

© International Baccalaureate Organization 2023

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 2023

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, 2023

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 3

11 May 2023

Zone A afternoon | Zone B morning | Zone C 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.
- 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 **[45 marks]**.

Section A	Questions
Answer all questions.	1 – 2

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	3 – 5
Option B — Biochemistry	6 – 14
Option C — Energy	15 – 17
Option D — Medicinal chemistry	18 – 28



Section A

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

1. One definition of atomic volume is given by the formula:

$$\text{Atomic volume} = \frac{\text{atomic mass (g mol}^{-1}\text{)}}{\text{density (g cm}^{-3}\text{)}}$$

The table gives the atomic volumes of the first nineteen elements, in the form in which they occur at STP.

Key:

0	← Atomic number
0.000	← Atomic volume (cm ³ mol ⁻¹)

1 11 240							2 22 400
3 13.00	4 4.870	5 4.620	6 5.459 (3.419)	7 11 200	8 11 200 (7460)	9 11 200	10 22 420
11 23.70	12 13.97	13 9.993	14 12.06	15 16.99 (13.24)	16 15.49 (16.36)	17 11 080	18 22 390
19 43.93	20 ?						

- (a) Outline why many elements have atomic volumes greater than 10 000 cm³ mol⁻¹. [1]

.....

.....

- (b) Outline why some of those with larger atomic volumes have values ~11 000 cm³ mol⁻¹ and others ~22 000 cm³ mol⁻¹. [1]

.....

.....

.....

(This question continues on the following page)



(Question 1 continued)

- (c) Suggest why some elements, such as carbon and oxygen, have more than one value for their atomic volume. [1]

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

- (d) Explain why the atomic volumes of elements 11, 12 and 13 show a steady decrease. [2]

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

- (e) Estimate the atomic volume, in $\text{cm}^3 \text{mol}^{-1}$, of element 20. [1]

.....
.....

- (f) Suggest, giving **one** reason, whether you could ever know the actual volume of a single atom. [1]

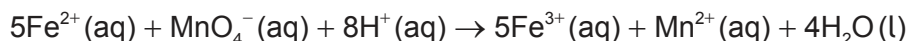
.....
.....
.....



2. To investigate how much kale would supply the daily recommended intake of iron a student:

- 1 weighed 79.6 g of kale leaves and blended with 500 cm³ of water
- 2 boiled, filtered and cooled
- 3 pipetted 10.0 cm³ of the filtrate into 20.0 cm³ of 2.00 mol dm⁻³ sulfuric acid in a flask
- 4 titrated with 0.00100 mol dm⁻³ potassium manganate (VII).

The reaction taking place is:



(a) All species are almost colourless except for MnO₄⁻, which has an intense purple colour, though the kale extract is coloured by the chlorophyll present.

(i) State the colour change at the end point. [1]

From:
To:

(ii) Outline how the addition of distilled water to the 10.0 cm³ aliquot before titration will affect the titrant volume at the end point. [1]

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

(b) State the class of errors that always affect results in a particular direction. [1]

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

(This question continues on the following page)



(Question 2 continued)

(c) The end point occurred when $3.1 \pm 0.1 \text{ cm}^3$ of the titrant had been added.

(i) Calculate the percentage uncertainty associated with the titre. [1]

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

(ii) Suggest **one** procedural modification which would reduce the percentage uncertainty for a single titration, other than using a burette with greater precision. [1]

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

(iii) The solution in the titration flask contained $8.66 \times 10^{-4} \text{ g}$ of iron. Determine, to three significant figures, the percentage of iron, by mass, in the kale leaves. [2]

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

(d) The value obtained is about 30 times greater than published values for the percentage of iron in kale. Suggest **one** reason, other than human error, why there might be such a large discrepancy. [1]

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



36EP05

Turn over

Section B

Answer **all** of the questions from **one** of the options. Answers must be written within the answer boxes provided.

Option A — Materials

3. Most metals have to be extracted from an ore. The way in which this is carried out depends on the reactivity of the metal.

(a) Identify a metal produced by reacting its oxide with carbon or carbon monoxide. Use section 25 of the data booklet. [1]

.....
.....

(b) Aluminium is produced by electrolytic reduction of a solution of aluminium oxide, Al_2O_3 , in molten cryolite, Na_3AlF_6 .

(i) Write the half equation for the reaction at the electrode where aluminium is formed. [1]

.....
.....

(ii) Calculate the atom economy for the production of aluminium from its oxide, assuming the products do not react with the electrodes. Use section 1 of the data booklet. [1]

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

(iii) Suggest **one** factor, other than atom economy, that indicates the production of aluminium from its ore has a significant environmental impact. [1]

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

(Option A continues on the following page)



(Option A, question 3 continued)

- (iv) Deduce why pure molten aluminium oxide is a poor conductor of electricity. Use sections 8 and 29 of the data booklet. [2]

.....

.....

.....

.....

.....

- (c) Inductively coupled plasma (ICP) techniques can be used to estimate the concentration of other metals in the aluminium produced.

- (i) Describe the plasma state. [1]

.....

.....

.....

- (ii) Explain how different metals are identified, and their concentrations determined, if ICP is coupled with Optical Emission Spectroscopy (OES). [2]

Identification:

.....

Concentration:

.....

(Option A continues on page 9)



36EP07

Turn over

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

Answers written on this page
will not be marked.



36EP08

(Option A, question 3 continued)

- (d) An aluminium matrix can be reinforced with carbon nanotubes. Outline why carbon nanotubes are so strong and rigid.

[1]

.....

.....

.....

(Option A continues on the following page)

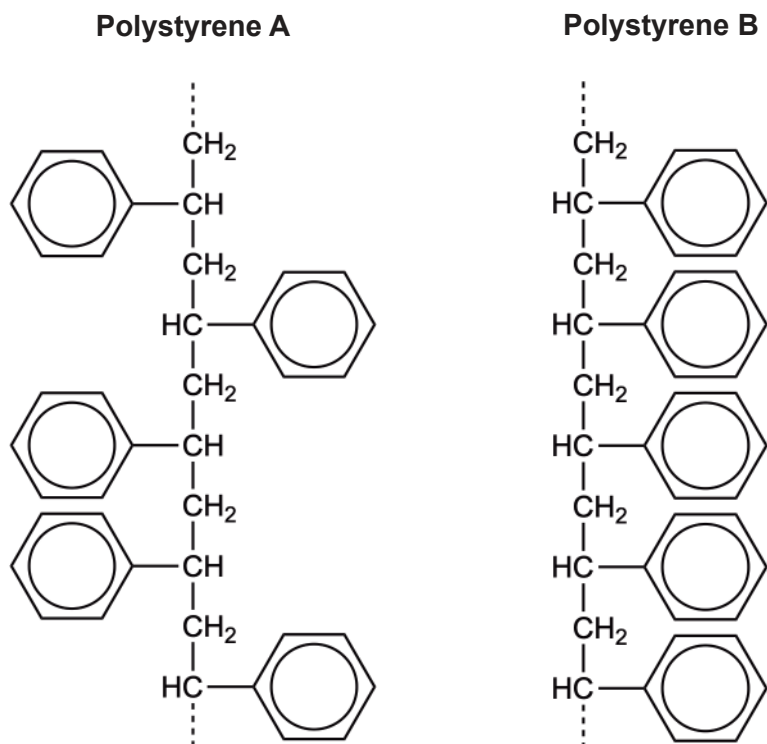


36EP09

Turn over

(Option A continued)

4. Sections of two forms of polystyrene are shown:



(a) (i) Draw the structural formula of the monomer from which they were formed.

[1]

(Option A continues on the following page)



36EP10

(Option A, question 4 continued)

(ii) Identify, giving **one** reason, the form with the higher melting point. [1]

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

(b) Explain how a substance in the same phase as the reactants can reduce the activation energy and act as a catalyst. [2]

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

(c) Solutions of substituted polystyrenes can form lyotropic liquid crystals. Outline how lyotropic liquid crystals differ from other liquid crystals. [1]

.....
.....

(Option A continues on the following page)



36EP11

Turn over

(Option A, question 4 continued)

(d) Expanded polystyrene (EPS) is a useful material.

(i) Explain how polystyrene is converted to EPS.

[2]

.....

.....

.....

.....

.....

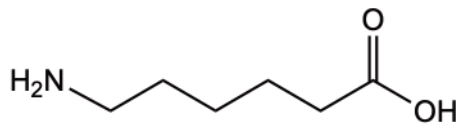
(ii) State **one** property of EPS that makes it a useful material.

[1]

.....

.....

Nylon-6 is a polymer that can be formed from the monomer:



(e) State the type of polymerization reaction that occurs and the structural characteristic of the monomer that allows this type of polymerization to occur.

[2]

Type of polymerization:

.....

Structural characteristic:

.....

(Option A continues on the following page)



(Option A, question 4 continued)

(f) Outline why plastics do not break down easily in the environment. [1]

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

(g) State the RIC number for polyamide plastic (nylon). Use section 30 of the data booklet. [1]

.....
.....

(Option A continues on the following page)



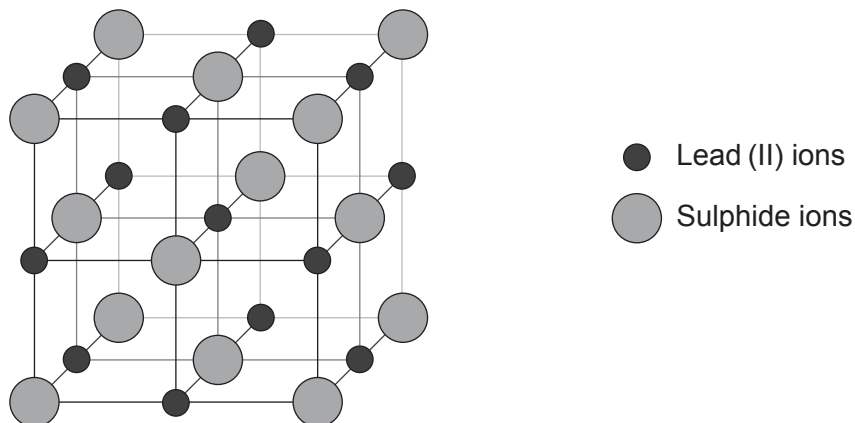
36EP13

Turn over

(Option A continued)

5. Lead can be removed from waste water by precipitation, for example as lead (II) sulfide, PbS, or lead (II) hydroxide, Pb(OH)₂.

(a) The unit cell of lead (II) sulfide is shown:



(i) State the coordination number of the lead (II) ion. [1]

.....
.....

(ii) There are 14 sulfide ions shown in the diagram. Explain why the unit cell is only considered to contain 4 sulfide ions. [2]

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

(iii) Identify **one** technique that could be used to determine the structure of lead (II) sulfide. [1]

.....
.....

(Option A continues on the following page)



(Option A, question 5 continued)

- (b) Lead hydroxide is best precipitated at pH 9. Determine the concentration of lead (II) ions present in an aqueous solution of a lead (II) salt at pH 9. Use section 32 of the data booklet.

[3]

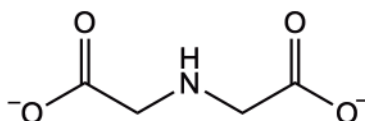
.....
.....
.....
.....
.....

- (c) An alternative method of removing lead (II) ions from aqueous solutions is chelation. A possible ligand for this is the anion of iminodiacetic acid.

Draw circles around the atoms on the following ligand, that would bond to the lead (II) ion when it forms a complex ion.

[1]

Anion of iminodiacetic acid



End of Option A



36EP15

Turn over

Option B — Biochemistry

6. State an equation for aerobic respiration. [1]

.....

7. Proteins are large polymers of 2-amino acids.

(a) Describe the interactions between amino acids occurring at the primary, secondary and tertiary levels within a protein. [3]

Structure Level	Interactions between amino acids
Primary
Secondary
Tertiary

(b) Explain how paper chromatography can separate and identify mixtures of amino acids. [2]

.....
--

(Option B continues on the following page)



(Option B, question 7 continued)

(c) Explain the concept of product inhibition in metabolic pathways.

[2]

.....

.....

.....

.....

.....

.....

(Option B continues on the following page)



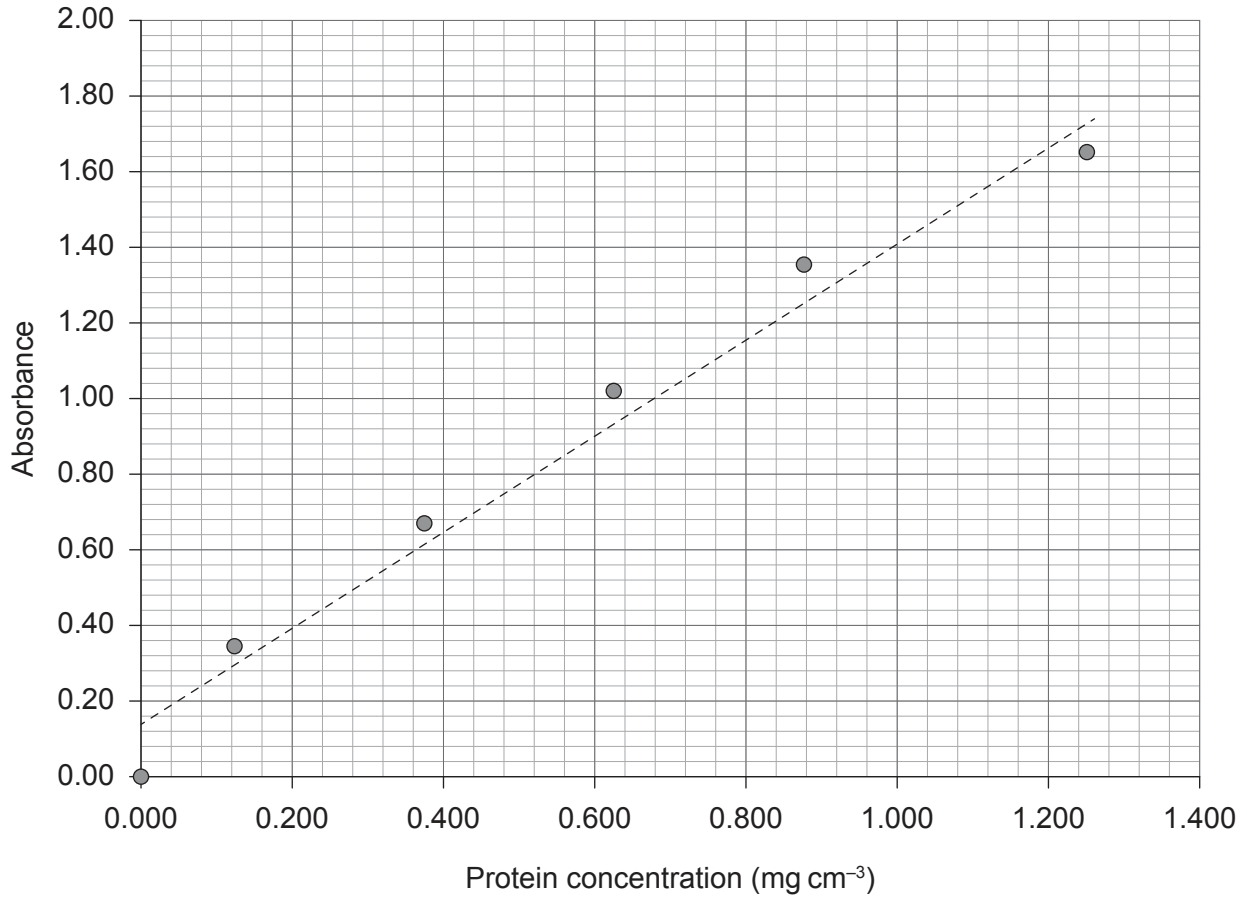
36EP17

Turn over

(Option B, question 7 continued)

The following diagram shows a protein calibration curve.

Protein calibration curve



(d) State the concentration, in mg cm⁻³, of a protein sample with an absorbance of 0.80. [1]

.....

.....

(Option B continues on the following page)



36EP18

(Option B continued)

8. Lipids are another group of biomolecules.

(a) Compare the hydrolytic and oxidative rancidity and contrast the site where the chemical changes occur. [2]

Compare rancidity:

.....

Contrast reaction site:

.....

(b) Calculate the iodine number for ozubondo acid, $C_{21}H_{33}COOH$. [2]

$$M_r = 330.56$$

.....

.....

.....

.....

.....

.....

(c) Explain **two** ways in which carbohydrates and lipids differ as sources of energy. [2]

.....

.....

.....

.....

(Option B continues on the following page)



36EP19

Turn over

(Option B continued)

9. Identify the type of bond and by-product when monosaccharides combine. [2]

Bond:
By-product:

10. Outline why we need vitamins/micronutrients in our diets. [1]

.....
.....

11. Outline how host-guest chemistry mimics enzymes in the removal of xenobiotics. [2]

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

(Option B continues on the following page)



36EP20

(Option B continued)

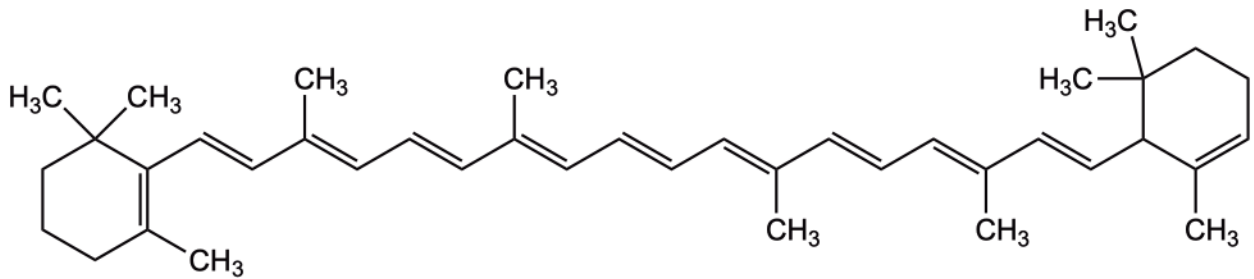
12. Identify **three** structural differences between DNA and RNA. Use section 34 of the data booklet. [3]

DNA	RNA
.....
.....
.....

13. Biological pigments are coloured compounds.

The following structure is the β -carotene:

β -carotene



(a) Explain in terms of its structure, why β -carotene appears orange in visible white light. Refer to section 17 of the data booklet. [2]

.....

.....

.....

.....

.....

.....

(Option B continues on the following page)



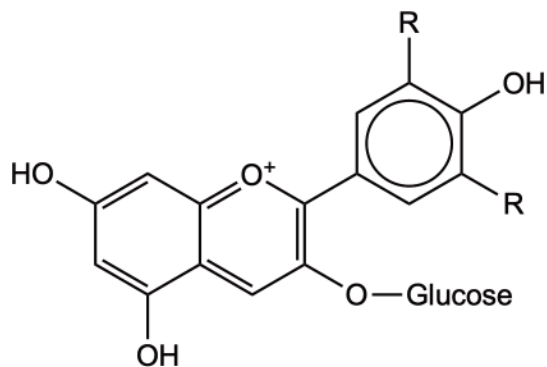
36EP21

Turn over

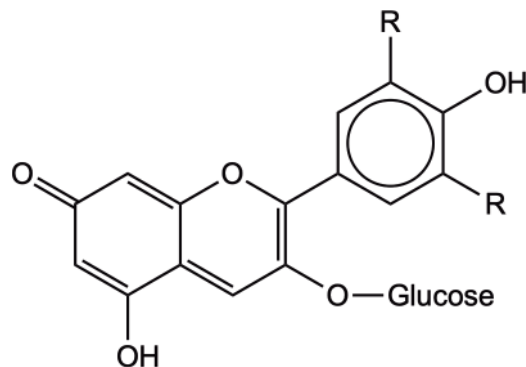
(Option B, question 13 continued)

Anthocyanins can act as acid-base indicators. The two examples shown, are the flavylium cation and the quinoidal base.

Flavylium cation (red)



Quinoidal base (blue)



(b) Explain how these anthocyanins can act as acid-base indicators as pH increases. [2]

.....

.....

.....

.....

(Option B continues on the following page)



(Option B continued)

14. Monosaccharides combine to form polymers.

(a) Identify **one** similarity and **one** difference between the structures of starch and cellulose. [2]

Similarity:
.....
Difference:
.....

(b) Outline why humans cannot digest cellulose. [1]

.....
.....

End of Option B



36EP23

Turn over

Option C — Energy

15. (a) Photosynthesis enables green plants to store energy from sunlight as glucose.

(i) Write the equation for photosynthesis. [1]

.....
.....

(ii) Identify the structural feature that allows chlorophyll to absorb light.
Use section 35 of the data booklet. [1]

.....
.....

(iii) Explain how photosynthesis is being employed to control global warming. [2]

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

(Option C continues on the following page)



(Option C, question 15 continued)

(b) Photovoltaic cells also convert sunlight into energy.

(i) State the form of energy produced by photosynthesis and photovoltaic cells. [1]

Photosynthesis:
.....
Photovoltaic:
.....

(ii) Explain how a silicon-based photovoltaic cell brings about this conversion. [3]

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

(Option C continues on the following page)

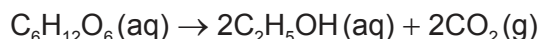


36EP25

Turn over

(Option C, question 15 continued)

(c) Glucose can be converted to ethanol through fermentation:



(i) Determine the energy efficiency of this conversion in terms of the enthalpies of combustion of the reactants and products. Use section 13 of the data booklet. [1]

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

(ii) Suggest **one** reason, other than energy density and specific energy, why ethanol may be considered a more useful fuel than glucose. [1]

.....
.....

(d) Both ethanol and glucose can be used to generate energy through fuel cells.

(i) Outline **one** way fuel cells differ from primary cells. [1]

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

(ii) State **one** way to increase the maximum current of a voltaic cell. [1]

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

(Option C continues on the following page)



(Option C continued)

16. Geological transformations produce fossil fuels.

(a) Combustion of coal emits particulates into the atmosphere.

(i) Outline why this affects global warming. [1]

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

(ii) State the major form of energy produced by the combustion of coal. [1]

.....
.....

(b) Conversion of petroleum to petrol (gasoline) involves fractional distillation and cracking.

Distinguish between these processes. [2]

Fractional distillation:

.....

.....

Cracking:

.....

.....

(Option C continues on the following page)

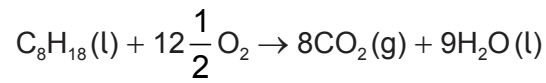


36EP27

Turn over

(Option C, question 16 continued)

(c) The equation for the combustion of octane is:



(i) Determine the mass of carbon dioxide, in g, produced when 1 kJ of energy is produced. Use section 13 of the data booklet.

[3]

.....

.....

.....

.....

.....

.....

.....

(ii) Suggest a piece of evidence that leads some people to not accept a causal link between the industrial emission of greenhouse gases, such as CO₂, and global warming.

[1]

.....

.....

.....

.....

.....

(Option C continues on the following page)



36EP28

(Option C continued)

17. Both fission and fusion reactions are potential sources of nuclear energy.

(a) Compare and contrast the nuclear changes and products formed in these processes giving **one** similarity and **one** difference. [2]

Similarity:
.....
.....
Difference:
.....
.....

(Option C continues on the following page)



36EP29

Turn over

(Option C, question 17 continued)

(b) Uranium is converted into a gaseous compound for enrichment.

(i) Identify the gaseous compound.

[1]

.....
.....

(ii) Determine the percentage difference in the rate of diffusion of molecules containing ^{235}U compared to those containing ^{238}U . The molar masses of these molecules are 349 and 352 respectively. Use section 1 of the data booklet.

[2]

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

(iii) Show how the dependence of the rate of diffusion on molar mass arises from kinetic theory. Use section 1 of the data booklet and:

$$E = \frac{1}{2} mv^2,$$

where E is energy of the particle, m its mass and v its velocity.

[2]

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

(Option C continues on the following page)



36EP30

(Option C, question 17 continued)

(c) Some reactors convert ^{238}U into another nucleus that can also undergo fission.

(i) Complete the equation for this process by identifying the reacting particle, **X**, and the isotope formed, **Y**. [2]



X:
Y:

(ii) The intermediate, ^{239}U , has a half-life of 23 minutes. Outline what is meant by half-life. [1]

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

End of Option C



36EP31

Turn over

Option D — Medicinal chemistry

18. Outline how these drug administration methods affect bioavailability. [2]

Oral:

.....

.....

Intravenous:

.....

.....

19. Aspirin is most commonly used as a mild analgesic. State **two** other common medical uses for aspirin. [2]

.....

.....

20. Suggest **two** reasons why the penicillin side-chain is modified. [2]

.....

.....

.....

.....

.....

.....

(Option D continues on the following page)



(Option D continued)

21. Explain how strong analgesics like morphine work. [2]

.....

.....

.....

.....

.....

.....

22. Aluminium hydroxide and ranitidine can be used to relieve indigestion.

(a) (i) Write an equation for the reaction of aluminium hydroxide with stomach acid. [1]

.....

.....

.....

.....

(ii) Calculate the mass, in g, of aluminium hydroxide needed to neutralize 100.0 cm³ of 5.00 × 10⁻³ mol dm⁻³ stomach acid. [2]

.....

.....

.....

.....

.....

.....

(Option D continues on the following page)



36EP33

Turn over

(Option D, question 22 continued)

(b) Explain how ranitidine (Zantac®) can also relieve excess stomach acid. [2]

.....

.....

.....

.....

.....

.....

23. Explain **two** different ways antiviral medications work. [2]

.....

.....

.....

.....

24. Distinguish between the hazards of high-level and low-level nuclear waste. [2]

.....

.....

.....

.....

25. Describe the original source of Taxol and the disadvantages of obtaining the medication from this source. [2]

.....

.....

.....

.....

(Option D continues on the following page)



36EP34

(Option D continued)

26. Nuclear medicine can be used to diagnose and treat diseases.

(a) Deduce the nuclear equation for the beta decay of cobalt-60. [1]

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

(b) Explain how Targeted Alpha Therapy (TAT) works and why it is used for treating cancers that have spread throughout the body. [3]

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

27. Ethanol can be identified by a variety of analytical techniques.

(a) Predict the structures of **three** possible fragments you would expect from the mass spectrum of ethanol. [3]

.....
.....

(b) Identify the **two** products formed when acidified potassium dichromate (VI), $K_2Cr_2O_7$, is used in a breathalyser test. [2]

.....
.....

(Option D continues on the following page)



(Option D continued)

28. The production of many pharmaceutical drugs involves the use of solvents.

(a) State **one** problem associated with chlorinated organic solvents as chemical waste. [1]

.....
.....

(b) Suggest how the principles of green chemistry can be used to overcome the environmental problems caused by organic solvents. [1]

.....
.....

End of Option D

References:

© International Baccalaureate Organization 2023



36EP36