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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.



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 CO₂ and 3.604 g of H₂O 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⁻¹. If you did not obtain an answer in (a) use CS, but this is not the correct answer. [1]

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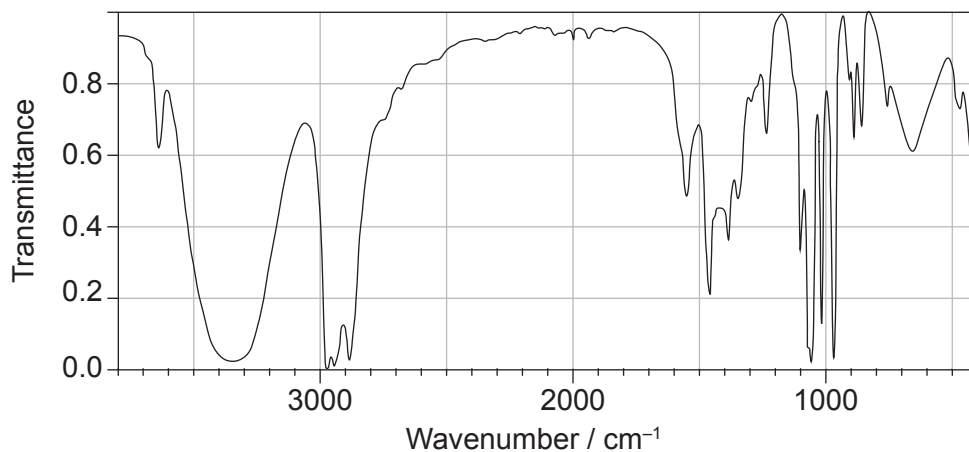
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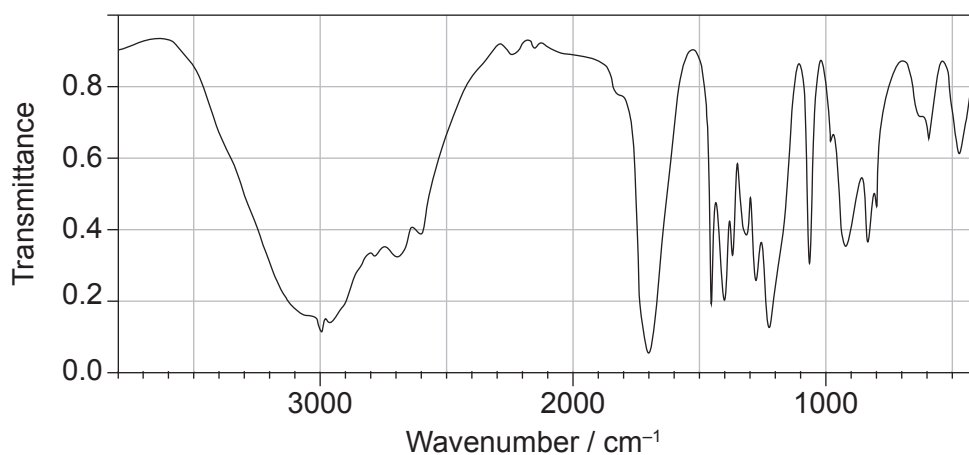
(Question 1 continued)

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

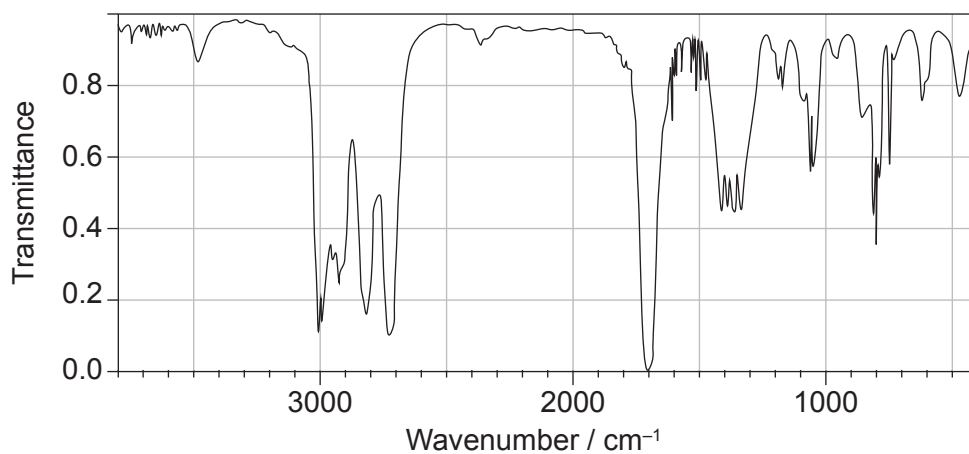
Spectrum A



Spectrum B



Spectrum C



(This question continues on the following page)



(Question 1 continued)

(c) Identify each compound from the spectra given, use absorptions from the range of 1700 cm^{-1} to 3500 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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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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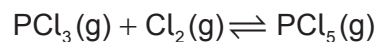
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(Question 3 continued)

(c) An equilibrium exists between PCl_3 and PCl_5 .



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

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

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

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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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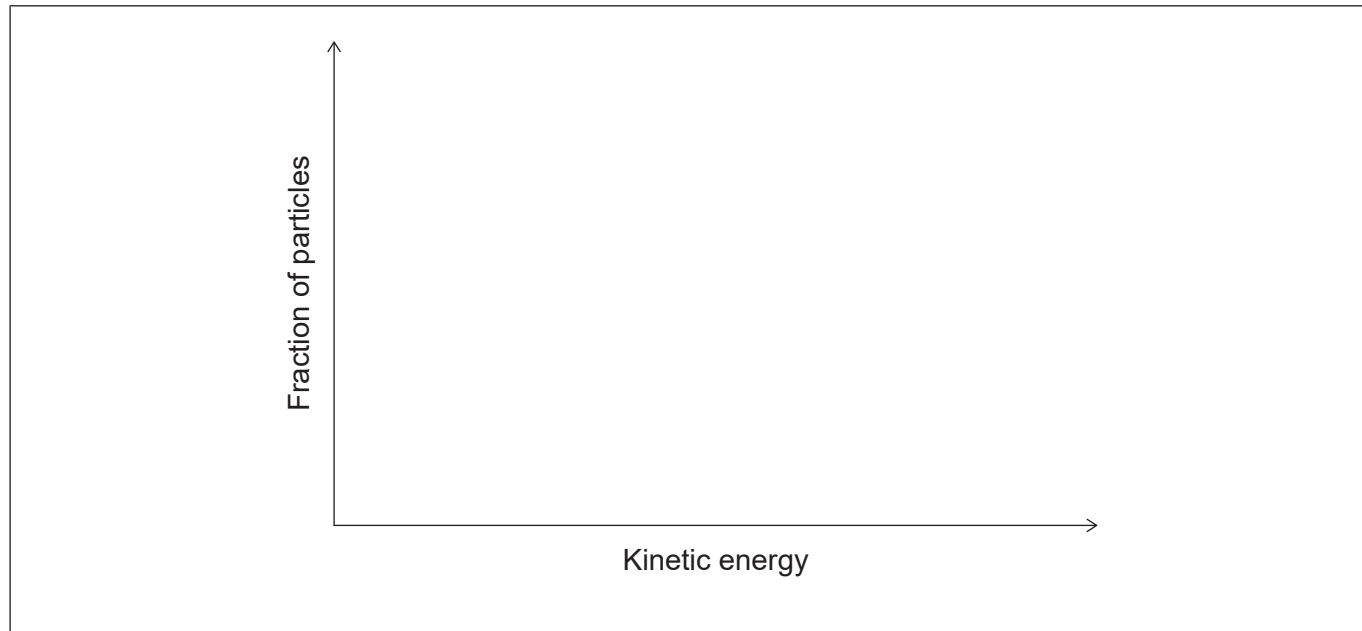
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(Question 4 continued)

(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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5. Phosphoric acid, H_3PO_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 H_2PO_4^- . [2]

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(c) Calculate the concentration of H_3PO_4 if 25.00 cm^3 is completely neutralised by the addition of 28.40 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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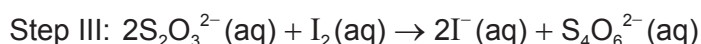
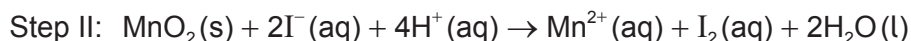
(b) A student dissolved 0.1240 ± 0.0001 g of $\text{Na}_2\text{S}_2\text{O}_3$ to make 1000.0 ± 0.4 cm³ of solution to use in the Winkler Method.

Determine the percentage uncertainty in the molar concentration.

[2]

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(c) A 25.00 cm³ sample of water was treated according to the Winkler Method.



The iodine produced was titrated with 37.50 cm³ of 5.000×10^{-4} mol dm⁻³ $\text{Na}_2\text{S}_2\text{O}_3$.

(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 O_2 consumed in step I to $\text{S}_2\text{O}_3^{2-}$ used in step III.

[1]

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(Question 6 continued)

(iii) Calculate the concentration of dissolved oxygen, in 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 8.75×10^{-4} moles are burned, raising the temperature of 20.0 g of water by 57.3°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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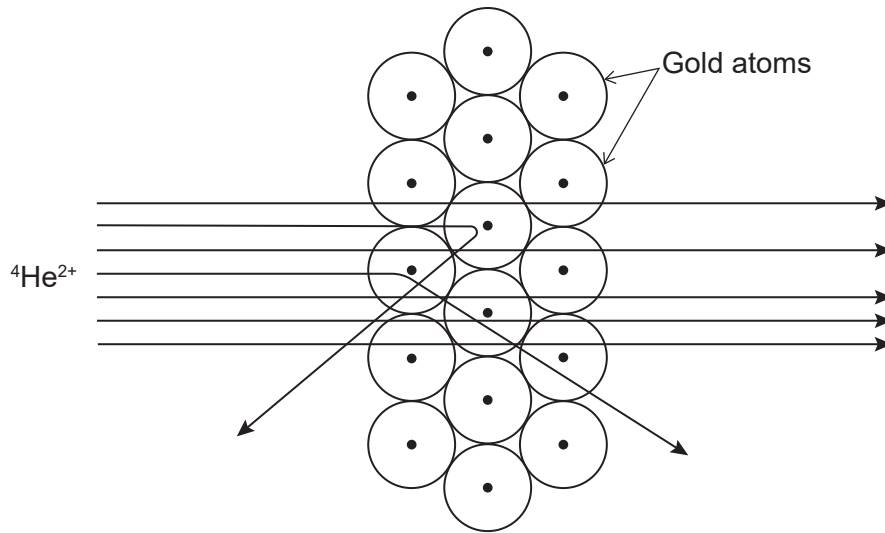
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8. Fast moving helium nuclei (${}^4\text{He}^{2+}$) were fired at a thin piece of gold foil with most passing undeflected but a few deviating largely from their path. The diagram illustrates this historic experiment.



(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 1996 The Open University and The University of Reading.

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