VICTORIAN CURRICULUM
AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2019

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

Letter

STUDENT NUMBER ☐☐ ☐☐☐ ☐☐☐ ☐

CHEMISTRY

Written examination

Tuesday 12 November 2019

Reading time: 9.00 am to 9.15 am (15 minutes)
Writing time: 9.15 am to 11.45 am (2 hours 30 minutes)

QUESTION AND ANSWER BOOK

Structure of book

Section	*Number of questions*	*Number of questions to be answered*	*Number of marks*
A	30	30	30
B	10	10	90
			Total 120

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or correction fluid/tape.

Materials supplied
- Question and answer book of 42 pages
- Data book
- Answer sheet for multiple-choice questions

Instructions
- Write your **student number** in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.
- All written responses must be in English.

At the end of the examination
- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the data book.

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

SECTION A – Multiple-choice questions

Instructions for Section A

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

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

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

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

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

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

Question 1

An understanding of Le Chatelier's principle is useful in the chemical industry.

The prediction that can be made using this principle is the effect of

A. catalysts on the rate of reaction.
B. catalysts on the position of equilibrium.
C. changes in temperature on the rate of reaction.
D. changes in the concentration of reactants on the position of equilibrium.

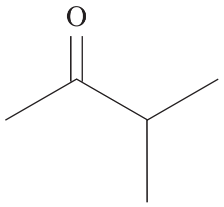
Question 2

The thermochemical equation for the complete combustion of glucose is

A. $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ $\Delta H = -2860 \text{ kJ mol}^{-1}$
B. $C_6H_{12}O_6 + 3O_2 \rightarrow 6CO + 6H_2O$ $\Delta H = -2011 \text{ kJ mol}^{-1}$
C. $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$ $\Delta H = -69 \text{ kJ mol}^{-1}$
D. $C_6H_{12}O_6 \rightarrow 2C_3H_6O_3$ $\Delta H = -120 \text{ kJ mol}^{-1}$

Question 3

A compound has the following skeletal formula.



The molar mass of the compound is

A. 71 g mol^{-1}
B. 74 g mol^{-1}
C. 85 g mol^{-1}
D. 86 g mol^{-1}

Question 4

Oxidative rancidity can be slowed down by adding

A. heat.

B. ultraviolet (UV) light.

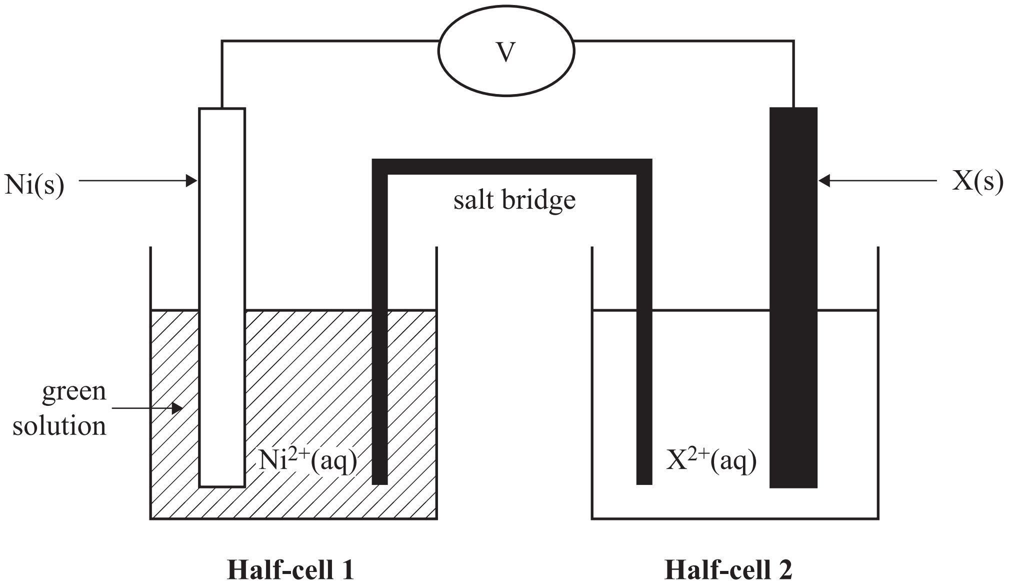
C. sodium ions.

D. a reducing agent.

Question 5

At the start of the day, a student set up a galvanic cell using two electrodes: nickel, Ni, and metal X.

This set-up is shown in the diagram below.



Consider the following alternative metals that could be used to replace metal X:

1. zinc, Zn 2. lead, Pb 3. cadmium, Cd 4. copper, Cu

At the end of the day, the student checked the colour of the solution in Half-cell 1 and observed that the solution was a darker green colour.

Which of the alternative metals could cause the colour of Half-cell 1 to become a darker green?

A. metals 1 and 3

B. metals 2 and 4

C. metals 1, 2 and 3

D. metals 3 and 4

Question 6

Which one of the following statements about enzymes is correct?

A. The induced fit model suggests that the shape of an enzyme remains constant throughout a catalysed reaction.

B. Enzymes may have their tertiary structure altered during a catalysed reaction.

C. Enzymes can catalyse most reactions over a broad range of temperatures.

D. Enzymes may change the equilibrium constant of a catalysed reaction.

Question 7

A molten mixture of equal parts aluminium fluoride, AlF_3, and sodium chloride, NaCl, undergoes electrolysis.

Which one of the following statements about this reaction is correct?

A. Sodium metal will be produced at the cathode and fluorine gas will be produced at the anode.

B. Sodium metal will be produced at the anode and chlorine gas will be produced at the cathode.

C. Aluminium metal will be produced at the cathode and chlorine gas will be produced at the anode.

D. Aluminium metal will be produced at the anode and fluorine gas will be produced at the cathode.

Question 8

Consider the following statements about galvanic cells and fuel cells.

Statement number	Statement
1	The overall reaction is exothermic.
2	Electrons are consumed at the negative electrode.
3	Both the reducing agent and the oxidising agent are stored in each half-cell.
4	The electrodes are in contact with the reactants and the electrolyte.
5	The production of electricity requires the electrodes to be replaced regularly.

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

A. statement numbers 2 and 3

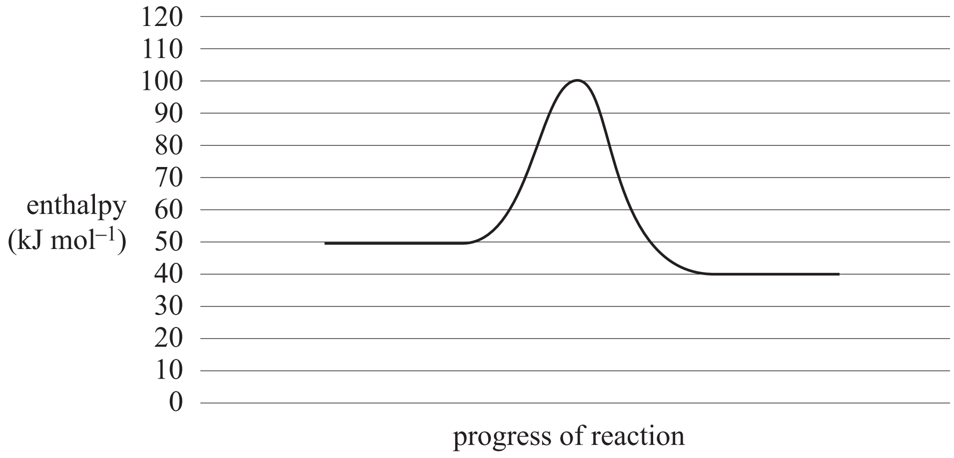
B. statement numbers 1 and 4

C. statement numbers 2, 4 and 5

D. statement numbers 1, 3 and 5

Question 9

A reaction has the energy profile diagram shown below.



Which of the following represents the energy profile of the **reverse** reaction?

	Final product energy (kJ mol^{-1})	ΔH (kJ mol^{-1})
A.	40	+10
B.	50	+10
C.	50	−10
D.	40	−10

Question 10

Which one of the following statements about coenzymes is correct?

A. Coenzymes alter the secondary structure of enzymes.

B. Coenzymes can react with enzymes to produce proteins.

C. Coenzymes can bind to enzymes to make a reaction occur.

D. The tertiary structure of coenzymes prevents them from binding with enzymes.

Question 11

5 mL of ethanol, CH_3CH_2OH, undergoes combustion in a test tube with a diameter of 1 cm. This experiment is performed in a fume cupboard. The temperature in the fume cupboard is 20 °C.

Which one of the following actions will reduce the rate of reaction?

A. Mix 2 mL of a dilute solution of sodium hydroxide, NaOH, with the ethanol.

B. Perform the experiment in a test tube with a diameter of 2 cm.

C. Increase the temperature in the fume cupboard to 25 °C.

D. Increase the volume of the ethanol to 7 mL.

Question 12

A compound has the molecular formula C_4H_9Cl.

Which type of chemical analysis would be **most** useful in determining whether this compound has a stereoisomer?

A. mass spectrometry

B. infra-red spectroscopy

C. high-performance liquid chromatography

D. nuclear magnetic resonance spectroscopy

Question 13

Which one of the following statements about flashpoints is correct?

A. The flashpoint of butane is lower than 25 °C.

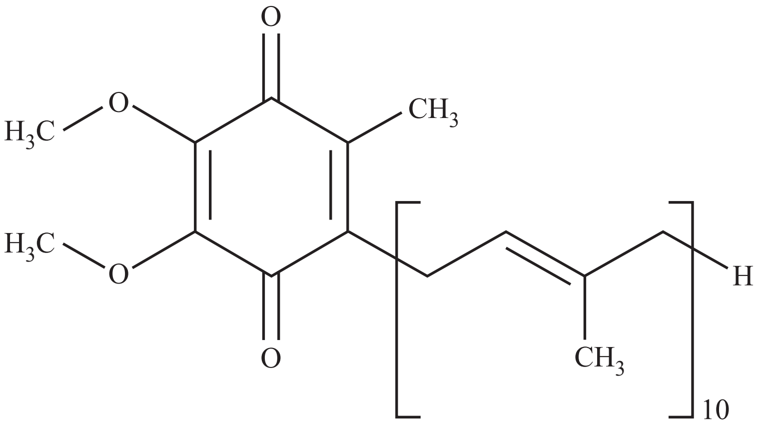
B. As a flashpoint increases, the viscosity decreases.

C. The flashpoint of a compound is higher than its boiling point.

D. The flashpoint of butane is greater than the flashpoint of butan-1-ol.

Question 14

The following diagram represents the structure of a non-essential vitamin.



This vitamin is

A. fat-soluble and can be produced by the human body.

B. water-soluble and can be produced by the human body.

C. fat-soluble and cannot be produced by the human body.

D. water-soluble and cannot be produced by the human body.

Question 15

Aspartame has only

A. one chiral centre.

B. two stereoisomers.

C. four optical isomers.

D. three structural isomers.

Question 16

The number of carbon-to-carbon double bonds (C=C) in a molecule can be identified by reacting the molecule with hydrogen gas, H_2. The type of reaction involved is an addition reaction.

10.0 g of a fatty acid becomes fully saturated after reacting with 0.263 g of H_2.

The fatty acid is

A. oleic acid ($M = 282\ g\ mol^{-1}$).

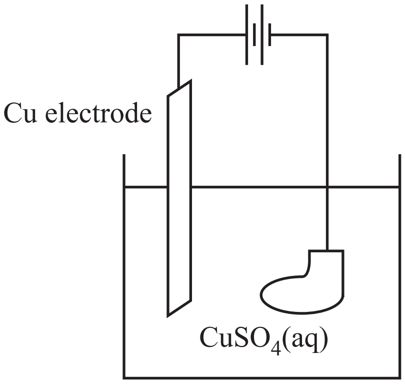
B. linolenic acid ($M = 278\ g\ mol^{-1}$).

C. arachidic acid ($M = 312\ g\ mol^{-1}$).

D. arachidonic acid ($M = 304\ g\ mol^{-1}$).

Question 17

The tradition of bronzing baby shoes dates back for generations. Before electroplating, the shoe is painted with a conductive material. The copper, Cu, electrode and copper sulfate, $CuSO_4$, solution cell used for electroplating a shoe is shown below.



During the electroplating process

A. the copper electrode is oxidised and its mass is unchanged.

B. the shoe is coated with copper metal at the cathode.

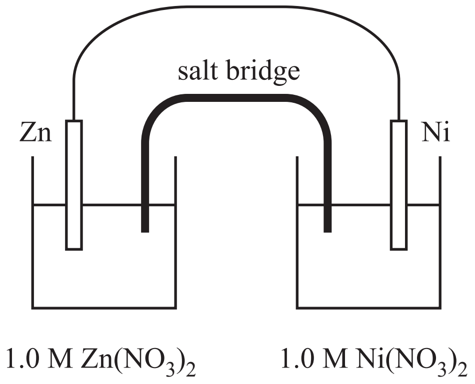
C. the copper electrode is the oxidising agent.

D. oxygen is produced at the cathode.

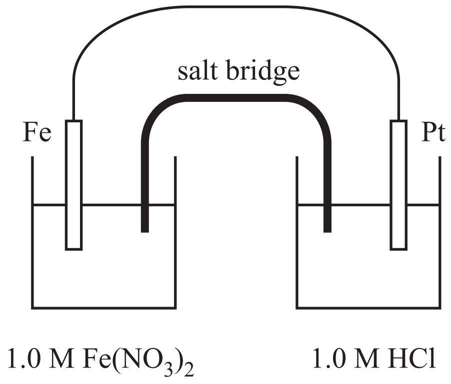
Question 18

Which one of the following galvanic cells will produce the largest cell voltage under standard laboratory conditions (SLC)?

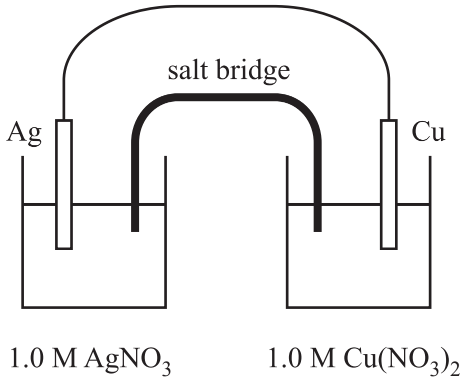
A.



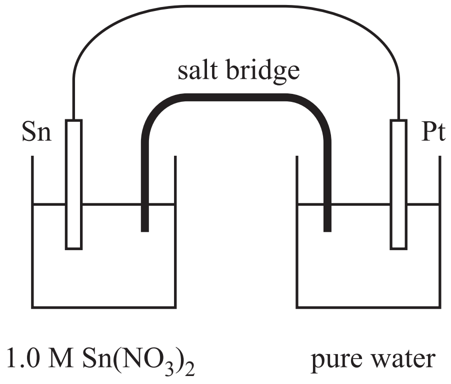
B.



C.



D.



Question 19

Lactose is commonly found in milk and milk products. The enzyme used to hydrolyse lactose in the human small intestine is lactase. Lactose intolerance describes the limited ability of humans to hydrolyse lactose.

Consider the following statements.

Statement number	Statement
1	Lactose-intolerant people produce too much lactase enzyme.
2	Insufficient lactase leads to some lactose not undergoing hydrolysis in the human body.
3	Lactose-intolerant people can add lactase drops to milk to help digestion.
4	Lactase assists in the hydrolysis of lactose into two glucose molecules.

Which one of the following sets of statements is correct?

A. statement numbers 1, 2 and 3

B. statement numbers 1, 2 and 4

C. statement numbers 2 and 3

D. statement numbers 3 and 4

Question 20

The oxidation of sulfur dioxide, SO_2, to sulfur trioxide, SO_3, can be represented by the following equation.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_c = 1.75\ M^{-1} \text{ at } 1000\ °C$$

An equilibrium mixture has a concentration of 0.12 M SO_2 and 0.16 M oxygen gas, O_2. The temperature of the container is 1000 °C.

The equilibrium concentration of SO_3 at 1000 °C is

A. 1.5×10^{-4} M

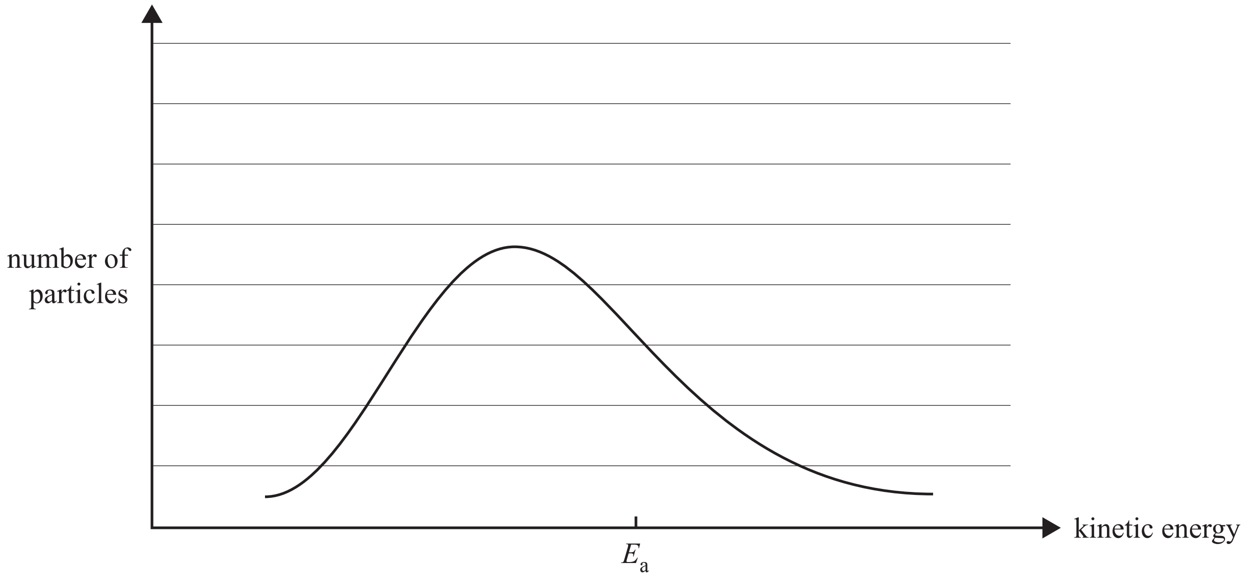
B. 4.0×10^{-3} M

C. 1.2×10^{-2} M

D. 6.3×10^{-2} M

Question 21

The diagram below represents the Maxwell-Boltzmann distribution of an uncatalysed reaction.



The effect of adding a catalyst could be:

1. the curve flattens to reflect the lower activation energy barrier
2. the curve shifts to the right
3. the E_a shifts to the left.

Which of the statements above are correct?

A. 1 only

B. 1 and 2

C. 2 and 3

D. 3 only

Question 22

Which one of the following statements about conducting an experiment is the **most** correct?

A. Precise results may be biased.

B. Accuracy is assured if sensitive instruments are used.

C. A method is valid if it identifies all controlled variables.

D. Repeating a procedure will remove the uncertainty of the results.

Question 23

Which one of the following statements about enthalpy change is correct?

A. The sign of the enthalpy change for an endothermic reaction is negative.

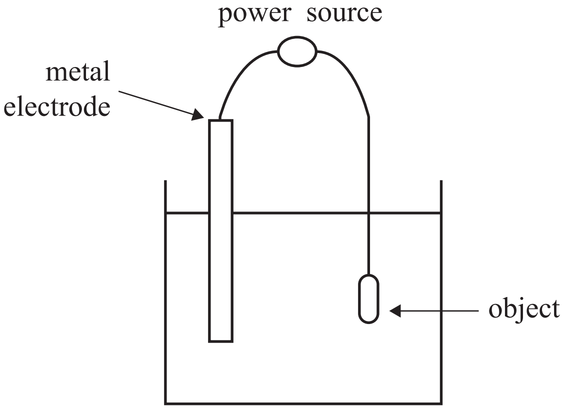
B. The sign of the enthalpy change for the condensation of a gas to a liquid is negative.

C. The enthalpy change is the difference between the activation energy and the energy of the reactants.

D. The enthalpy change is the difference between the activation energy and the energy of the products.

Question 24

The diagram below shows an electroplating cell.



The cell contains 1 L of an electroplating solution. The electroplating cell is run for one hour at 3 A.

Which one of the following electroplating solutions will deposit the largest mass of metal onto the object?

A. 1 M $AgNO_3$

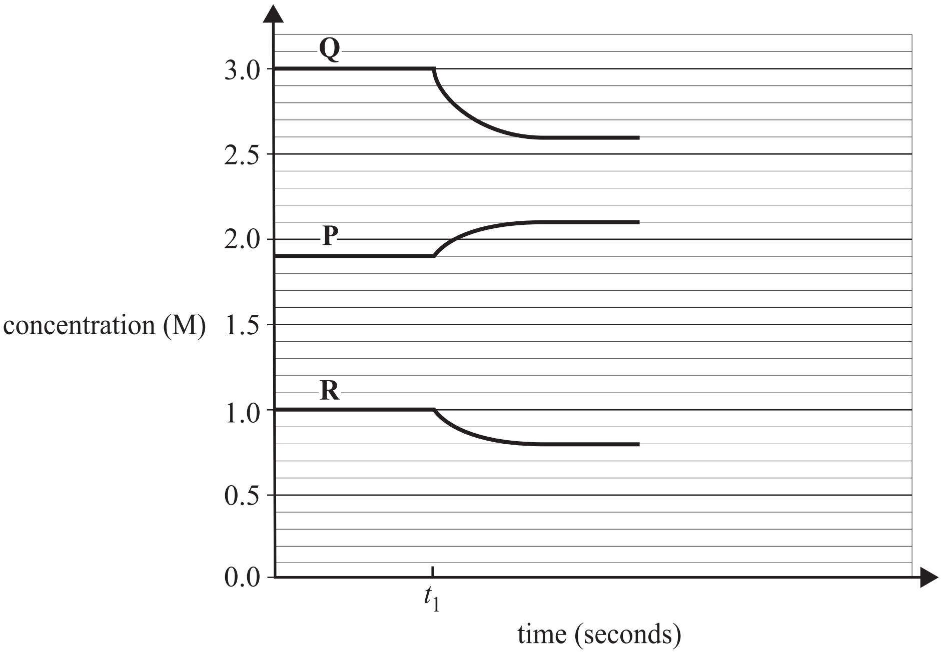
B. 1 M $Cd(NO_3)_2$

C. 1 M $Pb(NO_3)_2$

D. 1 M $Al(NO_3)_3$

Question 25

The following concentration–time graph refers to a mixture of three gases, P, Q and R, in an enclosed 5.0 L container. At time t_1 the mixture is heated.



The equilibrium system that represents the graph is

A. $P(g) \rightleftharpoons 2Q(g) + R(g)$ and the forward reaction is exothermic.

B. $2Q(g) \rightleftharpoons P(g) + R(g)$ and the forward reaction is endothermic.

C. $2Q(g) + R(g) \rightleftharpoons P(g)$ and the forward reaction is exothermic.

D. $P(g) + 2Q(g) \rightleftharpoons R(g)$ and the forward reaction is endothermic.

Question 26

The calibration factor of a bomb calorimeter was determined by connecting the calorimeter to a power supply. The calibration was done using 100 mL of water, 6.5 V and a current of 3.6 A for 4.0 minutes. The temperature of the water increased by 0.48 °C during the calibration.

4.20 g of sucrose underwent complete combustion in the bomb calorimeter. The temperature of the 100 mL of water increased from 19.6 °C to 25.8 °C.

$M(C_{12}H_{22}O_{11}) = 342 \text{ g mol}^{-1}$

The experimental heat of combustion of pure sucrose, in joules per gram, is

A. 5.9×10^6

B. 7.3×10^4

C. 1.7×10^4

D. 1.2×10^4

Question 27

An organic compound has a molar mass of 88 g mol^{-1}.

The ^{13}C NMR spectrum of the organic compound shows four distinct peaks.

The organic compound is **most** likely

A. butan-1-ol.
B. 2-methyl-butan-1-ol.
C. 2-methyl-butan-2-ol.
D. 2,2-dimethyl-propan-1-ol.

Question 28

The concentration of all of the gases in the equilibrium reactions below is 1.0 M.

Reaction 1 $CH_4(g) + 2H_2O(g) \rightleftharpoons CO_2(g) + 4H_2(g)$

Reaction 2 $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

Reaction 3 $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

Reaction 4 $2NO_2(g) \rightleftharpoons N_2O_4(g)$

In which reaction does $K_c = 1.0\ M^{-2}$?

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

Use the following information to answer Questions 29 and 30.

The concentration of vitamin C in a filtered sample of grapefruit juice was determined by titrating the juice with 9.367×10^{-4} M iodine, I_2, solution using starch solution as an indicator. The molar mass of vitamin C is 176.0 g mol^{-1}. The reaction can be represented by the following equation.

$$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2H^+(aq) + 2I^-(aq)$$

The following method was used:

1. Weigh a clean 250 mL conical flask.
2. Use a 10 mL measuring cylinder to measure 5 mL of grapefruit juice into the conical flask and reweigh it.
3. Add 20 mL of deionised water to the conical flask.
4. Add a drop of starch solution to the conical flask.
5. Titrate the diluted grapefruit juice against the I_2 solution.

Question 29

Which one of the following errors would result in an underestimation of the concentration of vitamin C in grapefruit juice?

A. 19 mL of deionised water was added to the conical flask.

B. The concentration of the I_2 solution was actually 9.178×10^{-4} M.

C. The initial volume of the I_2 solution in the burette was 1.50 mL, but it was read as 2.50 mL.

D. The balance was faulty and the measured mass of grapefruit juice was lower than the actual mass.

Question 30

If the measured mass of grapefruit juice was 4.90 g and the titre was 21.50 mL, what was the measured percentage mass/mass (% m/m) concentration of vitamin C in the grapefruit juice?

A. 0.00987

B. 0.0723

C. 0.354

D. 3.36

END OF SECTION A

CONTINUES OVER PAGE

SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided. Write using blue or black pen.

Give simplified answers to all numerical questions, with an appropriate number of significant figures; unsimplified answers will not be given full marks.

Show all working in your answers to numerical questions; no marks will be given for an incorrect answer unless it is accompanied by details of the working.

Ensure chemical equations are balanced and that the formulas for individual substances include an indication of state, for example, $H_2(g)$, NaCl(s).

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

Question 1 (9 marks)

A commercial chocolate spread is commonly used in sandwiches and desserts. This food contains high amounts of proteins, triglycerides and sucrose.

Proteins are an important part of food. Proteins are broken down into smaller molecules during digestion.

a. Proteins can be hydrolysed to produce alpha (α-) amino acids.

Identify **one** structural feature common to all alpha (α-) amino acids. 1 mark

b. i. What is the process by which amino acids are obtained from the chocolate spread? 1 mark

ii. Identify the chemical process in which amino acids are predominantly used in the body. 1 mark

iii. Two of the amino acids in the chocolate spread are aspartic acid and cysteine.

Draw the chemical structure of the dipeptide Cys-Asp at **high pH**. 2 marks

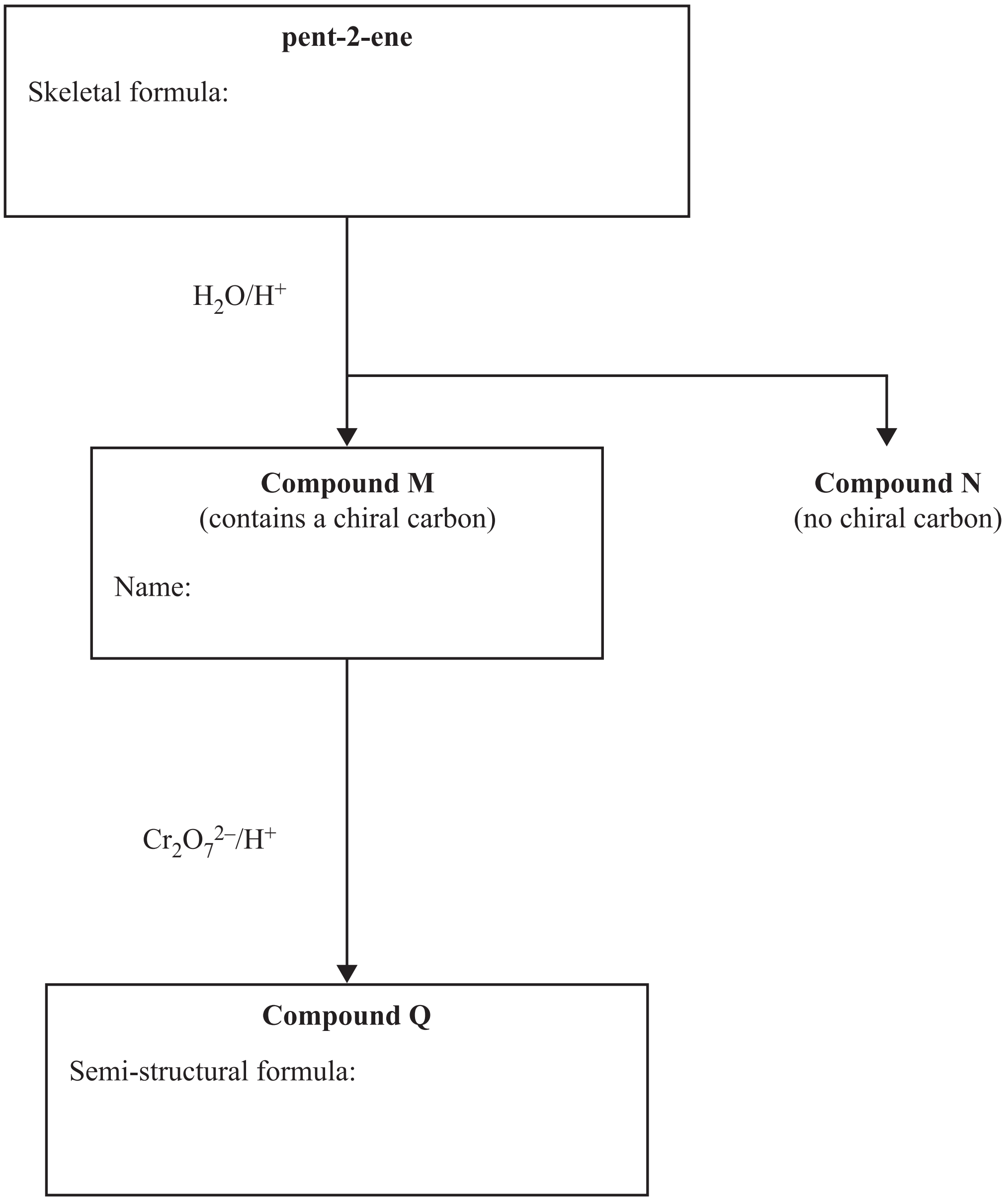
c. The triglycerides in the chocolate spread contain palmitic acid and palmitoleic acid.

Which of these fatty acids is likely to have a higher melting point? Explain your reasoning. 2 marks

d. Draw the structure of a triglyceride that contains only palmitoleic acid using semi-structural formulas. Circle and label the triglyceride functional group. 2 marks

Question 2 (8 marks)

a. The following diagram represents a reaction pathway for the synthesis of Compound Q from pent-2-ene.



i. Draw the skeletal formula for pent-2-ene in the box provided. 1 mark

Two structural isomers are possible when pent-2-ene is hydrolysed at a high temperature in the presence of an acid catalyst. Compounds M and N are formed. Compound M has a chiral carbon, but Compound N does not.

ii. Give the IUPAC name of Compound M in the box provided. 1 mark

iii. When Compound M is reacted with acidified dichromate ions, $Cr_2O_7^{2-}$, Compound Q is formed.

Draw the semi-structural formula of Compound Q in the box provided. 1 mark

b. 2-chloropropane can be reacted with ammonia to produce an uncharged organic molecule, Compound R.

i. Write the equation for the reaction that occurs. 1 mark

ii. Give the IUPAC name of Compound R. 1 mark

iii. Name the type of reaction that produces Compound R. 1 mark

iv. Calculate the percentage atom economy for the production of Compound R. 2 marks

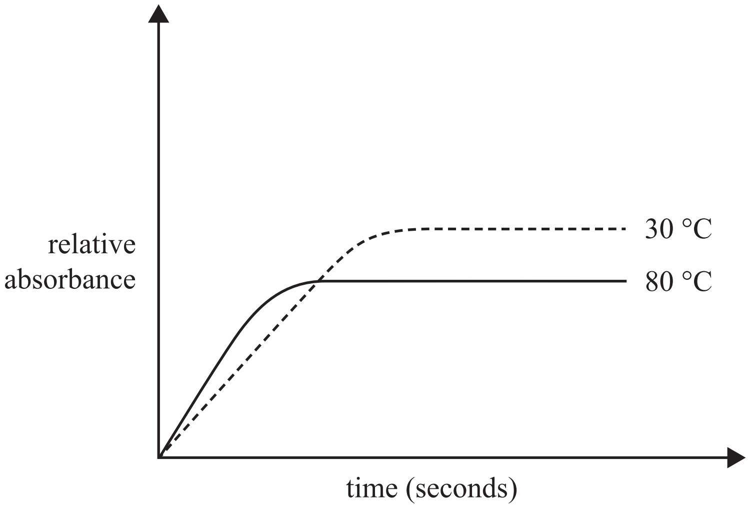
Question 3 (7 marks)

The cobalt(II) tetrachloride ion, $CoCl_4^{2-}$, dissociates into the cobalt(II) ion, Co^{2+}, and chloride ions, Cl^-, according to the following chemical equation.

$$\underset{\text{blue}}{CoCl_4^{2-}(aq)} \rightleftharpoons \underset{\text{pink}}{Co^{2+}(aq)} + 4Cl^-(aq)$$

20 mL samples of the equilibrium mixture were heated to two temperatures, 30 °C and 80 °C. The intensity of the pink colour of the Co^{2+} product was recorded every 30 seconds by measuring the absorbance of the solution. The higher the intensity of the pink colour, the higher the absorbance.

The results of this experiment are shown in the graph below.



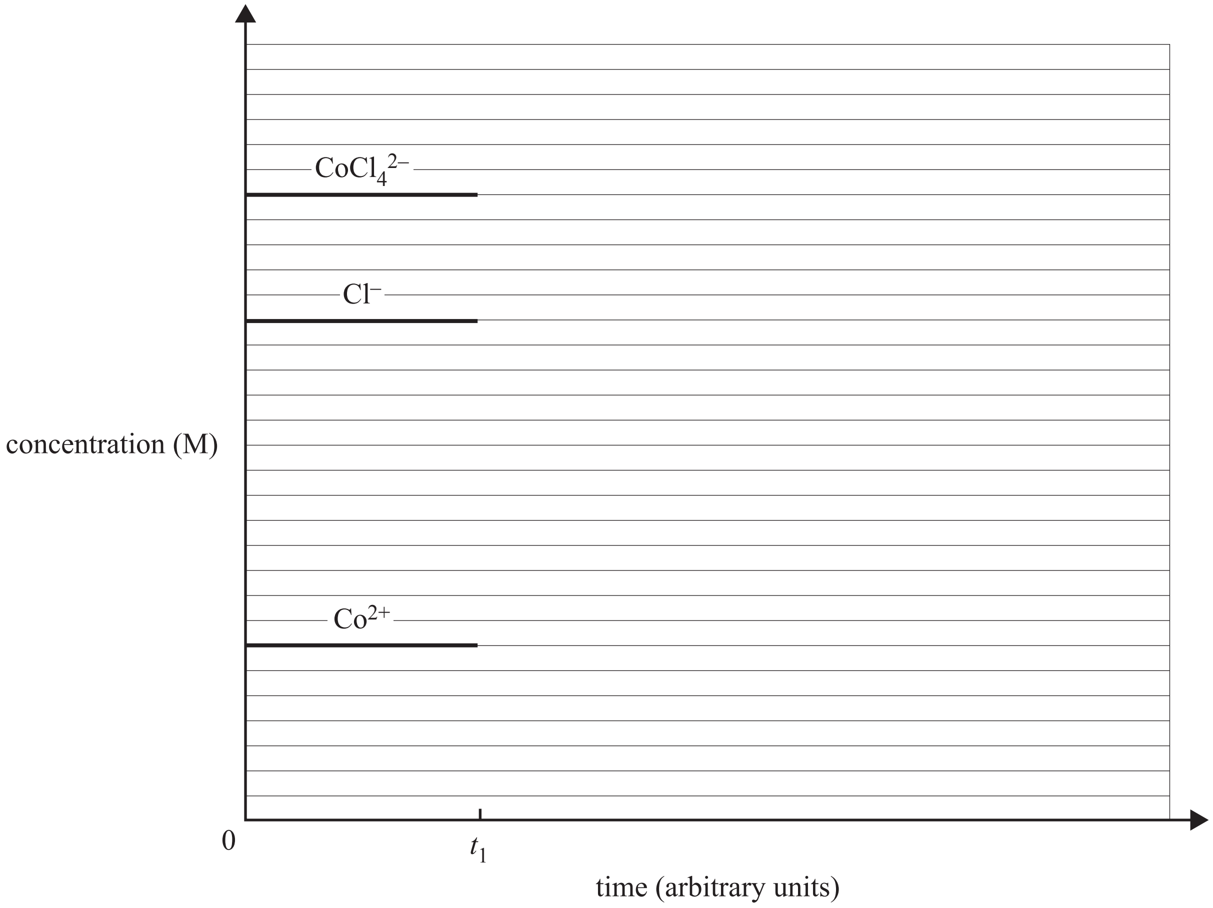
a. State whether the forward reaction is exothermic or endothermic. Justify your answer by referring to the graph. 2 marks

b. When 5 mL of water was added to the equilibrium mixture, the colour of the solution immediately became a lighter pink.

Describe the final colour of the solution once equilibrium is re-established. Explain your answer. 2 marks

DO NOT WRITE IN THIS AREA

c. Five drops of silver nitrate, $AgNO_3$, solution are added to the equilibrium mixture at time t_1.
A concentration–time graph for this reaction is shown below for times between zero and t_1.



Continue the graph to show the changes that occur to the system from t_1 until equilibrium is re-established. 3 marks

Question 4 (7 marks)

Internal combustion engines are used in large numbers of motor vehicles. Historically, internal combustion engines have used fuels obtained from crude oil as a source of power. As concerns for the environment have grown, efforts have been made to obtain fuel for combustion engines from other sources.

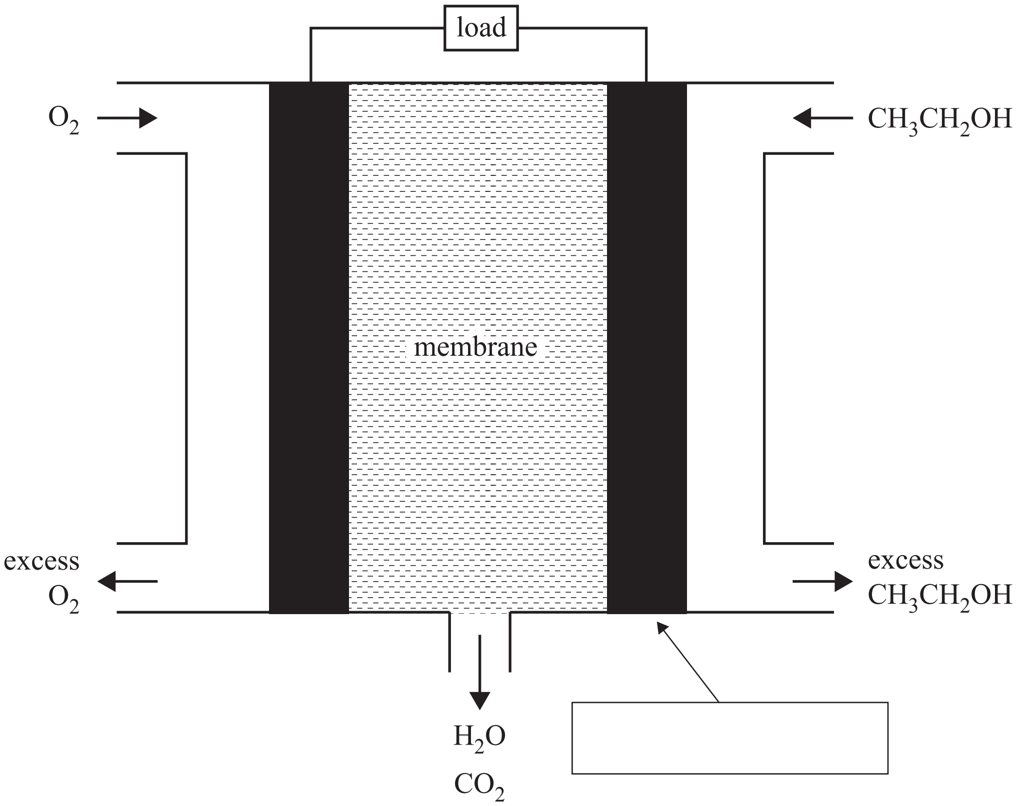
a. One way of reducing the environmental effects of fossil fuels is to blend them with biofuels. A common method is to blend petrol with ethanol in varying ratios. A fuel can be obtained by blending 1 mole of octane, C_8H_{18}, and 1 mole of ethanol, C_2H_5OH.

The chemical equation for the complete combustion of this fuel mixture is

$$C_8H_{18}(l) + C_2H_5OH(l) + 15\frac{1}{2}O_2(g) \rightarrow 10CO_2(g) + 12H_2O(g)$$

Calculate the energy released, in kilojoules, when 80 g of this fuel mixture undergoes complete combustion. Show your working. 3 marks

b. Some car manufacturers are exploring the use of an acidic ethanol fuel cell to power vehicles. In this fuel cell, the ethanol at one electrode reacts with water that has been produced at the other electrode. A membrane is used to transport ions between the electrodes. A diagram of an acidic ethanol fuel cell is shown below.



i. Identify the electrode as either the cathode or the anode in the box provided in the diagram above. 1 mark

ii. Write the half-equation for the reaction occurring at the anode. 1 mark

iii. The combustion of ethanol and the combustion of octane release about the same amount of energy per mole of carbon dioxide produced.

Identify **two** advantages of powering a vehicle using an ethanol fuel cell instead of an internal combustion engine powered by octane. 2 marks

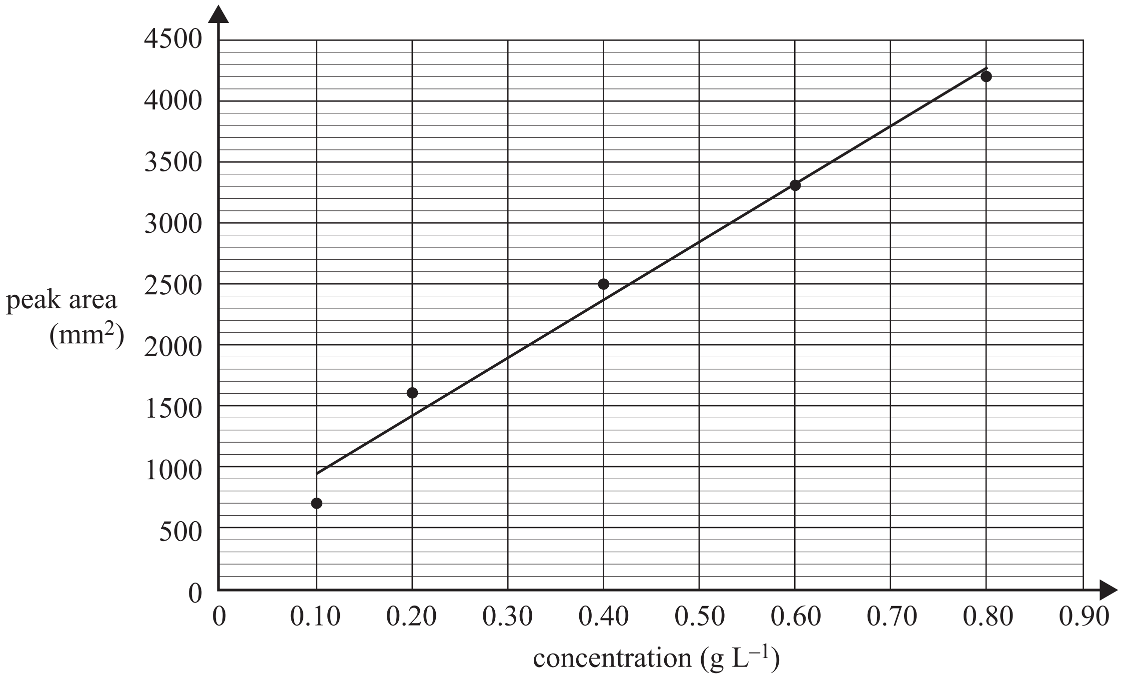
Question 5 (8 marks)

High-performance liquid chromatography (HPLC) was used to determine the sucrose concentration in a sample taken from a can of soft drink.

Standard solutions were made up using pure sucrose and deionised water. A 1 mL sample of each standard solution was injected into the HPLC column and its peak area was recorded, as shown in the table below.

Concentration of sucrose (g L^{-1})	**Peak area (mm^2)**
0.10	700
0.20	1600
0.40	2500
0.60	3300
0.80	4200

The experimental results (shown as dots) and a calibration line of the concentration of sucrose against peak area are shown in the graph below.



a. A 5.0 mL sample of the soft drink was diluted to 100 mL in a volumetric flask.

A 10.0 mL aliquot of this solution was transferred to a 250 mL volumetric flask and filled up to the calibration mark using deionised water.

A sample of this solution was injected into the HPLC column. The peak area of the sample solution at the same retention time and under the same conditions as those used to determine the calibration line was found to be 1900 mm^2.

i. Determine the sucrose content of the sample tested in the HPLC, in grams per litre. 1 mark

ii. Calculate the percentage mass/volume (% m/v) of sucrose in the 5.0 mL sample of soft drink. 2 marks

iii. The can used to obtain the sample contained 330 mL of soft drink.

Assuming that the only sugar in the soft drink is sucrose, calculate the mass of sucrose in the can of soft drink. 1 mark

b. Based on the results obtained, is the experimental method valid? Give your reasoning. 1 mark

c. Sucrose and aspartame are types of sweeteners.

Use your understanding of chemistry to explain why some people replace sugar with aspartame. In your answer, compare sucrose and aspartame in terms of:

- metabolic reactions
- glycaemic indices
- energy content.

3 marks

Question 6 (10 marks)

There are many varieties of bread available to consumers in Australia. The nutritional values for one type of wholemeal bread are given in the table below.

	Per 100 g
Energy	1000 kJ
Protein	9.1 g
Fats and oils	2.5 g
Carbohydrates	41.5 g
Sugars	3.0 g
Fibre	6.4 g

a. Calculate the energy, in kilojoules, provided by the protein and fats and oils in 100 g of this wholemeal bread. 1 mark

b. Name a model used to explain the mechanism by which an enzyme can break down proteins. 1 mark

c. Proteins can be denatured by an increase in temperature.

Describe what happens to the bonding in the protein structure when it is denatured by an increase in temperature. 1 mark

d. Carbohydrates can be present in the body in many forms.

i. Name the polysaccharide that is used to store energy within the body. 1 mark

ii. Explain the difference in the glycaemic index of amylose and amylopectin. 2 marks

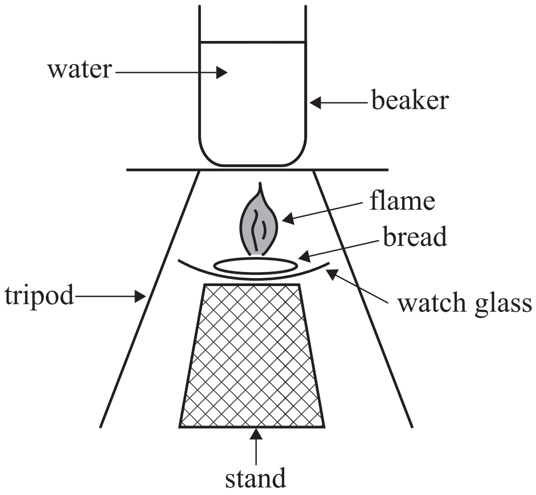
e. Canola oil is one of the usual ingredients in bread. Canola oil is a source of omega-3 fatty acids.

Why are these fatty acids classified as omega-3? 1 mark

f. The wholemeal bread undergoes complete combustion in a bomb calorimeter containing 200 g of water. Assume that all of the energy in the combustion is transferred to the water.

i. Calculate the mass of bread needed to raise the temperature of the water by 6 °C. 2 marks

ii. The combustion of the bread was investigated using a different method. The bread was ignited under a beaker containing 200 g of water, which was set on a tripod. The equipment used is shown below.



If 1.2 g of bread was needed to raise the temperature of the water by 6 °C using this different method, calculate the efficiency of the energy transfer in this combustion. 1 mark

Question 7 (8 marks)

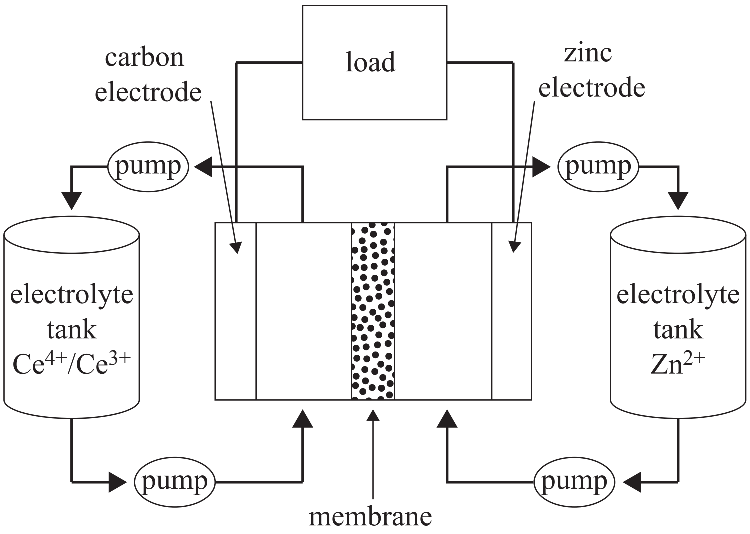
The zinc–cerium battery is a commercial rechargeable battery that comprises a series of cells.

During recharging, the cells use energy from wind farms or solar cell panels.

During discharging, energy is supplied to electric grids to power local factories and homes.

The electrolytes are stored in separate storage tanks, and are pumped into and out of each cell when in use. A membrane separates the two electrodes that are immersed in 1 M methanesulfonic acid, CH_3SO_3H.

A diagram representing a zinc–cerium cell is shown below.



The following half-cell reactions occur in the zinc–cerium cell.

$$Zn(CH_3SO_3)_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons Zn(s) + 2CH_3SO_3H(aq) \qquad E^0 = -0.76\ V$$

$$Ce(CH_3SO_3)_4(aq) + H^+(aq) + e^- \rightleftharpoons Ce(CH_3SO_3)_3(aq) + CH_3SO_3H(aq) \qquad E^0 = 1.64\ V$$

a. Write the equation for the overall discharge reaction. 1 mark

b. Identify the oxidising agent during discharging and justify your answer using oxidation numbers. 2 marks

c. Determine the theoretical voltage produced by a single cell as it discharges. 1 mark

d. Write the ionic equation for the reaction occurring at the positive electrode during recharging. 1 mark

e. Other than transporting ions between the electrodes, describe **one** function of the membrane in the zinc–cerium cell. 1 mark

f. Specify **one** factor that would limit the life of the zinc–cerium cell. 1 mark

g. Experts have regarded the zinc–cerium cell as a hybrid of a fuel cell and a secondary cell.

Why would this be the case? 1 mark

Question 8 (9 marks)

An unknown organic compound contains carbon, hydrogen and oxygen.

It is known that:

- the compound does not contain carbon-to-carbon double bonds (C=C)
- the molecular ion peak is found at a mass-to-charge ratio (m/z) of 74
- the ^{13}C NMR has three distinct peaks.

a. A small peak in the mass spectrum can be identified at m/z = 75.

Explain the presence of this peak. 1 mark

b. **i.** Use the information provided to give **two** possible molecular formulas for this compound. 2 marks

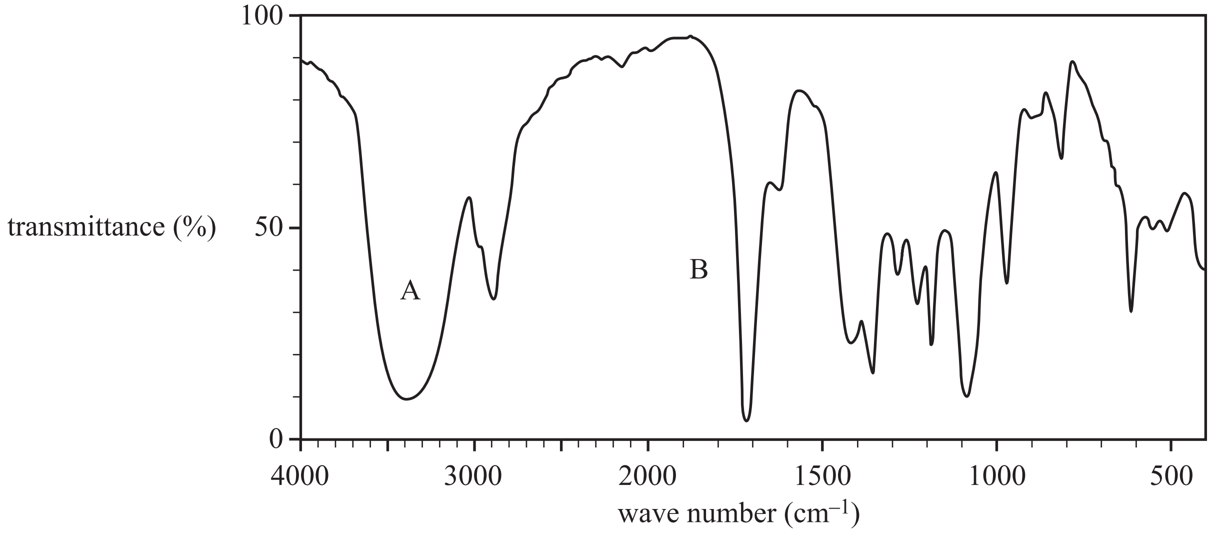
ii. The ^{1}H NMR spectrum of the compound shows three sets of peaks with a peak area ratio of 3:2:1.

What does this information tell you about the structure of the compound and its molecular formula? Justify your answer by referring to the information given about the peaks in the ^{1}H NMR spectrum. 2 marks

c. There are many structural isomers of this compound.

Draw the structural formulas of **two** possible isomers. 2 marks

d. The infra-red (IR) spectrum of the compound is shown below.



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

i. Identify the functional groups responsible for the absorption peaks labelled A and B in the IR spectrum. 1 mark

A ________

B ________

ii. Using the ^{1}H NMR information given in **part b.ii.** and the IR spectrum provided above, draw the structural formula of the compound. 1 mark

Question 9 (15 marks)

A student designed an experiment to investigate current efficiency during the electrolysis of a sodium chloride, NaCl, solution. Current efficiency is the amount of product produced, expressed as a percentage of the theoretical amount of product, calculated using Faraday's law.

When the products of an electrolysis are gases, current efficiency can be calculated using the following.

$$\text{current efficiency} = \frac{\text{volume of gas produced}}{\text{volume of gas expected based on Faraday's law}} \times 100\%$$

All experimental work was carried out under standard laboratory conditions (SLC). The experiment involved the use of a Hoffman electrolysis apparatus.

The following is the first section of the student's report.

What is the effect on current efficiency during electrolysis when the concentration of a sodium chloride, NaCl, solution is changed?

Aim

To investigate the effect on current efficiency during electrolysis when the concentration of a sodium chloride, NaCl, solution is changed

Procedure

Step 1: Rinse the Hoffman electrolysis apparatus with distilled water.

Step 2: Fill the Hoffman electrolysis apparatus with distilled water so that the bottom of the meniscus in both tubes is level with the 170 mL mark.

Step 3: Connect the power supply and ammeter to the electrodes of the Hoffman electrolysis apparatus.

Step 4: Turn on the power supply and start timing. Record the current displayed on the ammeter.

Step 5: After five minutes turn off the power supply and record the volume level on each of the tubes.

Step 6: Repeat steps 2–5 four times.

Step 7: Average the readings of the initial and final volumes at each electrode and current readings.

Step 8: Repeat steps 1–7 using 1.5 M NaCl solution instead of distilled water.

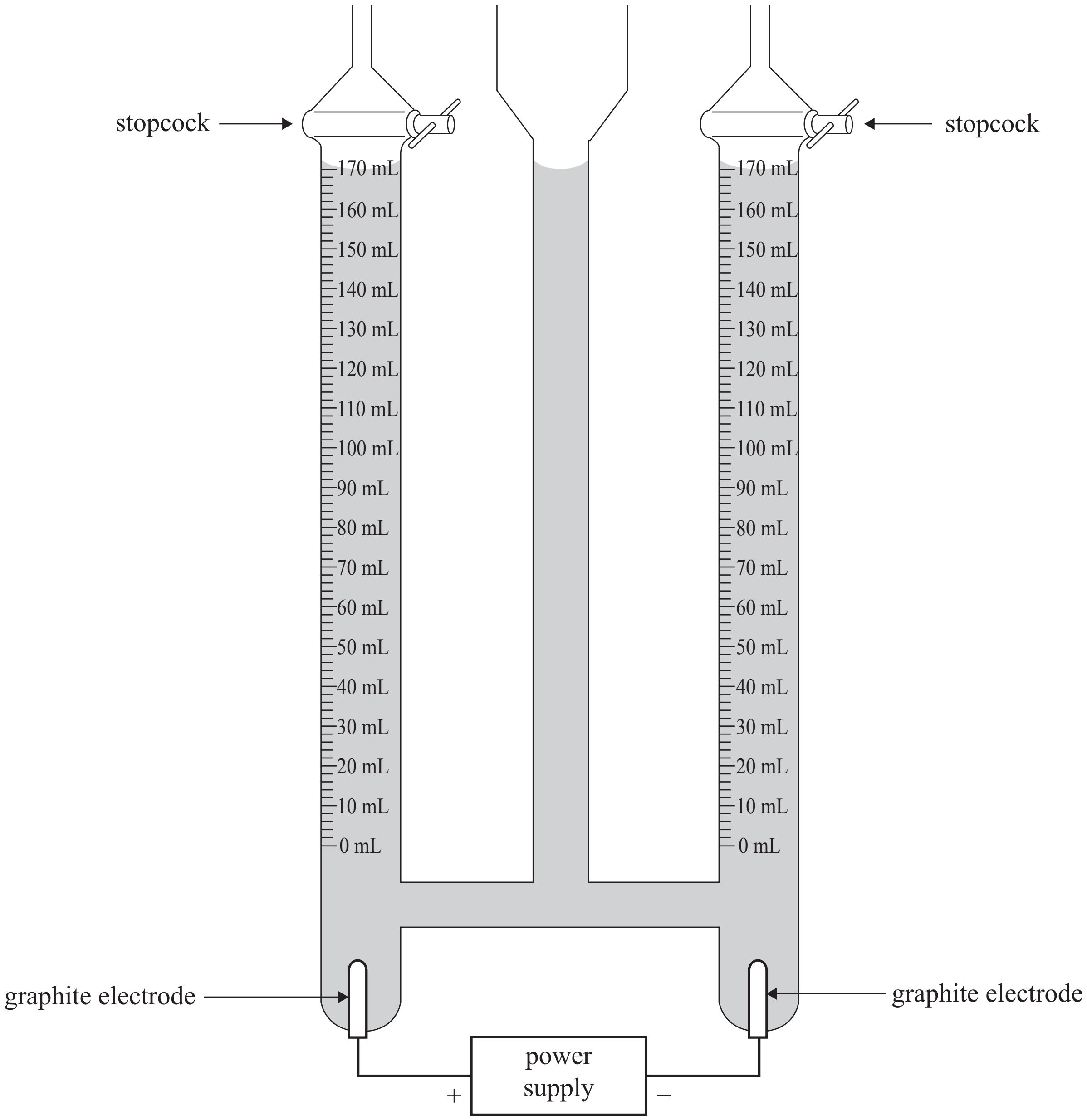
Step 9: Repeat steps 1–7 using 4 M NaCl solution instead of distilled water.

a. Identify the dependent variable. 1 mark

b. **i.** Identify a safety risk associated with the chemicals produced during the experiment. 1 mark

ii. What are the safety measures required to reduce the safety risk identified in **part b.i.**? 1 mark

A diagram of the Hoffman electrolysis apparatus, correctly filled as required in Step 2, is shown below.



The results for steps 1–7 of the procedure are given below in Part 1.

Part 1 – Distilled water

Trial	Initial volume (mL)		Final volume (mL)		Current (A)
	Negative electrode	Positive electrode	Negative electrode	Positive electrode	
1	170.0	170.0	100.2	135.3	2.0
2	170.0	170.0	100.3	135.3	2.0
3	170.0	170.0	99.9	135.0	2.0
4	170.0	170.0	99.8	134.8	2.0
5	170.0	170.0	100.1	135.1	2.0
Average	**170.0**	**170.0**	**100.1**	**135.1**	**2.0**

c. Are the results in Part 1 precise? Justify your answer. 1 mark

d. Write the half-equation for the reaction that would be expected to be observed at the negative electrode. 1 mark

e. **i.** Calculate the volume of gas expected at the negative electrode for Part 1 of the experiment using Faraday's law. 3 marks

ii. Calculate the current efficiency for Part 1 of the experiment. 1 mark

The results for steps 8 and 9 of the procedure are given below in Part 2 and Part 3.

Part 2 – 1.5 M NaCl (Step 8 of the procedure)

	Initial volume (mL)		**Final volume (mL)**		**Current (A)**
	Negative electrode	**Positive electrode**	**Negative electrode**	**Positive electrode**	
Average	170.0	170.0	98.0	133.2	2.0

Part 3 – 4 M NaCl (Step 9 of the procedure)

	Initial volume (mL)		**Final volume (mL)**		**Current (A)**
	Negative electrode	**Positive electrode**	**Negative electrode**	**Positive electrode**	
Average	170.0	170.0	95.2	100.0	2.0

f. What conclusion can be drawn from the results for parts 1, 2 and 3? Give your reasoning. 2 marks

g. State the change the student should make to their experimental design to ensure they achieve their aim. Justify your answer. 2 marks

h. Scientists may use scientific posters to convey their research results to other scientists.

State **two** different aspects of the electrolysis experiment that the student should include in the discussion section of their scientific poster. 2 marks

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Question 10 (9 marks)

Climate change has been identified as a threat to the environment. Fossil fuels are recognised as a significant contributor to the rise in carbon dioxide levels in the atmosphere. The replacement of fossil fuels as an energy source represents a challenge and has been the focus of research for a number of years. However, there are different opinions/views about the suitability of using a biofuel, such as biodiesel, as a replacement for fossil fuels. Some extracts representing different viewpoints are shown in the box below.

> [1]'Biofuels are fuels that are produced from biological sources such as trees, plants or microorganisms. They are carbon neutral, because they do not result in fossil carbon being released into the atmosphere.'
>
> [2]'All good solutions are needed in the energy transition required to achieve Europe's climate goals – and sustainable biofuels are critical to transport decarbonisation.'
>
> [3]'Many scientists view biofuels as inherently carbon-neutral: they assume the carbon dioxide (CO_2) plants absorb from the air as they grow completely offsets, or "neutralises," the CO_2 emitted when fuels made from plants burn.'
>
> [4]'… our analysis affirms that, as a cure for climate change, biofuels are "worse than the disease."'
>
> [5]'… although some forms of bioenergy can play a helpful role, dedicating land specifically for generating bioenergy is unwise.'

Sources: [1]CarbonNeutralEarth, <www.carbonneutralearth.com/biofuels.php>; [2]Sejersgård Fanø, quoted in Erin Voegele, 'EU reaches deal on REDII, sets new goals for renewables', *Biodiesel Magazine*, 15 June 2018, <www.biodieselmagazine.com>; [3 & 4]John DeCicco, 'Biofuels turn out to be a climate mistake – here's why', The Conversation, 5 October 2016, <http://theconversation.com/au>; [5]Andrew Steer and Craig Hanson, 'Biofuels are not a green alternative to fossil fuels', *The Guardian*, 30 January 2015, <www.theguardian.com/au>

a. Using the chemistry that you studied this year and the information above, discuss the carbon neutrality and the sustainability of using biodiesel as a fuel for transport. 4 marks

SECTION B – Question 10 – continued
TURN OVER

b. Hazelnuts are a tree crop that has been grown for many years in Mediterranean environments as a tree nut for food. They have been investigated as a potential sustainable and high-yielding feedstock for biodiesel. The species is well-adapted to less productive soil and produces a high amount of very good quality oil. In addition to oil yield, hazelnut oil has a unique fatty acid composition (high monounsaturated fatty acids, predominantly oleic acid).

Reference: Thomas Molnar, 'Growing hazelnuts for biofuel production', eXtension, 31 January 2014, <https://impact.extension.org/>

Petrodiesel produced from crude oil is mainly characterised as $C_{12}H_{24}$.

Compare biodiesel produced from hazelnut oil to petrodiesel in terms of:

- chemical structure
- energy content per kilogram
- flow through fuel lines.

In your answer, you should indicate how these differences have an impact on the selection of biodiesel as a transport fuel. 5 marks

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END OF QUESTION AND ANSWER BOOK

VICTORIAN CURRICULUM
AND ASSESSMENT AUTHORITY

Victorian Certificate of Education
2019

CHEMISTRY

Written examination

DATA BOOK

Instructions

This data book is provided for your reference.
A question and answer book is provided with this data book.

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

Table of contents

1. Periodic table of the elements

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

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

57 **La** 138.9 lanthanum	**58** **Ce** 140.1 cerium	**59** **Pr** 140.9 praseodymium	**60** **Nd** 144.2 neodymium	**61** **Pm** (145) promethium	**62** **Sm** 150.4 samarium	**63** **Eu** 152.0 europium	**64** **Gd** 157.3 gadolinium	**65** **Tb** 158.9 terbium	**66** **Dy** 162.5 dysprosium	**67** **Ho** 164.9 holmium	**68** **Er** 167.3 erbium	**69** **Tm** 168.9 thulium	**70** **Yb** 173.1 ytterbium	**71** **Lu** 175.0 lutetium

89 **Ac** (227) actinium	**90** **Th** 232.0 thorium	**91** **Pa** 231.0 protactinium	**92** **U** 238.0 uranium	**93** **Np** (237) neptunium	**94** **Pu** (244) plutonium	**95** **Am** (243) americium	**96** **Cm** (247) curium	**97** **Bk** (247) berkelium	**98** **Cf** (251) californium	**99** **Es** (252) einsteinium	**100** **Fm** (257) fermium	**101** **Md** (258) mendelevium	**102** **No** (259) nobelium	**103** **Lr** (262) lawrencium

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

2. Electrochemical series

Reaction	Standard electrode potential (E^0) in volts at 25 °C
$F_2(g) + 2e^- \rightleftharpoons 2F^-(aq)$	+2.87
$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightleftharpoons 2H_2O(l)$	+1.77
$Au^+(aq) + e^- \rightleftharpoons Au(s)$	+1.68
$Cl_2(g) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(1)$	+1.23
$Br_2(l) + 2e^- \rightleftharpoons 2Br^-(aq)$	+1.09
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$O_2(g) + 2H^+(aq) + 2e^- \rightleftharpoons H_2O_2(aq)$	+0.68
$I_2(s) + 2e^- \rightleftharpoons 2I^-(aq)$	+0.54
$O_2(g) + 2H_2O(l) + 4e^- \rightleftharpoons 4OH^-(aq)$	+0.40
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$S(s) + 2H^+(aq) + 2e^- \rightleftharpoons H_2S(g)$	+0.14
$2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$	0.00
$Pb^{2+}(aq) + 2e^- \rightleftharpoons Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	–0.25
$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$	–0.28
$Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	–0.44
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	–0.76
$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$	–0.83
$Mn^{2+}(aq) + 2e^- \rightleftharpoons Mn(s)$	–1.18
$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s)$	–1.66
$Mg^{2+}(aq) + 2e^- \rightleftharpoons Mg(s)$	–2.37
$Na^+(aq) + e^- \rightleftharpoons Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightleftharpoons Ca(s)$	–2.87
$K^+(aq) + e^- \rightleftharpoons K(s)$	–2.93
$Li^+(aq) + e^- \rightleftharpoons Li(s)$	–3.04

3. Chemical relationships

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

4. Physical constants and standard values

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

5. Unit conversions

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

6. Metric (including SI) prefixes

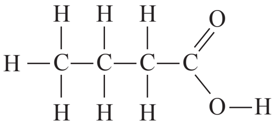
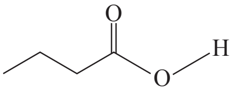
Metric (including SI) prefixes	Scientific notation	Multiplying factor
giga (G)	10^9	1 000 000 000
mega (M)	10^6	1 000 000
kilo (k)	10^3	1000
deci (d)	10^{-1}	0.1
centi (c)	10^{-2}	0.01
milli (m)	10^{-3}	0.001
micro (μ)	10^{-6}	0.000001
nano (n)	10^{-9}	0.000000001
pico (p)	10^{-12}	0.000000000001

7. Acid-base indicators

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

8. Representations of organic molecules

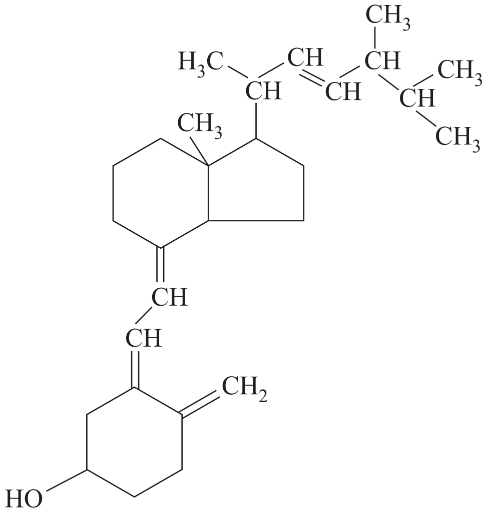
The following table shows different representations of organic molecules, using butanoic acid as an example.

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

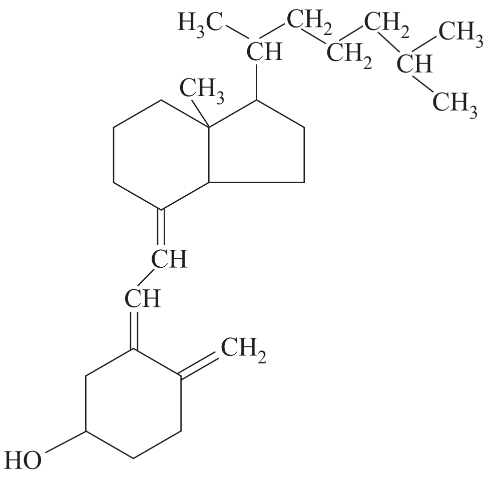
9. Formulas of some fatty acids

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

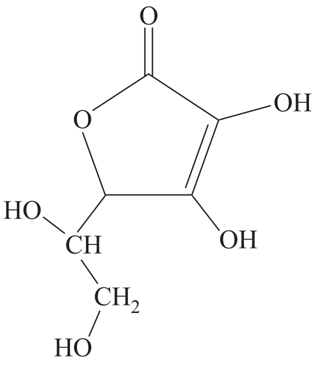
10. Formulas of some biomolecules



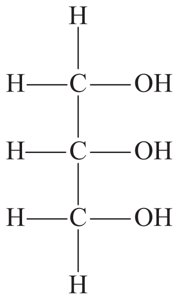
vitamin D_2 (ergocalciferol)



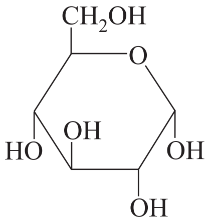
vitamin D_3 (cholecalciferol)



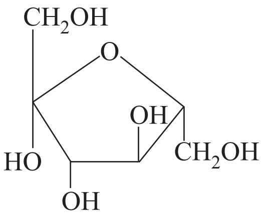
vitamin C (ascorbic acid)



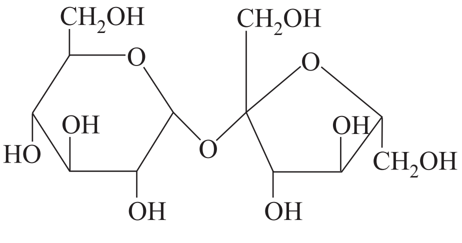
glycerol



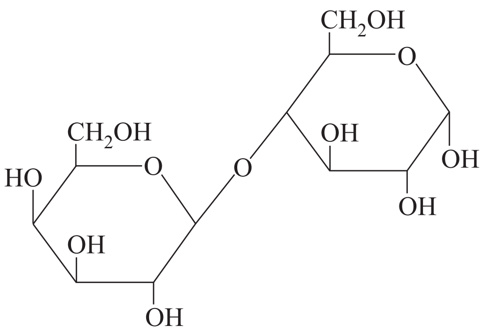
α-glucose



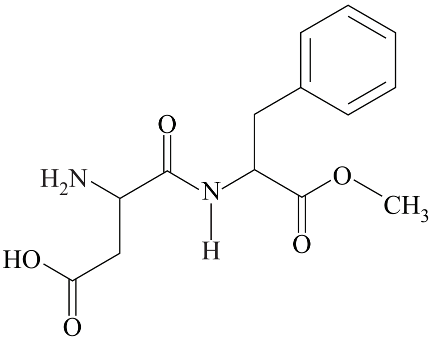
β-fructose



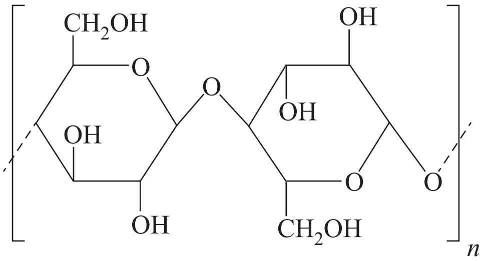
sucrose



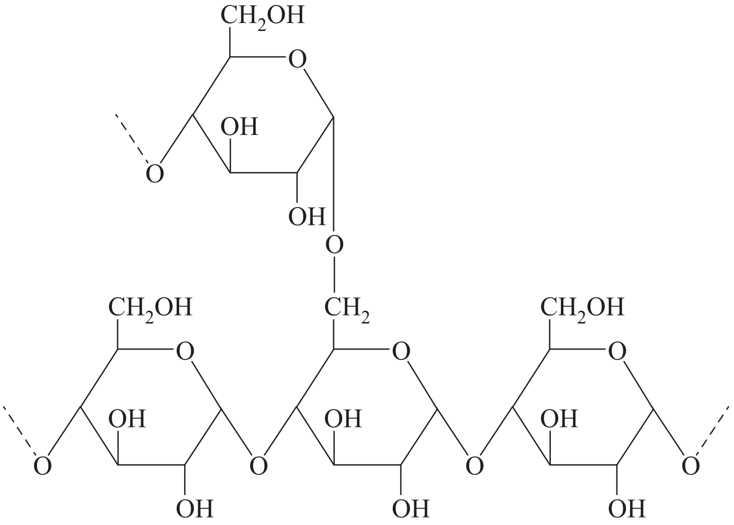
α-lactose



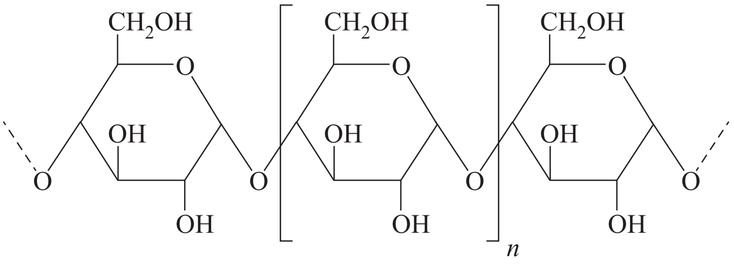
aspartame



cellulose



amylopectin (starch)



amylose (starch)

11. Heats of combustion of common fuels

The heats of combustion in the following table are calculated at SLC (25 °C and 100 kPa) with combustion products being CO_2 and H_2O. Heat of combustion may be defined as the heat energy released when a specified amount of a substance burns completely in oxygen and is, therefore, reported as a positive value, indicating a magnitude. Enthalpy of combustion, ΔH, for the substances in this table would be reported as negative values, indicating the exothermic nature of the combustion reaction.

Fuel	**Formula**	**State**	**Heat of combustion ($kJ\ g^{-1}$)**	**Molar heat of combustion ($kJ\ mol^{-1}$)**
hydrogen	H_2	gas	141	282
methane	CH_4	gas	55.6	890
ethane	C_2H_6	gas	51.9	1560
propane	C_3H_8	gas	50.5	2220
butane	C_4H_{10}	gas	49.7	2880
octane	C_8H_{18}	liquid	47.9	5460
ethyne (acetylene)	C_2H_2	gas	49.9	1300
methanol	CH_3OH	liquid	22.7	726
ethanol	C_2H_5OH	liquid	29.6	1360

12. Heats of combustion of common blended fuels

Blended fuels are mixtures of compounds with different mixture ratios and, hence, determination of a generic molar enthalpy of combustion is not realistic. The values provided in the following table are typical values for heats of combustion at SLC (25 °C and 100 kPa) with combustion products being CO_2 and H_2O. Values for heats of combustion will vary depending on the source and composition of the fuel.

Fuel	**State**	**Heat of combustion ($kJ\ g^{-1}$)**
kerosene	liquid	46.2
diesel	liquid	45.0
natural gas	gas	54.0

13. Energy content of food groups

Food	**Heat of combustion ($kJ\ g^{-1}$)**
fats and oils	37
protein	17
carbohydrate	16

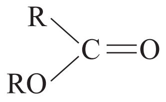
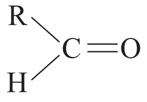
14. Characteristic ranges for infra-red absorption

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

15. ^{13}C NMR data

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

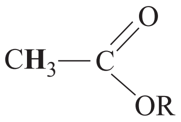
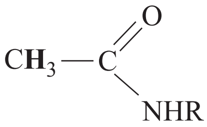
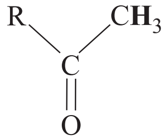
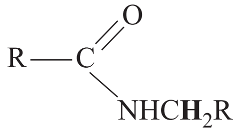
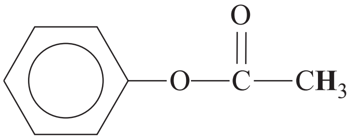
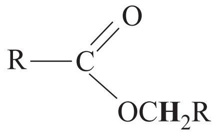
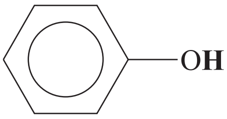
These can differ slightly in different solvents.

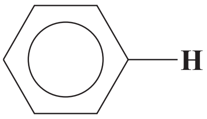
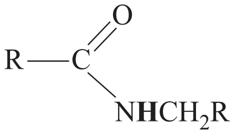
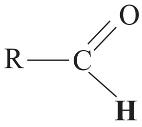
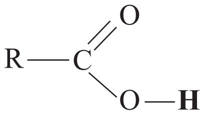
Type of carbon	Chemical shift (ppm)
$R–CH_3$	8–25
$R–CH_2–R$	20–45
$R_3–CH$	40–60
$R_4–C$	36–45
$R–CH_2–X$	15–80
$R_3C–NH_2$, $R_3C–NR$	35–70
$R–CH_2–OH$	50–90
$RC\equiv CR$	75–95
$R_2C=CR_2$	110–150
RCOOH	160–185
	165–175
	190–200
$R_2C=O$	205–220

16. ^{1}H NMR data

Typical proton shift values relative to TMS = 0

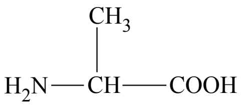
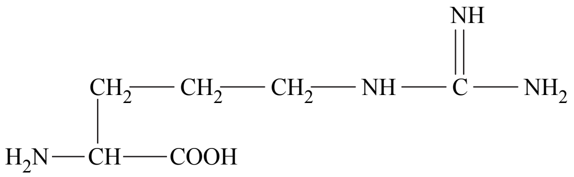
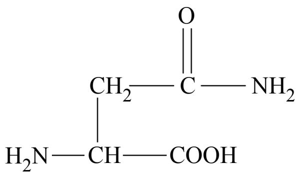
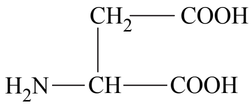
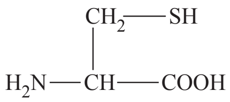
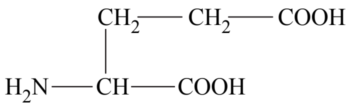
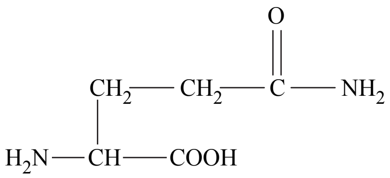
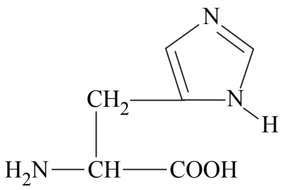
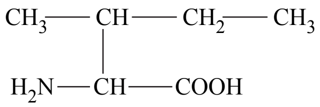
These can differ slightly in different solvents. The shift refers to the proton environment that is indicated in bold letters in the formula.

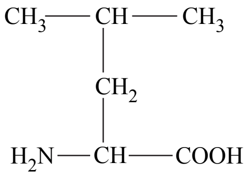
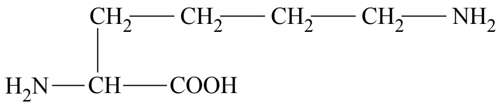
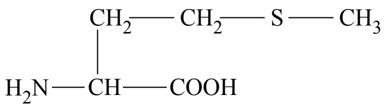
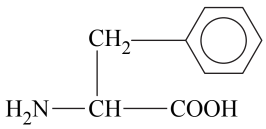
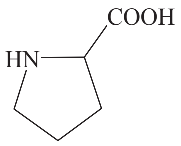
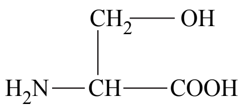
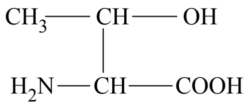
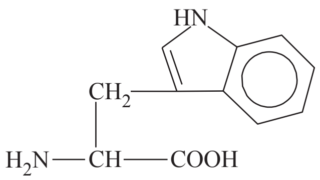
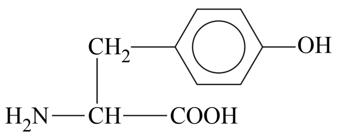
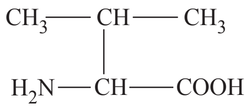
Type of proton	Chemical shift (ppm)
$\mathrm{R{-}C}\mathbf{H}_3$	0.9–1.0
$\mathrm{R{-}C}\mathbf{H}_2\mathrm{{-}R}$	1.3–1.4
$\mathrm{RCH{=}CH{-}C}\mathbf{H}_3$	1.6–1.9
$\mathrm{R_3{-}C}\mathbf{H}$	1.5
 or 	2.0
	2.1–2.7
$\mathrm{R{-}C}\mathbf{H}_2\mathrm{{-}X}$ (X = F, Cl, Br or I)	3.0–4.5
$\mathrm{R{-}C}\mathbf{H}_2\mathrm{{-}OH}$, $\mathrm{R_2{-}C}\mathbf{H}\mathrm{{-}OH}$	3.3–4.5
	3.2
$\mathrm{R{-}O{-}C}\mathbf{H}_3$ or $\mathrm{R{-}O{-}C}\mathbf{H}_2\mathrm{R}$	3.3–3.7
	2.3
	3.7–4.8
$\mathrm{R{-}O{-}}\mathbf{H}$	1–6 (varies considerably under different conditions)
$\mathrm{R{-}N}\mathbf{H}_2$	1–5
$\mathrm{RHC{=}C}\mathbf{H}\mathrm{R}$	4.5–7.0
	4.0–12.0

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

17. 2-amino acids (*α*-amino acids)

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

Name	Symbol	Structure
alanine	Ala	 $H_2N-\overset{\overset{\displaystyle CH_3}{\vert}}{CH}-COOH$
arginine	Arg	 $H_2N-\overset{\overset{\displaystyle CH_2-CH_2-CH_2-NH-\overset{\overset{\displaystyle NH}{\Vert}}{C}-NH_2}{\vert}}{CH}-COOH$
asparagine	Asn	 $H_2N-\overset{\overset{\displaystyle CH_2-\overset{\overset{\displaystyle O}{\Vert}}{C}-NH_2}{\vert}}{CH}-COOH$
aspartic acid	Asp	 $H_2N-\overset{\overset{\displaystyle CH_2-COOH}{\vert}}{CH}-COOH$
cysteine	Cys	 $H_2N-\overset{\overset{\displaystyle CH_2-SH}{\vert}}{CH}-COOH$
glutamic acid	Glu	 $H_2N-\overset{\overset{\displaystyle CH_2-CH_2-COOH}{\vert}}{CH}-COOH$
glutamine	Gln	 $H_2N-\overset{\overset{\displaystyle CH_2-CH_2-\overset{\overset{\displaystyle O}{\Vert}}{C}-NH_2}{\vert}}{CH}-COOH$
glycine	Gly	H_2N-CH_2-COOH
histidine	His	
isoleucine	Ile	 $H_2N-\overset{\overset{\displaystyle CH_3-CH-CH_2-CH_3}{\vert}}{CH}-COOH$

Name	Symbol	Structure
leucine	Leu	 $\begin{array}{l} \mathrm{CH_3-CH-CH_3} \\ \qquad\;\;\vert \\ \qquad\mathrm{CH_2} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$
lysine	Lys	 $\begin{array}{l} \qquad\;\;\mathrm{CH_2-CH_2-CH_2-CH_2-NH_2} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$
methionine	Met	 $\begin{array}{l} \qquad\;\;\mathrm{CH_2-CH_2-S-CH_3} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$
phenylalanine	Phe	
proline	Pro	
serine	Ser	 $\begin{array}{l} \qquad\;\;\mathrm{CH_2-OH} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$
threonine	Thr	 $\begin{array}{l} \mathrm{CH_3-CH-OH} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	 $\begin{array}{l} \mathrm{CH_3-CH-CH_3} \\ \qquad\;\;\vert \\ \mathrm{H_2N-CH-COOH} \end{array}$

END OF DATA BOOK