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## Chemistry Higher level Paper 2

Wednesday 10 November 2021 (afternoon)

Candidate session number									

2 hours 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 [90 marks].

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Please do not write on this page.

Answers written on this page will not be marked.



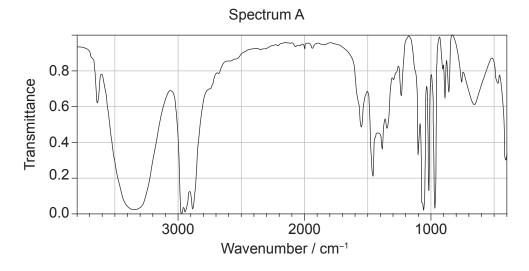
Answer all questions. Answers must be written within the answer boxes provided.

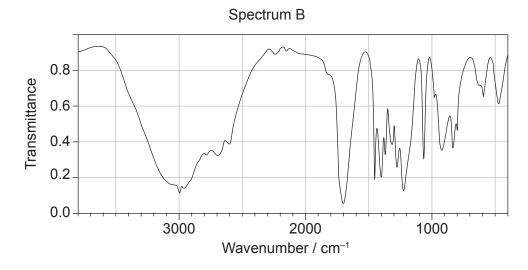
1. A 4.406g sample of a compound containing only C, H and O was burnt in excess oxygen. 8.802g of CO<sub>2</sub> and 3.604g of H<sub>2</sub>O were produced.
(a) Determine the empirical formula of the compound using section 6 of the data booklet. [3]
(b) Determine the molecular formula of this compound if its molar mass is 88.12g mol<sup>-1</sup>. If you did not obtain an answer in (a) use CS, but this is not the correct answer. [1]

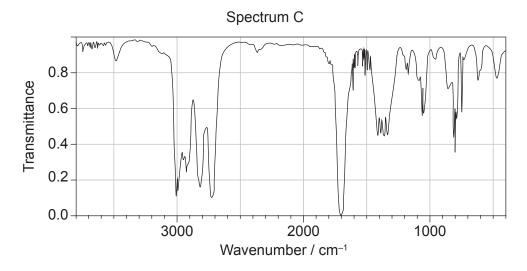


### (Question 1 continued)

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









## (Question 1 continued)

(c)	Identify each compound from the spectra given, use absorptions from the range of
	1700 cm <sup>-1</sup> to 3500 cm <sup>-1</sup> . Explain the reason for your choice, referring to section 26 of
	the data booklet.

[3]

Spectrum	Identity	Reason
Α		
В		
С		

(d) Predict the number of <sup>1</sup>H NMR signals, and splitting pattern of the –CH<sub>3</sub> seen for propanone (CH<sub>3</sub>COCH<sub>3</sub>) and propanal (CH<sub>3</sub>CH<sub>2</sub>CHO). [2]

Spectrum	Number of signals	Splitting pattern of –CH <sub>3</sub>
propanone		
propanal		

(e)	Predict the fragment that is responsible for a $m/z$ of 31 in the mass spectrum of propan-1-ol. Use section 28 of the data booklet.	[1

(a)	Explain the general increase in trend in the first ionization energies of the period 3 elements, Na to Ar.	[2
(b)	Sodium emits yellow light with a frequency of $5.09\times10^{14}\text{Hz}$ when electrons transition from 3p to 3s orbitals.	
	Calculate the energy difference, in J, between these two orbitals using sections 1 and 2 of the data booklet.	[′
White	e phosphorus is an allotrope of phosphorus and exists as P <sub>4</sub> .	
(a)	(i) Sketch the Lewis (electron dot) structure of the P <sub>4</sub> molecule, containing only single bonds.	[′



# (Question 3 continued) Write an equation for the reaction of white phosphorus (P<sub>4</sub>) with chlorine gas to form phosphorus trichloride (PCl<sub>3</sub>). [1] Deduce the electron domain and molecular geometry using VSEPR theory, and (b) (i) estimate the Cl-P-Cl bond angle in PCl<sub>3</sub>. [3] Electron domain geometry: Molecular geometry: Bond angle: (ii) Outline the reason why PCl<sub>5</sub> is a non-polar molecule, while PCl<sub>4</sub>F is polar. [3] PCl<sub>5</sub> is non-polar: PCl₄F is polar:



Turn over

### (Question 3 continued)

(c) An equilibrium exists between PCl<sub>3</sub> and PCl<sub>5</sub>.

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

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

$$\Delta H_{f}^{\ominus} PCl_{3}(g) = -306.4 \text{ kJ mol}^{-1}$$

$$\Delta H_{f}^{\ominus} PCl_{5}(g) = -398.9 \,\mathrm{kJ} \,\mathrm{mol}^{-1}$$
 [1]

.....

(ii) Calculate the entropy change,  $\Delta S$ , in  $J K^{-1} mol^{-1}$ , for this reaction.

Substance	Entropy J K <sup>-1</sup> mol <sup>-1</sup>
PCl <sub>3</sub> (g)	311.7
PCl₅(g)	364.5
Cl <sub>2</sub> (g)	223.0

[1]




# (Question 3 continued)

(iii)	Calculate the Gibbs free energy change ( $\Delta G$ ), in kJ mol <sup>-1</sup> , for this reaction at 25 °C. Use section 1 of the data booklet.	
	If you did not obtain an answer in c(i) or c(ii) use $-87.6\mathrm{kJmol^{-1}}$ and $-150.5\mathrm{Jmol^{-1}K^{-1}}$ respectively, but these are not the correct answers.	[2]
(iv)	Determine the equilibrium constant, <i>K</i> , for this reaction at 25 °C, referring to section 1 of the data booklet.	
	If you did not obtain an answer in (c)(iii), use $\Delta G = -43.5 \text{kJ}\text{mol}^{-1}$ , but this is not the correct answer.	[2]
(v)	State the equilibrium constant expression, $K_c$ , for this reaction.	[1]
(vi)	State, with a reason, the effect of an increase in temperature on the position of this equilibrium.	[1]



Turn over

1.	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]				
	(b)	Sket	reaction was repeated at a lower temperature. Such labelled Maxwell–Boltzmann energy distribution curves at the original operature $(T_1)$ and the new lower temperature $(T_2)$ .	[2]				
			Fraction of particles					
			Kinetic energy					



Phosphoric acid, H <sub>3</sub> PO <sub>4</sub> can form three different salts depending on the extent of neutralisation by sodium hydroxide.								
(a)	Formulate an equation for the reaction of one mole of phosphoric acid with one mole of sodium hydroxide.	[1]						
(b)	Formulate <b>two</b> equations to show the amphiprotic nature of H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> .	[2]						
(c)	Calculate the concentration of $\rm H_3PO_4$ 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 reasons that sodium hydroxide is considered a Brønsted–Lowry and Lewis base.	[1]						
	· · · · · · · · · · · · · · · · · · ·							
	(b) (c) (d) Brør	(b) Formulate <b>two</b> equations to show the amphiprotic nature of H <sub>2</sub> PO <sub>4</sub> .  (c) Calculate the concentration of H <sub>3</sub> PO <sub>4</sub> if 25.00 cm³ is completely neutralised by the addition of 28.40 cm³ of 0.5000 mol dm⁻³ NaOH.  (d) Outline the reasons that sodium hydroxide is considered a Brønsted–Lowry and						



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 $_2$ S $_2$ O $_3$ 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 <sup>3</sup> 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 $_2$ S $_2$ O $_3$ .						
		(i) Calculate the amount, in moles of Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub> 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]					



# (Question 6 continued)

(iii)	Calculate the concentration of dissolved oxygen, in mol dm <sup>-3</sup> , in the sample.	[2]
(iv)	The three steps of the Winkler Method are redox reactions.	
	Deduce the reduction half-equation for step II.	[1]
(v)	Suggest a reason that the Winkler Method used to measure biochemical oxygen demand (BOD) must be done at constant temperature.	[1]



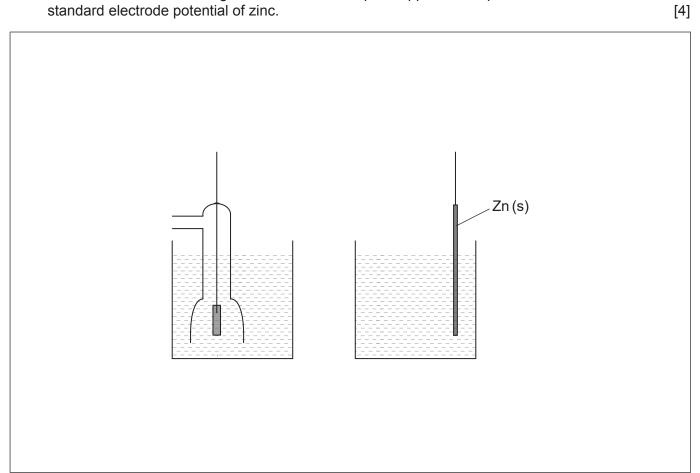
Turn over

7.	Alka	nes undergo combustion and substitution.	
	(a)	Determine the molar enthalpy of combustion of an alkane if $8.75\times10^{-4}$ moles are burned, raising the temperature of 20.0 g of water by $57.3^{\circ}$ C.	[2]
	(b)	Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane.	[3]



The standard electrode potential of zinc can be measured using a standard hydrogen 8. electrode (SHE).

Draw and annotate the diagram to show the complete apparatus required to measure the standard electrode potential of zinc.

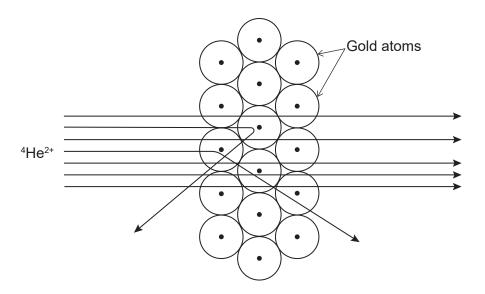




**Turn over** 

[2]

**9.** Fast moving helium nuclei (<sup>4</sup>He<sup>2+</sup>) 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.

Mos	t 4	He	2+	ра	as	si	ηę	9	st	ra	ai	gŀ	٦t	t	h	r	Οl	J(	gl	h	:																																		
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Very	/ fe	ew	<sup>4</sup> F	Нe	2+	d	e١	/ia	at	ir	ıg	l	a	rg	jе	į	y	fı	rc	or	n	1	t	h	ıe	Э	ii	r	p	) 6	at	:h	1:																						
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# (Question 9 continued)

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

	Draw diagrams of	1s, 2s and 2p.		[2]
	1s	2s	2p	
(ii)	State the electron	configuration of copper.		[1]
(iii)		ition metal that forms different co		
	Explain the cause booklet.	e of this colour change, using se	ections 3 and 15 from the data	[3]



Turn over

(a) (i) Disting	guish between a sigma and p	oi bond.	[
Sigma (σ) bond:			
Pi (π) bond:			
(ii) Identif	y the hybridization of carbon	in ethane, ethene and eth	yne. [
()	y and mysmalization of danson.	The canality, canonic and can	Je.
	Ethane	Ethene	Ethyne
lybridization of carbon			
(b) (i) State,	giving a reason, if but-1-ene	exhibits cis-trans isomeris	sm. [
	the type of reaction which oc m temperature.		
	the type of reaction which oc		nd hydrogen iodide



# (Question 10 continued)

(iii)	Explain the mechanism of the reaction between but-1-ene with hydrogen iodide, using curly arrows to represent the movement of electron pairs.	[4
(iv)	State, giving a reason, if the product of this reaction exhibits stereoisomerism.	[′

## (Question 10 continued)

(c) Experiments were carried out to investigate the mechanism of reaction between 2-chloropentane and aqueous sodium hydroxide.

Experiment	[NaOH] (mol dm <sup>-3</sup> )	[C₅H₁₁Cl] (mol dm⁻³)	Initial rate (mol dm <sup>-3</sup> s <sup>-1</sup> )
1	0.20	0.10	$2.50 \times 10^{-2}$
2	0.20	0.15	$3.75 \times 10^{-2}$
3	0.40	0.20	$1.00 \times 10^{-1}$
4	0.60	0.25	

(i)	Deduce the rate expression for this reaction.	[1]
(ii)	Deduce the units of the rate constant.	[1]
(iii)	Determine the initial rate of reaction in experiment 4.	[2]



# (Question 10 continued)

(a)	sodium hydroxide.	[1]
(e)	Discuss the reason benzene is more reactive with an electrophile than a nucleophile.	[2]
(e)	Discuss the reason benzene is more reactive with an electrophile than a nucleophile.	[2]
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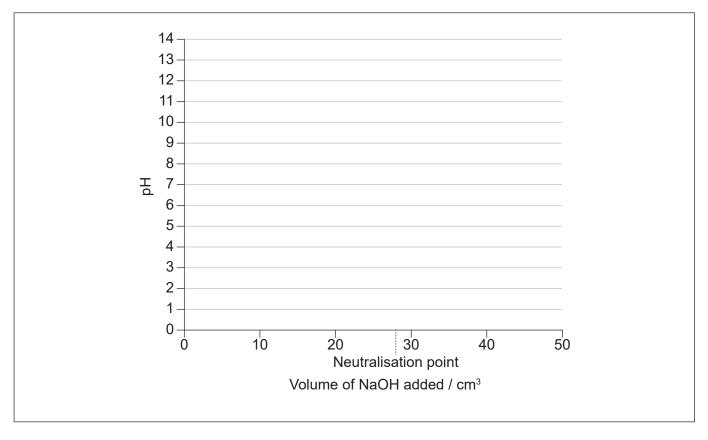
11.		moldm <sup>-3</sup> chloroethanoic acid.	
	(a)	Calculate the initial pH before any sodium hydroxide was added, using section 21 of the data booklet.	[2]
	(b)	The concentration of excess sodium hydroxide was 0.362 mol dm <sup>-3</sup> . Calculate the pH of the solution at the end of the experiment.	[1]



# (Question 11 continued)

(c) Sketch the neutralisation curve obtained **and** label the equivalence point.

[3]





#### 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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- 3. (c) (ii) Chemistry 2e, Chpt. 21 Nuclear Chemistry, Appendix G: Standard Thermodynamic Properties for Selected Substances https://openstax.org/books/chemistry-2e/pages/g-standard-thermodynamic-properties-for-selected-substances#page\_667adccf-f900-4d86-a13d-409c014086ea © 1999-2021, Rice University. Except where otherwise noted, textbooks on this site are licensed under a Creative Commons Attribution 4.0 International License. (CC BY 4.0) https://creativecommons.org/licenses/by/4.0/.
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