Surname _____

Forename(s) _____

Centre Number _____

Candidate Number _____

Candidate Signature _____

I declare this is my own work.

A-level

CHEMISTRY

Paper 3

7405/3

Friday 21 June 2024 Morning

Time allowed: 2 hours

[Turn over]

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On the front of this book, write your surname and forename(s), your centre number, your candidate number and add your signature.

MATERIALS

For this paper you must have:

- **the Periodic Table/Data Booklet, provided as an insert (enclosed)**
- **a ruler with millimetre measurements**
- **a scientific calculator, which you are expected to use where appropriate.**

[Turn over]

INSTRUCTIONS

- **Use black ink or black ball-point pen.**
- **Answer ALL questions.**
- **You must answer the questions in the spaces provided. Do NOT write on blank pages.**
- **If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).**
- **All working must be shown.**
- **Do all rough work in this book. Cross through any work you do not want to be marked.**

INFORMATION

- **The marks for questions are shown in brackets.**
- **The maximum mark for this paper is 90.**

ADVICE

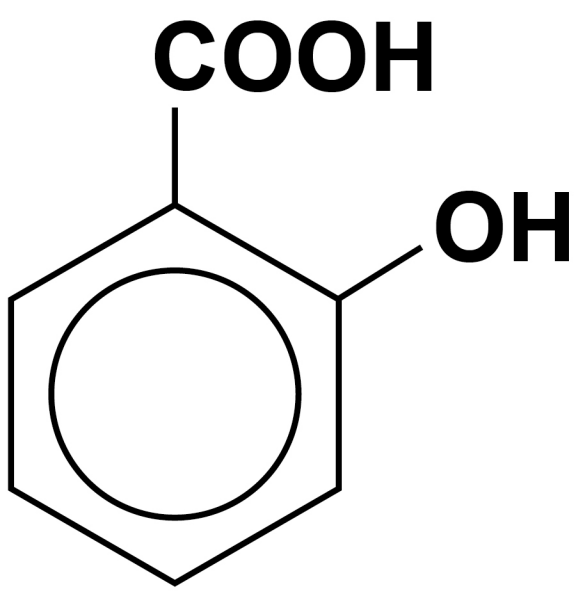
- **You are advised to spend 70 minutes on SECTION A and 50 minutes on SECTION B.**

DO NOT TURN OVER UNTIL TOLD TO DO SO

SECTION A

Answer ALL questions in this section.

0 1 The structure of 2-hydroxybenzenecarboxylic acid is shown.



0 1 . 1

Give the equation for the reaction of 2-hydroxybenzenecarboxylic acid with methanol.

In your equation, include the SKELETAL formula of the organic product.
[2 marks]

Aspirin is produced from 2-hydroxybenzenecarboxylic acid by reaction with ethanoic anhydride in the presence of concentrated phosphoric acid.

Method

1. **Add 2-hydroxybenzenecarboxylic acid to a conical flask.**
2. **Add excess ethanoic anhydride.**
3. **Add a few drops of concentrated phosphoric acid.**
4. **Heat the flask to 85 °C for 10 minutes.**
5. **Cool the flask and pour the contents into 150 cm^3 of cold water.**
6. **Filter and wash the impure solid aspirin.**
7. **Recrystallise the aspirin using a 50:50 mixture of water and ethanol.**
8. **Check the purity of the aspirin.**

0 1 . 2

Aspirin can also be produced by reacting 2-hydroxybenzenecarboxylic acid with ethanoyl chloride.

State why ethanoic anhydride is preferred to ethanoyl chloride for this preparation. [1 mark]

0 1 . 3

Give the name of the mechanism for the reaction of 2-hydroxybenzenecarboxylic acid with ethanoic anhydride. [1 mark]

0 1 . 4

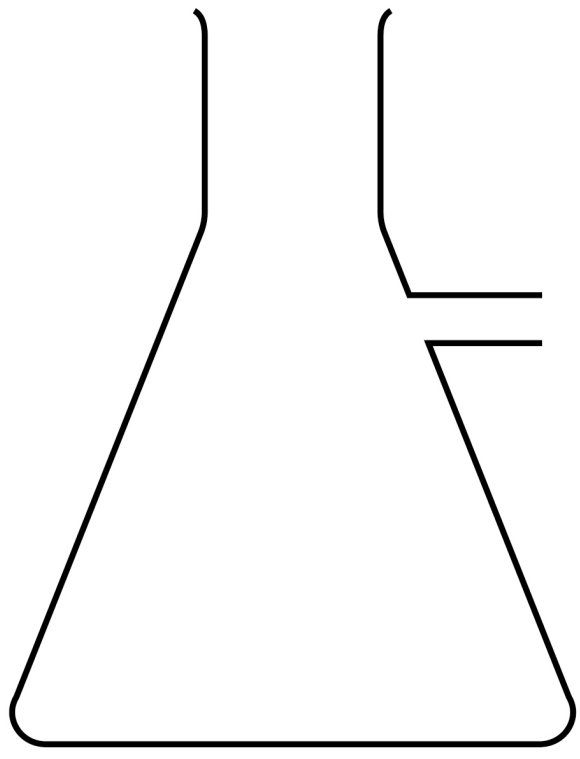
Suggest the role of the concentrated phosphoric acid. [1 mark]

0 1 . 5

Suggest why reflux is NOT essential when the flask is heated to 85 °C for 10 minutes. [1 mark]

0 1 . 6

Complete and label the diagram to show how the impure solid is filtered. [2 marks]



[Turn over]

0 1 . 7

Suggest the identity of TWO impurities present in the filtered solid aspirin before it is washed in Step 6, on page 8 of the method. [2 marks]

Impurity 1 _____

_____

Impurity 2 _____

_____

0 1 . 8

Describe the recrystallisation process used to purify the aspirin.

Include the method and apparatus used.
[6 marks]

0 1 . 9

State the physical property that is measured to check the purity of the aspirin.

Describe TWO ways the result would show that the product is impure.
[3 marks]

Physical property _____

_____

1 _____

_____

_____

2 _____

_____

_____

19

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[Turn over]

0 2

The rate of reaction between calcium carbonate and hydrochloric acid is investigated using a continuous monitoring method.

Method

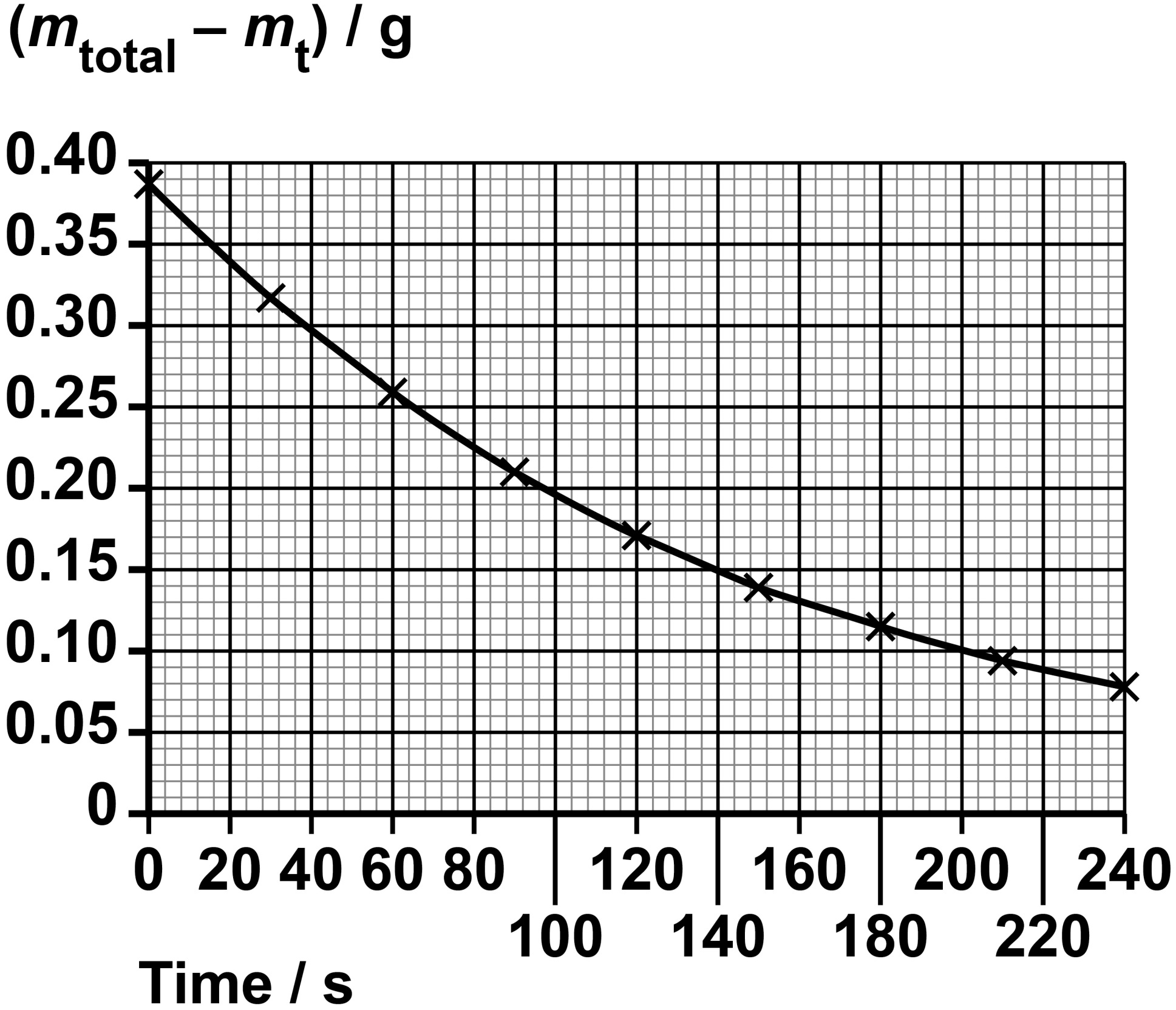
- **Place a conical flask on a balance and add approximately 20 g of large marble chips.**
- **Add 50 cm^3 of 0.4 mol dm^{-3} hydrochloric acid.**
- **Place a loose cotton wool plug in the neck of the flask.**
- **Zero the mass reading on the balance.**
- **Start a timer.**
- **Record the loss in mass (m_t) every 30 seconds for 4 minutes.**

- **Wait for the reaction to finish and record the total mass loss (m_{total}).**
- **Plot a graph of ($m_{total} - m_t$) against time.**

[Turn over]

FIGURE 1 shows a graph of the results obtained during the first 240 s

FIGURE 1



0 2 . 1

Suggest why a loose cotton wool plug is placed in the neck of the flask, instead of leaving the flask open or inserting a bung. [2 marks]

Instead of leaving the flask open

Instead of inserting a bung

0 2 . 2

20 g of large marble chips is a large excess of calcium carbonate.

Suggest why using a large excess of calcium carbonate means that the rate is only affected by the changing concentration of the hydrochloric acid. [1 mark]

0 2 . 3

The mass of carbon dioxide produced in time *t* is equal to m_t.

The total mass of CO_2 produced during the reaction is equal to m_{total}.

Explain why ($m_{total} - m_t$) is proportional to the concentration of hydrochloric acid remaining in the flask at time *t*. [2 marks]

0 2 . 4

TABLE 1 shows the rate of reaction, calculated from the gradient of the curve, at five different times.

($m_{total} - m_t$) is proportional to the concentration of unreacted HCl at time *t*.

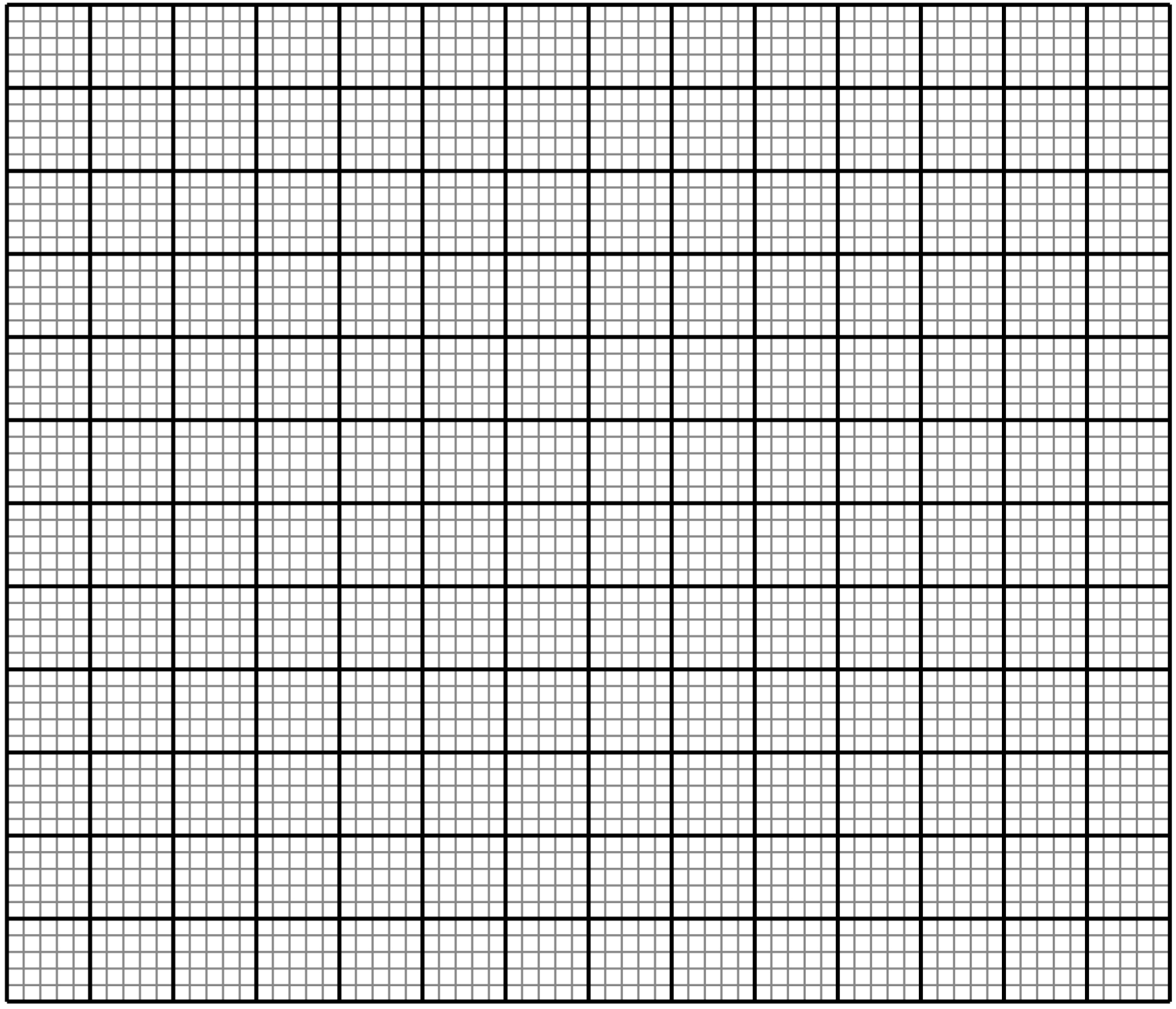
TABLE 1

Rate of reaction / g s^{-1}	**23.0×10^{-4}**	**19.0×10^{-4}**	**15.7×10^{-4}**	**11.5×10^{-4}**	**6.67×10^{-4}**
($m_{total} - m_t$) / g	**0.340**	**0.280**	**0.225**	**0.170**	**0.100**

25 On the grid in FIGURE 2, on page 26, plot the rate of reaction (*y*-axis) against ($m_{total} - m_t$) (*x*-axis). [3 marks]

[Turn over]

FIGURE 2



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[Turn over]

0 2 . 5

State how the graph in FIGURE 2, on page 26, confirms that the rate equation for this reaction is

***Rate* = *k*[HCl]**

[1 mark]

0 2 . 6

In this experiment the variable measured is mass loss.

The rate of this reaction at a constant temperature can be investigated in other ways.

Suggest TWO other variables that can be measured instead of mass loss.
[2 marks]

1 _____

_____

2 _____

0 3

The thermal decomposition of but-3-en-1-ol is investigated at different temperatures (*T*).

The results from the investigation are used to calculate the rate constant, *k*, at each temperature.

TABLE 2, on the opposite page, shows some of the results.

TABLE 2

T / K	$\frac{1}{T}$ / K^{-1}	k / s^{-1}	ln k
553	1.81×10^{-3}	4.6×10^{-4}	–7.68
563	1.78×10^{-3}	8.4×10^{-4}	–7.08
573		15.6×10^{-4}	
583	1.72×10^{-3}	28.0×10^{-4}	–5.88
593	1.69×10^{-3}	49.9×10^{-4}	–5.30

0 3 . 1

Complete TABLE 2 with the missing values at 573 K [1 mark]

[Turn over]

0 3 . 2

The overall order of the reaction can be deduced from a piece of information in one of the column headings in TABLE 2, on page 31.

Identify this piece of information and deduce the overall order. [2 marks]

Piece of information _____

_____

Overall order _____

_____

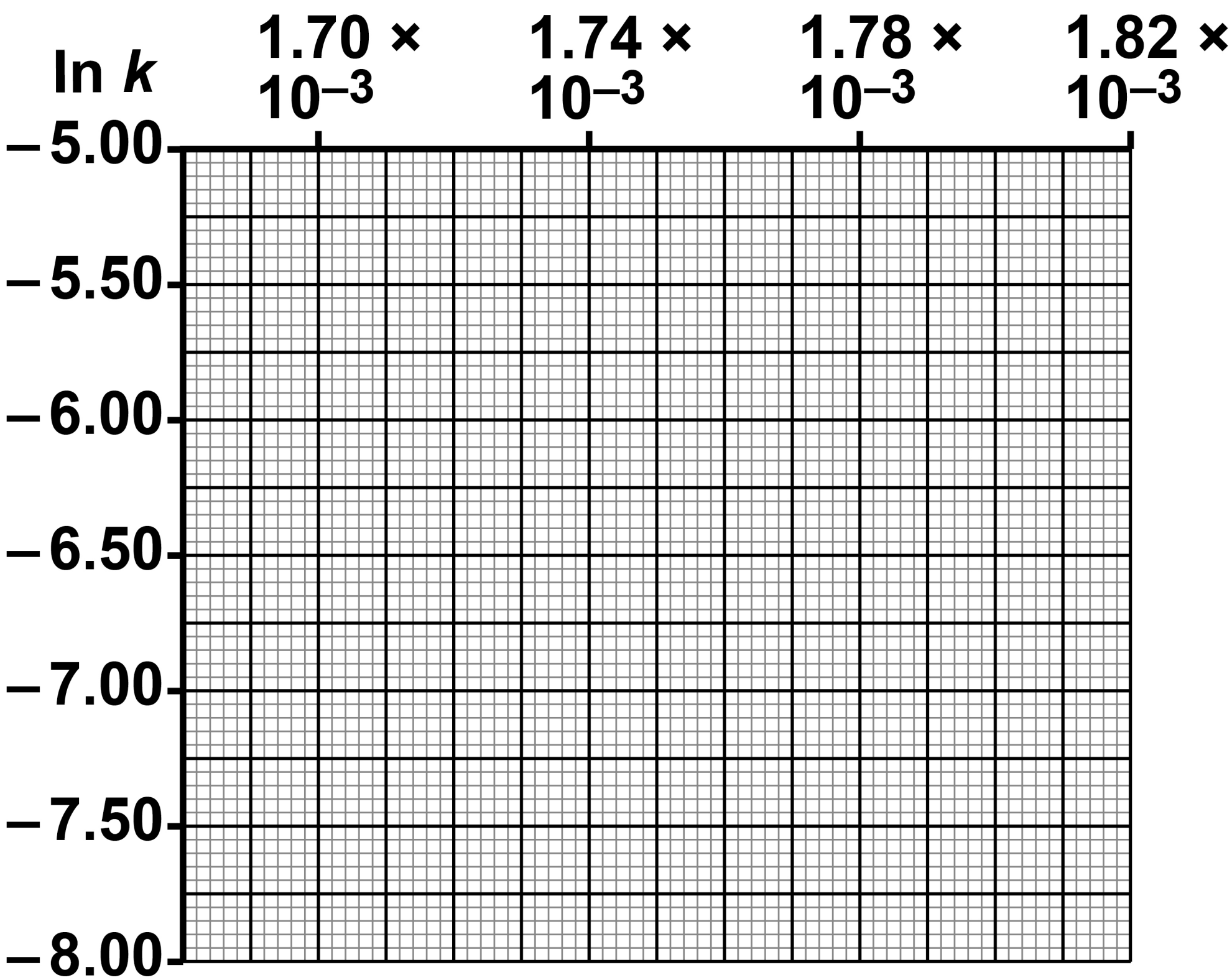
0 3 . 3

The Arrhenius equation can be written in the form shown.

$$\ln k = \ln A - \frac{E_a}{RT}$$

On the grid in FIGURE 3 plot a graph of ln *k* against $\frac{1}{T}$ [2 marks]

FIGURE 3



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0 3 . 4

Use your graph from Question 03.3, on page 33, to calculate a value for E_a, in kJ mol^{-1}, for the thermal decomposition of but-3-en-1-ol.

The gas constant, R = 8.31 J K^{-1} mol^{-1}

[3 marks]

E_a _____ **kJ mol^{-1}**

[Turn over]

0 3 . 5

2-Methylpent-4-en-2-ol decomposes in a similar way to but-3-en-1-ol, to produce an alkene and a carbonyl compound.

Deduce the structures of the alkene and the carbonyl compound. [2 marks]

alkene **+** **carbonyl compound**

10

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[Turn over]

0 4

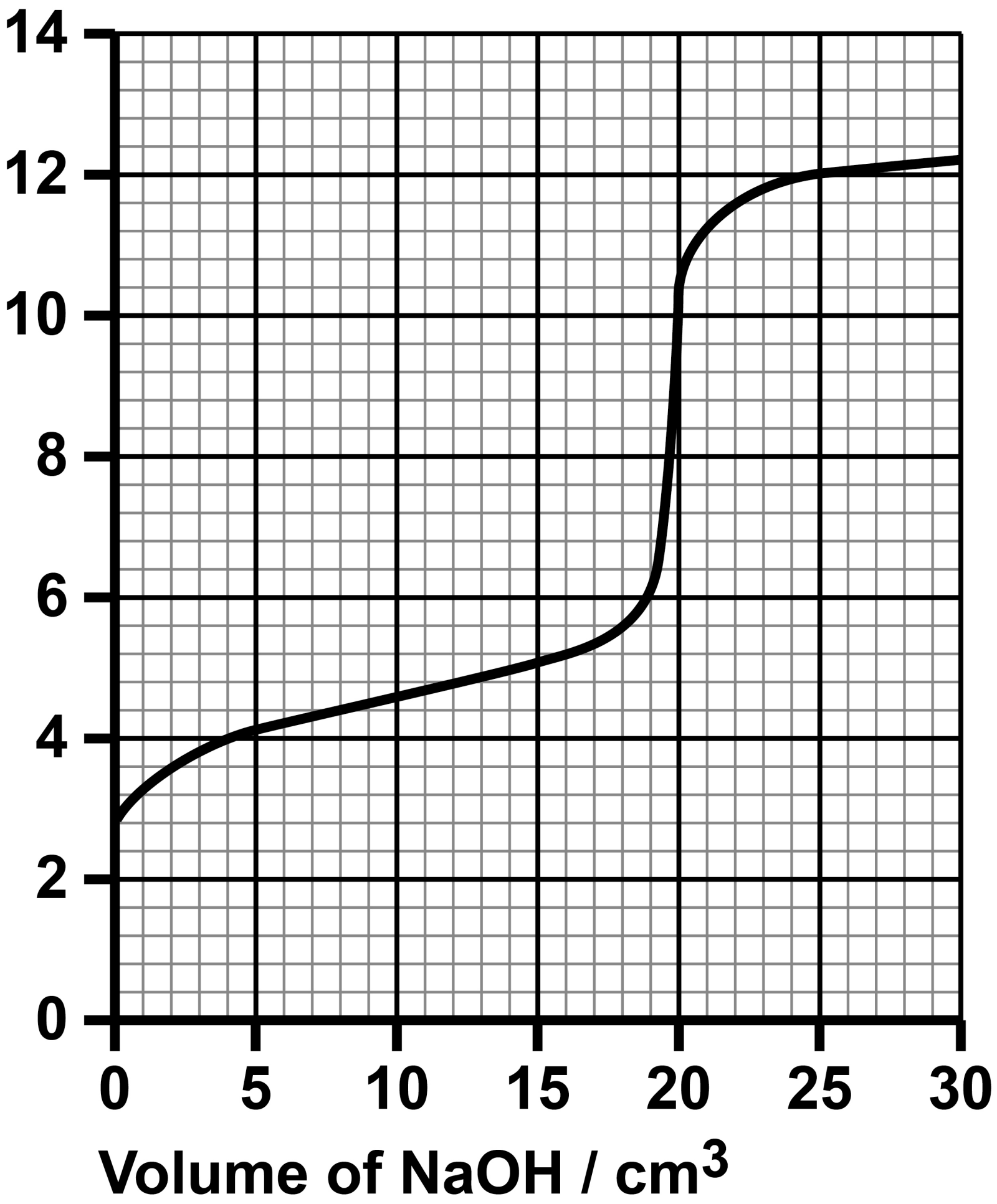
FIGURE 4, on the opposite page, shows how the pH changes as 0.100 mol dm^{-3} sodium hydroxide solution is added to 25.0 cm^3 of 0.0800 mol dm^{-3} aqueous propanoic acid at 298 K

0 4 . 1

Propanoic acid is a weak acid.

State the meaning of weak in this context. [1 mark]

FIGURE 4



[Turn over]

0 4 . 2

Suggest why a student doing an experiment to produce the curve in FIGURE 4, on page 39, would add the sodium hydroxide solution dropwise around the equivalence point. [1 mark]

0 4 . 3

Give an expression for K_a for propanoic acid (CH_3CH_2COOH).

Use this expression to show that $pH = pK_a$ when half of the propanoic acid has reacted with sodium hydroxide.
[3 marks]

K_a

[Turn over]

0 4 . 4

Use the pH from FIGURE 4, on page 39, when half of the propanoic acid has reacted, to calculate K_a at 298 K

[2 marks]

K_a _____ **mol dm^{-3}**

0 4 . 5

When sodium hydroxide solution is added to aqueous propanoic acid, the solution formed acts as a buffer when between 5 cm^3 and 15 cm^3 have been added.

Explain why the pH stays approximately constant during this part of the experiment. [2 marks]

0 4 . 6

Methyl orange and universal indicator are NOT suitable indicators for the titration of solutions of propanoic acid with sodium hydroxide.

State the reason why each indicator is NOT suitable. [2 marks]

Methyl orange _____

_____

_____

Universal indicator _____

_____

11

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[Turn over]

0 5 . 1

Some complexes containing transition metal ions are coloured.

- **Explain why some complexes containing transition metal ions are coloured.**
- **List the factors that affect the colour.**
- **Describe how colorimetry can be used to determine the concentration of a coloured complex.**

[6 marks]

[Turn over]


4 8

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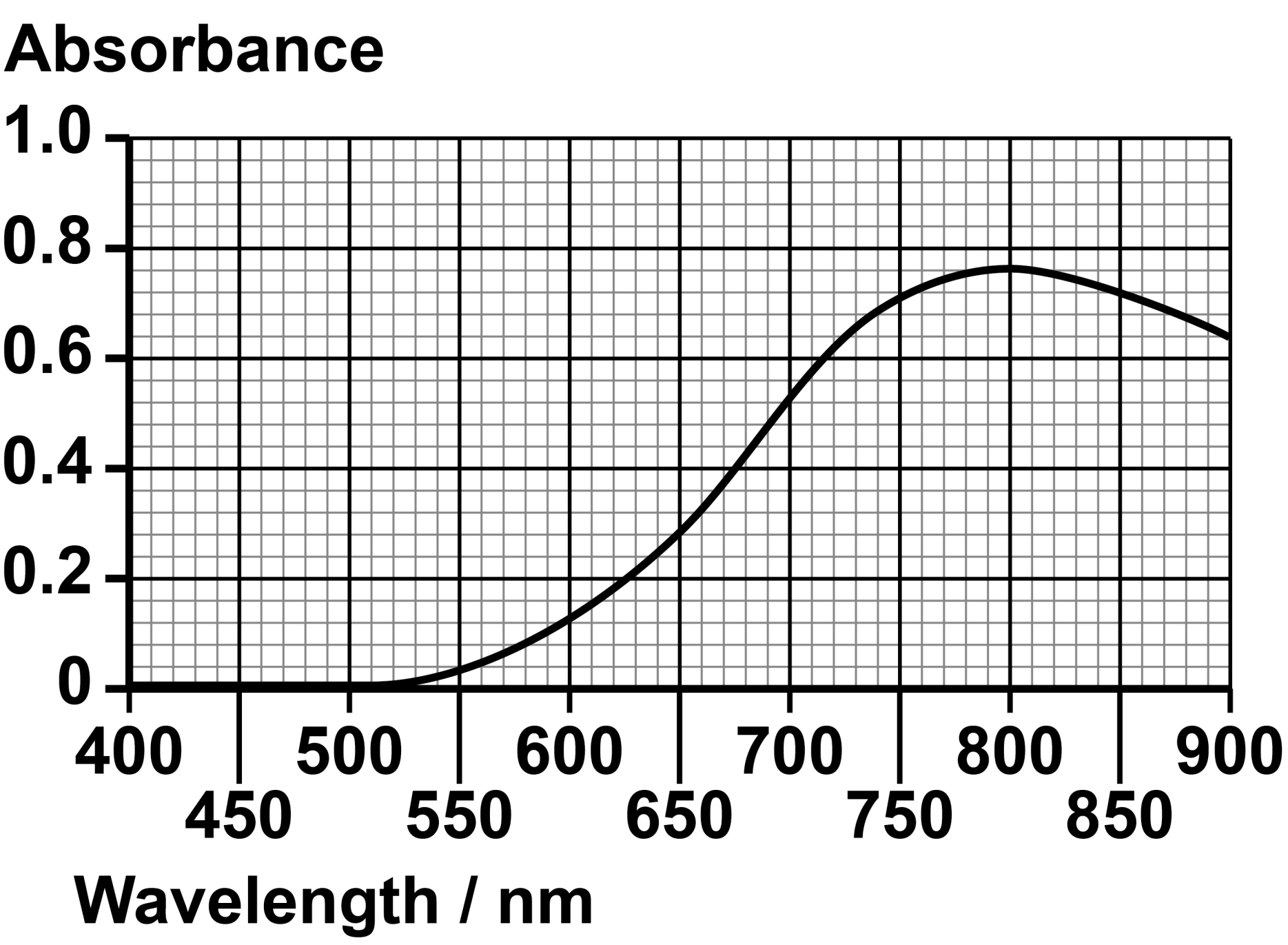
[Turn over]

0 5 . 2

FIGURE 5 shows the visible spectrum of $[Cu(H_2O)_6]^{2+}$

FIGURE 5



Use the wavelength at the peak of the curve in FIGURE 5 to calculate the change in energy, in J, of an electron when it absorbs radiation with this wavelength.

the Planck constant, $h = 6.63 \times 10^{-34}$ J s

speed of light, $c = 3.00 \times 10^{8}$ m s^{-1}

[3 marks]

Change in energy _____ J

[Turn over]

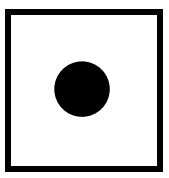
9

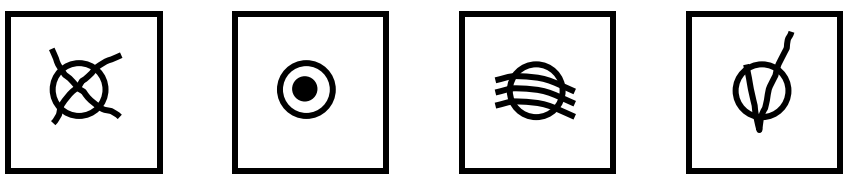
SECTION B

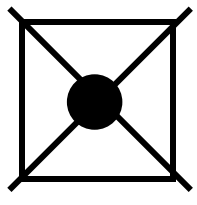
Answer ALL questions in this section.

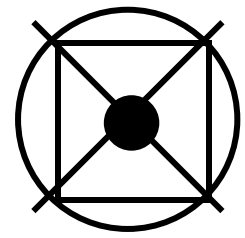
Only ONE answer per question is allowed.

For each question completely fill in the circle alongside the appropriate answer.

CORRECT METHOD 

WRONG METHODS 

If you want to change your answer you must cross out your original answer as shown. 



If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do NOT use additional sheets for this working.

[Turn over]

0 6

Which row contains two species with different numbers of electrons? [1 mark]

○ **A** NH_3 **and HF**

○ **B** CO_3^{2-} **and** NO_3^-

○ **C** H_3O^+ **and** HF_2^+

○ **D** CH_4 **and** NH_2^-

0 7

Which element has the highest third ionisation energy? [1 mark]

○ **A Li**

○ **B Be**

○ **C K**

○ **D Ca**

0 8

Compound P is converted into compound R by a two-stage synthesis via compound Q.

The yields for the individual steps are:

P ⟶ Q 50%
Q ⟶ R 30%

What is the overall yield of R in this synthesis? [1 mark]

○ **A 15%**

○ **B 30%**

○ **C 40%**

○ **D 80%**

0 9

What is the formula of ammonium ethanedioate? [1 mark]

○ **A** $NH_4(C_2O_4)_2$

○ **B** $(NH_4)_2C_2O_4$

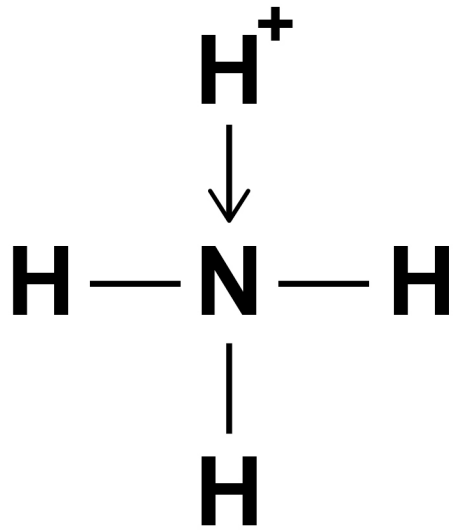
○ **C** $NH_4C_2O_4$

○ **D** $(NH_4)_2(C_2O_4)_3$

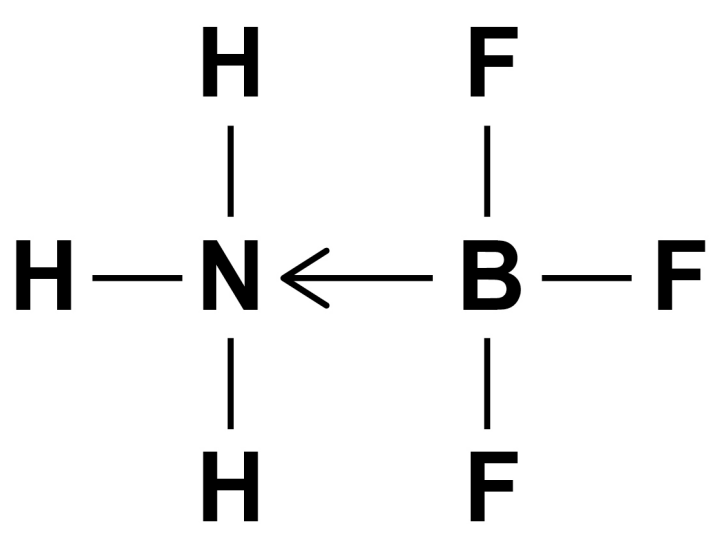
1 0

Which diagram, below and on the opposite page, shows the formation of a dative covalent bond? [1 mark]

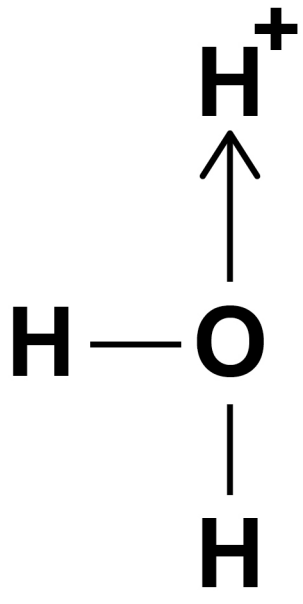
○ **A**



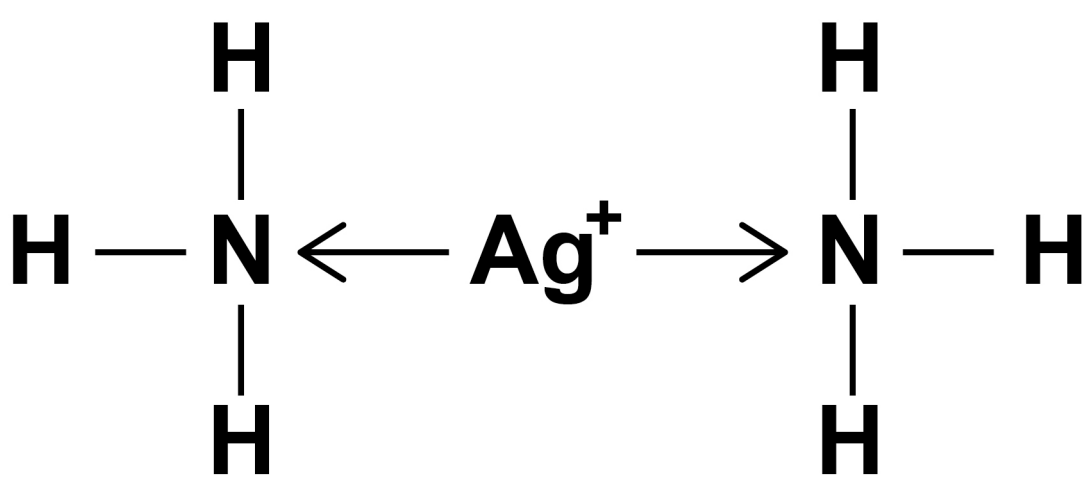
○ **B**



○ **C**



○ **D**



[Turn over]

1	1

Which substance does NOT have any bond angles of 120°? [1 mark]

○ **A benzene**

○ **B boron trifluoride**

○ **C cyclohexane**

○ **D graphite**

1 2

Which molecule does NOT have a permanent dipole? [1 mark]

○ **A** NH_3

○ **B** PCl_3

○ **C** SCl_2

○ **D** $SiCl_4$

1	3

Which compound forms the greatest number of hydrogen bonds per molecule in the liquid state? [1 mark]

○ **A** CH_3CH_2COOH

○ **B** $CH_3CH_2OCH_3$

○ **C** CH_3CH_2CHO

○ **D** $CH_3CH_2CH_2OH$

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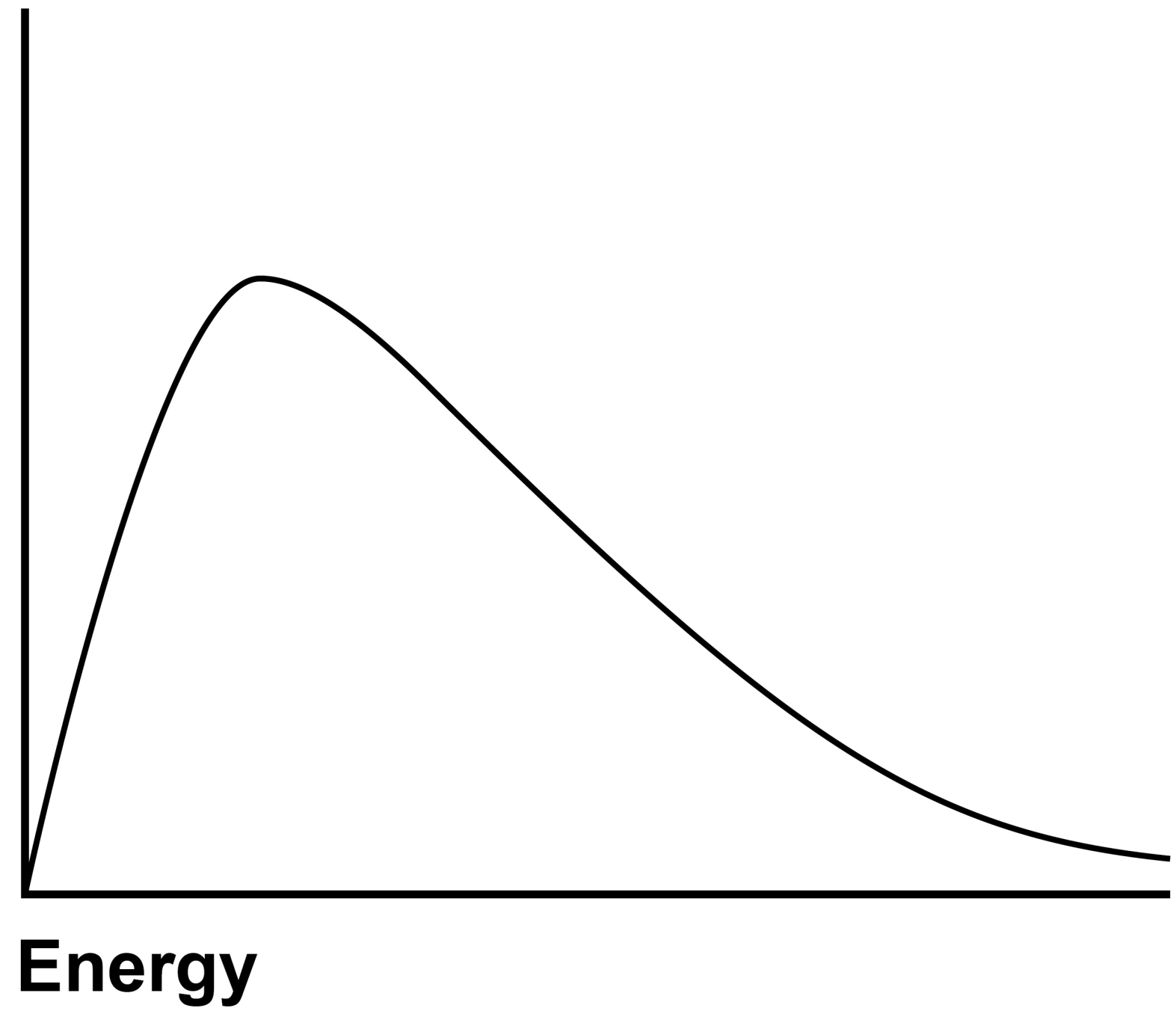
[Turn over]

1	4

The Maxwell–Boltzmann distribution curve is shown for a gaseous reaction mixture.



What is represented by the total area under the curve? [1 mark]

○ **A** The total energy of the molecules in the reaction mixture

○ **B** The total energy of reacting molecules in the reaction mixture

○ **C** The total number of molecules in the reaction mixture

○ **D** The total number of reacting molecules in the reaction mixture

[Turn over]

1 5

A student investigated the reaction between magnesium and hydrochloric acid.

$$Mg(s) + 2\,HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$$

The results are plotted on the graph on the opposite page.

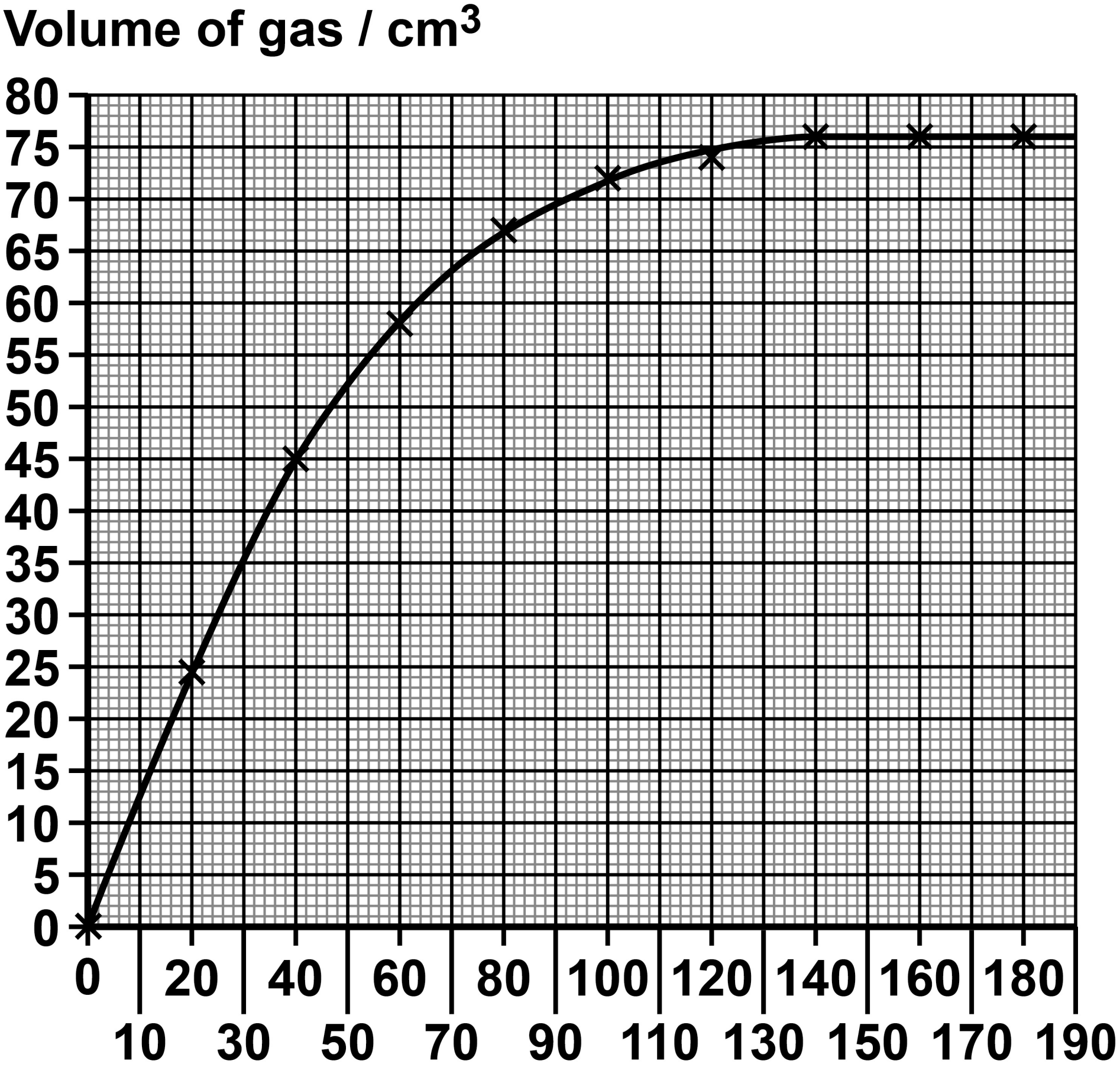
Which value is closest to the rate of reaction, in $cm^3\ s^{-1}$, at 70 s? [1 mark]

○ **A 0.4**

○ **B 0.9**

○ **C 1.1**

○ **D 2.5**


Volume of gas / cm3
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
120
140
160
180
10
30
50
70
90
110
130
150
170
190
Time / s

[Turn over]

1 6

Which statement, below and on the opposite page, explains why the rate of a reaction increases when a catalyst is added at a constant temperature?
[1 mark]

○ **A** **The collision frequency increases because there is a decrease in activation energy.**

○ **B** **The collision frequency increases because there is an increase in the average energy of the particles.**

○ **C** **The proportion of successful collisions increases because there is a decrease in activation energy.**

○ **D** **The proportion of successful collisions increases because there is an increase in the average energy of the particles.**

[Turn over]

1 7

A cell with EMF = +2.15 V is made from two electrodes.

The half-equations for the two electrodes are shown.

positive electrode:

$$PbO_2(s) + 3\,H^+(aq) + HSO_4^-(aq) + 2\,e^- \longrightarrow PbSO_4(s) + 2\,H_2O(l)$$

negative electrode:

$$PbSO_4(s) + H^+(aq) + 2\,e^- \longrightarrow Pb(s) + HSO_4^-(aq)$$

$E^\ominus = -0.46$ V

7 1

What is the standard electrode potential of the PbO_2 / $PbSO_4$ electrode? [1 mark]

○ **A** **–2.61 V**

○ **B** **–1.69 V**

○ **C** **+1.69 V**

○ **D** **+2.61 V**

[Turn over]

1	8

Values of the ionic product of water (K_w) at different temperatures are given.

$K_w = 6.40 \times 10^{-15}$ mol^2 dm^{-6} at 18 °C

$K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6} at 25 °C

Which statement is correct? [1 mark]

○ **A The concentration of hydroxide ions in water at 18 °C is 8.00×10^{-8} mol dm^{-3}**

○ **B The dissociation of water into ions is an exothermic process.**

○ **C The pH of water is the same at 25 °C and at 18 °C**

○ **D Water becomes less acidic as the temperature is raised.**

1 9

Consider the Period 3 elements from sodium to chlorine.

Which statement is correct? [1 mark]

○ **A** **Sodium has the smallest atomic radius.**

○ **B** **Aluminium has the highest melting point.**

○ **C** **Sulfur is the most electronegative.**

○ **D** **Chlorine has the highest first ionisation energy.**

[Turn over]

2	0

Which statement correctly describes a trend down Group 7 from Cl to I?

X represents Cl, Br or I [1 mark]

○ **A** **The boiling point of HX increases.**

○ **B** **The bond dissociation energy of H–X increases.**

○ **C** **The standard electrode potential value for**

$$X_2(aq) + 2e^- \longrightarrow 2X^-(aq)$$

becomes more positive.

○ **D** **The solubility of AgX in ammonia increases.**

2 1

Which statement about chloride ions is correct? [1 mark]

○ **A** **They are oxidised by concentrated sulfuric acid.**

○ **B** **They form a cream precipitate with silver nitrate solution.**

○ **C** **They form a cobalt(II) complex with a tetrahedral shape.**

○ **D** **They have the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^4$**

[Turn over]

2	2

Aqueous aluminium sulfate is added to aqueous sodium carbonate.

What are the formulas of the precipitate and the gas formed? [1 mark]

- ○ **A** $Al_2(CO_3)_3$ and SO_2
- ○ **B** $Al_2(CO_3)_3$ and CO_2
- ○ **C** $Al(H_2O)_3(OH)_3$ and SO_2
- ○ **D** $Al(H_2O)_3(OH)_3$ and CO_2

2	3

What is the correct structural formula for 4-chloro-2-methylpent-2-enoic acid?
[1 mark]

○ **A** $CH_3CCl=CHCH(CH_3)COOH$

○ **B** $(CH_3)_2C=CHCHClCOOH$

○ **C** $CH_3CHClCH=C(CH_3)COOH$

○ **D** $(CH_3)_2CHCH=CClCOOH$

[Turn over]

2 4

In which conversion does a nucleophile attack the organic reactant? [1 mark]

○ **A** $CH_3CH_2CH_3 \longrightarrow CH_3CHClCH_3$

○ **B** $CH_3CH{=}CH_2 \longrightarrow CH_3CHBrCH_3$

○ **C** $CH_3CH_2CH_2OH \longrightarrow CH_3CH{=}CH_2$

○ **D** $CH_3CH_2CHO \longrightarrow CH_3CH_2CH(OH)CN$

2 5

Compound Y has the structural formula $CH_3COOCH_2CH(CH_3)_2$

Which compound is a position isomer of Y? [1 mark]

○ **A 5-hydroxyhexan-3-one**

○ **B butyl ethanoate**

○ **C hexanoic acid**

○ **D propyl propanoate**

2 6

Which compound shows *E*–*Z* isomerism? [1 mark]

○ **A 2,3-dimethylbut-1-ene**

○ **B 2,3-dimethylbut-2-ene**

○ **C 2-methylpent-2-ene**

○ **D 3-methylpent-2-ene**

2 7

What is the product when 3-methylbutan-2-one reacts with acidified KCN? [1 mark]

○ **A** 2-hydroxy-2,3-dimethylbutanenitrile

○ **B** 3-hydroxy-2,3-dimethylbutanenitrile

○ **C** 2-hydroxy-3-methylpentanenitrile

○ **D** 3-hydroxy-2-methylpentanenitrile

2	8

Which statement concerning nylon-6,6 is correct? [1 mark]

○ **A** **Butanedioic acid is one of the reactants used to make nylon-6,6**

○ **B** **Nylon-6,6 is an addition polymer.**

○ **C** **Nylon-6,6 can be hydrolysed by aqueous sodium hydroxide.**

○ **D** **All molecules of nylon-6,6 have the same relative molecular mass.**

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[Turn over]

2	9

Which statement about the industrial production of ethanol from ethene at 300 °C is correct?

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

$$\Delta H = -46 \text{ kJ mol}^{-1}$$

[1 mark]

○ **A** The use of an acid catalyst increases the yield of ethanol.

○ **B** The reaction is slower than fermentation.

○ **C** An increase in temperature, at constant pressure, increases the value of K_p.

○ **D** An increase in pressure, at constant temperature, increases the equilibrium yield of ethanol.

3	0

Which compound is formed by the acid hydrolysis of phenyl benzenecarboxylate? [1 mark]

○ **A** $C_6H_5CH_2OH$

○ **B** C_6H_5CHO

○ **C** $C_6H_5COCH_3$

○ **D** C_6H_5COOH

[Turn over]

3 1

Which type of polymer is most difficult to hydrolyse? [1 mark]

○ **A polyalkene**

○ **B polyamide**

○ **C polyester**

○ **D protein**

3 2

In which polymer does hydrogen bonding occur between the polymer chains? [1 mark]

○ **A a polyalkene**

○ **B a polyamide**

○ **C a polychloroalkene**

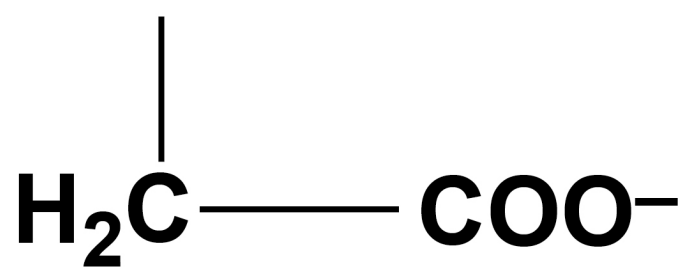
○ **D a polyester**

3 3

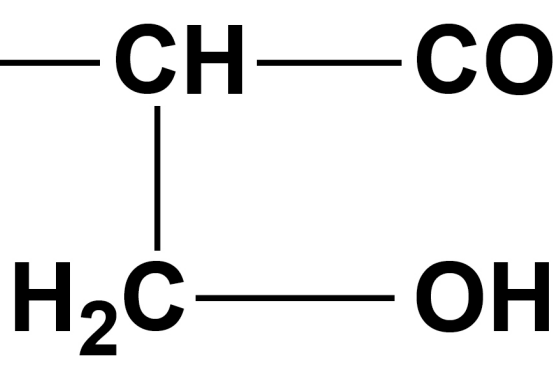
Which structure shows a zwitterion of an amino acid? [1 mark]

○ **A**

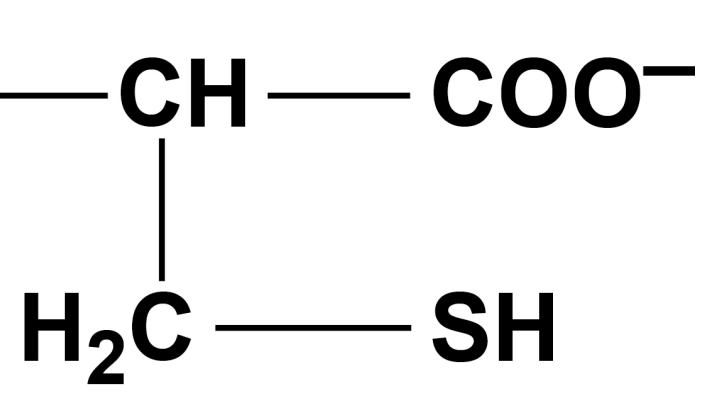
○ **B**



○ **C**



○ **D**



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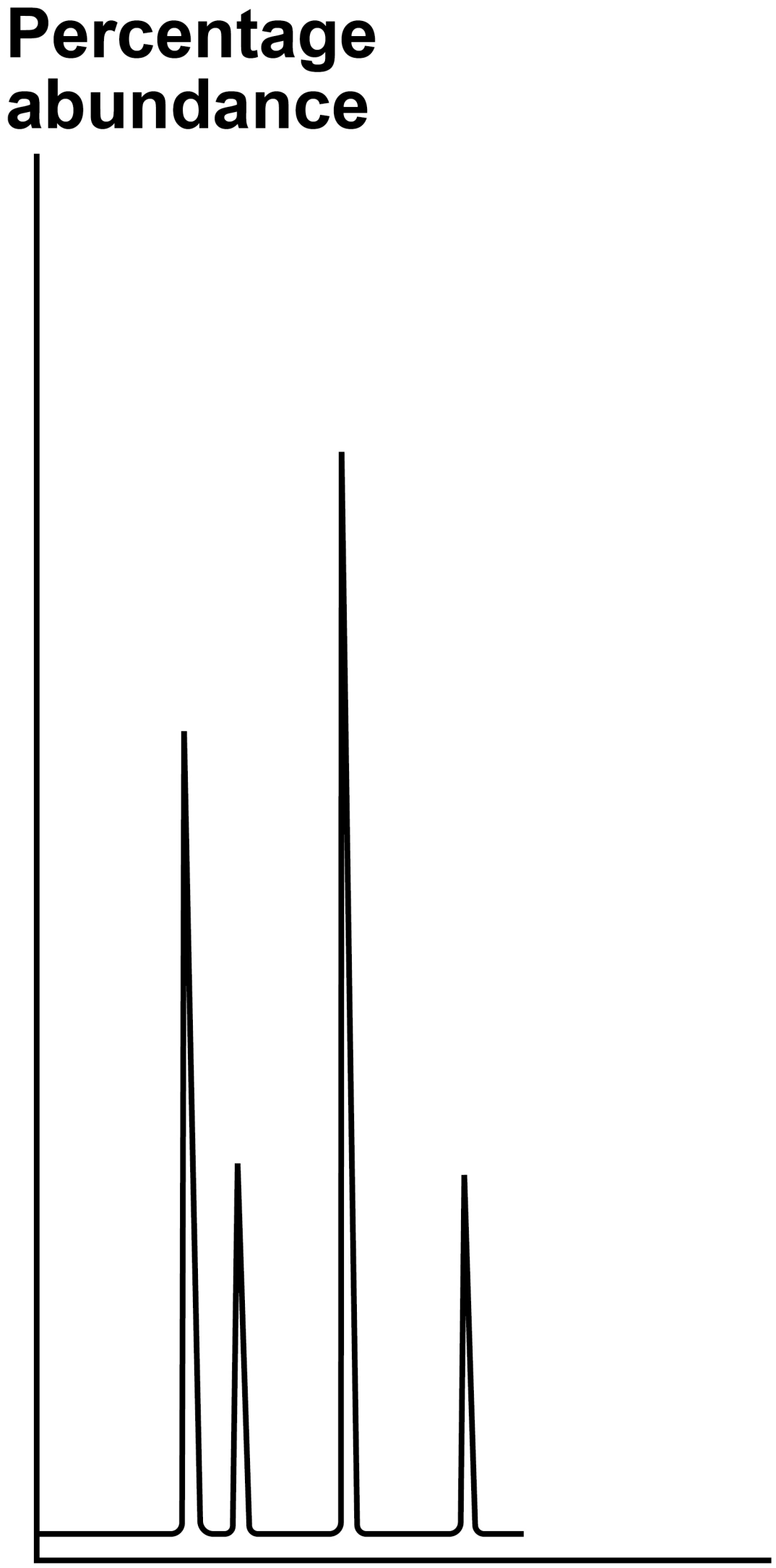
[Turn over]

3	4

The diagram, on the opposite page, shows a gas chromatogram for a sample containing four isomers with the molecular formula $C_6H_{12}O_2$

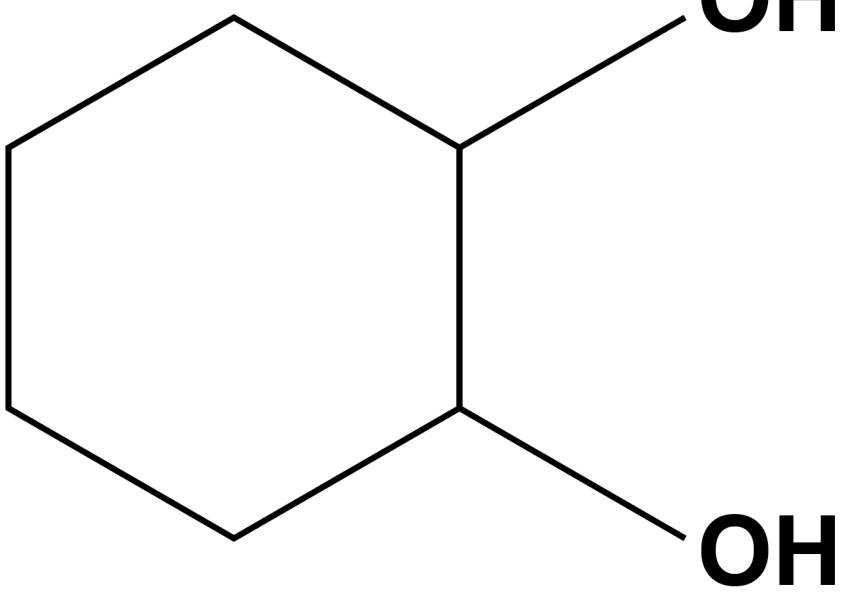
The carrier gas is nitrogen and the stationary phase is polar.



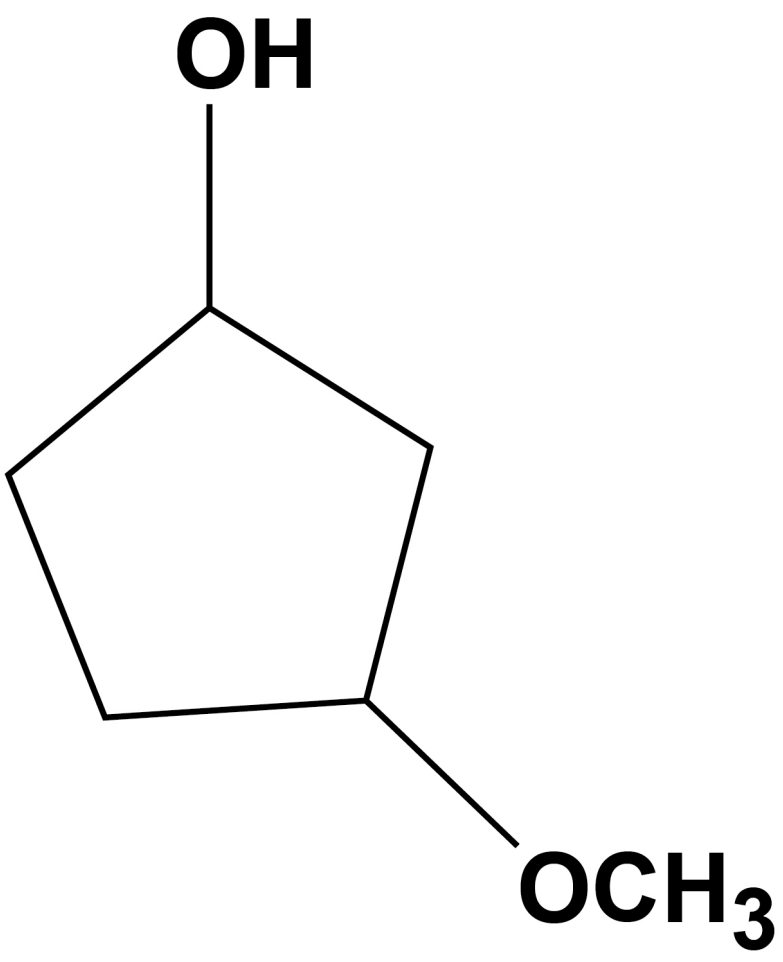
[Turn over]

Which of the four isomers, below and on the opposite page, in this sample is the most abundant? [1 mark]

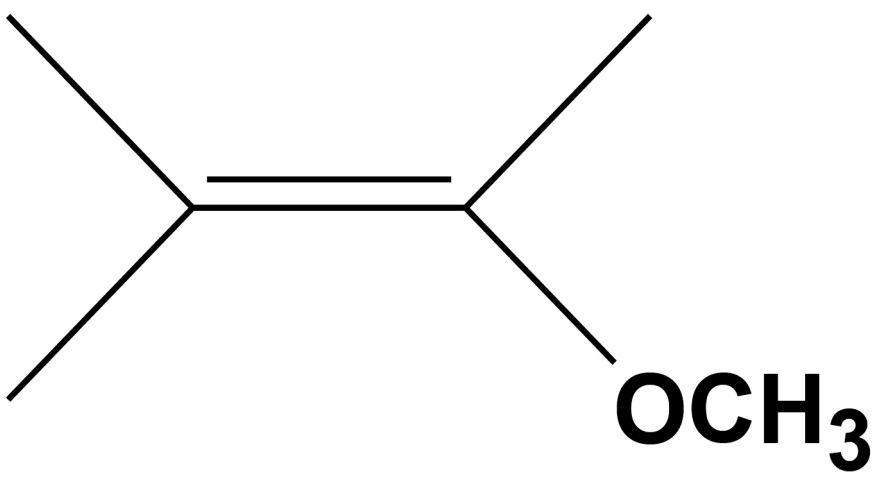
○ **A**



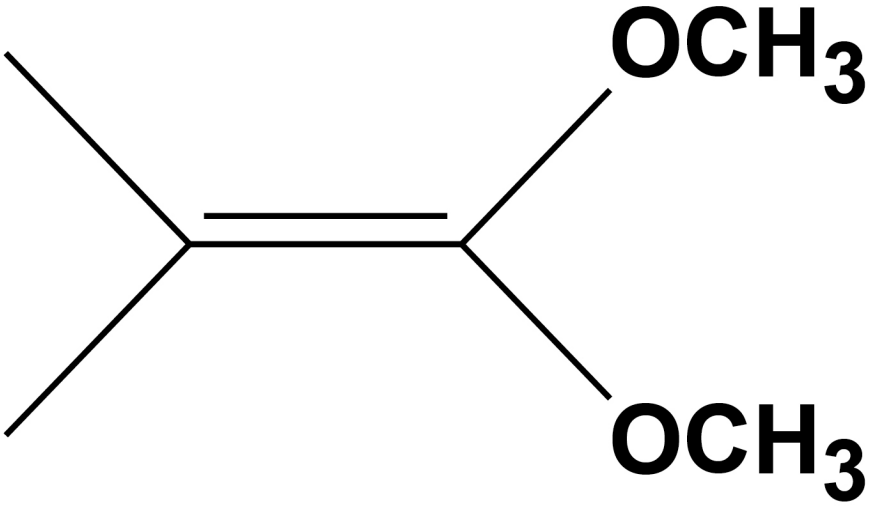
○ **B**



○ C



○ D

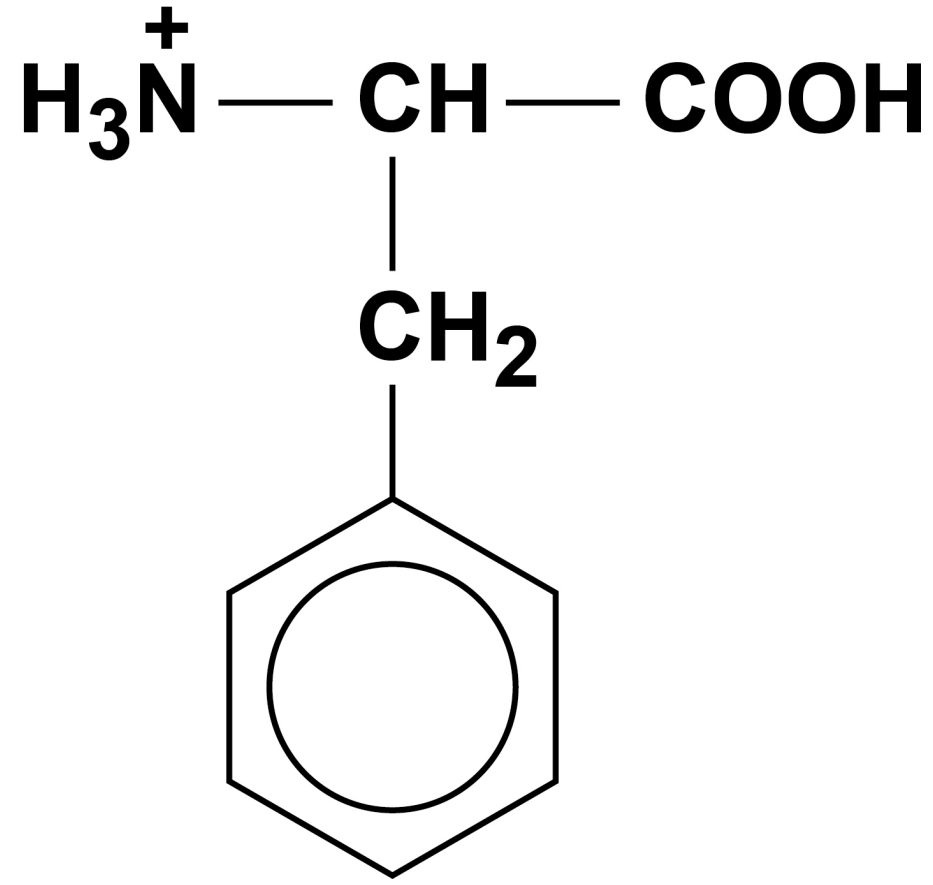


[Turn over]

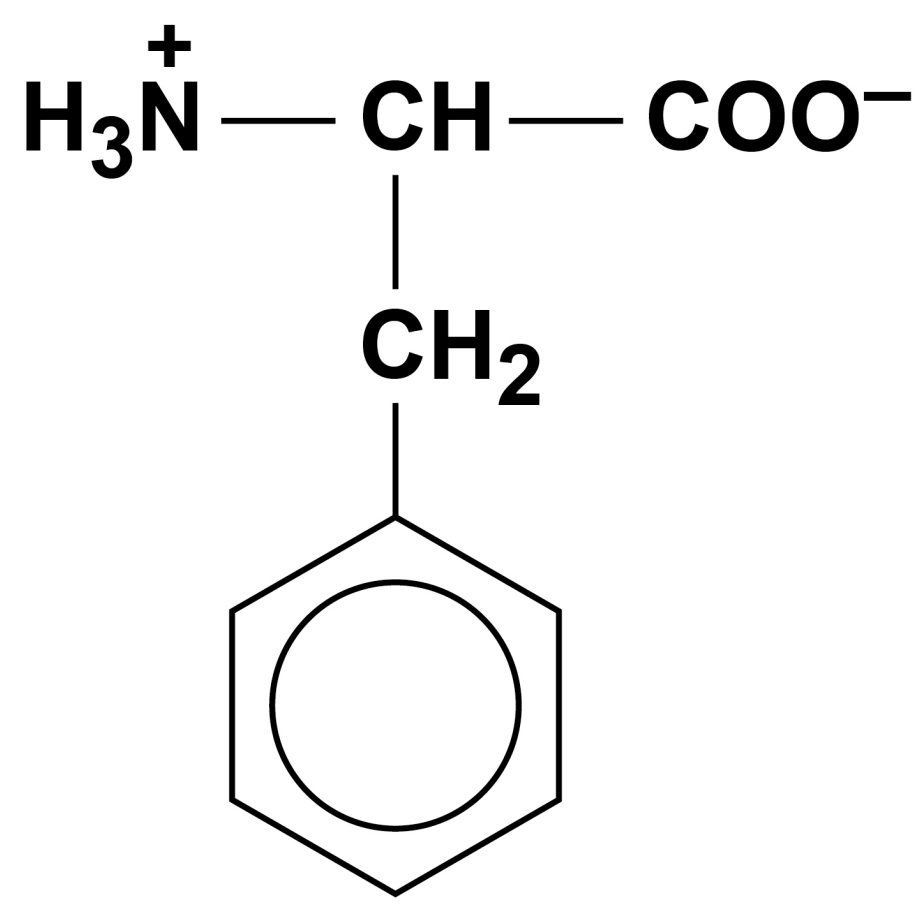
3	5

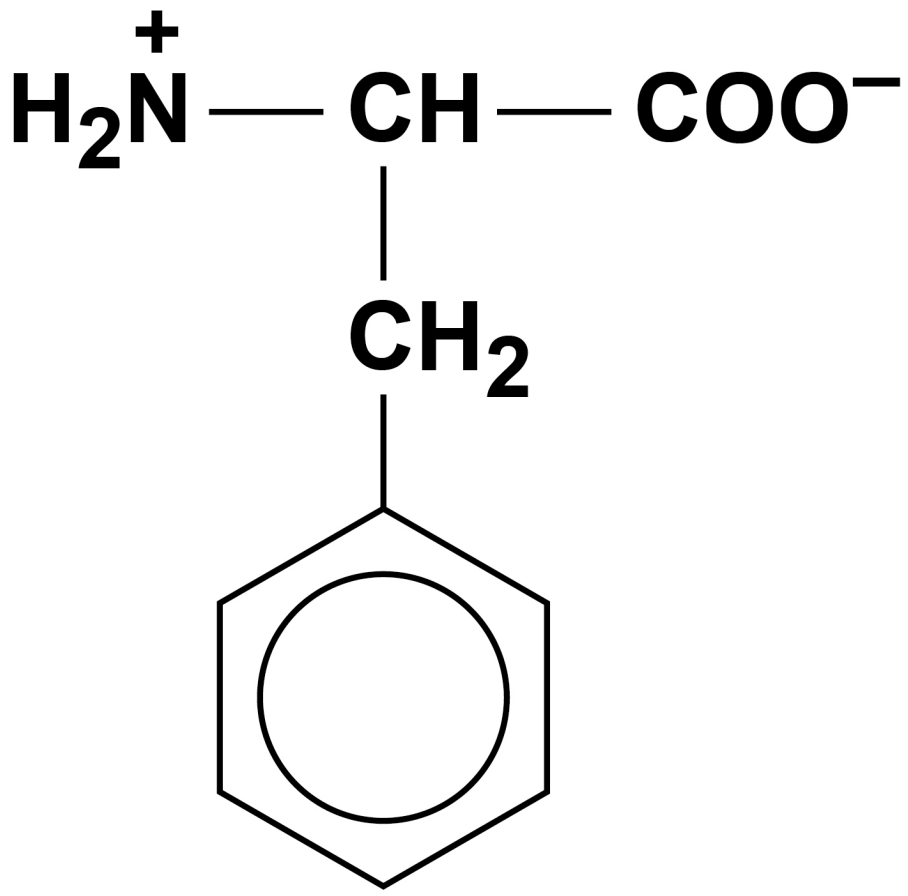
Which structure, below and on the opposite page, is formed by phenylalanine in solution at pH = 3? [1 mark]

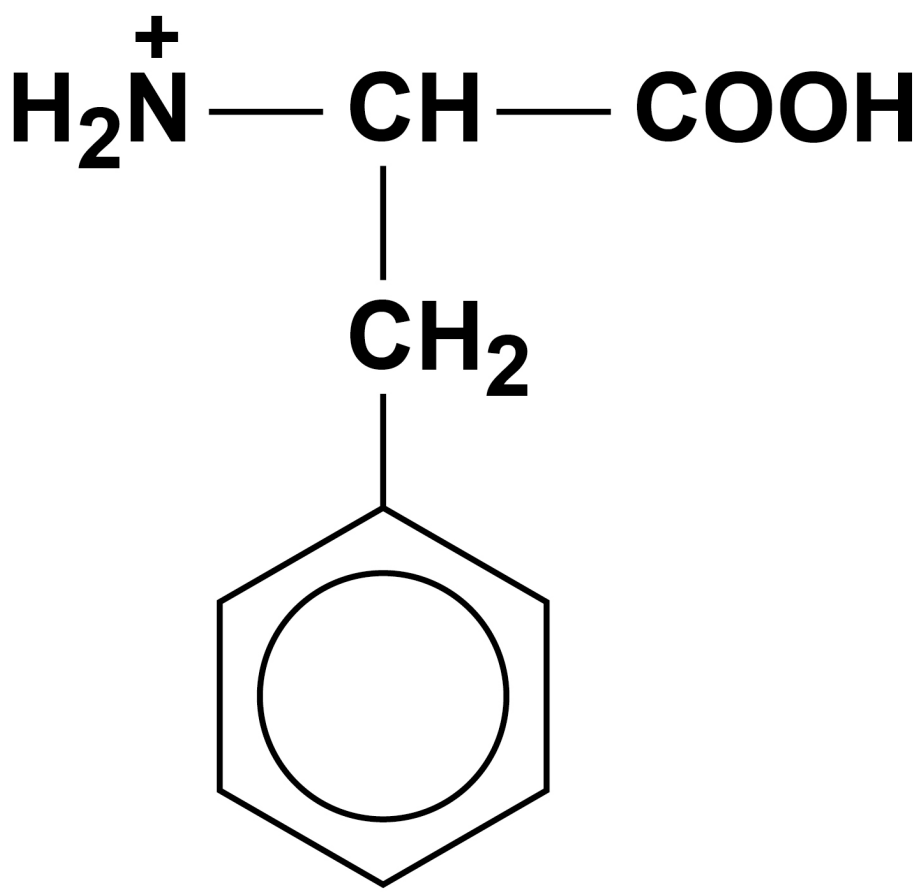
○ **A**



○ **B**



C 

D 

END OF QUESTIONS

30

Additional page, if required.

Write the question numbers in the left-hand margin.

Additional page, if required.

Write the question numbers in the left-hand margin.

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For Examiner's Use	
Question	Mark
1	
2	
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Section B	
TOTAL	