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

Chemistry

Question and Answer Book

VCE Examination – Monday 10 November 2025

- Reading time is **15 minutes**: 9.00 am to 9.15 am
- Writing time is **2 hours 30 minutes**: 9.15 am to 11.45 am

Approved materials

- One scientific calculator

Materials supplied

- Question and Answer Book of 40 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

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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 identifies the renewability of biomethane and natural gas?

	Biomethane	Natural gas
A.	renewable	renewable
B.	renewable	not renewable
C.	not renewable	renewable
D.	not renewable	not renewable

Question 2

A 65.0 g snack bar contains:

- 45.0 g of carbohydrate
- 10.0 g of protein
- 10.0 g of fats.

The total energy content per 100 g of the snack bar is closest to

A. 1.3×10^3 J

B. 1.9×10^3 J

C. 1.3×10^6 J

D. 1.9×10^6 J

Question 3

Which one of the following statements about all exothermic reactions is true?

A. There is a net input of energy from the surroundings.

B. The enthalpy of the products is greater than the enthalpy of the reactants.

C. The energy required to break the bonds of the reactants is less than the energy released when the products are formed.

D. The energy required to break the bonds of the reactants is greater than the energy released when the products are formed.

Question 4

The circular economy of a bioethanol production process could be improved by

A. increasing the fermentation temperature to accelerate the reaction rate.

B. using a new strain of yeast to produce a higher yield of ethanol from glucose.

C. developing a separate process that converts waste carbon dioxide into a useful product.

D. carrying out advanced distillation techniques to reduce energy consumption.

Question 5

Oscar calibrated a solution calorimeter by passing a current of 2.50 A through a heater with a voltage of 12.0 V for 150 s. He measured the temperature of the water, which increased from 22.3 °C to 28.4 °C.

The calibration factor (CF) of the calorimeter was

A. $16.1\ J\ °C^{-1}$

B. $158\ J\ °C^{-1}$

C. $202\ J\ °C^{-1}$

D. $738\ J\ °C^{-1}$

Question 6

The molar enthalpy for combustion of glucose, $C_6H_{12}O_6$, is $-2840\ kJ\ mol^{-1}$.

Which one of the following describes what occurs to one mole of carbon dioxide, CO_2, during photosynthesis?

A. 473.3 kJ of energy is absorbed.

B. 2840 kJ of energy is absorbed.

C. 473.3 kJ of energy is released.

D. 2840 kJ of energy is released.

Use the following information to answer Questions 7–9.

Due to copyright restrictions, this material is not supplied.

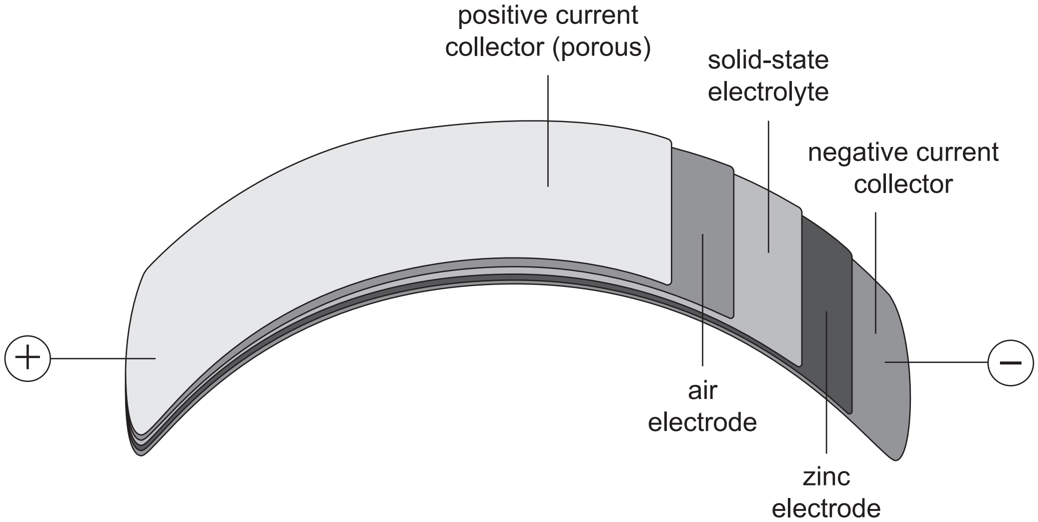
The rapid popularization of wearable electronics, soft robots and implanted medical devices has stimulated extensive research in flexible batteries, which are bendable, foldable, knittable, wearable, and/or stretchable …

Different from the conventional batteries that utilize rigid and bulky electrodes, current collectors, metal anodes, liquid electrolytes, and packages, flexible batteries require the flexibility of each component to accommodate diverse shapes or sizes.

Sources: Xiao Zhu et al., 'Recent progress of flexible rechargeable batteries', *Science Bulletin*, vol. 69, issue 23, 2024 (extract); tradeKorea, <www.tradekorea.com/main.do> (image)

Metal–air batteries are considered a suitable option for flexible batteries. Oxygen, O_2, in the air reacts with a metal electrode in all cells. Sodium, Na, magnesium, Mg, aluminium, Al, and zinc, Zn, are being investigated using polymer and gel electrolytes.

A diagram of one of the cells in a flexible zinc–air battery is shown below.



Source: Adapted from Fu, Jing et al., 'Electronically rechargeable zinc-air batteries: Progress, challenges and perspectives', *Advanced Materials*, vol. 10, 2016

Question 7

Which one of the following shows the migration that occurs through the polymer/gel electrolyte when the flexible cell is producing electrical energy?

A. Electrons flow from the anode to the cathode.

B. Metal ions flow from the anode to the cathode.

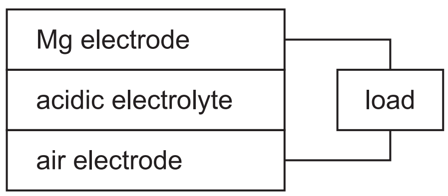
C. Electrons flow from the cathode to the anode.

D. Metal ions flow from the cathode to the anode.

Question 8

Which one of the following cells being investigated for use in flexible applications has the highest potential difference?

A.



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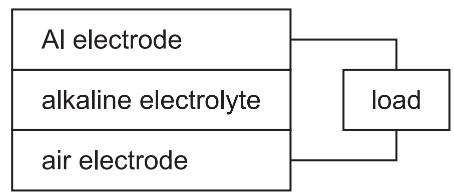
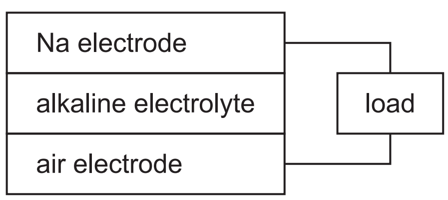


C.



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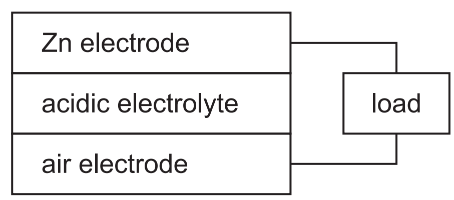


Question 9

Unwanted side reactions may occur in metal–air cells when moisture is present.

This is **less** likely in

A. Al–air cells.

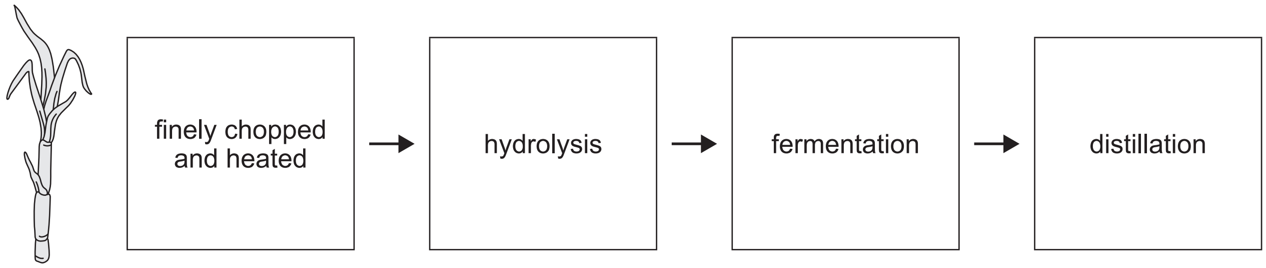
B. Mg–air cells.

C. Na–air cells.

D. Zn–air cells.

Question 10

The production of bioethanol from sugar cane follows the steps shown below.



Consider the following statements:

I Oxidation occurs during fermentation.

II Enzymes catalyse only two of the steps shown.

III Glucose is a product of the hydrolysis step.

Which of the statements about the production of bioethanol is/are correct?

A. II only

B. I and II

C. I and III

D. II and III

Question 11

Consider a fuel cell using gaseous reactants.

Which one of the following design features would significantly enhance fuel cell efficiency?

A. including a dense, non-porous electrode to limit gas diffusion

B. using liquid electrolytes to transport reactants between the electrodes

C. incorporating porous electrodes to maximise the surface area for catalytic reactions

D. using a solid, impermeable membrane between electrodes to minimise gas loss between half-cells

Question 12

A fuel cell utilises the reaction between hydrogen, H_2, and oxygen, O_2, to produce water, as shown in the reaction below.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

When a fuel cell produces 36 000 C of charge, the mass of O_2 consumed is closest to

A. 11.9 g

B. 2.98 g

C. 1.49 g

D. 0.373 g

Question 13

In a nickel–cadmium cell, the following reaction occurs during discharge.

$$2NiO(OH) + Cd + 2H_2O \rightarrow 2Ni(OH)_2 + Cd(OH)_2$$

Which one of the following represents the half-equation for reduction during recharge?

A. $NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$

B. $Cd + 2OH^- \rightarrow Cd(OH)_2 + 2e^-$

C. $Ni(OH)_2 + OH^- \rightarrow NiO(OH) + H_2O + e^-$

D. $Cd(OH)_2 + 2e^- \rightarrow Cd + 2OH^-$

Question 14

The reaction to produce methanal, CH_2O, is shown below.

$$2CH_3OH(g) + O_2(g) \xrightarrow{\text{catalyst}} 2CH_2O(g) + 2H_2O(g)$$

The primary role of the catalyst in the production of CH_2O is to increase the

A. speed of all particles.

B. number of collisions per unit time.

C. proportion of particles that react.

D. overall kinetic energy of the system.

Question 15

Consider the following two reactions that are at equilibrium at 500 °C.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad K_c = 2.86 \times 10^{-1}\ M^{-2}$$

$$4NH_3(g) \rightleftharpoons 2N_2(g) + 6H_2(g)$$

The magnitude of the value of K_c for the second reaction is

A. 8.18×10^{-2}

B. 5.72×10^{-1}

C. 1.75×10^{0}

D. 1.22×10^{1}

Question 16

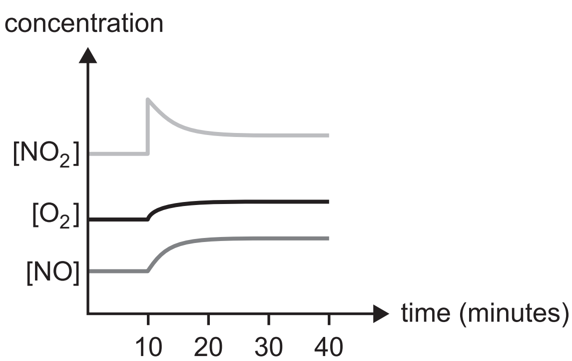
The system below is at equilibrium.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H < 0$$

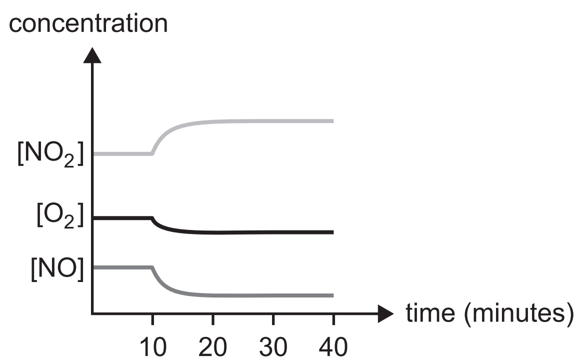
At time $t = 10$ minutes, the temperature is increased.

Which one of the following concentration–time graphs represents the change in concentrations?

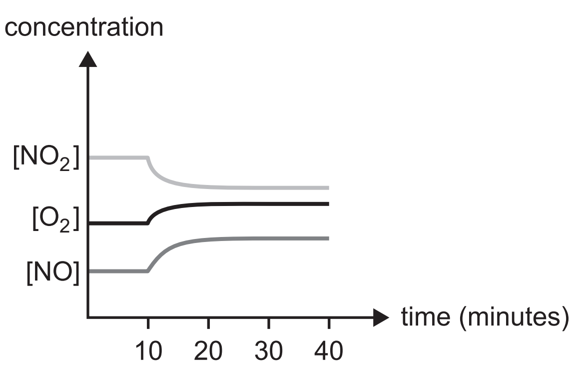
A.



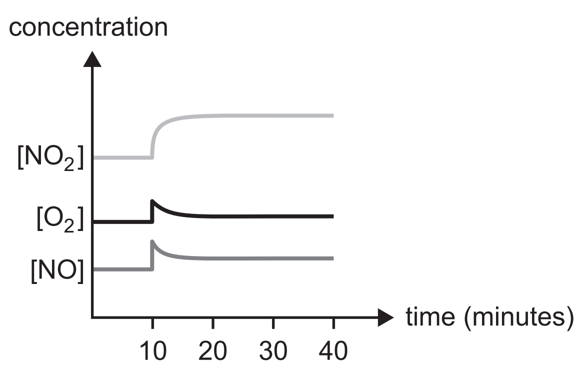
B.



C.

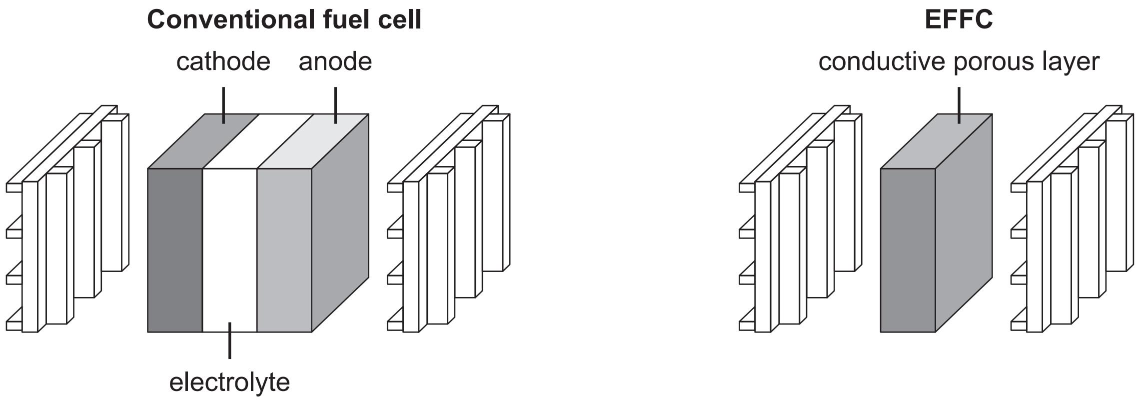


D.



Question 17

In innovative fuel cells, like the electrolyte-free (layer-free) fuel cell (EFFC), the internal cathode–electrolyte–anode structure commonly found in conventional fuel cells is replaced with a single conductive porous layer, as shown in the diagram below.



Source: Adapted from Yuzheng Lu et al., 'Progress in electrolyte-free fuel cells', *Frontiers in Energy Research*, vol. 4, 2016

Manufacturers of the EFFC claim the following benefits:

I The single porous layer can be made from material with superior conductive properties.

II Fewer internal interfaces, compared to conventional fuel cells, result in less heat loss.

Which of the claims above describes how the operation of the EFFC aligns with the green chemistry principle of design for energy efficiency?

A. I only

B. II only

C. both I and II

D. neither I nor II

Question 18

In artificial photosynthesis

A. water is oxidised and hydrogen gas, H_2, is produced.

B. the same products are produced as in natural photosynthesis.

C. hydrogen ions, H^+, are reduced to produce hydrogen gas, H_2, at the anode.

D. electrical energy from an external power supply is required to oxidise water.

Use the following information to answer Questions 19 and 20.

Irfan is conducting an experiment in which two aqueous solutions, hydrogen peroxide, H_2O_2, and a vitamin C solution are reacted together in a beaker. This reaction is known to have a delayed but obvious colour change.

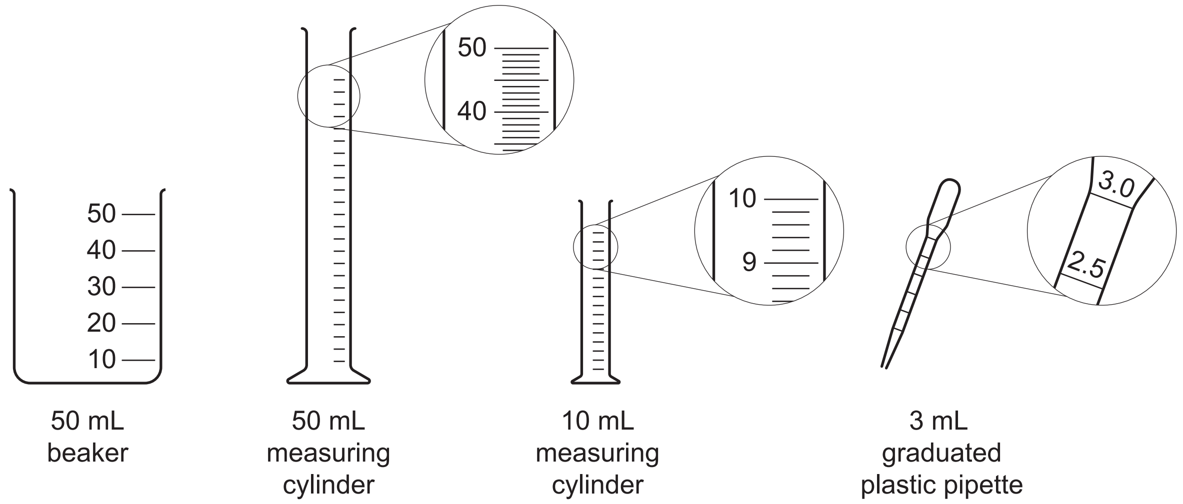
The vitamin C solution is prepared by crushing a vitamin C tablet and dissolving it in deionised water, then adding iodine, I_2.

Irfan is investigating how changing the concentration of vitamin C in the solution affects the time taken for the colour change to occur. The concentration is changed by adding different volumes of deionised water to 5.0 mL of the vitamin C solution before reacting it with H_2O_2.

Irfan repeats the experiment twice for each concentration.

Question 19

Some of the equipment used during the experiment is shown below.



The resolution of the equipment shown, from lowest to highest, is

A. 3 mL graduated plastic pipette < 10 mL measuring cylinder < 50 mL measuring cylinder < 50 mL beaker

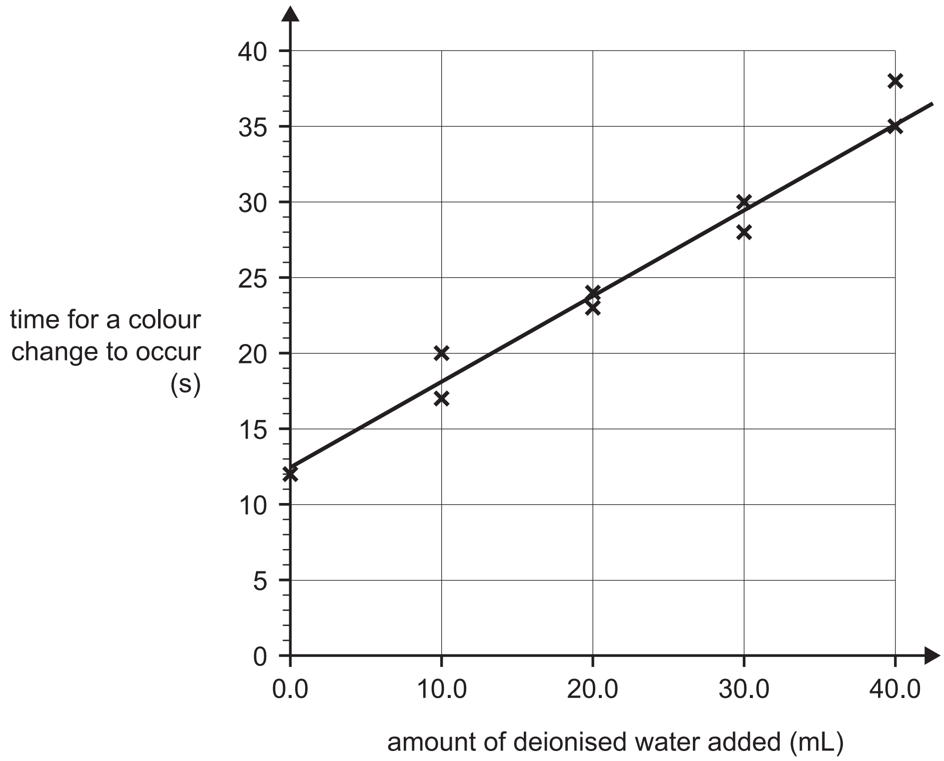
B. 10 mL measuring cylinder < 3 mL graduated plastic pipette < 50 mL measuring cylinder < 50 mL beaker

C. 50 mL beaker < 50 mL measuring cylinder < 3 mL graduated plastic pipette < 10 mL measuring cylinder

D. 50 mL beaker < 50 mL measuring cylinder < 10 mL measuring cylinder < 3 mL graduated plastic pipette

Question 20

A graph showing the time for a colour change to occur versus the amount of deionised water added is shown below.



Which one of the following factors is most likely responsible for the variability shown in the graph above?

A. judging when the colour change occurs

B. volume of iodine remaining in the tip of the plastic pipette

C. some of the vitamin C tablet not completely dissolving

D. changes in the laboratory room temperature during the experiment

Question 21

A key advantage of using renewable feedstocks in the manufacture of organic compounds is that they

A. eliminate any associated environmental impact.

B. reduce reliance on finite natural resources.

C. lead to the production of fewer by-products.

D. reduce the energy requirements of the manufacturing process.

Question 22

The major organic product formed when propan-1-ol, $CH_3CH_2CH_2OH$, reacts with butanoic acid, $CH_3CH_2CH_2COOH$, in the presence of sulfuric acid, H_2SO_4, is

A. $CH_3CH_2COOCH_2CH_2CH_2CH_3$

B. $CH_3CH_2CH_2CH_2OCOCH_2CH_3$

C. $CH_3CH_2OCOCH_2CH_2CH_2CH_3$

D. $CH_3CH_2CH_2COOCH_2CH_2CH_3$

Question 23

In a protein hydrolytic reaction, which one of the following combinations is correct?

A.	The amino acids react to form amide links.	Water is a reactant.
B.	The amino acids react to form amide links.	Water is a product.
C.	The amide links in the protein break.	Water is a reactant.
D.	The amide links in the protein break.	Water is a product.

Question 24

The manufacturing process for a medicine is shown below.

If the overall yield is 16%, the yield for step 2 is closest to

A. 2.8%

B. 7.2%

C. 29%

D. 36%

Question 25

During fermentation, yeast will produce other volatile polar compounds that have similar boiling points to ethanol, C_2H_6O.

Which one of the following methods would be most suitable to separate these compounds from C_2H_6O?

A. solvent extraction

B. simple distillation

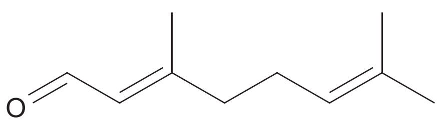
C. fractional distillation

D. solvent extraction and distillation

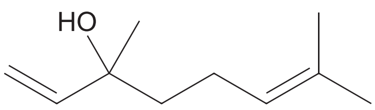
Use the following information to answer Questions 26 and 27.

Geranial and linalool are two natural organic compounds found in essential oils extracted from some citrus fruits. The skeletal structures for geranial and linalool are given below.

geranial



linalool



Question 26

The molecular formulas for geranial and linalool are

A. $C_{10}H_{15}O$ and $C_{10}H_{17}O$

B. $C_{10}H_{15}O$ and $C_{10}H_{18}O$

C. $C_{10}H_{16}O$ and $C_{10}H_{18}O$

D. $C_{10}H_{16}O$ and $C_{10}H_{17}O$

Question 27

Which one of the following laboratory tests could be used to confirm that a sample is pure geranial and **not** pure linalool?

A. React the sample with acidified dichromate ion, $H^+/Cr_2O_7^{2-}$. The colour of the solution will change from orange to green.

B. React the sample with acidified permanganate ion, H^+/MnO_4^-. The colour of the solution will change from pale pink to purple.

C. React the sample with bromine solution. The colour of the solution will change from brown to colourless.

D. React the sample with solid sodium hydrogen carbonate, $NaHCO_3$. Bubbles will be produced.

Question 28

Vanillin is a widely used ingredient in the food industry. Pure vanillin has a melting point of 82–83 °C. To reduce costs, it is often blended with significant amounts of cheaper compounds that have similar melting points.

A blended sample was tested.

The melting point range of the blend would be closest to

A. 68–79 °C

B. 79–80 °C

C. 82–83 °C

D. 100–109 °C

Question 29

One mole of a triglyceride containing only one type of fatty acid reacts completely with 6 moles of iodine, I_2.

Which one of the following could be the fatty acid?

A. linolenic acid

B. linoleic acid

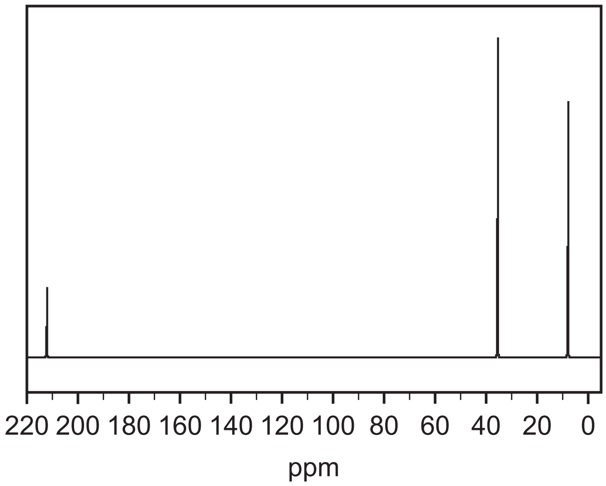
C. oleic acid

D. stearic acid

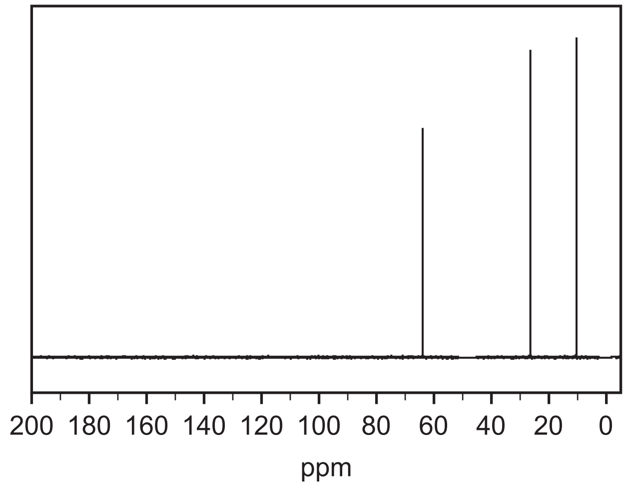
Question 30

Which one of the following shows the ^{13}C NMR spectrum of pentan-3-one, $C_5H_{10}O$?

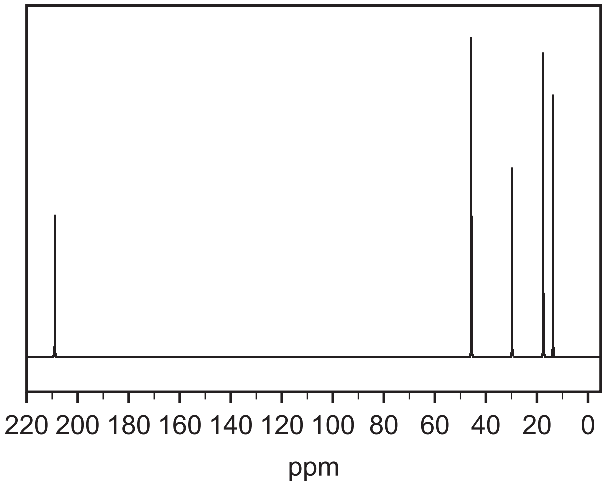
A.



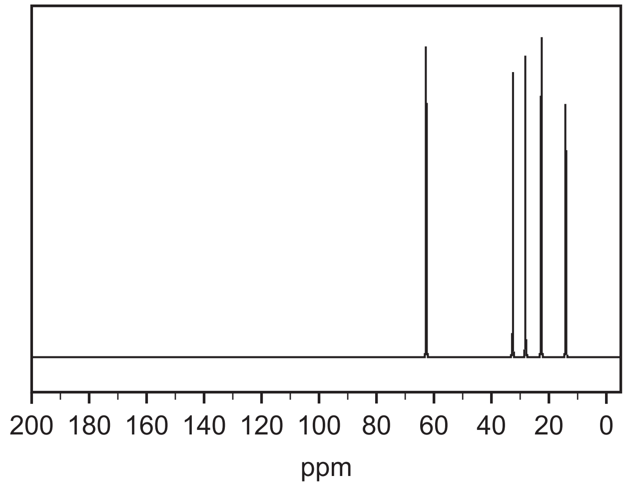
B.



C.



D.



Data: ChemicalBook, <www.chemicalbook.com>

End of Section A

Section B

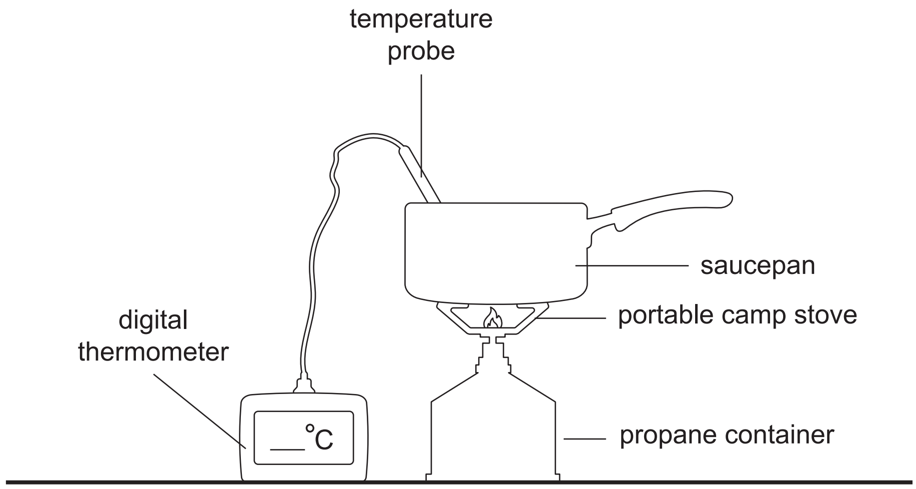
Instructions

- 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 (13 marks)

Kim investigated the energy efficiency of two different fuels, propane, C_3H_8, and pure bioethanol, C_2H_5OH, for heating water.

Kim placed a saucepan with 166.0 g of tap water on a portable camp stove and heated it using C_3H_8. The set-up for the experiment is shown below.



The following results were recorded.

initial temperature of water	24.1 °C
final temperature of water	90.1 °C
mass of C_3H_8 combusted	9.0 g

a. Write a balanced thermochemical equation for the complete combustion of C_3H_8. 2 marks

b. Using **item 13** of the Data Book, calculate the amount of energy released by the complete combustion of 9.0 g of C_3H_8 ($M = 44.0$ g mol^{-1}). 2 marks

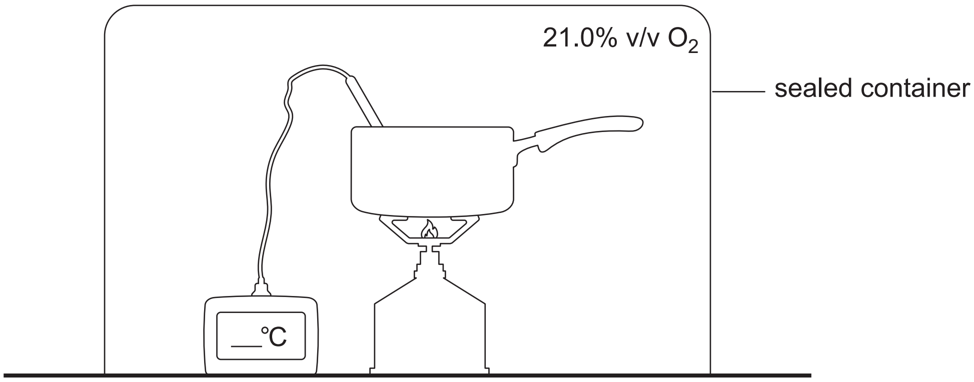
c. **i.** Calculate the energy absorbed by the water in the saucepan. 2 marks

ii. Determine the overall energy efficiency of heating the water in the saucepan. 1 mark

Question 1 continues on the next page.

Kim placed all of the equipment inside a sealed container with a total air volume of 0.125 m^3 and repeated the investigation.

The air in the enclosure contained 21.0% v/v oxygen, O_2, at standard laboratory conditions (SLC).



d. 9.0 g of C_3H_8 was combusted in the sealed container shown above.

Determine the mass of the reactant in excess. 4 marks

e. In another investigation, Kim found that 15.3 g of C_2H_5OH ($M = 46.0$ g mol^{-1}) was required to produce the same change in water temperature as the 9.0 g of C_3H_8.

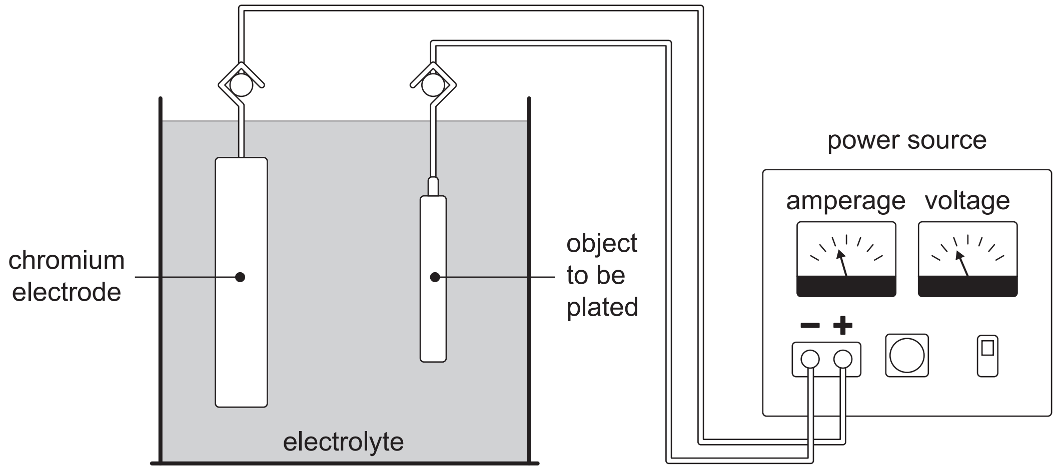
Explain why different masses of the fuels were required to produce the same temperature change. 2 marks

Do not write in this area.

Question 2 (13 marks)

Stef is an engineer working in the electroplating industry. Electroplating is a process that uses electrolysis to coat objects with a thin layer of metal to protect the object or improve its appearance.

Traditionally objects are electroplated with chromium, Cr, using the set-up shown below. The electrolyte used is chromium(III) sulfate, $Cr_2(SO_4)_3(aq)$, with a small amount of sulfuric acid, $H_2SO_4(aq)$.



Source: Adapted from US Chrome, <www.uschrome.com>

The half-equation for chromium electroplating is

$$Cr^{3+}(aq) + 3e^- \rightleftharpoons Cr(s) \qquad E^0 = -0.74 \text{ V}$$

a. Explain, using oxidation numbers, why this is a reduction reaction. 2 marks

b. Explain why the effective electroplating of an object requires the same ion to be involved in both the anode and cathode reactions. 2 marks

Question 2 continues on the next page.

c. Small amounts of $H_2SO_4(aq)$ are used in this electroplating cell.

Use **item 1** of the Data Book to justify why the amount must be carefully managed. 3 marks

d. Over a period of 2.50 hours, a mass of 7.80 g of Cr (A_r = 52.0 amu) was electroplated onto an object.

Calculate the current, in amperes, required to achieve this electroplating. 4 marks

e. Stef is investigating innovation in the industry and is comparing the use of other metals to chromium in electroplating.

Stef has found that rhodium, Rh (A_r = 102.9 amu), can be used to electroplate parts for wind turbines because it is harder and more resistant to salt corrosion than Cr.

$$Rh^{3+}(aq) + 3e^- \rightleftharpoons Rh(s) \qquad E^0 = +0.76 \text{ V}$$

Explain why less current would be required to plate the same mass of Rh compared to Cr. 2 marks

Question 3 (12 marks)

Methanol, CH_3OH, is widely used as a starting material for a range of products, including paints and pharmaceuticals. A chemical reaction for the synthesis of CH_3OH is

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H < 0$$

a. Define the term 'reversible reaction'. 1 mark

b. The operating conditions used for producing CH_3OH are 500 K and 10 000 kPa in the presence of a catalyst.

i. The rate of the reaction can be increased by increasing the temperature.

Explain the impact this would have on the yield. 2 marks

ii. Using Le Châtelier's principle, state **one** way in which the yield of CH_3OH could be increased at a constant temperature. Justify your response. 2 marks

Question 3 continues on the next page.

A mixture of carbon monoxide, CO, hydrogen, H_2, and CH_3OH gases inside a sealed container is at equilibrium at 500 K. The equilibrium expression is

$$K_c = \frac{[CH_3OH]}{[CO] \times [H_2]^2} = 1.21\ M^{-2} \text{ at } 500\ K$$

A change to the system is applied at time t_1. The concentrations at t_1 are measured to be:

- $[CO] = 2.00$ M
- $[H_2] = 1.25$ M
- $[CH_3OH] = 5.60$ M

c. Determine what needs to happen for the system to return to equilibrium. Use calculations to support your response. 3 marks

d. 5.00 mol of CO and an unknown amount of H_2 were injected into an evacuated 1.00 L sealed container at 500 K. Once equilibrium was established, the concentration of CH_3OH was determined to be 1.30 M.

Calculate the amount of H_2, in moles, initially added to the container. 4 marks

Do not write in this area.

Question 4 (17 marks)

Many industries, such as the pharmaceutical industry, need to produce a range of organic compounds.

a. Simple hydrocarbons are the usual raw material used to produce haloalkanes, amines, alcohols, carboxylic acids and esters.

i. Write a balanced equation to show the production of C_3H_7Cl from C_3H_8. Include the reaction conditions. 2 marks

ii. Name **two** reactants required to form propan-1-amine, C_3H_9N, in a single substitution reaction. 2 marks

Question 4 continues on the next page.

During the production process, routine quality testing occurs. After testing, the samples are collected as organic waste. In order to dispose of the waste safely, the components must be separated.

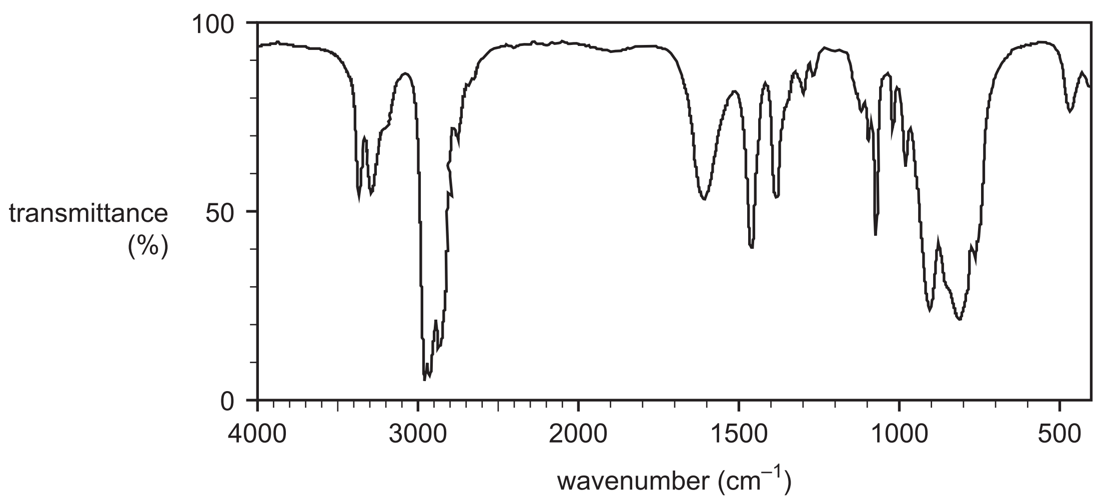
b. The waste from one laboratory was a mixture of amines and carboxylic acids. The amines were separated from the carboxylic acids on the basis of their different boiling points.

Boiling points of the first three compounds in the carboxylic acid and amine series are listed in the table below.

carboxylic acids	HCOOH 101 °C	CH_3COOH 118 °C	CH_3CH_2COOH 141 °C
amines	CH_3NH_2 –6 °C	$CH_3CH_2NH_2$ 17 °C	$CH_3CH_2CH_2NH_2$ 48 °C

i. Referring to their structures, explain why the homologous series of carboxylic acids have higher boiling points than the corresponding amines. 2 marks

One of the samples that was separated from this waste mixture produced the IR spectrum shown below.



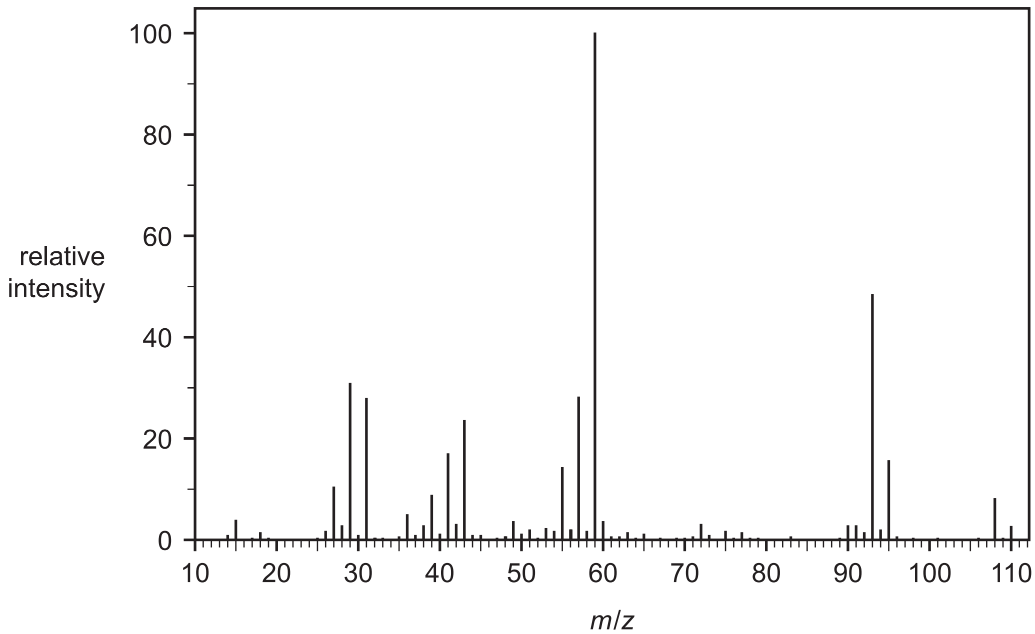
Data: National Institute of Advanced Industrial Science and Technology, SDBS Web, <https://sdbs.db.aist.go.jp>

ii. State whether this spectrum was produced by an amine or a carboxylic acid. 1 mark

Compound X, known to contain both oxygen and chlorine, was purified from a waste sample to enable it to be re-used.

c. The mass spectrum of Compound X is shown below:

- The only stable isotope of oxygen is ^{16}O.
- The two naturally occurring, stable isotopes of chlorine are ^{35}Cl and ^{37}Cl.



Data: Adapted from ChemicalBook, <www.chemicalbook.com>

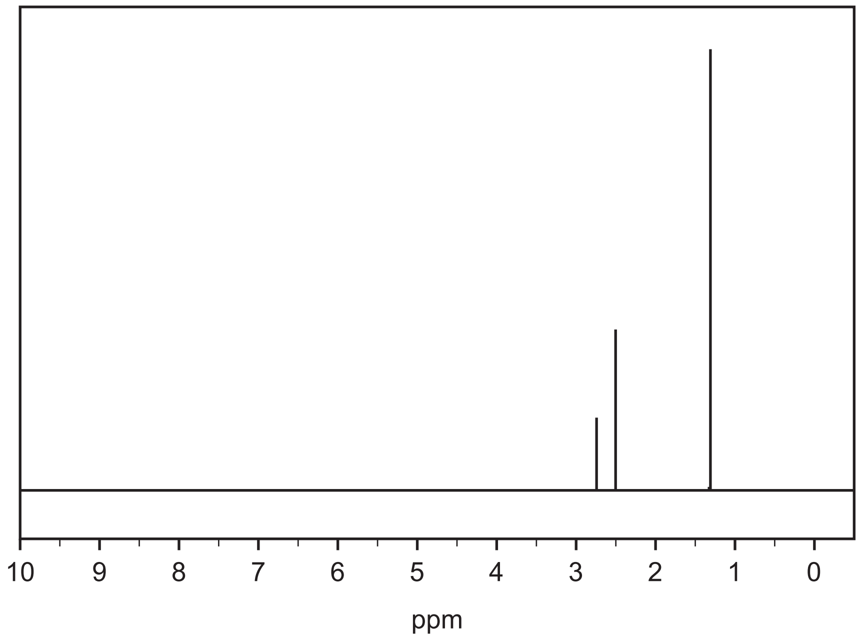
i. Identify the *m*/*z* of the base peak. 1 mark

ii. State why all the possible isomers of Compound X would have the same peak at *m*/*z* = 108. 1 mark

iii. Identify the formula of the species responsible for the peak at *m*/*z* = 95. 1 mark

Question 4 continues on the next page.

d. The high-resolution ^{1}H NMR spectrum for Compound X is shown below.



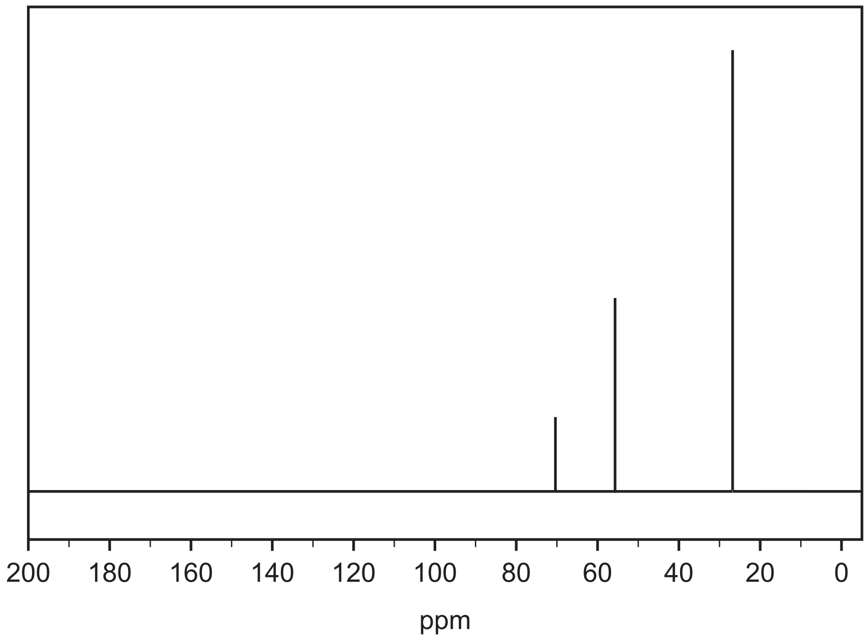
Data: Adapted from ChemicalBook, <www.chemicalbook.com/>

Data obtained from the ^{1}H NMR spectrum for Compound X is shown in the table below.

Chemical shift (ppm)	**Relative peak area**
2.8	16.7
2.5	33.3
1.3	100

Referring to the ^{1}H NMR spectrum and the table above, deduce **three** things about the structure of Compound X. 3 marks

e. The ^{13}C NMR spectrum for Compound X is shown below.



Data: ChemicalBook, <www.chemicalbook.com/>

What does the ^{13}C NMR spectrum indicate about the structure of Compound X? 2 marks

f. **i.** In the space provided below, draw the skeletal diagram of Compound X that is consistent with the information provided in **parts c–e**. 1 mark

ii. Write the IUPAC name of Compound X. 1 mark

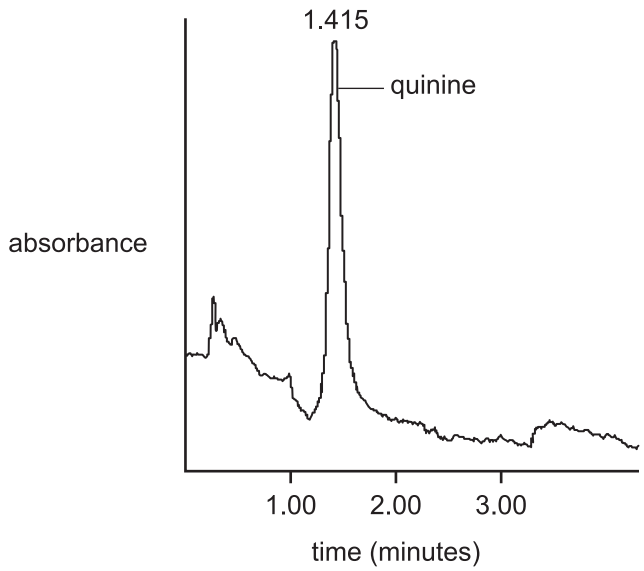
Do not write in this area.

Question 5 (13 marks)

Traditionally the quinine tree has been used to treat many illnesses, including malaria, due to the range of different compounds contained in its bark. One of the useful medicinal compounds in its bark is quinine, $C_{20}H_{24}N_2O_2$, which is used to make tonic water. Tonic water sold today has a much lower concentration of quinine than in the past.

a. High-performance liquid chromatography (HPLC) is commonly used to detect both the presence and concentration of quinine in tonic water.

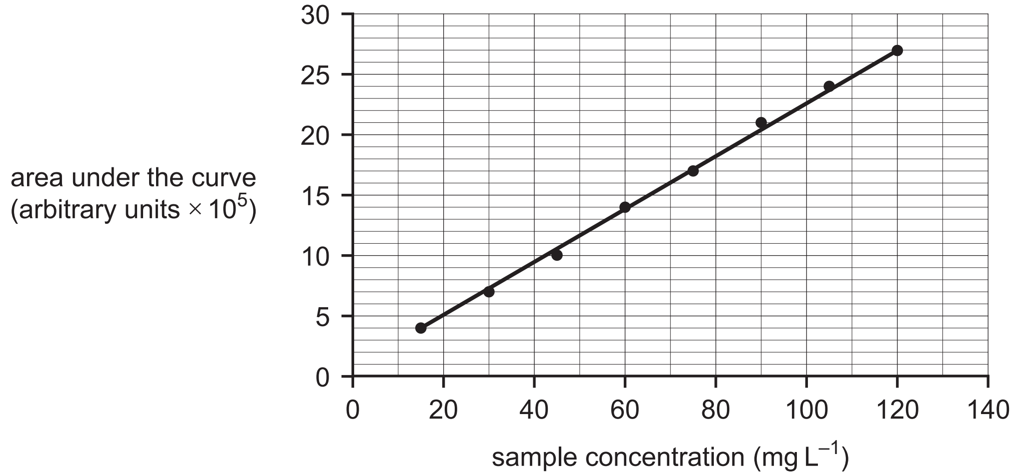
The HPLC chromatograph of a sample of tonic water is shown below.



Data: Adapted from Xesús Feás et al., 'Toxicological aspects of the consumption of soft drinks containing quinine', *Nutricion Clinica y Dietetica Hospitalaria*, vol. 28(2), January 2008

i. Explain how retention time can be used to confirm the presence of quinine in the sample of tonic water. 2 marks

Calibration curve



Various concentrations of quinine solutions were run through an HPLC instrument to produce the calibration curve shown above.

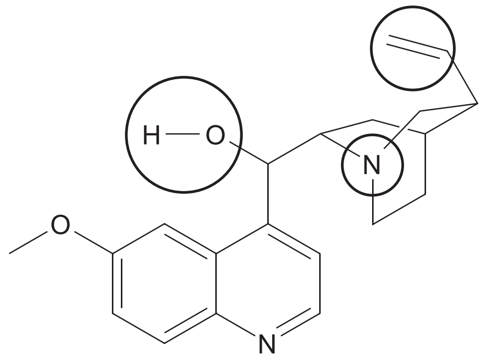
A sample of tonic water is to be tested to determine the concentration of quinine.

ii. Explain why solutions of known concentration must be run through the HPLC instrument under controlled conditions. 2 marks

iii. State why the calibration curve should **not** be used to test a sample of tonic water that has a mean concentration of 130 mg L^{-1}. 1 mark

Question 5 continues on the next page.

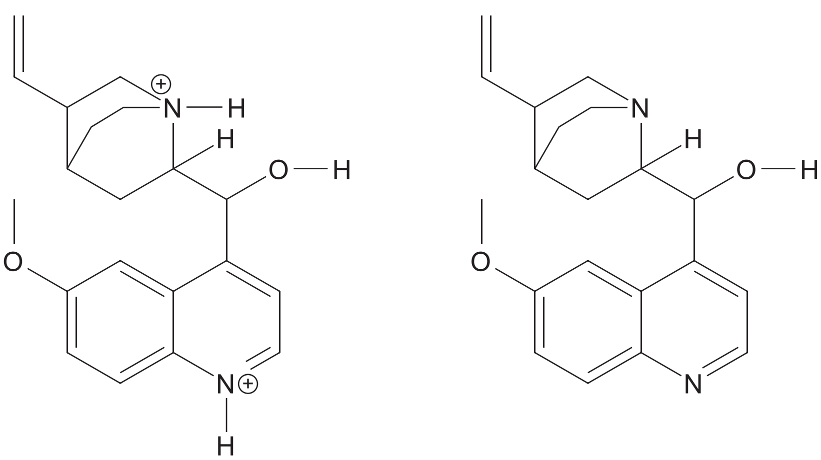
b. A representation for quinine is shown below with three functional groups circled.



i. Using **item 19** of the Data Book, name the functional group with the highest priority when following IUPAC nomenclature. 1 mark

Malaria is caused by the malaria parasite, which enters red blood cells and feeds on haemoglobin. Experiments have shown that the malaria parasite enzymes involved in this reaction are most effective at a pH of 4.7

The structure of the quinine molecule can vary with pH. Representations of two possible structures are shown below.



Structure Q **Structure R**

ii. Identify which structure, Q or R, is most likely to occur at a low pH. Justify your response. 2 marks

c. Quinine has four chiral centres. Only one of its isomers is an effective medicine in the treatment of malaria.

i. Referring to the term 'chiral centre' in your response, explain why only one isomer of quinine is effective. 3 marks

ii. Quinine acts as a competitive inhibitor in the prevention of malaria.

Explain why quinine is more effective as a competitive inhibitor at pH 4.7 than at a higher pH. You may draw a diagram to support your response. 2 marks

Question 6 (14 marks)

Many vegetables contain compounds that taste bitter because of the oxalate ion, $C_2O_4^{2-}$. Removing the bitterness can be achieved through different cooking methods, including boiling and steaming.

VCE Chemistry student Karolina undertook research to collect background information for her scientific investigation and learnt that oxalate compounds can be water-soluble and water-insoluble.

From her research Karolina developed the following hypothesis: ‘The boiling process will remove 75% of the oxalate compounds in spinach leaves.’

Karolina tested her hypothesis by investigating the effectiveness of boiling to remove $C_2O_4^{2-}$ from spinach leaves.

The method developed by Karolina is outlined below.

Part A – Preparation of oxalate ion solution

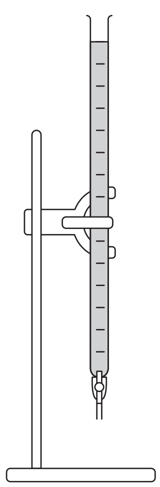
Step 1
Place chopped spinach leaves into a beaker. Add 1 M HCl and mix.

→ **Step 2**
Filter the spinach mixture into a 500 mL volumetric flask. Fill to the level with deionised water.

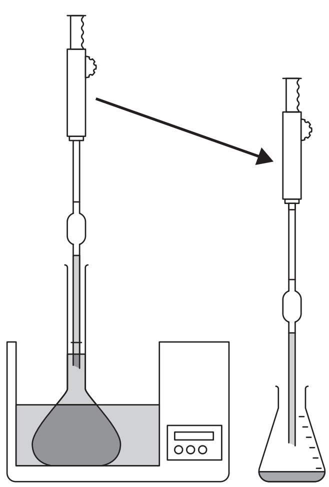
→ **Step 3**
Heat the volumetric flask in a hot water bath to reach 50 °C. Leave the flask in the bath.

Part B – Titration

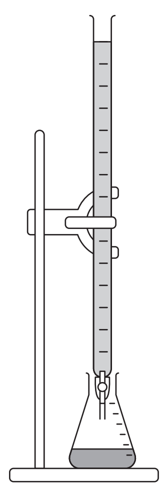
Step 1
Fill a 50.00 mL burette with 0.0020 M acidified potassium permanganate, $KMnO_4$, solution.



→ **Step 2**
From the volumetric flask in the 50 °C hot water bath, pipette a 25.0 mL aliquot into a conical flask. See diagram below.



→ **Step 3**
Immediately titrate until a permanent colour change is observed in the conical flask.



a. Circle the scientific investigation methodology that Karolina most likely used to develop her hypothesis. 1 mark

case study fieldwork literature review modelling

$C_2O_4^{2-}$ reacts with permanganate ions, MnO_4^-, according to the equation below.

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

b. Refer to **item 7** of the Data Book. What specific observation did Karolina use to determine the end point of the titration? 1 mark

c. The reaction was conducted at 50 °C rather than at room temperature.

i. Use collision theory to state why this is a preferred temperature at which to conduct the reaction. 1 mark

ii. State why the experiment might no longer be valid if the reaction is conducted at room temperature. 1 mark

Do not write in this area.

Question 6 continues on the next page.

Results

Karolina recorded the titration results for the uncooked spinach in the table below.

Trial	Initial volume (mL)	Final volume (mL)	Titre (mL)
1	1.10	17.20	16.10
2	17.20	32.65	15.45
3	32.65	48.05	15.40
4	11.00	26.40	15.40

d. Calculate the average titre of MnO_4^- used in the experiment. 1 mark

e. A 15.15 g sample of uncooked spinach was used.

Calculate the mass of $C_2O_4^{2-}$ ($M = 88.0$ g mol^{-1}) in the sample using the experimental results above. Give your answer in grams. 4 marks

Karolina then prepared a second 15.15 g sample of spinach as follows:

- boiled in deionised water for two minutes
- thoroughly rinsed with deionised water using a sieve
- left overnight to dry

This cooked sample was then tested using the steps outlined in Part A and Part B on page 32.

f. Karolina calculated the mass of $C_2O_4^{2-}$ to be 0.0545 g in this sample.

Determine the percentage change of $C_2O_4^{2-}$ that resulted by boiling the spinach in this experiment. 1 mark

g. Rinsing is an essential step in the process for testing the cooked spinach.

Explain why insufficient rinsing of the cooked sample before commencing Step 2 of Part A on page 32 would lead to a calculated $C_2O_4^{2-}$ concentration that is higher than the true value. 2 marks

h. Discuss whether the findings support Karolina's hypothesis. 2 marks

Question 7 (8 marks)

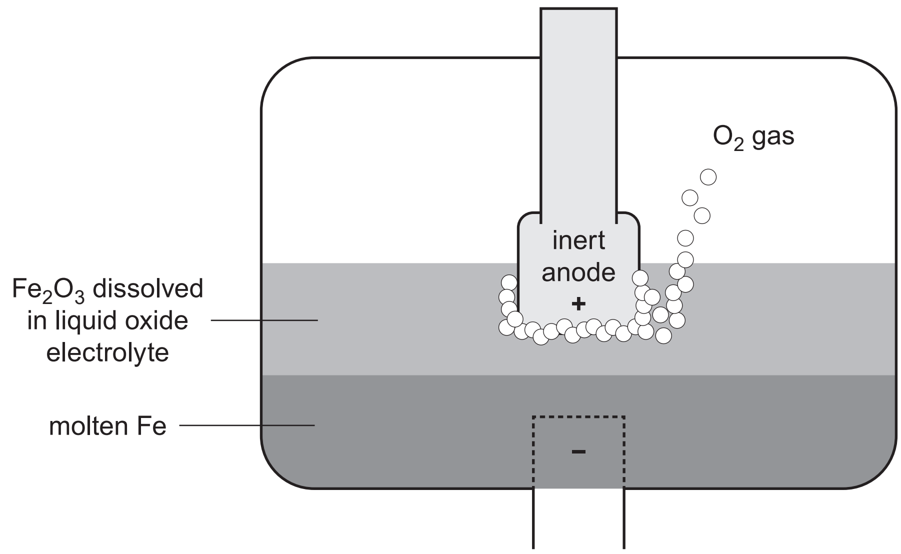
Steel is an essential component of modern life. In 2023, approximately 1.9 billion tonnes of steel was made worldwide and steel production was responsible for 8% of global carbon dioxide, CO_2, emissions.

In traditional steelmaking, iron ore, which is primarily iron(III) oxide, Fe_2O_3, is reduced with a form of carbon, C, known as coke. This occurs in a blast furnace with temperatures between 2200 °C and 2300 °C, producing molten iron, Fe, and forming CO_2 as a by-product.

One alternative process being considered is molten oxide electrolysis (MOE). In MOE, Fe_2O_3 is heated to approximately 1600 °C and dissolved in a liquid oxide electrolyte such as calcium oxide, CaO. Fe is formed at the cathode and oxygen gas, $O_2(g)$, is formed at the inert anode. The inert anode needs to be highly stable and corrosion resistant. Materials being considered for the anode include:

- platinum, Pt
- iridium, Ir
- ceramic–metal oxides.

The MOE process



Source: Adapted from R Campbell, 'The green edge of steel: Cutting through carbon', 28 June 2021, <www.whitecase.com>

The table below provides a summary of the key characteristics of the two processes.

Process	**Overall equation**	**CO_2 emissions per tonne of steel produced (kg)**	**Electricity used per tonne of steel produced (MJ)**
blast furnace	$2Fe_2O_3(l) + 3C(s) \rightarrow 4Fe(l) + 3CO_2(g)$	1600	850
MOE	$2Fe_2O_3(l) \rightarrow 4Fe(l) + 3O_2(g)$	~0	14 400

1 tonne = 1000 kg

a. Goal 12 of the United Nations Sustainable Development Goals is 'responsible consumption and production'.

Describe a necessary requirement for the MOE process to have a positive impact on this goal while still meeting society's needs for steel. 2 marks

Question 7 continues on the next page.

b. Evaluate the MOE and the blast furnace processes with respect to green chemistry principles. Refer to **item 26 ii** of the Data Book, the information on pages 36 and 37 and content you have learnt in VCE Chemistry in your response.

Your response must:

- include **two** relevant green chemistry principles and compare both methods against each principle
- describe **one** ethical factor that is important to the challenge of producing steel to meet global needs
- include a concluding statement that is consistent with your evaluation. 6 marks

End of examination questions

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Chemistry

2025 Data Book

Contents pages

You may keep this Data Book.

VICTORIAN CURRICULUM AND ASSESSMENT AUTHORITY

VICTORIA State Government

1. 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
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$PbO_2(s) + 4H^+(aq) + 2e^- \rightleftharpoons Pb^{2+}(aq) + 2H_2O(l)$	+1.47
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightleftharpoons 2Cr^{3+}(aq) + 7H_2O(l)$	+1.36
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+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
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	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
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−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

2. Chemical relationships

Name	Formula
amount of substance (number of moles)	$n = \frac{m}{M}$; $n = cV$; $n = \frac{V}{V_m}$
universal gas equation	$pV = nRT$
chemical calibration factor (CF) for calorimetry	$CF = \frac{E}{\Delta T}$
electrical calibration factor (CF)	$CF = \frac{VIt}{\Delta T}$
thermal energy transferred	$q = mc\Delta T$
molar enthalpy change	$\Delta H = \frac{q}{n}$
electric charge	$Q = It$
amount of electrons (number of moles)	$n(e^-) = \frac{Q}{F}$
% atom economy	$\frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times \frac{100}{1}$
% yield	$\frac{\text{actual yield}}{\text{theoretical yield}} \times \frac{100}{1}$
equilibrium constant	$K = \frac{[C]^c \times [D]^d \times \ldots}{[A]^a \times [B]^b \times \ldots}$ for the equation $aA + bB + \ldots \rightleftharpoons cC + dD + \ldots$

3. Physical constants and standard values

Name	Symbol	Value
Avogadro constant	N_A or L	6.02×10^{23} mol^{-1}
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	1.0 g mL^{-1}
molar latent heat of vaporisation of water at 25 °C	$\Delta H_{vap}(H_2O)$	+44.0 kJ mol^{-1}
molar latent heat of vaporisation of water at 100 °C	$\Delta H_{vap}(H_2O)$	+40.7 kJ mol^{-1}

4. Unit conversions

Measured value	Conversion
0 °C	273 K
100 kPa	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

5. Metric prefixes

The following prefixes are commonly used within the International System of Units (SI) to modify the base units and express quantities in multiples or fractions of those units.

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

6. 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

7. Colours of selected conjugate redox reagents

Redox reagent in oxidised state		Redox reagent in reduced state	
Name/formula	**Colour**	**Name/formula**	**Colour**
bromine, Br_2	brown	bromide ion, Br^-	colourless
chlorine, Cl_2	yellow/green	chloride ion, Cl^-	colourless
copper(II) ion, Cu^{2+}	blue	copper(I) ion, Cu^+	red
dichromate ion, $Cr_2O_7^{2-}$	orange	chromium(III) ion, Cr^{3+}	green
iodine, I_2	brown in aqueous solutions	iodide ion, I^-	colourless
iron(III) ion, Fe^{3+}	yellow/brown	iron(II) ion, Fe^{2+}	pale green
manganese(IV) dioxide, MnO_2	black/brown	manganese(II) ion, Mn^{2+}	very pale pink
permanganate ion, MnO_4^-	intense purple	manganese(II) ion, Mn^{2+}	very pale pink

8. Formulas and charges for selected ions

Cations

1+		2+		3+	
Name	**Formula**	**Name**	**Formula**	**Name**	**Formula**
ammonium	NH_4^+	barium	Ba^{2+}	aluminium	Al^{3+}
copper(I)	Cu^+	calcium	Ca^{2+}	chromium(III)	Cr^{3+}
hydronium	H_3O^+	copper(II)	Cu^{2+}	iron(III)	Fe^{3+}
lithium	Li^+	iron(II)	Fe^{2+}	**4+**	
potassium	K^+	lead(II)	Pb^{2+}	titanium(IV)	Ti^{4+}
silver	Ag^+	magnesium	Mg^{2+}		
sodium	Na^+	mercury(II)	Hg^{2+}		
		nickel(II)	Ni^{2+}		
		tin(II)	Sn^{2+}		
		zinc	Zn^{2+}		

Anions

1−		2−		3−	
Name	**Formula**	**Name**	**Formula**	**Name**	**Formula**
bromide	Br^-	carbonate	CO_3^{2-}	citrate	$C_6H_5O_7^{3-}$
chlorate	ClO_3^-	chromate	CrO_4^{2-}	nitride	N^{3-}
chloride	Cl^-	dichromate	$Cr_2O_7^{2-}$	phosphate	PO_4^{3-}
chlorite	ClO_2^-	monohydrogen phosphate	HPO_4^{2-}		
cyanide	CN^-	oxide	O^{2-}		
dihydrogen phosphate	$H_2PO_4^-$	peroxide	O_2^{2-}		
ethanoate	CH_3COO^-	sulfate	SO_4^{2-}		
fluoride	F^-	sulfide	S^{2-}		
hydrogen carbonate	HCO_3^-	sulfite	SO_3^{2-}		
hydrogen sulfate	HSO_4^-	thiosulfate	$S_2O_3^{2-}$		
hydrogen sulfide	HS^-				
hydrogen sulfite	HSO_3^-				
hydroxide	OH^-				
hypochlorite	ClO^-				
iodide	I^-				
nitrate	NO_3^-				
nitrite	NO_2^-				
perchlorate	ClO_4^-				
permanganate	MnO_4^-				

9. Solubility table

Salts	Soluble	Insoluble
sodium	All	None
potassium		
ammonium		
nitrate		
ethanoate		
bromide, chloride, iodide	Most are soluble.	lead(II), silver, $CuBr_2$, CuI_2
sulfate	Most are soluble.	barium, calcium, lead(II), silver
carbonate	Group 1 ions, ammonium	Most are insoluble.
phosphate	Group 1 ions, ammonium	Most are insoluble.
hydroxide	Group 1 ions, ammonium	Most are insoluble.

10. Average bond enthalpies at 25 °C – single bonds

Δ*H* (kJ mol^{-1})								
	C	H	O	N	Br	Cl	F	I
C	346	414	358	286	285	324	492	228
H	414	436	463	391	366	431	567	298
O	358	463	144	214	201	206	191	234
N	286	391	214	158		192	278	

11. Average bond enthalpies at 25 °C – multiple bonds

Bond	**Δ*H* (kJ mol^{-1})**
C=C	614
C≡C	839
C=N	615
C≡N	890
C=O	804
O=O	498
N=N	470
N≡N	945

12. Energy content of food groups

The energy that is typically available for the body to use as a result of the digestion and absorption of fats and oils, proteins and carbohydrates is shown in the table below. These values may vary based on the specific composition of foods and individual metabolic factors.

Food	Energy content ($kJ\ g^{-1}$)
fats and oils	37
protein	17
carbohydrate	16

13. Molar enthalpies of combustion

The molar enthalpies of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being $CO_2(g)$ and $H_2O(l)$. Enthalpies of combustion, ΔH, for the substances in this table are reported for one mole of fuel and are shown as negative values, indicating the exothermic nature of the combustion reaction.

$$C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l) \qquad \Delta H = -1560\ kJ\ mol^{-1}$$

Fuel	Formula	Molar enthalpy of combustion ($kJ\ mol^{-1}$)
hydrogen	$H_2(g)$	−286
methane	$CH_4(g)$	−890
ethane	$C_2H_6(g)$	−1560
propane	$C_3H_8(g)$	−2220
butane	$C_4H_{10}(g)$	−2880
octane	$C_8H_{18}(l)$	−5470
methanol	$CH_3OH(l)$	−726
ethanol	$C_2H_5OH(l)$	−1370
carbon (graphite)	$C(s)$	−394
glucose	$C_6H_{12}O_6(s)$	−2840

14. Heats of combustion of selected 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(g) and H_2O(l). Values for heats of combustion will vary due to the composition of the different fuels. Additionally, for natural gas, the values may vary based on the source and processing.

Fuel	State	Heat of combustion (kJ g^{-1})	Heat of combustion (kJ mL^{-1})
diesel	liquid	45	37
kerosene	liquid	46	37
natural gas	gas	54	0.035
petrol	liquid	45	34

15. Heats of combustion of selected biofuels

The following table provides typical values for the heat of combustion of selected biofuels. The values may vary significantly, particularly for biogas, depending on the source of the biofuel and, hence, its composition. The amount of energy consumed during any purification process must also be considered when determining the net energy obtained from a biofuel.

Fuel	State	Heat of combustion (kJ g^{-1})
biodiesel	liquid	Approx 37
bioethanol	liquid	29.7
biogas	gas	14–24 This depends on its methane content, which can vary from 45% to 75% methane by volume, depending on its source. The other main constituent is CO_2, which does not burn.

16. Periodic table of the elements

Key	
atomic number	79
electronegativity value	2.5
symbol of element	Au
relative atomic mass	197.0
name of element	gold

1 2.2 **H** 1.0 hydrogen								
3 1.0 **Li** 6.9 lithium	**4** 1.6 **Be** 9.0 beryllium							
11 0.9 **Na** 23.0 sodium	**12** 1.3 **Mg** 24.3 magnesium							
19 0.8 **K** 39.1 potassium	**20** 1.0 **Ca** 40.1 calcium	**21** 1.4 **Sc** 45.0 scandium	**22** 1.5 **Ti** 47.9 titanium	**23** 1.6 **V** 50.9 vanadium	**24** 1.7 **Cr** 52.0 chromium	**25** 1.6 **Mn** 54.9 manganese	**26** 1.8 **Fe** 55.8 iron	**27** 1.9 **Co** 58.9 cobalt
37 0.8 **Rb** 85.5 rubidium	**38** 1.0 **Sr** 87.6 strontium	**39** 1.2 **Y** 88.9 yttrium	**40** 1.3 **Zr** 91.2 zirconium	**41** 1.6 **Nb** 92.9 niobium	**42** 2.2 **Mo** 96.0 molybdenum	**43** 1.9 **Tc** (98) technetium	**44** 2.2 **Ru** 101.1 ruthenium	**45** 2.3 **Rh** 102.9 rhodium
55 0.8 **Cs** 132.9 caesium	**56** 0.9 **Ba** 137.3 barium	**57–71** lanthanoids	**72** 1.3 **Hf** 178.5 hafnium	**73** 1.5 **Ta** 180.9 tantalum	**74** 2.4 **W** 183.8 tungsten	**75** 1.9 **Re** 186.2 rhenium	**76** 2.2 **Os** 190.2 osmium	**77** 2.2 **Ir** 192.2 iridium
87 0.7 **Fr** (223) francium	**88** 0.9 **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

57 1.1 **La** 138.9 lanthanum	**58** 1.1 **Ce** 140.1 cerium	**59** 1.1 **Pr** 140.9 praseodymium	**60** 1.1 **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** 1.2 **Sm** 150.4 samarium	**63** **Eu** 152.0 europium
89 1.1 **Ac** (227) actinium	**90** 1.3 **Th** 232.0 thorium	**91** 1.5 **Pa** 231.0 protactinium	**92** 1.4 **U** 238.0 uranium	**93** 1.4 **Np** (237) neptunium	**94** 1.3 **Pu** (244) plutonium	**95** 1.3 **Am** (243) americium

								2 **He** 4.0 helium
			5 2.0 **B** 10.8 boron	6 2.6 **C** 12.0 carbon	7 3.0 **N** 14.0 nitrogen	8 3.4 **O** 16.0 oxygen	9 4.0 **F** 19.0 fluorine	10 **Ne** 20.2 neon
			13 1.6 **Al** 27.0 aluminium	14 1.9 **Si** 28.1 silicon	15 2.2 **P** 31.0 phosphorus	16 2.6 **S** 32.1 sulfur	17 3.2 **Cl** 35.5 chlorine	18 **Ar** 39.9 argon
28 1.9 **Ni** 58.7 nickel	29 1.9 **Cu** 63.5 copper	30 1.7 **Zn** 65.4 zinc	31 1.8 **Ga** 69.7 gallium	32 2.0 **Ge** 72.6 germanium	33 2.2 **As** 74.9 arsenic	34 2.6 **Se** 79.0 selenium	35 3.0 **Br** 79.9 bromine	36 3.0 **Kr** 83.8 krypton
46 2.2 **Pd** 106.4 palladium	47 1.9 **Ag** 107.9 silver	48 1.7 **Cd** 112.4 cadmium	49 1.8 **In** 114.8 indium	50 2.0 **Sn** 118.7 tin	51 2.1 **Sb** 121.8 antimony	52 2.1 **Te** 127.6 tellurium	53 2.7 **I** 126.9 iodine	54 2.6 **Xe** 131.3 xenon
78 2.3 **Pt** 195.1 platinum	79 2.5 **Au** 197.0 gold	80 2.0 **Hg** 200.6 mercury	81 1.6 **Tl** 204.4 thallium	82 2.3 **Pb** 207.2 lead	83 2.0 **Bi** 209.0 bismuth	84 2.0 **Po** (210) polonium	85 2.2 **At** (210) astatine	86 **Rn** (222) radon
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

64 1.2 **Gd** 157.3 gadolinium	65 **Tb** 158.9 terbium	66 1.2 **Dy** 162.5 dysprosium	67 1.2 **Ho** 164.9 holmium	68 1.2 **Er** 167.3 erbium	69 1.3 **Tm** 168.9 thulium	70 **Yb** 173.1 ytterbium	71 1.3 **Lu** 175.0 lutetium

96 1.3 **Cm** (247) curium	97 1.3 **Bk** (247) berkelium	98 1.3 **Cf** (251) californium	99 1.3 **Es** (252) einsteinium	100 1.3 **Fm** (257) fermium	101 1.3 **Md** (258) mendelevium	102 1.3 **No** (259) nobelium	103 1.3 **Lr** (262) lawrencium

Values in brackets indicate the mass number of the longest-lived isotope.

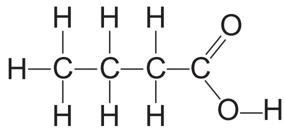
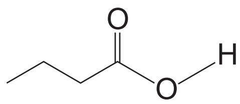
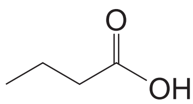
17. Names of selected elements

Element	Symbol	Atomic number	Relative atomic mass (amu)
aluminium	Al	13	27.0
argon	Ar	18	39.9
arsenic	As	33	74.9
barium	Ba	56	137.3
beryllium	Be	4	9.0
boron	B	5	10.8
bromine	Br	35	79.9
cadmium	Cd	48	112.4
caesium	Cs	55	132.9
calcium	Ca	20	40.1
carbon	C	6	12.0
chlorine	Cl	17	35.5
chromium	Cr	24	52.0
cobalt	Co	27	58.9
copper	Cu	29	63.5
fluorine	F	9	19.0
gallium	Ga	31	69.7
germanium	Ge	32	72.6
gold	Au	79	197.0
helium	He	2	4.0
hydrogen	H	1	1.0
iodine	I	53	126.9
iron	Fe	26	55.8
krypton	Kr	36	83.8
lead	Pb	82	207.2
lithium	Li	3	6.9

Element	Symbol	Atomic number	Relative atomic mass (amu)
magnesium	Mg	12	24.3
manganese	Mn	25	54.9
mercury	Hg	80	200.6
neon	Ne	10	20.2
nickel	Ni	28	58.7
nitrogen	N	7	14.0
oxygen	O	8	16.0
phosphorus	P	15	31.0
platinum	Pt	78	195.1
potassium	K	19	39.1
rubidium	Rb	37	85.5
scandium	Sc	21	45.0
selenium	Se	34	79.0
silicon	Si	14	28.1
silver	Ag	47	107.9
sodium	Na	11	23.0
strontium	Sr	38	87.6
sulfur	S	16	32.1
tin	Sn	50	118.7
titanium	Ti	22	47.9
tungsten	W	74	183.8
vanadium	V	23	50.9
xenon	Xe	54	131.3
yttrium	Y	39	88.9
zinc	Zn	30	65.4
zirconium	Zr	40	91.2

18. 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	 or 

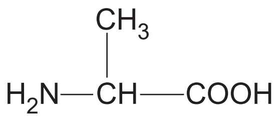
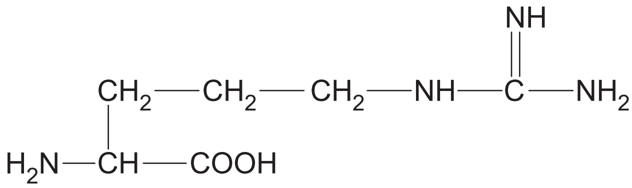
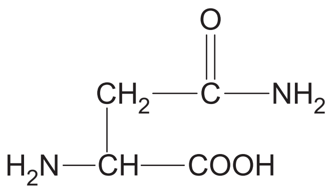
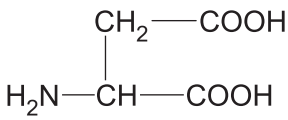
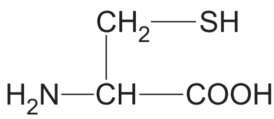
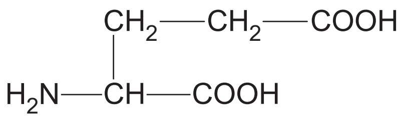
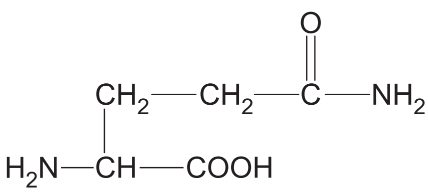
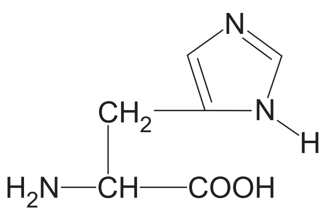
19. Functional group nomenclature in organic chemistry

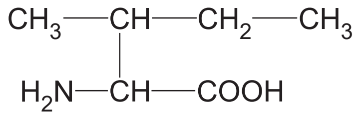
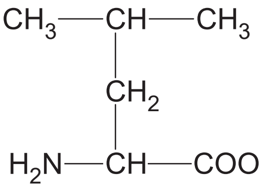
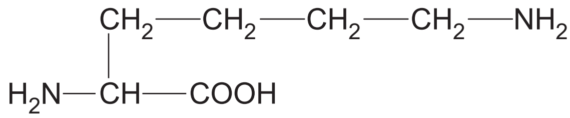
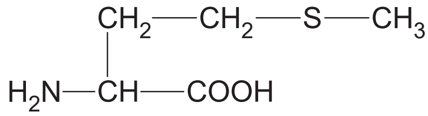
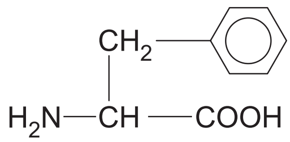
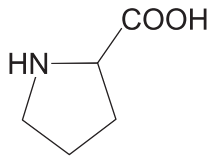
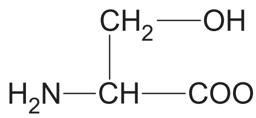
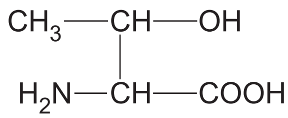
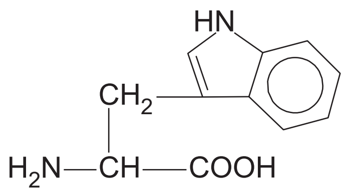
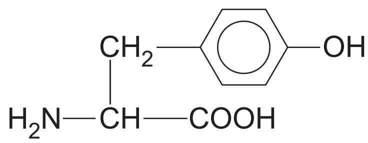
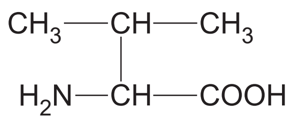
The following table shows the priority of functional groups when naming organic compounds that contain more than one functional group.
The functional group with the highest priority determines the suffix of the compound.

Class of compound	Functional group name	Prefix	Suffix
carboxylic acid	carboxyl	–	-oic acid
ester	ester	–	-oate
amide	amide	–	-amide
aldehyde	carbonyl	–	-al
ketone	carbonyl	–	-one
alcohol	hydroxy/ hydroxyl	hydroxy-	-ol
amine	amino	amino-	-amine
alkene	alkenyl	–	-ene
halogen	‘halo’ (i.e. bromo, chloro, fluoro, iodo)	bromo- chloro- fluoro- iodo-	–

20. 2-amino acids (α-amino acids)

The table below provides simplified structures for amino acids. These amino acids may all be classified as '2-amino acids' since the amino group (-NH_2) is attached to the second carbon atom in the carbon chain, numbered from the carboxyl (-COOH) end. They may also be classified as 'α-amino acids', since both the amino group and the carboxyl group are attached to the same carbon atom, known as the alpha carbon. These structures may be used as the basis for drawing zwitterions, identifying the products of protein hydrolysis and drawing the structures formed in the 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	$H_2N—CH_2—COOH$
histidine	His	

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

21. Formulas of selected fatty acids

Name	Molecular formula	Semi-structural formula
caproic	$C_6H_{12}O_2$	$CH_3(CH_2)_4COOH$
capric	$C_{10}H_{20}O_2$	$CH_3(CH_2)_8COOH$
lauric	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$
myristic	$C_{14}H_{28}O_2$	$CH_3(CH_2)_{12}COOH$
palmitic	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$
palmitoleic	$C_{16}H_{30}O_2$	$CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$
stearic	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$
oleic	$C_{18}H_{34}O_2$	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$
linoleic	$C_{18}H_{32}O_2$	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$
linolenic	$C_{18}H_{30}O_2$	$CH_3(CH_2CH{=}CH)_3(CH_2)_7COOH$
arachidic	$C_{20}H_{40}O_2$	$CH_3(CH_2)_{18}COOH$
arachidonic	$C_{20}H_{32}O_2$	$CH_3(CH_2)_4(CH{=}CHCH_2)_3CH{=}CH(CH_2)_3COOH$

22. Characteristic ranges for infrared absorption

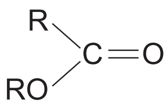
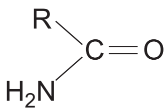
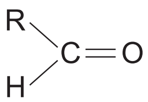
Bond	Wave number (cm^{-1})
C=O (amides)	1630–1680
C=O (aldehydes)	1660–1745
C=O (acids)	1680–1740
C=O (ketones)	1680–1850
C=O (esters)	1720–1840

Bond	Wave number (cm^{-1})
C–H (alkanes, alkenes, arenes)	2850–3090
O–H (acids)	2500–3500
O–H (alcohols)	3200–3600
N–H (amines and amides)	3300–3500

23. ^{13}C NMR data

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

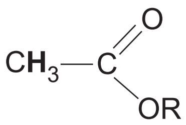
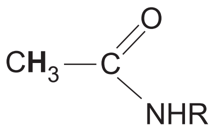
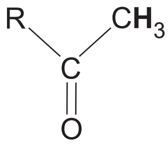
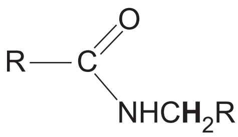
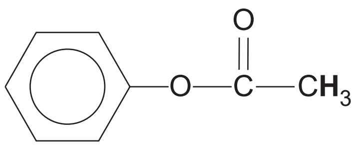
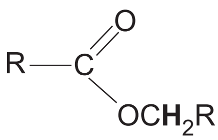
These can differ slightly in different solvents.

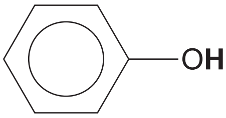
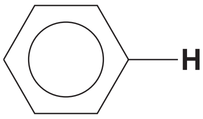
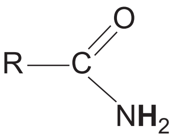
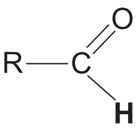
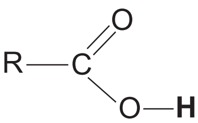
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$R_2C=CR_2$	110–150
arenes $C_6H_5–R$	110–150
RCOOH	160–185
	165–175
	165–185
	190–200
$R_2C=O$	205–220

24. ^{1}H NMR data

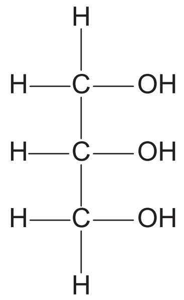
Typical proton shift values relative to TMS = 0

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

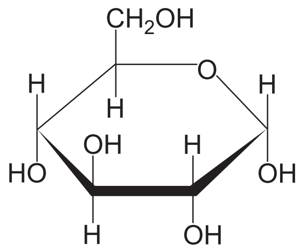
Type of proton	Chemical shift (ppm)
$R{-}C\mathbf{H}_3$	0.9–1.0
$R{-}C\mathbf{H}_2{-}R$	1.3–1.4
$RCH{=}CH{-}C\mathbf{H}_3$	1.6–1.9
$R_3{-}C\mathbf{H}$	1.5
 or 	2.0
	2.1–2.7
$R{-}C\mathbf{H}_2{-}X$ (X = F, Cl, Br or I)	3.0–4.5
$R{-}C\mathbf{H}_2{-}OH$, $R_2{-}C\mathbf{H}{-}OH$	3.3–4.5
	3.2
$R{-}O{-}C\mathbf{H}_3$ 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
	6.0–8.0
	9.4 –10.0
	9.0–13.0

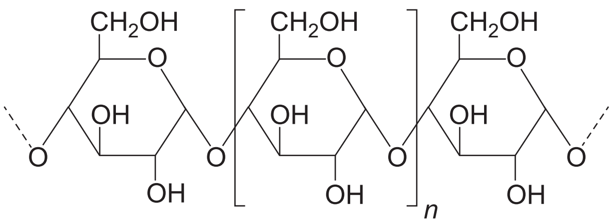
25. Representations of selected biomolecules



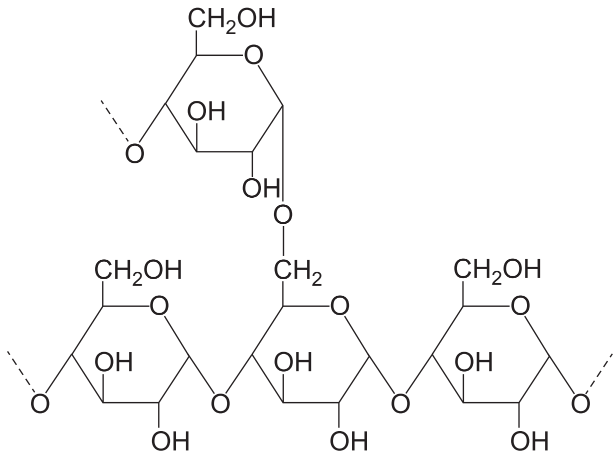
glycerol



α-D-glucose



amylose (starch)



amylopectin (starch)

26. Sustainability

i. United Nations Sustainable Development Goals

The following nine goals are relevant to VCE Chemistry:

- Goal 2: Zero hunger
- Goal 6: Clean water and sanitation
- Goal 7: Affordable and clean energy
- Goal 9: Industry, innovation and infrastructure
- Goal 11: Sustainable cities and communities
- Goal 12: Responsible consumption and production
- Goal 13: Climate action
- Goal 14: Life below water
- Goal 15: Life on land

Source: Adapted from 'The 17 Goals',
Department of Economic and Social Affairs,
Sustainable Development, United Nations
<https://sdgs.un.org./goals>

ii. Green chemistry principles

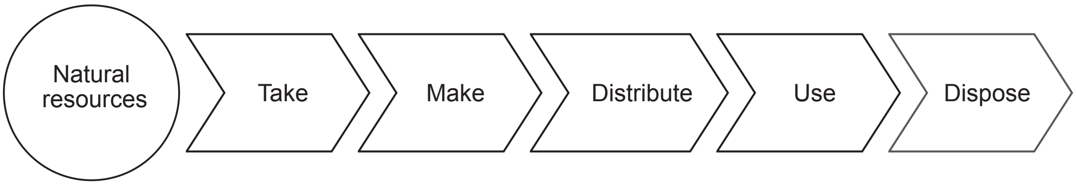
The following seven green chemistry principles are relevant to VCE Chemistry:

- Atom economy: Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
- Catalysis: Catalysts should be selected to generate the same desired product(s) with less waste and using less energy and reagents in reaction processes/pathways.
- Design for degradation: Chemical products should be designed so that at the end of their use they break down into harmless degradation products and do not persist in the environment.
- Design for energy efficiency: Processes/pathways should be designed for maximum energy efficiency and with minimal negative environmental and economic impacts.
- Designing safer chemicals: Chemical products should be designed to achieve their intended function while minimising toxicity.
- Prevention of wastes: It is better to prevent waste than to treat or clean up waste after it has been produced.
- Use of renewable feedstocks: Raw materials or feedstocks should be made from renewable (mainly plant-based) materials, rather than from fossil fuels, whenever practicable.

Source: Adapted from PT Anastas and JC Warner,
Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998, p.30

iii. Types of economies

Linear



Circular