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National Qualifications 2025

Mark

X813/76/01

Chemistry Paper 2

THURSDAY, 1 MAY

10:10 AM – 12:30 PM

X8137601

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day Month Year

Scottish candidate number

Total marks — 95

Attempt ALL questions.

You may use a calculator.

You may refer to the Chemistry Data Booklet for Higher and Advanced Higher.

Write your answers clearly in the spaces provided in this booklet. Additional space for answers and rough work is provided at the end of this booklet. If you use this space you must clearly identify the question number you are attempting. Any rough work must be written in this booklet. Score through your rough work when you have written your final copy.

Use **blue** or **black** ink.

Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

SQA

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Total marks — 95

Attempt ALL questions

1. Some metal ions are required for a healthy diet.

(a) Sodium, magnesium and calcium form positively charged ions.

The table shows the values for ionisation energies for these elements.

Element	Ionisation energies ($kJ\,mol^{-1}$)			
	First	Second	Third	Fourth
Sodium	496	4562	6910	9543
Magnesium	738	1451	7733	10543
Calcium	590	1145	4912	6491

(i) Write the equation for the first ionisation of sodium. 1

(ii) Using the ionisation energies from the table, calculate the energy required, in $kJ\,mol^{-1}$, for the following reaction. 1

$$Ca(g) \rightarrow Ca^{2+}(g) + 2e^-$$

(iii) Explain **fully** why the second ionisation energy of sodium is much higher than the second ionisation energy of magnesium. 2

1. (a) (continued)

(iv) The Mg^{2+} ion and the Na^{+} ion have the same number of occupied energy levels.

Explain why the Mg^{2+} ion is smaller than the Na^{+} ion. 1

(b) Potassium forms ionic bonds.

(i) State what is meant by the term ionic bond. 1

(ii) Adults with low potassium levels may be advised to take tablets or eat potassium-rich foods.

An adult takes eight potassium tablets per day for seven days. Each tablet contains 0.0012 moles of potassium ($GFM = 39.1$ g).

A banana contains an average mass of 450 mg of potassium.

Calculate the number of whole bananas the adult would have to consume to provide the same mass of potassium provided by eight tablets per day for seven days. 2

[Turn over

2. Information about four elements from the third period of the periodic table is shown in the table.

Element	Bonding	Structure
Sodium		lattice
Silicon	covalent	
Phosphorus		molecular
Chlorine	covalent	

(a) Complete the table to show the bonding and structure for each element. **2**

(An additional table, if required, can be found on *page 34*.)

(b) Covalent radius is half the distance between the nuclei of two covalently bonded atoms of an element.

(i) State the trend in covalent radius going from sodium to chlorine. **1**

(ii) Suggest why no covalent radius is listed in the data booklet for argon. **1**

2. **(continued)**

(c) Explain **fully** why the boiling points of the noble gases increase going down group 0.

In your answer you should name the van der Waals forces involved. 3

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

3. Pure covalent bonding and ionic bonding can be considered as opposite ends of a bonding continuum.

Using your knowledge of chemistry, comment on how the position of a compound on the bonding continuum can be explained and how this can be used to predict its bonding and properties. 3

4. Alcohols and carboxylic acids are used in many laboratory experiments.

(a) Alcohols can take part in combustion reactions.

(i) Balance the equation for the enthalpy of combustion of propan-1-ol. 1

$$C_3H_7OH \quad + \quad O_2 \quad \rightarrow \quad CO_2 \quad + \quad H_2O$$

(ii) An experiment was carried out to determine the enthalpy of combustion of propan-1-ol. The results are shown in the table.

Volume of water heated (cm^3)	150
Initial temperature of water (°C)	21.2
Final temperature of water (°C)	35.1
Mass of propan-1-ol burned (g)	0.498
Mass of one mole of propan-1-ol (g)	60

Calculate the enthalpy of combustion of propan-1-ol, in $kJ\,mol^{-1}$, for this experiment. 3

(iii) Name the pieces of laboratory equipment that are essential for carrying out this experiment. 2

[Turn over

4. (a) (continued)

(iv) Suggest a reason why the enthalpy of combustion determined experimentally is lower than the value given in the data booklet. 1

(b) Alcohols can undergo oxidation reactions.

(i) Oxidation reactions involve a change in the oxygen to hydrogen ratio.

Determine the oxygen to hydrogen ratio for the alcohol ethane-1,2-diol. 1

(ii) A primary alcohol, **X**, with the formula C_4H_9OH can undergo oxidation to compound **Y**.

(A) Suggest a suitable oxidising agent for this reaction. 1

(B) Compound **Y** can be oxidised to give product **Z**, which turns universal indicator red.

Draw a structural formula for product **Z**. 1

(C) Alcohol **X**, C_4H_9OH, has an isomer that is a secondary alcohol.

Name the product that would be formed by oxidation of this isomer. 1

4. (continued)

MARKS | DO NOT WRITE IN THIS MARGIN

(c) The concentration of a solution of ethanoic acid can be determined using sodium hydroxide solution.

(i) A solution of ethanoic acid was prepared using a piece of glassware that allows the volume to be made up to exactly 250 cm^3.

Name this piece of glassware. 1

(ii) A titration was carried out to calculate the accurate concentration of the ethanoic acid solution.

(A) A burette was rinsed with deionised water and then filled with sodium hydroxide solution.

Suggest an improvement that could be made to this step in the titration procedure. 1

(B) Four 25.0 cm^3 samples of the ethanoic acid solution were titrated with 0.105 mol l^{-1} sodium hydroxide solution.

The results are shown in the table.

	Titration			
	1	2	3	4
Initial reading (cm^3)	0.2	21.0	0.4	20.4
Final reading (cm^3)	21.0	41.5	20.4	40.7
Volume used (cm^3)	20.8	20.5	20.0	20.3

Use these results to calculate the average volume used in cm^3. 1

4. (c) (ii) (continued)

(C) In another experiment, 25.0 cm^3 samples of ethanoic acid were titrated with 0.105 mol l^{-1} sodium hydroxide solution. The average volume of sodium hydroxide solution used was 19.8 cm^3.

One mole of sodium hydroxide reacts with one mole of ethanoic acid.

Calculate the concentration, in mol l^{-1}, of the ethanoic acid. 3

(iii) An impure sample of ethanoic acid, CH_3COOH, contained traces of potassium ethanoate.

(A) Write the ionic formula for potassium ethanoate. 1

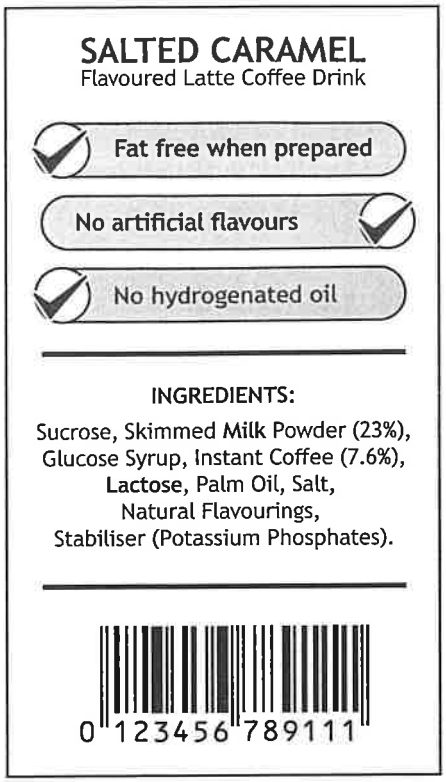
(B) A solution of the impure sample was prepared.

The concentration of ethanoic acid ($GFM = 60$ g) was found to be 0.45 mol l^{-1}.

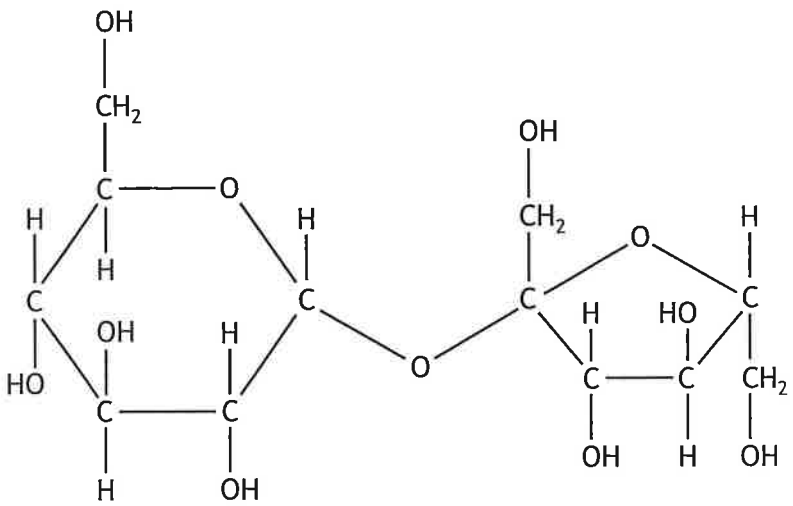
Calculate the mass, in g, of ethanoic acid in 200 cm^3 of this solution. 1

5. The label from a packet of instant latte coffee drink is shown below.

MARKS | DO NOT WRITE IN THIS MARGIN



(a) Sucrose is the main ingredient in the latte coffee drink. The structure of sucrose is shown.



Explain **fully** why sucrose is water soluble. 2

5. (continued)

(b) Skimmed milk powder contains peptide molecules that are formed by joining together amino acid molecules.

Amino acids can be represented by the first three letters of their name; for example, Phe represents phenylalanine.

(i) Hydrolysis of a peptide molecule found in milk gave a mixture of three smaller peptide molecules with the following amino acid sequences.

Tyr-Pro-Phe

Gly-Pro-Phe

Iso-Pro-Gly-Pro

The original peptide molecule was formed from seven amino acids joined together.

Write the amino acid sequence for the original peptide molecule. 1

_____-_____-_____-_____-_____-_____-_____

(ii) Phenylalanine is an amino acid that cannot be made in the human body.

State the term used to describe amino acids that the body cannot make. 1

(c) Palm oil used in the latte coffee drink is an edible oil.

(i) State the class of compounds to which edible oils belong. 1

(ii) When palm oil is hydrolysed, mixtures of fatty acids and another compound are produced.

(A) Name the other compound produced. 1

5. (c) (ii) (continued)

(B) The table gives information on the fatty acids obtained on hydrolysis of palm oil.

Fatty acid	Formula
Palmitic acid	$C_{15}H_{31}COOH$
Oleic acid	$C_{17}H_{33}COOH$
Linoleic acid	$C_{17}H_{31}COOH$
Linolenic acid	$C_{17}H_{29}COOH$

Name the saturated fatty acid obtained on hydrolysis of palm oil. 1

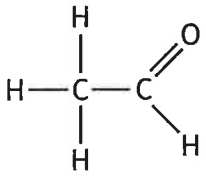
(iii) The latte coffee drink packet states it contains 'no hydrogenated oil'.

Hydrogenation takes place when unsaturated edible oils react with hydrogen.

State another name for this type of reaction. 1

(d) Coffee contains many different compounds.

(i) Acetaldehyde gives coffee a strong fruity aroma.

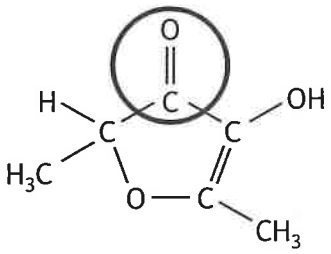


acetaldehyde

State the systematic name for acetaldehyde. 1

5. (d) (continued)

(ii) Furaneol gives coffee a caramel flavour.



furaneol

Name the functional group circled in furaneol. 1

(iii) Terpenoid molecules are also responsible for the aroma of coffee.

Terpenoids are classified by the number of isoprene units (2-methylbuta-1,3-diene) in the molecule.

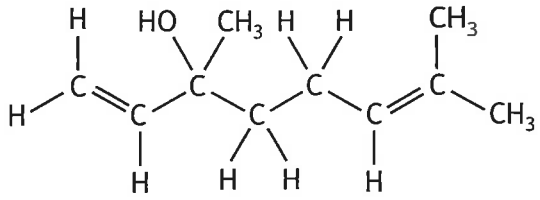
Class of terpenoid	Number of isoprene units
Hemiterpenoid	1
Monoterpenoid	2
Sesquiterpenoid	3
Diterpenoid	4
Sesterterpenoid	5

(A) Cafestol, $C_{20}H_{28}O_3$, is a terpenoid found in coffee.

Name the class of terpenoids to which cafestol belongs. 1

5. (d) (iii) (continued)

(B) Linalool is a monoterpenoid found in coffee with the following structure.



Circle an isoprene unit on the linalool structure above. 1

(An additional structure, if required, can be found on *page 34*.)

(e) One cup of the latte coffee drink contains 125.0 mg of caffeine. Consuming up to 5.7 mg of caffeine per kg of body mass per day is recommended to be safe for an adult.

Calculate the maximum number of cups of the latte coffee drink a 66 kg adult could safely drink without exceeding this recommendation. 1

[Turn over

6. The reaction between iodide ions and hydrogen peroxide in the presence of thiosulfate ions, with starch as the indicator, can be used to determine the relationship between concentration and rate.

(a) Hydrogen peroxide, $H_2O_2(aq)$, reacts with iodide ions in acidic solution to form iodine.

$$H_2O_2(aq) + 2H^+(aq) + 2I^-(aq) \rightarrow 2H_2O(\ell) + I_2(aq)$$

Write the ion-electron equation for the reduction reaction taking place. 1

(b) As iodine molecules are produced, they immediately react with thiosulfate ions, $S_2O_3^{2-}$, and are converted back to iodide ions.

$$2S_2O_3^{2-}(aq) \rightarrow S_4O_6^{2-}(aq) + 2e^-$$

$$I_2(aq) + 2e^- \rightarrow 2I^-(aq)$$

Combine the two ion-electron equations to give the overall redox equation. 1

6. (continued)

(c) In the reaction, the mixture remains colourless until all the thiosulfate ions have been used up. This is shown by the sudden appearance of a blue/black colour.

A set of experiments were carried out to determine the relationship between concentration and rate. The concentration of iodide solution was varied by diluting the original concentration with water and keeping the total volume of solutions the same in each experiment. The time taken for the blue/black colour to appear was recorded.

The results of the experiments are shown.

	Experiment				
	1	2	3	4	5
Volume of iodide solution (cm^3)	25	20	15	10	5
Volume of water (cm^3)	0	5		15	20
Time to turn blue/black (s)	8	10	13	20	40
Rate of reaction (1/t) (s^{-1})	0.120	0.100	0.077	0.050	0.025

(i) Complete the table to show the volume of water needed for experiment 3. 1

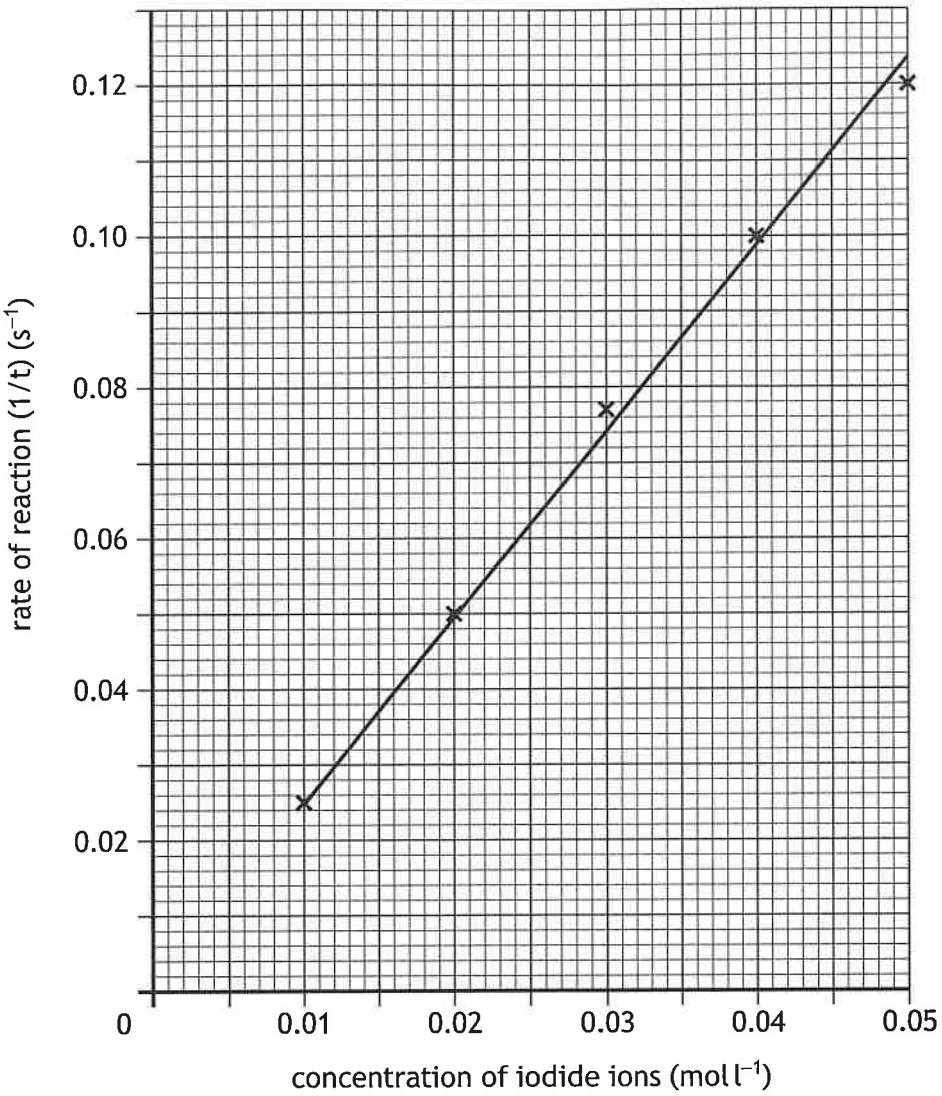
(ii) A dry beaker must be used for each experiment.

Suggest a reason why the beaker should be dry. 1

[Turn over

6. (continued)

(d) A graph of the rate of reaction against the concentration of iodide ions is shown for these results.



(i) Use information from the graph to state what happens to the rate of reaction when the concentration of iodide ions is doubled. 1

(ii) Use information from the graph to calculate the reaction time, in seconds, when the concentration of the iodide ions was 0.025 mol l^{-1}. 1

MARKS | DO NOT WRITE IN THIS MARGIN

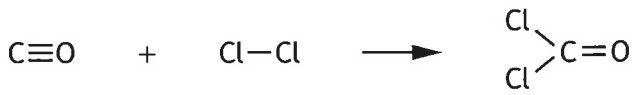
6. (d) (continued)

(iii) Explain **fully** why increasing the concentration causes an increase in reaction rate. 2

[Turn over

7. Carbon monoxide is a gas used in industry.

(a) Carbon monoxide can be used to produce carbonyl dichloride, a chemical used in manufacturing plastics.



The enthalpy change, ΔH, for this reaction is -107.6 kJ mol^{-1}.

Using this data and the bond enthalpy values shown in the data booklet, calculate the bond enthalpy, in kJ mol^{-1}, of the C≡O bond. **2**

(b) Carbon monoxide can react with hydrogen to form methane.

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g) \qquad \Delta H = -206 \text{ kJ mol}^{-1}$$

Cooling the reaction mixture from 400 °C to 80 °C moves the position of equilibrium to the right, increasing the yield of methane.

State **two** reasons why the yield of methane is increased. **2**

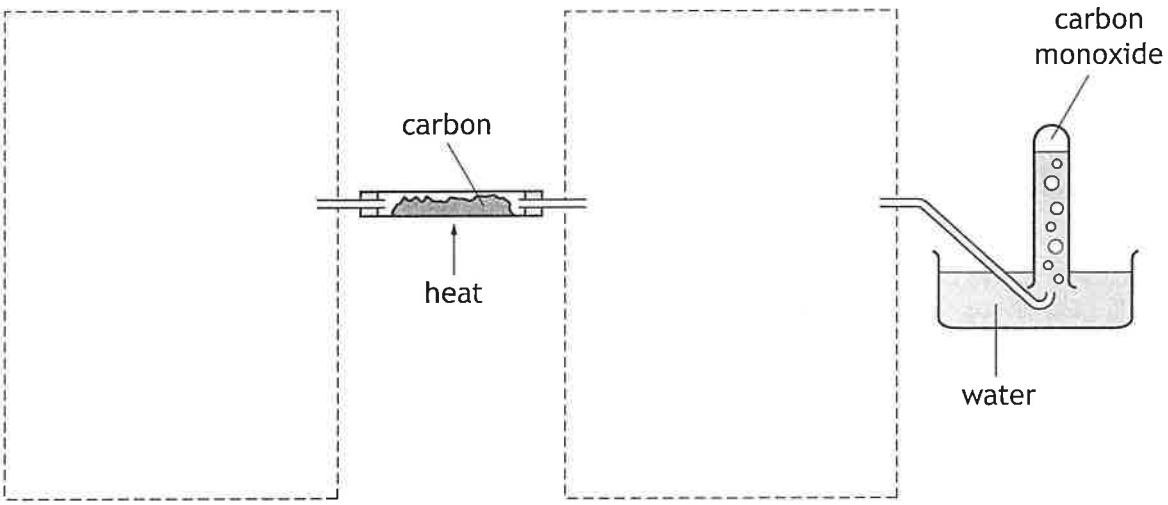
MARKS | DO NOT WRITE IN THIS MARGIN

(c) Carbon monoxide can be produced in several ways.

(i) One method of producing carbon monoxide is to react carbon dioxide with hot carbon.

The carbon dioxide is made by the reaction of dilute hydrochloric acid with solid calcium carbonate.

Unreacted carbon dioxide is removed by passing through a sodium hydroxide solution before the carbon monoxide is collected by displacement of water.



Complete the diagram to show how the carbon dioxide can be produced and how the unreacted carbon dioxide can be removed.

Your answer should include labels. 2

(An additional diagram, if required, can be found on *page 34*.)

(ii) Carbon monoxide can also be produced by the reaction of zinc with calcium carbonate.

Zn	+	$CaCO_3$	→	ZnO	+	CaO	+	CO
$GFM =$ 65.4 g		$GFM =$ 100.1 g		$GFM =$ 81.4 g		$GFM =$ 56.1 g		$GFM =$ 28.0 g

Calculate the atom economy for the production of carbon monoxide. 2

8. Metals can be extracted from their compounds by different methods.

(a) The extraction of tin from tin(IV) oxide, SnO_2, by heating with carbon has been investigated in a series of experiments.

(i) In one experiment the effect of temperature on the percentage yield of tin was investigated.

$SnO_2(s)$	+	$C(s)$	→	$Sn(\ell)$	+	$CO_2(g)$
$GFM =$ 150.7 g				$GFM =$ 118.7 g		

At 850 °C, the percentage yield of tin is 64%.

Calculate the mass of tin oxide required, in g, to produce a mass of 100 g of tin at this temperature. **2**

(ii) In a second experiment, 25.2 g of tin(IV) oxide reacted with 3.0 g of carbon.

$SnO_2(s)$	+	$C(s)$	→	$Sn(\ell)$	+	$CO_2(g)$
$GFM =$ 150.7 g		$GFM =$ 12.0 g				

Name the reactant in excess **and** calculate the number of moles of this reactant left unreacted. **2**

8. (a) (continued)

(iii) In a third experiment, 26.5 litres of carbon dioxide was produced.

$$SnO_2(s) + C(s) \rightarrow Sn(\ell) + CO_2(g)$$

Calculate the mass of tin(IV) oxide ($GFM = 150.7$ g) that reacted. 2

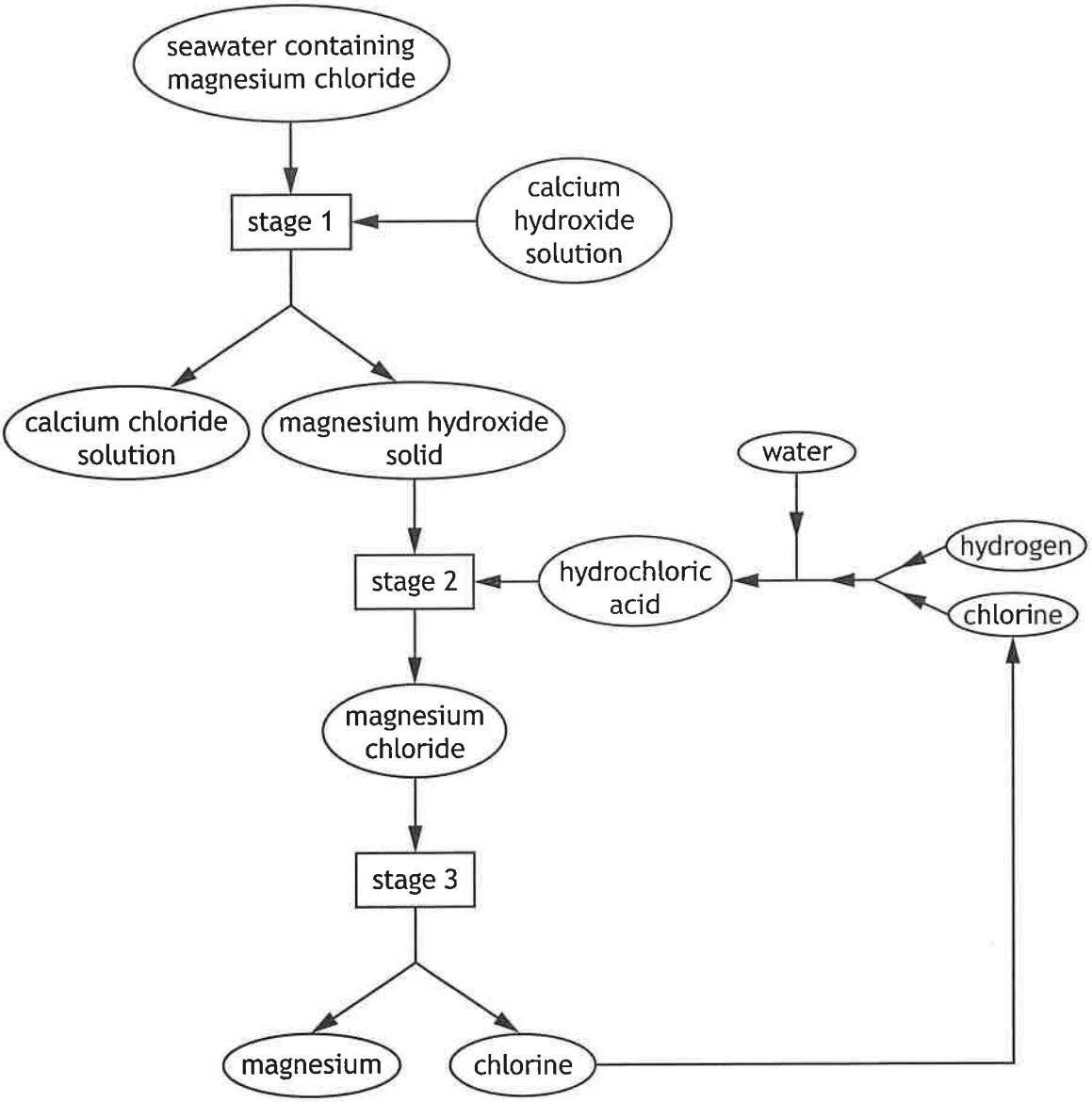
Take the volume of one mole of carbon dioxide gas to be 80 litres.

[Turn over

8. (continued)

MARKS | DO NOT WRITE IN THIS MARGIN

(b) Magnesium metal can be extracted from magnesium chloride present in seawater, as shown in the flow diagram.



(i) Suggest how the magnesium hydroxide and calcium chloride produced in stage 1 can be separated. 1

(ii) Chlorine produced in stage 3 is recycled back into stage 2.

From the flow diagram, suggest another way that profit is maximised. 1

MARKS | DO NOT WRITE IN THIS MARGIN

9. Hydrogen peroxide, H_2O_2, is highly reactive and can cause damage to proteins and fatty acids in the human body.

(a) Hydrogen peroxide, H_2O_2, can react to form hydroxyl radicals (HO•) starting a chain reaction. AH, BH and CH represent molecules found in the human body.

Reaction step	Name of step
$H_2O_2 \rightarrow 2HO\bullet$	initiation
$HO\bullet + AH \rightarrow HOH + A\bullet$ $A\bullet + BH \rightarrow AH + B\bullet$ $B\bullet + CH \rightarrow BH + C\bullet$	
$A\bullet + HO\bullet \rightarrow AOH$	termination

(i) Complete the table to show the name of the missing step. 1

(An additional table, if required, can be found on *page 35*.)

(ii) The free radicals shown in the table are written as, for example, A•

State what is represented by the symbol • 1

(b) When hydroxyl free radicals react with enzymes, they can break bonds between the protein molecule chains causing them to unfold and change shape.

State the term used to describe this change in shape. 1

(c) Free radical scavengers are molecules that react to prevent chain reactions.

Give an example of a type of consumer product that has free radical scavengers added. 1

[Turn over

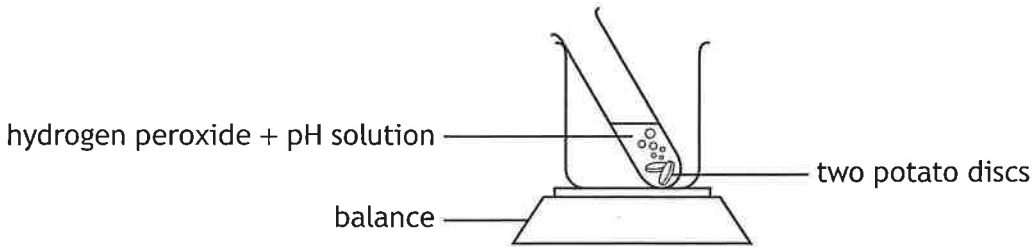
9. (continued)

(d) In some living organisms an enzyme called catalase breaks down hydrogen peroxide into water and oxygen.

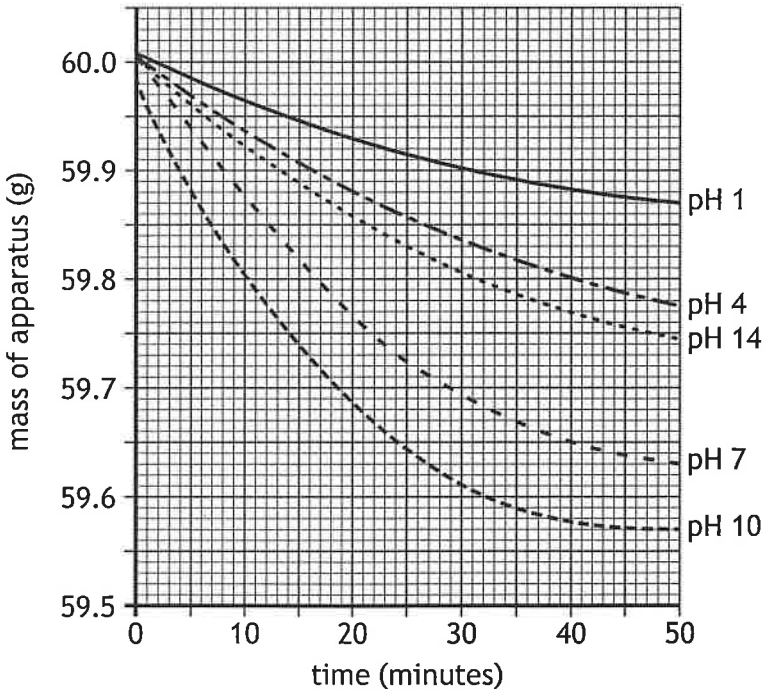
$$2H_2O_2(aq) \rightarrow 2H_2O(\ell) + O_2(g)$$

A student investigated how changes in pH affected the rate of reaction that was followed by measuring the mass lost over time.

Potato discs were placed in solutions with different pH values and the change in mass recorded.



The results are shown in the graph.



(i) Suggest why the mass of the apparatus decreased over time. 1

9. (d) (continued)

(ii) In each experiment, two potato discs were added to 1.0 cm^3 of hydrogen peroxide and 15.0 cm^3 of pH solution in a boiling tube.

State another **two** variables that the student should have kept constant. **2**

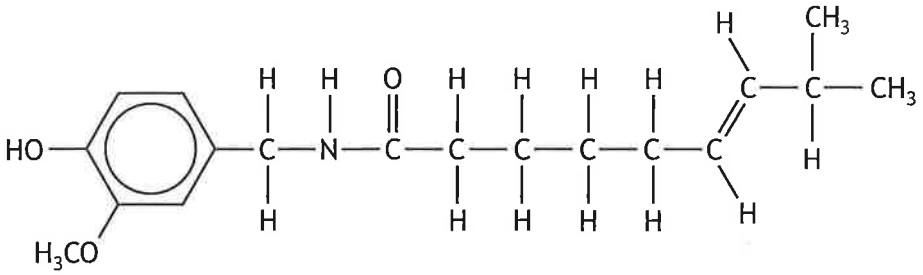
(iii) Using the graph, describe the effect that changing pH has on the rate of the breakdown of hydrogen peroxide by catalase in potatoes. **1**

[Turn over

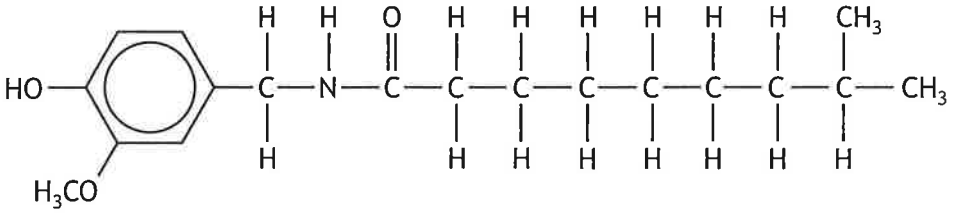
MARKS | DO NOT WRITE IN THIS MARGIN

10. Chilli peppers produce a burning sensation in the mouth. Chemists have identified a group of compounds found in chilli peppers called capsaicinoids that cause this sensation.

(a) The structures of two capsaicinoids are shown below.



capsaicin (CAP)



dihydrocapsaicin (DHC)

(i) Circle the amide link in the CAP structure above. 1

(An additional structure, if required, can be found on *page 35*.)

(ii) Describe a chemical test, and the expected result, that could be used to distinguish between CAP and DHC. 1

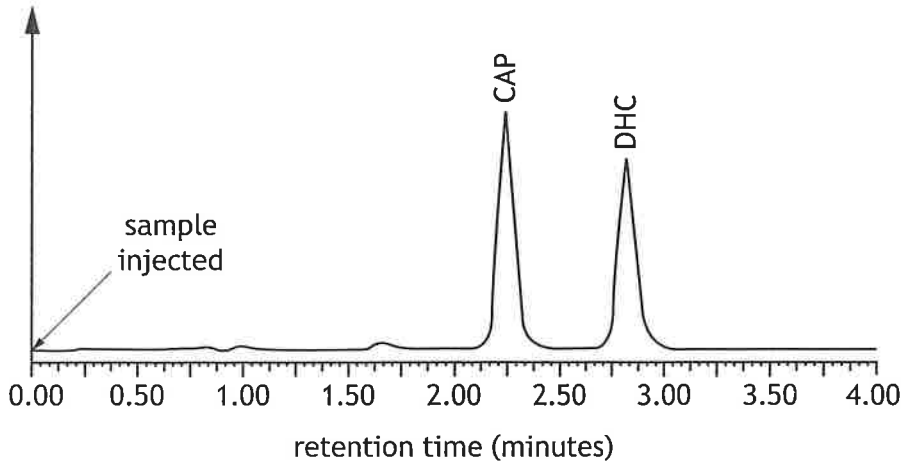
(b) Taking a drink of water has little effect on the burning sensation in the mouth produced by capsaicinoids.

Suggest why the burning sensation produced by capsaicinoids is not affected by drinking water. 1

10. (continued)

(c) High pressure liquid chromatography, HPLC, can be used to separate different capsaicinoids present in chilli peppers.

The time taken for a substance to travel through the HPLC apparatus is known as its retention time and is the time between the sample being injected and the centre of the peak.



Determine the retention time, **in seconds**, of CAP. **1**

[Turn over

10. (continued)

(d) Creams containing CAP are sold for pain relief.

A 60 g tube of cream contains 0.025% CAP.

CAP costs £1930.32 for 1.0 kg.

Calculate the cost, in pence, of the CAP in one tube of cream. 2

(e) Chilli peppers are a good source of vitamin C, $C_6H_8O_6$.

Complete the ion electron equation for the oxidation of vitamin C. 1

$$C_6H_8O_6(aq) \rightarrow C_6H_6O_6(aq)$$

11. Sodium hydrogencarbonate, $NaHCO_3$, is a water-soluble solid and is present in indigestion tablets.

When sodium hydrogencarbonate is heated to 112 °C it breaks down and carbon dioxide gas is given off.

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(g) + CO_2(g)$$

Sodium hydrogencarbonate also reacts with acids to form salts. The hydrogencarbonate ions react with hydrogen ions from the acid to form water and carbon dioxide gas.

$$HCO_3^-(aq) + H^+(aq) \rightarrow H_2O(\ell) + CO_2(g)$$

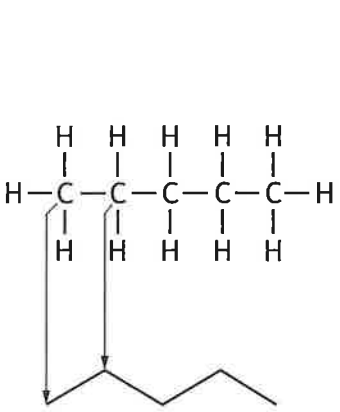
Using your knowledge of chemistry, comment on how the mass of sodium hydrogencarbonate in an indigestion tablet could be determined by experiment. 3

12. Chemists can represent the structures of carbon-chain molecules in a simplified way known as skeletal formulae.

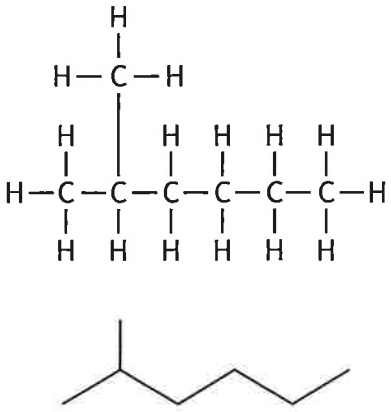
In a skeletal formula, the symbols for carbons, and for the hydrogens attached to carbons, are not shown. The carbon-chain structure is shown as a zig-zag line in which each bend represents a carbon atom. The ends of the zig-zag line also represent carbon atoms.

Each carbon atom is understood to have the correct number of hydrogen atoms attached.

Some examples are shown below.

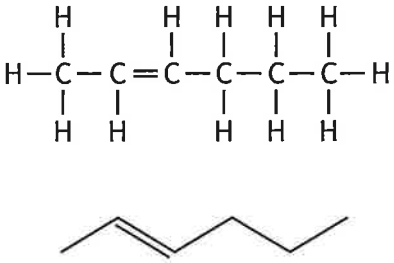


pentane



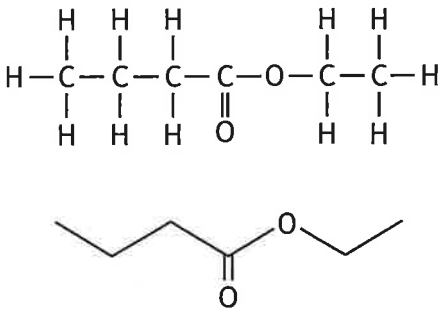
2-methylhexane

A double bond is shown by a double line in the zig-zag line.

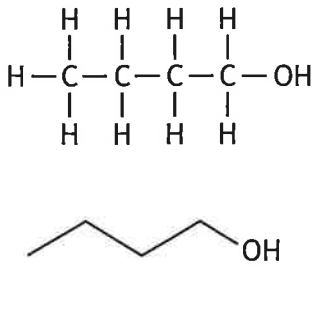


hex-2-ene

Other atoms, such as oxygen, are shown by their symbols attached to the appropriate part of the zig-zag line.



ethyl butanoate

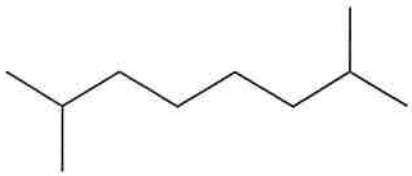


butan-1-ol

DO NOT WRITE IN THIS MARGIN

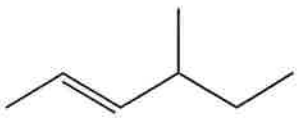
12. (continued)

(a) A skeletal formula is shown.



Name this molecule. 1

(b) Draw the full structural formula for the molecule shown below. 1



(c) Draw the skeletal formula for pentanoic acid. 1

[END OF QUESTION PAPER]