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

Chemistry

Question and Answer Book

VCE Examination – Tuesday 12 November 2024

- 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 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 pages

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Section A – Multiple-choice questions

Instructions

- Answer **all** questions in pencil on the 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

Photosynthesis is an

A. exothermic redox reaction.

B. endothermic redox reaction.

C. exothermic condensation reaction.

D. endothermic condensation reaction.

Question 2

Which one of the following statements is correct?

A. The oxidation of glucose is reversible in the body.

B. The combustion of glucose provides less energy per gram than the combustion of hydrogen.

C. The oxidation of glucose is given by the equation $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.

D. The combustion of oxygen occurs during cellular respiration.

Question 3

0.50 mol of ethane, C_2H_6, and 100.0 g of air that is 22.0% m/m oxygen, O_2, are injected into a combustion chamber.

The equation of the combustion of ethane is $C_2H_6(g) + 3\frac{1}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$.

If complete combustion takes place, which reactant is in excess and by how much?

	Reactant in excess	Amount of reactant in excess
A.	C_2H_6	0.25 mol
B.	C_2H_6	0.30 mol
C.	O_2	12 g
D.	O_2	97 g

Question 4

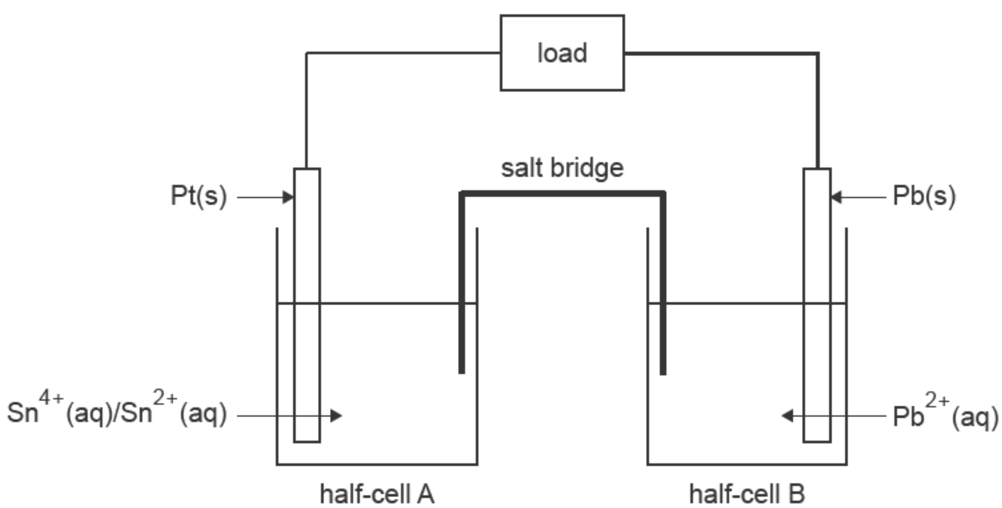
Consider the following reaction.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6I^-(aq) \rightarrow 2Cr^{3+}(aq) + 3I_2(aq) + 7H_2O(l)$$

Which one of the following correctly identifies the oxidising agent and a conjugate redox pair (in the form oxidising agent/reducing agent)?

	Oxidising agent	Conjugate redox pair (oxidising agent/reducing agent)
A.	$Cr_2O_7^{2-}$	I_2/I^-
B.	$Cr_2O_7^{2-}$	I^-/I_2
C.	I^-	$Cr_2O_7^{2-}/Cr^{3+}$
D.	I^-	$Cr^{3+}/Cr_2O_7^{2-}$

Question 5



When the galvanic cell is operating

A. total chemical energy is increasing and electrons flow to half-cell A.

B. total chemical energy is increasing and electrons flow to half-cell B.

C. total chemical energy is decreasing and electrons flow to half-cell A.

D. total chemical energy is decreasing and electrons flow to half-cell B.

Question 6

Consider the following half-equation.

$$IO_3^-(aq) + 6H^+(aq) + 5e^- \rightleftharpoons \frac{1}{2}I_2(aq) + 3H_2O(l) \qquad E^0 = +1.20\ V$$

A galvanic cell is set up using inert electrodes and the following chemicals:

- half-cell 1: 1.0 M acidified solution of potassium iodate/iodine solution, $KIO_3(aq)/I_2(aq)$
- half-cell 2: oxygen gas, $O_2(g)$, in an alkaline solution.

Which one of the following statements is correct when the galvanic cell is operating?

A. Hydrogen gas is produced at the cathode.

B. The oxidising agent is IO_3^- and the reducing agent is O_2.

C. The concentration of OH^- ions decreases at the negative electrode.

D. The mass of the electrode in half-cell 1 decreases.

Question 7

In a galvanic cell, copper(II) ions, Cu^{2+}, are converted to copper metal, Cu.

What mass of Cu is deposited for each 0.50 mol of electrons transferred in the cell?

A. 1.6×10 g

B. 3.2×10 g

C. 6.4×10 g

D. 1.3×10^2 g

Question 8

Consider the following statements about hydrogen fuel cells.

I The use of porous electrodes reduces cell efficiency.

II As the ratio of the amount of hydrogen supplied to the amount of electricity produced increases, the efficiency increases.

Which of the statements about hydrogen fuel cells is/are correct?

A. I only

B. II only

C. both I and II

D. neither I nor II

Question 9

The overall reaction in an alkaline–ethanol fuel cell is shown below.

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

What amount of hydroxide ions, OH^-, reacts with 1 mol of ethanol, C_2H_5OH, at the negative electrode of the fuel cell?

A. 4 mol

B. 6 mol

C. 8 mol

D. 12 mol

Question 10

Consider the following statements regarding fuels.

I Bioethanol fuel is sustainable because it results in no net release of carbon dioxide into the atmosphere.

II Hydrogen peroxide, H_2O_2, can be used as an oxidising agent in fuel cells.

Which of the statements regarding fuels is/are correct?

A. I only

B. II only

C. both I and II

D. neither I nor II

Question 11

Iron is produced from iron ore using heat and a reducing agent.

Using hydrogen, produced from fossil fuels, as the reducing agent to produce iron is consistent with

A. the concept of a linear economy.

B. the concept of a circular economy.

C. the United Nations Sustainable Development Goal 2: Zero hunger.

D. the United Nations Sustainable Development Goal 11: Sustainable cities and communities.

Question 12

The combustion reaction between butane gas, C_4H_{10}, and oxygen gas, O_2, is considered irreversible because

A. the forward reaction is exothermic.

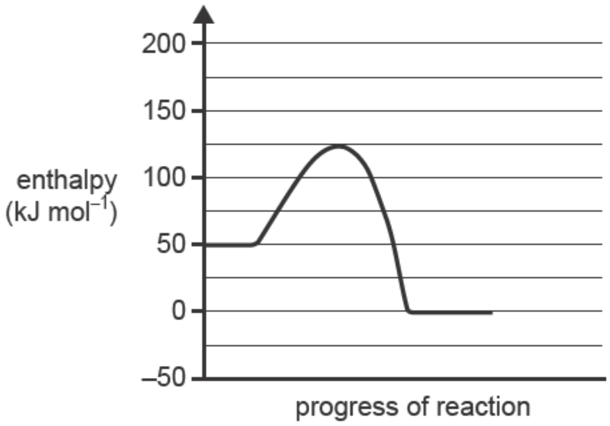
B. the products are less stable than the reactants.

C. the rate of the reverse reaction is so slow that it can be ignored.

D. an unlimited supply of oxygen will favour the forward reaction.

Question 13

Consider the following energy profile diagram for an **uncatalysed** gaseous reaction. A solid catalyst is available for this reaction.



Which one of the following statements is correct?

A. Adding the catalyst to the uncatalysed reaction will increase the energy of the reactants.

B. Removing the catalyst from the catalysed reaction will increase the rate of the reaction.

C. Removing the catalyst from the catalysed reaction will increase the activation energy.

D. Adding the catalyst to the uncatalysed reaction will make the reaction endothermic.

Question 14

Consider the following reaction.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H > 0$$

Which reaction conditions would give the greatest yield of nitrogen dioxide, NO_2?

A. 200 kPa and 100 °C

B. 200 kPa and 25 °C

C. 100 kPa and 100 °C

D. 100 kPa and 25 °C

Question 15

An example of a homogeneous equilibrium is the decomposition of sulfur trioxide, $SO_3(g)$, to form sulfur dioxide, $SO_2(g)$, and oxygen, $O_2(g)$.

Some $SO_3(g)$ is placed in an empty container, which is then sealed.

Which one of the following statements is true at all temperatures when the sealed system reaches equilibrium?

A. The mass of $SO_2(g)$ is 4.0 times the mass of $O_2(g)$.

B. The mass of $SO_2(g)$ is 80.0% of the mass of $SO_3(g)$.

C. The amount in mol of $SO_2(g)$ and $O_2(g)$ are the same.

D. The amount in mol of $SO_2(g)$ and $SO_3(g)$ are the same.

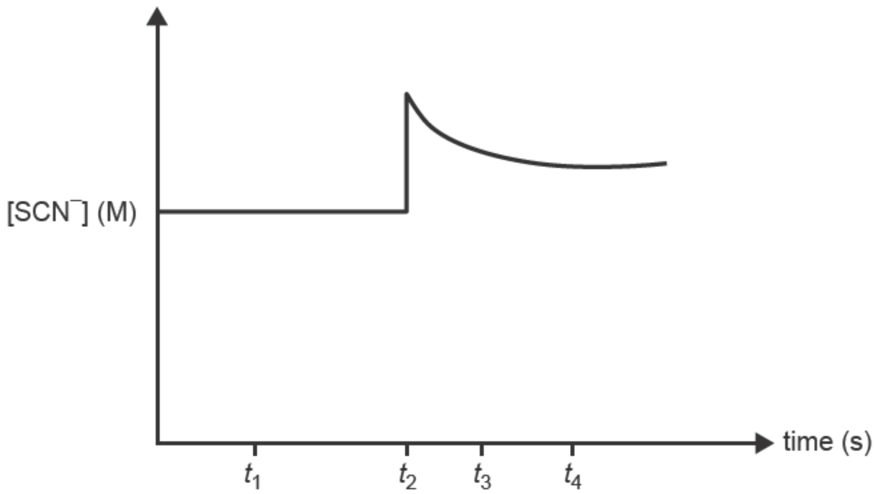
Question 16

The reaction between iron(III) ions, $Fe^{3+}(aq)$, and thiocyanate ions, $SCN^{-}(aq)$, produces iron(III) thiocyanate ions, $FeSCN^{2+}(aq)$.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq) \qquad \Delta H < 0$$

A few drops of sodium thiocyanate solution, NaSCN(aq), are added to 200 mL of the equilibrium mixture at constant temperature.

The concentration–time graph shows the change in concentration of $SCN^{-}(aq)$.



Which one of the following statements is true?

A. The equilibrium constant at t_4 is lower than at t_1.

B. The chemical energy of the system increases between t_3 and t_4.

C. The rate of the reverse reaction is less than the rate of the forward reaction at t_3.

D. Both the concentrations of Fe^{3+} and $FeSCN^{2+}$ are higher at t_3 than at t_1.

Question 17

A piece of blister copper contains 98.5% copper. The blister copper also contains other metals, including silver, iron and nickel. Electrolysis in an aqueous solution of Cu^{2+} ions is used to produce 99.99% pure copper from the blister copper.

In the electrolysis of the blister copper

A. blister copper is used as the cathode.

B. solid iron falls to the bottom of the electrolysis cell.

C. the 99.99% pure copper product should be removed as it forms.

D. the concentration of Cu^{2+} ions in the electrolyte changes during the electrolysis.

Question 18

Each of the following compounds has a molar mass of 88 g mol^{-1}.

Which one has the highest boiling point?

A. $CH_3CH_2OCOCH_3$

B. $CH_3(CH_2)_2COOH$

C. $CH_3(CH_2)_3CH_2OH$

D. $CH_3NH(CH_2)_2NHCH_3$

Question 19

Which one of the following statements about cyclohexane and benzene is correct?

A. Both have structural isomers that are not cyclic.

B. Both have the same average bond strength between their carbon atoms.

C. Both are members of the same homologous series.

D. Each carbon in cyclohexane has one more valence electron than each carbon in benzene.

Question 20

Consider the structural isomers of $C_5H_{10}O$ that are aldehydes.

Which one of the following statements is correct?

A. There are three isomers.

B. There is one isomer with an ethyl side branch.

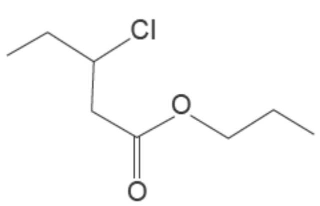
C. There are two isomers that have one methyl side branch.

D. Each isomer has a functional group on the second carbon atom.

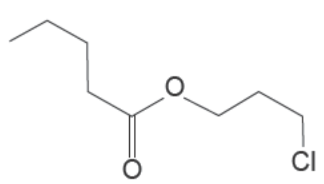
Question 21

Which one of the following represents the skeletal structure for 3-chlorobutyl butanoate?

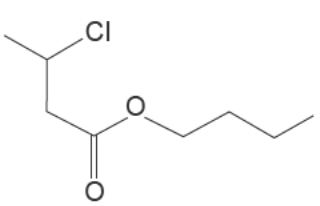
A.



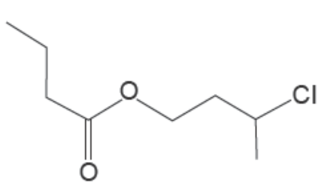
B.



C.



D.



Use the following information to answer Questions 22 and 23.

A triglyceride is reacted with methanol, CH_3OH, in the presence of concentrated KOH(aq). The products of this reaction are glycerol and Compound J.

Question 22

The molecular formula of Compound J is $C_{19}H_{30}O_2$.

What is the molecular formula of the triglyceride?

A. $C_{54}H_{82}O_3$

B. $C_{54}H_{82}O_6$

C. $C_{57}H_{84}O_3$

D. $C_{57}H_{86}O_6$

Question 23

When the triglyceride is reacted with methanol to produce glycerol and Compound J

A. H_2O should be added to the KOH directly, because KOH is corrosive and causes skin burns.

B. H_2O should not be added to the reaction mixture because it interferes with the desired reaction.

C. H_2O should be added to separate the triglyceride from glycerol since the triglyceride is soluble in water.

D. H_2O should not be added to the reaction mixture because it increases the frequency of successful collisions.

Question 24

Evelyn titrates 10.0 mL of 0.100 M potassium permanganate, $KMnO_4$, with 0.100 M oxalic acid, $C_2H_2O_4$.

The half-equation for the oxidation of oxalic acid in acidic conditions is

$$C_2H_2O_4(aq) \rightarrow 2CO_2(g) + 2H^+(aq) + 2e^-$$

What volume of $C_2H_2O_4$ should be added to reach the equivalence point?

A. 4.0 mL

B. 10.0 mL

C. 12.0 mL

D. 25.0 mL

Use the following information to answer Questions 25 and 26.

A chemist runs a mixture of hexane, hexan-1-ol and hexan-2-one through a high-performance liquid chromatography (HPLC) column using a polar mobile phase and a non-polar stationary phase.

Question 25

Which of the following shows the chemicals in order of their retention times, from lowest to highest?

A. hexane, hexan-2-one, hexan-1-ol

B. hexane, hexan-1-ol, hexan-2-one

C. hexan-2-one, hexan-1-ol, hexane

D. hexan-1-ol, hexan-2-one, hexane

Question 26

The chemist wants to determine the concentration of hexane in the mixture.

Which one of the following will provide information to allow the hexane concentration to be accurately calculated?

A. running a series of known concentrations of hexane through the HPLC column under the same conditions

B. running the HPLC experiment using a non-polar mobile phase and a polar stationary phase

C. using published retention times and peak sizes of standard hexane chromatographs

D. reducing the HPLC column temperature to achieve better separation of the compounds

Question 27

Which one of the following statements is correct?

A. The presence of chiral carbons in a compound is shown more clearly by performing a volumetric analysis than by its IR spectrum.

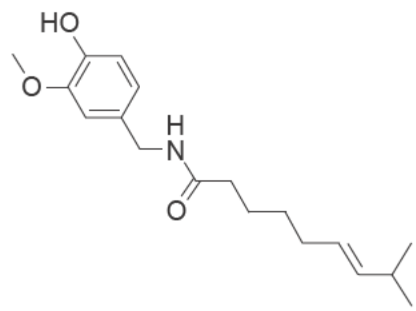
B. The presence of chlorine in a compound is shown more clearly in its ^{13}C NMR spectrum than in its mass spectrum.

C. The number of carbon–carbon double bonds in a compound is shown more clearly in its HPLC spectrum than by using an iodine test on the compound.

D. The presence of a primary hydroxyl group in a compound is shown more clearly in its ^{1}H NMR spectrum than by adding acidified potassium permanganate to the compound.

Question 28

Capsicum frutescens is a plant used to reduce inflammation and pain. One active ingredient of this plant is shown below.



Which functional groups are present in this active ingredient?

A. alkenyl, amide, hydroxyl

B. alkenyl, amino, hydroxyl

C. amide, carboxyl, carbonyl

D. amine, carboxyl, carbonyl

Question 29

A reaction between sulfur atoms in proteins

A. contributes to the quaternary structure through ionic bonding.

B. contributes to the secondary structure through hydrogen bonding.

C. leads to the formation of covalent bonds, and contributes to the tertiary structure.

D. leads to the formation of disulfide linkages, and contributes to the primary structure.

Question 30

Salim is writing a scientific poster to report on his laboratory analysis of a compound.

Consider the following three statements.

I A 50 mL solution of 0.1 M HCl was placed in a conical flask.

II The average concentration is within the range claimed by the manufacturer.

III The table shows the titres from the titration.

Which section of the poster should include these statements?

	I	II	III
A.	results	results	discussion
B.	method	results	discussion
C.	method	discussion	results
D.	results	discussion	results

End of Section A

Section B

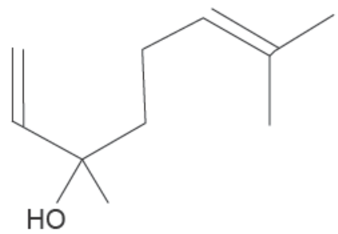
Instructions

- 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 (8 marks)

a. How can melting point determination be used to check the components and purity of solid consumer products? 2 marks

b. Linalool, $C_{10}H_{18}O$, is a colourless oil found in lavender plants. Linalool may be useful in the human body to reduce inflammation. The molar mass of linalool is 154 g mol^{-1}.



i. How many chiral centres are present in each linalool molecule? 1 mark

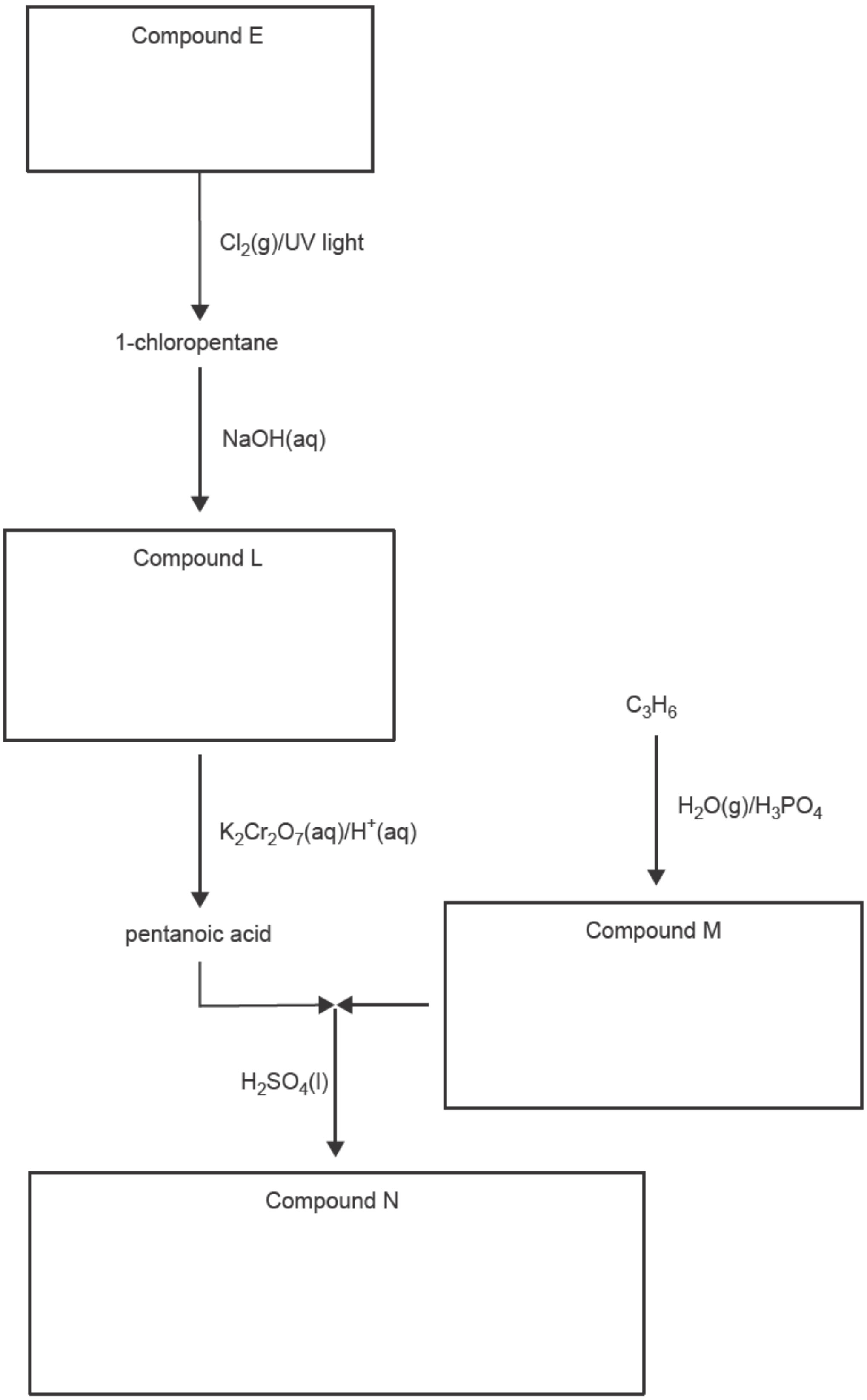
ii. A 15.0 g mixture of linalool and hexane, C_6H_{14}, was reacted with an excess of iodine, I_2. It was found that 0.042 mol of I_2 reacted with the mixture.

Calculate the percentage by mass of linalool in the original mixture. 3 marks

iii. Identify **two** processes used to obtain purified linalool from crushed lavender. 2 marks

Question 2 (8 marks)

A reaction pathway begins with a hydrocarbon, Compound E.



a. **i.** Write the molecular formula of Compound E in the box provided on page 14. 1 mark

ii. State the type of reaction that produces 1-chloropentane from Compound E. 1 mark

____

b. 1-chloropentane is reacted with NaOH to produce Compound L.

Write the semi-structural formula for Compound L in the box provided on page 14. 1 mark

c. C_3H_6 reacts with H_2O in the presence of a H_3PO_4 catalyst to produce Compound M, which is a primary alcohol.

Write the IUPAC name of Compound M in the box provided on page 14. 1 mark

d. Pentanoic acid is reacted with Compound M to form Compound N in the presence of concentrated sulfuric acid, $H_2SO_4(l)$.

i. State a qualitative test to detect the presence of the functional group in pentanoic acid, and state the expected observation(s). 2 marks

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____

____

____

ii. Draw the skeletal structure of Compound N in the box provided on page 14. 2 marks

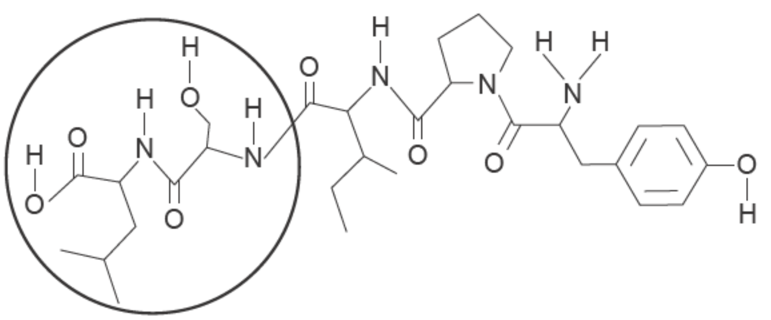
Question 3 (9 marks)

A label on a bread packet has the following information.

Nutritional information	
	Mass per 100 g of bread
Protein	9.5 g
Fat	3.4 g
Carbohydrates	47.3 g

a. Use **item 12** of the Data Book to calculate the energy typically available for the body to use in 100 g of bread. 1 mark

b. Gluten exorphin C is derived from gluten found in bread. The skeletal structure of gluten exorphin C is shown below.



i. Name the bond that joins the monomers in gluten exorphin C. 1 mark

ii. Name the type of reaction that results in the formation of the bond between the monomers in gluten exorphin C. 1 mark

iii. Use **item 20** of the Data Book to name a monomer that reacted to form the circled section of the gluten exorphin C molecule shown on page 16. 1 mark

c. The fats in bread can be broken down into compounds including oleic acid and stearic acid. Refer to **item 21** of the Data Book.

i. Identify a structural difference between oleic acid and stearic acid. 1 mark

ii. Write the reaction for the complete combustion of oleic acid. States are not required. 2 marks

iii. Predict whether oleic acid or stearic acid would have a higher molar heat of combustion. Explain your answer with reference to **item 10** and **item 11** of the Data Book. No calculations are required. 2 marks

Question 4 (8 marks)

Ammonia gas, $NH_3(g)$, can be made by reacting a mixture of nitrogen gas, $N_2(g)$, and hydrogen gas, $H_2(g)$, using an iron catalyst.

The reaction can be represented by the equation

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92.3 \text{ kJ}$$

The equilibrium constant, K_p, at 400 °C is 1.60×10^{-8} kPa^{-2}.

In a mixture that is at equilibrium at 400 °C, the partial pressure of H_2 is 88.7 kPa and the partial pressure of N_2 is 43.4 kPa.

a. Write the expression for the equilibrium constant, K_p. 1 mark

b. Determine the partial pressure of NH_3, in kPa, in the equilibrium mixture at 400 °C. 1 mark

c. At a **constant temperature** of 400 °C, a change was made to the equilibrium system. Just after the change was made, the reaction quotient, Q, was 1.20×10^{-9} kPa^{-2}.

Identify a change to the system that would result in this reaction quotient. Explain how the system would respond to the change. 3 marks

d. Explain how the iron catalyst addresses the conflict between optimal rate and temperature considerations in the production of NH_3. Support your answer with reference to **one** green chemistry principle. Refer to **item 26.ii** of the Data Book. 3 marks

Do not write in this area.

Question 5 (11 marks)

a. A container with 100.0 g of water was heated using a butane, C_4H_{10}, gas burner. The following results were obtained.

Mass of C_4H_{10} combusted	0.580 g
Temperature increase of water	35.6 °C

i. Use **item 13** of the Data Book to calculate the amount of energy released by the combustion of C_4H_{10}. 2 marks

ii. Calculate the amount of energy absorbed by the 100.0 g of water. 1 mark

iii. Calculate the percentage energy efficiency of the system used to heat the water. 2 marks

b. Minh is provided with solutions of 0.500 M lead(II) nitrate, $Pb(NO_3)_2(aq)$, and 0.960 M potassium iodide, KI(aq), to investigate the reaction below

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq) \qquad \Delta H = -49.0 \text{ kJ}$$

Minh calibrated a solution calorimeter and found its calibration factor to be 470.0 J °C^{-1}. Minh performed the reaction above in the calibrated calorimeter. The initial temperature of each solution was 25.0 °C. Minh stirred the mixture continuously during the reaction.

i. Explain why a calorimeter needs to be calibrated before it can be used to calculate enthalpy changes. 2 marks

ii. Calculate the maximum temperature that could be reached by the solution in the calorimeter if 0.048 mol of KI(aq) reacted. 3 marks

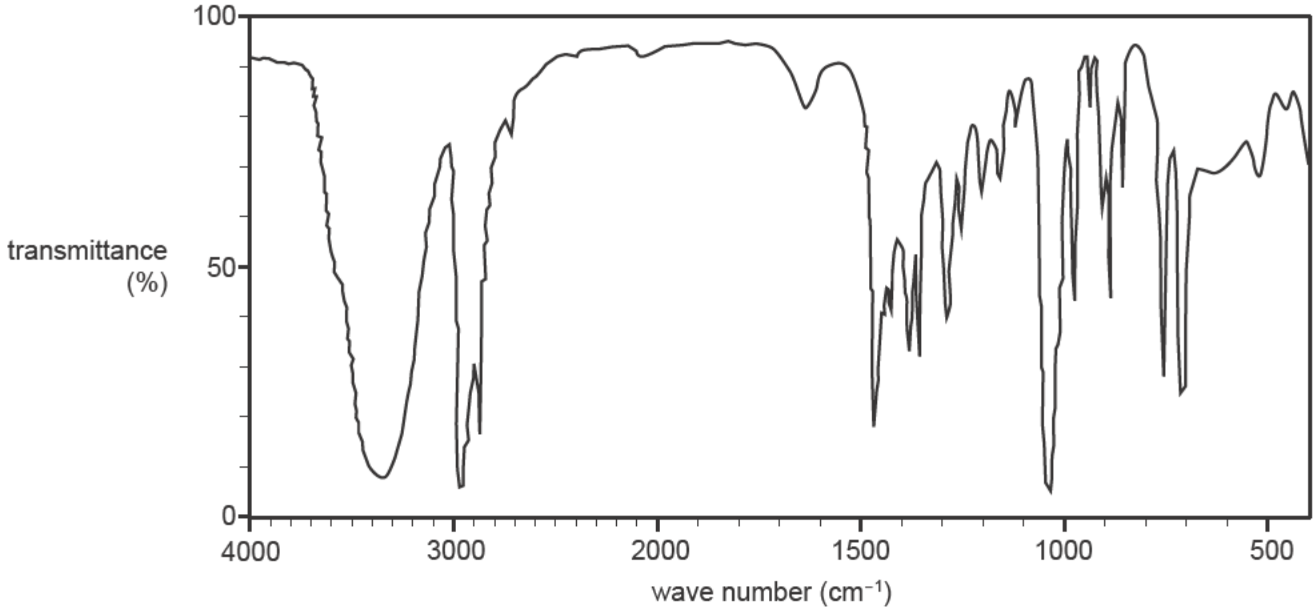
iii. Minh repeated the experiment with the $Pb(NO_3)_2(aq)$ and KI(aq) solutions three times in the calibrated calorimeter. The experiment was found to have a high degree of repeatability. The average maximum temperature from the four trials was greater than the expected value.

State **one** reason that would explain why the average was greater than the expected value. 1 mark

Question 6 (13 marks)

Compound X has a molecular formula of $C_5H_{11}ClO$.

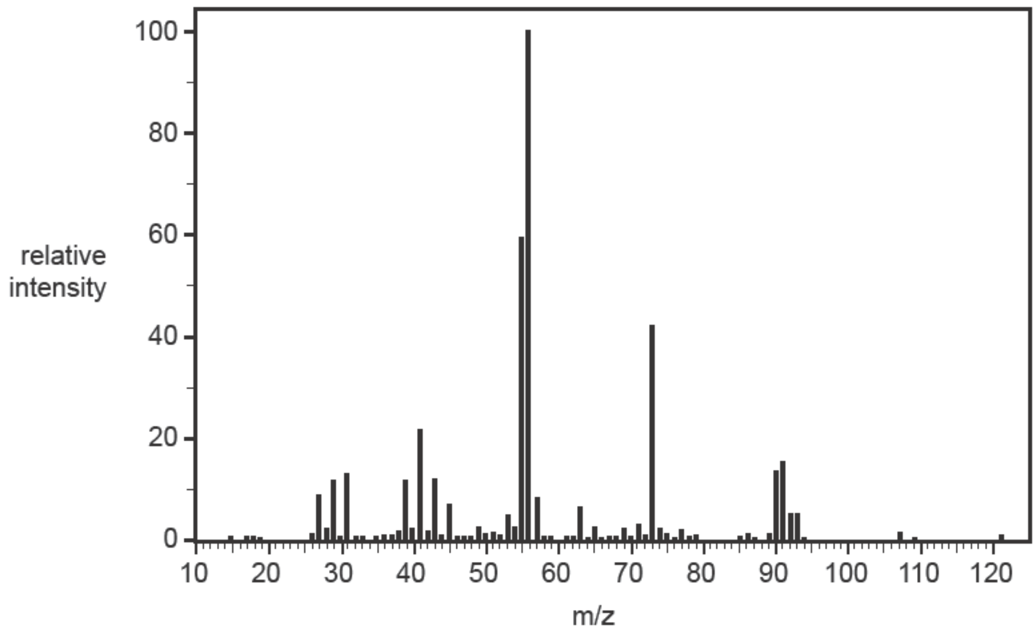
The infrared spectrum of Compound X is shown below.



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

a. Use **item 22** of the Data Book to identify the bond type in Compound X that has the highest wave number. 1 mark

b. The mass spectrum of Compound X, $C_5H_{11}ClO$, is shown below.



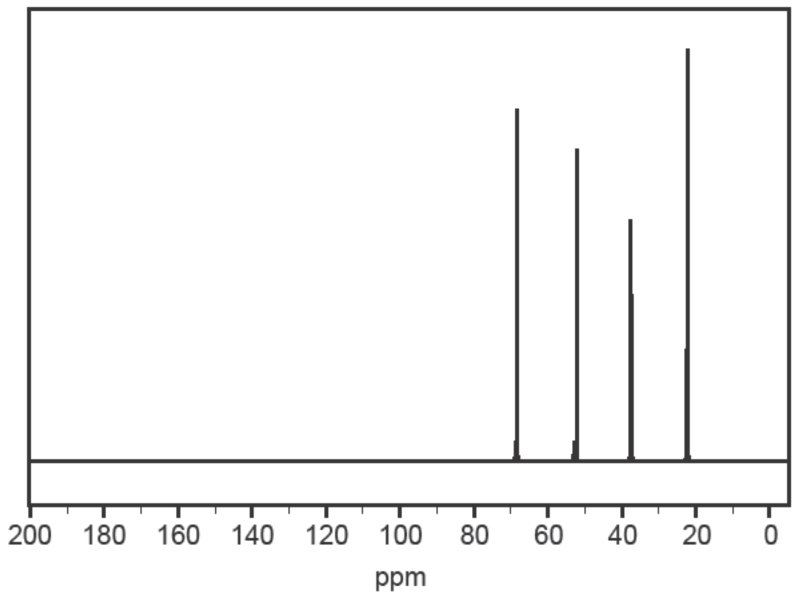
Data: National Institute of Advanced Industrial Science and Technology, SDBS Web <https://sdbs.db.aist.go.jp>

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

ii. Identify the formula of the species that is responsible for the peak at m/z = 73. 1 mark

Question 6 continues on the next page.

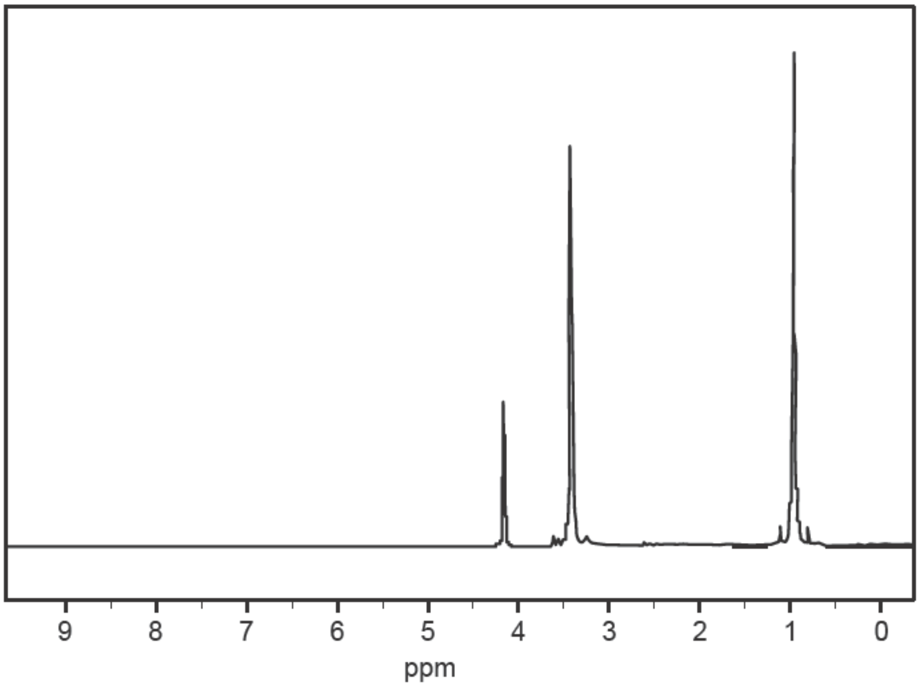
c. The ^{13}C NMR spectrum for Compound X is shown below.



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

What information do the four peaks in the ^{13}C NMR spectrum provide about the **arrangement** of the five carbon atoms in the structure of Compound X? Justify your answer. 3 marks

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



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

i. Each peak in the ^{1}H NMR spectrum for Compound X is a singlet.
Each peak has an associated integration curve.

In general, what feature of a ^{1}H NMR peak is represented by its integration curve? 1 mark

ii. ^{1}H NMR spectral analysis can provide information about the molecular structure of compounds.

In general, what information does the relative size of the integration curves for any given ^{1}H NMR spectrum provide about the molecular structure of the compound analysed? 1 mark

Question 6 continues on the next page.

iii. The expected integration curves for Compound X are shown in the table below.

Chemical shift (ppm)	Splitting pattern	Integration curve
4.16	singlet	
3.44	singlet	
3.39	singlet	
0.96	singlet	

State what the relative size of the integration curves in the table above indicates about the molecular structure of Compound X. 1 mark

iv. Consider the chemical shift and the size of the integration curve for the peak at 0.96 ppm. Refer to **item 24** of the Data Book.

What does this information indicate about the structure of Compound X? 2 marks

e. In the space provided below, draw the structural diagram of Compound X, using the information provided in **parts a–d** of Question 6. 2 marks

Do not write in this area.

Question 7 (12 marks)

a. Svante adds a 1 M solution of sodium nitrate, $NaNO_3(aq)$, to a beaker. An electric current from a 3 V power supply is then passed between an iron, Fe(s), electrode and a platinum, Pt(s), electrode placed into the solution.

The positive terminal of the power supply is attached to the Fe electrode and the negative terminal of the power supply is attached to the Pt electrode.

Refer to **item 1** of the Data Book.

i. State which metal electrode is the anode. 1 mark

___

ii. Write the half-equation for the reaction that occurs at the Pt electrode when the power supply is turned on. 1 mark

___

iii. State why no reaction occurs when the power supply is turned off. 1 mark

___

___

b. Lithium-ion cells are used in many electronic products. When the cell is recharging, the following reactions occur at the electrodes.

Electrode X: $LiCoO_2 \rightarrow CoO_2 + Li^+ + e^-$

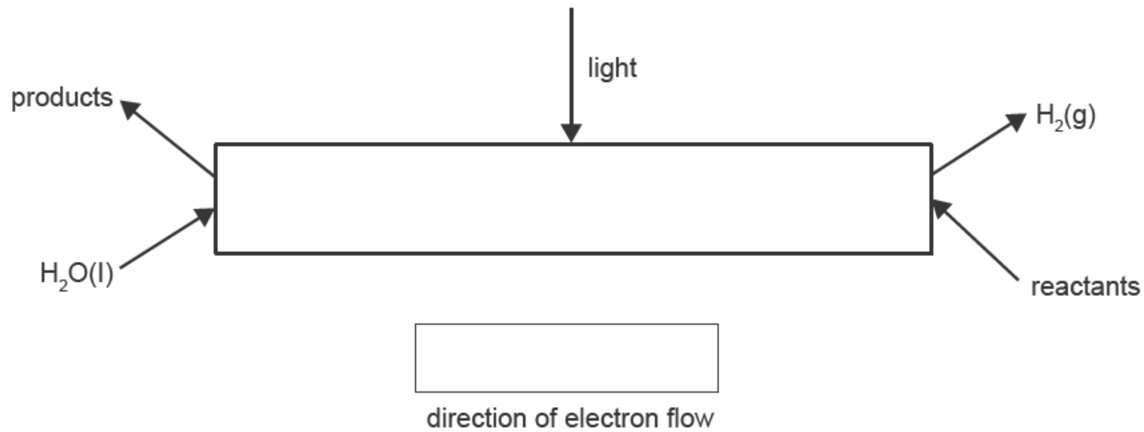
Electrode Y: $6C + Li^+ + e^- \rightarrow LiC_6$

i. State the polarity of Electrode X during recharging. 1 mark

___

ii. Calculate the mass of LiC_6 produced when the cell is recharged using a current of 1.25 A for 1.00 hour. 4 marks

c. Artificial photosynthesis can be used to produce hydrogen from water in acidic conditions. A simplified diagram of the acidic artificial photosynthesis process is shown below.



i. Identify the overall energy transformation that occurs during artificial photosynthesis. 1 mark

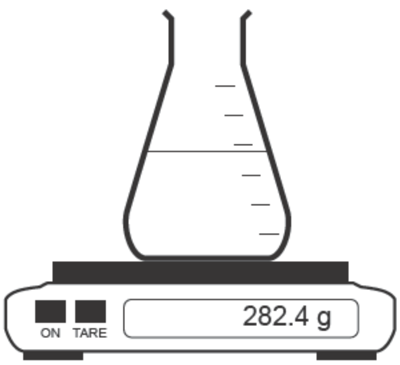
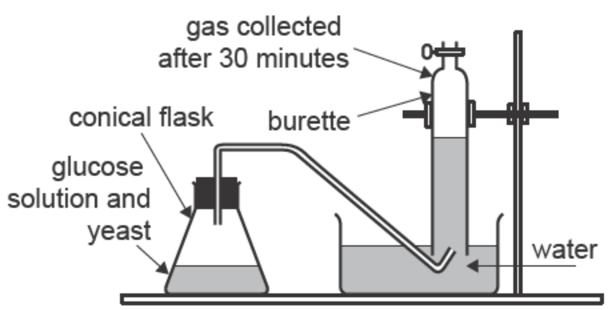
ii. In the box shown in the diagram, draw an arrow to indicate the direction of electron flow. 1 mark

iii. Explain how the electrical charge in artificial photosynthesis processes is balanced given that electrons only flow in one direction. 2 marks

Question 8 (12 marks)

Lucia, a VCE student, investigated the production of bioethanol from the fermentation of glucose solution in the presence of yeast. Enzymes in yeast assist with the fermentation reaction.

Lucia trialled two methods for the investigation, Method A and Method B. Both methods were trialled once.

Method A	**Method B**
1. Dissolve 5.0 g of glucose in 100 mL of water at 35 °C in a 250 mL conical flask. 2. Add 2.0 g of yeast to the glucose solution and stir to mix. 3. Quickly place the conical flask on a balance and record the mass to one decimal place. 4. After 30 minutes, record the mass of the conical flask to one decimal place.  	1. Dissolve 5.0 g of glucose in 100 mL of water at 35 °C in a 250 mL conical flask. 2. Add 2.0 g of yeast to the glucose solution and stir to mix. 3. Quickly place a stopper fitted with a delivery tube in the mouth of the conical flask. 4. Submerge the end of the delivery tube in an inverted burette filled with water at 25 °C. 5. After 30 minutes, record the volume of gas in the burette. 

a. **i.** Write a balanced chemical equation for the production of bioethanol from glucose. 1 mark

___

ii. Why is boiling water not used in Step 1 of Method A and Method B? Do not refer to safety considerations in your answer. 1 mark

___

b. Lucia recorded the following results for Method A and Method B.

Method A	
Time (minutes)	Mass (g)
0	282.5
30	282.4

Method B	
Time (minutes)	Volume (mL)
0	0.5
30	32.5

i. Calculate the amount, in mol, of gas produced using Method A. The molar mass of the gas produced is 44.0 g mol^{-1}. 1 mark

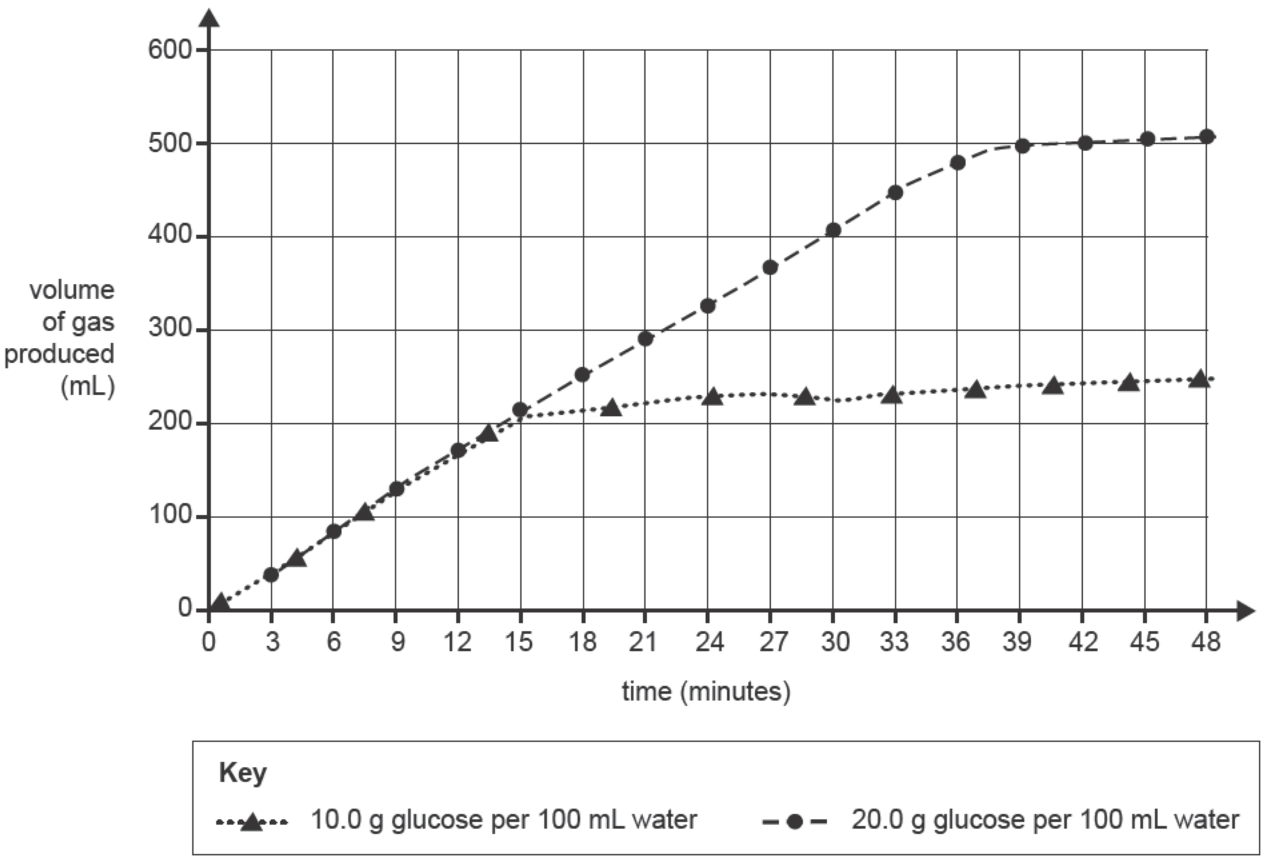
ii. Calculate the amount, in mol, of gas produced using Method B at standard laboratory conditions (SLC). 1 mark

iii. State an assumption on which the calculation in **part b.ii** is based. 1 mark

iv. Compare the resolution of the data in Method A and Method B. 2 marks

Question 8 continues on the next page.

c. Lucia decided to use Method B with different amounts of glucose to test how changing the concentration of the glucose solution affects the rate of bioethanol production. Lucia recorded the volume of gas produced at three-minute intervals instead of only after 30 minutes. The graph below shows the data produced.



Lucia's hypothesis was that the rate of the reaction would increase as the concentration of glucose solution increased.

i. Identify the independent variable. 1 mark

____

____

ii. Does the graph support Lucia's hypothesis? Explain your answer. 2 marks

____

____

____

____

d. **i.** Identify one limitation of Method B. Your answer must be different to your answer for **part b.iii**. 1 mark

ii. Which section of the scientific poster for the investigation should include the limitation identified in **part d.i**? 1 mark

Question 9 (9 marks)

Paracetamol, $C_8H_9NO_2$, can be made using two different reactions, Reaction P1 and Reaction P2.

Reaction P1

Liquid ethanoic anhydride, $C_4H_6O_3(l)$, is added to a mixture of solid 4-aminophenol, $C_6H_7NO(s)$, and water. The resulting mixture of all reactants is heated in a hot-water bath for 10 minutes.

$$\underset{\substack{\text{4-aminophenol} \\ (M = 109\ \text{g mol}^{-1})}}{C_6H_7NO} + \underset{\substack{\text{ethanoic anhydride} \\ (M = 102\ \text{g mol}^{-1})}}{C_4H_6O_3} \xrightarrow{60\ ^\circ\text{C},\ H_2O} \underset{\substack{\text{paracetamol} \\ (M = 151\ \text{g mol}^{-1})}}{C_8H_9NO_2} + \underset{\substack{\text{ethanoic acid} \\ (M = 60\ \text{g mol}^{-1})}}{C_2H_4O_2}$$

Reaction P2

Liquid ethanoic acid, $C_2H_4O_2(l)$, is mixed with solid 4-aminophenol, $C_6H_7NO(s)$. The reactant mixture is heated in a hot water bath for 10 minutes.

$$\underset{\substack{\text{4-aminophenol} \\ (M = 109\ \text{g mol}^{-1})}}{C_6H_7NO} + \underset{\substack{\text{ethanoic acid} \\ (M = 60\ \text{g mol}^{-1})}}{C_2H_4O_2} \overset{\text{heat}}{\rightleftharpoons} \underset{\substack{\text{paracetamol} \\ (M = 151\ \text{g mol}^{-1})}}{C_8H_9NO_2} + \underset{\substack{\text{water} \\ (M = 18\ \text{g mol}^{-1})}}{H_2O}$$

Results

- For Reaction P1, the percentage yield is 87% and the percentage atom economy is 72%.
- For every 1.4 g of 4-aminophenol reacted in Reaction P2, 0.80 g of paracetamol is produced.

a. **i.** Calculate the percentage yield and percentage atom economy of Reaction P2, and compare them to the results for Reaction P1. 4 marks

ii. Use your **answer to part a.i** to discuss which reaction is better aligned with green chemistry. Support your answer by referencing the relevant green chemistry principle.

Refer to **item 26.ii** of the Data Book. 2 marks

b. Prevention of waste is a green chemistry principle. Refer to **item 26.ii** of the Data Book.

Discuss Reaction P1 and Reaction P2 in terms of this green chemistry principle. 3 marks

End of Question and Answer Book

Chemistry

2024 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

ΔH (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	ΔH (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.

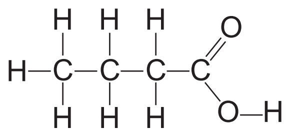
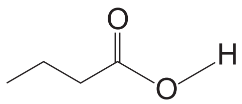
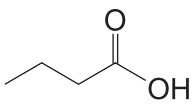
17. Names of selected elements

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 

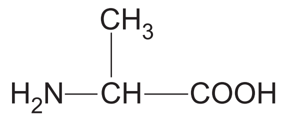
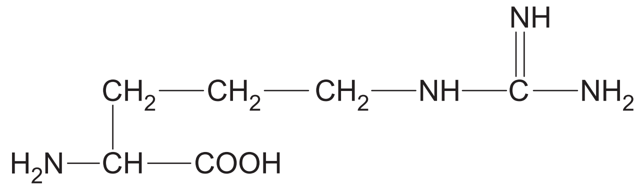
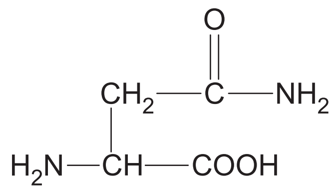
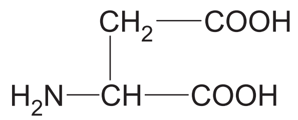
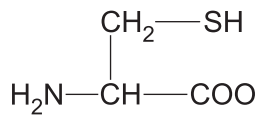
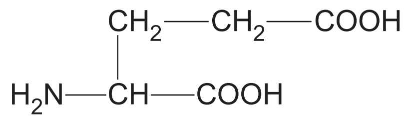
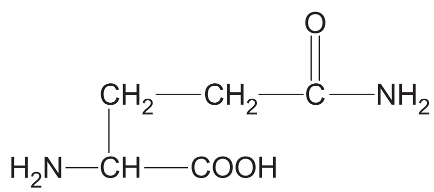
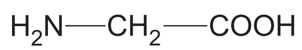
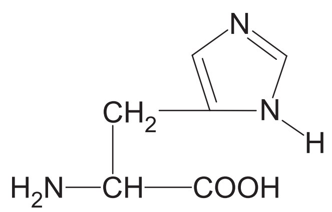
19. Functional group nomenclature in organic chemistry

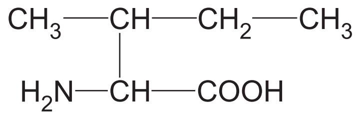
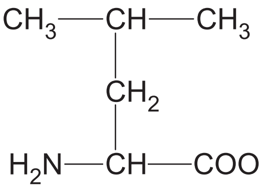
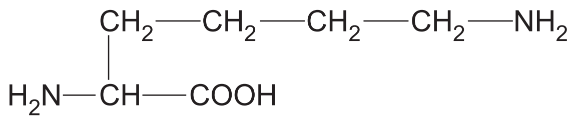
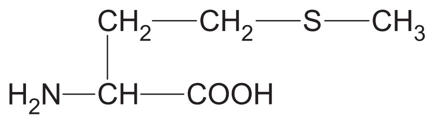
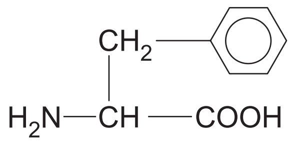
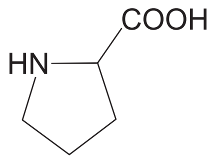
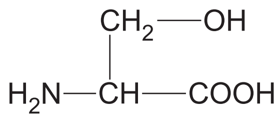
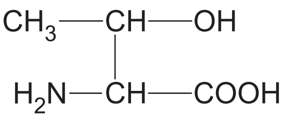
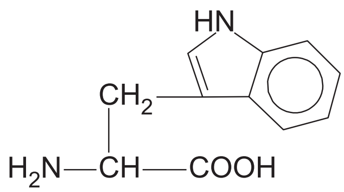
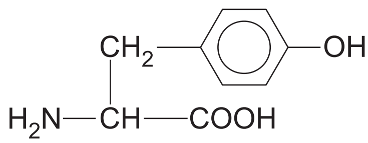
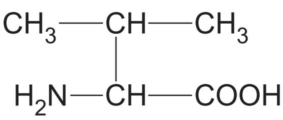
The following table shows the priority of functional groups when naming organic compounds that contain more than one functional group.
The functional group with the highest priority determines the suffix of the compound.

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	
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

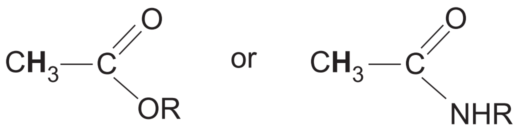
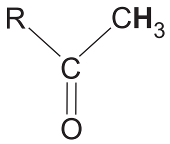
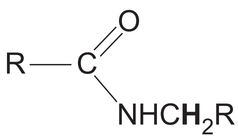
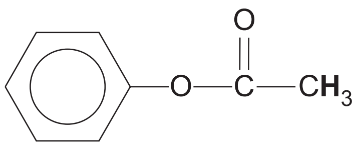
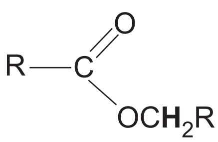
These can differ slightly in different solvents.

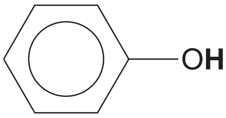
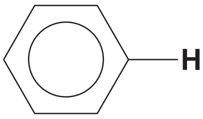
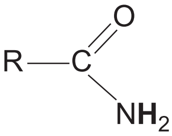
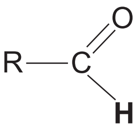
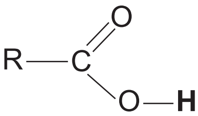
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$R_2C=CR_2$	110–150
arenes $C_6H_5–R$	110–150
RCOOH	160–185
$R(RO)C=O$	165–175
$R(H_2N)C=O$	165–185
$R(H)C=O$	190–200
$R_2C=O$	205–220

24. ^{1}H NMR data

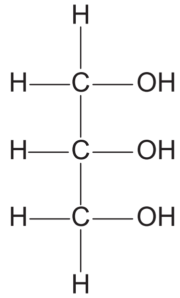
Typical proton shift values relative to TMS = 0

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

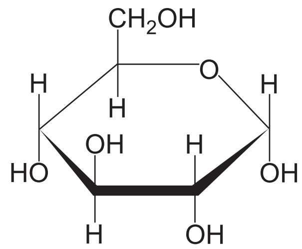
Type of proton	Chemical shift (ppm)
$R{-}C\mathbf{H}_3$	0.9–1.0
$R{-}C\mathbf{H}_2{-}R$	1.3–1.4
$RCH{=}CH{-}C\mathbf{H}_3$	1.6–1.9
$R_3{-}C\mathbf{H}$	1.5
	2.0
	2.1–2.7
$R{-}C\mathbf{H}_2{-}X$ (X = F, Cl, Br or I)	3.0–4.5
$R{-}C\mathbf{H}_2{-}OH$, $R_2{-}C\mathbf{H}{-}OH$	3.3–4.5
	3.2
$R{-}O{-}C\mathbf{H}_3$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

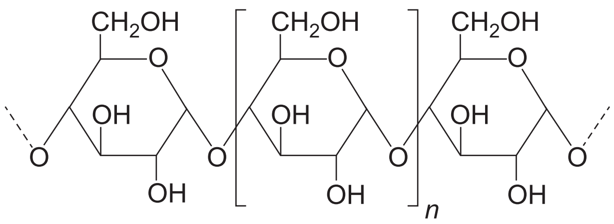
25. Representations of selected biomolecules



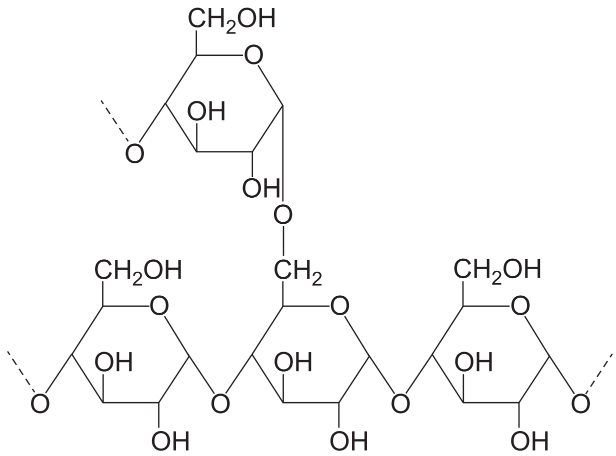
glycerol



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

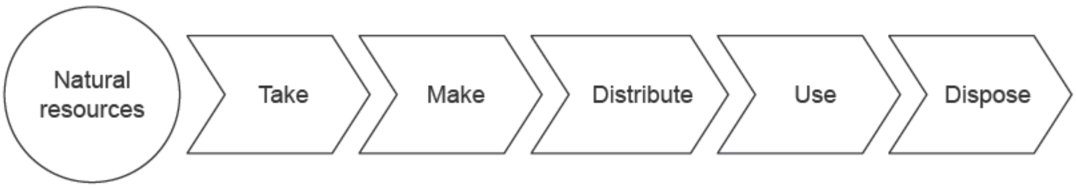
The following seven green chemistry principles are relevant to VCE Chemistry:

- 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.

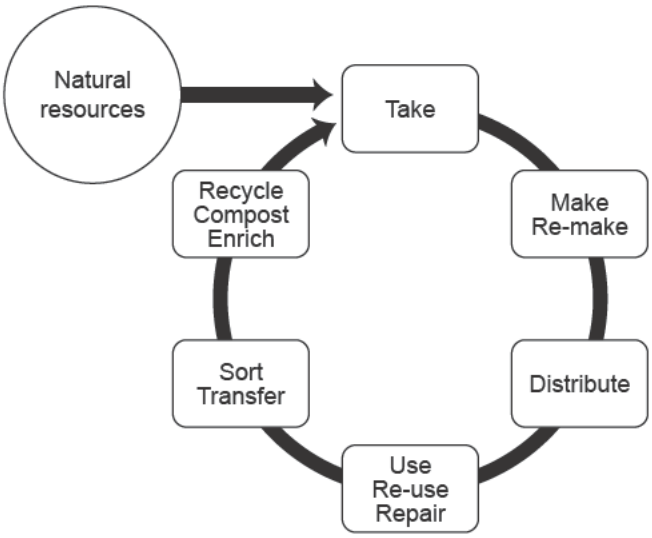
Source: Adapted from PT Anastas and JC Warner,
Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998, p.30

iii. Types of economies

Linear



Circular



End of Chemistry Data Book