



Chemistry Higher level Paper 3

2 November 2023

Zone A morning | Zone B morning | Zone C morning

Candidate session number

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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

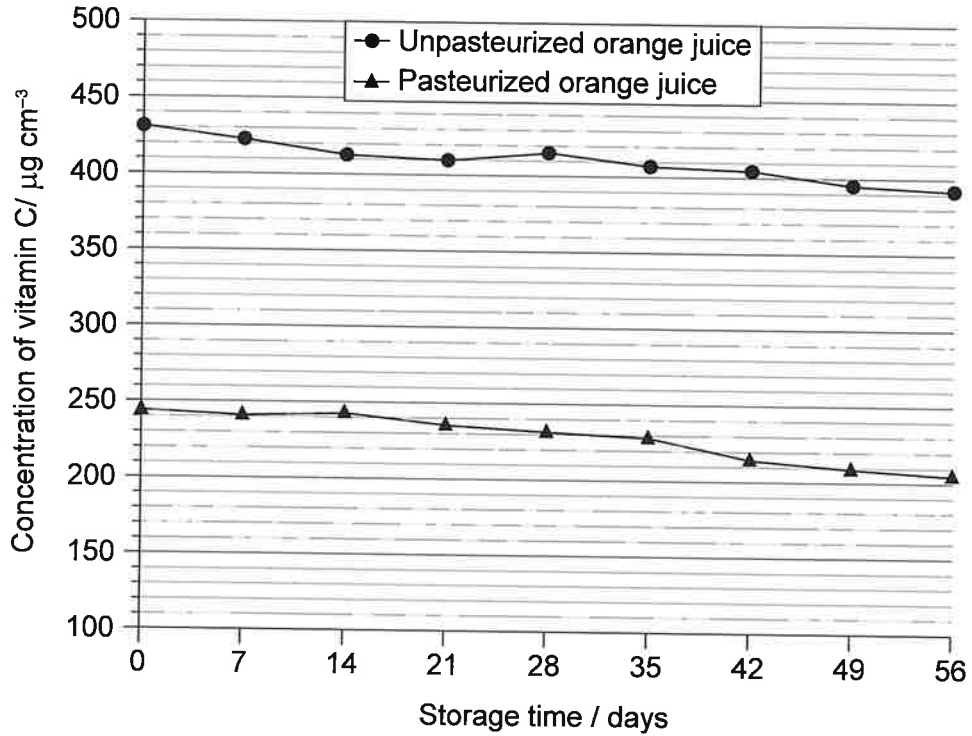
Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	2 – 5
Option B — Biochemistry	6 – 11
Option C — Energy	12 – 15
Option D — Medicinal chemistry	16 – 19



Section A

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

1. Pasteurization is used to eliminate pathogenic bacteria. The concentration of vitamin C was monitored over a period of time in pasteurized and unpasteurized orange juice.



- (a) (i) Identify the dependent variable represented in the graph. [1]

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- (ii) Calculate the decrease in the concentration of vitamin C, in $\mu\text{g cm}^{-3}$, caused by pasteurization. [1]

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(This question continues on the following page)



(Question 1 continued)

- (iii) Calculate the average rate of decrease of vitamin C concentration for pasteurized juice, in $\mu\text{g cm}^{-3}\text{ day}^{-1}$, for the first 56 days. [1]

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- (iv) Deduce, referring to the graph, whether pasteurization affects the rate of change of vitamin C concentration during storage of orange juice. [1]

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- (v) The absolute uncertainty in each vitamin C concentration measurement was $\pm 2 \mu\text{g cm}^{-3}$. Deduce, with a reason, whether the concentration of vitamin C in pasteurized or unpasteurized orange juice has a larger percentage uncertainty. [1]

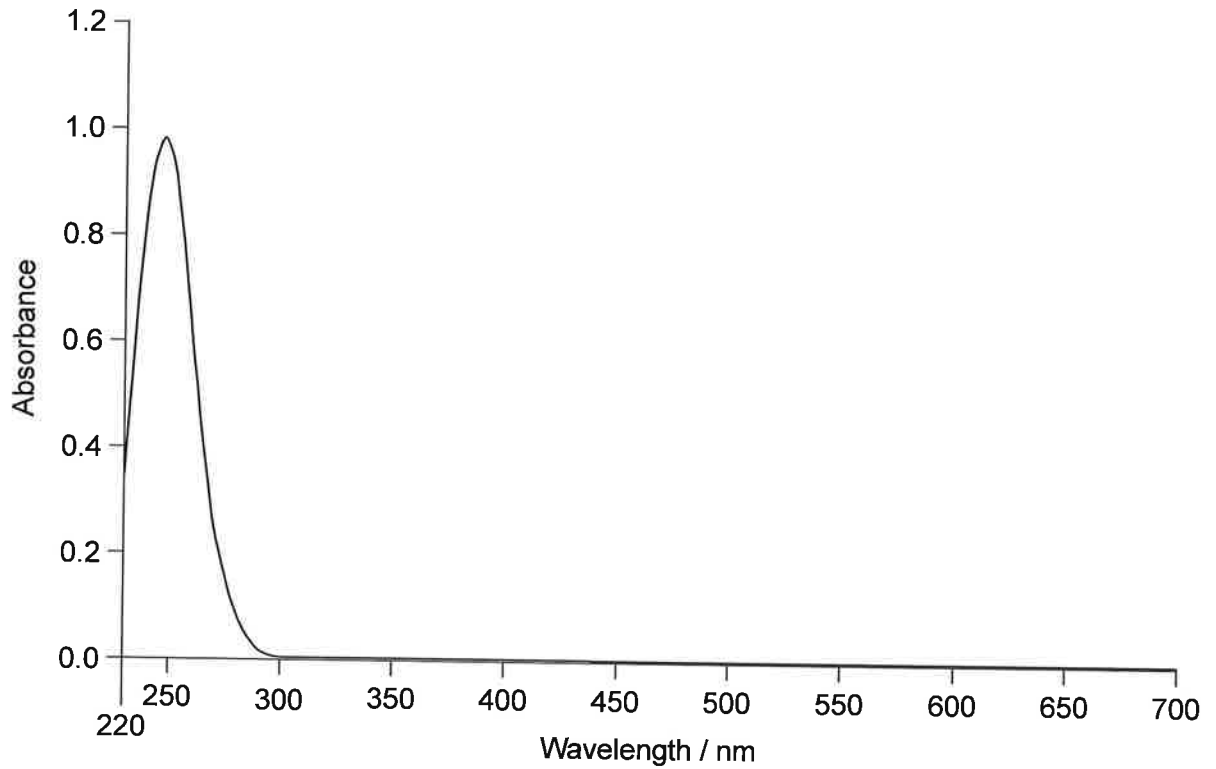
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(Question 1 continued)

- (b) UV treatment is an alternative to pasteurization that minimizes loss of nutritional components.
 - (i) Deduce the type of electromagnetic radiation absorbed in the absorption spectrum of vitamin C. Use section 3 of the data booklet.



[1]

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- (ii) Deduce, giving a reason, the colour of vitamin C.

[1]

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- (iii) Suggest why the use of UV light is not effective for the elimination of pathogenic bacteria in orange juice.

[1]

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(This question continues on the following page)



(Question 1 continued)

(iv) Identify **two** ways to decrease the rate of change of vitamin C concentration due to oxidation during the storage of orange juice. [2]

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(c) The concentration of vitamin C and pH of different fruits were measured.

	Concentration of vitamin C / mg dm ⁻³	pH
Watermelon	29	5.07
Banana	46	5.05
Apple	69	4.18
Pineapple	139	3.51
Orange	185	4.25

Deduce, with a reason, whether the data show a correlation between concentration of vitamin C and pH. [1]

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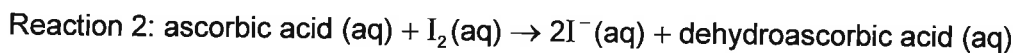
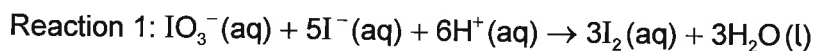
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Turn over

(Question 1 continued)

- (d) The concentration of vitamin C (ascorbic acid) can be measured by performing a redox titration using acidified iodate, IO_3^- , and iodide ions. Starch reacts with excess iodine once the vitamin C is consumed to produce a dark-blue complex.



- (i) Identify the oxidizing agent in reaction 1.

[1]

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- (ii) The student recorded the end point and then noticed the blue colour in the conical flask disappeared. Suggest why this occurred.

[1]

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- (iii) State the effect the recorded end point has on the value of the calculated concentration of vitamin C.

[1]

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- (iv) Suggest why this method cannot be used to measure the concentration of vitamin C in blueberry juice.

[1]

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Section B

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

Option A — Materials

2. Sodium hydride forms a crystalline lattice.

- (a) Deduce, giving a reason, whether sodium hydride could be classified as a Brønsted–Lowry acid or a Brønsted–Lowry base. [1]

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- (b) Materials with high ion-exchange capacity, such as zeolites, can be used to soften water by replacing calcium ions with sodium ions. Outline **two** reasons for using zeolites for ion exchange. [2]

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(Option A continues on the following page)



(Option A continued)

3. Properties of materials are dependent upon their chemical structure.

(a) Outline why polar molecules can exhibit liquid crystal behaviour.

[2]

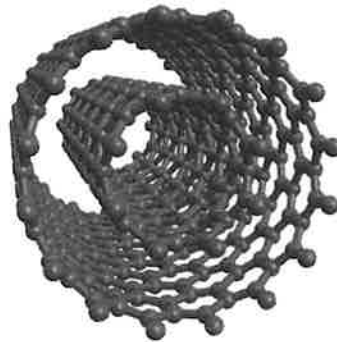
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(b) Suggest why double walled carbon nanotubes are excellent conductors of heat along the tube but poor conductors across the width of the tube.



[2]

Good conductors along the length of the tube:

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Poor conductors across the width of the tube:

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(Option A continues on the following page)



(Option A, question 3 continued)

(c) Outline how an inductively coupled plasma (ICP) torch converts argon into plasma. [3]

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(d) (i) Contrast the physical properties of polymers with extensive covalently bonded cross-links to polymers which only have a few of these links, giving an example of each. [4]

	Physical properties	Example
Extensive covalent cross-links:
Few covalent cross-links:

(Option A continues on page 11)



Turn over

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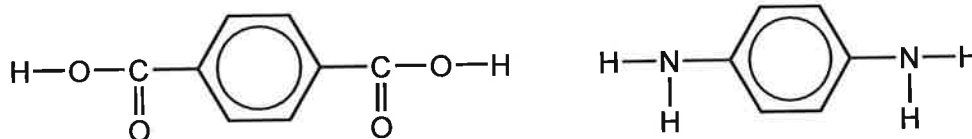
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40EP10

(Option A, question 3 continued)

- (ii) Kevlar® has extensive hydrogen bond cross-links. The polymer can be formed from benzene 1,4-dicarboxylic acid and benzene-1,4-diamine.



Draw one repeating unit of Kevlar®.

[1]

- (iii) Suggest **two** reasons for the degradation of Kevlar® on contact with concentrated acids.

[2]

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- (iv) Suggest **one** Resin Identification Code (RIC) for a non-recyclable plastic, with a reason for it not being recycled. Use section 30 of the data booklet.

[1]

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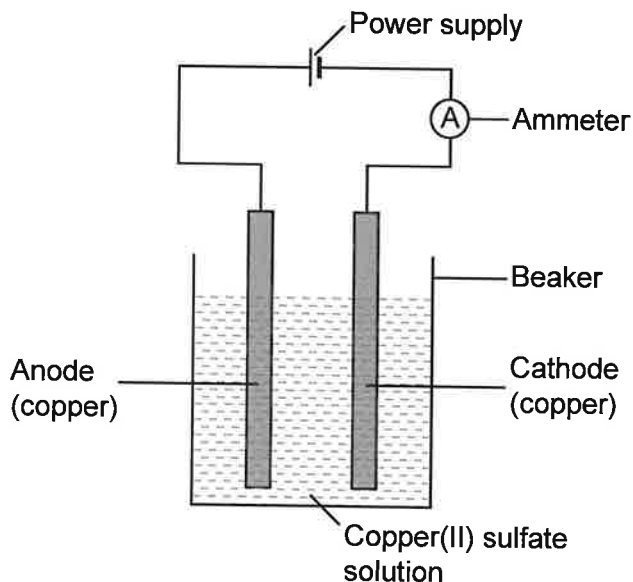
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(Option A continues on the following page)



(Option A continued)

4. Copper can be obtained by electrolysis as well as precipitation.
- (a) An experiment to calculate Faraday's constant (F) was performed by electrolysis of a solution of copper(II) sulfate using pure copper electrodes. A charge of 900.0C was passed through the cell resulting in a mass loss of 0.296g at the anode.



Suggest why mass gained at the cathode is a less accurate measure of electrolysed copper than mass loss at the anode.

[1]

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- (b) Calculate a value for Faraday's constant from this experiment.

[2]

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(Option A continues on the following page)



(Option A, question 4 continued)

- (c) Copper can be removed from solution by precipitating aqueous Cu^{2+} ions as copper(II) hydroxide.

Calculate the molar solubility of $\text{Cu}^{2+}(\text{aq})$ in a solution of pH 10.00.

$$K_{\text{sp}} \text{Cu}(\text{OH})_2 = 2.2 \times 10^{-20} \quad [2]$$

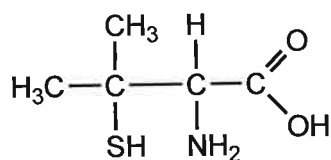
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- (d) D-penicillamine is a chelating agent used to remove excess copper in people suffering from Wilson's disease. Explain how D-penicillamine chelates as a bidentate ligand with Cu^{2+} .



D-penicillamine

[3]

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(Option A continues on page 15)



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(Option A continued)

5. Superconducting Magnetic Levitation (MAGLEV) trains use a niobium–titanium alloy that becomes a Type 2 superconductor when cooled with liquid helium.

(a) Outline **one** difference between Type 1 and Type 2 superconductors. [1]

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(b) Explain how superconductivity occurs in terms of Bardeen–Cooper–Schrieffer (BCS) theory. [3]

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End of Option A



Option B — Biochemistry

6. A variety of methods are used to analyse proteins.

(a) State the type of bonding involved in the primary level of protein structure.

[1]

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(b) (i) Outline how to use paper chromatography to identify the composition of amino acids in a polypeptide.

[3]

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(ii) Isoleucine was identified as one of the amino acids. Draw the structure of the predominant form of this amino acid at pH = 4.50. Use section 33 of the data booklet.

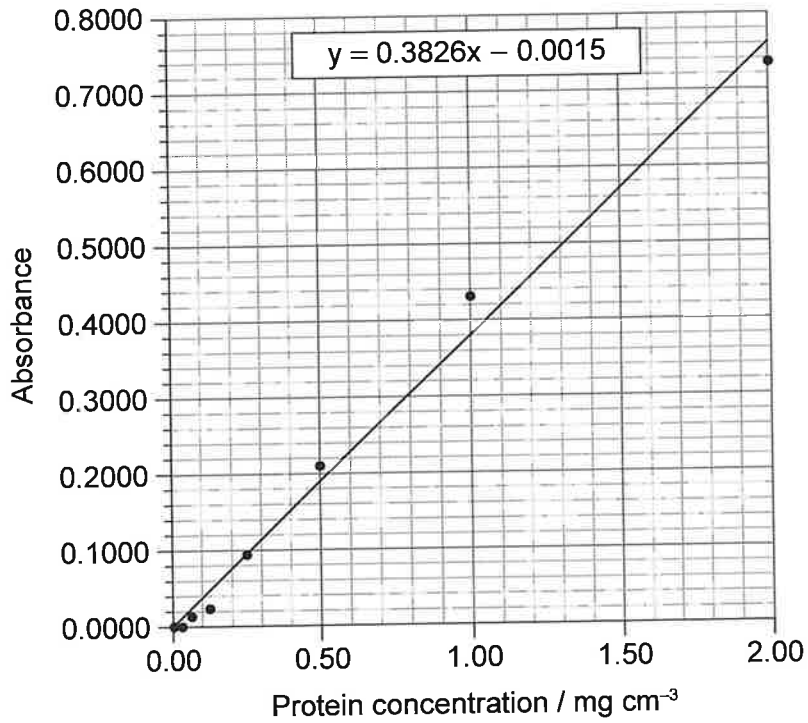
[1]

(Option B continues on the following page)



(Option B, question 6 continued)

- (c) The calibration curve for the absorbance of dyed protein, at 595 nm, as a function of concentration is given.



Calculate, using the linear equation, the concentration of protein in a sample with an absorbance of 0.5000.

[1]

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(Option B continues on the following page)



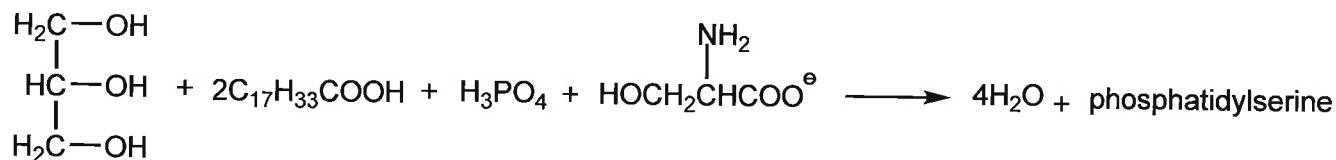
40EP17

Turn over

(Option B continued)

7. Phosphatidylserine is an example of a phospholipid.

(a) Phosphatidylserine may be formed from propane-1,2,3-triol, 2 oleic acid molecules, phosphoric acid and the serine anion.



Sketch the structural formula of phosphatidylserine.

[2]

$$\begin{array}{c}
 \text{H}_2\text{C} \text{-----} \\
 | \\
 \text{HC} \text{-----} \\
 | \\
 \text{H}_2\text{C} \text{-----}
 \end{array}$$

(b) (i) Phosphatidylserine can be composed of different fatty acids such as stearic acid and linoleic acid.

Predict, giving **two** reasons, which of these fatty acids would have a higher melting point. Use section 34 of the data booklet.

[2]

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(Option B continues on the following page)



(Option B, question 7 continued)

- (ii) Suggest **one** advantage and **one** disadvantage of the hydrogenation of vegetable oil by the food industry. [2]

Advantage:
Disadvantage:

- (c) Contrast the processes of hydrolytic and oxidative rancidity in fats with respect to the site of reactivity and conditions, other than temperature, that favour reaction. [2]

	Hydrolytic rancidity	Oxidative rancidity
Site of reactivity:
Conditions that favour reaction:

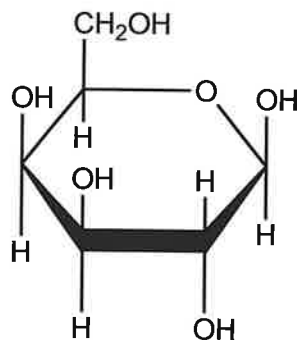
(Option B continues on the following page)



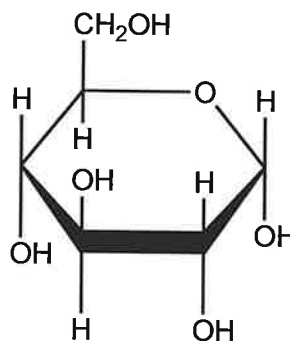
(Option B continued)

8. Lactose is the main disaccharide in milk.

(a) Lactose is composed of galactose and glucose.



Galactose



Glucose

(i) Draw the structure of lactose.

[2]

(ii) State the type of reaction that forms the disaccharide from monosaccharides.

[1]

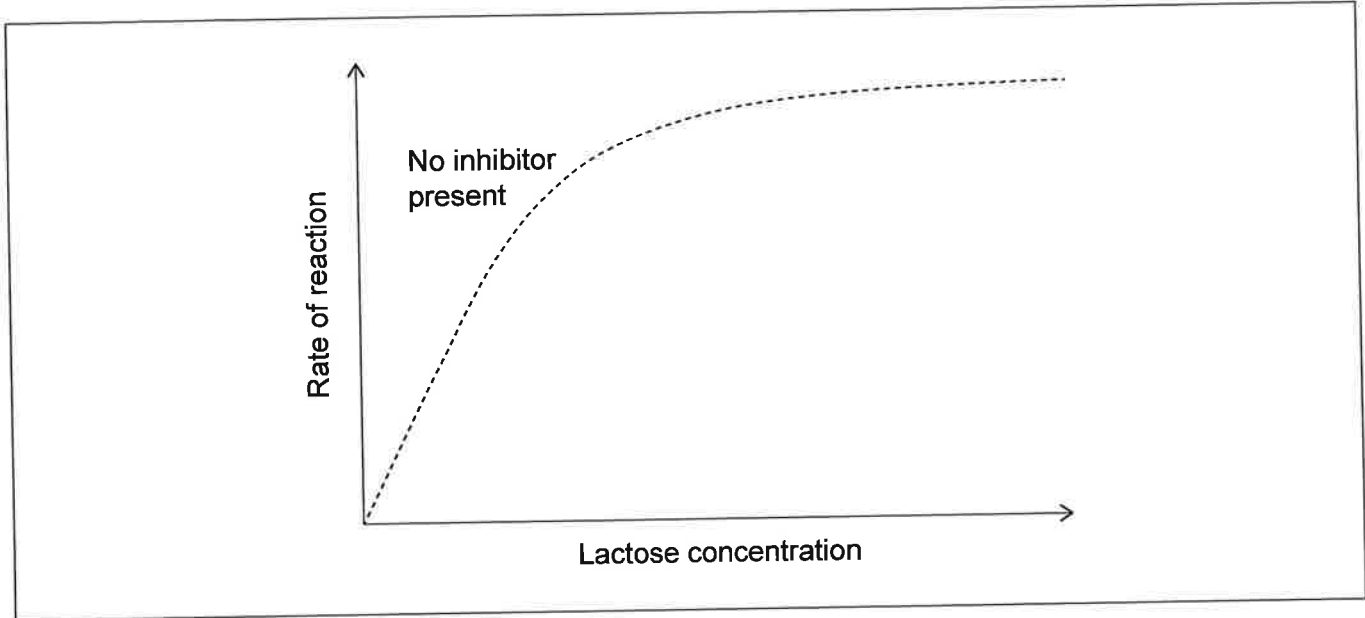
(Option B continues on the following page)



(Option B, question 8 continued)

(b) (i) Lactase is the enzyme that converts lactose into the monosaccharides.

Sketch a curve to show how the activity of lactase varies when a competitive inhibitor is present. [1]



(ii) State, giving a reason, the effect of the competitive inhibitor on the value of K_m . [1]

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(c) Milk is fortified with vitamin D. State a disease related to vitamin D deficiency. [1]

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(Option B continues on page 23)



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40EP22

(Option B continued)

9. Host-guest chemistry has been used for the removal of xenobiotics in the environment.

(a) Outline what is meant by *xenobiotic*.

[1]

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(b) Compare the bonding of synthetic host molecules and enzymes to substrates.

[1]

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(c) Suggest a specific environmental application of host-guest chemistry.

[1]

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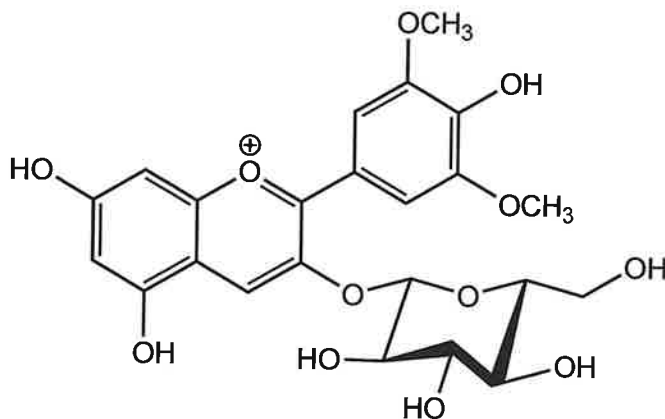
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(Option B continues on the following page)



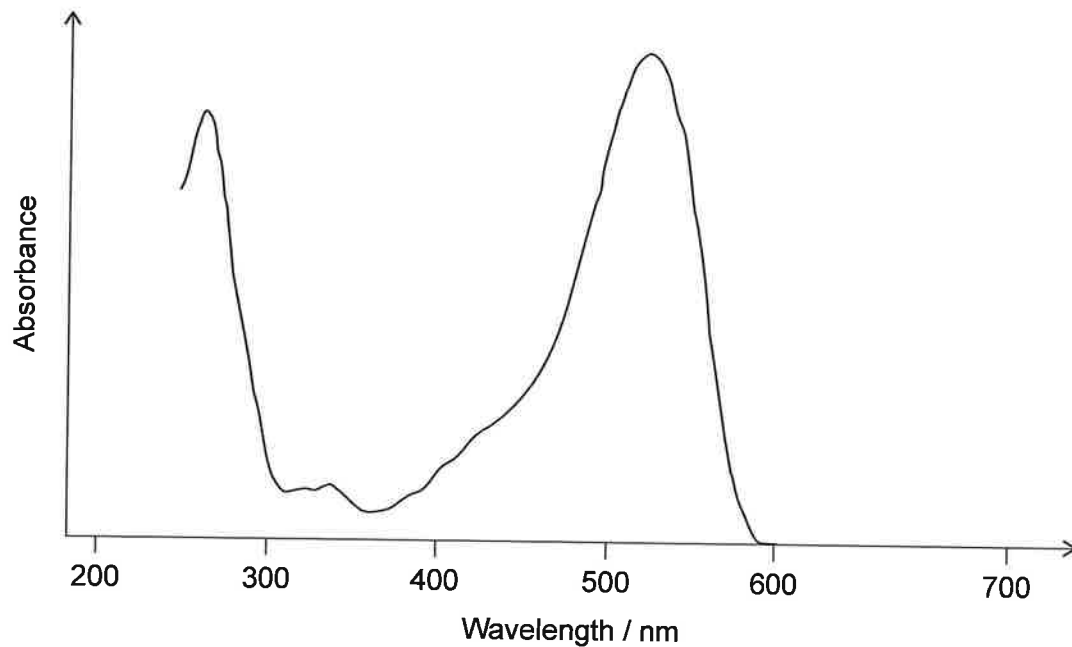
(Option B continued)

10. Anthocyanins, such as oenin, are pigments in plants.



oenin

(a) The absorption spectrum of oenin, taken in acidic condition, is given.



Identify, giving a reason, the colour of a plant containing oenin. Use section 17 of the data booklet.

[2]

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(Option B continues on the following page)



(Option B, question 10 continued)

(b) Explain how oenin acts as an acid–base indicator. Refer to its structure. [2]

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11. Cells contain both DNA and RNA.

(a) Contrast **two** differences between the structures of DNA and RNA. [2]

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(b) It is now possible to send a sample of DNA for analysis and receive results of ancestral background. Every year these results are more accurate. Suggest how this is possible even though the technology has not changed. [1]

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End of Option B



Option C — Energy

12. The spontaneity of nuclear fission and fusion reactions can be explained by changes in nuclear binding energy.

(a) State what is meant by nuclear binding energy.

[1]

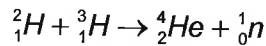
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(b) (i) A deuteron, or deuterium nucleus, ${}^2\text{H}$, has a mass of 3.343583×10^{-27} kg. Determine the nuclear binding energy of deuteron, in J, using $E = mc^2$ and section 4 of the data booklet.

[2]

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(ii) Determine the energy released, in MeV, when a helium-4 nucleus (${}^4\text{He}$) is formed from deuteron (${}^2\text{H}$) and triton (${}^3\text{H}$). Use section 36 of the data booklet.



[2]

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(c) (i) The average energy release in the fission of one atom of ${}^{235}\text{U}$ is 193.4 MeV. Calculate the specific energy of ${}^{235}\text{U}$ in MJ per gram.

$$1 \text{ MeV} = 1.60 \times 10^{-19} \text{ MJ.}$$

[1]

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(Option C continues on the following page)



(Option C, question 12 continued)

- (ii) Explain whether the energy density, in MJ dm^{-3} , or specific energy, in MJ kg^{-1} , of hydrogen has a higher value at standard conditions of temperature and pressure. [1]

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- (d) (i) Write the nuclear alpha decay equation of ^{235}U forming a helium-4 nucleus and a product with a much shorter half-life. [1]

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- (ii) The half-life of the product is 25.5 hours. Calculate the time taken, in hours, for 1.000 g of the product to decay to 0.03125 g. [2]

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(Option C continues on the following page)



(Option C continued)

13. Many molecules interact with light.

- (a) (i) Contrast, at the molecular level, how carbon dioxide and a coloured pigment, such as chlorophyll, interact with electromagnetic radiation.

[4]

Carbon dioxide:

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Chlorophyll:

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- (ii) Identify the range of wavelengths absorbed by carbon dioxide and chlorophyll. Use section 3 of the data booklet.

[1]

Carbon dioxide:

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Chlorophyll:

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- (b) Upper atmosphere temperatures recorded by satellites are becoming lower over time.

Suggest how greenhouse gases could be responsible for this trend.

[2]

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(Option C continues on the following page)



(Option C, question 13 continued)

- (c) Explain the high efficiency of dye-sensitized solar cells (DSSC) which use nanoparticles coated with a black dye.

[2]

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(Option C continues on the following page)



40EP29

Turn over

(Option C continued)

14. Natural gas is a fossil fuel.

(a) State the chemical process by which fossil fuels were formed from biological compounds. [1]

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(b) State the main component of natural gas. [1]

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(c) Outline **one** advantage and **one** disadvantage, apart from cost, of using natural gas over other fossil fuels. [2]

Advantage:
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Disadvantage:
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(d) Suggest a reason why syngas, produced from coal or biomass gasification, may be considered a viable alternative to crude oil. [1]

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(Option C continues on the following page)



(Option C continued)

15. Electrochemical cells generate electricity from a spontaneous redox reaction.

- (a) Species of *Geobacter* bacteria can be used in microbial fuel cells to oxidize aqueous ethanoate ions, CH_3COO^- (aq), to carbon dioxide gas. Deduce the half-equations for the reactions, in acidic conditions, at both electrodes. [2]

Negative electrode (anode):

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Positive electrode (cathode):

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- (b) Describe, in detail, how both fuel cells and secondary cells can be reused. [2]

Fuel cells:

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Secondary cells:

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- (c) Calculate the cell potential (E), in V, of a voltaic cell which consists of a magnesium electrode in a solution of $2.00 \text{ mol dm}^{-3} \text{ Mg}^{2+}$ (aq) and a silver electrode in a solution of $0.0100 \text{ mol dm}^{-3} \text{ Ag}^+$ (aq). Use sections 1 and 24 of the data booklet. [2]

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End of Option C



40EP31

Turn over

Option D — Medicinal chemistry

16. Aspirin and morphine are two analgesics.

(a) State the site and mode of action of aspirin.

[2]

Site of action:

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Mode of action:

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(b) (i) Aspirin is synthesized from salicylic acid. Discuss **two** ways in which the melting point of crystallized aspirin can indicate the presence of impurities.

[2]

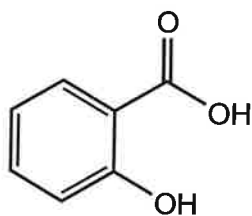
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(ii) Deduce the range of wavenumbers in the IR spectrum which would indicate that the impure aspirin contains salicylic acid. Use sections 26 and 37 of the data booklet.



Salicylic acid

[1]

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(Option D continues on the following page)



(Option D, question 16 continued)

(c) Morphine can be administered both orally and intravenously.

Suggest **one** reason why drugs administered orally have lower bioavailability than drugs administered intravenously. [1]

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(d) Morphine has a much greater affinity for the opioid receptor in the central nervous system compared to diamorphine.

Explain why diamorphine is a more potent analgesic. Use section 37 of the data booklet. [2]

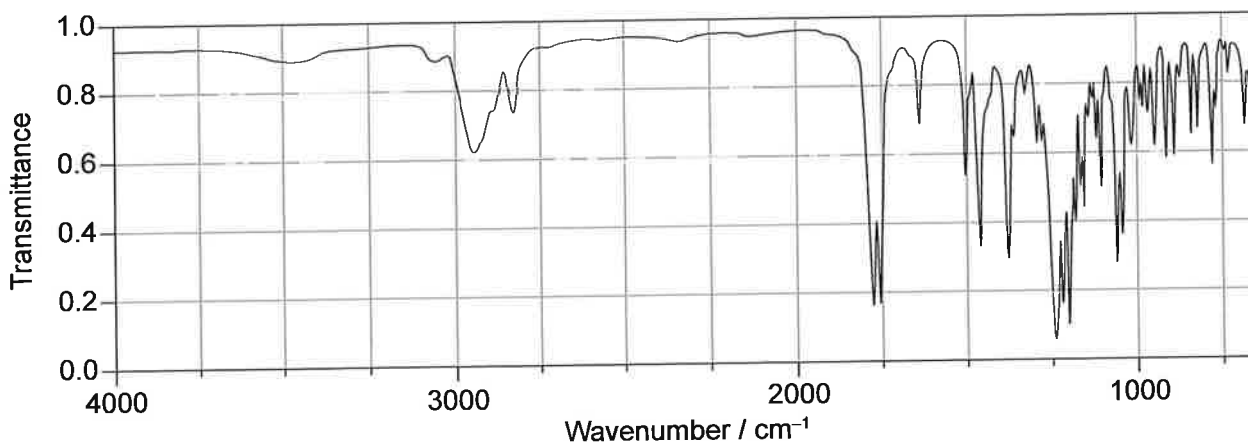
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(e) Deduce, giving **two** reasons, whether the product is morphine or diamorphine, referring to structure and the spectrum. Use sections 26 and 37 of the data booklet. [2]



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(Option D continues on the following page)



Turn over

(Option D continued)

17. Excess stomach acid is a common health condition.

(a) Explain how omeprazole regulates stomach pH.

[2]

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(b) Write an equation for the reaction of a solution of sodium hydrogen carbonate with stomach acid, including state symbols.

[1]

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(c) Predict, with a reason, whether the neutralization of acid by ranitidine in a titration is a reliable measure of its effectiveness in regulating stomach acid.

[1]

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(d) Deduce, giving a reason, whether the ^1H NMR spectrum of oseltamivir or omeprazole has signals with chemical shifts in the 7.0–8.1 ppm range. Use sections 27 and 37 of the data booklet.

[1]

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(Option D continues on the following page)



(Option D continued)

18. Viruses and bacteria must be targeted in different ways.

- (a) (i) Describe how oseltamivir (Tamiflu) works as a preventative agent against flu viruses. [2]

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- (ii) The production of oseltamivir requires shikimic acid, a precursor originally obtained from star anise.
Comment on an advancement made in the production of shikimic acid and its importance in terms of green chemistry. [2]

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- (b) (i) Describe the role of the beta-lactam ring in the action of penicillin against bacteria. [2]

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- (ii) State a consequence of bacteria gaining increased resistance to antibiotics. [1]

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(Option D continues on the following page)



Turn over

(Option D continued)

19. Radiotherapy and chemotherapy are two approaches to cancer treatment.

(a) (i) State a common side effect of radiotherapy. [1]

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(ii) State **one** advantage of using a gamma emitter over a beta emitter in nuclear medicine. [1]

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(iii) Write an equation for the beta decay of Lutetium-177. [1]

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(iv) A typical dose of Lu-177 is $2.00\mu\text{g}$ and its half-life is 6.71 days. Determine the mass of Lu-177, in μg , remaining after one week. Use section 1 of the data booklet. [2]

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(Option D continues on the following page)



(Option D, question 19 continued)

- (b) (i) Taxol, a drug used in chemotherapy, is synthesized using chiral auxiliaries. Describe how the chiral auxiliary is used to produce the desired product. [2]

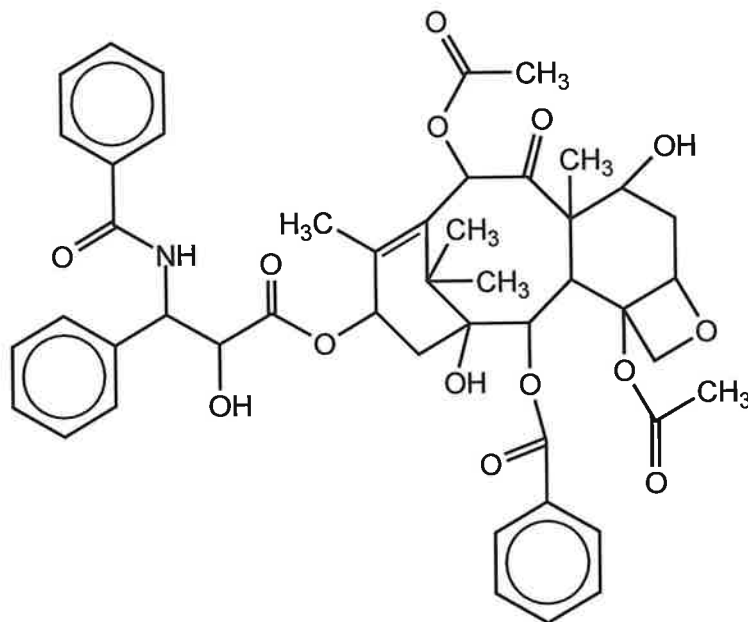
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- (ii) Mass spectroscopy of taxol ($M_r = 854$) shows an m/z peak at 836. Suggest a fragment, the loss of which could be responsible for this peak. Use section 28 of the data booklet.



Taxol [1]

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End of Option D



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References:

1. Oulé, M., Dickman, M., Arul, J., 2013. *Properties of Orange Juice with Supercritical Carbon Dioxide Treatment*. [graph] Available at: <https://www.researchgate.net/publication/263368607_Properties_of_Orange_Juice_with_Supercritical_Carbon_Dioxide_Treatment> [Accessed 4 May 2020]. SOURCE ADAPTED.
- 1(b)(i). Usaga, J., Manns, D.C., Moraru, C.L., et al., 2017. *Ascorbic acid and selected preservatives influence effectiveness of UV treatment of apple juice*. [article] Available at: <<https://reader.elsevier.com/reader/sd/pii/S0023643816305229?token=A3FAD2436231649D2FF7CA3C9AA0AB538319ABAFB004F1F648985EF24CA2F7C0654E4F1A28343BA03B930CFF324B4B2F>> [Accessed 4 May 2020]. SOURCE ADAPTED.

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