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**Chemistry**  
**Standard level**  
**Paper 2**

Wednesday 10 November 2021 (afternoon)

Candidate session number

1 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 **[50 marks]**.



Please **do not** write on this page.

Answers written on this page  
will not be marked.



16EP02

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

1. A 4.406 g sample of a compound containing only C, H and O was burnt in excess oxygen. 8.802 g of CO<sub>2</sub> and 3.604 g of H<sub>2</sub>O were produced.

(a) Determine the empirical formula of the compound using section 6 of the data booklet. [3]

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(b) Determine the molecular formula of this compound if its molar mass is 88.12 g mol<sup>-1</sup>. If you did not obtain an answer in (a) use CS, but this is not the correct answer. [1]

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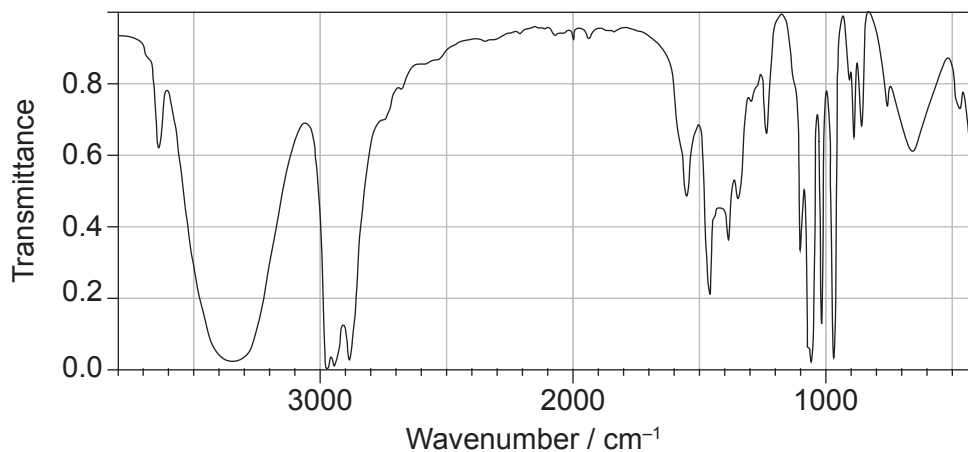
16EP03

Turn over

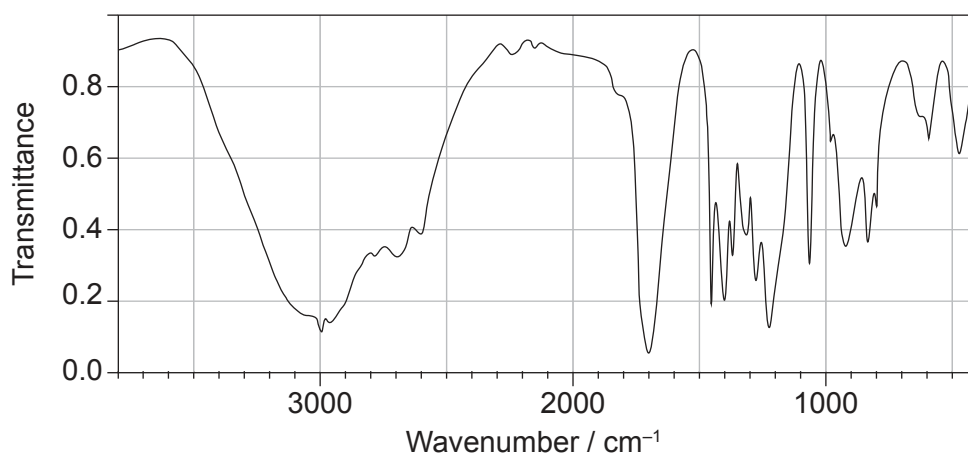
**(Question 1 continued)**

The following spectrums show the Infrared spectra of propan-1-ol, propanal and propanoic acid.

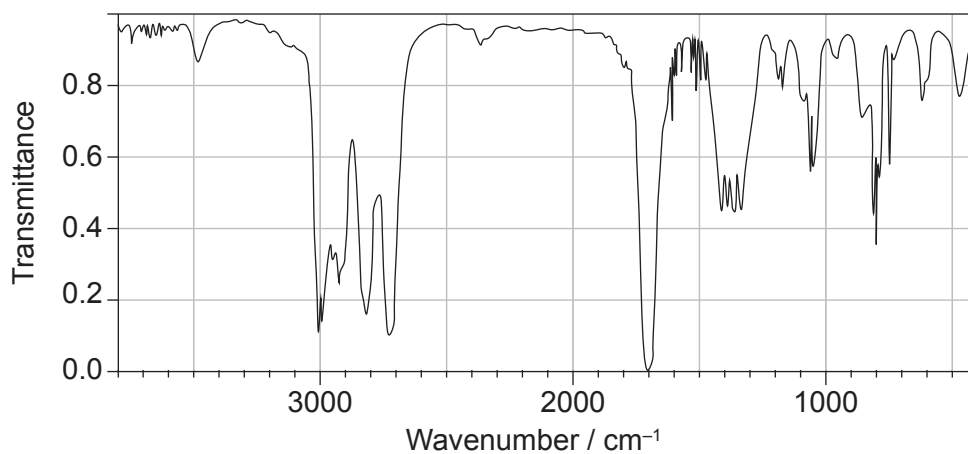
**Spectrum A**



**Spectrum B**



**Spectrum C**



**(This question continues on the following page)**



16EP04

**(Question 1 continued)**

(c) Identify each compound from the spectra given, use absorptions from the range of  $1700\text{ cm}^{-1}$  to  $3500\text{ cm}^{-1}$ . Explain the reason for your choice, referring to section 26 of the data booklet. [3]

Spectrum	Identity	Reason
A	..... .....	..... .....
B	..... .....	..... .....
C	..... .....	..... .....

2. Explain the general increase in trend in the first ionization energies of the period 3 elements, Na to Ar. [2]

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16EP05

Turn over

3. White phosphorus is an allotrope of phosphorus and exists as  $P_4$ .

(a) (i) Sketch the Lewis (electron dot) structure of the  $P_4$  molecule, containing only single bonds. [1]

(ii) Write an equation for the reaction of white phosphorus ( $P_4$ ) with chlorine gas to form phosphorus trichloride ( $PCl_3$ ). [1]

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(b) (i) Deduce the electron domain and molecular geometry using VSEPR theory, and estimate the Cl-P-Cl bond angle in  $PCl_3$ . [3]

Electron domain geometry:

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Molecular geometry:

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Bond angle:

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(ii) Explain the polarity of  $PCl_3$ . [1]

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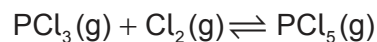
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**(Question 3 continued)**

(c) An equilibrium exists between  $\text{PCl}_3$  and  $\text{PCl}_5$ .



(i) Calculate the standard enthalpy change ( $\Delta H^\ominus$ ) for the forward reaction in  $\text{kJ mol}^{-1}$ .

$$\Delta H_f^\ominus \text{PCl}_3(\text{g}) = -306.4 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus \text{PCl}_5(\text{g}) = -398.9 \text{ kJ mol}^{-1} \quad [1]$$

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(ii) State the equilibrium constant expression,  $K_c$ , for this reaction. [1]

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(iii) State, with a reason, the effect of an increase in temperature on the position of this equilibrium. [1]

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4. 1-chloropentane reacts with aqueous sodium hydroxide.

(a) (i) Identify the type of reaction. [1]

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(ii) Outline the role of the hydroxide ion in this reaction. [1]

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(iii) Suggest, with a reason, why 1-iodopentane reacts faster than 1-chloropentane under the same conditions. Use section 11 of the data booklet for consistency. [2]

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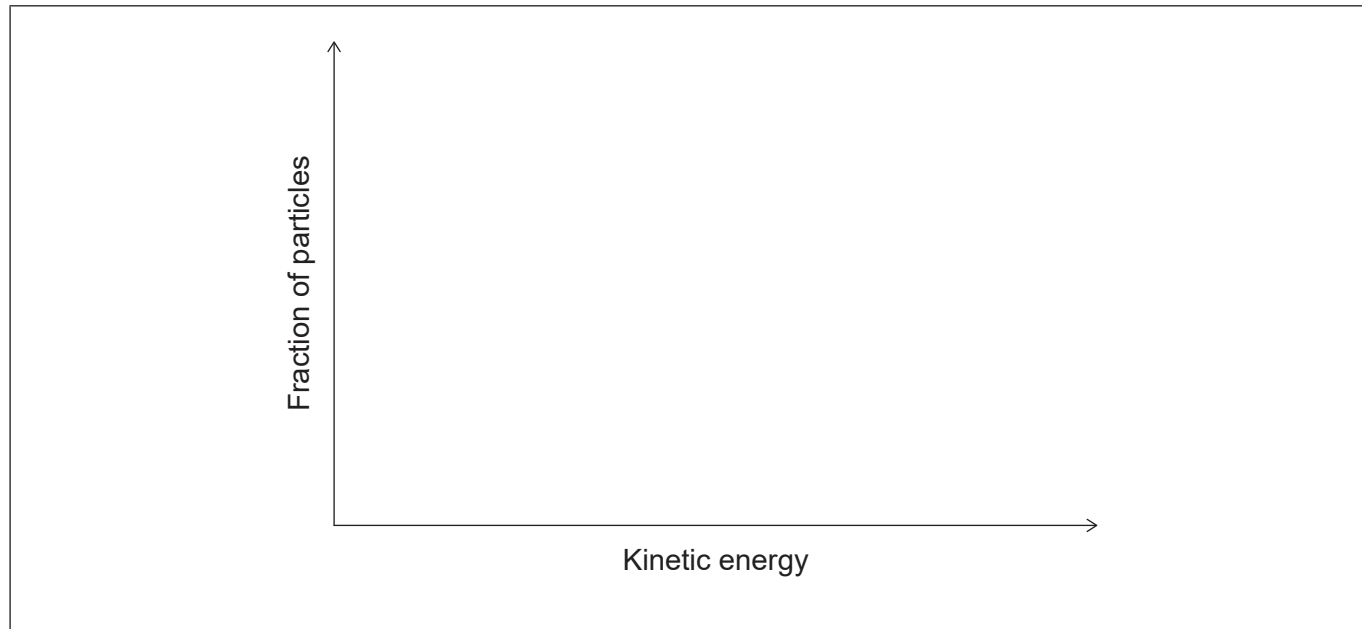
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**(Question 4 continued)**

(b) The reaction was repeated at a lower temperature.

(i) Sketch labelled Maxwell-Boltzmann energy distribution curves at the original temperature ( $T_1$ ) and the new lower temperature ( $T_2$ ). [2]



(ii) Explain the effect of lowering the temperature on the rate of the reaction. [2]

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16EP10

5. Phosphoric acid,  $\text{H}_3\text{PO}_4$ , can undergo stepwise neutralization, forming amphiprotic species.

(a) Formulate an equation for the reaction of one mole of phosphoric acid with one mole of sodium hydroxide. [1]

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(b) Formulate **two** equations to show the amphiprotic nature of  $\text{H}_2\text{PO}_4^-$ . [2]

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(c) Calculate the concentration of  $\text{H}_3\text{PO}_4$  if  $25.00\text{ cm}^3$  is completely neutralised by the addition of  $28.40\text{ cm}^3$  of  $0.5000\text{ mol dm}^{-3}$  NaOH. [2]

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(d) Outline the reason that sodium hydroxide is considered a Brønsted-Lowry base. [1]

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6. Biochemical oxygen demand (BOD) can be determined by the Winkler Method.

(a) Outline what is measured by BOD.

[1]

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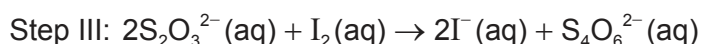
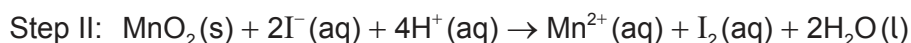
(b) A student dissolved  $0.1240 \pm 0.0001$  g of  $\text{Na}_2\text{S}_2\text{O}_3$  to make  $1000.0 \pm 0.4$  cm<sup>3</sup> of solution to use in the Winkler Method.

Determine the percentage uncertainty in the molar concentration.

[2]

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(c) A 25.00 cm<sup>3</sup> sample of water was treated according to the Winkler Method.



The iodine produced was titrated with 37.50 cm<sup>3</sup> of  $5.000 \times 10^{-4}$  mol dm<sup>-3</sup>  $\text{Na}_2\text{S}_2\text{O}_3$ .

(i) Calculate the amount, in moles of  $\text{Na}_2\text{S}_2\text{O}_3$  used in the titration.

[1]

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(ii) Deduce the mole ratio of  $\text{O}_2$  consumed in step I to  $\text{S}_2\text{O}_3^{2-}$  used in step III.

[1]

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16EP12

**(Question 6 continued)**

(iii) Calculate the concentration of dissolved oxygen, in  $\text{mol dm}^{-3}$ , in the sample. [2]

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(iv) The three steps of the Winkler Method are redox reactions.  
Deduce the reduction half-equation for step II. [1]

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**7. Alkanes undergo combustion and substitution.**

(a) Determine the molar enthalpy of combustion of an alkane if  $8.75 \times 10^{-4}$  moles are burned, raising the temperature of 20.0 g of water by  $57.3^\circ\text{C}$ . [2]

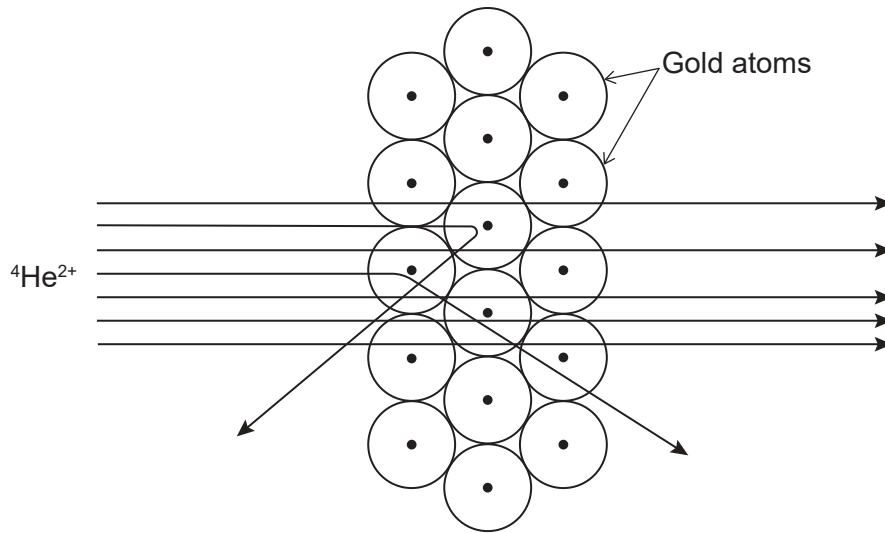
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(b) Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane. [3]

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8. Fast moving helium nuclei ( ${}^4\text{He}^{2+}$ ) were fired at a thin piece of gold foil with most passing undeflected but a few deviating largely from their path. The diagram illustrates this historic experiment.



(a) Suggest what can be concluded about the gold atom from this experiment.

[2]

Most  ${}^4\text{He}^{2+}$  passing straight through:

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Very few  ${}^4\text{He}^{2+}$  deviating largely from their path:

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**(Question 8 continued)**

- (b) (i) Subsequent experiments showed electrons existing in energy levels occupying various orbital shapes.

Sketch diagrams of 1s, 2s and 2p.

[2]

1s	2s	2p

- (ii) State the electron configuration of copper.

[1]

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## References:

1. (c) NIST Mass Spectrometry Data Center Collection © 2021 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. All rights reserved. Available at: <https://webbook.nist.gov/cgi/cbook.cgi?ID=C71238&Units=SI&Type=IRSPEC&Index=3#IR-SPEC> [Accessed 6 May 2020]. Source adapted.  
  
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8. Figure from *PPLATO / FLAP (Flexible Learning Approach To Physics)*, [http://www.met.reading.ac.uk/pplato2/h-flap/phys8\\_1.html#top](http://www.met.reading.ac.uk/pplato2/h-flap/phys8_1.html#top) 1996 The Open University and The University of Reading.

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