

© International Baccalaureate Organization 2025

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 2025

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, 2025

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

19 May 2025

Zone A morning | Zone B morning | Zone C morning

Candidate session number

--	--	--	--	--	--	--	--	--	--

2 hours 30 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. Hydrogen cyanide, HCN, is a very toxic compound.

(a) Pure HCN is a volatile liquid, boiling at 26 °C.

(i) Draw the Lewis formula of the HCN molecule.

[1]

(ii) Deduce the hybridization of the carbon atom and the number of sigma and pi bonds that it forms.

[2]

Hybridization:

Sigma bonds:

Pi bonds:

(iii) State and explain the molecular geometry of HCN without referring to hybridization. [2]

Molecular geometry:

Explanation:

.....

.....

(iv) HCN is a polar molecule. Deduce which atom carries a partial positive charge and which carries a partial negative charge.

[1]

Partial positive charge:

Partial negative charge:

(This question continues on the following page)



(Question 1 continued)

(v) Explain why nitrogen gas, N_2 , has a much lower boiling point than HCN. [2]

.....
.....

(b) HCN acts as a weak acid in aqueous solution.

(i) Write an equation to show this behaviour. [1]

.....
.....

(ii) Outline **two** ways in which you could determine that a solution was 0.1 mol dm^{-3} HCN rather than 0.1 mol dm^{-3} HCl. [2]

Method 1:

.....

Method 2:

.....

(iii) Calculate the pH of a $0.100 \text{ mol dm}^{-3}$ solution, given the K_a of HCN is $4.90 \times 10^{-10} \text{ mol dm}^{-3}$. [2]

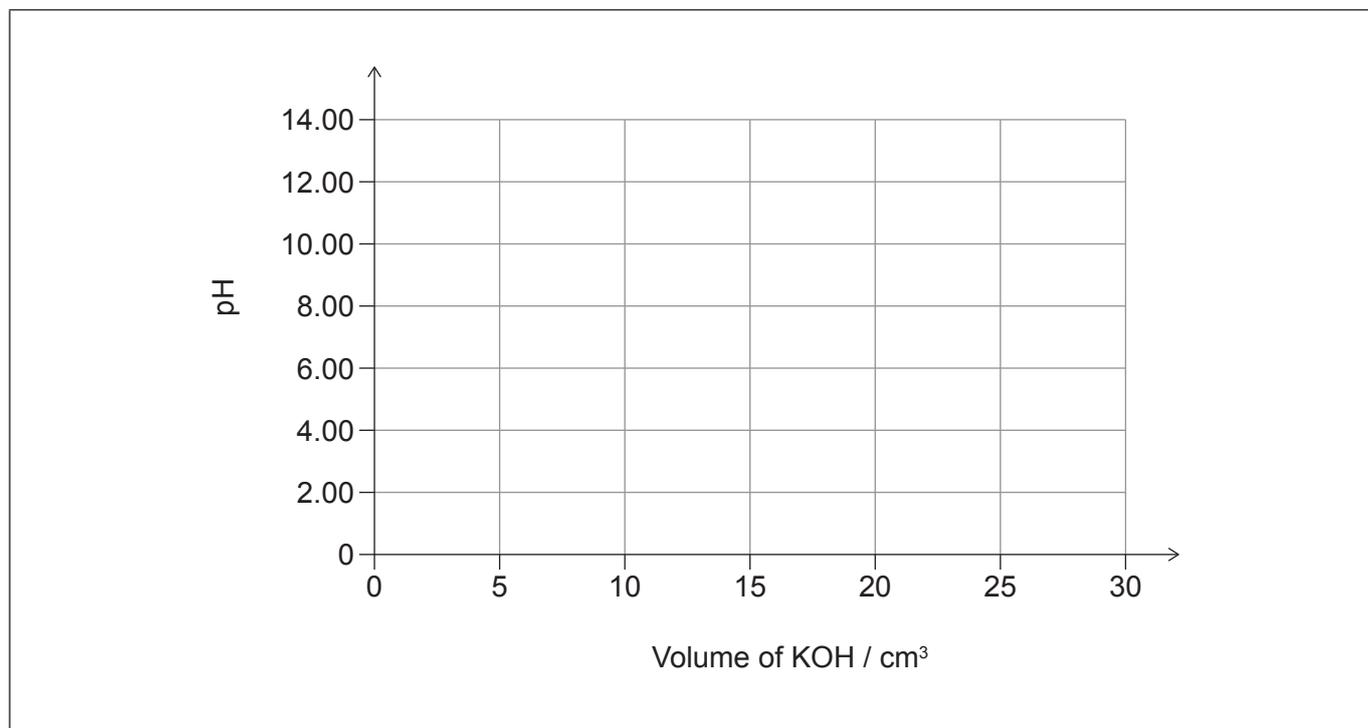
.....
.....
.....
.....
.....

(This question continues on the following page)



(Question 1 continued)

- (iv) Sketch the variation in pH that would occur if 30.0 cm³ of 0.200 mol dm⁻³ KOH was gradually added to 20.0 cm³ of 0.100 mol dm⁻³ HCN. [3]



- (v) Deduce the point on the graph in (b)(iv) at which the solution would only contain KCN(aq) and label it "Salt". [1]

- (vi) Calculate the temperature rise of the solution when 30.0 cm³ of 0.200 mol dm⁻³ KOH is mixed with 20.0 cm³ of 0.100 mol dm⁻³ HCN. Use enthalpy of neutralization of HCN = -13.3 kJ mol⁻¹ and sections 1 and 2 of the data booklet. [2]

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

(This question continues on the following page)



(Question 1 continued)

(c) The cyanide ion, CN^- , can form complex ions, such as $[\text{Fe}(\text{CN})_6]^{4-}$.

(i) State the precise type of bond formation between the cyanide ion and the iron ion. [1]

..... bond

(ii) Deduce the oxidation state of iron in the complex ion. [1]

.....
.....

(iii) Explain why transition element ions, such as $[\text{Fe}(\text{CN})_6]^{4-}$, are usually coloured. [3]

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

(iv) $[\text{Fe}^{2+}]$ is $2.20 \times 10^{-7} \text{ mol dm}^{-3}$ in a 1.00 mol dm^{-3} solution of the complex ion.

Determine the value of the equilibrium constant, K , for the formation of $[\text{Fe}(\text{CN})_6]^{4-}$ from its constituent ions. [3]

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

(This question continues on the following page)



(Question 1 continued)

- (v) Outline, giving a reason, whether $[\text{Fe}(\text{CN})_6]^{3-}$ is a stronger or weaker oxidizing agent than $\text{Fe}^{3+}(\text{aq})$.

Use $E^\ominus [\text{Fe}(\text{CN})_6]^{3-}(\text{aq}) + \text{e}^- \rightleftharpoons [\text{Fe}(\text{CN})_6]^{4-}(\text{aq}) = +0.37\text{V}$ and section 19 of the data booklet.

[2]

.....

.....

.....

.....

.....

- (d) The cyanide ion reacts with iodomethane, CH_3I .

- (i) Draw the structural formula of the organic product.

[1]

.....

- (ii) Predict, giving a reason, whether this reaction will occur by an $\text{S}_\text{N}1$ or $\text{S}_\text{N}2$ mechanism.

[1]

.....

.....

.....

- (iii) Explain how you might **experimentally** conclude whether the mechanism of this reaction is $\text{S}_\text{N}1$ or $\text{S}_\text{N}2$.

[2]

.....

.....

.....

.....

.....



2. Thallium is a heavy metal in group 13 of the periodic table.

(a) 30% of thallium atoms contain 122 neutrons and the remainder 124 neutrons.

(i) Deduce the nuclear symbol of the isotope of thallium containing 122 neutrons. Use section 7 of the data booklet. [1]

	Tl

(ii) Calculate, to **two** decimal places, the relative atomic mass of thallium. [2]

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

(b) Thallium(I) sulfate has the formula Tl_2SO_4 .

(i) The compound contains both ionic and covalent bonds. State which particles are joined by covalent bonds and which are joined by ionic bonds. [2]

Covalent bond between:	and
Ionic bond between:	and

(ii) Contrast covalent and ionic bonds based on the valence electron interactions. [1]

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

(This question continues on the following page)



Turn over

(Question 2 continued)

- (iii) State the enthalpy term that characterises the strength of the bonding between the ions in an ionic solid. [1]

.....
.....

- (iv) Write an equation for producing thallium (I) sulfate solution by reacting solid thallium (I) hydroxide with sulfuric acid. [2]

.....
.....

- (v) Calculate the volume of 2.00 mol dm^{-3} sulfuric acid required to react completely with 10.0g of thallium (I) hydroxide. [3]

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

- (vi) Predict whether or not thallium (I) hydroxide is amphoteric, considering the position of thallium in the periodic table. [1]

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

(This question continues on the following page)



(Question 2 continued)

(vii) Discuss how the relative reactivity of copper and thallium could be established using the metals and aqueous solutions of their sulfates. [2]

.....

.....

.....

.....

.....

(viii) Discuss the products at the electrodes when aqueous thallium (I) sulfate is electrolyzed.

Use standard reduction potential of $Tl^+(aq) + e^- \rightleftharpoons Tl(s) = -0.34 V$ and section 19 of the data booklet. [2]

Anode (positive electrode):

.....

.....

Cathode (negative electrode):

.....

.....

(This question continues on the following page)



(Question 2 continued)

(c) Thallium has an atomic emission spectrum with a strong green line.

(i) State the feature of the atomic emission spectrum that may be used to find the ionization energy of the element. [1]

.....
.....

(ii) Calculate the wavelength that corresponds to the ionization energy of thallium. Use sections 1, 2 and 9 of the data booklet. [3]

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

(iii) Explain why, in terms of nuclear charge and the shielding of the valence electrons, the first ionization energy of thallium is lower than that of lead. [2]

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



3. Phosgene (carbonyl dichloride, Cl_2CO) is an important industrial intermediate.

(a) Phosgene may be formed by the free-radical reaction between carbon monoxide, CO , and chlorine, Cl_2 , which is initiated by UV light.

(i) Write an equation for the initiation reaction. [1]

.....
.....

(ii) State the type of bond fission that is occurring. [1]

.....
.....

(iii) Determine the enthalpy change for the reaction between carbon monoxide and chlorine from bond enthalpies. Use section 12 of the data booklet. [3]

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

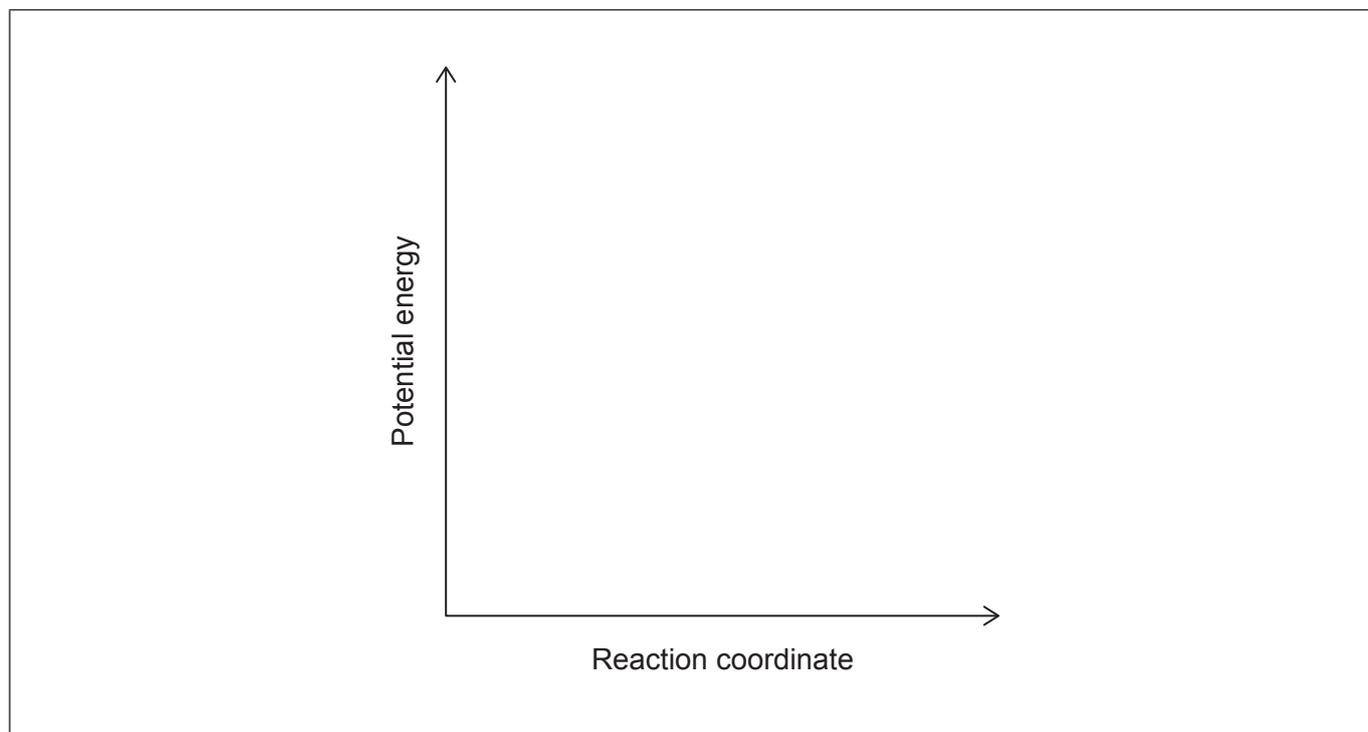
(This question continues on the following page)



(Question 3 continued)

- (iv) Sketch an energy profile for this reaction and label the "Reactants", "Products" and " ΔH ".

[2]



- (v) Calculate the standard entropy change, ΔS^\ominus , of the reaction between carbon monoxide and chlorine to form phosgene. Use section 13 of the data booklet and the following data:

Standard entropy S^\ominus , of chlorine = $223 \text{ J mol}^{-1} \text{ K}^{-1}$

Standard entropy S^\ominus , of phosgene = $284 \text{ J mol}^{-1} \text{ K}^{-1}$

[1]

.....

.....

.....

(This question continues on the following page)



(Question 3 continued)

- (vi) Deduce whether the reaction would go to completion or reach equilibrium at 298 K. Use sections 1 and 2 of the data booklet along with your answers to (a)(iii) and (a)(v).

If you did not get an answer to (a)(iii) and/or (a)(v) use the following values, though these are not the correct answers: (a)(iii) = -120 kJ mol^{-1} , (a)(v) = $-150 \text{ J mol}^{-1} \text{ K}^{-1}$.

[3]

.....

.....

.....

.....

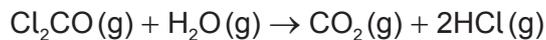
.....

.....

.....

.....

- (b) Phosgene gradually decomposes in the environment according to the equation:



- (i) Suggest how the rate of this reaction could be followed at constant temperature. [1]

.....

.....

.....

- (ii) Outline why some collisions between reactant molecules do not result in a reaction occurring. [2]

.....

.....

.....

.....

.....

(This question continues on the following page)



(Question 3 continued)

- (iii) Write the rate equation for the reaction if it is first order with respect to each reactant.

[1]

.....
.....

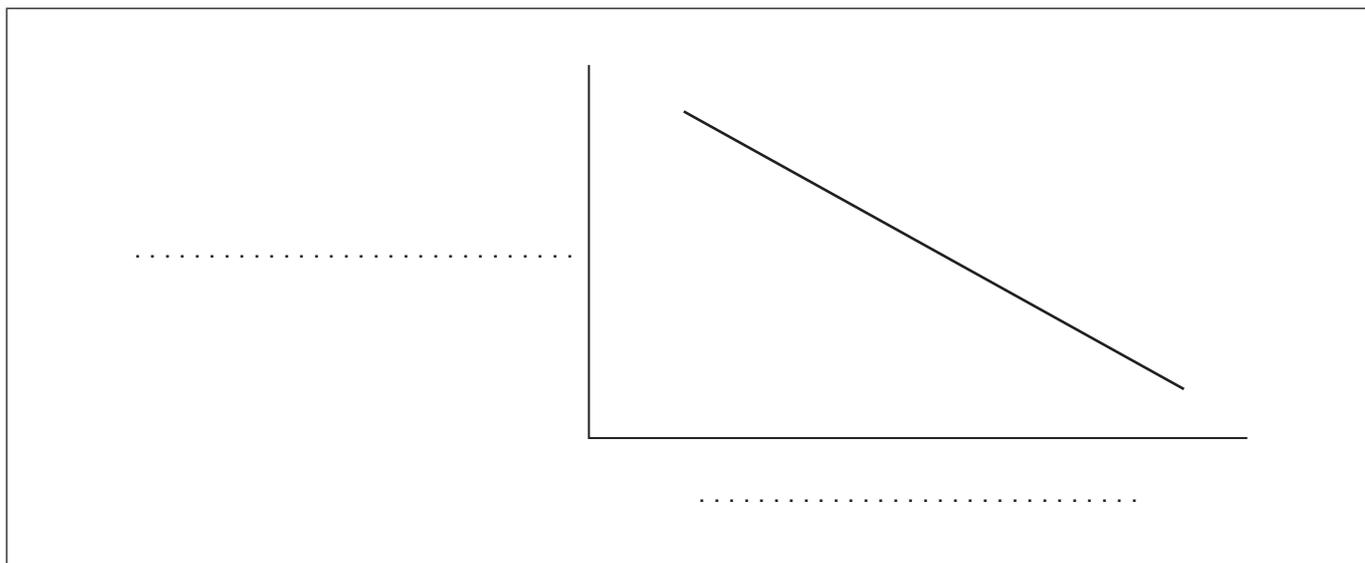
- (iv) If the reaction occurs in a dilute aqueous solution of phosgene it appears to be first order overall.

Outline why this is consistent with the answer to (b)(iii).

[1]

.....
.....

- (v) The activation energy of this reaction was found by measuring the reaction rate over a range of absolute temperatures, T . The following graph was plotted:



State and label the axes of the graph.

[1]

- (vi) Calculate the gradient of the line on the graph in (b)(v) if the activation energy is 12 kJ mol^{-1} . Use sections 1 and 2 of the data booklet.

[1]

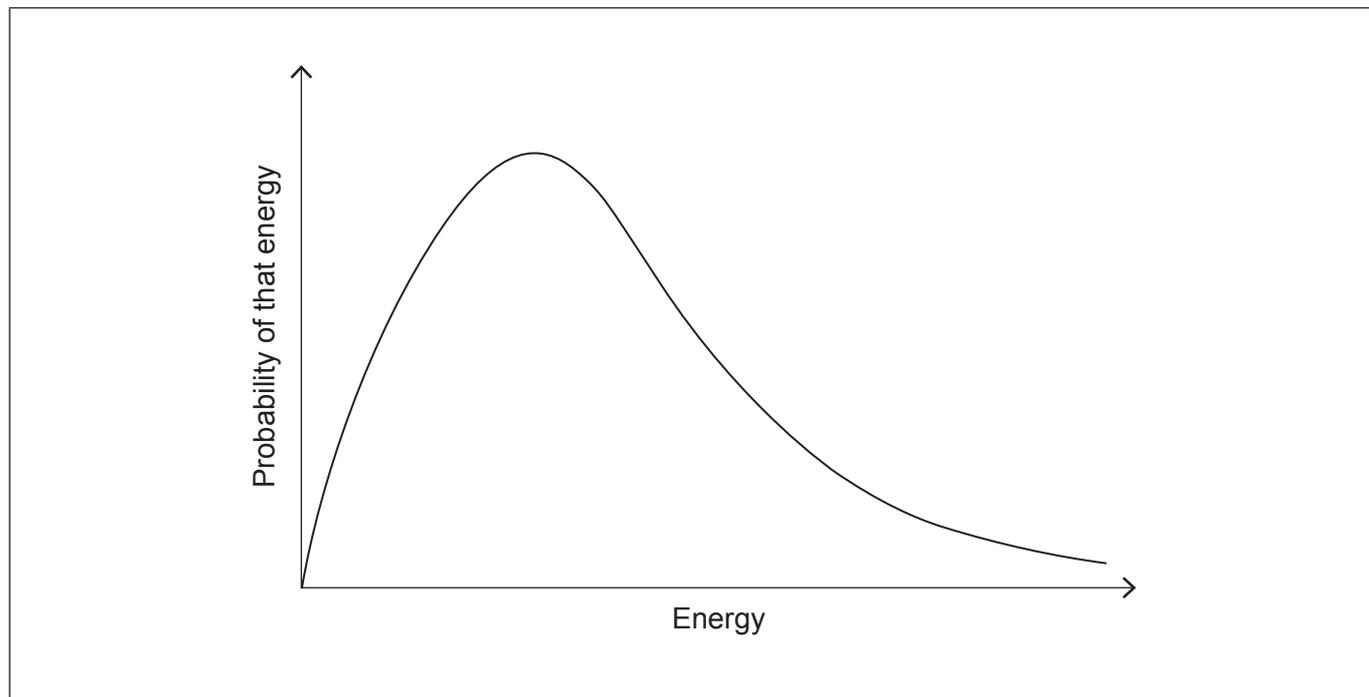
.....
.....
.....

(This question continues on the following page)



(Question 3 continued)

(vii) Sketch a Maxwell-Boltzmann energy distribution curve at a higher temperature than the one shown. [1]



(viii) Explain why the rate of reaction increases as the temperature is increased. Support your answer by annotating the diagram in (b)(vii). [2]

.....

.....

.....

(ix) Describe **two** observations which confirm that a solid, added to the reaction mixture, is acting as a catalyst. [2]

.....

.....

.....

.....

(This question continues on page 17)



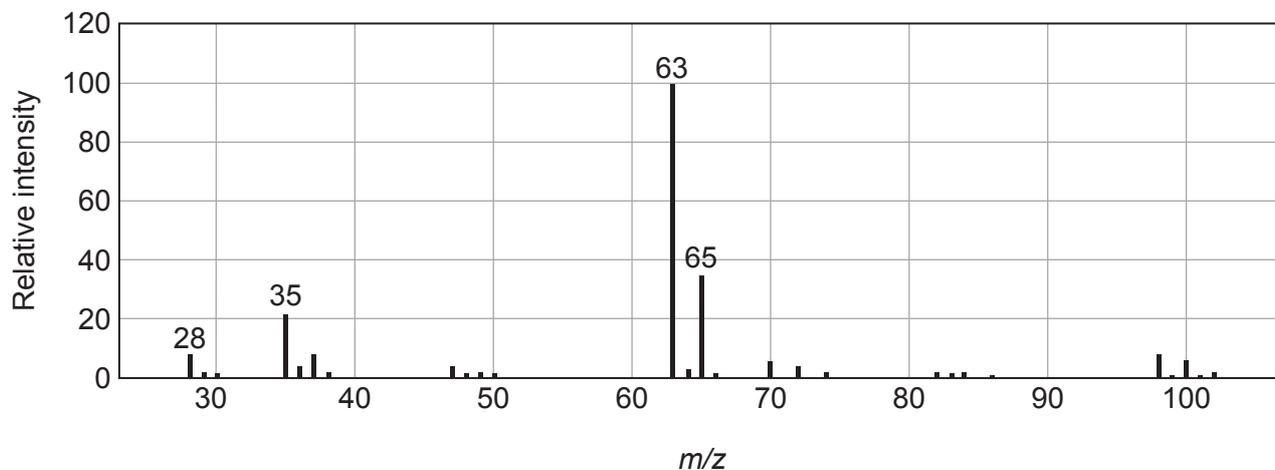
Please **do not** write on this page.

Answers written on this page
will not be marked.



(Question 3 continued)

(c) The mass spectrum of phosgene is shown.



[Source: Used with permission. © United States of America as represented by the Secretary of Commerce.]

(i) Outline why there are peaks at m/z values less than that of the molecular ion. [1]

.....

.....

(ii) Deduce the formula of the fragment that occurs at $m/z = 63$. [1]

.....

.....

(iii) Predict the main features of IR and ^1H NMR spectra of phosgene. Use section 20 of the data booklet. [2]

IR:

.....

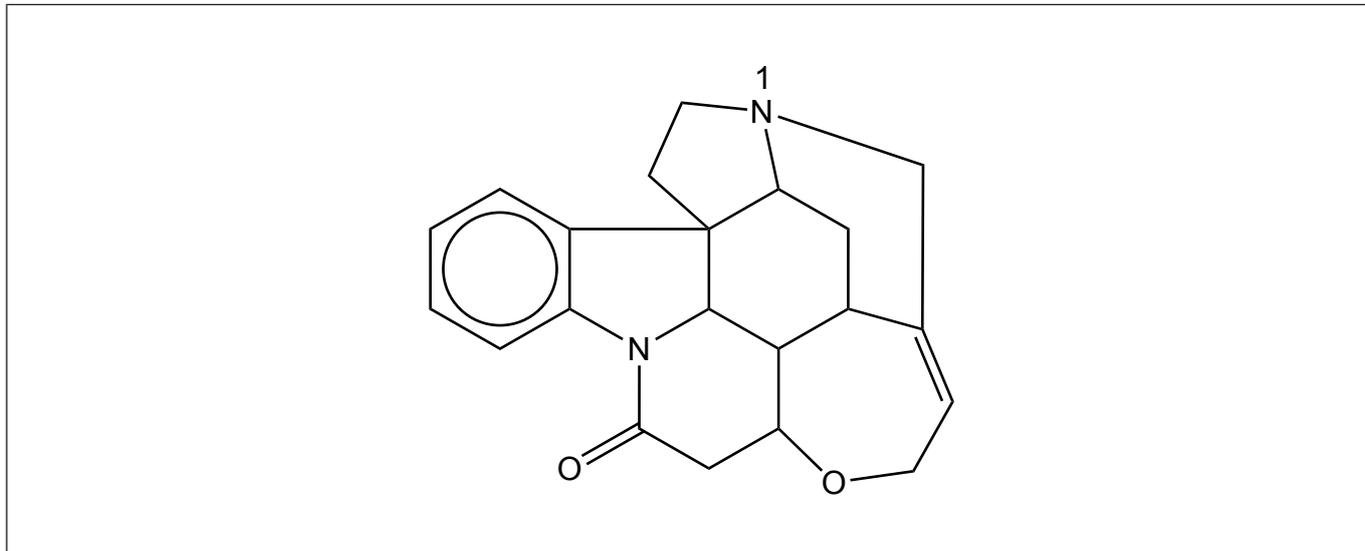
^1H NMR:

.....



4. Strychnine, $C_{21}H_{22}N_2O_2$ ($M_r = 334.4$), is a white crystalline solid obtained from plants.

(a) The formula of strychnine is:



(i) State the name of the functional group containing the nitrogen atom labelled "1". [1]

.....
.....

(ii) Outline how the functional group containing N_1 affects the pH when strychnine is dissolved in water. [1]

Direction of pH change:
Reason for change:
.....

(iii) Circle a functional group that would react with bromine in the dark on the diagram in (a). [1]

(iv) State the number of rings in strychnine's structure. [1]

.....
.....

(This question continues on the following page)



(Question 4 continued)

- (v) The strychnine structure contains *chiral* carbon atoms. Outline what is meant by this term. [1]

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

- (b) 48.73 g of strychnine was converted into its sulfate by the reaction:



Determine the percentage yield if 51.41 g of product was obtained. Use section 7 of the data booklet. [2]

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



Disclaimer:

Content used in IB assessments is taken from authentic, third-party sources. The views expressed within them belong to their individual authors and/or publishers and do not necessarily reflect the views of the IB.

References:

3(c) Used with permission. © United States of America as represented by the Secretary of Commerce.

All other texts, graphics and illustrations © International Baccalaureate Organization 2025



20EP20