Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Standard level
Paper 3

4 November 2024

Zone A afternoon | **Zone B** afternoon | **Zone C** afternoon

Candidate session number

1 hour

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 **[35 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 – 9
Option C — Energy	10 – 12
Option D — Medicinal chemistry	13 – 15

8824 – 9545

28 pages

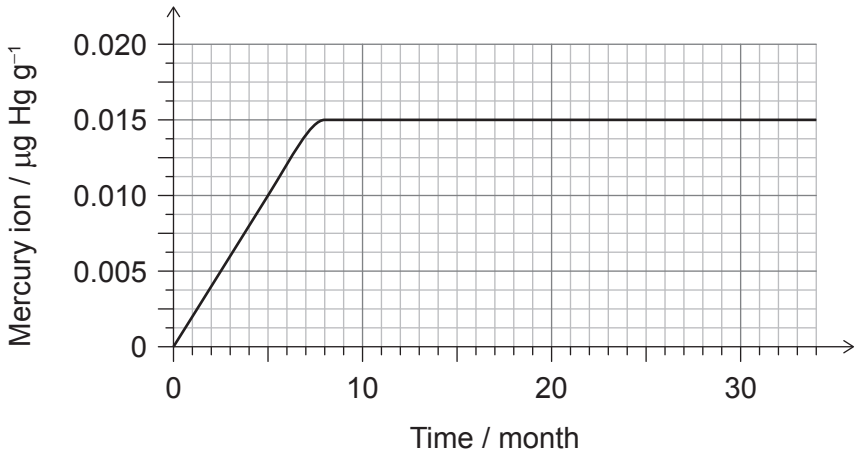
Section A

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

1. Water contaminated with mercury contains methylmercury ions, CH_3Hg^+. These ions are absorbed by living organisms, then slowly metabolized and excreted.

Young fish were taken at regular intervals from a mercury contaminated lake and tested to determine mercury ion content.

Mercury ion content in muscle tissue of fish



(a) (i) The mercury ion concentration follows a linear trend during the first five months. Deduce the equation for this part of the graph. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Suggest why the mercury ion concentrations changed very little after 8 months. [1]

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 1 continued)

(iii) State why CH_3Hg^+ is more likely to be absorbed by fish than mercury, Hg. [1]

. . . . . .

. . . . . .

. . . . . .

(b) The concentration of mercury ion in a sample of the fish is $0.0052 \pm 0.0001\,\mu g\,Hg\,g^{-1}$.

(i) Calculate the mass of Hg, in μg, in 3.723 g of the sample. [1]

. . . . . .

. . . . . .

(ii) Calculate the percentage uncertainty of $[CH_3Hg^+]$. [1]

. . . . . .

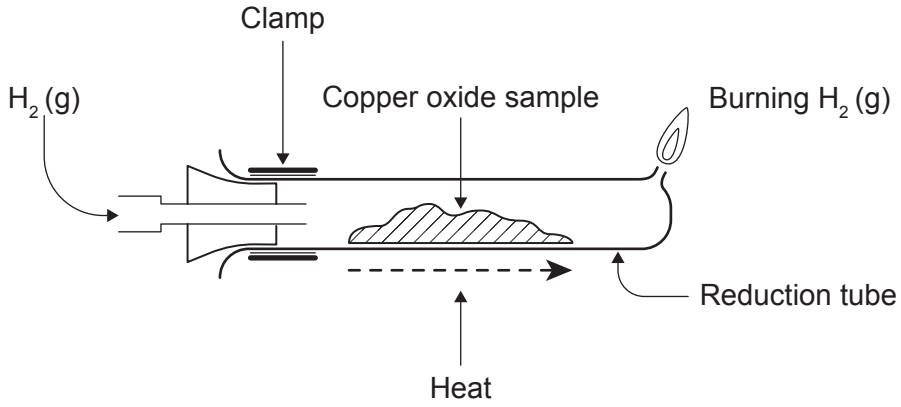
. . . . . .

(c) Suggest **two** variables which should be controlled when sampling the muscle tissues. [2]

. . . . . .

. . . . . .

2. Pure copper oxide is heated in the presence of hydrogen (H_2). The copper oxide is reduced to metallic copper. The formula of the oxide can then be determined.



(a) Suggest why it is important that the hydrogen gas flows continuously from before heating begins until the product has cooled. [2]

Before heating: . . . . . .

. . . . . .

. . . . . .

Until product has cooled: . . . . . .

. . . . . .

. . . . . .

(b) (i) State **two** measurements needed to determine the empirical formula of the oxide. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(Question 2 continued)

(ii) Outline how the mass of oxygen can be determined. [1]

. . . . . .

. . . . . .

. . . . . .

(c) Suggest why the amount of oxygen per mole of copper is often less than expected and how the error could be minimized. [2]

. . . . . .

. . . . . .

. . . . . .

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. Aluminium is useful as a metal, in alloys, and in ceramic compounds.

(a) (i) Using graphite electrodes, aluminium is extracted by the electrolysis of a molten mixture containing alumina, Al_2O_3.

Explain why adding cryolite to the molten electrolyte improves the process. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Aluminium oxide is a hard ceramic. Outline the bonding and electrical conductivity of this ceramic. Use sections 8 and 29 of the data booklet. [3]

Bonding: . . . . . .

. . . . . .

. . . . . .

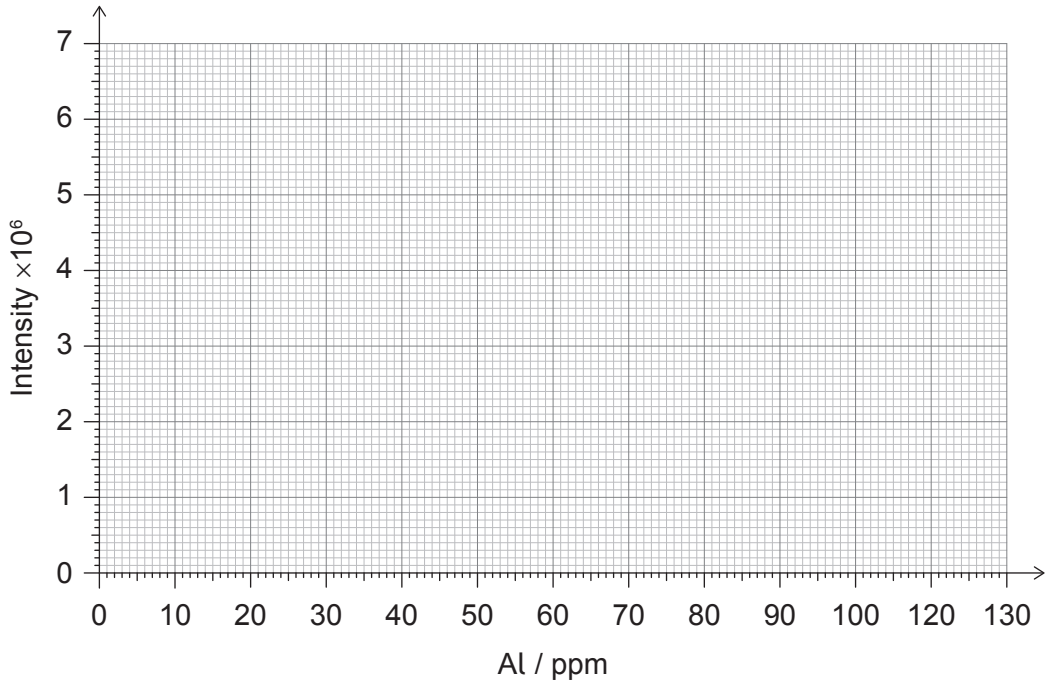
. . . . . .

Electrical conductivity: . . . . . .

(Option A continues on the following page)

(Option A, question 3 continued)

(b) Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is used for quantifying trace amounts of aluminium in samples. On the axes, draw a graph of intensity against the concentration of aluminium, given that a concentration of 40 ppm of Al has an intensity of 2×10^6. Assume the only species yielding a signal is Al. [1]



(Option A continues on the following page)

(Option A, question 3 continued)

(c) (i) Alloys of aluminium containing nickel are used to make engine parts. Explain, by referring to the structure of these alloys, why they are less malleable than pure aluminium. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Raney nickel catalysts are produced by treating a Ni–Al alloy with sodium hydroxide to remove some of the aluminium, which creates a porous material.

Deduce the coefficients to complete the balanced equation for this process. [1]

$$\_\_\ Al(s) + \_\_\ NaOH(aq) + \_\_\ H_2O(l) \rightarrow \_\_\ Na[Al(OH)_4](aq) + \_\_\ H_2(g)$$

(iii) Ni is used as a catalyst for hydrogenation reactions. Suggest why Raney nickel is particularly effective for this reaction. [1]

. . . . . .

. . . . . .

(iv) Suggest how the catalytic activity of Ni could have been discovered before the way it works was understood. [1]

. . . . . .

. . . . . .

. . . . . .

(Option A continues on the following page)

(Option A continued)

4. Carbon nanotube (CNT) fibres have been manufactured with much higher tensile strength than Kevlar. These are produced by chemical vapour deposition (CVD).

(a) State a source of carbon atoms in CVD. [1]

. . . . . .

. . . . . .

(b) Outline how the carbon atoms are obtained using CVD and formed into CNT. [2]

Obtained using CVD: . . . . . .

. . . . . .

. . . . . .

Formed into CNT: . . . . . .

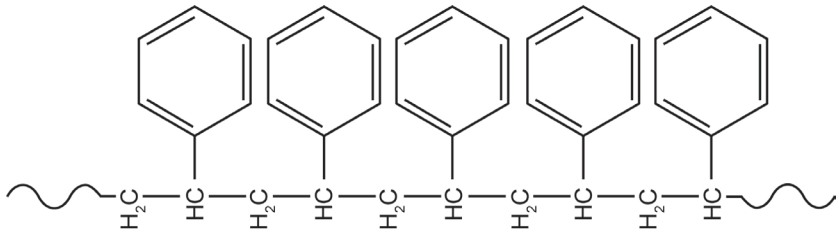
. . . . . .

(Option A continues on the following page)

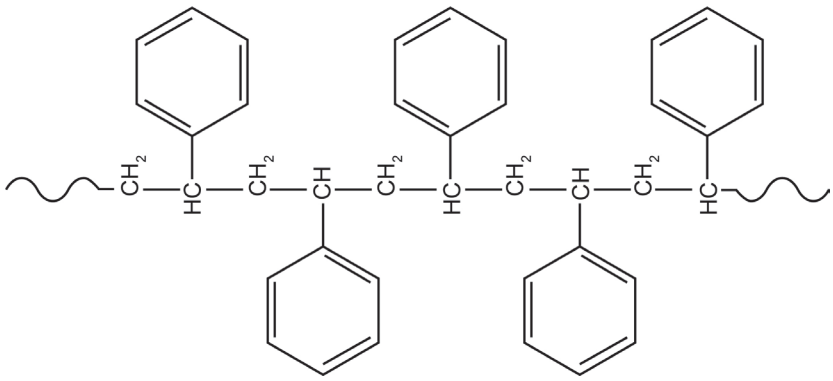
(Option A continued)

5. Plastics can form many varied structures.

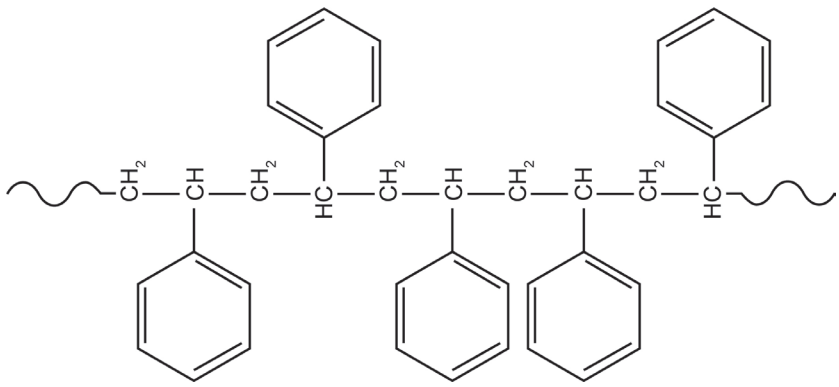
(a) Classify the branching of the following polystyrene diagrams as atactic, isotactic, or neither. [1]



. . . . . .



. . . . . .



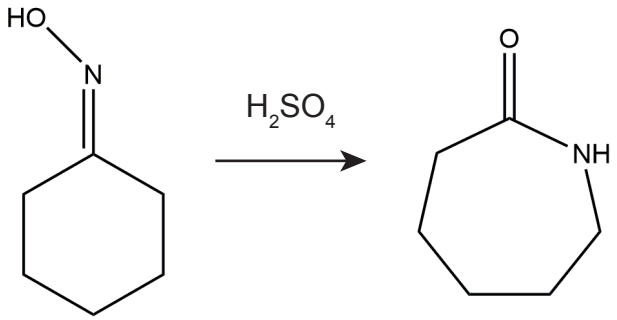
. . . . . .

(Option A continues on the following page)

(Option A, question 5 continued)

(b) Prior to green chemistry techniques, caprolactam, $C_6H_{11}NO$, used in the manufacture of nylon, was formed from cyclohexanone oxime.

Cyclohexanone oxime **Caprolactam**



The equation for the overall reaction is:

$$C_6H_{11}NO\,(aq) + 1.5\ H_2SO_4\,(aq) + 3\ NH_3(aq) \rightarrow C_6H_{11}NO\,(aq) + 1.5\ (NH_4)_2SO_4\,(aq)$$

M_r(caprolactam) = 113.18.

Determine the atom economy of this overall reaction. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

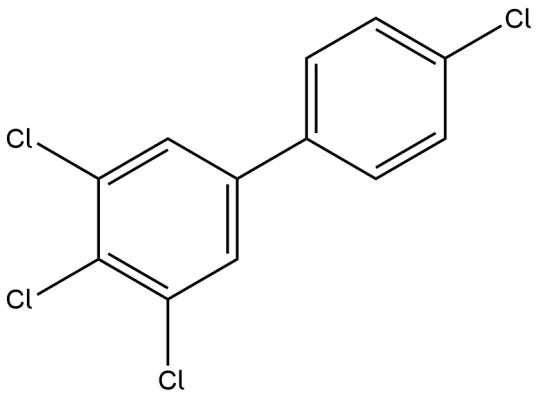
. . . . . .

(Option A continues on the following page)

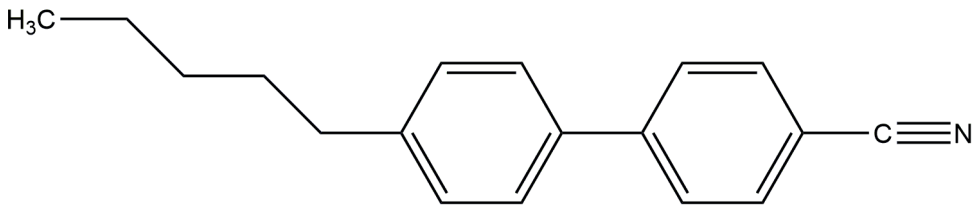
(Option A, question 5 continued)

(c) Structures of two compounds, 3,4,4',5-Tetrachlorobiphenyl and 4'-pentylbiphenyl-4-carbonitrile, are given and labelled as BP1 and BP2 respectively.

BP1



BP2



(i) Suggest, with a reason, whether BP1 or BP2 would be more likely to act as a liquid crystal. [1]

. . . . . .

. . . . . .

. . . . . .

(Option A continues on the following page)

(Option A, question 5 continued)

(ii) State how the structures of BP1 and BP2 differ from those of polychlorinated dibenzodioxins. [1]

. . . . . .

. . . . . .

(iii) Suggest, with a reason, which of BP1 and BP2 is more likely to lead to dioxin-like toxicity. [1]

. . . . . .

. . . . . .

. . . . . .

End of Option A

Option B — Biochemistry

6. Lipids form when glycerol reacts with fatty acids.

(a) (i) Write an equation for the reaction of glycerol and three fatty acid molecules, showing the structural formula of the organic product. [2]

(ii) State the name of this type of reaction. [1]

. . . . . .

. . . . . .

(b) (i) Determine the iodine number of a fatty acid with the formula $C_{17}H_{31}COOH$. $M_r = 280.50$. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option B continues on the following page)

(Option B, question 6 continued)

(ii) Explain why the melting point of $C_{17}H_{31}COOH$ is higher than $C_{17}H_{29}COOH$. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

7. Proteins and disaccharides are comprised of smaller organic molecules.

(a) Outline why proteins separate in gel electrophoresis. [2]

. . . . . .

. . . . . .

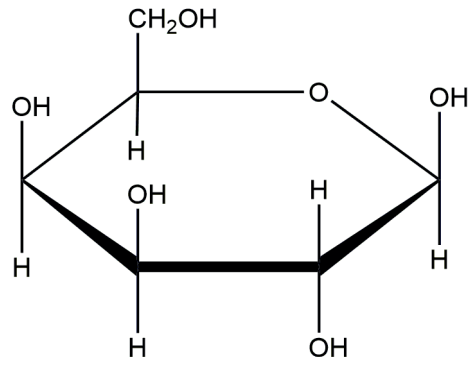
. . . . . .

(Option B continues on the following page)

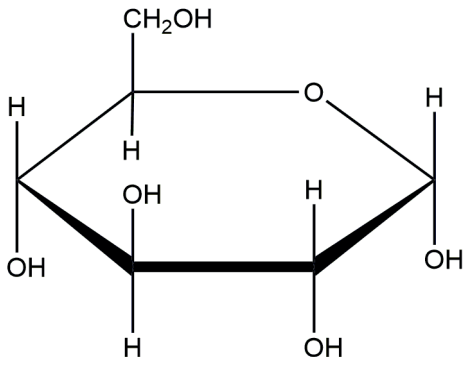
(Option B, question 7 continued)

(b) The structures of galactose and glucose are shown.

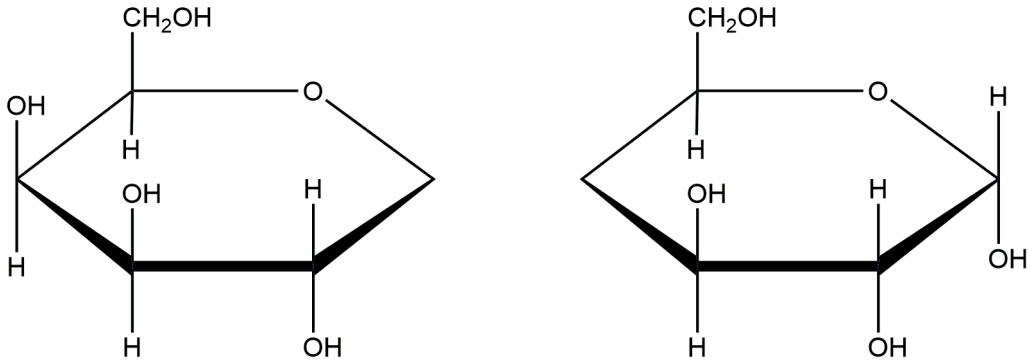
β-galactose



α-glucose



(i) Complete the structural formula of the disaccharide α-lactose, formed from β-galactose and α-glucose. [1]



(ii) State the names of the functional groups present in the straight chain form of glucose. [2]

. . . . . .

. . . . . .

. . . . . .

(Option B continues on the following page)

(Option B, question 7 continued)

(c) Outline how the enzyme lactase hydrolyses lactose to monosaccharides. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

8. Vitamins are a necessary component of a healthy diet. Outline why it is important to regularly consume a range of fresh fruit and vegetables for their vitamin content. [1]

. . . . . .

. . . . . .

. . . . . .

(Option B continues on the following page)

(Option B continued)

9. Reducing the quantity of pollutants in the environment is important.

(a) Explain how host–guest chemistry is used to remove caesium-137 ions from contaminated nuclear waste sites. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Biodegradable plastics have been developed by adding starch during the manufacturing process. Suggest **one** disadvantage of biodegradable plastics. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

End of Option B

Option C — Energy

10. The Sun, composed mainly of hydrogen and helium, is the main source of energy on Earth.

(a) (i) A reaction that occurs in the Sun is the fusion of deuterium, ^{2}H, with tritium, ^{3}H, to form helium, ^{4}He. State the nuclear equation for this reaction. [1]

. . . . . .

. . . . . .

(ii) Explain why this fusion reaction releases energy. Refer to section 36 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Absorption spectra provide evidence of the Sun's composition. Explain how absorption spectra are formed. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

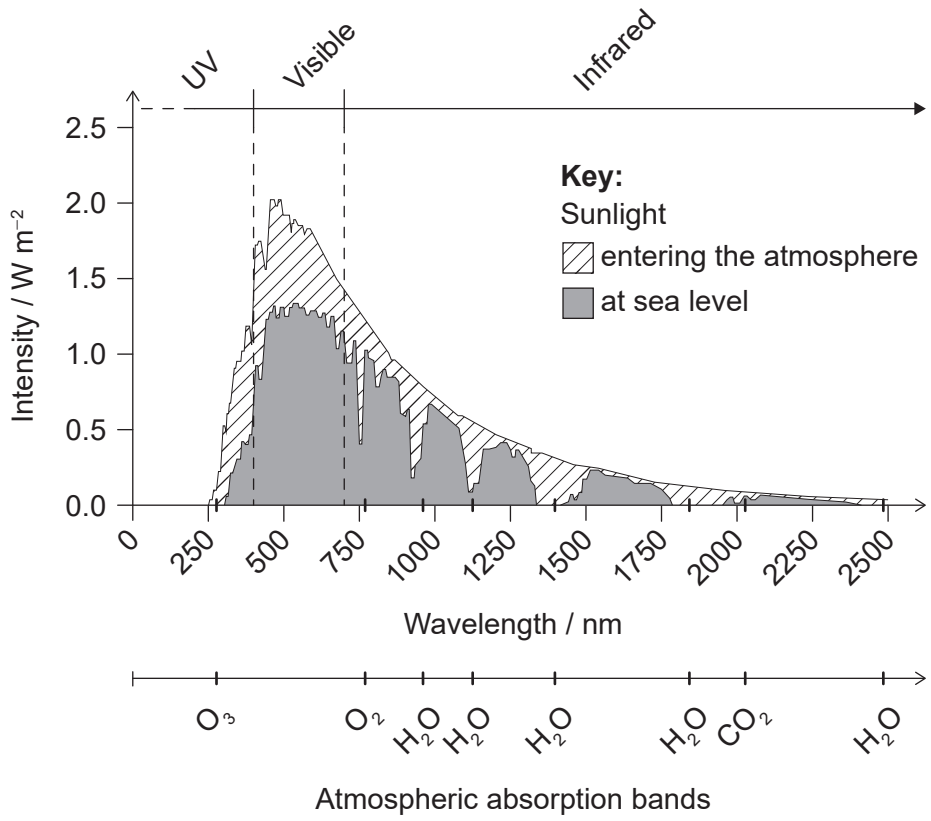
. . . . . .

(Option C continues on the following page)

(Option C continued)

11. The chart shows how sunlight changes as it passes through the earth's atmosphere. The light grey area shows the intensity at different wavelengths of sunlight entering the atmosphere. The dark grey area shows how much reaches sea level. Various molecules which interact with sunlight and the wavelengths they absorb are indicated on the following chart.

Spectrum of solar radiation (Earth)



(a) Suggest why solar panels on the International Space Station are designed to make use of ultraviolet, UV, light while conventional solar panels on homes use the visible spectrum. Use section 3 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option C continues on the following page)

(Option C, question 11 continued)

(b) Determine the peak power output, in watts, W, generated by absorbance at 550 nm of a $3.0\,m^2$ solar panel on a house. Assume the solar panel is 20 % efficient. [2]

. . . . . .

. . . . . .

. . . . . .

(c) Identify the structural feature of an organic molecule required for it to absorb visible light. [1]

. . . . . .

. . . . . .

(d) Explain how water molecules absorb infrared radiation and why there is more than one absorption band. [3]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) Identify a major greenhouse gas not given in the diagram. [1]

. . . . . .

. . . . . .

(Option C continues on the following page)

(Option C continued)

12. Adding bioethanol to gasoline increases the octane rating of the fuel and lowers the carbon footprint caused by fuel consumption.

(a) Calculate the carbon footprint for octane, C_8H_{18}, in terms of kg CO_2 produced per kg of octane burned. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) (i) Write the equation for the fermentation of glucose, $C_6H_{12}O_6$, which produces ethanol. [1]

. . . . . .

. . . . . .

(ii) State a reason why adding bioethanol to gasoline lowers the carbon footprint. [1]

. . . . . .

. . . . . .

. . . . . .

(c) Outline, giving a reason, how higher octane fuels reduce knocking and affect engine efficiency. [1]

. . . . . .

. . . . . .

. . . . . .

(Option C continues on the following page)

(Option C, question 12 continued)

(d) State **one** chemical method of reducing the carbon dioxide emissions that have already been produced in an industrial process. [1]

. . . . . .

. . . . . .

. . . . . .

End of Option C

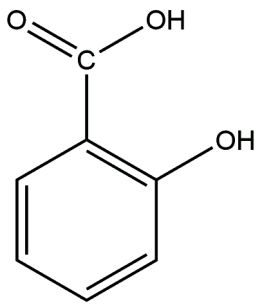
Option D — Medicinal chemistry

13. Aspirin and morphine are analgesics.

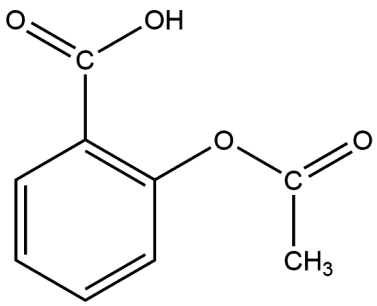
(a) Aspirin was synthesized by mixing 0.897 g of salicylic acid with excess ethanoic anhydride.

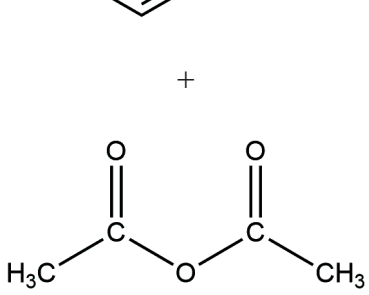
M_r (salicylic acid) = 138.13 M_r (aspirin) = 180.17.

Salicylic acid



Aspirin





Ethanoic anhydride

Ethanoic acid

(i) Calculate the theoretical yield of aspirin, in g. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(ii) Water was added and 1.31 g of solid product was isolated. Suggest, giving a reason, the identity of **one** possible impurity. [1]

. . . . . .

. . . . . .

. . . . . .

(Option D continues on the following page)

(Option D, question 13 continued)

(iii) Suggest **two** ways in which the melting point of an impure sample would differ from that of pure aspirin. [1]

. . . . . .

. . . . . .

(b) (i) Compare the way in which aspirin and morphine act as pain relievers. [2]

Aspirin: . . . . . .

. . . . . .

. . . . . .

Morphine: . . . . . .

. . . . . .

. . . . . .

(ii) State **one** side effect of morphine other than its addictive property. [1]

. . . . . .

. . . . . .

(c) Outline **one** benefit of administering morphine to a person with late-stage cancer. [1]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option D continues on the following page)

(Option D, question 13 continued)

(d) Explain, in molecular terms, why morphine, diamorphine and codeine differ in their potency as analgesic drugs. Refer to section 37 of the data booklet. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(e) Discuss the advantages, other than cost, of the synthesis of drugs in the laboratory and of deriving them from natural sources. [2]

Laboratory synthesis: . . . . . .

. . . . . .

. . . . . .

Derivation from natural sources: . . . . . .

. . . . . .

. . . . . .

(Option D continues on the following page)

(Option D continued)

14. Penicillin is effective against some bacteria but has no effect on viruses.

(a) Describe how the opening of the beta-lactam ring in penicillin destroys bacteria. [2]

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

(b) Outline how the inclusion of antibiotics in livestock food can harm the environment. [1]

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

(c) (i) Describe **one** way, other than the effect of antibiotics, in which viruses differ from bacteria. [1]

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

(ii) Outline **two** ways in which antiviral medications work. [2]

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

(Option D continues on the following page)

(Option D continued)

15. Many people require medication to regulate the pH of their stomachs.

(a) Write an equation for the neutralization reaction of calcium hydroxide and stomach acid. [1]

. . . . . .

. . . . . .

(b) Calculate the pH, to 2 decimal places, of an antacid that contains $0.0150\,\text{mol}\,\text{dm}^{-3}$ carbonate ions and $0.0200\,\text{mol}\,\text{dm}^{-3}$ hydrogencarbonate ions. Use section 1 of the data booklet. K_a (hydrogencarbonate ion) $= 4.80 \times 10^{-11}$. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

End of Option D

References:

5.(a) Kathy L. Singfield, Ashley J. Rowe. Experiment to Teach Multiple Melting Phenomena in Semicrystalline Polymers Using Differential Scanning Calorimetry. *World Journal of Chemical Education*. Vol. 9, No. 3, 2021, pp. 68–76. https://pubs.sciepub.com/wjce/9/3/1 Licensed under CC BY 4.0 https://creativecommons.org/licenses/by/4.0/. Image adapted.

5.(b) Zong, B., Sun, B., Cheng, S. Mu, X., Yang, K., Zhao, J. Zhang, X and Wu, W., 2017. Green Production Technology of the Monomer of Nylon-6: Caprolactam. *Engineering*, 3 (3), pp. 379–384. Under licence Creative Commons CC BY 4.0 https://creativecommons.org/licenses/by/4.0/. Source adapted.

11. Robert A. Rohde. Solar spectrum en.svg. https://commons.wikimedia.org/wiki/File:Solar_spectrum_en.svg. Under Creative Commons licence CC BY-SA 3.0 https://creativecommons.org/licenses/by-sa/3.0/deed.en. Source adapted.