Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

8 May 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 – 4
Option B — Biochemistry	5 – 12
Option C — Energy	13 – 16
Option D — Medicinal chemistry	17 – 24

2224 – 6203

43 pages

Section A

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

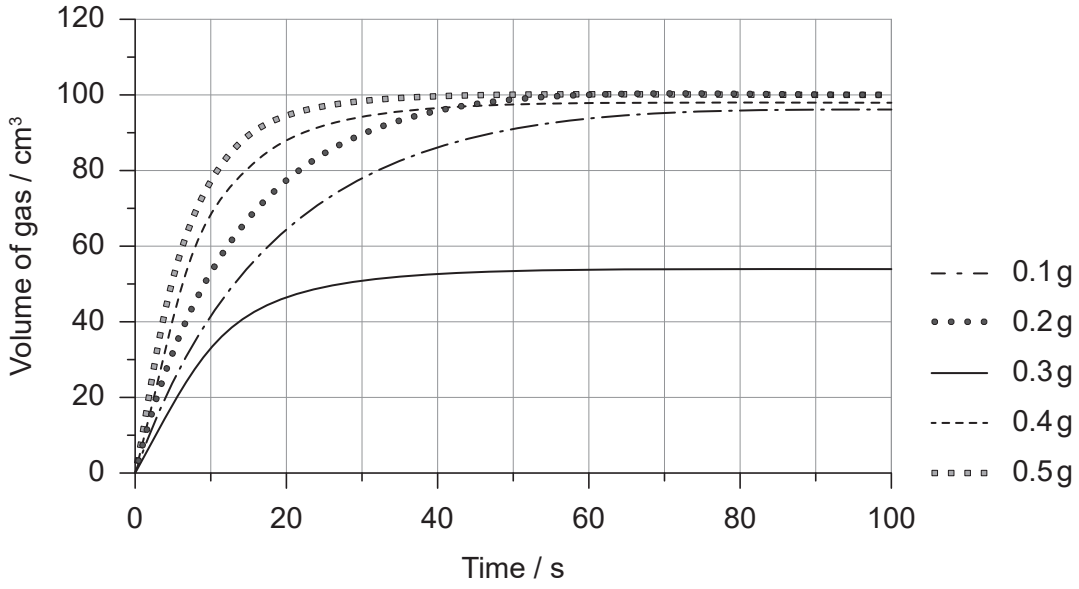
1. Hydrogen peroxide decomposes to form water and oxygen.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The reaction is catalysed by solid manganese(IV) oxide, $MnO_2(s)$.

A student carried out a series of experiments to determine how the rate of decomposition depends on the mass of catalyst. Each time a different mass of MnO_2 was added to 25.0 cm^3 of hydrogen peroxide solution. The oxygen was collected in a graduated gas syringe and the volume recorded at regular intervals.

Figure 1



(a) The 0.3 g data seems to be anomalous. Suggest a possible cause for this. [1]

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(This question continues on the following page)

(Question 1 continued)

(b) The student hypothesized, based on underlying theory, that doubling the mass of MnO_2 would double the rate of the catalysed reaction.

(i) Suggest why it is important to have hypotheses on the outcome of experiments. [1]

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(ii) Explain how the student's hypothesis might be supported by collision theory. [2]

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(iii) Identify the critical controlled variable that is not specified in the description of the method. [1]

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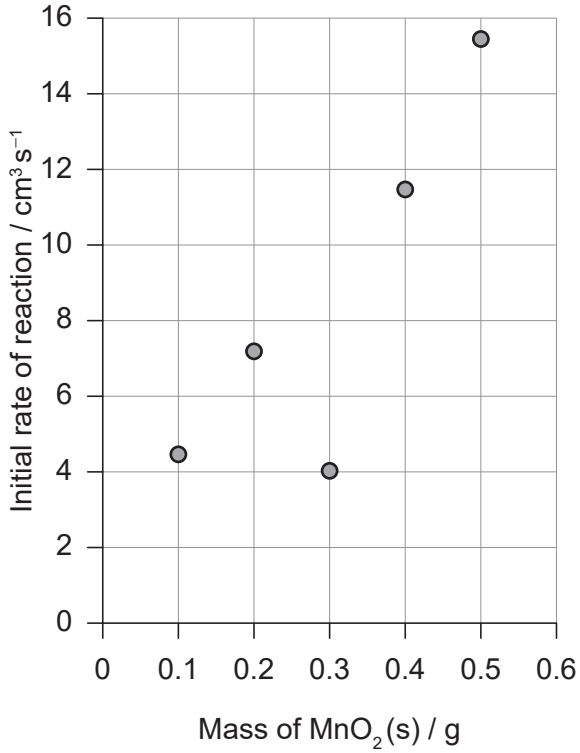
(This question continues on the following page)

(Question 1 continued)

(c) The results from **Figure 1** were processed to produce a graph showing how the initial rate varied with the mass of catalyst.

Figure 2



(i) Outline how the y-axis values on **Figure 2** were obtained from the results in **Figure 1**. [2]

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(ii) Suggest, giving a reason, whether a best-fit line for **Figure 2** should pass through the origin. [1]

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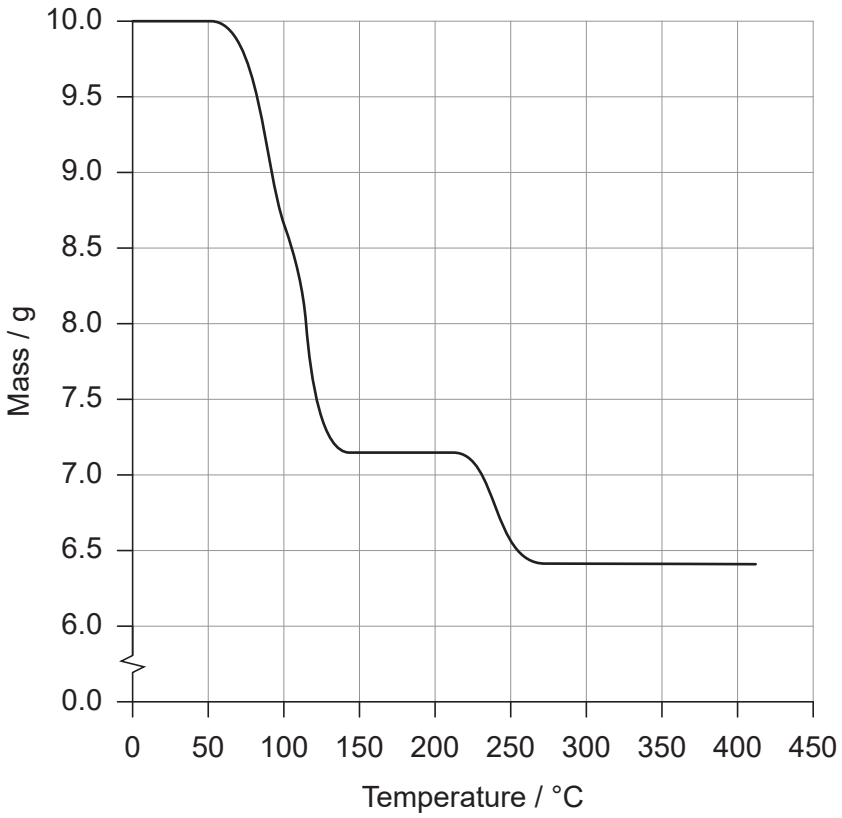
2. The **Figure 3** shows the change in mass when 10.0 g of copper (II) sulfate crystals are heated from 20 °C to 400 °C. Only water vapour is lost during this process and no further water vapour is lost on heating to higher temperatures.

Figure 3



(a) Demonstrate that this data is consistent with the formula $CuSO_4 \cdot 5H_2O$. [2]

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(This question continues on the following page)

(Question 2 continued)

(b) The uncertainty in the mass readings is $\pm$ 0.05 g.

(i) Calculate the percentage uncertainty in mass loss. [2]

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(ii) From your answer in (b)(i), calculate the absolute uncertainty of the ratio of $CuSO_4$:H_2O in $CuSO_4 \cdot 5H_2O$ (the uncertainty in the 5), to two significant figures. [1]

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(c) Deduce what the graph shows about the water in hydrated copper (II) sulfate. [2]

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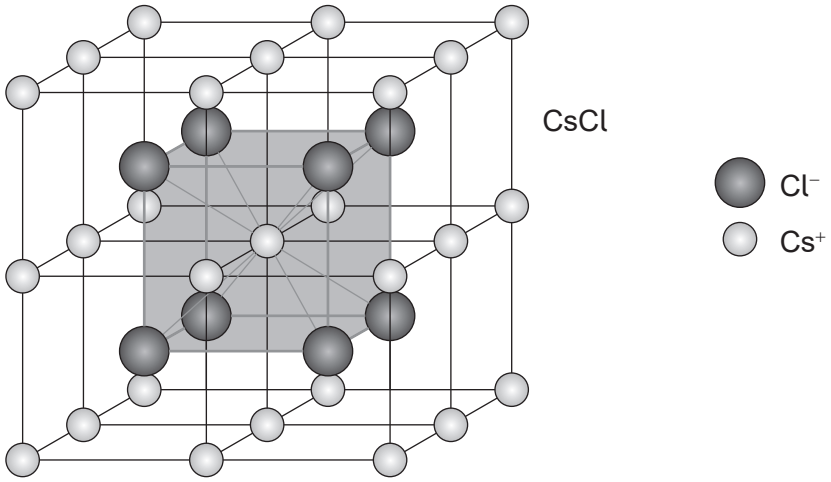
Section B

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

Option A — Materials

3. Caesium chloride, CsCl, has the ionic lattice structure shown.



(a) (i) Demonstrate, using sections 8 and 29 of the data booklet, how this type of bonding could be predicted. [2]

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(ii) Outline the nature of the forces holding this structure together. [1]

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(iii) Outline why caesium chloride crystals are very brittle. [1]

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(Option A continues on the following page)

(Option A, question 3 continued)

(b) Justify why caesium chloride is diamagnetic. [1]

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(c) Caesium metal is produced by electrolysis of molten caesium chloride.

(i) Outline why caesium can only be produced by electrolysis. [1]

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(ii) State the half-equation for the formation of caesium by electrolysis. [1]

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(iii) Determine the charge, in C, required to produce 1.00 g of caesium.
Use sections 2 and 6 of the data booklet. [2]

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(Option A continues on the following page)

(Option A, question 3 continued)

(d) Caesium metal and Cu–Ni nanoparticles are combined as the heterogeneous catalyst in the synthesis of long-chain alcohols.

(i) Compare and contrast homogeneous and heterogeneous catalysts. [2]

One similarity:

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One difference:

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(ii) State why many heterogeneous catalysts involve nanoparticles. [1]

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(iii) Nanoparticles are often produced by chemical vapour deposition (CVD). Suggest why this is carried out in an inert atmosphere. [1]

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(iv) Suggest **one** ethical concern about the use of nanoparticles. [1]

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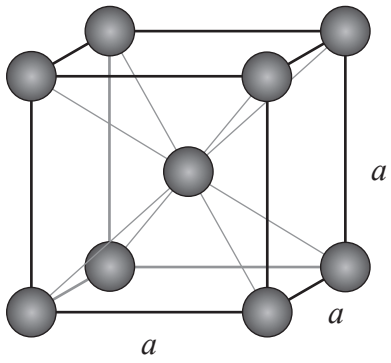
(Option A continues on the following page)

(Option A, question 3 continued)

(e) Caesium metal has a body centred cubic, BCC, structure.



(i) Deduce the number of metal atoms in the unit cell. [1]

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(ii) The side of the unit cell, a, is 614 pm (6.14×10^{-8} cm). Calculate the volume of the unit cell. [1]

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(iii) Determine the density of caesium metal, in g cm^{-3}. Use your answers to (e)(i), (e)(ii) and sections 2 and 6 of the data booklet. [2]

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(Option A continues on the following page)

(Option A, question 3 continued)

(f) Caesium-137, a dangerous radioisotope, can be removed from radioactive waste by forming a complex ion with a polydentate ligand.

Outline why this complex ion is more stable than one in which caesium forms bonds to many monodentate ligands. [1]

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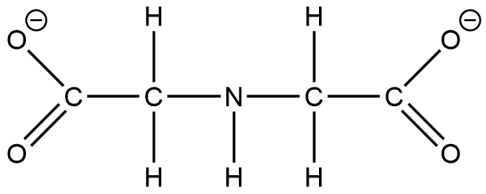
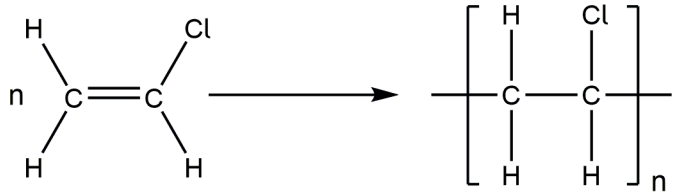
(g) The iminodiacetate ion, shown below, is an example of a polydentate ligand. Circle the atoms that bond to a metal ion. [1]



(Option A continues on the following page)

(Option A continued)

4. Polychloroethene, often known as polyvinylchloride or PVC, is synthesized from chloroethene.



(a) Phthalates are often added as plasticisers to PVC.

Outline, giving a reason, how these affect the physical properties of the plastic. [2]

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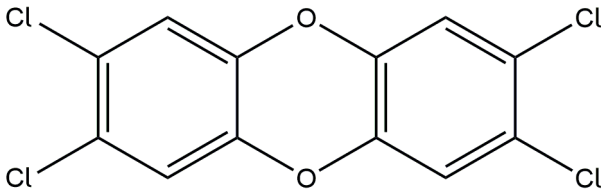
(b) The formula of a toxic product from the combustion of PVC is shown.



Identify the class of compounds to which it belongs and one harmful effect it has on humans. [2]

Class:

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Effect:

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(Option A continues on the following page)

(Option A, question 4 continued)

(c) Plastics are often stamped with a resin identification code, RIC.

(i) State the principal reason for RIC. [1]

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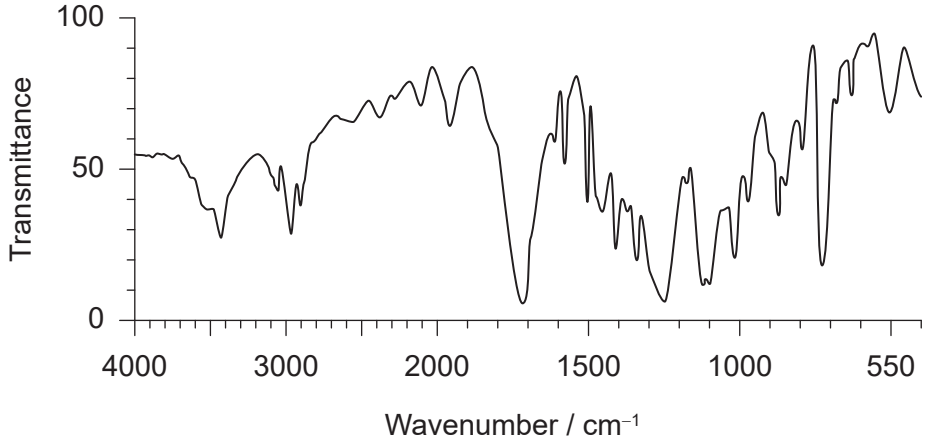
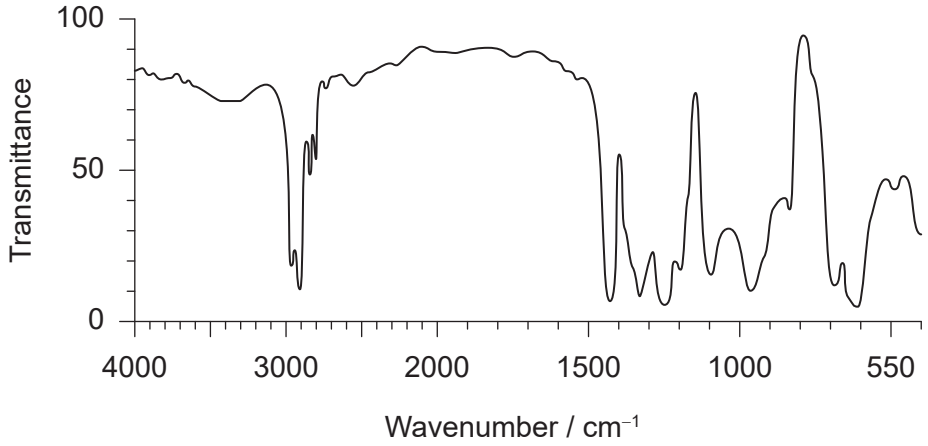
(ii) The IR spectra below are those of plastics with RIC 1 and 3.

Spectrum A



Spectrum B



[Source: SDBS, National Institute of Advanced Industrial Science and Technology.]

Deduce, giving a reason, which spectrum shows RIC 1. Use sections 26 and 30 of the data booklet. [1]

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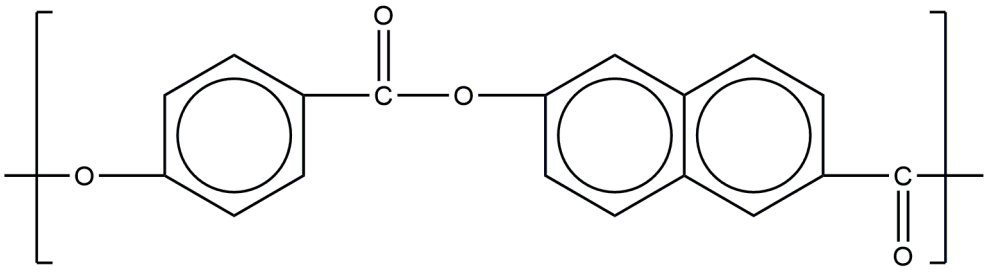
(Option A continues on the following page)

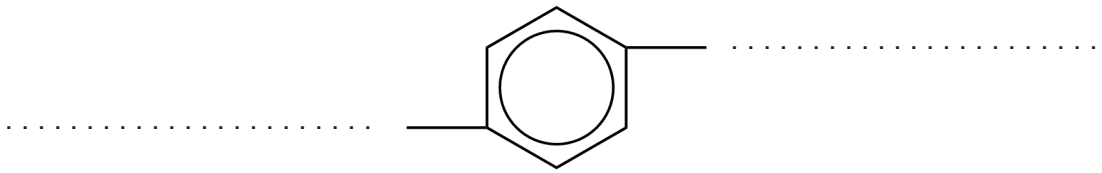
(Option A, question 4 continued)

(d) Vectran™ is a condensation polymer produced from two monomers. The structure of a small section of the polymer chain is shown.

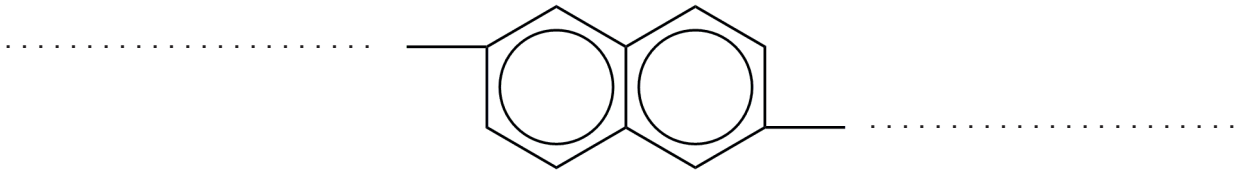


Draw the functional groups of the two monomers on the structures below. [2]

Monomer A



Monomer B



(Option A continues on the following page)

(Option A, question 4 continued)

(e) Vectran™ can behave as a liquid crystal when it is dissolved in a solvent or when molten.

(i) Describe what is meant by a liquid crystal. [1]

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(ii) State, giving a reason, whether Vectran™ should be dissolved or melted to produce a lyotropic liquid crystal phase. [1]

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End of Option A

Option B — Biochemistry

5. Glucose is an energy-rich molecule that can be synthesized in plants.

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

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(b) (i) Glucose is polymerized in the plant cell to form starch. Identify the type of reaction and the by-product. [1]

Type of reaction:

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By-product:

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(ii) Outline, in terms of its properties, why starch cannot be used as a direct energy source. [1]

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(iii) State how the energy in starch can be made available for respiration. [1]

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(Option B continues on the following page)

(Option B continued)

6. Lipids, such as fats and oils, are triglycerides of fatty acids. The table shows the fatty acid composition of commonly used oils and fats.

Source	Fatty acids / %		
	Saturated	**Monounsaturated**	**Polyunsaturated**
Corn oil	13	28	59
Sunflower oil	10	48	42
Olive oil	14	75	11
Canola oil	8	64	28
Butter	66	30	4

(a) Suggest, with a reason, which lipid will be most likely to undergo oxidative rancidity. [1]

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(b) 5.00 g of olive oil reacts completely with 33.0 cm^3 of 0.500 mol dm^{-3} iodine solution. Calculate the iodine number of olive oil. [3]

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(c) Explain why butter is solid at room temperature with reference to the structure and bonding of its fatty acids. [2]

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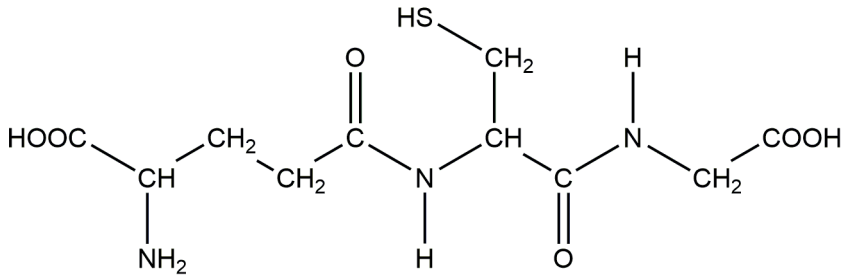
(Option B continues on the following page)

(Option B continued)

7. 2-amino acids can be combined to form peptides and proteins.

(a) The tripeptide glutathione is shown. Circle all the amide links. [1]



(b) Glutathione can undergo hydrolysis in the cell. Identify the products using section 33 of the data booklet. [1]

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(c) Identify the amino acid obtained in (b) which is not chiral. [1]

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(d) The products of the hydrolysis were analysed by electrophoresis using a buffer of pH = 4.8. Deduce which amino acid will move to the positive electrode when the voltage is applied. Use section 33 of the data booklet. [1]

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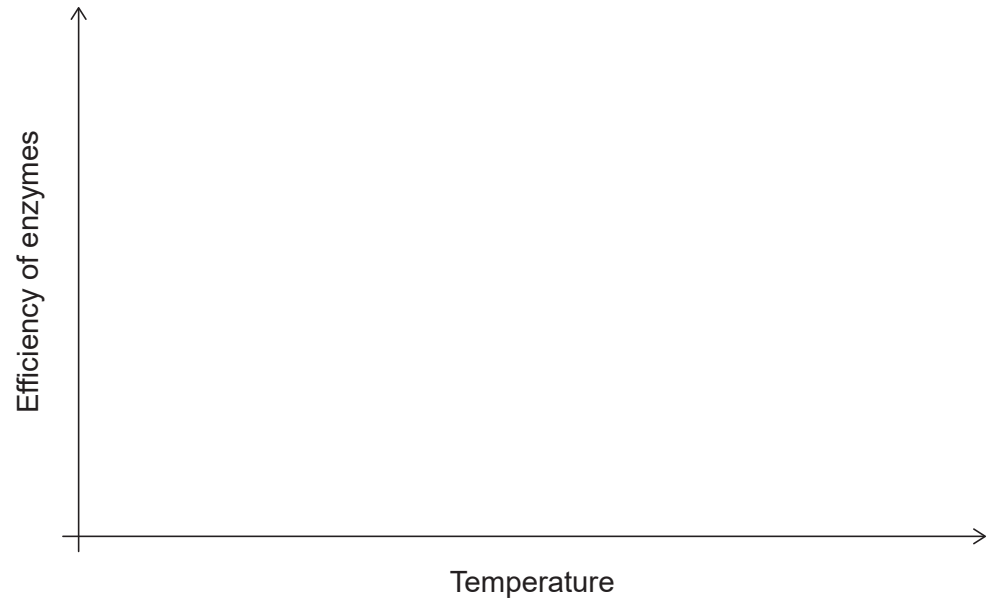
(Option B continues on the following page)

(Option B continued)

8. Biological laundry detergents contain enzymes that can efficiently remove stains at low temperatures.

(a) Sketch a graph to show how the efficiency of the enzyme varies with temperature. [1]



(b) Suggest why biological detergents have a lower environmental impact than non-biological detergents. [1]

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(c) State **one** use of enzymes and microorganisms to reduce environmental damage resulting from human activities. [1]

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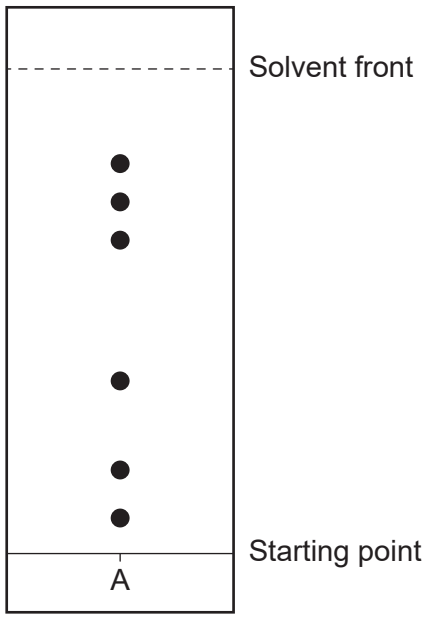
(Option B continues on the following page)

(Option B continued)

9. Green algae are a rich source of pigments such as chlorophylls and carotenoids.

Thin-layer chromatography (TLC) was used to investigate the presence of the carotenoid lutein in an algae extract. A chromatogram with 6 coloured spots was obtained.

R_f	Pigment
0.08	Xantophyll Y
0.17	Xantophyll X
0.36	Lutein
0.64	Chlorophyll b
0.72	Chlorophyll a
0.80	β-carotene



(a) Determine if lutein is present by calculating R_f values of the spots and comparing them with the data in the table. [1]

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(b) Explain, with reference to their structures, why chlorophylls and carotenoids are coloured. Use section 35 of the data booklet. [2]

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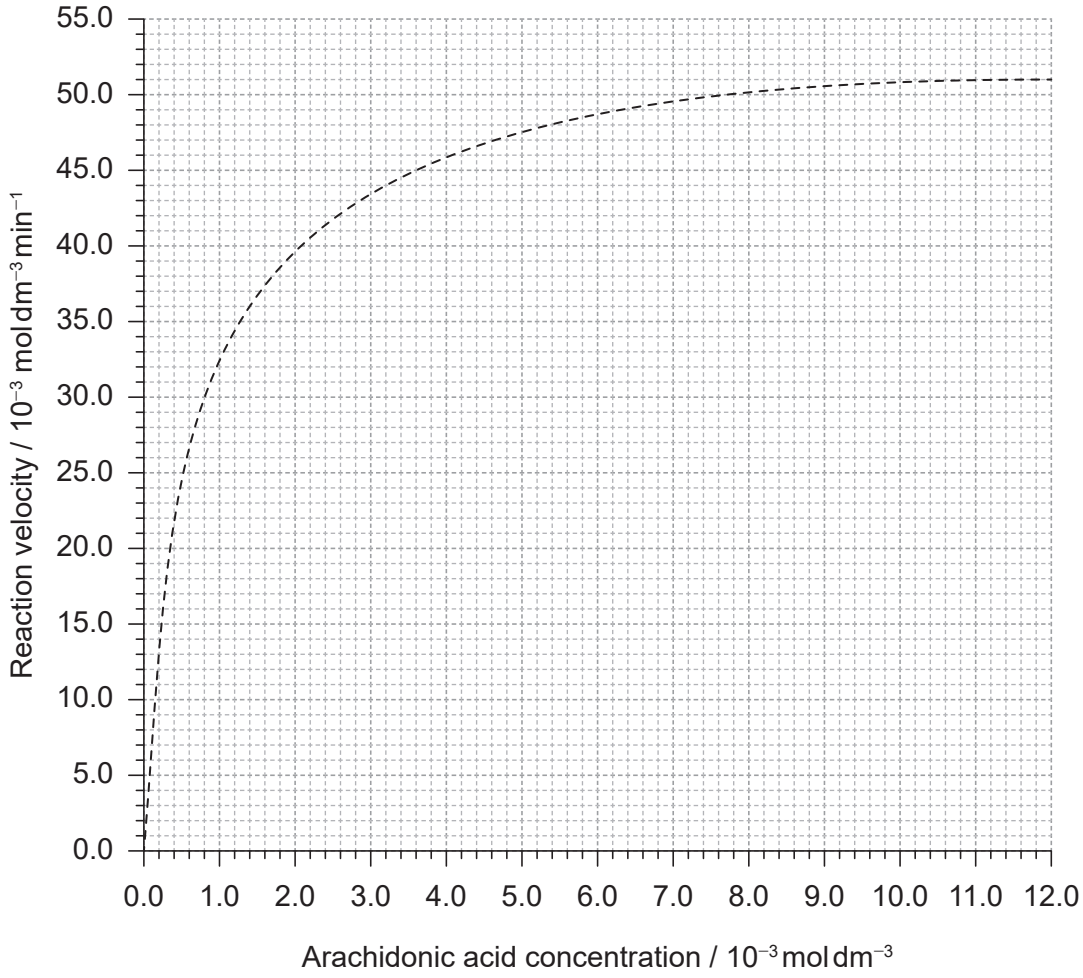
(Option B continues on the following page)

(Option B continued)

10. An enzyme catalyzes the conversion of arachidonic acid into the precursor of most prostaglandins associated with inflammation and pain.

(a) Determine the K_m and V_{max} of the reaction using the Michaelis–Menten graph. [2]



K_m: . . . . . .

V_{max}: . . . . . .

(b) Ibuprofen is a competitive inhibitor of this enzyme. Sketch a graph on the same axes in (a) showing the effect of the presence of this compound on the rate of reaction. [1]

(Option B continues on the following page)

(Option B, question 10 continued)

(c) Discuss how the presence of ibuprofen affects the production of the prostaglandin precursor. [2]

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11. Citrus fruit juices are good sources of ascorbic acid (vitamin C). Explain why vitamin C is soluble in water, referring to its structure. Use section 35 of the data booklet. [2]

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(Option B continues on the following page)

(Option B continued)

12. DNA is a double helix of two polynucleotide strands.

(a) Outline how these strands are held together and the components of the strands involved. [2]

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(b) Deduce the nucleotide sequence of a complementary strand of a fragment of DNA with the nucleotide sequence ATGGCAAGC. [1]

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End of Option B

Option C — Energy

13. Methane clathrate looks like ice but burns when ignited because it turns back to water and methane.

(a) Write an equation for the complete combustion of methane. [1]

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(b) The formula of methane clathrate is $(CH_4)_4(H_2O)_{23}$ and its molar mass is $478.7\,g\,mol^{-1}$. Calculate the specific energy of methane clathrate. Use sections 1, 6 and 13 of the data booklet. [2]

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(c) Suggest why methane clathrate has a lower specific energy but higher energy density than methane. [2]

Lower specific energy:

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Higher energy density:

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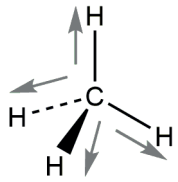
(Option C continues on the following page)

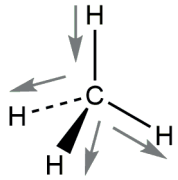
(Option C, question 13 continued)

(d) Methane has both symmetric and asymmetric stretching modes as illustrated.

Symmetric stretch



Asymmetric stretch



State, giving a reason, which of these modes is responsible for greenhouse gas activity. [1]

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(e) There are significant quantities of methane clathrate on the ocean bed and in arctic permafrost layers.

Suggest why burning methane clathrate is preferable to allowing the methane it contains to escape into the atmosphere. [1]

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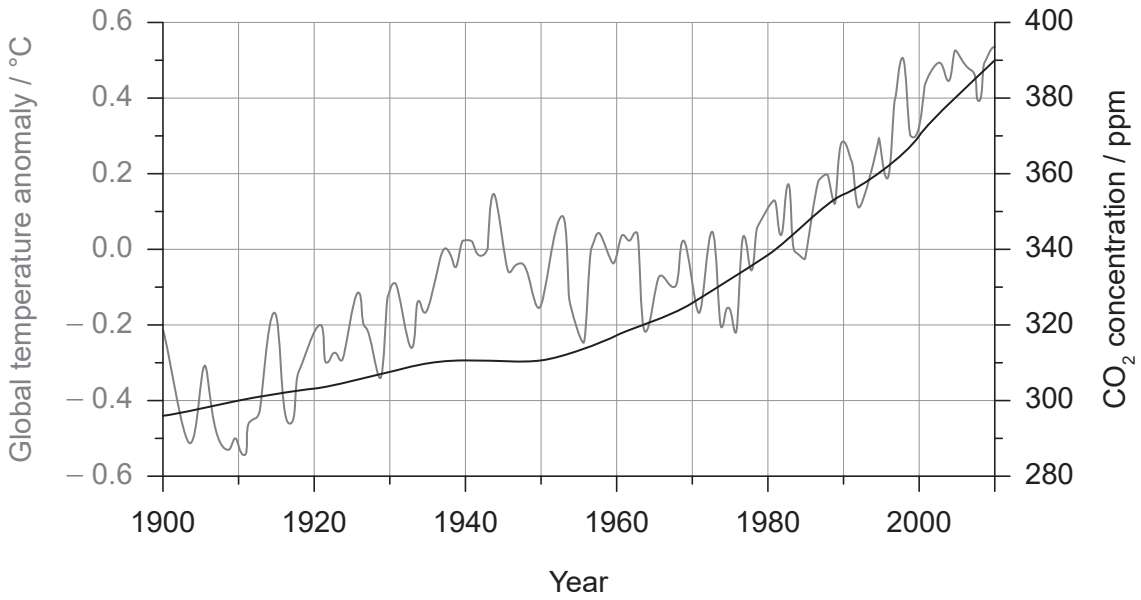
(Option C continues on the following page)

(Option C, question 13 continued)

(f) The graph shows the increase in temperature and the level of carbon dioxide in the atmosphere.



Discuss how this data could be used to both support and refute the theory that carbon dioxide is a cause of global warming. [2]

Support:

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Refute:

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(Option C continues on the following page)

(Option C continued)

14. Methane, gasoline and biodiesel are used as fuels for transport.

(a) (i) Outline why the combustion of methane has a lower environmental impact than gasoline. [2]

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(ii) Suggest why gasoline is more widely used than methane as a car fuel, even though it is more expensive in most countries. [1]

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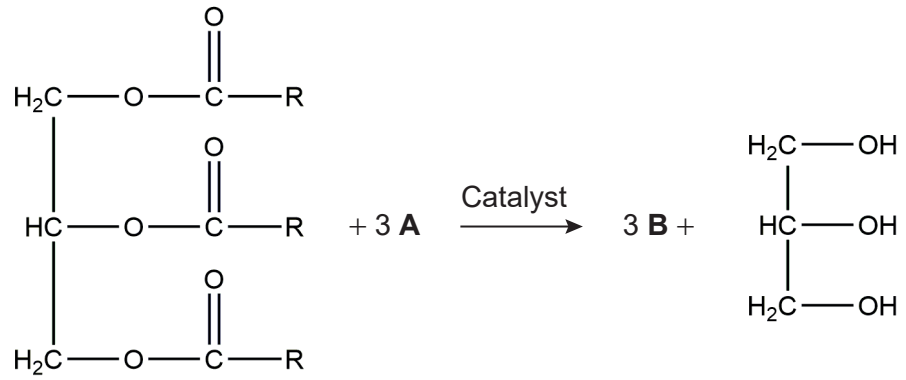
(Option C continues on the following page)

(Option C, question 14 continued)

(b) Transesterification is used to convert vegetable oils into a sustainable alternative fuel for internal combustion engines.

(i) Complete the equation for transesterification. [1]



A: . . . . . .

B: . . . . . .

(ii) Vegetable oils cannot be used directly as a fuel in a standard internal combustion engine.

Outline why the product can however be used as a fuel, giving the underlying reason in terms of intermolecular forces. [2]

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(Option C continues on the following page)

(Option C continued)

15. Fusion and fission both involve changes to atomic nuclei.

(a) Compare and contrast the nuclear processes involved in fusion and fission. [2]

Similarity:

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Difference:

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(b) Outline how we know that helium, the product of hydrogen fusion, is present in the sun. [1]

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(c) Many of the products of nuclear fission reactors are harmful to life because they are radioactive. Identify a species produced in the body, by radioactive particles, that is responsible for this biological damage. [1]

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(d) Suggest why, apart from the inherent dangers of radioactive materials, some countries would like to prevent others building nuclear fission reactors. [1]

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(Option C continues on the following page)

(Option C, question 15 continued)

(e) Natural uranium needs to be enriched before it can be used as a fuel in nuclear reactors.

(i) Outline why enrichment is necessary. [1]

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(ii) Outline why uranium is converted to uranium hexafluoride, UF_6, for enrichment. [1]

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(iii) Outline the reason why the isotopes separate in the enrichment process. [1]

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(Option C continues on the following page)

(Option C continued)

16. The use of photovoltaic devices is being encouraged to combat global warming.

(a) Explain the operation of dye-sensitized solar cells (DSSCs). [4]

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(b) At night, rechargeable batteries can be used to power installations connected to photovoltaic systems.

(i) Identify the substances which are converted to lead (II) sulfate, $PbSO_4$, during discharge of a lead-acid cell. [2]

Positive electrode (cathode):

. . . . . .

Negative electrode (anode):

. . . . . .

(ii) Outline why lithium ion batteries are now generally preferred to lead-acid batteries. [1]

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End of Option C

Option D — Medicinal chemistry

17. Penicillin was the first of a class of antibiotics known as β-lactams.

(a) Suggest, with reference to their mechanism of action, why these antibiotics affect bacteria but not animal cells. [1]

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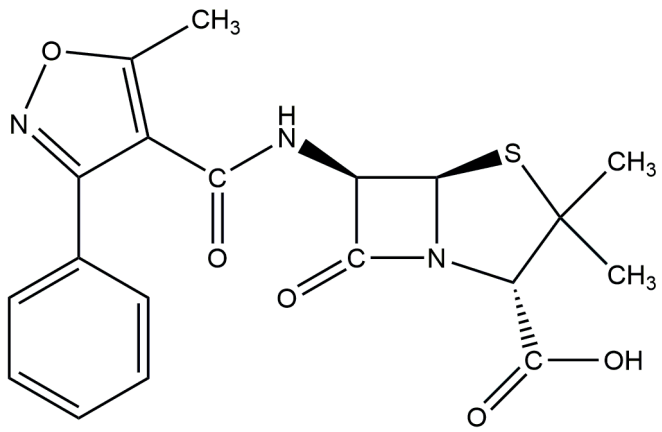
(b) Oxacillin was developed to treat infections with bacteria that produce beta-lactamase.



(i) Suggest why modifying the side-chain generates penicillinase resistance. [1]

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(ii) The sodium salt of oxacillin is used to increase its solubility in water. Draw a circle on the structure in (b) identifying the group in the oxacillin molecule that can react with a base to form the salt. [1]

(Option D continues on the following page)

(Option D, question 17 continued)

(c) Explain how the addition of antibiotics to animal feeds has contributed to the development of antibiotic-resistant bacteria. [2]

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(Option D continues on the following page)

(Option D continued)

18. Morphine and its derivatives (opiates) are only used to treat severe pain due to their side effects.

(a) State **one** side effect of the long-term use of opiates. [1]

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(b) Codeine ($M_r = 299.40$) is generally produced by semi-synthesis from morphine ($M_r = 285.37$).

(i) Describe how the morphine molecule must be modified to produce codeine. Use section 37 of the data booklet. [1]

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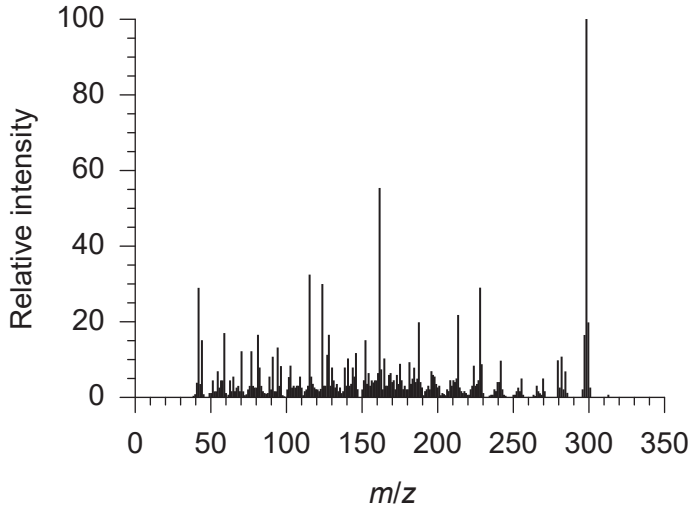
(ii) The product of the reaction in (b)(i) was analysed in a mass spectrometer.



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Suggest how this spectrum indicates that codeine was produced. [1]

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(Option D continues on the following page)

(Option D, question 18 continued)

(iii) Codeine is less potent than morphine. Suggest, with reference to their structures, why you would expect the opposite. [2]

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19. Aspirin is a mild analgesic and can reduce fever and inflammation.

(a) State **one** other effect of aspirin. [1]

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(b) Suggest why aspirin should not be taken together with alcohol. [1]

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(Option D continues on the following page)

(Option D continued)

20. Excessive acidity of gastric juice can be treated at different levels.

(a) Outline how omeprazole reduces stomach acidity. [1]

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(b) In the intestine, the gastric juice is buffered.

$$H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq) \quad pK_a = 6.31 \text{ (at } 37\,^\circ\text{C)}$$

Calculate the concentration of HCO_3^- in a buffer of pH = 7.43 when the concentration of H_2CO_3 is $2.03 \times 10^{-3}\,\text{mol}\,\text{dm}^{-3}$. Use section 1 of the data booklet. [2]

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(Option D continues on the following page)

(Option D continued)

21. Antiviral drugs act by interfering with the virus replication cycle.

(a) Osetalmivir and zanamivir are two antiviral drugs used to prevent flu.

Outline how these drugs work. [2]

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(b) Predict, with a reason, which of the two drugs is more soluble in water. Use section 37 of the data booklet. [1]

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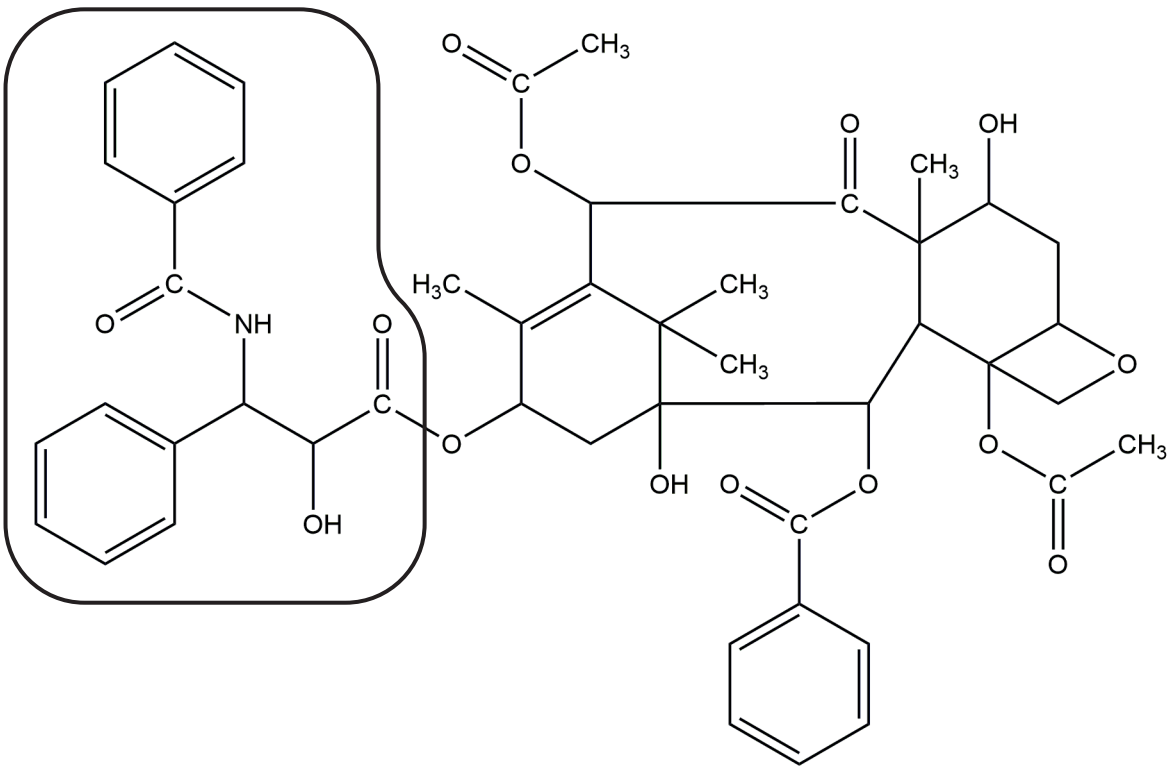
(Option D continues on the following page)

(Option D continued)

22. Taxol is an anticancer drug that is obtained semi-synthetically by addition of a side-chain to a precursor.

(a) The side-chain, circled in the structure has two chiral centres. Identify these chiral centres with asterisks,*. [1]



(b) Suggest why a chiral auxiliary must be used to obtain only the active molecule. [1]

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(Option D continues on the following page)

(Option D continued)

23. Targeted alpha therapy (TAT) is a technique used in nuclear medicine.

(a) Describe how TAT works. [3]

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(b) One of the radionuclides used for this therapy is lead-212, which rapidly decays to bismuth-212.

(i) Bismuth-212 decays emitting an alpha particle. Deduce the product of this decay reaction. [1]

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(ii) Bismuth-212 has a half-life of 61.0 minutes. Calculate the time needed to reduce the original quantity by 90 %, using section 1 of the data booklet. [2]

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(Option D continues on page 41)

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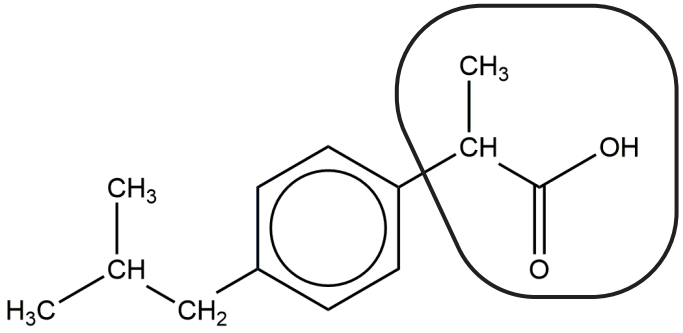
(Option D continued)

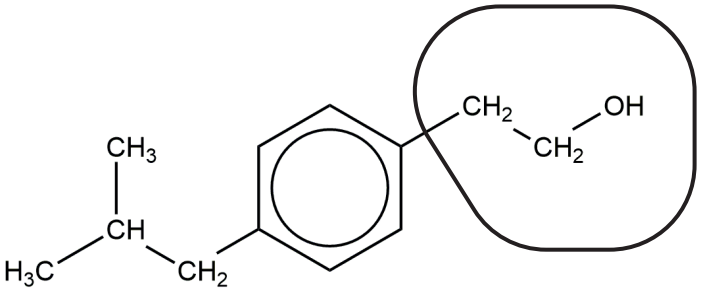
24. Structures of compounds can be determined by spectroscopic methods.

Ibuprofen is obtained by synthesis and often contains impurities.

Ibuprofen



Impurity X



(a) Predict the number of signals and relative areas you would expect to see in the ^{1}H NMR spectrum of the circled side-chain of each compound. [2]

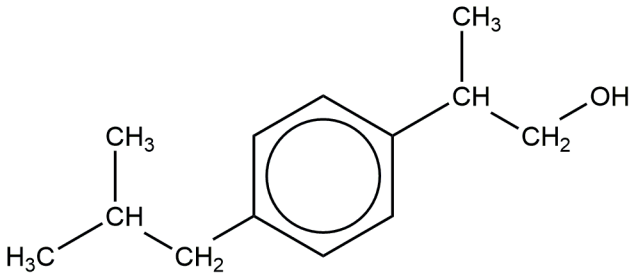
Compound	Number of signals	Relative areas
Ibuprofen	. . . . .	. . . . .
Impurity **X**	. . . . .	. . . . .

(Option D continues on the following page)

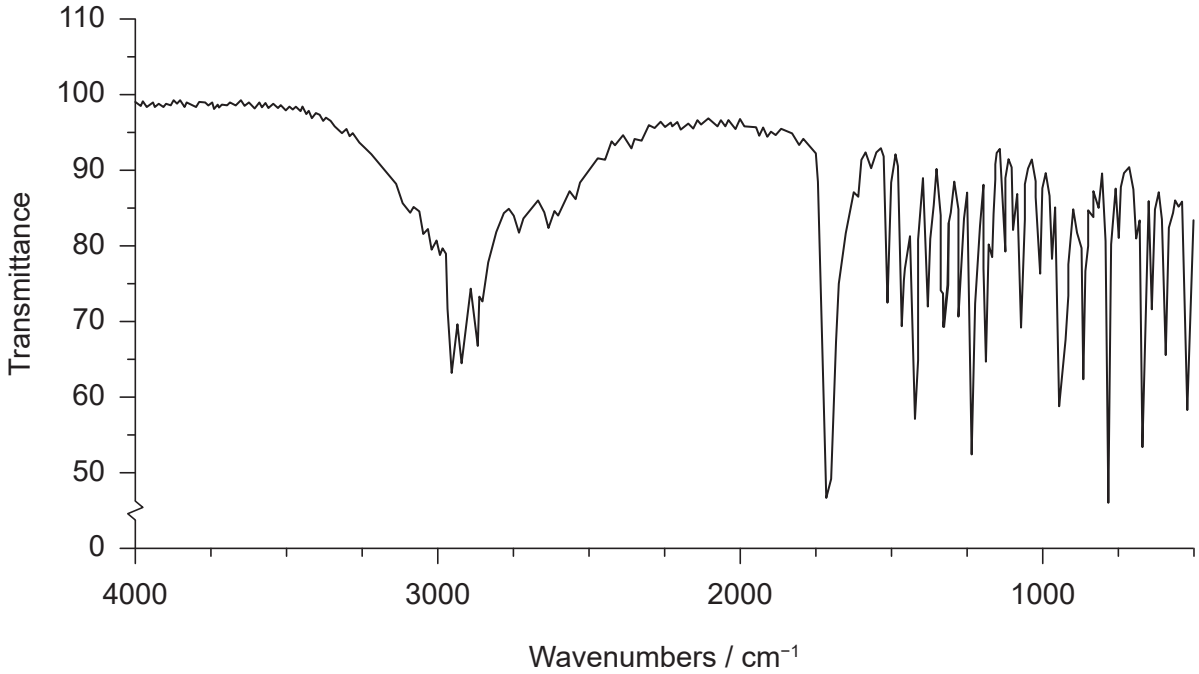
(Option D, question 24 continued)

(b) The infrared spectra of ibuprofen and another side product, impurity **Y**, are shown.

Impurity Y



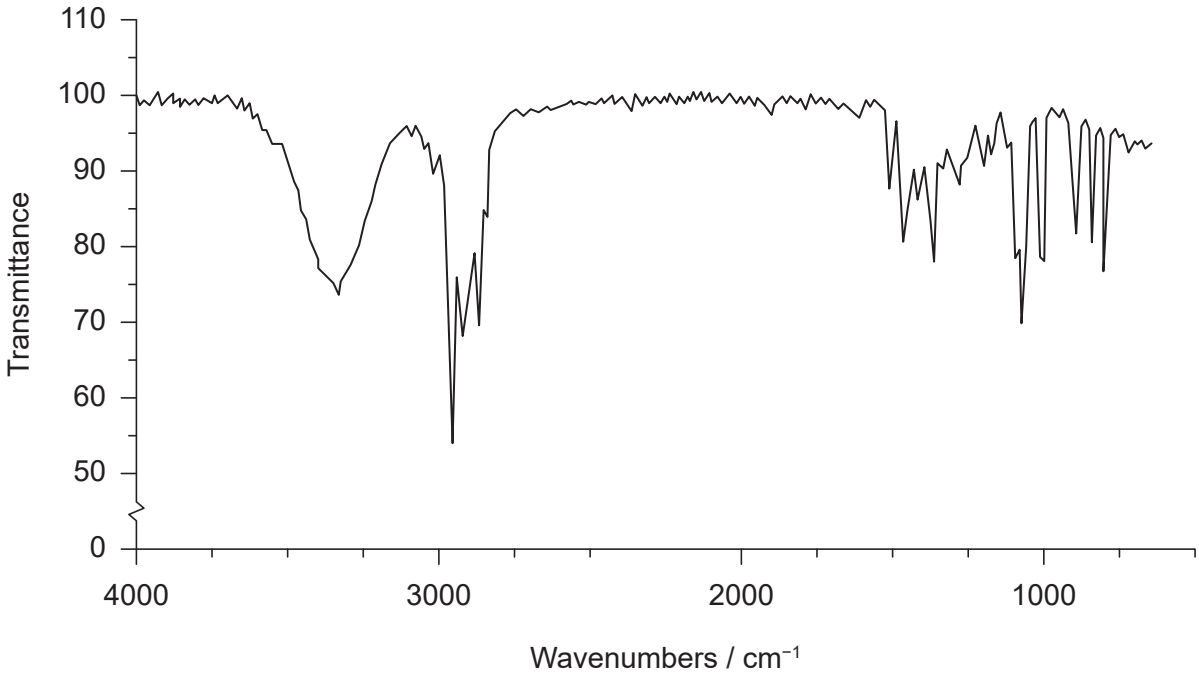
Spectrum A



(Option D continues on the following page)

(Option D, question 24 continued)

Spectrum B



Deduce, giving **two** reasons, which spectrum belongs to the impurity **Y**. Use section 26 of the data booklet. [2]

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End of Option D

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References:

4.(c)(ii) SDBS, National Institute of Advanced Industrial Science and Technology.

6. U.S. Department of Agriculture (USDA). FoodData Central - Oil, corn, industrial and retail, all purpose salad or cooking. https://fdc.nal.usda.gov/fdc-app.html#/food-details/171029/nutrients. Public domain. Source adapted.

13.(f) Van der Werf, G., *Global temperature anomaly*. [graph] Available at: https://www.geo.vu.nl/~gwerf/climate.html [Accessed 3 April 2019]. Source adapted.

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24.(b) (Spectrum A) With permission from The Royal Society of Chemistry.

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