Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

2 November 2023

Zone A morning | **Zone B** morning | **Zone C** morning

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

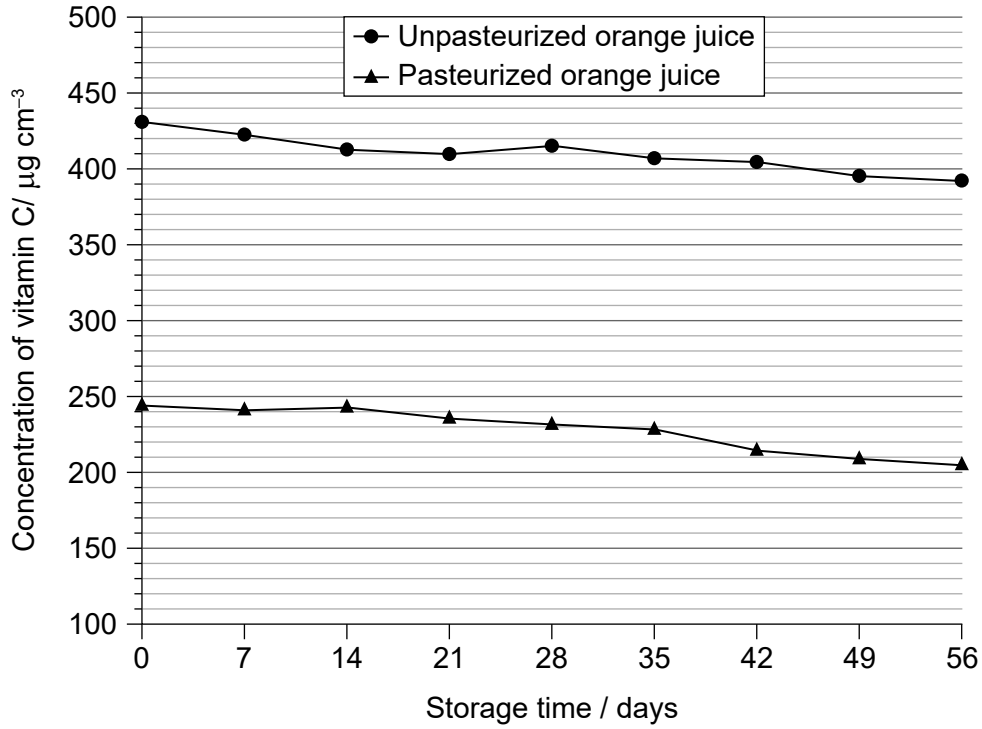
Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	2 – 5
Option B — Biochemistry	6 – 11
Option C — Energy	12 – 15
Option D — Medicinal chemistry	16 – 19

8823 – 6109

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]

. . . . . .

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

. . . . . .

. . . . . .

(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 $\mu g\,cm^{-3}day^{-1}$, for the first 56 days. [1]

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

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

. . . . . .

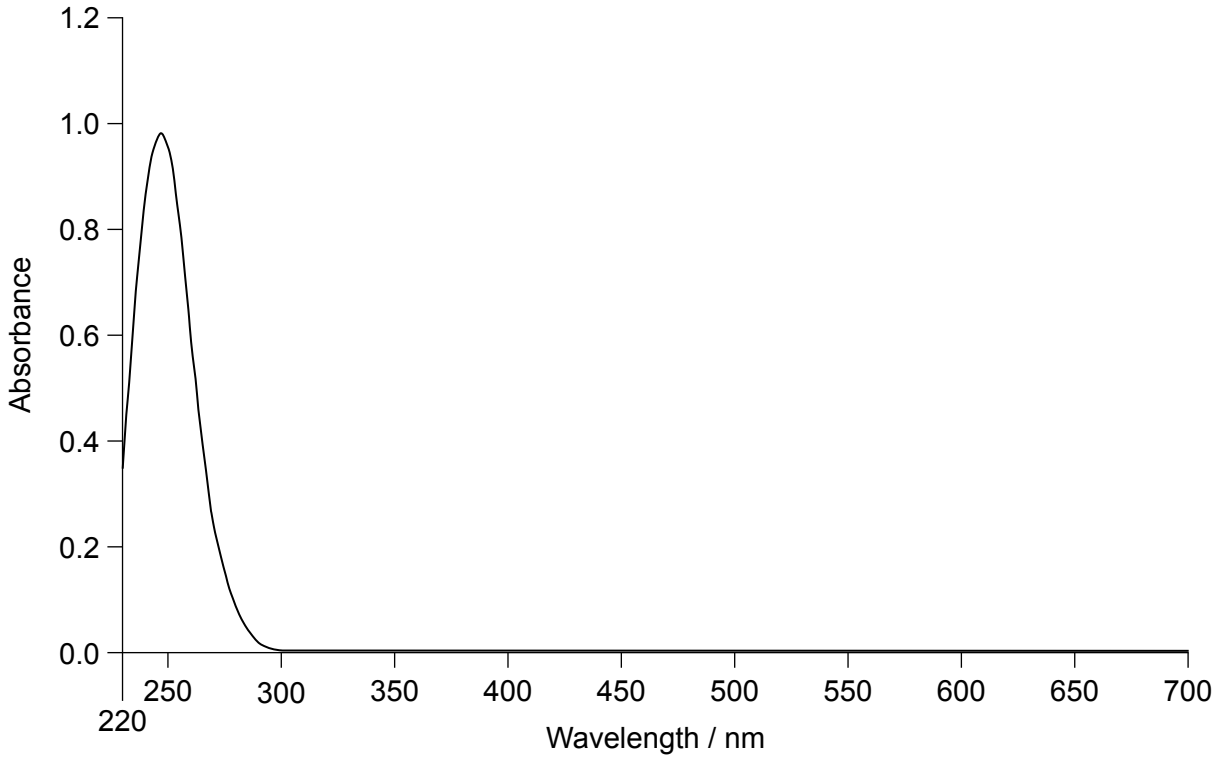
. . . . . .

(This question continues on the following page)

(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]

. . . . . .

(ii) Deduce, giving a reason, the colour of vitamin C. [1]

. . . . . .

. . . . . .

(iii) Suggest why the use of UV light is not effective for the elimination of pathogenic bacteria in orange juice. [1]

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(This question continues on the following page)

(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.

Reaction 1: $IO_3^-(aq) + 5I^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$

Reaction 2: ascorbic acid (aq) + $I_2(aq) \rightarrow 2I^-(aq)$ + dehydroascorbic acid (aq)

(i) Identify the oxidizing agent in reaction 1. [1]

. . . . . .

(ii) The student recorded the end point and then noticed the blue colour in the conical flask disappeared. Suggest why this occurred. [1]

. . . . . .

. . . . . .

(iii) State the effect the recorded end point has on the value of the calculated concentration of vitamin C. [1]

. . . . . .

(iv) Suggest why this method cannot be used to measure the concentration of vitamin C in blueberry juice. [1]

. . . . . .

. . . . . .

. . . . . .

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]

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

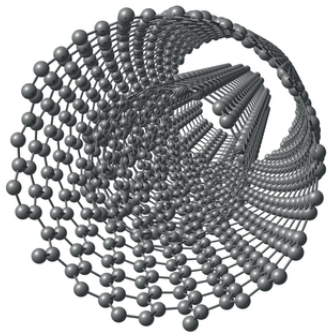
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]



[Source: iStock.com/ollaweila.]

Good conductors along the length of the tube:

. . . . . .

. . . . . .

Poor conductors across the width of the tube:

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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:	. . . . .	. . . . .

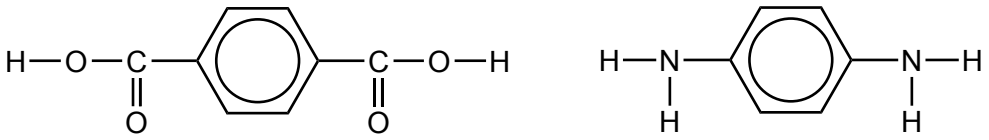
(Option A continues on page 11)

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

Answers written on this page
will not be marked.

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

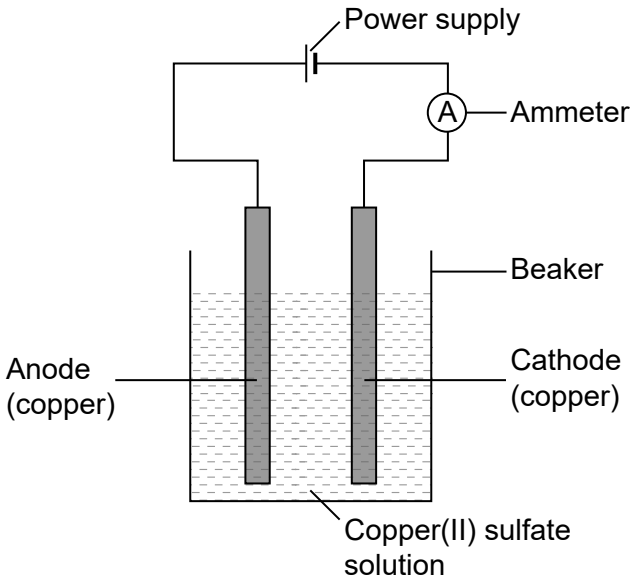
. . . . . .

(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 electrolysing a solution of copper(II) sulfate using pure copper electrodes. A charge of 900.0 C was passed through the cell resulting in a mass loss of 0.296 g 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]

. . . . . .

. . . . . .

(b) Calculate a value for Faraday's constant from this experiment. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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 $Cu^{2+}(aq)$ in a solution of pH 10.00.

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

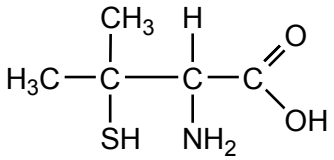
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option A continues on page 15)

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

Answers written on this page
will not be marked.

(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]

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

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

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

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]

. . . . . .

(b) (i) Outline how to use paper chromatography to identify the composition of amino acids in a polypeptide. [3]

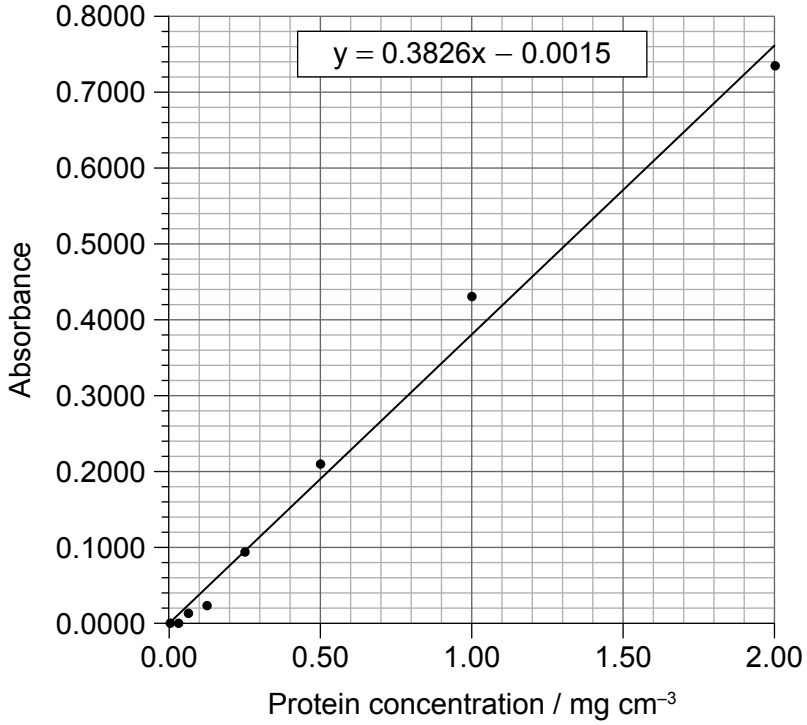
. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .

(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]

. . . . . .

. . . . . .

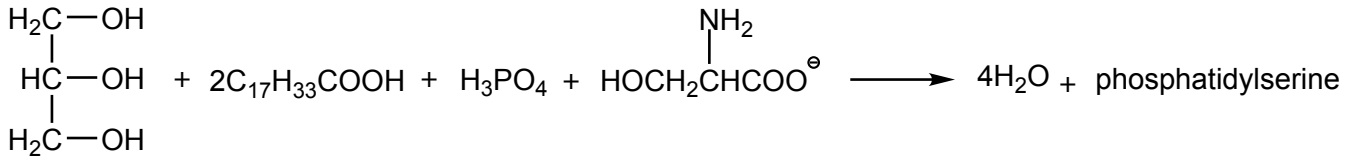
. . . . . .

(Option B continues on the following page)

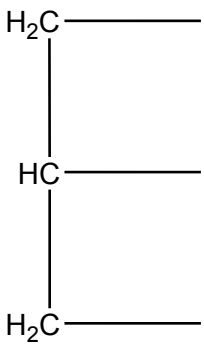
(Option B continued)

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]



(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

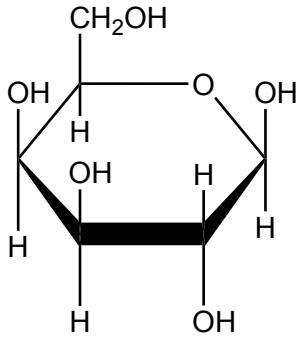
	Hydrolytic rancidity	**Oxidative rancidity**
Site of reactivity:	. . . .	. . . .
Conditions that favour reaction:	. . . .	. . . .

(Option B continues on the following page)

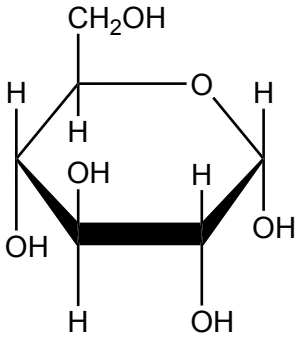
(Option B continued)

8. Lactose is the main disaccharide in milk.

(a) Lactose is composed of galactose and glucose.

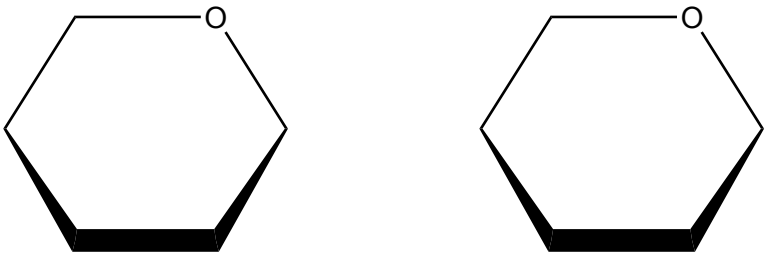


Galactose



Glucose

(i) Draw the structure of lactose. [2]



(ii) State the type of reaction that forms the disaccharide from monosaccharides. [1]

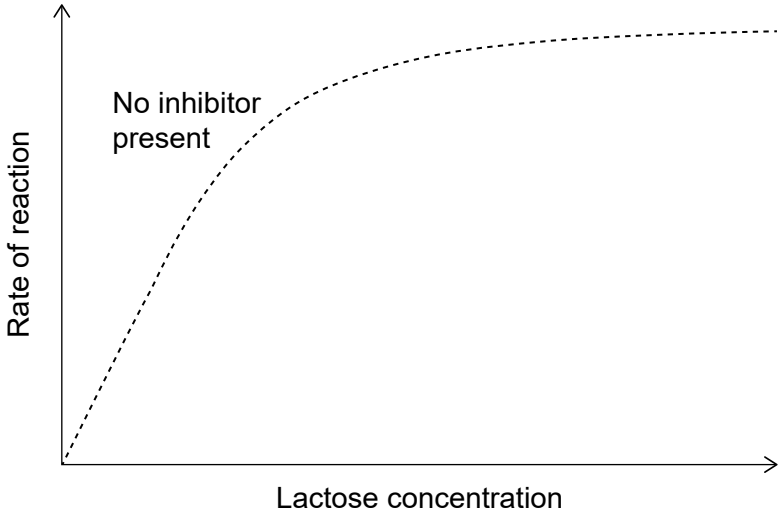
. . . . . .

(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]

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

(Option B continues on page 23)

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

Answers written on this page
will not be marked.

(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]

. . . . . .

. . . . . .

(b) Compare the bonding of synthetic host molecules and enzymes to substrates. [1]

. . . . . .

. . . . . .

. . . . . .

(c) Suggest a specific environmental application of host–guest chemistry. [1]

. . . . . .

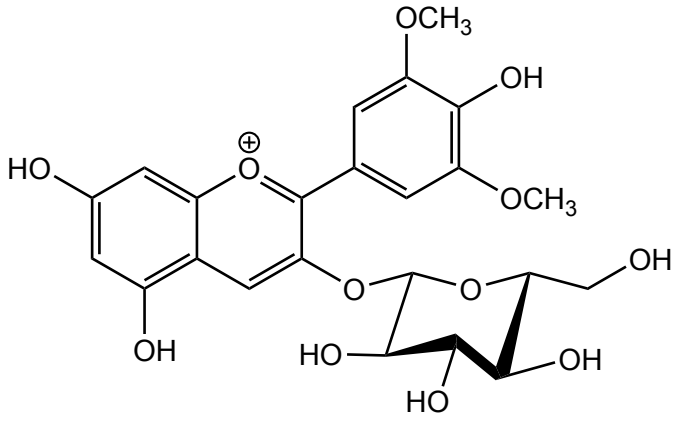
. . . . . .

. . . . . .

(Option B continues on the following page)

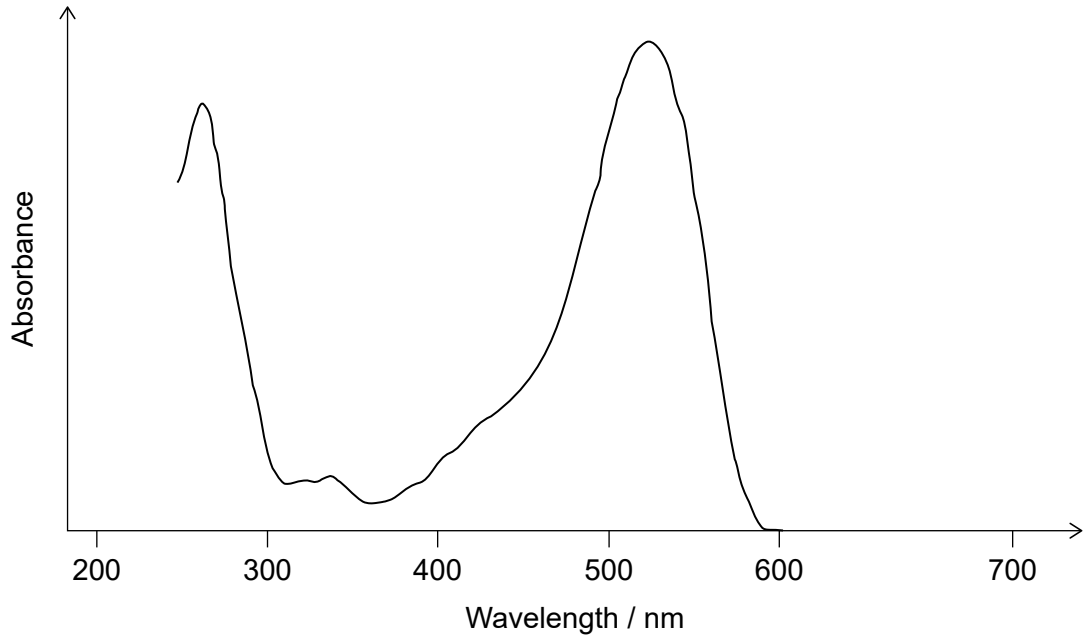
(Option B continued)

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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

11. Cells contain both DNA and RNA.

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

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]

. . . . . .

. . . . . .

(b) (i) A deuteron, or deuterium nucleus, ^{2}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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n$$ [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

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

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

(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:

. . . . . .

. . . . . .

. . . . . .

Chlorophyll:

. . . . . .

. . . . . .

. . . . . .

(ii) Identify the range of wavelengths absorbed by carbon dioxide and chlorophyll. Use section 3 of the data booklet. [1]

Carbon dioxide:

. . . . . .

Chlorophyll:

. . . . . .

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

Suggest how greenhouse gases could be responsible for this trend. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option C continues on the following page)

(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]

. . . . . .

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

. . . . . .

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

Advantage:

. . . . . .

. . . . . .

Disadvantage:

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

(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):

. . . . . .

. . . . . .

Positive electrode (cathode):

. . . . . .

. . . . . .

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

Fuel cells:

. . . . . .

. . . . . .

. . . . . .

Secondary cells:

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

End of Option C

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:

. . . . . .

Mode of action:

. . . . . .

. . . . . .

. . . . . .

(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]

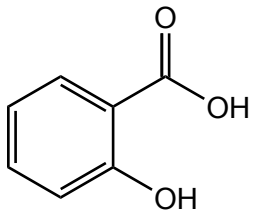
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

(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]

. . . . . .

. . . . . .

(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]

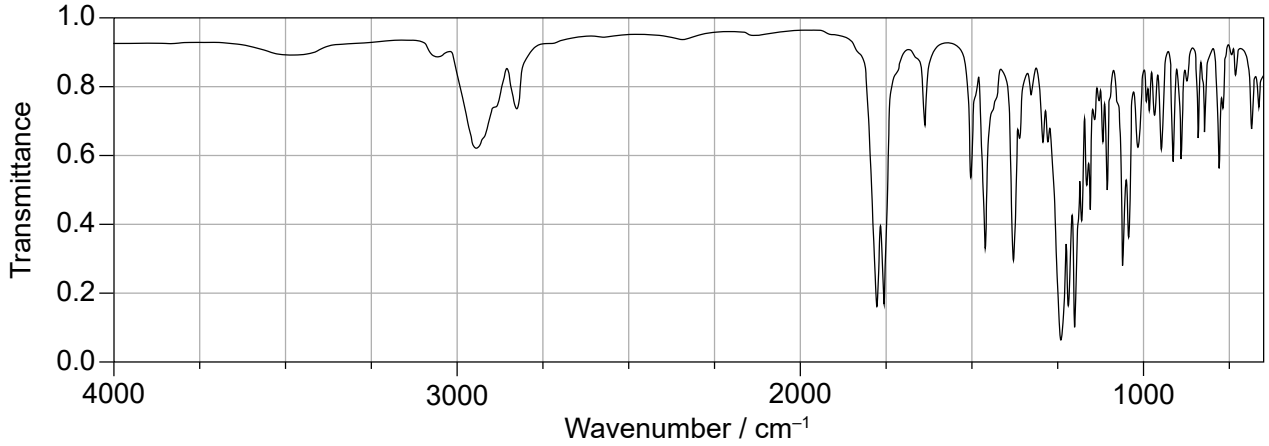
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(Option D continues on the following page)

(Option D continued)

17. Excess stomach acid is a common health condition.

(a) Explain how omeprazole regulates stomach pH. [2]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(b) Write an equation for the reaction of a solution of sodium hydrogen carbonate with stomach acid, including state symbols. [1]

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

(d) Deduce, giving a reason, whether the ^{1}H 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]

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

(Option D continues on the following page)

(Option D continued)

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

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

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

. . . . . .

. . . . . .

(iv) A typical dose of Lu-177 is 2.00 μg 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]

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

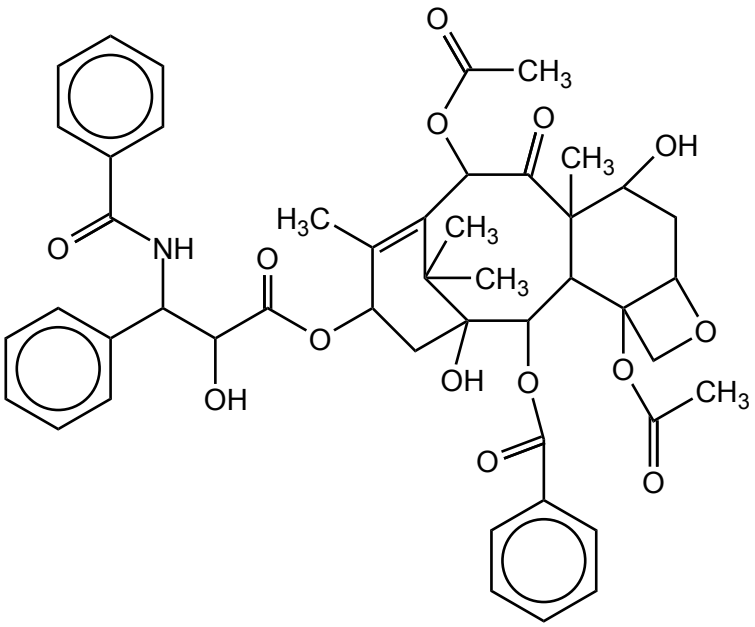
. . . . . .

. . . . . .

. . . . . .

. . . . . .

(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]

. . . . . .

End of Option D

Disclaimer:

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

References:

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). Koutchma, T., 2010. *UV irradiation improves safety of foods and beverages*. [graph] Available at: https://www.researchgate.net/figure/Measured-absorption-spectra-of-apple-juice-and-vitamin-C-as-well-as-emission-spectra-of_fig1_274630712 [Accessed 4 May 2020]. Source adapted.

1(c). Unaegbu, M., Godwill, E. A., et al., 2016. *Heavy metal, nutrient and antioxidant status of selected fruit samples sold in Enugu, Nigeria*. [table] Available at: https://www.researchgate.net/figure/pH-acidity-ascorbic-acid-and-antioxidantactivity-of-fruit-samples_tbl2_305691722 [Accessed 4 May 2020]. Under creative commons CC BY 4.0 DEED licence. https://creativecommons.org/licenses/by/4.0/. Source adapted (table simplified and redrawn).

3(b). iStock.com/ollaweila.

6(c). Chowdry, T. *Variability and inheritance of proteins in Apris mellifera eggs*. “BSA Calibration Curve” [graph] Available at: https://www.researchgate.net/publication/235329683_Variability_and_inheritance_of_proteins_in_Apis_mellifera_eggs [Accessed 4 May 2020]. Source adapted.

10(a). NotWith, 2012. *Spectra Chlorophyll ab oenin*. [graph] Available at: https://en.wikipedia.org/wiki/Anthocyanin#/media/File:Spectra_Chlorophyll_ab_oenin_(1).PNG [Accessed 4 May 2020]. Licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license https://creativecommons.org/licenses/by-sa/3.0/deed.en. Source adapted (redrawn and simplified).

16(e). Reprinted with permission from NIST © United States of America as represented by the Secretary of Commerce. Graph redrawn.

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

Answers written on this page
will not be marked.

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

Answers written on this page
will not be marked.