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National Qualifications 2024

Mark

# X813/76/01

# Chemistry Paper 2

THURSDAY, 23 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 ©

*X8137601 01*

**Total marks — 95**

**Attempt ALL questions**

**1.** Nitrogen and phosphorus are group 5 elements.

(a) The first ionisation energy of phosphorus is lower than the first ionisation energy of nitrogen.

(i) State what is meant by the term **first ionisation energy**. **1**

(ii) Write the equation for the first ionisation of phosphorus. **1**

(b) The melting points of phosphorus and nitrogen are shown.

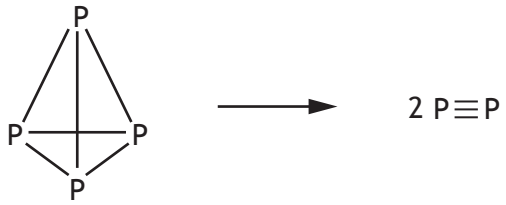
| Element | Melting point (°C) |
|---|---|
| Nitrogen | −210 |
| Phosphorus | 44 |

Explain why the melting point of phosphorus, $P_4$, is much higher than that of nitrogen, $N_2$. **3**

In your answer you should refer to the intermolecular forces involved.

**1. (continued)**

(c) At very high temperatures the following reaction occurs.




| Bond | Bond enthalpy (kJ mol$^{-1}$) |
|---|---|
| P — P | 201 |
| P ≡ P | 488 |

Use the bond enthalpy values in the table to calculate the enthalpy change, in kJ mol$^{-1}$, for the reaction. **2**

**[Turn over**

**1. (continued)**

(d) Phosphorus can be obtained by reacting calcium phosphate with silicon dioxide and carbon.

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C \rightarrow 6CaSiO_3 + 10CO + P_4$$

$GFM = 310.3$ g $\qquad\qquad$ $GFM = 124.0$ g

(i) 750 g of calcium phosphate, $Ca_3(PO_4)_2$, produced 115.5 g of phosphorus.

Calculate the percentage yield of phosphorus, $P_4$. **2**

(ii) Suggest a term that can be used to describe the action of carbon in this reaction. **1**

(iii) At 1500 °C, 280 g of carbon monoxide gas ($GFM = 28.0$ g) was produced and occupied a volume of 1450 litres.

Use this information to determine the molar volume, in litres, of carbon monoxide at this temperature. **2**

**2.** Air bags in cars are intended to prevent injuries in a car crash. When an air bag is activated, a series of reactions takes place.

(a) In the first reaction, sodium azide decomposes into sodium metal and nitrogen gas. The nitrogen gas inflates the air bag.

(i) An ignitor supplies the energy required for the reaction to occur.

State the term used to describe the minimum kinetic energy required by particles before a reaction can occur successfully. **1**

(ii) A typical car air bag contains 80 g of sodium azide, $NaN_3$.

Calculate the energy released, in kJ, when 80 g of sodium azide decomposes. **1**

$$NaN_3 \rightarrow Na + 1\tfrac{1}{2}N_2 \qquad \Delta H = -42.6 \text{ kJ mol}^{-1}$$

$GFM = 65.0$ g

(iii) Sodium azide is an ionic compound.

State the charge on the azide group ion. **1**

**[Turn over**

**2. (continued)**

(b) In the second reaction, sodium reacts with potassium nitrate, $KNO_3$, forming metal oxides and more nitrogen gas.

$$Na + KNO_3 \rightarrow K_2O + Na_2O + N_2$$

Balance this equation. **1**

(c) In the third reaction, the metal oxides react with silicon dioxide, $SiO_2$, to form less harmful by-products.

Silicon dioxide has a melting point of 1713 °C.

Explain **fully**, in terms of structure and bonding, why silicon dioxide has a high melting point. **2**

**2. (continued)**

(d) The first and second reactions generate the nitrogen gas needed to inflate the air bag.

For every mole of sodium azide ($GFM = 65.0$ g) that reacts, a total of 1.6 moles of nitrogen gas is formed.

Calculate the volume of gas, in litres, formed when 80 g of sodium azide reacts. **2**

*Take the volume of 1 mole of nitrogen to be 24 litres.*

(e) The reactants used in air bags are fine powders to ensure the reactions are fast enough to inflate the air bag quickly.

Explain, in terms of collision theory, why fine powders ensure fast reactions in the air bag. **2**

**[Turn over**

**3.** Alcohols, aldehydes and ketones can be distinguished using chemical tests.

**Using your knowledge of chemistry**, describe the experimental procedures, including the expected results, that could be used to distinguish between alcohols, aldehydes and ketones. Any suitable chemicals and apparatus can be used. **3**

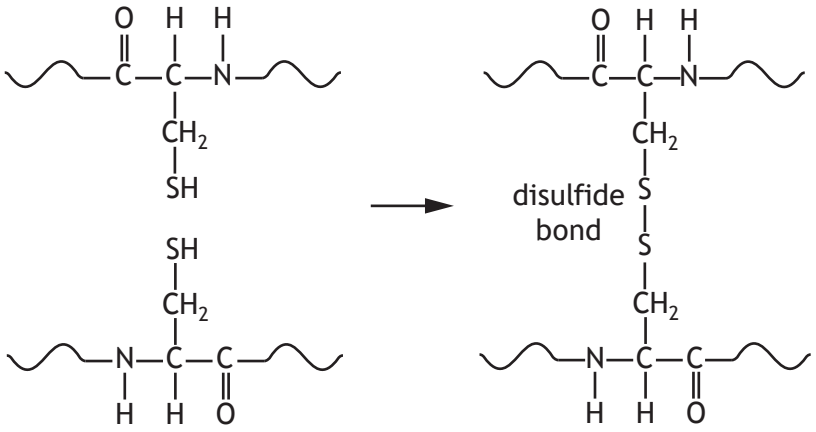
**4.** Hair and skin contain proteins.

(a) Most of the protein in human hair is keratin.

Approximately 25% of keratin is made from the amino acid cysteine.

(i) Name the other product formed when amino acids join to form proteins such as keratin. **1**

(ii) Cysteine gives keratin a very rigid structure, as it can form strong covalent links, called disulfide bonds, between adjacent keratin fibres.




Suggest a name for the type of reaction occurring when a disulfide bond is formed. **1**

(iii) Keratin also contains smaller percentages of the essential amino acids methionine and histidine.

State what is meant by an essential amino acid. **1**

**[Turn over**

**4. (a) (continued)**

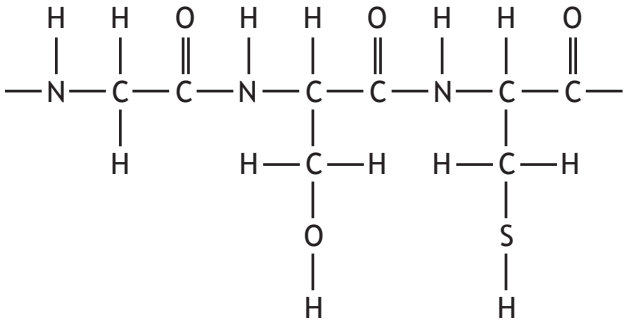
(iv) Hair can be straightened using chemicals.

(A) In the first stage of the straightening process, a chemical is applied that causes the protein fibres to change shape.

Name the process occurring when protein fibres change shape. **1**

(B) In the second stage of the process, short chains of keratin are applied to the hair.

The diagram shows the structure of a section of keratin.



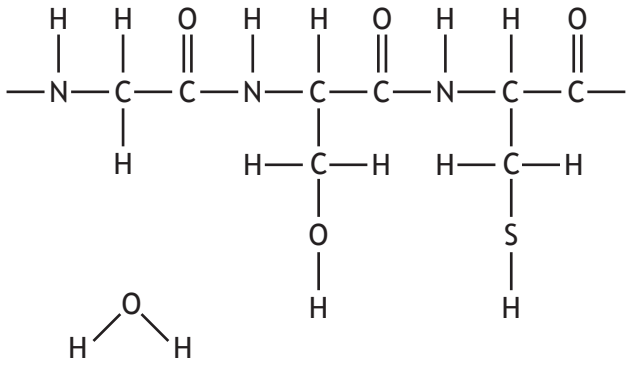
Draw one of the amino acids that make up this section of keratin. **1**

**4. (a) (iv) (continued)**

(C) The short chains of keratin absorb water, making the hair appear thicker. The water forms hydrogen bonds to parts of the keratin.

Complete the diagram to show where hydrogen bonding could occur between the keratin and a water molecule. **1**

(An additional diagram, if required, can be found on *page 36*.)



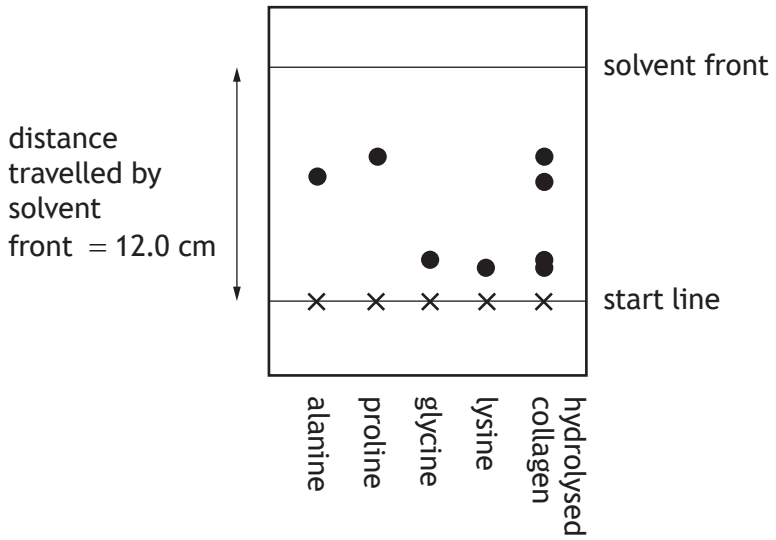
**[Turn over**

**4. (continued)**

(b) Collagen is a protein that is found in skin and blood vessels.

A sample of collagen was analysed using paper chromatography to determine its amino acid composition. Amino acid samples were spotted onto paper at the start line, along with a hydrolysed collagen sample. The spots represent the distances travelled by the amino acids carried by the solvent.

The chromatogram obtained is shown.




The $R_f$ value for an amino acid is found using the following equation.

$$R_f = \frac{\text{distance travelled by amino acid}}{\text{distance travelled by solvent front}}$$

The table shows the distances travelled by the amino acids in this sample.

| Amino acid | Distance travelled (cm) |
|---|---|
| Alanine | 5.2 |
| Proline | 5.6 |
| Glycine | 1.8 |
| Lysine | 1.6 |

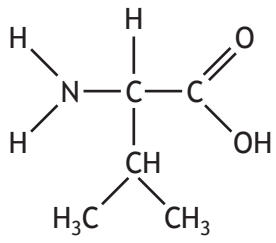
(i) Calculate the $R_f$ value for proline. **1**

**4. (b) (continued)**

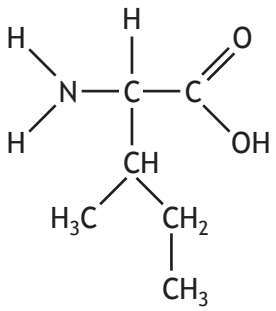
(ii) The sample of collagen contained all four amino acids.

Suggest why there are only three spots in the chromatogram from hydrolysed collagen. **1**

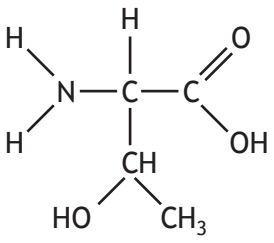
(iii) More polar amino acids are carried for shorter distances by the solvent, as they attach more firmly to the chromatography paper.



valine



isoleucine



threonine

Predict which of the amino acids shown would have the smallest $R_f$ value. **1**

**[Turn over**

MARKS | DO NOT WRITE IN THIS MARGIN

**5.** Edible fats and oils form part of a balanced diet.

(a) State a reason why fats and oils form part of a balanced diet. **1**

(b) Fats and oils are formed using the alcohol glycerol.

(i) Draw a structural formula for glycerol. **1**

(ii) Name the functional group present in all fats and oils. **1**

**5. (continued)**

(c) Explain **fully** why fats have higher melting points than oils. **3**
In your answer you should refer to the structure of fats and oils.

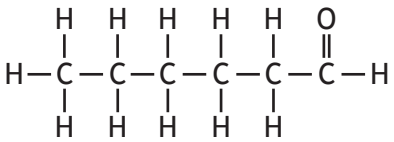
**[Turn over**

**5. (continued)**

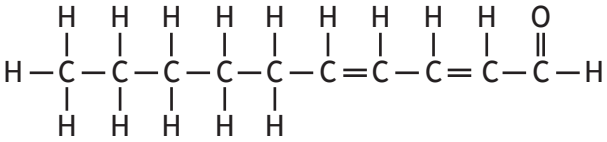
(d) Fats and oils can react with oxygen from the air.

(i) State the term used to describe the resulting unpleasant flavour. **1**

(ii) Two of the molecules responsible for the unpleasant flavour are shown below.



molecule A



molecule B

Describe a chemical test, and the expected result, that could be used to distinguish between these two molecules. **1**

**5. (d) (continued)**

(iii) (A) The reaction of fats and oils with oxygen takes place via a free radical chain reaction.

State what is meant by the term free radical. **1**

(B) The steps in the reaction are shown below, RH is used to represent a fat or oil molecule.

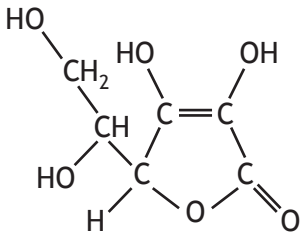
| Step | Reactions |
|---|---|
| 1 | $RH \rightarrow R^{\bullet} + H^{\bullet}$ |
| 2 | $R^{\bullet} + O_2 \rightarrow ROO^{\bullet}$<br>$ROO^{\bullet} + RH \rightarrow ROOH + R^{\bullet}$ |
| 3 | $R^{\bullet} + R^{\bullet} \rightarrow R{-}R$<br>$ROO^{\bullet} + R^{\bullet} \rightarrow ROOR$ |

Name Step 1. **1**

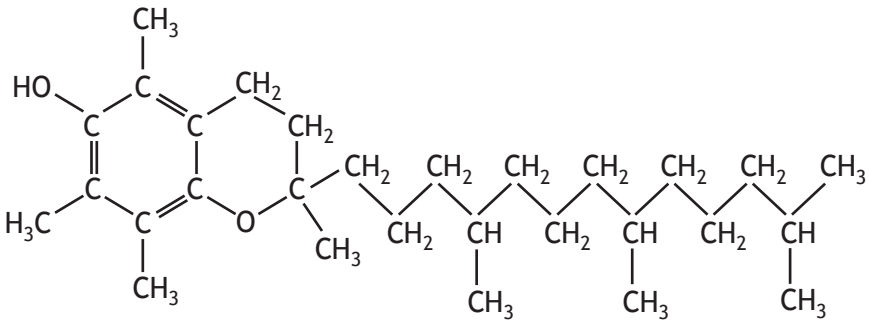
**[Turn over**

**5. (d) (continued)**

(iv) Vitamin C and vitamin E are antioxidants used in some foods.



vitamin C



vitamin E

(A) Antioxidants, such as vitamin C and E, can prevent oxidation by acting as free radical scavengers.

State how free radical scavengers prevent chain reactions from occurring. **1**

(B) Antioxidants are used as preservatives in oils and fatty foods.

Explain **fully** why vitamin E is more suitable than vitamin C as an antioxidant in oils and fatty foods. **2**

**5. (continued)**

(e) Soaps are formed by the alkaline hydrolysis of edible fats and oils.

(i) Soaps are salts of fatty acids. One common fatty acid used in soaps is myristic acid, $C_{13}H_{27}COOH$.

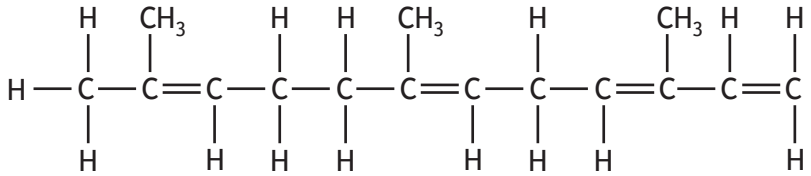
Write a formula for the sodium salt of myristic acid. **1**

(ii) Explain why soapless detergents are used in areas of hard water instead of soaps. **1**

(iii) (A) Essential oils containing terpenes can be added to soaps to provide fragrance. Terpenes are formed by joining together isoprene units.

State the systematic name for an isoprene unit. **1**

(B) Farnesene is a terpene often found in floral essential oils.



farnesene

State the number of isoprene units in farnesene. **1**

**[Turn over**

**6.** Biodiesel is a fuel that can be made from plant oils and is a mixture of compounds.

(a) Oils are converted into biodiesel in a process called trans-esterification.

$$\text{oil} + \text{methanol} \rightleftharpoons \text{biodiesel} + \text{glycerol}$$

(i) One of the compounds in biodiesel is the ester shown.

$$CH_3(CH_2)_6COOCH_3$$

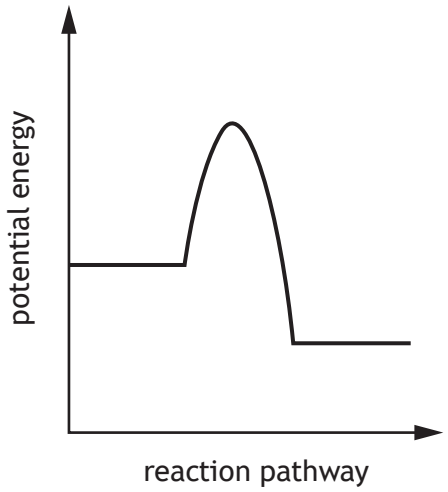
State the systematic name for this ester. **1**

(ii) Esters can be prepared in the laboratory by heating a carboxylic acid with an alcohol and a few drops of catalyst. Some of the reactants and products are volatile and flammable, so it is important to prevent vapours from escaping.

(A) Draw a labelled diagram to show apparatus suitable for preparing an ester. **2**

**6. (a) (ii) (continued)**

(B) The potential energy diagram below shows the change in potential energy for the reaction to make an ester using a catalyst.




Add a dotted line to the diagram to show the change in potential energy for the formation of an ester carried out **without** a catalyst. **1**

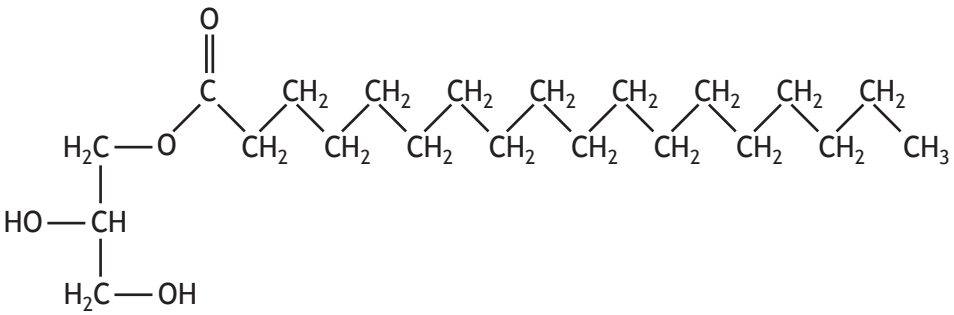
(An additional diagram, if required, can be found on *page 36*.)

**[Turn over**

**6. (continued)**

(b) Emulsifiers are added to biodiesel so that a stable emulsion can be formed with any water present.

An emulsifier molecule is shown.



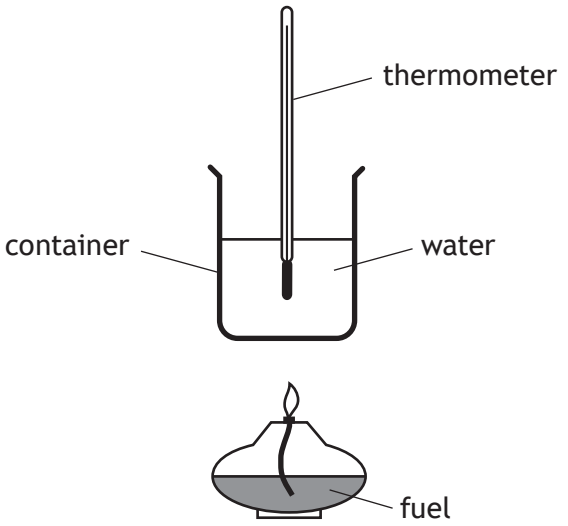
(i) Explain **fully** the reasons this molecule can act as an emulsifier. **2**

(ii) The emulsifiers used in biodiesel and foods can be made from edible oils.

State how emulsifiers are made from edible oils. **1**

**6. (continued)**

(c) The energy released per gram of fuel can be measured using the following apparatus.




A student wanted to compare the energy released by different types of biodiesel.

(i) Suggest one variable the student would need to keep the same in both experiments to make a fair comparison. **1**

(ii) Heat is lost to the surroundings during the experiment.

Suggest an improvement to the apparatus that would prevent heat loss to the surroundings. **1**

**[Turn over**

**6. (c) (continued)**

(iii) The student's results for one type of biodiesel are shown in the table.

| | |
|---|---|
| Mass of biodiesel burned (g) | 0.420 |
| Volume of water ($cm^3$) | 200 |
| Initial temperature of water (°C) | 17 |
| Final temperature of water (°C) | 38 |

Calculate the energy released, in $kJ\,g^{-1}$, when 1.0 g of the biodiesel was burned. **3**

(d) E20 is a mixture of 20% biodiesel and 80% regular diesel and is sold for use in diesel vehicles. Biodiesel costs £0.85 per litre.

Calculate the cost of the biodiesel used to produce 75 litres of E20. **1**

**7.** Seawater contains several dissolved salts.

(a) The salinity of seawater is a measure of the total amount of dissolved salts and can be calculated using the following formula.

Salinity (parts per thousand) = chloride ion concentration ($mg\,l^{-1}$) × 0.0018066

A sample of seawater had a salinity of 35 parts per thousand.

Calculate the chloride ion concentration, in $\mathbf{g\,l^{-1}}$, of this sample. **2**

(b) Another sample of seawater was analysed to determine the mass of chloride ions present. The sample was titrated with a standard solution of silver nitrate solution.

(i) (A) State what is meant by a standard solution. **1**

(B) Describe how a pipette should be prepared and used to accurately measure the sample of seawater. **2**

(ii) An indicator was added to the seawater in a conical flask.

State why an indicator is used. **1**

**[Turn over**

**7. (b) (continued)**

(iii) Three 10.0 $cm^3$ samples of seawater were titrated with a 0.5 mol $l^{-1}$ silver nitrate solution.

The table shows the results obtained.

| Sample | Volume of silver nitrate used ($cm^3$) |
|---|---|
| 1 | 11.90 |
| 2 | 11.60 |
| 3 | 11.50 |

(A) Explain why the average titre value is 11.55 $cm^3$, not 11.70 $cm^3$. **1**

(B) In this titration, one mole of chloride ions, $Cl^-(aq)$, reacts with one mole of silver ions, $Ag^+(aq)$.

Using the average titre value, calculate the concentration, in mol $l^{-1}$, of chloride ions in the seawater. **3**

**7. (b) (iii) (continued)**

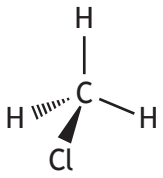
(C) Another sample of a different seawater contained 0.00492 moles of chloride ions in a 10 $cm^3$ sample.

Calculate the mass of chloride ions, in grams, in one litre of seawater. **2**

**[Turn over**

**7. (continued)**

(c) Some micro-organisms living in seawater convert chloride ions to chloromethane. The chloromethane then evaporates.




Explain **fully** why chloromethane has a lower boiling point than water. **2**

In your answer you should refer to the intermolecular forces involved.

**8.** Reversible reactions can cause challenges for chemists trying to maximise yields in chemical processes.

**Using your knowledge of chemistry**, suggest how yields can be maximised in reversible reactions. **3**

**9.** Titanium is a metal which is expensive to extract and purify.

It can be extracted from an ore in a two-step process called the Kroll process.

(a) The first step involves heating the ore with chlorine and carbon to convert titanium dioxide, $TiO_2$, to titanium chloride, $TiCl_4$.

$$TiO_2 + 2Cl_2 + C \rightarrow TiCl_4 + CO_2$$

$GFM = 79.9$ g $\quad GFM = 71.0$ g

The largest reactors can process 1600 kg of titanium dioxide per day.

(i) Calculate the mass of chlorine, in kg, required to react with 1600 kg of titanium dioxide, $TiO_2$. **2**

(ii) Titanium chloride is a liquid at room temperature.

Suggest the type of **bonding and structure** present in titanium chloride. **1**

**9. (continued)**

(b) In the second step, titanium chloride reacts with magnesium to produce titanium metal. The reaction is carried out in a sealed vessel, in an argon atmosphere, at 1500 °C.

$$\underset{GFM = 189.9\text{ g}}{TiCl_4} + \underset{GFM = 24.3\text{ g}}{2Mg} \rightarrow \underset{GFM = 47.9\text{ g}}{Ti} + \underset{GFM = 95.3\text{ g}}{2MgCl_2}$$

(i) Calculate the atom economy for the production of titanium in this reaction. **2**

(ii) Write the ion-electron equation for the oxidation of magnesium atoms. **1**

(iii) In a reaction, 1900 kg of titanium chloride was reacted with 750 kg of magnesium. Magnesium was the reactant in excess.

Calculate the number of moles of magnesium left unreacted. **3**

**9. (b) (continued)**

(iv) Suggest why the reaction is carried out in an argon atmosphere. **1**

(c) A new process for extraction of titanium has been developed.

An electric current is passed through molten titanium dioxide at a temperature of 900 °C. Titanium metal is produced and the only by-product is carbon dioxide.

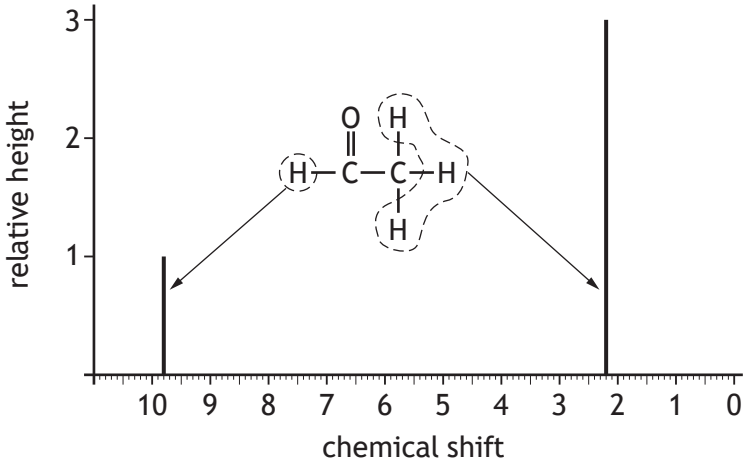
Suggest why this method could be considered preferable to the Kroll process. **1**

**10.** A hydrogen NMR spectrum can be used to help determine the structure of an organic molecule.

In a hydrogen NMR spectrum:

- a vertical line represents the hydrogen atom(s) in a specific structural environment in a molecule
- the position of the vertical line on the x-axis gives the 'chemical shift' value for the hydrogen atom(s) in that structural environment
- the height of the vertical line is related to the number of hydrogen atom(s) in that structural environment.

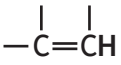
An example showing a hydrogen NMR spectrum for ethanal is shown.




(a) Chemical shift values of hydrogen atoms in different structural environments fall within a range and are listed on *page 17* of the data booklet.

For example, the chemical shift value for the hydrogen atom in the aldehyde group shown falls within the range 10.0−9.4.

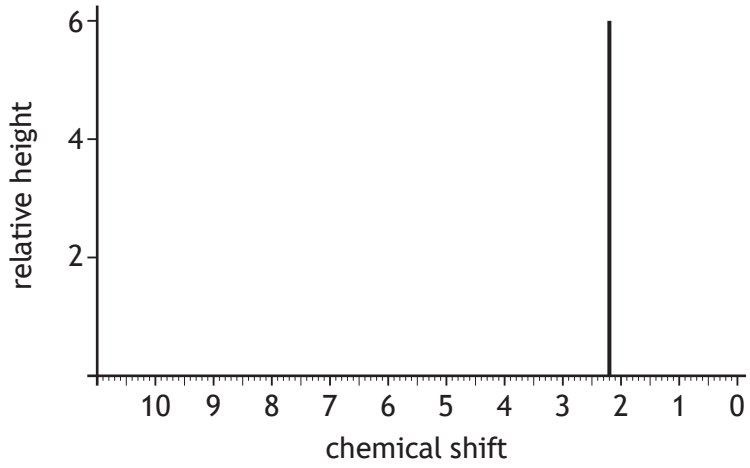

Use the data booklet to find the range in the chemical shift values for the hydrogen atom in the following structural environment. **1**




**[Turn over**

**10. (continued)**

(b) The hydrogen NMR spectrum for a compound with the molecular formula $C_3H_6O$ is shown.




Suggest a name for this compound. **1**

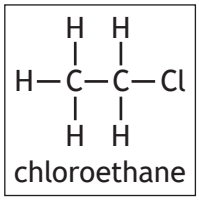
**10. (continued)**

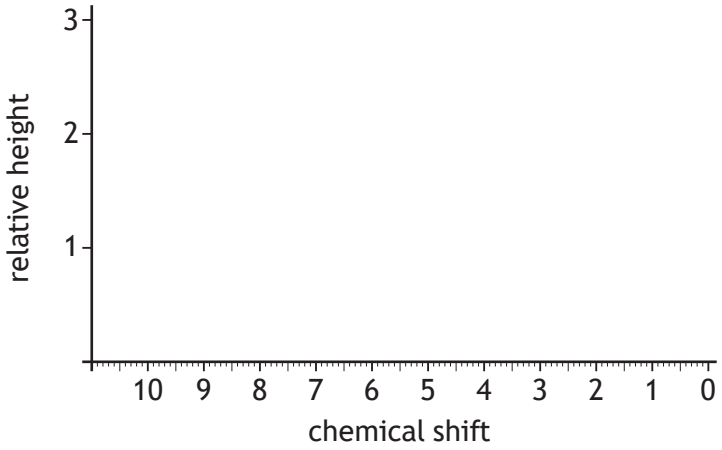
(c) The chemical shift values shown in the table are based on the range of values given in the data booklet.

| Structural environments of hydrogen atoms | Chemical shift |
|---|---|
| $-CH_3$ | 1.0 |
| $-CH_2Cl$ | 3.7 |

Using information from the table above, draw the hydrogen NMR spectrum that would be obtained for chloroethane. **1**

(An additional diagram, if required, can be found on *page 37*.)

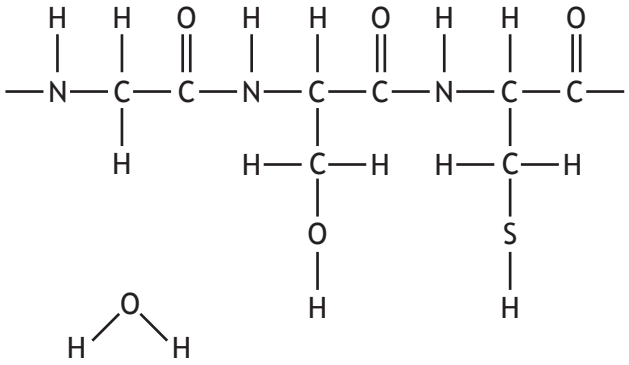


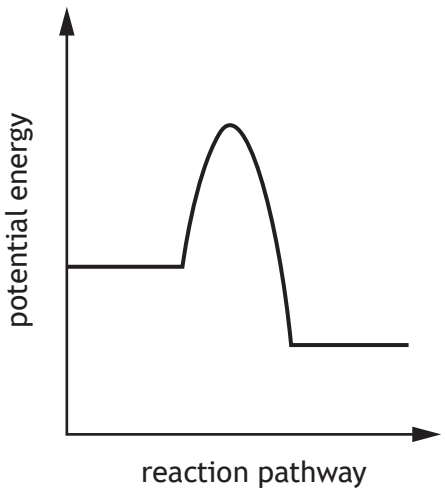

**[END OF QUESTION PAPER]**

## ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

Additional diagram for question 4 (a) (iv) (C)

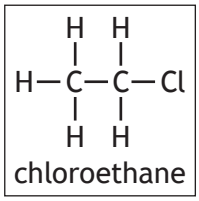


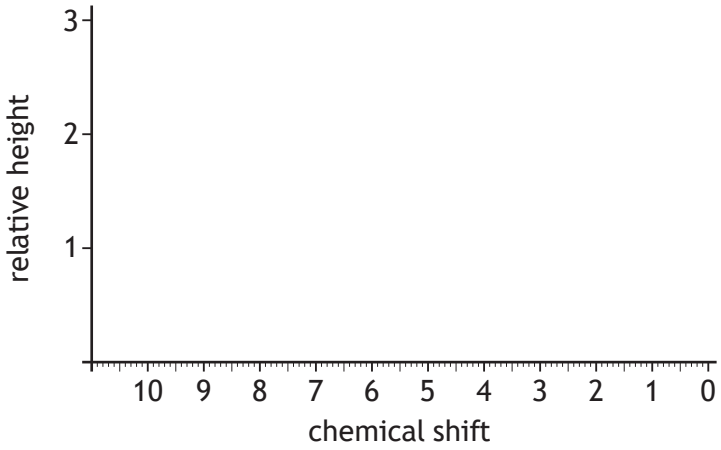
Additional diagram for question 6 (a) (ii) (B)



## ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

Additional diagram for question 10 (c)



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**ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK**

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**ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK**

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