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Chemistry Higher level Paper 2

9 May 2024

Zone A morning | Zone B morning | Zone C morning

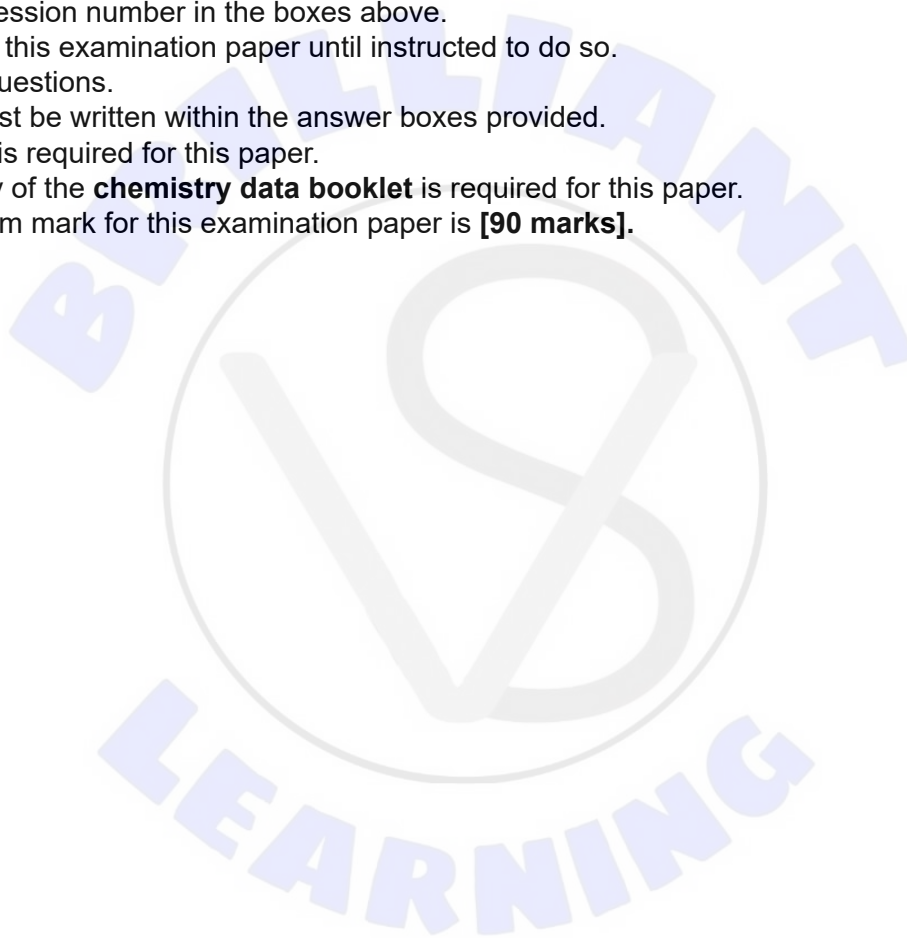
Candidate session number

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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]**.



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

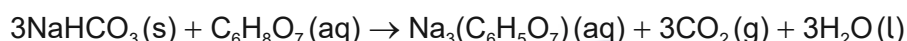
1. A powder has the following percentage composition by mass:

30.0% sucrose, $C_{12}H_{22}O_{11}$

45.0% citric acid, $C_6H_8O_7$

25.0% sodium hydrogencarbonate, $NaHCO_3$

In the presence of water, the powder effervesces as the citric acid reacts with the sodium hydrogencarbonate:



(a) (i) Determine the limiting reactant when 1.00 g of this powder reacts. [3]

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(ii) Determine the volume, in dm^3 at SATP, of carbon dioxide released in the reaction in (a)(i). Use sections 1 and 2 of the data booklet. [2]

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(This question continues on the following page)



(Question 1 continued)

- (iii) Calculate the percentage yield obtained by a student who collected 0.043 dm^3 of carbon dioxide from 1.00 g of the powder.

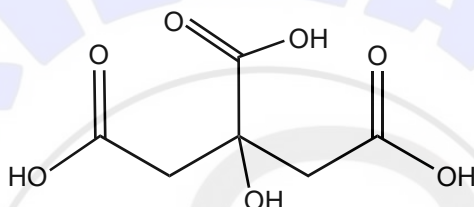
If you did not obtain an answer to (a)(ii), use 0.068 dm^3 , but this is not the correct value.

[1]

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- (b) (i) State the number of acidic hydrogens in the citric acid molecule shown.

[1]



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- (ii) Deduce the structural formula of the conjugate base of citric acid.

[1]

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- (iii) Predict, giving a reason, the strength of citric acid.

[1]

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(This question continues on page 5)





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Answers written on this page
will not be marked.



(Question 1 continued)

(iv) Explain why sodium citrate solutions are basic. [1]

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(c) Calculate the pH of a solution with a hydrogen ion concentration, $[H^+] = 0.0025 \text{ mol dm}^{-3}$ [1]

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(d) Describe the bonding in solid sodium citrate. [2]

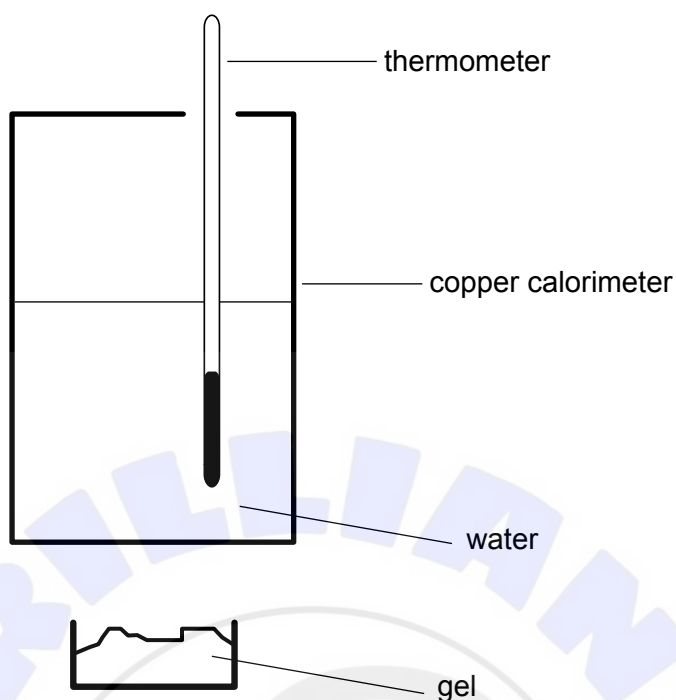
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(e) State, giving a reason, how the lattice and hydration enthalpies would differ if potassium ions were present instead of sodium ions. [2]

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2. A student investigated the use of hand sanitising gel containing propan-1-ol as a camping fuel.



Mass of water / g ± 0.02 g	400.00
Initial temperature of water / $^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$	19.0
Final temperature of water / $^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$	40.0
Initial mass of gel / g ± 0.01 g	20.00
Final mass of gel / g ± 0.01 g	18.20

(a) (i) Calculate the heat energy absorbed by the water, in J. Use sections 1 and 2 of the data booklet.

[1]

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(ii) Calculate the percentage uncertainty of your answer in (a)(i).

[2]

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(This question continues on the following page)



(Question 2 continued)

(iii) Suggest a way to reduce the random uncertainty of the answer. [1]

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(b) (i) Calculate the enthalpy of combustion of propan-1-ol, in kJ mol^{-1} , stating **one** assumption.

If you did not obtain an answer to (a)(i), use 30 000 J, though this is not the correct value. [3]

Calculation:

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Assumption:

(ii) Calculate the percentage error, using section 13 of the data booklet. [1]

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(iii) Suggest the main source of error, and a way to reduce it. [1]

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(This question continues on the following page)



(Question 2 continued)

- (c) The student also investigates a second gel containing ethanol, with the same percentage by mass as the propan-1-ol in the first gel.

Determine whether the second gel would release more or less energy per gram than the first gel. Use section 13 of the data booklet.

[3]

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- (d) Ethanol and propan-1-ol are members of a homologous series.

- (i) State the names of the class of compound and the functional group of this series. [2]

Class:

Functional group:

- (ii) State the strongest intermolecular force present in ethanol and propan-1-ol. [1]

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- (iii) Predict an intermolecular force which would be stronger in the next member of the homologous series, butan-1-ol. [1]

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(This question continues on the following page)



(Question 2 continued)

(e) Butan-2-ol is optically active.

(i) Sketch **two** enantiomers of butan-2-ol to show the relationship between them. [2]

(ii) Deduce the organic products when butan-1-ol and butan-2-ol are separately heated under reflux with acidified potassium dichromate (VI). [2]

Butan-1-ol:

Butan-2-ol:

(f) Propan-1-ol can be produced from 1-chloropropane.

(i) Identify a nucleophile which could be used for this reaction. [1]

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(This question continues on page 11)





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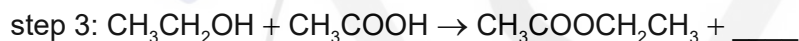
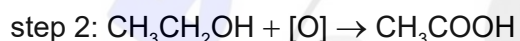
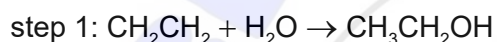
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(Question 2 continued)

- (ii) Sketch the mechanism of the reaction between 1-chloropropane and the nucleophile in (f)(i), using curly arrows. [3]

- (g) Ethyl ethanoate can be produced from ethene via a three-step synthetic route.



- (i) State the conditions necessary for the reaction in step 1. [1]

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- (ii) Identify the type of reaction occurring in step 3. [1]

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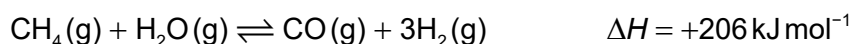
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- (iii) Identify the second product formed in step 3. [1]

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3. Hydrogen is manufactured from methane by a process called steam reforming:



(a) Deduce the equilibrium constant, K_c , expression for the reaction. [1]

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(b) Predict, with a reason, the effect of increasing the temperature on the position of equilibrium. [1]

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(c) Explain why the reaction rate increases with temperature, adding annotations to the following Maxwell-Boltzmann graph to assist your explanation. [3]

Explanation:

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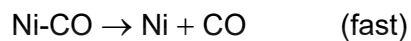
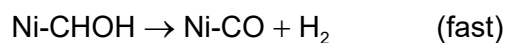
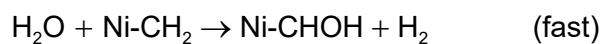
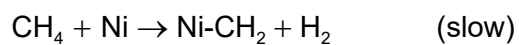
(d) Annotate this Maxwell-Boltzmann distribution graph in (c) to show the effect of a catalyst. [1]

(This question continues on the following page)



(Question 3 continued)

(e) The reactants, CH₄ and H₂O, are passed over nickel metal. The following mechanism is proposed:



(i) Deduce, giving a reason, the role of nickel in the reaction. [1]

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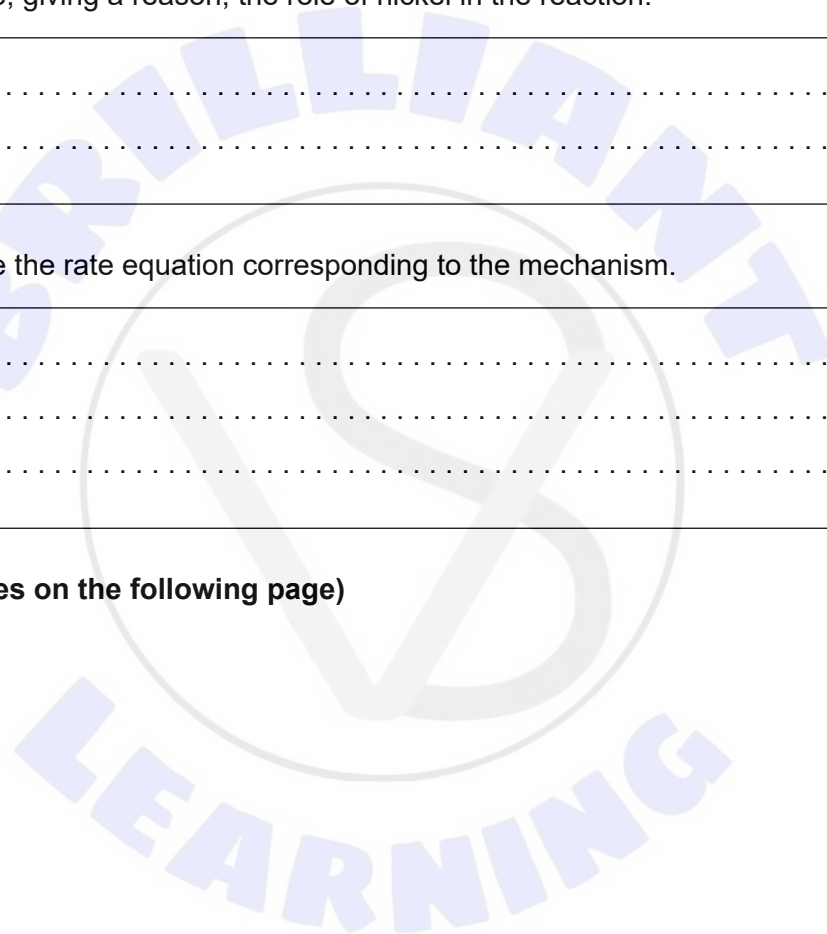
(ii) Deduce the rate equation corresponding to the mechanism. [1]

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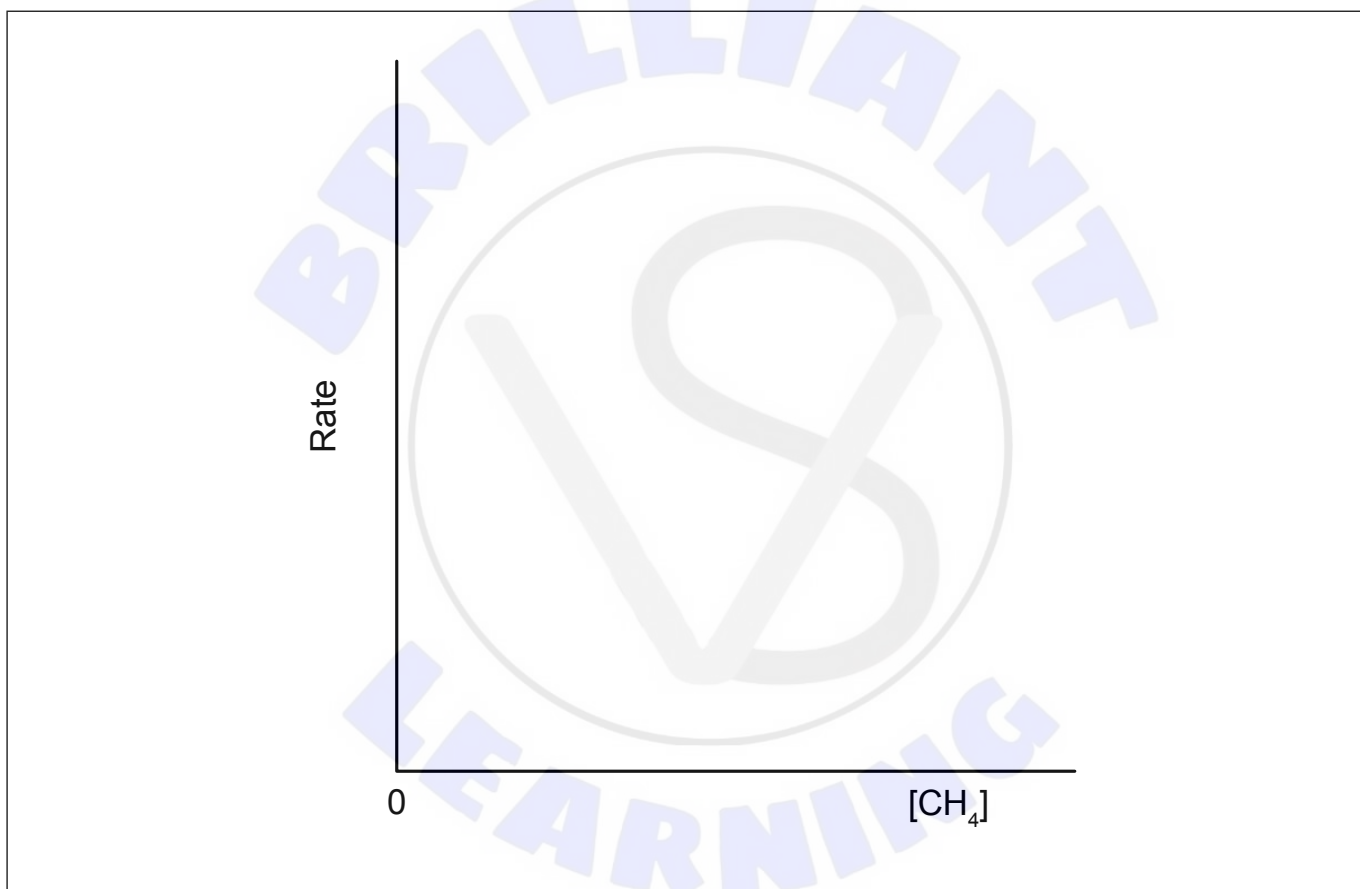


(Question 3 continued)

- (iii) Suggest why experimental confirmation of the rate equation would not prove that the mechanism is correct. [1]

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- (iv) Sketch a graph of the relationship between the rate of this reaction and the concentration of methane. [1]

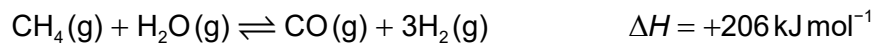


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(Question 3 continued)

- (f) Calculate the standard entropy change, ΔS^\ominus , of the forward reaction, in JK^{-1} .



Use section 12 of the data booklet, and the standard entropy of hydrogen:

$$S^\ominus(\text{H}_2(\text{g})) = +130.7 \text{ JK}^{-1} \text{ mol}^{-1} \quad [1]$$

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- (g) Calculate the Gibbs Free energy, ΔG , and the equilibrium constant K_c , for the forward reaction, at 1500 K. Use sections 1 and 2 of the data booklet.

(If you were unable to obtain an answer for part (f) use 227 JK^{-1} , but this is not the correct value.)

[2]

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- (h) Determine the temperature, in K, at which the forward reaction becomes spontaneous. Use section 1 of the data booklet.

[2]

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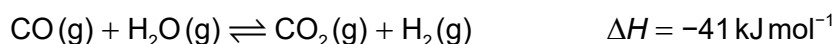
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4. The water-gas shift reaction is another way to manufacture hydrogen.



(a) (i) State the oxidation state of carbon in carbon monoxide and carbon dioxide. [1]

carbon monoxide:
carbon dioxide:

(ii) Identify the oxidising and reducing agents, and the species oxidised and reduced, in the forward reaction. [2]

	CO(g)	H ₂ O(g)
oxidising or reducing agent?		
species oxidised or reduced?		

(b) (i) Draw the Lewis structure of carbon dioxide. [1]

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(ii) Annotate the Lewis structure in (b)(i) to show the polarity of the bonds by adding the symbols δ+ and δ- as appropriate. [1]

(iii) Explain the molecular geometry and polarity of the carbon dioxide molecule. [2]

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(This question continues on the following page)



(Question 4 continued)

- (iv) State the hybridization of the carbon atom in carbon monoxide and in carbon dioxide. [1]

carbon monoxide:

carbon dioxide:

- (v) State the number of σ and π bonds in a carbon monoxide molecule. [1]

σ bonds:

π bonds:

- (vi) Determine the bond enthalpy of carbon monoxide, in kJ mol^{-1} . Use section 11 of the data booklet and the equation:



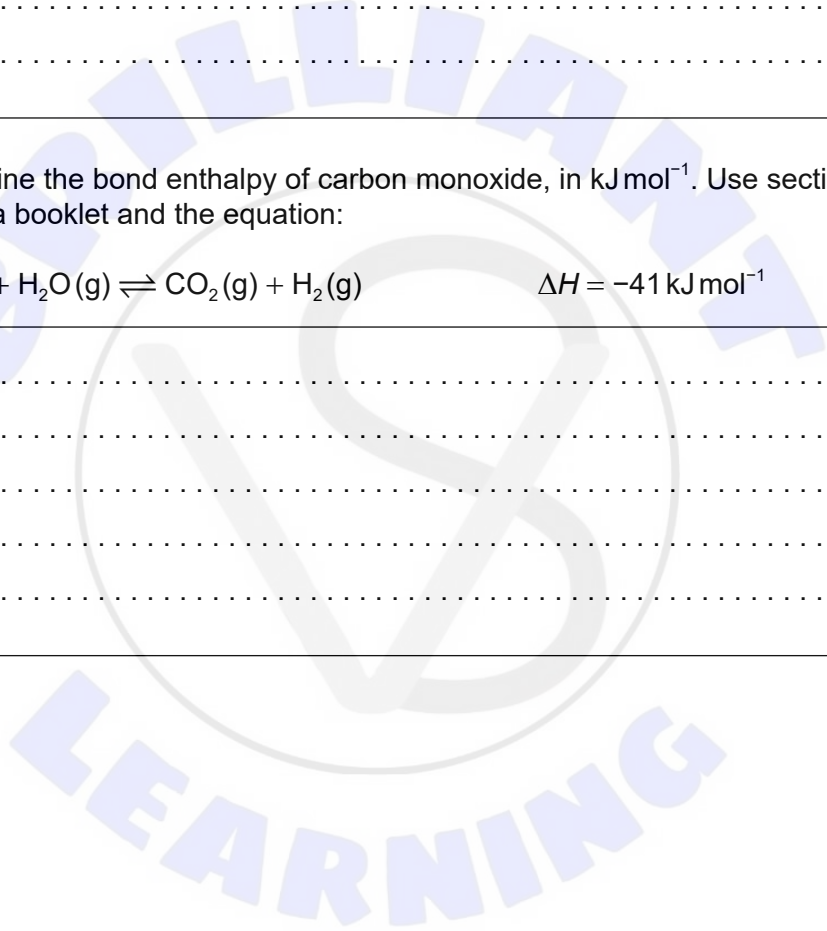
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5. Successive ionization energies of an element (E) are shown. E is not the real symbol of the element.

Number of ionization energy	first	second	third	fourth	fifth	sixth	seventh
IE / kJ mol ⁻¹	1000	2295	3375	4565	6950	8490	27 107

- (a) Identify the group of the periodic table in which element E is located, giving a reason. [1]

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- (b) Element E forms an oxide EO₃. Two possible Lewis structures are shown.

- (i) Show which structure is most likely, using the concept of formal charge. [3]

<p>Structure 1</p> <pre> .. O :: E :: O :: :O: .. </pre>	<p>Structure 2</p> <pre> .. O :: E :: O :: :O: .. </pre>
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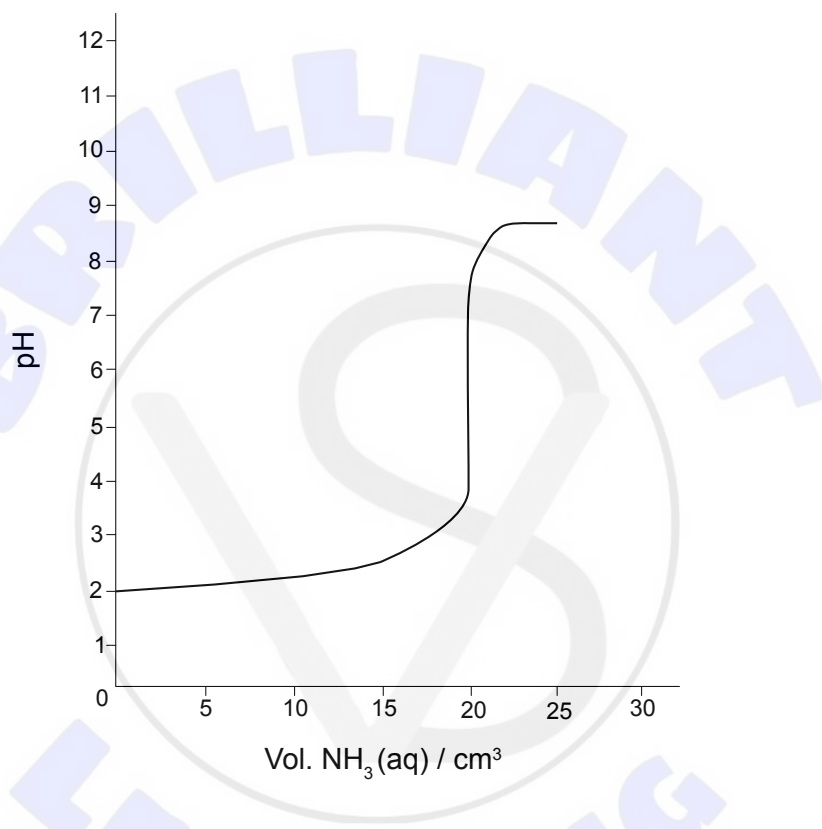


(Question 5 continued)

(ii) Write the balanced equation for the reaction of EO_3 with water. [1]

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(c) A strong acid was titrated with 0.01 mol dm^{-3} ammonia solution, $\text{NH}_3(\text{aq})$. The pH curve for the titration is shown.



(i) Identify the best indicator for this titration, using section 22 of the data booklet. [1]

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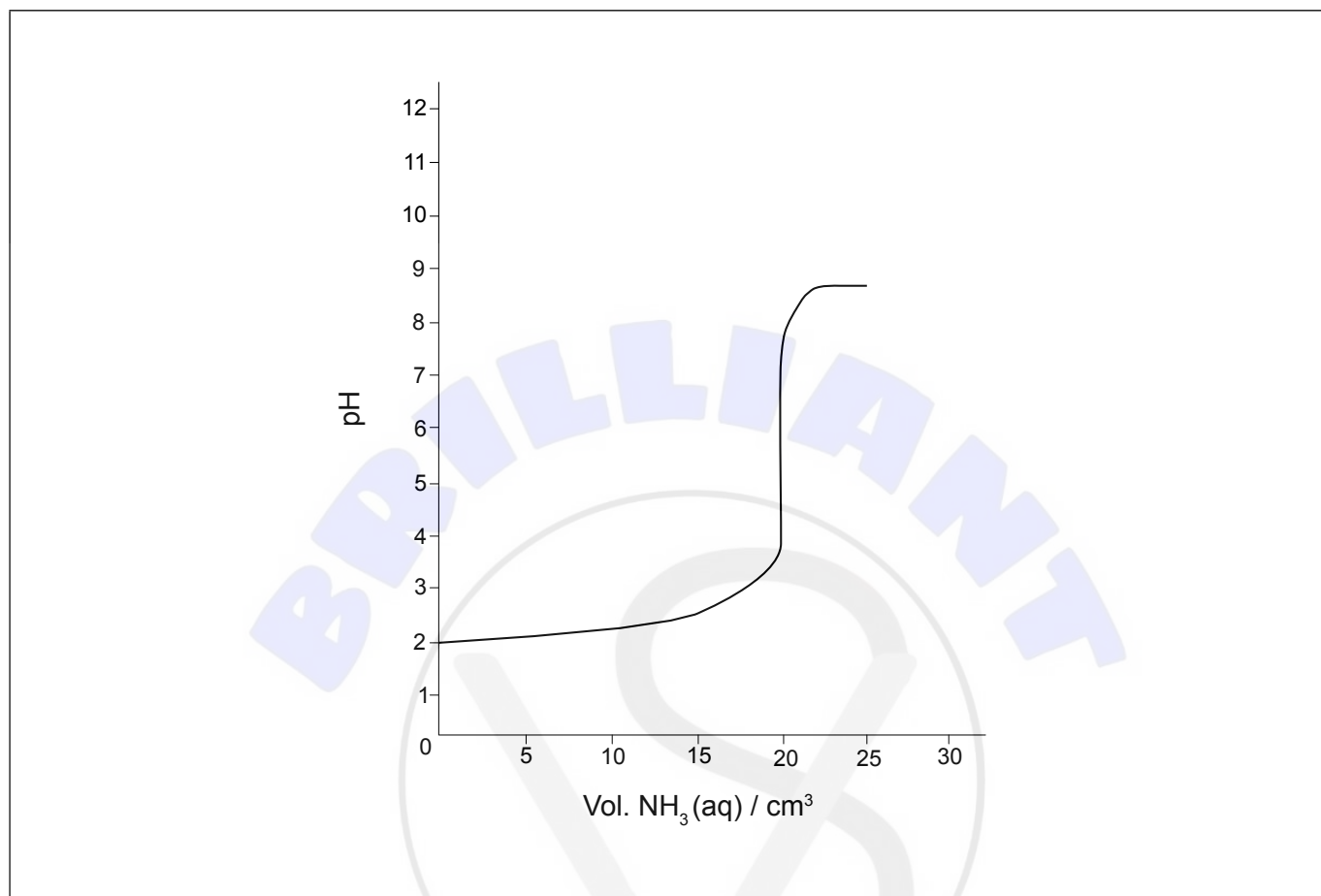
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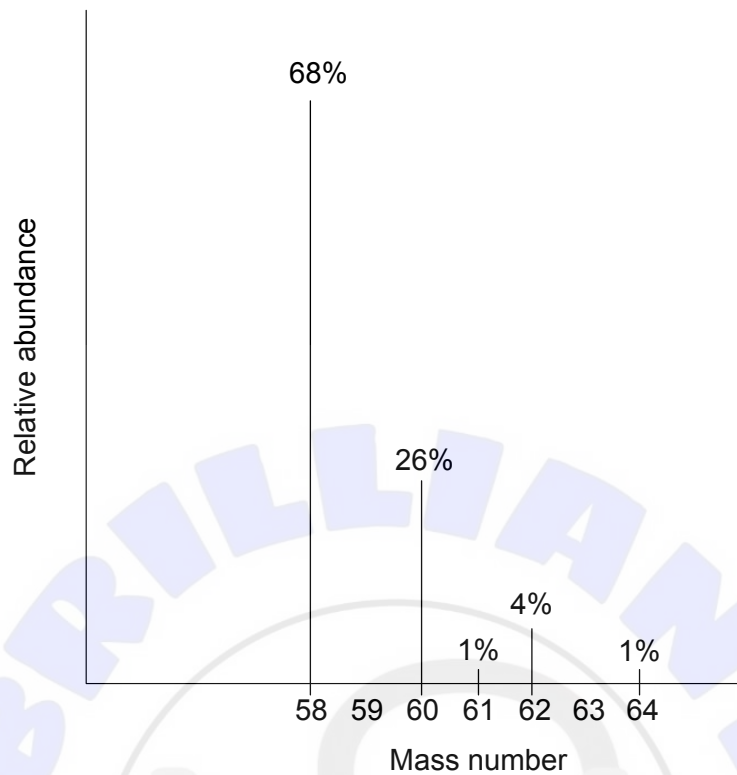
(Question 5 continued)

- (ii) Sketch on the following graph the curve expected if $0.01 \text{ mol dm}^{-3} \text{ NaOH (aq)}$ is used instead of the $0.01 \text{ mol dm}^{-3} \text{ NH}_3 \text{ (aq)}$.

[2]



6. (a) Determine the relative atomic mass of nickel from the mass spectrum shown. [1]



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- (b) (i) Deduce the nuclear symbol, A_ZX , for an ion of nickel-58 with 26 electrons. [1]

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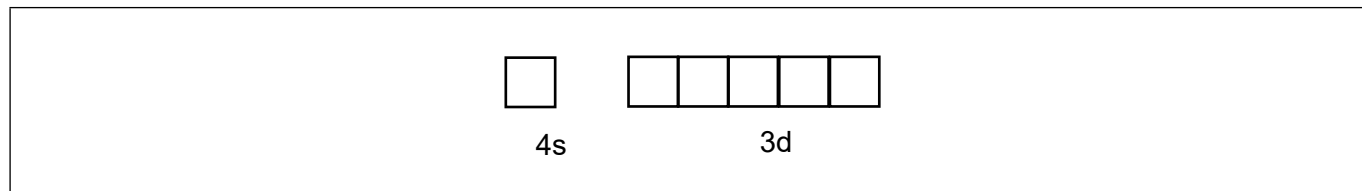
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(Question 6 continued)

- (ii) Draw arrows to represent electrons in the orbital diagram for this ion. [1]



- (iii) Predict, giving a reason, whether Ni²⁺ is para- or diamagnetic. [1]

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- (c) Nickel forms the green complex ion [Ni(H₂O)₆]²⁺

- (i) Explain why [Ni(NH₃)₆]²⁺ is blue-violet. Use sections 15 and 17 of the data booklet. [2]

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- (ii) Identify, with a reason, whether ammonia acts as a Lewis acid or Lewis base in the complex ion, [Ni(NH₃)₆]²⁺. [1]

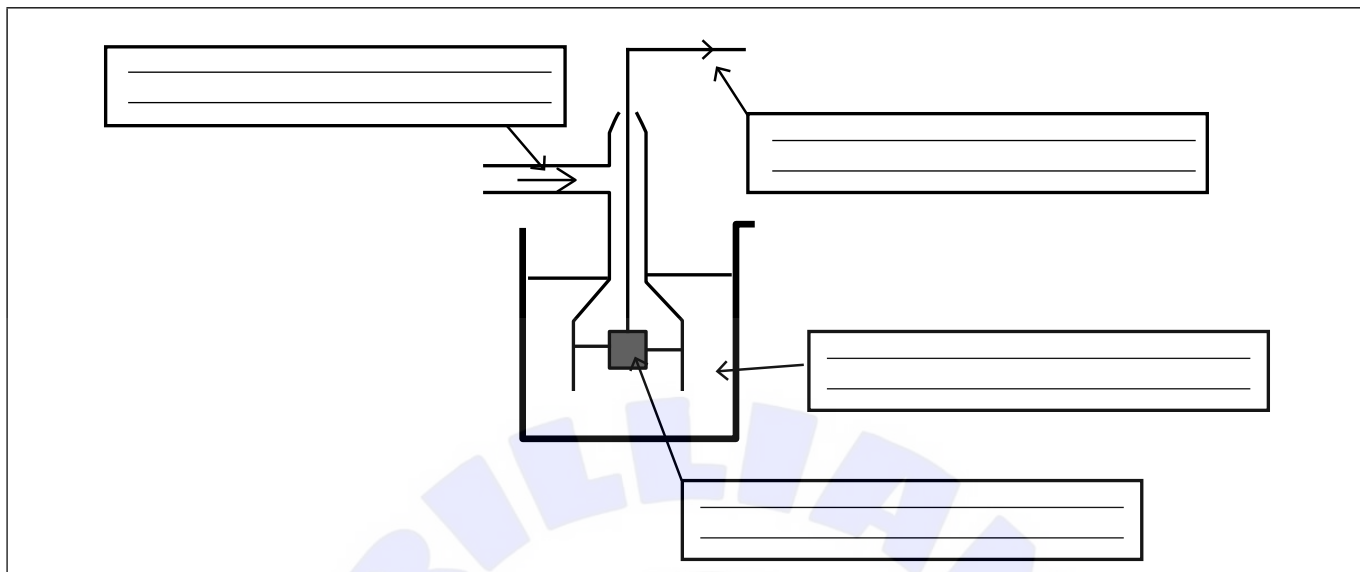
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- (iii) Describe whether ammonia acts as a Brønsted-Lowry acid or base in its reaction with water. Include an equation in your answer. [2]

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7. (a) Label the figure with the essential features of the standard hydrogen electrode, by writing in the boxes. [2]



- (b) A standard hydrogen electrode is connected to a copper-copper (II) nitrate half-cell.

- (i) Formulate a cell diagram for the spontaneous reaction, representing phase boundaries with “|” and the salt bridge with “||”. Use section 24 of the data booklet. [1]

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- (ii) Calculate the standard Gibbs free energy of the cell, in kJ mol^{-1} . Use sections 1, 2 and 24 of the data booklet. [2]

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