

**Chemistry**  
**Higher level**  
**Paper 2**

Wednesday 16 May 2018 (afternoon)

Candidate session number

2 hour 15 minutes

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**Instructions to candidates**

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[95 marks]**.



Answer **all** questions. Answers must be written within the answer boxes provided.

1. A student determined the percentage of the active ingredient magnesium hydroxide,  $\text{Mg}(\text{OH})_2$ , in a 1.24 g antacid tablet.

The antacid tablet was added to  $50.00 \text{ cm}^3$  of  $0.100 \text{ mol dm}^{-3}$  sulfuric acid, which was in excess.

- (a) Calculate the amount, in mol, of  $\text{H}_2\text{SO}_4$ . [1]

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- (b) Formulate the equation for the reaction of  $\text{H}_2\text{SO}_4$  with  $\text{Mg}(\text{OH})_2$ . [1]

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- (c) The excess sulfuric acid required  $20.80 \text{ cm}^3$  of  $0.1133 \text{ mol dm}^{-3}$  NaOH for neutralization.

Calculate the amount of excess acid present. [1]

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- (d) Calculate the amount of  $\text{H}_2\text{SO}_4$  that reacted with  $\text{Mg}(\text{OH})_2$ . [1]

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**(Question 1 continued)**

(e) Determine the mass of  $\text{Mg}(\text{OH})_2$  in the antacid tablet. [2]

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(f) Calculate the percentage by mass of magnesium hydroxide in the 1.24 g antacid tablet to three significant figures. [1]

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(g) Outline why repeating quantitative measurements is important. [1]

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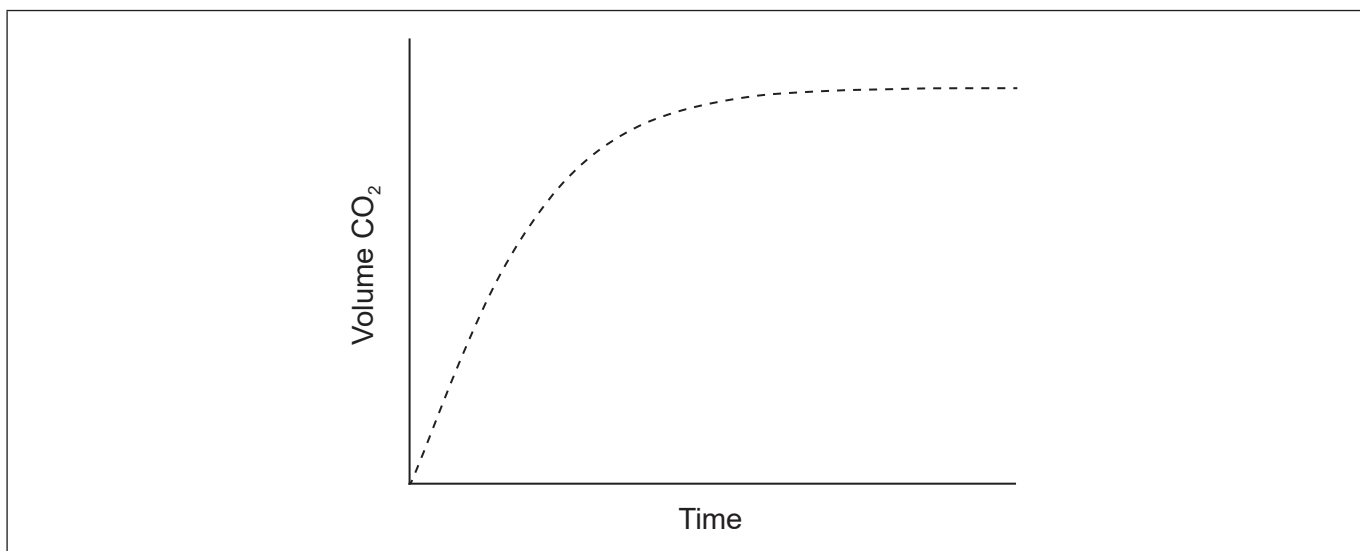


2. Graphing is an important tool in the study of rates of chemical reactions.

- (a) Sketch a Maxwell–Boltzmann distribution curve for a chemical reaction showing the activation energies with and without a catalyst. [3]



- (b) Excess hydrochloric acid is added to lumps of calcium carbonate. The graph shows the volume of carbon dioxide gas produced over time.



- (i) Sketch a curve on the graph to show the volume of gas produced over time if the same mass of crushed calcium carbonate is used instead of lumps. All other conditions remain constant. [1]

(This question continues on the following page)



**(Question 2 continued)**

- (ii) State and explain the effect on the rate of reaction if ethanoic acid of the same concentration is used in place of hydrochloric acid. [2]

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- (c) Outline why pH is more widely used than  $[H^+]$  for measuring relative acidity. [1]

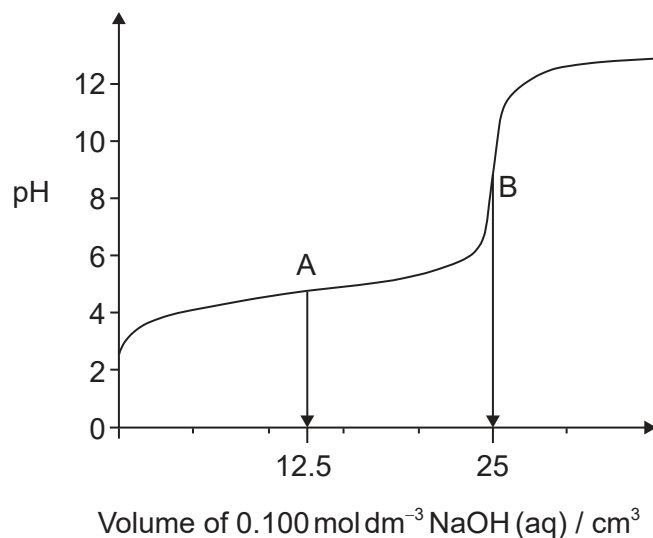
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(Question 2 continued)

- (d) (i) The graph represents the titration of 25.00 cm<sup>3</sup> of 0.100 mol dm<sup>-3</sup> aqueous ethanoic acid with 0.100 mol dm<sup>-3</sup> aqueous sodium hydroxide.



Deduce the **major** species, other than water and sodium ions, present at points A and B during the titration.

[2]

A:

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B:

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- (ii) Calculate the pH of 0.100 mol dm<sup>-3</sup> aqueous ethanoic acid.

$$K_a = 1.74 \times 10^{-5}$$

[2]

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24EP06

**(Question 2 continued)**

(iii) Outline, using an equation, why sodium ethanoate is basic. [1]

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(iv) Predict whether the pH of an aqueous solution of ammonium chloride will be greater than, equal to or less than 7 at 298 K. [1]

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(e) (i) Formulate the equation for the reaction of nitrogen dioxide,  $\text{NO}_2$ , with water to form two acids. [1]

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(ii) Formulate the equation for the reaction of one of the acids produced in (e)(i) with calcium carbonate. [1]

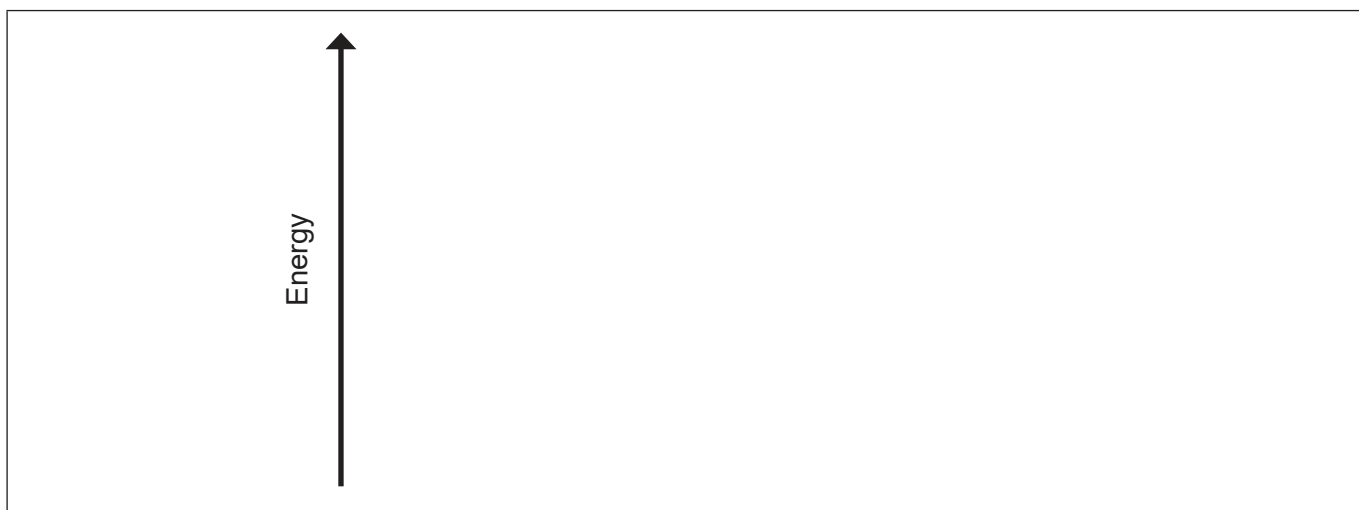
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3. The emission spectrum of an element can be used to identify it.

- (a) (i) Draw the first four energy levels of a hydrogen atom on the axis, labelling  $n = 1, 2, 3$  and  $4$ .

[1]



- (ii) Draw the lines, on your diagram, that represent the electron transitions to  $n = 2$  in the emission spectrum.

[1]

- (iii) Hydrogen spectral data give the frequency of  $3.28 \times 10^{15} \text{ s}^{-1}$  for its convergence limit.

Calculate the ionization energy, in J, for a single atom of hydrogen using sections 1 and 2 of the data booklet.

[1]

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- (iv) Calculate the wavelength, in m, for the electron transition corresponding to the frequency in (a)(iii) using section 1 of the data booklet.

[1]

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**(Question 3 continued)**

(b) Elements show trends in their physical properties across the periodic table.

(i) Outline why atomic radius decreases across period 3, sodium to chlorine. [1]

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(ii) Outline why the ionic radius of  $K^+$  is smaller than that of  $Cl^-$ . [2]

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(c) (i) Copper is widely used as an electrical conductor.

Draw arrows in the boxes to represent the electronic configuration of copper in the 4s and 3d orbitals. [1]

	4s		3d			

(ii) Impure copper can be purified by electrolysis. In the electrolytic cell, impure copper is the anode (positive electrode), pure copper is the cathode (negative electrode) and the electrolyte is copper(II) sulfate solution.

Formulate the half-equation at each electrode. [2]

Anode (positive electrode):  
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Cathode (negative electrode):  
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24EP09

Turn over

**(Question 3 continued)**

(iii) Outline where and in which direction the electrons flow during electrolysis. [1]

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(iv) Deduce any change in the colour of the electrolyte during electrolysis. [1]

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(v) Deduce the gas formed at the anode (positive electrode) when graphite is used in place of copper. [1]

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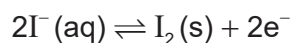
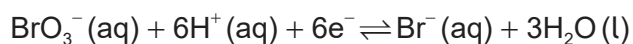
(d) Explain why transition metals exhibit variable oxidation states in contrast to alkali metals. [2]

Transition metals:  
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Alkali metals:  
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4. (a) In acidic solution, bromate ions,  $\text{BrO}_3^- (\text{aq})$ , oxidize iodide ions,  $\text{I}^- (\text{aq})$ .



Formulate the equation for the redox reaction.

[1]

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- (b) The change in the free energy for the reaction under standard conditions,  $\Delta G^\ominus$ , is  $-514 \text{ kJ}$  at  $298 \text{ K}$ .

Determine the value of  $E^\ominus$ , in  $\text{V}$ , for the reaction using sections 1 and 2 of the data booklet.

[2]

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- (c) Calculate the standard electrode potential, in  $\text{V}$ , for the  $\text{BrO}_3^-/\text{Br}^-$  reduction half-equation using section 24 of the data booklet.

[1]

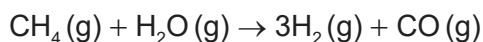
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5. Enthalpy changes depend on the number and type of bonds broken and formed.

(a) Hydrogen gas can be formed industrially by the reaction of natural gas with steam.



Determine the enthalpy change,  $\Delta H$ , for the reaction, in kJ, using section 11 of the data booklet.

Bond enthalpy for  $\text{C}\equiv\text{O}$ :  $1077 \text{ kJ mol}^{-1}$

[3]

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(b) The table lists the standard enthalpies of formation,  $\Delta H_f^\ominus$ , for some of the species in the reaction above.

	<b>CH<sub>4</sub>(g)</b>	<b>H<sub>2</sub>O(g)</b>	<b>CO(g)</b>	<b>H<sub>2</sub>(g)</b>
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	-74.0	-242	-111	

(i) Outline why no value is listed for H<sub>2</sub>(g).

[1]

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(ii) Determine the value of  $\Delta H^\ominus$ , in kJ, for the reaction using the values in the table.

[1]

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24EP12

(Question 5 continued)

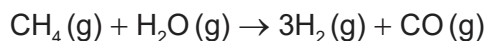
- (iii) Outline why the value of enthalpy of reaction calculated from bond enthalpies is less accurate. [1]

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- (c) The table lists standard entropy,  $S^\ominus$ , values.

	<b>CH<sub>4</sub> (g)</b>	<b>H<sub>2</sub>O (g)</b>	<b>CO (g)</b>	<b>H<sub>2</sub> (g)</b>
$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$	+186	+189	+198	+131

Calculate the standard entropy change for the reaction,  $\Delta S^\ominus$ , in  $\text{J K}^{-1}$ .



[1]

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- (d) Calculate the standard free energy change,  $\Delta G^\ominus$ , in kJ, for the reaction at 298 K using your answer to (b)(ii). [1]

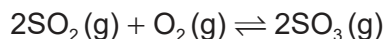
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- (e) Determine the temperature, in K, above which the reaction becomes spontaneous. [1]

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6. A mixture of 1.00 mol SO<sub>2</sub>(g), 2.00 mol O<sub>2</sub>(g) and 1.00 mol SO<sub>3</sub>(g) is placed in a 1.00 dm<sup>3</sup> container and allowed to reach equilibrium.



- (a) Distinguish between the terms reaction quotient,  $Q$ , and equilibrium constant,  $K_c$ . [1]

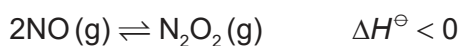
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- (b) The equilibrium constant,  $K_c$ , is 0.282 at temperature T.

Deduce, showing your work, the direction of the initial reaction. [2]

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- (c) (i) Nitrogen oxide is in equilibrium with dinitrogen dioxide.



Deduce, giving a reason, the effect of increasing the temperature on the concentration of N<sub>2</sub>O<sub>2</sub>. [1]

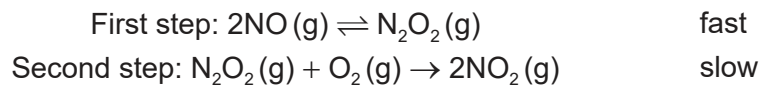
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**(Question 6 continued)**

- (ii) A two-step mechanism is proposed for the formation of  $\text{NO}_2(\text{g})$  from  $\text{NO}(\text{g})$  that involves an exothermic equilibrium process.



Deduce the rate expression for the mechanism. [2]

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- (d) The rate constant for a reaction doubles when the temperature is increased from  $25.0\text{ }^\circ\text{C}$  to  $35\text{ }^\circ\text{C}$ .

Calculate the activation energy,  $E_a$ , in  $\text{kJ mol}^{-1}$  for the reaction using section 1 and 2 of the data booklet. [2]

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7. Some physical properties of molecular substances result from the different types of forces between their molecules.

- (a) (i) Explain why the hydrides of group 16 elements ( $\text{H}_2\text{O}$ ,  $\text{H}_2\text{S}$ ,  $\text{H}_2\text{Se}$  and  $\text{H}_2\text{Te}$ ) are polar molecules. [2]

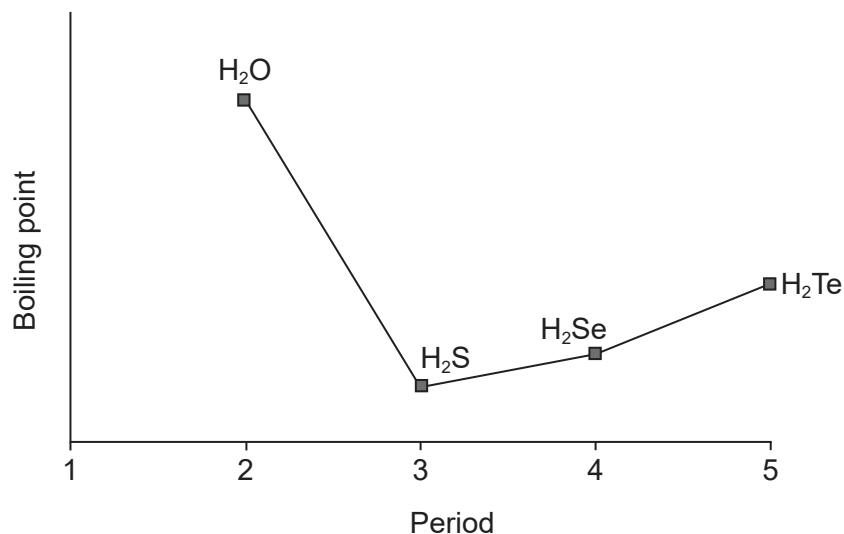
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(Question 7 continued)

(ii) The graph shows the boiling points of the hydrides of group 16 elements.



Explain the increase in the boiling point from H<sub>2</sub>S to H<sub>2</sub>Te.

[2]

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(b) Lewis structures show electron domains and are used to predict molecular geometry.

Deduce the electron domain geometry and the molecular geometry for the NH<sub>2</sub><sup>-</sup> ion.

[2]

Electron domain geometry:

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Molecular geometry:

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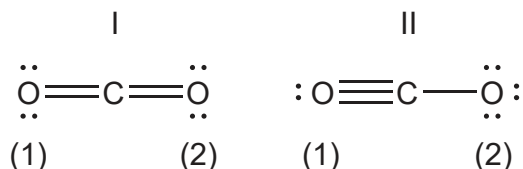
24EP16



**(Question 7 continued)**

(c) Resonance structures exist when a molecule can be represented by more than one Lewis structure.

(i) Carbon dioxide can be represented by at least two resonance structures, I and II.



Calculate the formal charge on each oxygen atom in the two structures. [2]

Structure	I	II
O atom labelled (1)	.....	.....
O atom labelled (2)	.....	.....

(ii) Deduce, giving a reason, the more likely structure. [1]

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(d) Absorption of UV light in the ozone layer causes the dissociation of oxygen and ozone.

Identify, in terms of bonding, the molecule that requires a longer wavelength to dissociate. [2]

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(Question 7 continued)

- (e) Carbon and silicon are elements in group 14.

Explain why CO<sub>2</sub> is a gas but SiO<sub>2</sub> is a solid at room temperature.

[2]

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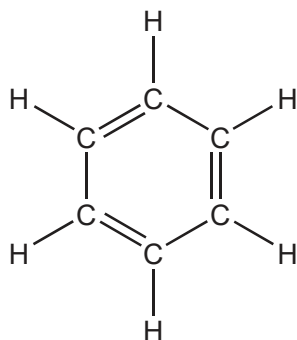
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8. The structure of an organic molecule can help predict the type of reaction it can undergo.

- (a) The Kekulé structure of benzene suggests it should readily undergo addition reactions.



Discuss two pieces of evidence, **one** physical and **one** chemical, which suggest this is not the structure of benzene.

[2]

Physical evidence:

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Chemical evidence:

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**(Question 8 continued)**

- (b) (i) Formulate the ionic equation for the oxidation of propan-1-ol to the corresponding aldehyde by acidified dichromate(VI) ions. Use section 24 of the data booklet. [2]

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- (ii) The aldehyde can be further oxidized to a carboxylic acid.

Outline how the experimental procedures differ for the synthesis of the aldehyde and the carboxylic acid. [2]

Aldehyde:  
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Carboxylic acid:  
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- (c) Improvements in instrumentation have made identification of organic compounds routine.

The empirical formula of an unknown compound containing a phenyl group was found to be  $C_4H_4O$ . The molecular ion peak in its mass spectrum appears at  $m/z = 136$ .

- (i) Deduce the molecular formula of the compound. [1]

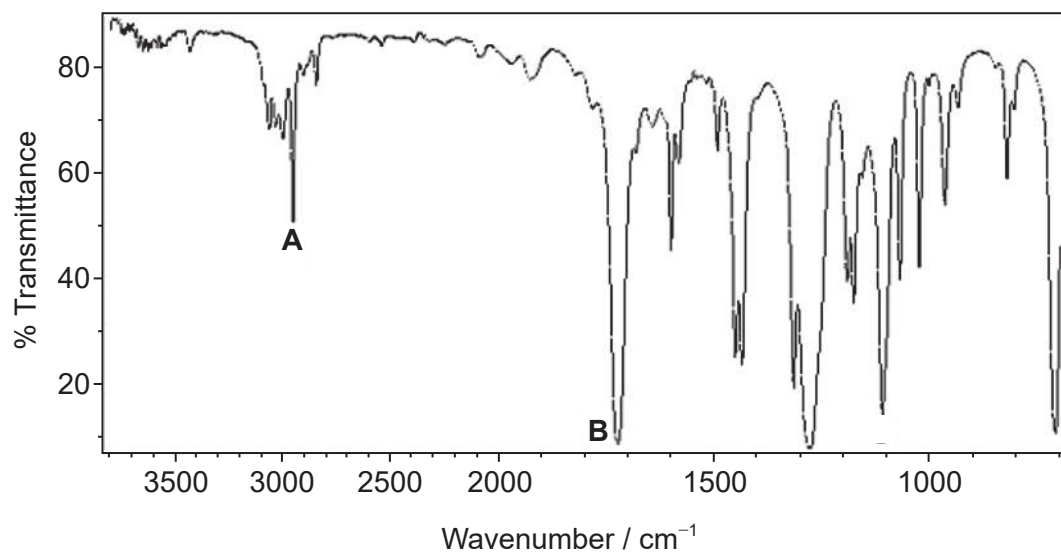
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(Question 8 continued)

- (ii) Identify the bonds causing peaks **A** and **B** in the IR spectrum of the unknown compound using section 26 of the data booklet. [1]



[Source: Food and Agriculture Organization of the United Nations, [http://www.fao.org/fileadmin/user\\_upload/jecfa/img/851.gif](http://www.fao.org/fileadmin/user_upload/jecfa/img/851.gif).  
Reproduced with permission]

A:

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B:

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- (iii) Deduce full structural formulas of **two** possible isomers of the unknown compound, both of which are esters. [2]

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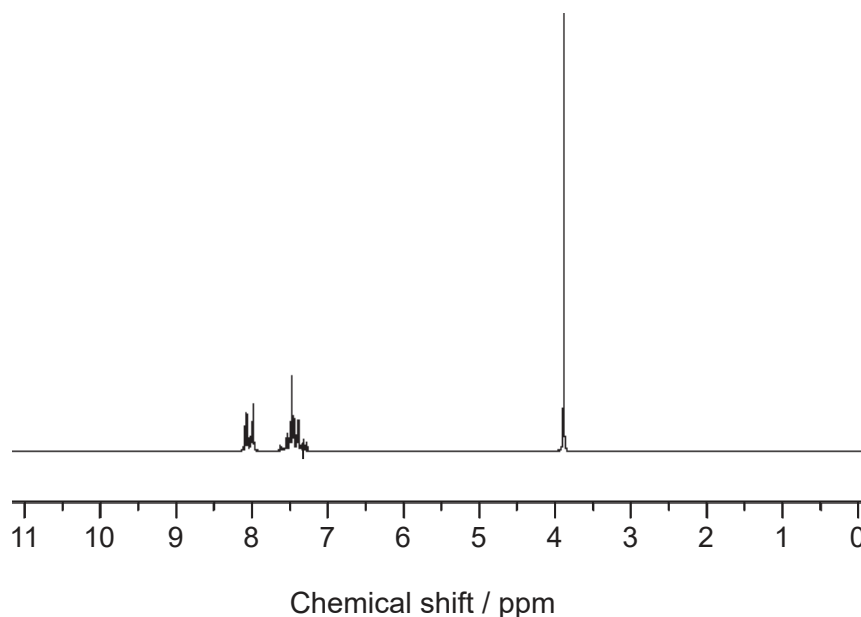


24EP20

**(Question 8 continued)**

- (iv) Deduce the formula of the unknown compound based on its  $^1\text{H}$  NMR spectrum using section 27 of the data booklet.

[1]



[Source: SDBS, National Institute of Advanced Industrial Science and Technology.]

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9. (a) Organic compounds often have isomers.

A straight chain molecule of formula  $\text{C}_5\text{H}_{10}\text{O}$  contains a carbonyl group. The compound cannot be oxidized by acidified potassium dichromate(VI) solution.

- (i) Deduce the structural formulas of the two possible isomers.

[2]

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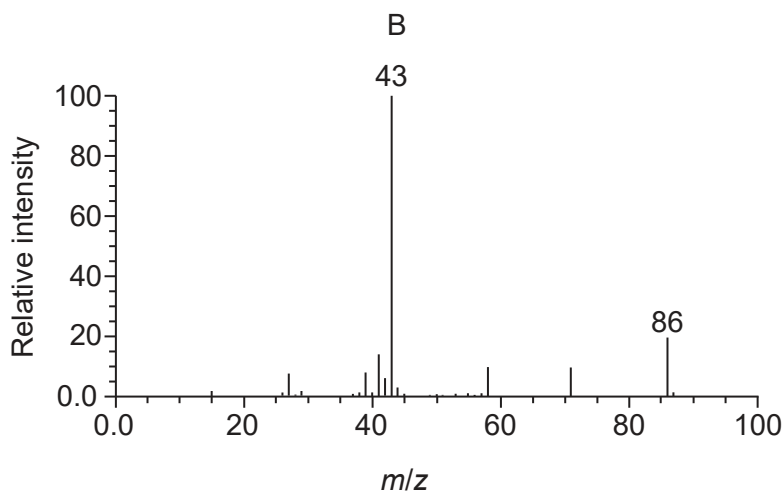
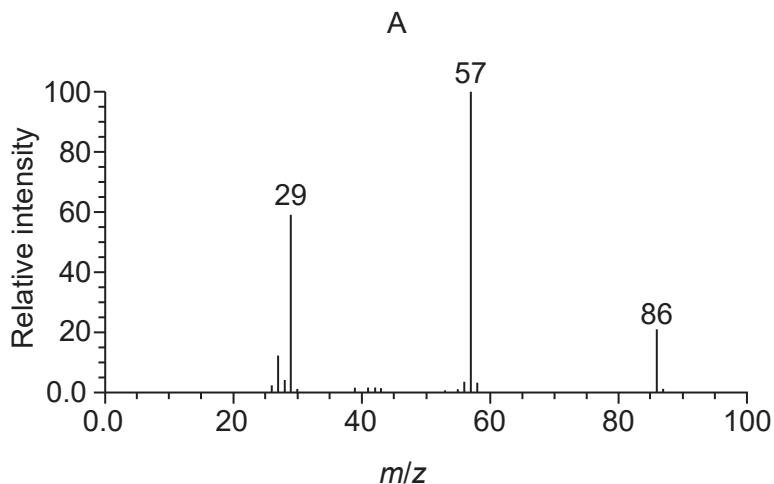


24EP21

Turn over

(Question 9 continued)

(ii) Mass spectra **A** and **B** of the two isomers are given.



[Source: NIST Mass Spec Data Center, S.E. Stein, director, "Mass Spectra" in *NIST Chemistry WebBook*, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, doi:10.18434/T4D303, (retrieved May 31, 2018).]

Explain which spectrum is produced by each compound using section 28 of the data booklet.

[2]

A:

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B:

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24EP22

**(Question 9 continued)**

(b) A tertiary halogenoalkane with three different alkyl groups,  $(R_1R_2R_3)C-X$ , undergoes a  $S_N1$  reaction and forms two isomers.

(i) State the type of bond fission that takes place in a  $S_N1$  reaction. [1]

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.....

(ii) State the type of solvent most suitable for the reaction. [1]

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(iii) Draw the structure of the intermediate formed stating its shape. [2]

Shape:  
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(iv) Suggest, giving a reason, the percentage of each isomer from the  $S_N1$  reaction. [2]

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24EP23

Turn over

**(Question 9 continued)**

(c) Nitrobenzene,  $C_6H_5NO_2$ , can be converted to phenylamine via a two-stage reaction.

In the first stage, nitrobenzene is reduced with tin in an acidic solution to form an intermediate ion and tin(II) ions. In the second stage, the intermediate ion is converted to phenylamine in the presence of hydroxide ions.

Formulate the equation for each stage of the reaction.

[2]

Stage one:

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Stage two:

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