

© International Baccalaureate Organization 2024

All rights reserved. No part of this product may be reproduced in any form or by any electronic or mechanical means, including information storage and retrieval systems, without the prior written permission from the IB. Additionally, the license tied with this product prohibits use of any selected files or extracts from this product. Use by third parties, including but not limited to publishers, private teachers, tutoring or study services, preparatory schools, vendors operating curriculum mapping services or teacher resource digital platforms and app developers, whether fee-covered or not, is prohibited and is a criminal offense.

More information on how to request written permission in the form of a license can be obtained from <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

© Organisation du Baccalauréat International 2024

Tous droits réservés. Aucune partie de ce produit ne peut être reproduite sous quelque forme ni par quelque moyen que ce soit, électronique ou mécanique, y compris des systèmes de stockage et de récupération d'informations, sans l'autorisation écrite préalable de l'IB. De plus, la licence associée à ce produit interdit toute utilisation de tout fichier ou extrait sélectionné dans ce produit. L'utilisation par des tiers, y compris, sans toutefois s'y limiter, des éditeurs, des professeurs particuliers, des services de tutorat ou d'aide aux études, des établissements de préparation à l'enseignement supérieur, des fournisseurs de services de planification des programmes d'études, des gestionnaires de plateformes pédagogiques en ligne, et des développeurs d'applications, moyennant paiement ou non, est interdite et constitue une infraction pénale.

Pour plus d'informations sur la procédure à suivre pour obtenir une autorisation écrite sous la forme d'une licence, rendez-vous à l'adresse <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

© Organización del Bachillerato Internacional, 2024

Todos los derechos reservados. No se podrá reproducir ninguna parte de este producto de ninguna forma ni por ningún medio electrónico o mecánico, incluidos los sistemas de almacenamiento y recuperación de información, sin la previa autorización por escrito del IB. Además, la licencia vinculada a este producto prohíbe el uso de todo archivo o fragmento seleccionado de este producto. El uso por parte de terceros —lo que incluye, a título enunciativo, editoriales, profesores particulares, servicios de apoyo académico o ayuda para el estudio, colegios preparatorios, desarrolladores de aplicaciones y entidades que presten servicios de planificación curricular u ofrezcan recursos para docentes mediante plataformas digitales—, ya sea incluido en tasas o no, está prohibido y constituye un delito.

En este enlace encontrará más información sobre cómo solicitar una autorización por escrito en forma de licencia: <https://ibo.org/become-an-ib-school/ib-publishing/licensing/applying-for-a-license/>.

Chemistry Higher level Paper 2

9 May 2024

Zone A morning | Zone B morning | Zone C morning

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]**.



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

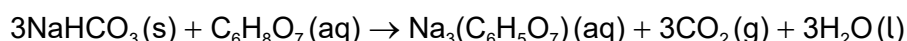
1. A powder has the following percentage composition by mass:

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]

.....

.....

.....

.....

.....

.....

(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]

.....

.....

.....

.....

(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.

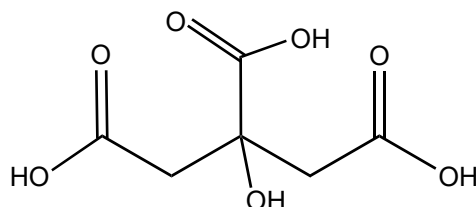
If you did not obtain an answer to (a)(ii), use 0.068 dm^3 , but this is not the correct value.

[1]

.....
.....
.....

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

[1]



.....

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

[1]

.....
.....
.....

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

[1]

.....
.....

(This question continues on page 5)



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

Answers written on this page
will not be marked.



(Question 1 continued)

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

.....
.....
.....

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

.....
.....

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

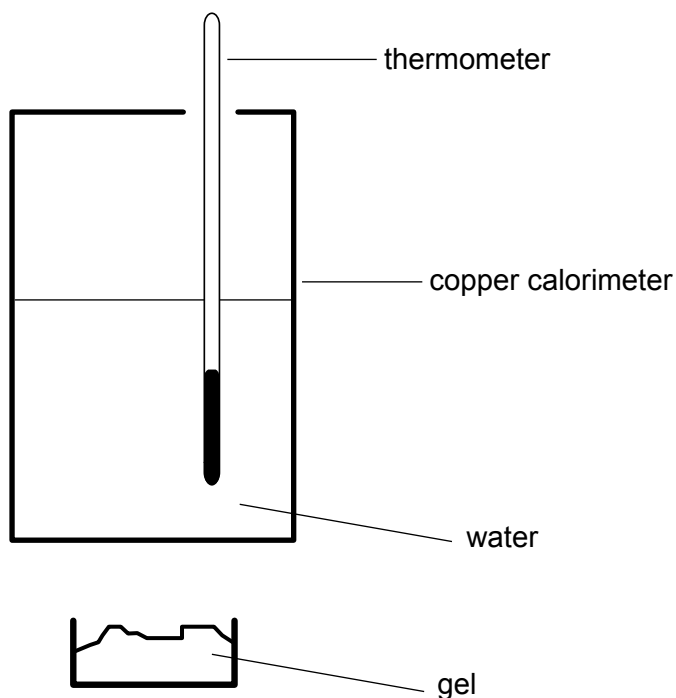
.....
.....
.....

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

.....
.....
.....
.....



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]

.....

.....

.....

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

[2]

.....

.....

.....

(This question continues on the following page)



(Question 2 continued)

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

.....
.....

(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:

.....
.....
.....
.....
.....

Assumption:

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

.....
.....
.....

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

.....
.....

(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]

.....

.....

.....

.....

.....

.....

.....

.....

- (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]

.....

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

.....

.....

.....

(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]

.....

.....

(This question continues on page 11)



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

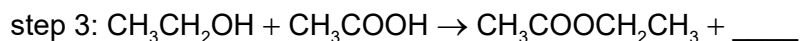
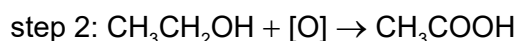
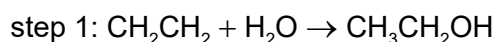
Answers written on this page
will not be marked.



(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]

.....

.....

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

.....

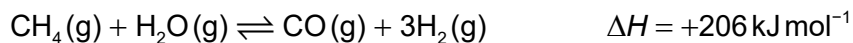
.....

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

.....



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



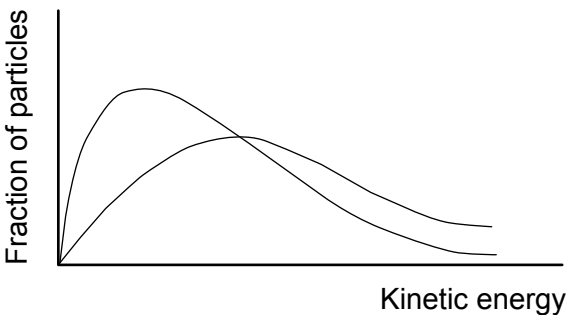
(a) Deduce the equilibrium constant, K_c , expression for the reaction. [1]

.....
.....

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

.....
.....
.....

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



Explanation:

.....
.....
.....

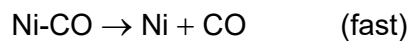
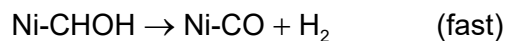
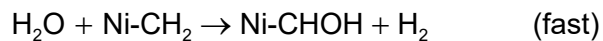
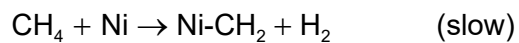
(d) Annotate this Maxwell-Boltzmann distribution graph in (c) to show the effect of a catalyst. [1]

(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]

.....
.....

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

.....
.....
.....

(This question continues on the following page)



(Question 3 continued)

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

[1]

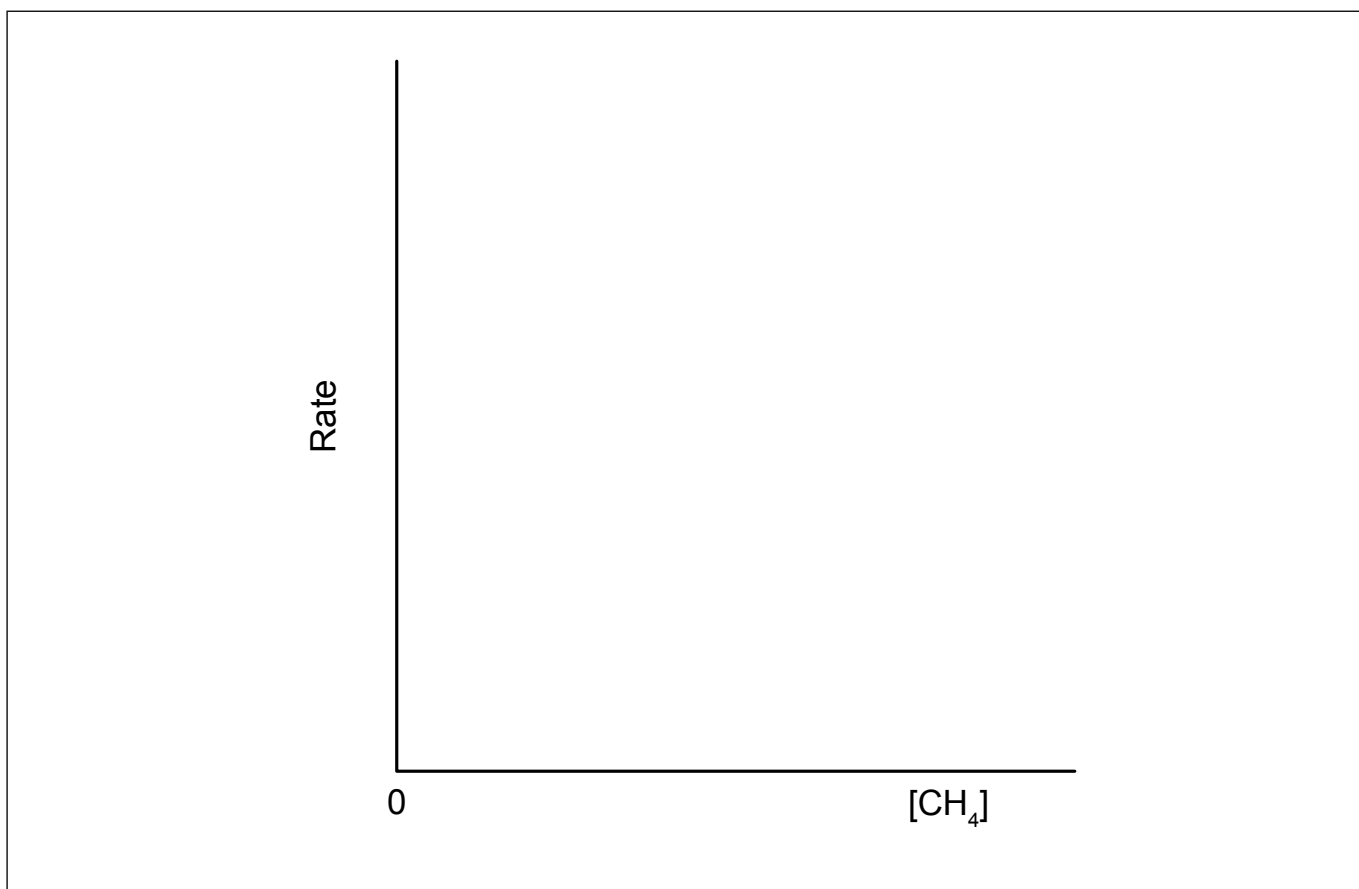
.....

.....

.....

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

[1]

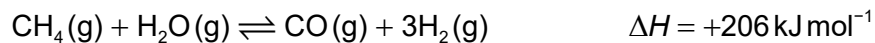


(This question continues on the following page)



(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:

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

.....

.....

.....

- (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]

.....

.....

.....

.....

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

[2]

.....

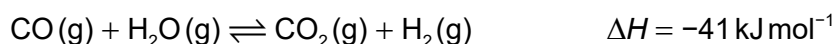
.....

.....

.....



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]

.....
.....
.....
.....

(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]

.....
.....
.....
.....

(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]

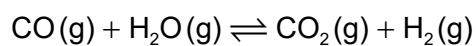
carbon monoxide:
carbon dioxide:

(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:



$$\Delta H = -41 \text{ kJ mol}^{-1}$$

[2]

.....
.....
.....
.....
.....



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]

.....

.....

.....

- (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> $\begin{array}{c} \ddot{\text{O}} \text{ : : } \text{E} \text{ : : } \ddot{\text{O}} \text{ : :} \\ \text{ : } \text{O} \text{ : } \end{array}$	<p>Structure 2</p> $\begin{array}{c} \ddot{\text{O}} \text{ : : } \text{E} \text{ : : } \ddot{\text{O}} \\ \text{ : } \text{O} \text{ : } \end{array}$
---	---

.....

.....

.....

.....

.....

.....

(This question continues on the following page)

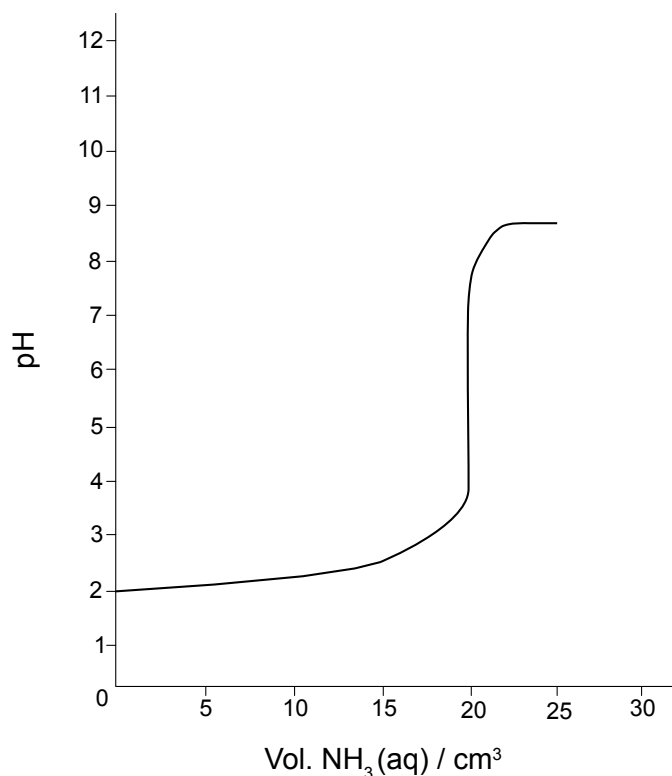


(Question 5 continued)

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

.....
.....

(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]

.....
.....

(This question continues on page 21)



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

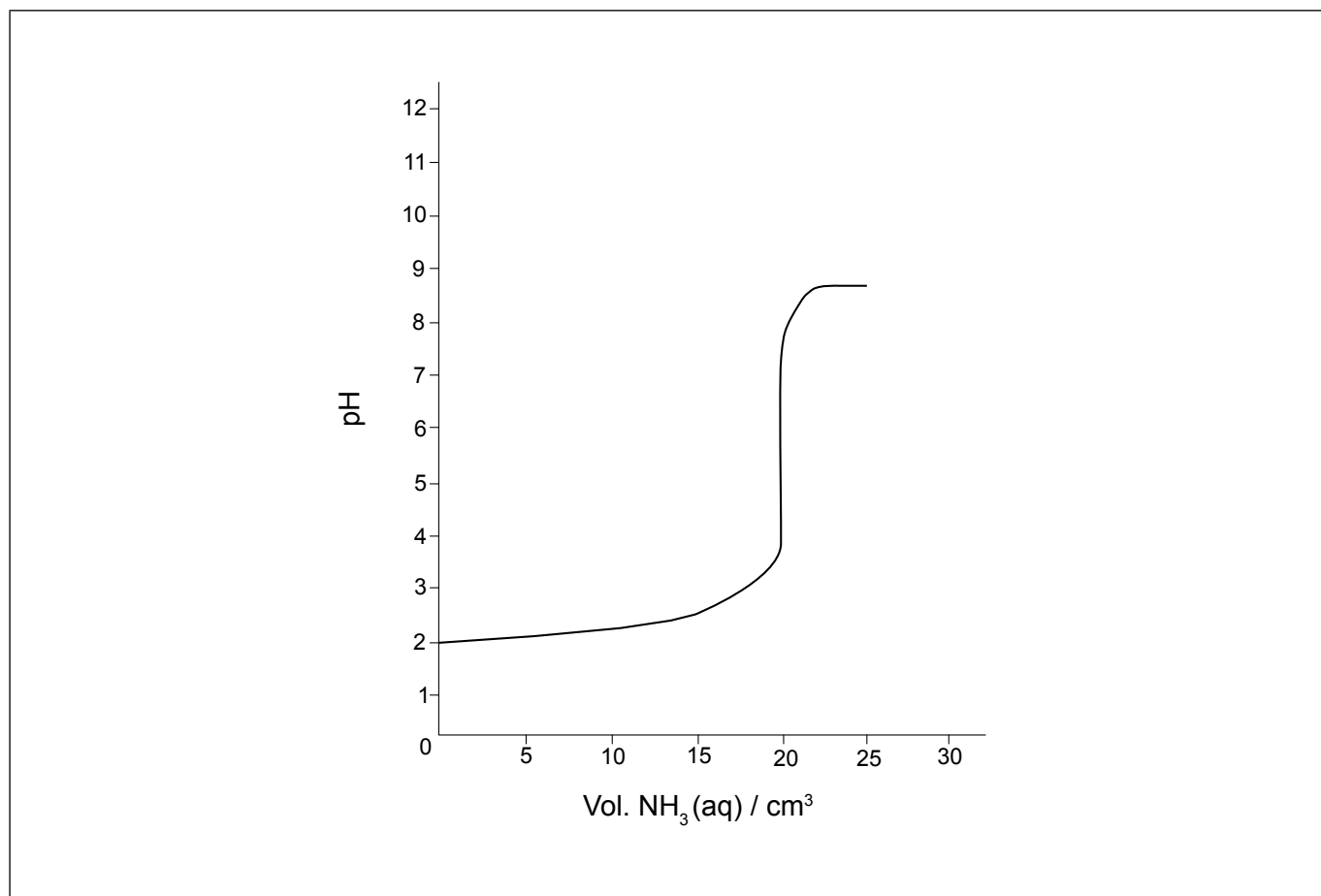
Answers written on this page
will not be marked.



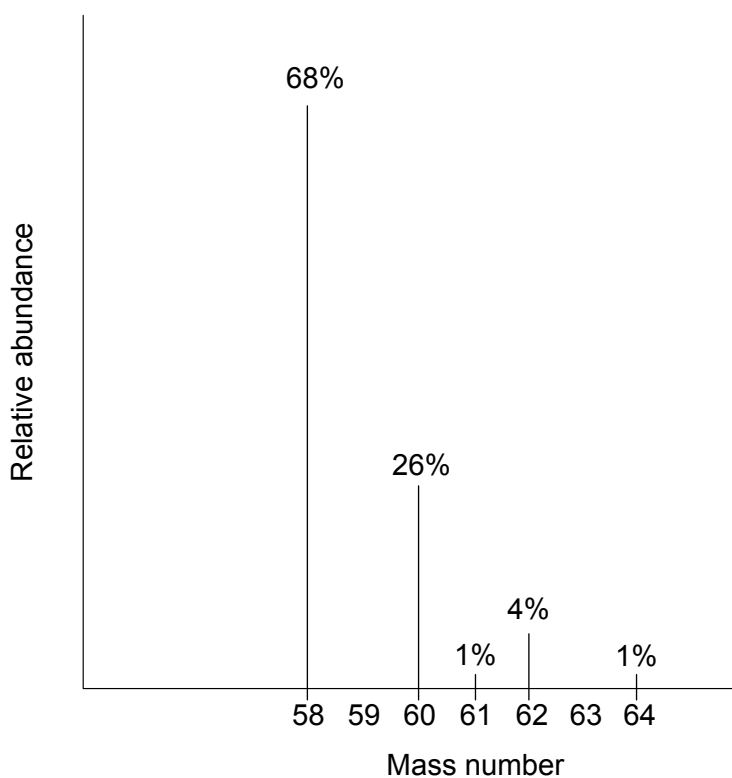
(Question 5 continued)

- (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]



.....

.....

.....

.....

- (b) (i) Deduce the nuclear symbol, ${}^A_Z\text{X}$, for an ion of nickel-58 with 26 electrons. [1]

.....

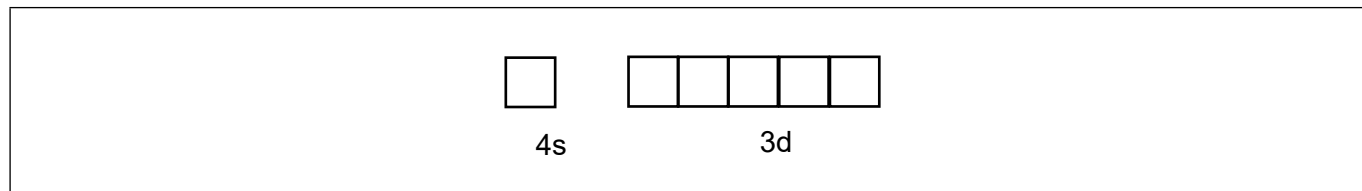
.....

(This question continues on the following page)



(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]

.....
.....

(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]

.....
.....
.....
.....

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

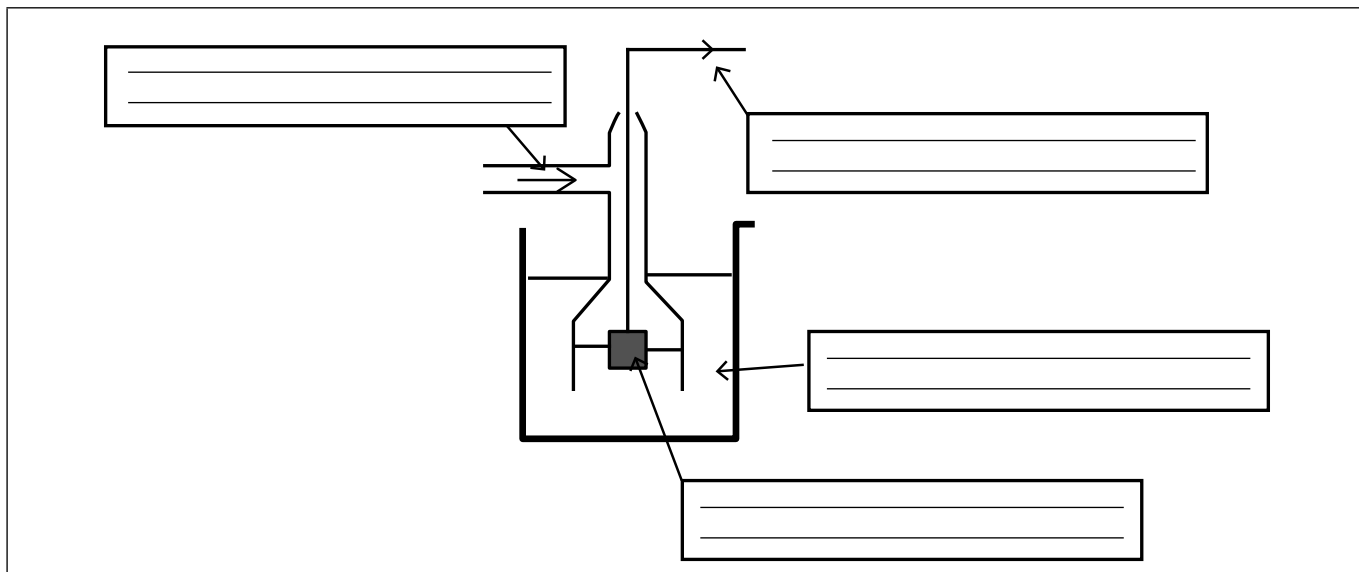
.....
.....
.....

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

.....
.....
.....
.....



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]

.....
.....

- (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]

.....
.....
.....
.....

