Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 2

Wednesday 10 November 2021 (afternoon)

Candidate session number

1 hour 15 minutes

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]**.

8821 – 6105

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 CO_2 and 3.604 g of H_2O were produced.

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

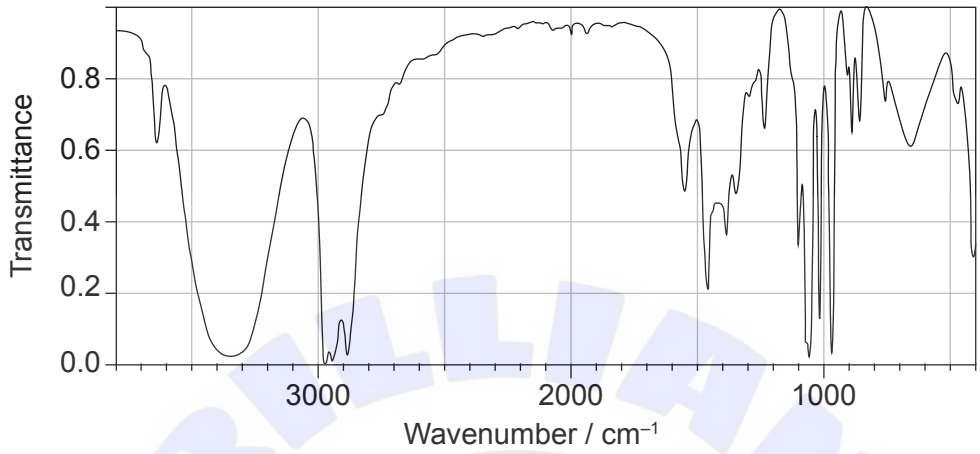
. . . . . .

(This question continues on the following page)

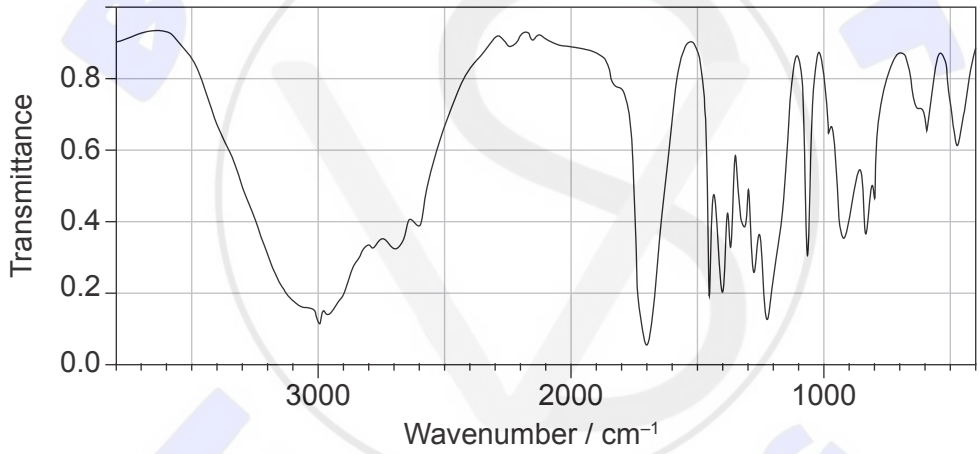
(Question 1 continued)

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

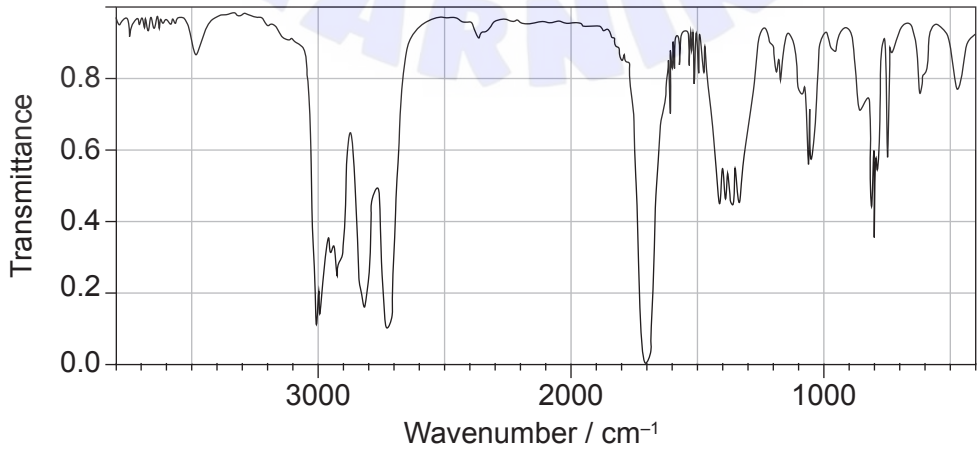
Spectrum A



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]

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

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]

. . . . . .

. . . . . .

(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:

. . . . . .

Molecular geometry:

. . . . . .

Bond angle:

. . . . . .

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

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 3 continued)

(c) An equilibrium exists between PCl_3 and PCl_5.

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$$

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

$$\Delta H^{\ominus}_f PCl_3(g) = -306.4\,kJ\,mol^{-1}$$

$$\Delta H^{\ominus}_f PCl_5(g) = -398.9\,kJ\,mol^{-1}$$ [1]

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

4. 1-chloropentane reacts with aqueous sodium hydroxide.

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

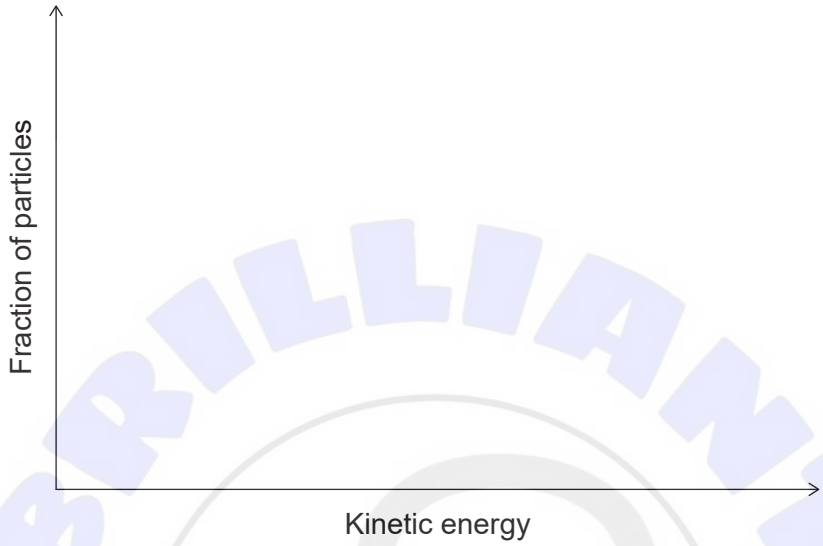
. . . . . .

(This question continues on the following page)

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

Answers written on this page
will not be marked.

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]

. . . . . .

. . . . . .

(b) Formulate **two** equations to show the amphiprotic nature of $H_2PO_4^-$. [2]

. . . . . .

. . . . . .

. . . . . .

(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 $mol\,dm^{-3}$ NaOH. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

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

(a) Outline what is measured by BOD. [1]

. . . . . .

. . . . . .

(b) A student dissolved $0.1240 \pm 0.0001\,g$ of $Na_2S_2O_3$ to make $1000.0 \pm 0.4\,cm^3$ of solution to use in the Winkler Method.

Determine the percentage uncertainty in the molar concentration. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(c) A $25.00\,cm^3$ sample of water was treated according to the Winkler Method.

Step I: $2Mn^{2+}(aq) + O_2(g) + 4OH^-(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$

Step II: $MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$

Step III: $2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

The iodine produced was titrated with $37.50\,cm^3$ of $5.000 \times 10^{-4}\,mol\,dm^{-3}$ $Na_2S_2O_3$.

(i) Calculate the amount, in moles of $Na_2S_2O_3$ used in the titration. [1]

. . . . . .

. . . . . .

(ii) Deduce the mole ratio of O_2 consumed in step I to $S_2O_3^{2-}$ used in step III. [1]

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 6 continued)

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

. . . . . .

. . . . . .

. . . . . .

(iv) The three steps of the Winkler Method are redox reactions.

Deduce the reduction half-equation for step II. [1]

. . . . . .

. . . . . .

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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

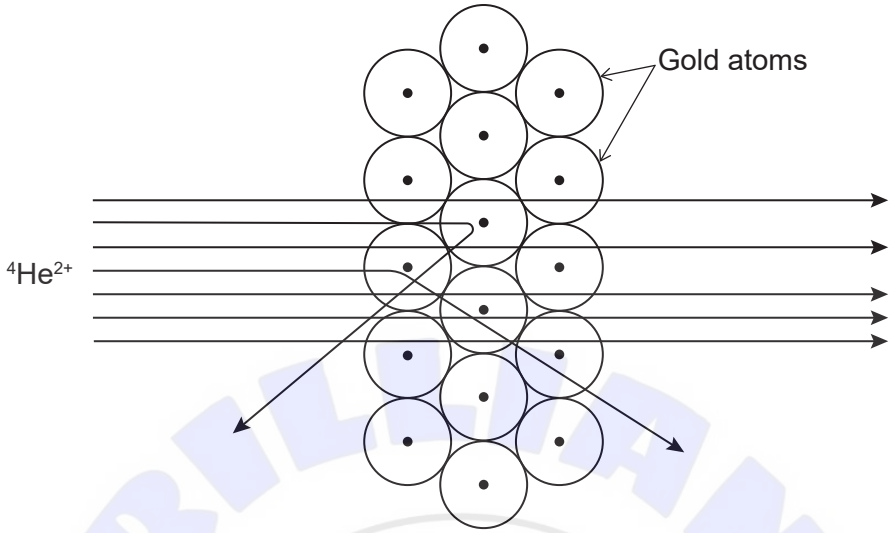
. . . . . .

. . . . . .

. . . . . .

. . . . . .

8. Fast moving helium nuclei ($^4He^{2+}$) 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 $^4He^{2+}$ passing straight through:

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(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]

. . . . . .

. . . . . .

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.

NIST Mass Spectrometry Data Center Collection © 2021 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. Available at: https://webbook.nist.gov/cgi/cbook.cgi?ID=C79094&Units=SI&Mask=80#IR-Spec [Accessed 6 May 2020]. Source adapted.

NIST Mass Spectrometry Data Center Collection © 2021 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. Available at: https://webbook.nist.gov/cgi/cbook.cgi?Name=propanal&Units=SI&cIR=on&cTZ=on#IRSpec [Accessed 6 May 2020]. Source adapted.

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.