methylpentan-3-ol	tertiary
D.	4-methylpentan-3-ol	tertiary

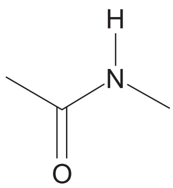
Question 21

Which one of the following skeletal formulas represents a product of the condensation reaction between methanoic acid and ethanamine?

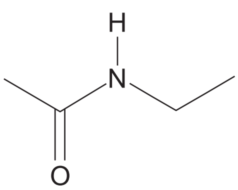
A.



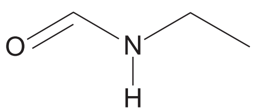
B.



C.



D.



Question 22

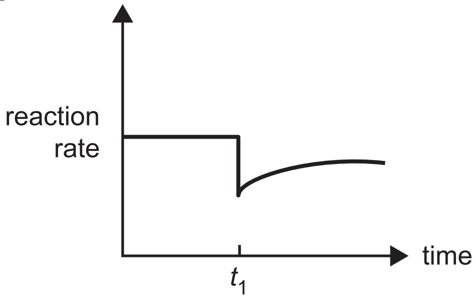
Consider the following reaction.

$$J(g) + L(g) \rightleftharpoons T(g); \qquad \Delta H \text{ is negative}$$

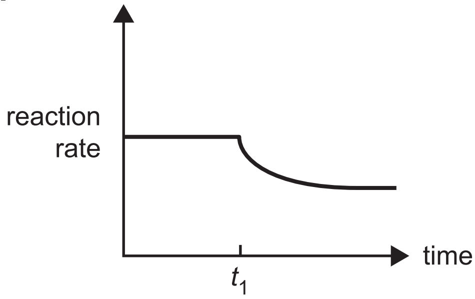
A reaction vessel containing J(g), L(g) and T(g) is initially at equilibrium. At time t_1, the temperature of the reaction vessel is increased.

Which graph best shows how the rate of the forward reaction changes after t_1?

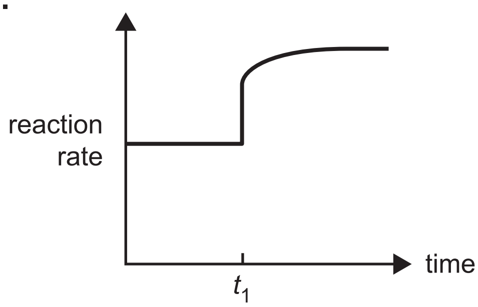
A.



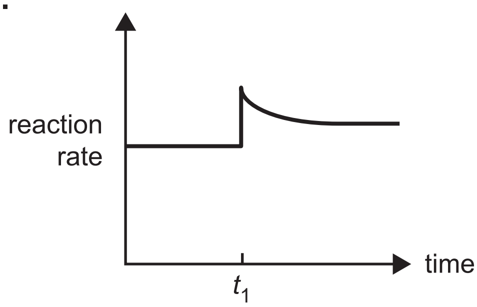
B.



C.



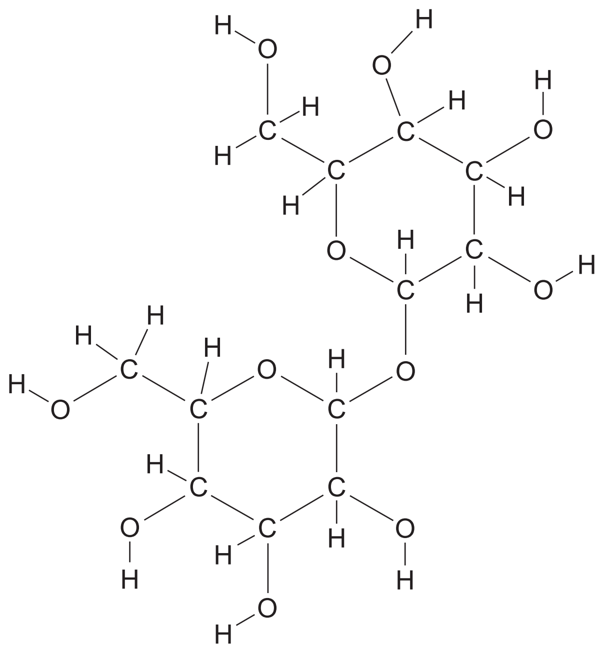
D.



Question 23

Trehalose, $C_{12}H_{22}O_{11}$, is a molecule found in mushrooms. Its molar mass is 342.0 g mol^{-1}. Almost all humans produce an enzyme in their small intestines called trehalase, which breaks trehalose down into smaller molecules.

The structural formula of trehalose is shown below.



Which of the following statements regarding trehalose is/are correct?

1 The products of trehalose digestion can be hydrolysed to form glycogen.

2 Eating trehalose causes an increase in blood glucose levels in most people.

3 Digestion of trehalose produces two products that have a total molar mass of 324.0 g mol^{-1}.

A. 1 only

B. 2 only

C. 1 and 3

D. 2 and 3

Question 24

Which one of the following statements about energy profile diagrams is correct?

A. The horizontal axis of an energy profile diagram is labelled 'Time'.

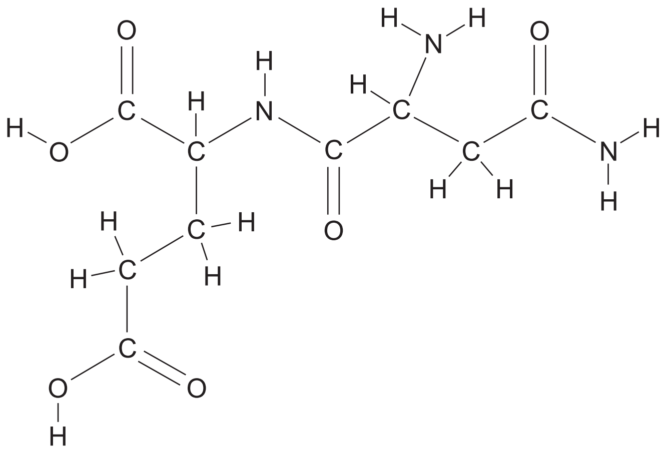
B. The shape of the energy profile diagram is not changed if one reactant is in excess.

C. The energy profile diagram represents the average chemical energy of a reaction mixture.

D. The energy profile diagram for a chemical reaction can be determined using a bomb calorimeter.

Question 25

A dipeptide is shown below.



The correct names for the two amino acid residues in the dipeptide are

A. glutamine and asparagine.

B. glutamine and aspartic acid.

C. glutamic acid and asparagine.

D. glutamic acid and aspartic acid.

Question 26

One molecule of chlorine gas, Cl_2, reacts with one molecule of 2-methylbutane, C_5H_{12}, in the presence of UV light.

The number of possible products that have an optical isomer is

A. zero.

B. one.

C. two.

D. three.

Question 27

Lithium-ion cells are secondary cells used in mobile phones.

Which one of the following statements about lithium-ion cells is correct?

A. The extent of reaction increases after each recharge.

B. A high battery voltage indicates a high rate of reaction.

C. A high battery voltage indicates a high extent of reaction.

D. The battery current is affected by the surface area of the electrodes.

NHT

Question 28

The Maxwell-Boltzmann distribution describes a particular sample of gas.

The area under the Maxwell-Boltzmann distribution curve represents the

A. total number of particles in the sample.

B. temperature of the particles in the sample.

C. chemical energy of the particles in the sample.

D. collision frequency of the particles in the sample.

Question 29

Consider the methanol-oxygen, CH_3OH/O_2, fuel cell and an experimental galvanic cell. Both the fuel cell and the experimental galvanic cell are at standard laboratory conditions (SLC) and use an acidic electrolyte. The experimental galvanic cell is constructed using the following cell set up.

$$CH_3OH(aq) \mid CO_2(g) \parallel HCrO_4(aq) \mid Cr^{3+}(aq)$$

Which one of the following statements is correct for every mole of CH_3OH reacted?

A. At the positive electrode, the same amounts of water are produced in both cells.

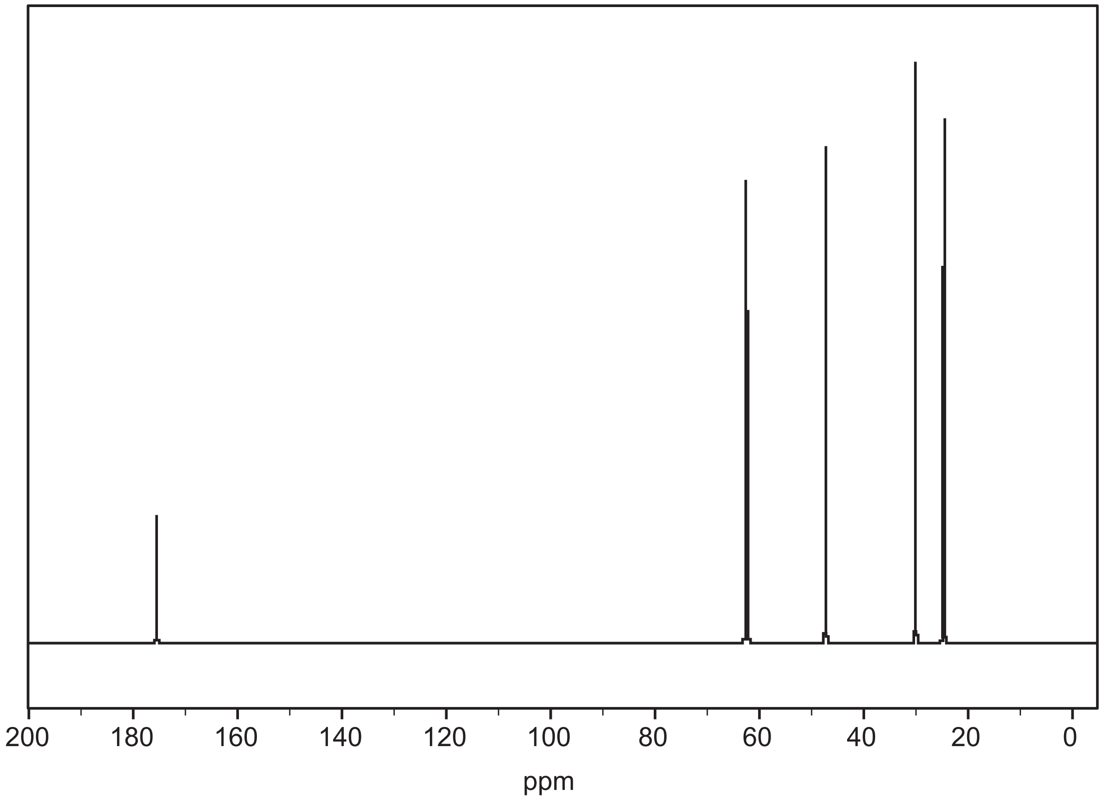
B. At the negative electrode, the same amounts of greenhouse gases are produced in both cells.

C. At the negative electrode, the amount of greenhouse gases produced is lower in the experimental galvanic cell than in the fuel cell.

D. At the positive electrode, the amount of water produced is lower in the experimental galvanic cell than in the fuel cell.

Question 30

Five peaks in the ^{13}C NMR spectrum of a pure amino acid are shown below.



Source: <sdbs.db.aist.go.jp>

The amino acid is

A. valine.

B. proline.

C. glutamic acid.

D. aspartic acid.

End of Section A

N
H
T

Do not write in this area.

Section B

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 (6 marks)

a. Soybeans contain all the essential amino acids.

What is an essential amino acid? 1 mark

b. Trypsin is an enzyme in the human body that helps to break down proteins.
Raw soybeans contain a blocker protein that stops this function of trypsin. However, trypsin can help break down the proteins in soybeans that are boiled in water.

State what happens to the structure of the blocker protein when soybeans are boiled in water. Explain the molecular changes that occur during this process. 3 marks

Question 1 continues on the next page.

c. Soybeans contain Vitamin C.

State how boiling soybeans in water affects their Vitamin C content. Explain your answer with reference to the structure of Vitamin C. 2 marks

Question 2 (13 marks)

The nutrition content of a ripe banana is shown in the table below.

Food component	Mass per 100 g of banana
Total carbohydrates	22.8 g
Total fats	0.30 g
Protein	1.1 g

Source: adapted from <www.drlogy.com>

a. Use the information in the table to calculate the energy content of the ripe banana in kilojoules per gram. 2 marks

b. Banana cells respire in the same way as human cells.

Write the balanced equation for cellular respiration. 1 mark

Question 2 continues on the next page.

c. Sucrose is one of the chemical substances that make ripe bananas taste sweet. Aspartame is an ester used as an artificial sweetener.

i. Draw the structural formula of the smallest product formed when aspartame is hydrolysed. 1 mark

ii. Compare the energy content per gram and glycaemic index of aspartame and sucrose. Explain any differences. 3 marks

d. The fatty acids found in a ripe banana include lauric acid, linoleic acid and linolenic acid.

i. Which of these fatty acids would most readily undergo oxidative rancidity? Justify your answer. 3 marks

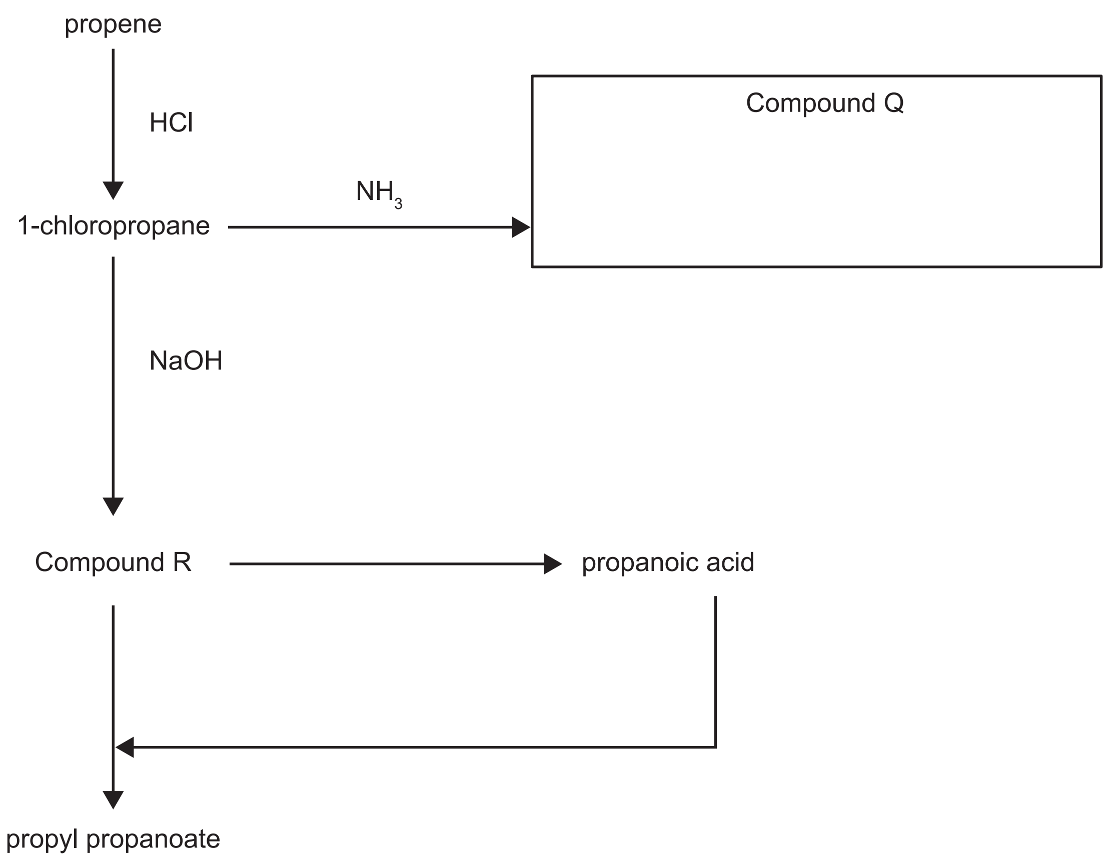
ii. Write the molecular formula of the triglyceride made from three lauric acid molecules. 1 mark

e. Bananas contain Vitamin B_3, which is used in the human body to form a coenzyme, NADH.

Explain how coenzymes assist enzyme-catalysed chemical reactions in the body. 2 marks

Question 3 (11 marks)

The diagram below shows a reaction pathway starting with propene.



a. Propene can react with hydrochloric acid, HCl, to form 1-chloropropane. Name the type of reaction that forms 1-chloropropane. 1 mark

b. 1-chloropropane reacts with ammonia, NH_3, to produce Compound Q.

i. Write the balanced equation for the reaction that produces Compound Q from 1-chloropropane. States are not required. 2 marks

ii. Write the IUPAC name of Compound Q in the box provided in the diagram above. 1 mark

iii. Calculate the percentage atom economy for this reaction. 3 marks

c. Compound R can be formed from 1-chloropropane.

Draw the structural formula of Compound R. 1 mark

d. Compound R can react to form propanoic acid.

Identify the reagent(s) required for this reaction. 1 mark

e. Compound R and propanoic acid react to form propyl propanoate.

i. Draw the skeletal formula for propyl propanoate. 1 mark

ii. Identify the other product formed in this reaction. 1 mark

Question 4 (11 marks)

Nickel-hydrogen cells are rechargeable.

The following half-cell reactions occur in the nickel-hydrogen cell.

$$NiOOH(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq) \qquad E^0 = 0.52\ V$$

$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2(g) \qquad E^0 = -0.83\ V$$

a. Identify the oxidising agent of the nickel-hydrogen cell during discharge. Justify your answer using oxidation numbers. 2 marks

b. Identify a suitable material for the negative electrode of a nickel-hydrogen cell. 1 mark

c. Write the overall recharge reaction for the nickel-hydrogen cell. 2 marks

d. State the voltage required to recharge the nickel-hydrogen cell under standard conditions. 1 mark

e. State how the operation of the nickel-hydrogen cell changes when it is nearing the end of its cell life. 1 mark

f. Explain how oxygen can be produced in the nickel-hydrogen cell. Include the relevant half-cell equation in your answer. 2 marks

g. Explain why the production of oxygen in the cell does not present a problem for the operation of the nickel-hydrogen cell. Do not refer to safety considerations in your answer. 2 marks

Question 5 (7 marks)

Nitrogen dioxide, $NO_2(g)$, forms dinitrogen tetroxide, $N_2O_4(g)$, in an equilibrium system according to the chemical reaction below.

$$2NO_2(g) \rightleftharpoons N_2O_4(g); \qquad \Delta H = -58 \text{ kJ mol}^{-1}$$

a. Write the expression for the equilibrium constant, K_c, for the reaction above. 1 mark

b. 0.25 mol of $NO_2(g)$ is placed into an evacuated and sealed container with a volume of 4.0 L at 25 °C. The reaction proceeds until it reaches equilibrium. At equilibrium, there is 1.49×10^{-2} mol $N_2O_4(g)$ in the reaction container.

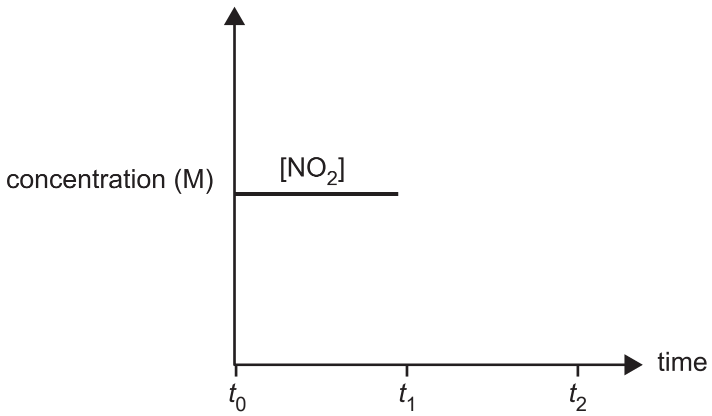
Calculate the equilibrium constant, K_c, at 25 °C. 3 marks

Do not write in this area.

c. The following occurs in the system:

- Between t_0 and t_1, the system is at equilibrium.
- At t_1, additional $NO_2(g)$ is added into the container.
- The system re-establishes equilibrium at t_2.

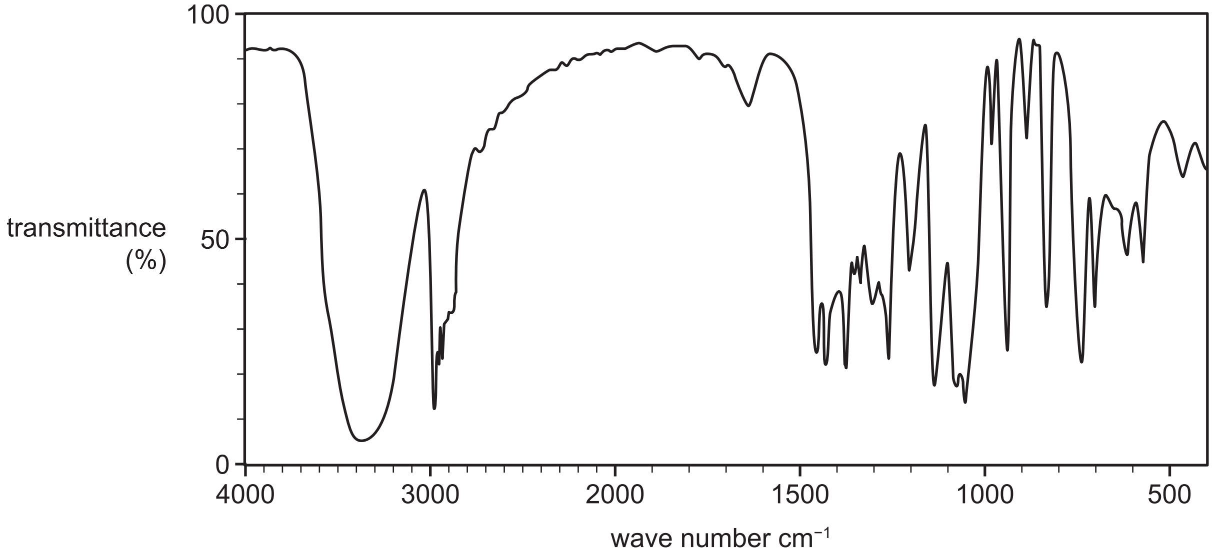
On the graph below, draw the concentration of $NO_2(g)$ from time t_1 until after equilibrium is re-established at t_2. 3 marks



Question 6 (10 marks)

A **non-cyclic** organic compound is analysed using different types of spectroscopy. The compound contains one chlorine atom and does not contain any nitrogen atoms.

The infrared (IR) spectrum of the compound is shown below.

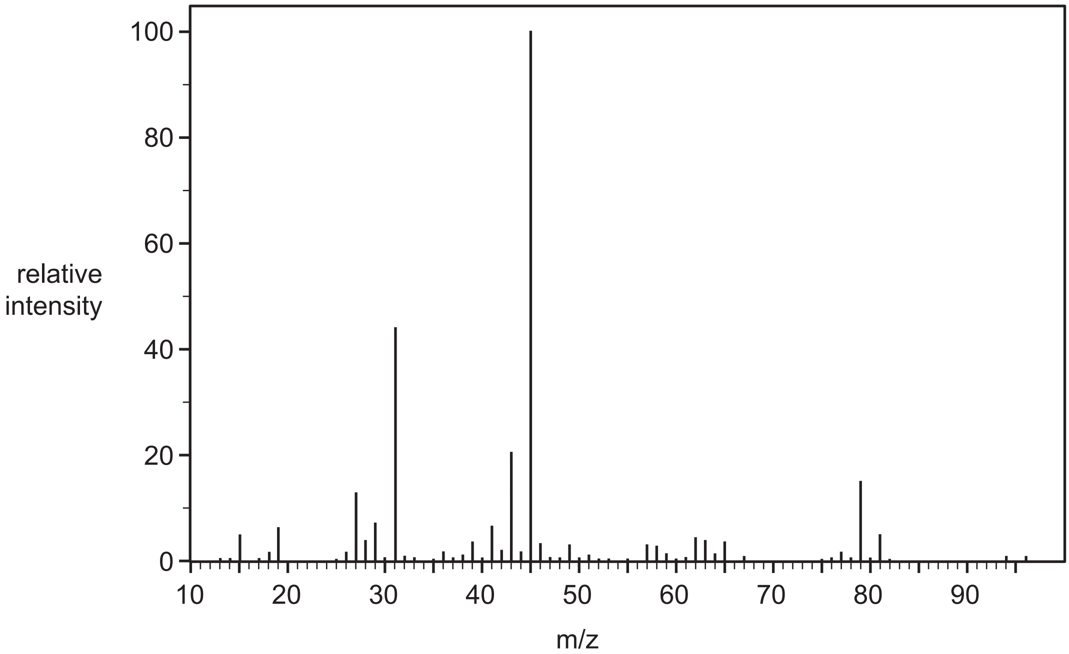


Source: <sdbs.db.aist.go.jp>

a. The molecule includes a chloro functional group.

What does the spectrum indicate about **one** other (non C-H) functional group that is in the compound? Give your reasoning. 2 marks

b. The mass spectrum for the chemical is shown below.



Source: adapted from <sdbs.db.aist.go.jp>

i. State the m/z of the base peak. 1 mark

ii. The peaks with the highest m/z values are at 94 and 96. Explain the presence of these two peaks. 2 marks

Question 6 continues on the next page.

c. The ^{1}H NMR spectrum of the compound consists of four distinct peaks. The chemical shift and the relative peak area of each peak are summarised in the table below.

Chemical shift (ppm)	**Relative peak area**
1.3	3
3.2	1
3.5	2
4.0	1

Identify **one** piece of information from the table and explain how it relates to the structure of the compound. 2 marks

d. Draw the structural formula of a compound that is consistent with the ^{1}H NMR, the mass spectrum and the IR spectrum. Your structure must contain one chlorine atom and no nitrogen atoms. 1 mark

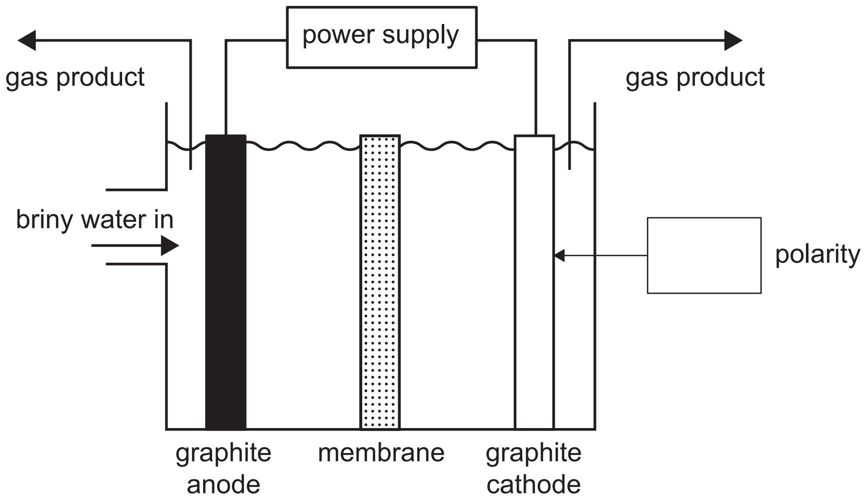
e. Without using your answers to **parts a** or **c**, explain **two** ways in which your structure in **part d** is consistent with the spectrum information given above. 2 marks

Question 7 (9 marks)

Lithium hydroxide, $LiOH(aq)$, is used in a range of industries.

Concentrated solutions of lithium chloride, $LiCl(aq)$, found deep underground are referred to as briny water. Briny water can be electrolysed industrially to produce $LiOH(aq)$.

A simplified diagram of a briny water electrolytic cell is shown below.



Source: <www.mdpi.com>

a. In the box provided in the diagram, label the polarity of the cathode. 1 mark

b. State **one** function of the membrane in the briny water electrolytic cell. 1 mark

c. Chlorine gas, $Cl_2(g)$, is produced at the anode. What gas is produced at the cathode? 1 mark

d. Describe how the operation of the cell would change if the graphite anode was replaced with a zinc anode. State any relevant chemical equation(s). 3 marks

Question 7 continues on the next page.

e. Calculate the time required, in seconds, to produce 0.500 g of $Cl_2(g)$ in the briny water electrolytic cell when a current of 0.895 A passes through the cell. 3 marks

Question 8 (15 marks)

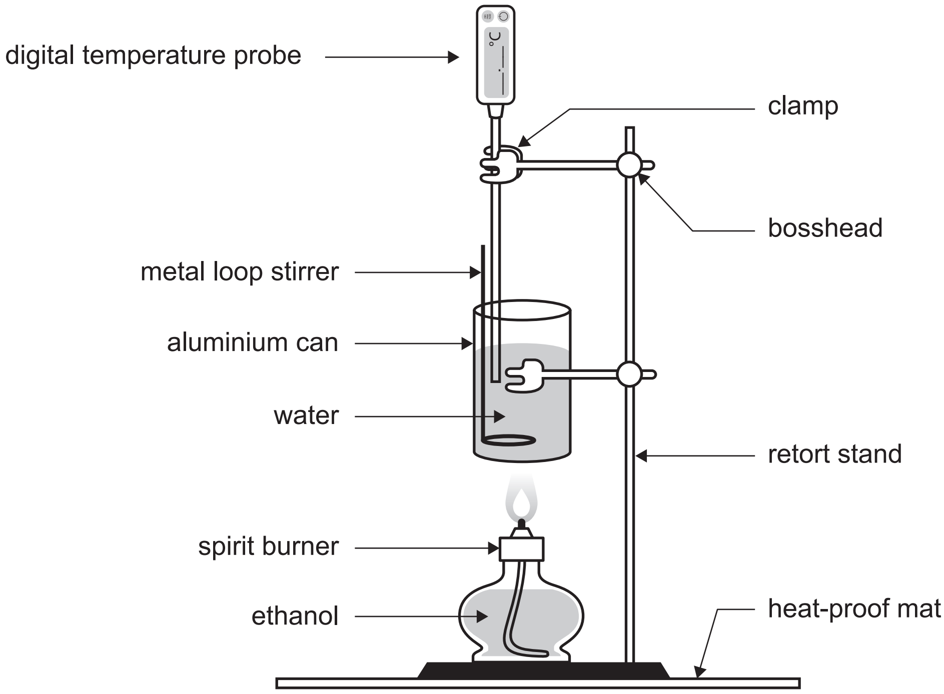
A VCE student performs an experiment to determine how the structure of an alcohol affects its molar heat of combustion.

Aim

To determine how the structure of an alcohol affects its molar heat of combustion.

Method

1. Half-fill a clean spirit burner with pure ethanol, C_2H_5OH.
2. Use an electronic balance to measure and record the initial mass (in grams) of the spirit burner and C_2H_5OH to three decimal places.
3. Clamp a clean aluminium can to a retort stand as shown in the diagram below. Ensure that the aluminium can is 3 cm above the string of the spirit burner.



4. Measure 100 mL of deionised water with a measuring cylinder. Pour the deionised water into the aluminium can.
5. Record the initial temperature of the deionised water.
6. Light the string of the spirit burner. Stir the water in the aluminium can continuously with the metal loop stirrer while the string is lit.
7. Record the temperature of the deionised water every 30 seconds.
8. When the temperature has increased by 15 °C, extinguish the flame.
9. Continue stirring the water until the temperature of the water starts to decrease.
10. Record the highest temperature reached by the 100 mL of deionised water.
11. When the spirit burner has cooled down to room temperature, record the new mass of the spirit burner and ethanol to three decimal places.
12. Repeat steps 1 to 11 with propan-1-ol, C_3H_7OH.
13. Repeat steps 1 to 11 with butan-1-ol, C_4H_9OH.

Question 8 continues on the next page.

The student's results for the experiment are shown in the table below.

	Type of alcohol		
Measurement	**Ethanol**	**Propan-1-ol**	**Butan-1-ol**
Initial temperature of deionised water (°C)	22.00	25.20	23.20
Final temperature of deionised water (°C)	37.50	40.20	38.20
Initial mass of spirit burner and fuel (g)	214.655	210.099	218.556
Final mass of spirit burner and fuel (g)	214.263	209.713	218.173

a. Identify the independent variable. 1 mark

b. What properties of this variable are linked to the aim? 1 mark

c. Use the results in the table to calculate the experimental heat of combustion of butan-1-ol in kJ g^{-1}. 4 marks

NHT

Do not write in this area.

d. Carbon monoxide gas, $CO(g)$, can be produced when C_4H_9OH burns in air.

i. Write a balanced chemical equation to show the formation of $CO(g)$ from C_4H_9OH. 2 marks

ii. Explain why $CO(g)$ inhalation can result in poisoning. Refer to the chemical concepts you studied this year in your answer. 2 marks

iii. Identify **one** way the student could minimise the danger of inhaling $CO(g)$ while doing this experiment. 1 mark

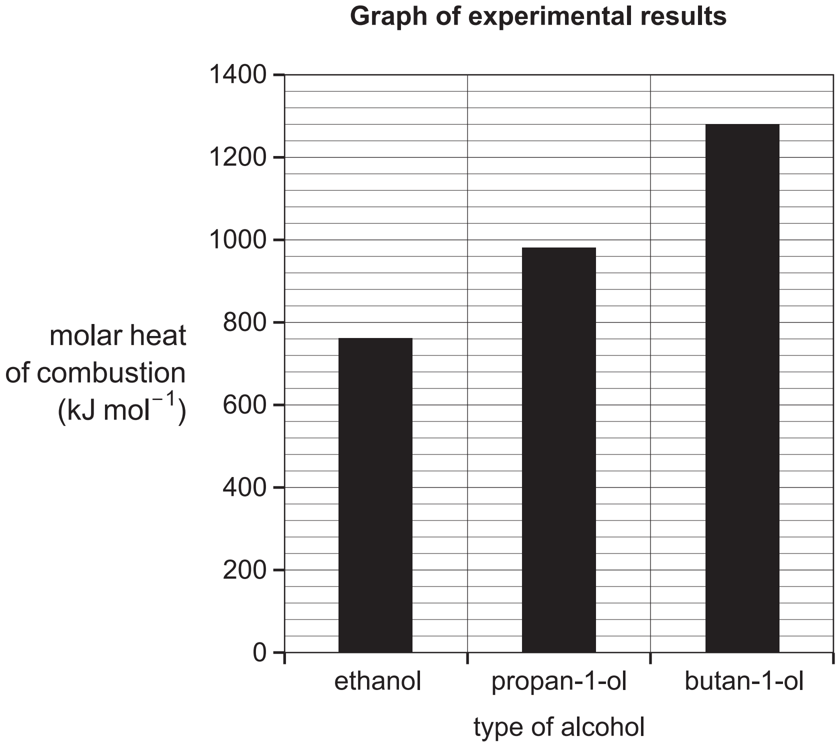
e. Heat loss from the system causes experimental errors.

i. Identify **one** other possible source of experimental error in this experiment. 1 mark

ii. Explain how the error identified in **part e.i** could affect the accuracy of the measurements made in the experiment. 2 marks

Question 8 continues on the next page.

f. The student's experimental results are shown in the graph below.



Write a valid conclusion for this experiment based on the experimental results. 1 mark

____

____

____

NHT

Do not write in this area.

Question 9 (8 marks)

a. 'Research suggests that biofuel production may give rise to several undesirable effects. Potential drawbacks include changes to land use patterns that may increase greenhouse gas emissions.'

Source: <www.epa.gov>

Evaluate the benefits of using biofuels instead of fossil fuels in terms of greenhouse gas emissions. 5 marks

Question 9 continues on the next page.

b. ‘Biodiesel can be blended and used in many different concentrations. The most common are B5 (up to 5% biodiesel) and B20 (6% to 20% biodiesel). B100 (pure biodiesel) is typically used as a blendstock to produce lower percentage blends and is rarely used as a transportation fuel.’

Source: <afdc.energy.gov>

Use the chemical structure of biodiesel and diesel to discuss why B100 is rarely used as a transportation fuel. 3 marks

End of examination questions

This page is blank.

2 0 2 4
N H T

Chemistry

Data Book

Contents pages

You may keep this Data Book.

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

This page is blank.

1. Periodic table of the elements

Key	
79	atomic number
Au	symbol of element
197.0	relative atomic mass
gold	name of element

1 H 1.0 hydrogen																	2 He 4.0 helium
3 Li 6.9 lithium	4 Be 9.0 beryllium											5 B 10.8 boron	6 C 12.0 carbon	7 N 14.0 nitrogen	8 O 16.0 oxygen	9 F 19.0 fluorine	10 Ne 20.2 neon
11 Na 23.0 sodium	12 Mg 24.3 magnesium											13 Al 27.0 aluminium	14 Si 28.1 silicon	15 P 31.0 phosphorus	16 S 32.1 sulfur	17 Cl 35.5 chlorine	18 Ar 39.9 argon
19 K 39.1 potassium	20 Ca 40.1 calcium	21 Sc 45.0 scandium	22 Ti 47.9 titanium	23 V 50.9 vanadium	24 Cr 52.0 chromium	25 Mn 54.9 manganese	26 Fe 55.8 iron	27 Co 58.9 cobalt	28 Ni 58.7 nickel	29 Cu 63.5 copper	30 Zn 65.4 zinc	31 Ga 69.7 gallium	32 Ge 72.6 germanium	33 As 74.9 arsenic	34 Se 79.0 selenium	35 Br 79.9 bromine	36 Kr 83.8 krypton
37 Rb 85.5 rubidium	38 Sr 87.6 strontium	39 Y 88.9 yttrium	40 Zr 91.2 zirconium	41 Nb 92.9 niobium	42 Mo 96.0 molybdenum	43 Tc (98) technetium	44 Ru 101.1 ruthenium	45 Rh 102.9 rhodium	46 Pd 106.4 palladium	47 Ag 107.9 silver	48 Cd 112.4 cadmium	49 In 114.8 indium	50 Sn 118.7 tin	51 Sb 121.8 antimony	52 Te 127.6 tellurium	53 I 126.9 iodine	54 Xe 131.3 xenon
55 Cs 132.9 caesium	56 Ba 137.3 barium	57–71 lanthanoids	72 Hf 178.5 hafnium	73 Ta 180.9 tantalum	74 W 183.8 tungsten	75 Re 186.2 rhenium	76 Os 190.2 osmium	77 Ir 192.2 iridium	78 Pt 195.1 platinum	79 Au 197.0 gold	80 Hg 200.6 mercury	81 Tl 204.4 thallium	82 Pb 207.2 lead	83 Bi 209.0 bismuth	84 Po (210) polonium	85 At (210) astatine	86 Rn (222) radon
87 Fr (223) francium	88 Ra (226) radium	89–103 actinoids	104 Rf (261) rutherfordium	105 Db (262) dubnium	106 Sg (266) seaborgium	107 Bh (264) bohrium	108 Hs (267) hassium	109 Mt (268) meitnerium	110 Ds (271) darmstadtium	111 Rg (272) roentgenium	112 Cn (285) copernicium	113 Nh (280) nihonium	114 Fl (289) flerovium	115 Mc (289) moscovium	116 Lv (292) livermorium	117 Ts (294) tennessine	118 Og (294) oganesson

57 La 138.9 lanthanum	58 Ce 140.1 cerium	59 Pr 140.9 praseodymium	60 Nd 144.2 neodymium	61 Pm (145) promethium	62 Sm 150.4 samarium	63 Eu 152.0 europium	64 Gd 157.3 gadolinium	65 Tb 158.9 terbium	66 Dy 162.5 dysprosium	67 Ho 164.9 holmium	68 Er 167.3 erbium	69 Tm 168.9 thulium	70 Yb 173.1 ytterbium	71 Lu 175.0 lutetium
89 Ac (227) actinium	90 Th 232.0 thorium	91 Pa 231.0 protactinium	92 U 238.0 uranium	93 Np (237) neptunium	94 Pu (244) plutonium	95 Am (243) americium	96 Cm (247) curium	97 Bk (247) berkelium	98 Cf (251) californium	99 Es (252) einsteinium	100 Fm (257) fermium	101 Md (258) mendelevium	102 No (259) nobelium	103 Lr (262) lawrencium

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

2. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.04

3. Chemical relationships

Name	Formula
number of moles of a substance	$n = \frac{m}{M}$; $n = cV$; $n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$
calibration factor (CF) for bomb calorimetry	$\mathrm{CF} = \frac{VIt}{\Delta T}$
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	6.02×10^{23} mol^{-1}
charge on one electron (elementary charge)	e	-1.60×10^{-19} C
Faraday constant	F	96 500 C mol^{-1}
molar gas constant	R	8.31 J mol^{-1} 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 kJ kg^{-1} K^{-1} or 4.18 J g^{-1} 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

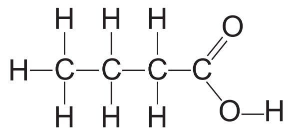
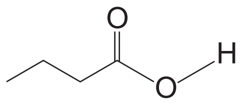
Metric (including SI) prefixes	Scientific notation	Multiplying factor
giga (G)	10^9	1 000 000 000
mega (M)	10^6	1 000 000
kilo (k)	10^3	1000
deci (d)	10^{-1}	0.1
centi (c)	10^{-2}	0.01
milli (m)	10^{-3}	0.001
micro (μ)	10^{-6}	0.000001
nano (n)	10^{-9}	0.000000001
pico (p)	10^{-12}	0.000000000001

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

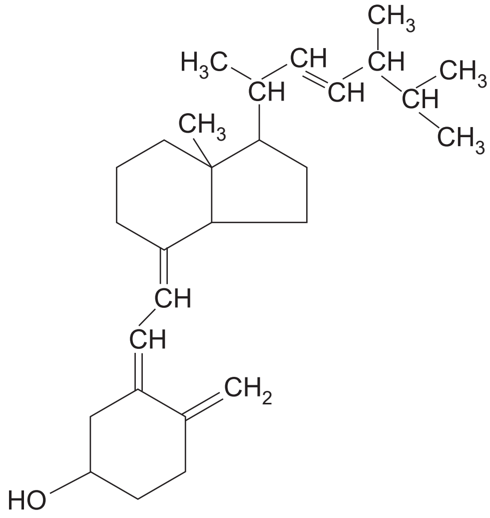
The following table shows different representations of organic molecules, using butanoic acid as an example.

Formula	Representation
molecular formula	$C_4H_8O_2$
structural formula	
semi-structural (condensed) formula	$CH_3CH_2CH_2COOH$ or $CH_3(CH_2)_2COOH$
skeletal structure	

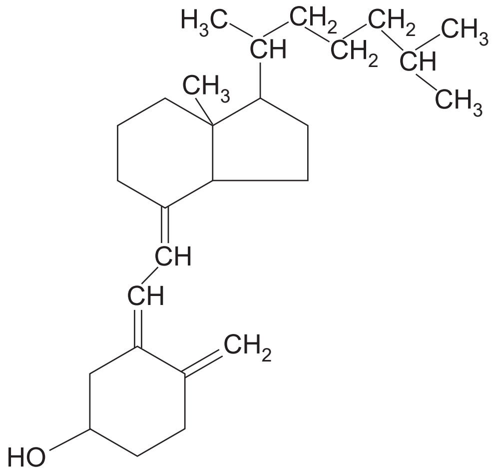
9. Formulas of some fatty acids

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	$C_{19}H_{31}COOH$	$CH_3(CH_2)_4(CH{=}CHCH_2)_3CH{=}CH(CH_2)_3COOH$

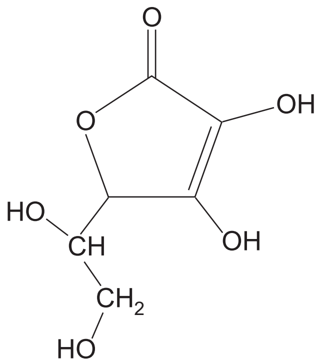
10. Formulas of some biomolecules



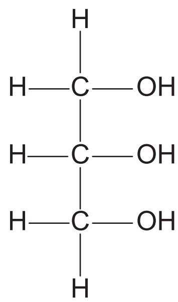
vitamin D_2 (ergocalciferol)



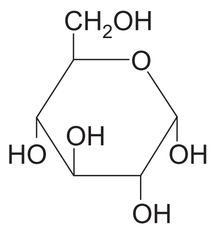
vitamin D_3 (cholecalciferol)



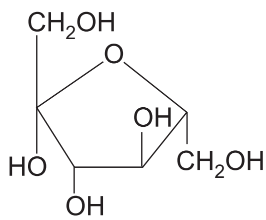
vitamin C (ascorbic acid)



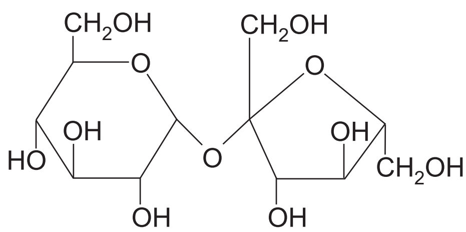
glycerol



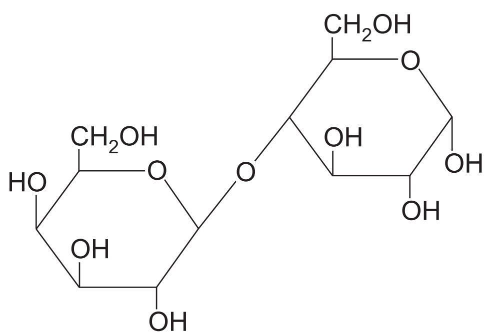
α-glucose



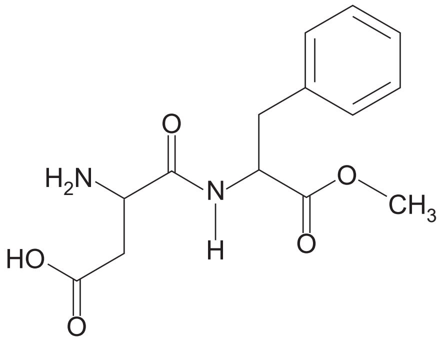
β-fructose



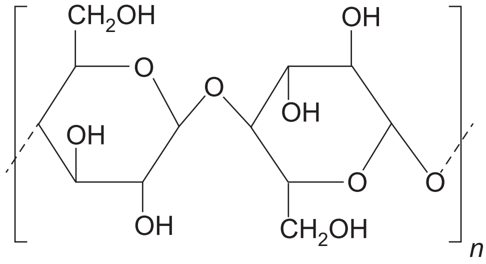
sucrose



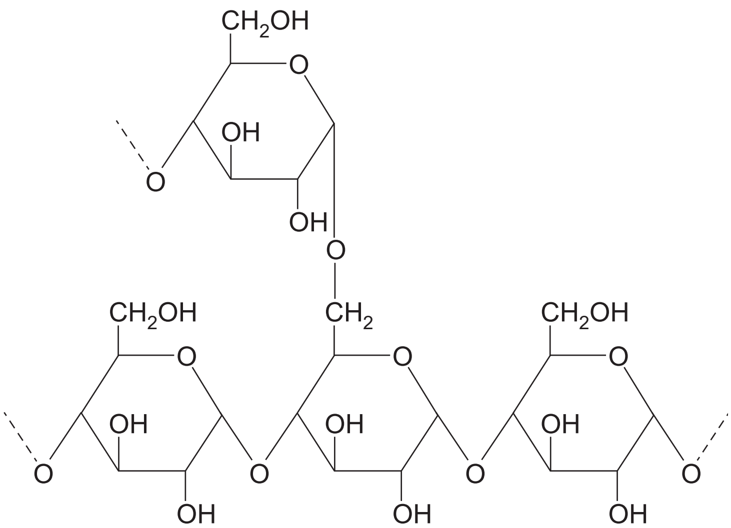
α-lactose



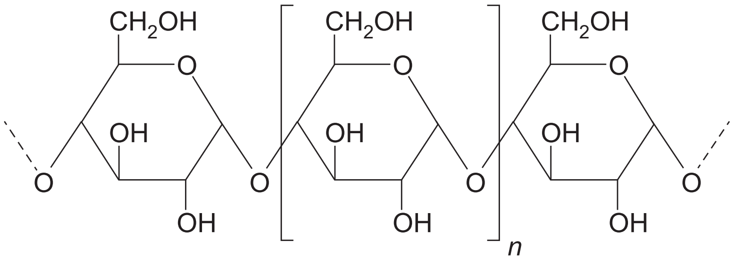
aspartame



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 CO_2 and H_2O. 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_2H_6	gas	51.9	1560
propane	C_3H_8	gas	50.5	2220
butane	C_4H_{10}	gas	49.7	2880
octane	C_8H_{18}	liquid	47.9	5460
ethyne (acetylene)	C_2H_2	gas	49.9	1300
methanol	CH_3OH	liquid	22.7	726
ethanol	C_2H_5OH	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 CO_2 and H_2O. 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

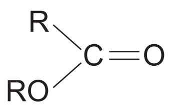
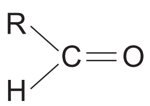
14. Characteristic ranges for infrared absorption

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. ^{13}C NMR data

Typical ^{13}C shift values relative to TMS = 0

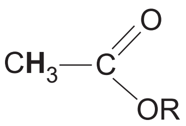
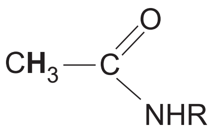
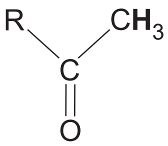
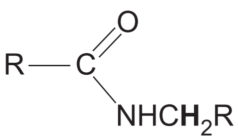
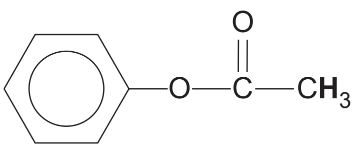
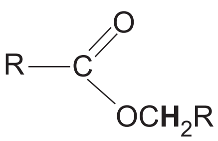
These can differ slightly in different solvents.

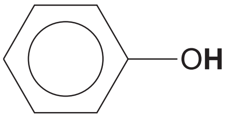
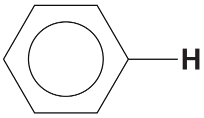
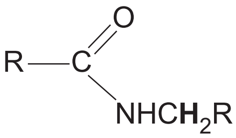
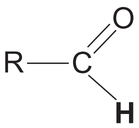
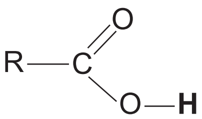
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
RC≡CR	75–95
$R_2C=CR_2$	110–150
RCOOH	160–185
	165–175
	190–200
R2C=O	205–220

16. ¹H NMR data

Typical proton shift values relative to TMS = 0

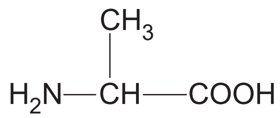
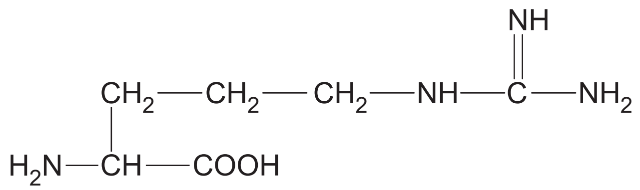
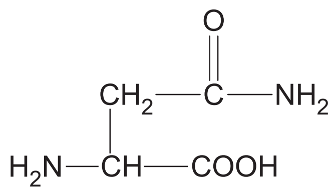
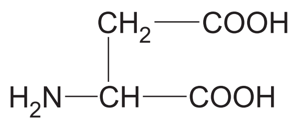
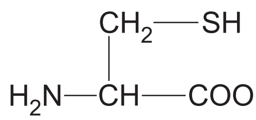
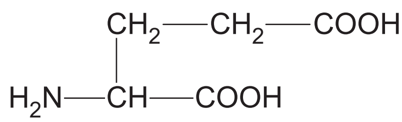
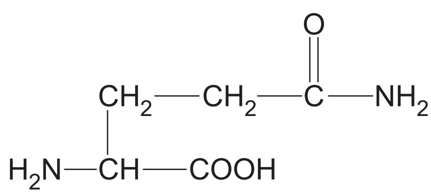
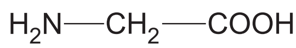
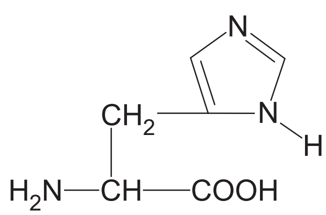
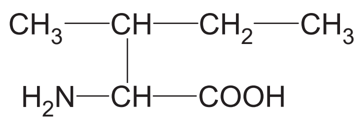
These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

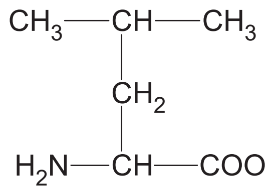
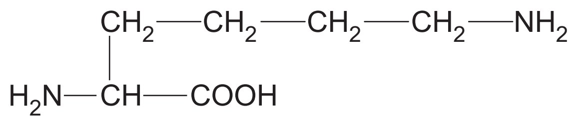
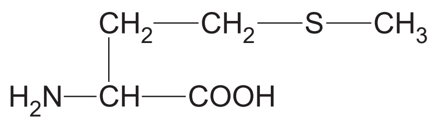
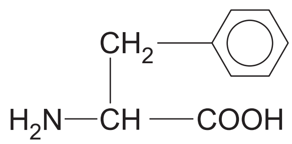
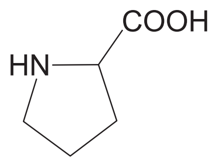
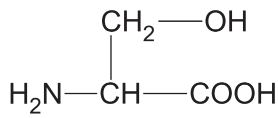
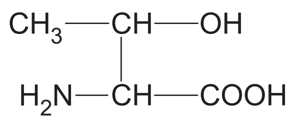
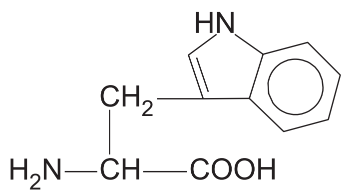
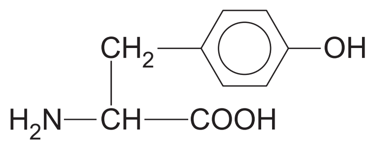
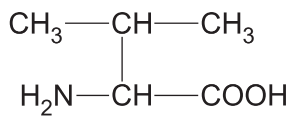
Type of proton	Chemical shift (ppm)
$R{-}C\mathbf{H}_3$	0.9–1.0
$R{-}C\mathbf{H}_2{-}R$	1.3–1.4
$RCH{=}CH{-}C\mathbf{H}_3$	1.6–1.9
$R_3{-}C\mathbf{H}$	1.5
 or 	2.0
	2.1–2.7
$R{-}C\mathbf{H}_2{-}X$ (X = F, Cl, Br or I)	3.0–4.5
$R{-}C\mathbf{H}_2{-}OH$, $R_2{-}C\mathbf{H}{-}OH$	3.3–4.5
	3.2
$R{-}O{-}C\mathbf{H}_3$ or $R{-}O{-}C\mathbf{H}_2R$	3.3–3.7
	2.3
	3.7–4.8
$R{-}O{-}\mathbf{H}$	1–6 (varies considerably under different conditions)
$R{-}N\mathbf{H}_2$	1–5
$RHC{=}C\mathbf{H}R$	4.5–7.0

Type of proton	Chemical shift (ppm)
	4.0–12.0
	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	
arginine	Arg	
asparagine	Asn	
aspartic acid	Asp	
cysteine	Cys	
glutamic acid	Glu	
glutamine	Gln	
glycine	Gly	
histidine	His	
isoleucine	Ile	

Name	Symbol	Structure
leucine	Leu	
lysine	Lys	
methionine	Met	
phenylalanine	Phe	
proline	Pro	
serine	Ser	
threonine	Thr	
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	

End of Chemistry Data Book