Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

4 November 2024

Zone A afternoon | Zone B afternoon | 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 – 6
Option B — Biochemistry	7 – 11
Option C — Energy	12 – 15
Option D — Medicinal chemistry	16 – 20

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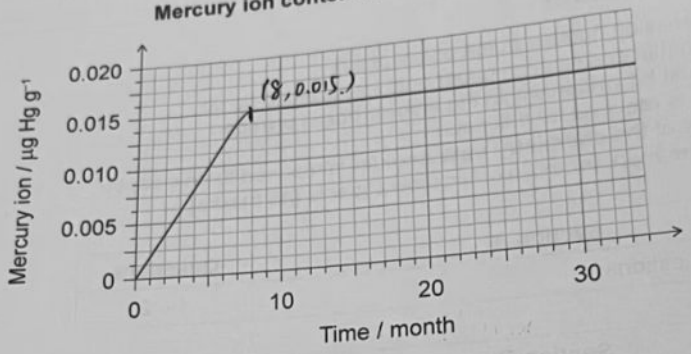
Section A

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]

$[Hg] = \frac{0.015}{8} = 1.875 \times 10^{-3}$

$[Hg] = 1.875 \times 10^{-3} \cdot Time$

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

~~the~~ equilibrium between fish tissue and ~~water~~ Hg^{2+} in water. fish already absorb all the Hg in it its growth. After 8 month it already finish the growth of muscle.

(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]

Hg in room temperature is liquid state, have low solubility in water. CH_3Hg^+ can ~~not~~ dissolve in water, also carry charge, have high absorbent on muscle tissue

(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]

$0.0052 \times 3.723 = 0.019\ g$

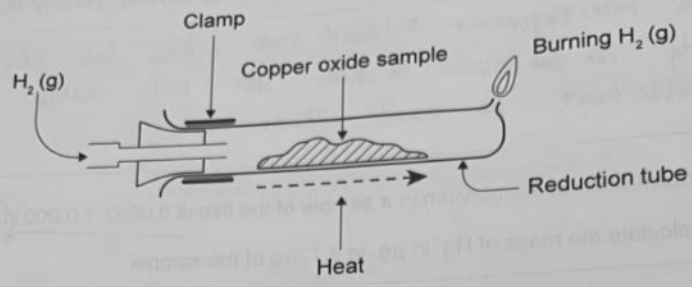
(ii) Calculate the percentage uncertainty of $[CH_3Hg^+]$. [1]

$\frac{0.0001}{0.0052} \times 100\% = 1.9\%$

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

mass, temperature, part of body muscle

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: to evacuate the air in this tube. avoid explosion
avoid blast because of the impurity of H_2

Until product has cooled: avoid reoxidation of copper

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

Initial mass of copper oxide
final mass of copper

(This question continues on the following page)

(Question 2 continued)

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

~~A(CuO) = mass of~~

Initial mass of CuO minus final mass of Cu.

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

not fully reduction of copper oxide.

make copper oxide have higher contact area with th(g).

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]

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(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: .....

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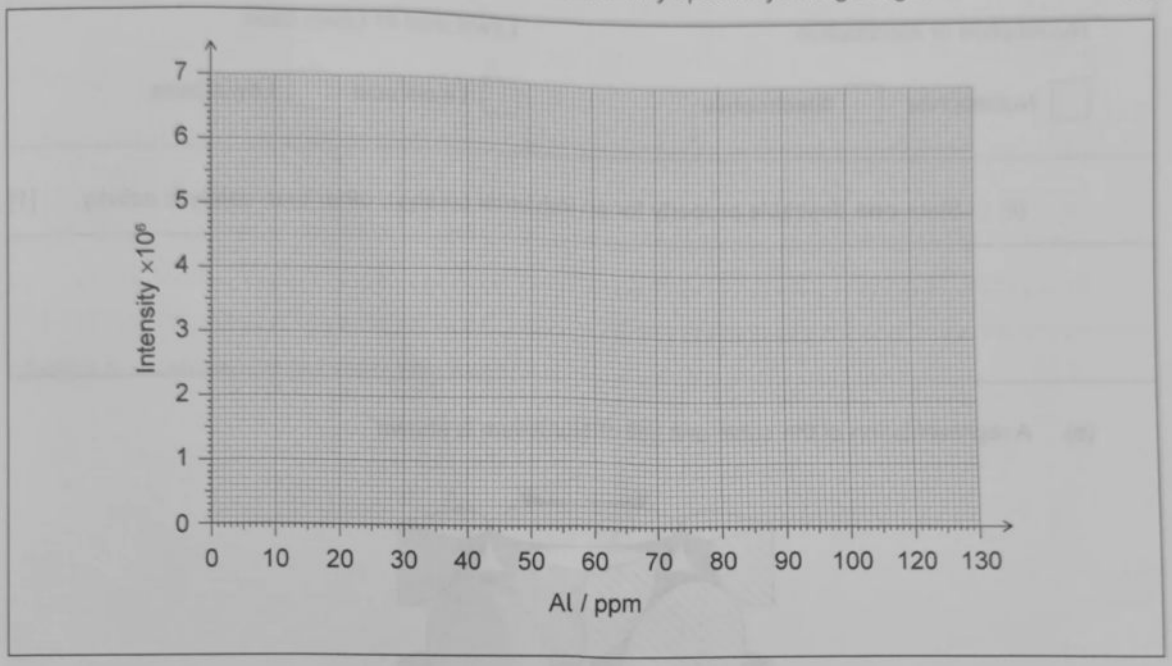
Electrical conductivity: .....

(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]



(c) 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]

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(Option A continues on the following page)

(Option A, question 3 continued)

(d) (i) Aluminium chloride, $AlCl_3$, can be used as a catalyst for substitution reactions with aromatic hydrocarbons. Deduce whether the aluminium in the catalyst acts as a nucleophile or electrophile, and as a Lewis acid or Lewis base. [1]

Nucleophile or electrophile: ☐ Nucleophile ☐ Electrophile

Lewis acid or Lewis base: ☐ Lewis acid ☐ Lewis base

(ii) State **one** desirable property for an industrial catalyst, other than catalytic activity. [1]

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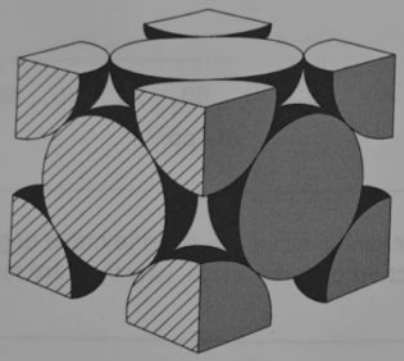
(e) A representation of the cubic unit cell of aluminium is shown.



(i) Calculate the number of atoms per unit cell of aluminium, showing your working. [2]

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(Option A continues on the following page)

(Option A, question 3 continued)

(ii) The edge length of the aluminium unit cell is 4.05×10^{-8} cm. Determine the density of aluminium, in $g\,cm^{-3}$, using sections 2 and 6 of the data booklet. [3]

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(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.

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

Obtained using CVD: .....

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Formed into CNT: .....

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(c) Compare and contrast the bonding and intermolecular forces in Kevlar and CNT.

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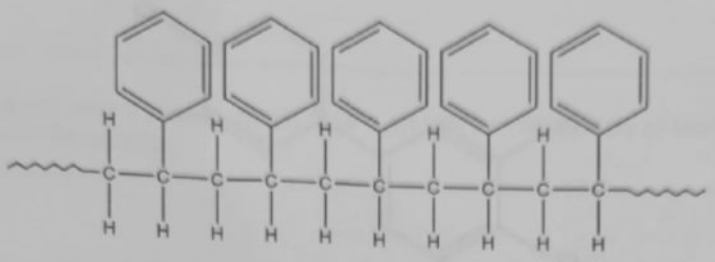
(Option A continues on the following page)

(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]



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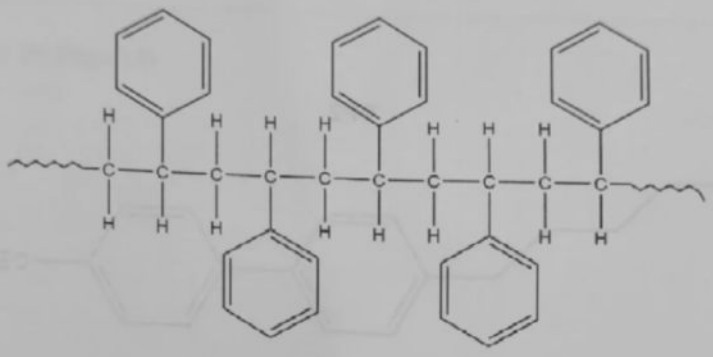

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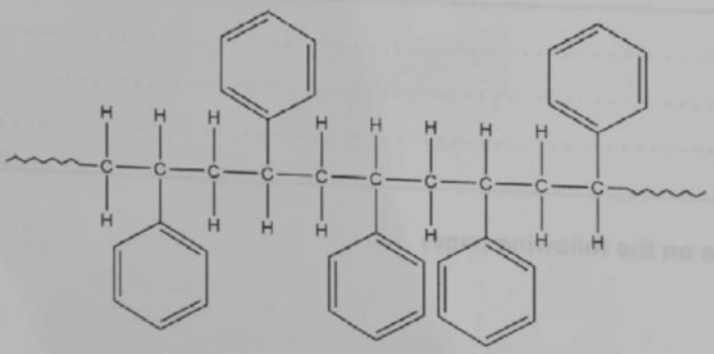

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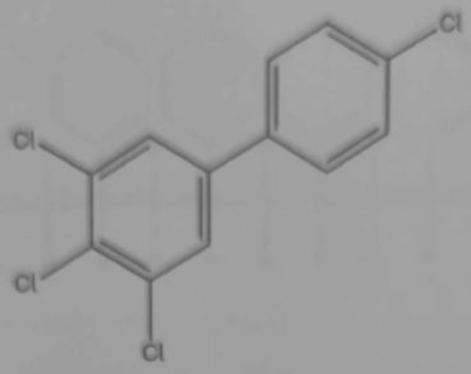
(Option A continues on the following page)

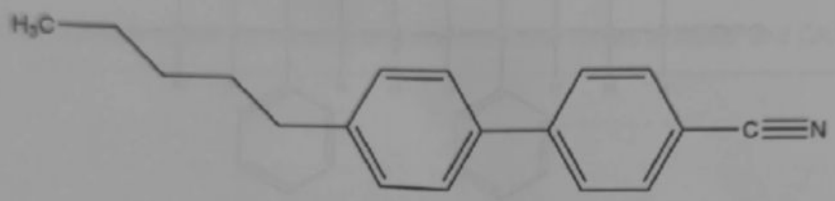
(Option A, question 5 continued)

(b) 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]

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(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]

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

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(Option A continues on page 15)

(Option A continued)

6. The superoxide ion, $\cdot O_2^-$, and hydrogen peroxide, H_2O_2, are some naturally occurring products of cell metabolism.

(a) Write the equation for the Haber–Weiss reaction between these two species, which produces the ·OH free radical. [1]

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(b) Show how $Fe^{2+}(aq)$ acts as a catalyst for this reaction to create the same products in a two-step mechanism. The initial reactants are given. [2]

Step one:

$Fe^{2+}(aq) + H_2O_2(aq) \rightarrow$ .....

Step two:

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(c) Outline why the cadmium ion, Cd^{2+}, is unable to catalyse redox reactions but the copper ion, Cu^{2+}, is able to. [1]

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(d) Cadmium competes for mineral binding sites in the body and is highly toxic. Suggest **one** way to remove cadmium from the body. [1]

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End of Option A

ption C — Energy

. 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]

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

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ption C continues on the following page)

(Option C, question 12 continued)

(b) Tritium can be obtained by the fission of lithium-6 according to the following equation.

$$^{6}Li + {}^{1}n \rightarrow {}^{3}H + {}^{4}He$$

The masses of the particles involved in this fission reaction are:

Particle	Mass / amu
^{6}Li	6.01512
Neutron	1.00867
^{3}H	3.01605
^{4}He	4.00260

Calculate the energy released, in J, when one lithium-6 nucleus undergoes fission. Use section 2 of the data booklet and $E = mc^2$. [3]

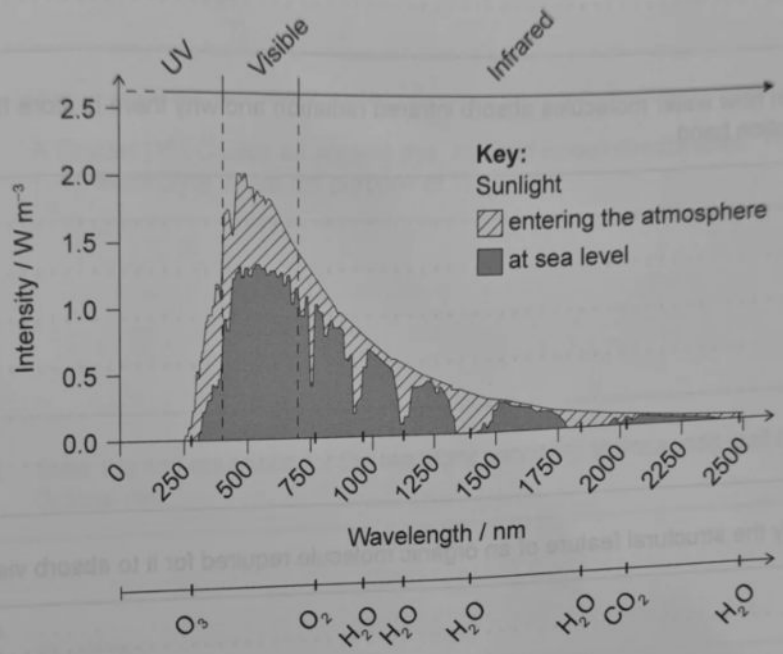
(c) Absorption spectra provide evidence of the Sun's composition. Explain how absorption spectra are formed. [2]

(Option C continues on the following page)

(Option C continued)

13. 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)



Atmospheric absorption bands

(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]

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(Option C continues on the following page)

(Option C, question 13 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]

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

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

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(Option C continues on the following page)

(Option C, question 13 continued)

(e) (i) State **two** advantages that a dye-sensitized solar cell (DSSC) might have over a traditional silicon-based photovoltaic cell. [2]

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(ii) A Grätzel DSSC uses an organic dye, titanium oxide nanoparticles, TiO_2, and an I^-/I_3^- electrolyte. State the purpose of TiO_2. [1]

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(iii) State the half-equations for the reactions occurring at the anode and cathode of a Grätzel cell. [2]

Anode: .....

Cathode: .....

(Option C continues on the following page)

(Option C continued)

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

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

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

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

(Option C continues on the following page)

(Option C continued)

15. Batteries are a portable source of energy.

(a) Outline how a rechargeable battery differs from a primary cell. [1]

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(b) Calculate the potential, in V, of a voltaic cell constructed of a zinc half-cell with $[Zn^{2}+(aq)] = 1.0$ mol dm^{-3} and a hydrogen half-cell with pH 10 at 298 K. Use the following equation and sections 1 and 24 of the data booklet. [2]

$$Zn(s) + 2H^{+}(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

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(c) Explain how the chemical nature and quantities of reactants in a voltaic cell affect the electrical output of the cell. [2]

Chemical nature: .....

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Quantities: .....

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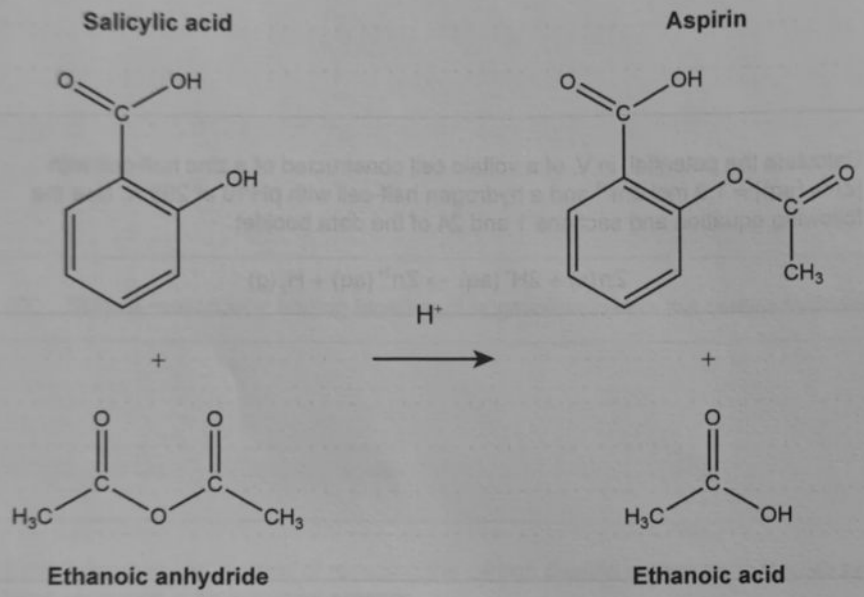
End of Option C

Option D — Medicinal chemistry

16. 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.



(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 16 continued)

(iii) Outline how the aspirin sample could be purified by recrystallization. [3]

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(iv) Deduce **one** absorption in the IR spectra of both aspirin and ethanoic anhydride, and **one** in the IR spectrum of aspirin only. Use section 26 of the data booklet. [2]

In both spectra: .....

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In aspirin spectrum only: .....

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

Aspirin: .....

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Morphine: .....

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(Option D continues on the following page)

(Option D, question 16 continued)

(c) 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]

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17. Taxol was once obtained from yew trees but is now more commonly synthetically produced.

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

Laboratory synthesis: .....

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Derivation from natural sources: .....

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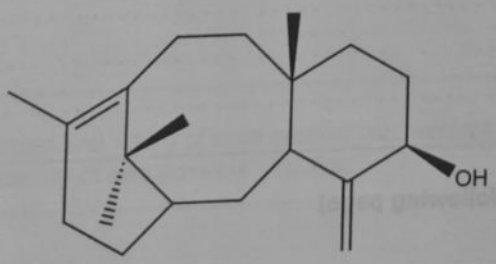
(b) There are several chiral carbon atoms in this structure of a taxol precursor. Draw circles around **two** of them. [1]



(Option D continues on the following page)

(Option D, question 17 continued)

(c) Explain how a polarimeter can be used to confirm if a desired enantiomer has been obtained. [2]

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18. 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]

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

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(Option D continues on the following page)

(Option D continued)

19. 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]

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(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]

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(c) Explain how ranitidine (Zantac) regulates stomach acid. [2]

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20. Nuclear medicine involves the use of radioisotopes.

(a) (i) Radioactive iodine is used to treat thyroid cancer. Write an equation for the β-decay of iodine-131. [1]

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(Option D continues on the following page)

(Option D, question 20 continued)

(ii) Iodine-131 has a half-life of 8.02 days. Calculate the percentage of iodine-131 which is remaining after 6.0 days. Use section 1 of the data booklet. [1]

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(b) Targeted alpha therapy (TAT) uses alpha-radiation. Suggest **one** reason why alpha-particles are particularly suitable for cancer treatment. [1]

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(c) Outline how targeted alpha therapy (TAT) is used to treat dispersed cancers. [2]

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