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 – 5
Option B — Biochemistry	6 – 10
Option C — Energy	11 – 13
Option D — Medicinal chemistry	14 – 20

2224 – 6209

31 pages

Section A

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

1. This question is about the rate of reaction between bromine and methanoic acid.

$$Br_2\,(aq) + HCOOH\,(aq) \rightarrow 2Br^-\,(aq) + 2H^+\,(aq) + CO_2\,(g)$$

(a) State and explain how the rate of this reaction, measured in **mol dm^{-3} s^{-1}**, could be monitored experimentally. [3]

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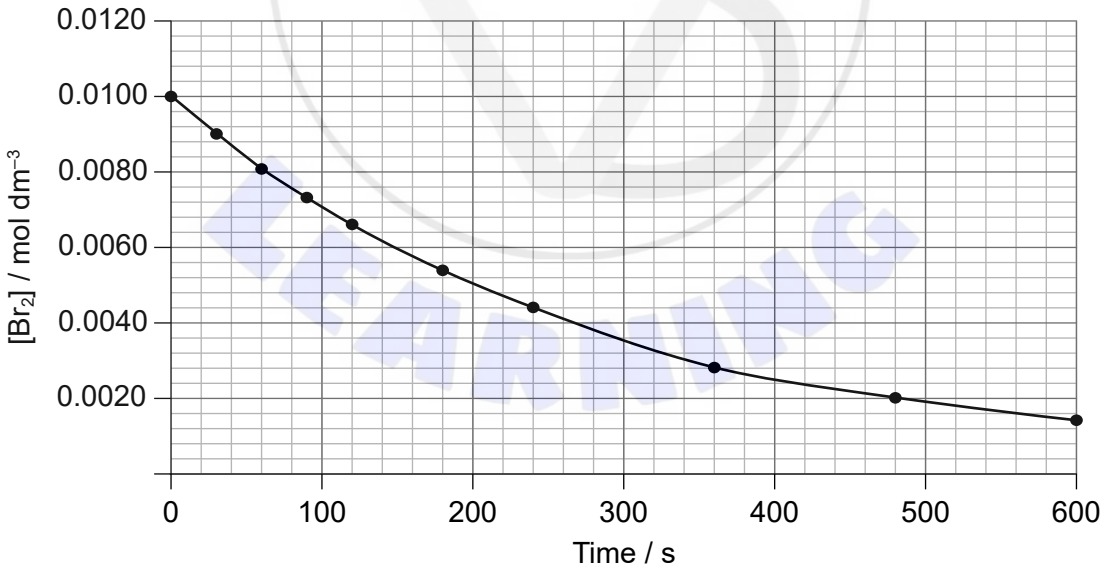
(b) The change in bromine concentration was monitored.



(This question continues on the following page)

(Question 1 continued)

(i) Determine the instantaneous rate of reaction to two significant figures when $[Br_2] = 0.0080\ mol\ dm^{-3}$. [3]

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(ii) Outline why the graph has a negative non-linear slope. [2]

Reason for negative slope:

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Reason for non-linear slope:

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

Answers written on this page
will not be marked.

2. Green chemistry focuses on the design and implementation of chemical processes to reduce waste, conserve energy and discover replacements for hazardous substances.

(a) (i) Four metrics of green chemistry effectiveness are:

Metric	**Definition**	**Result that yields maximum effective green chemistry**
Process mass intensity (PMI)	ratio of the masses of all materials used (water, organic solvents, raw materials, reagents, process aids) to the mass of the desired product	1
E-factor	mass of waste divided by mass of desired product	. . . . .
Atom economy	total mass of desired product divided by total mass of all reactants	. . . . .
Eco-Scale	100 minus penalty points (points deducted for low yield, price, safety, technical setup, temperature/time, and purification)	. . . . .

The number that yields the maximum effective green chemistry result is given for PMI.

Estimate a number for each of the other three metrics. [2]

(ii) Identify the metric that does not account for solvent use. [1]

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(iii) Suggest a reason why the pharmaceutical industry has a much worse PMI measure of green chemistry than other chemical industries, such as the oil refining industry or bulk chemical production. [1]

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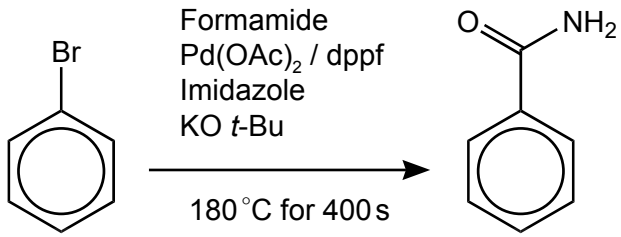
(This question continues on the following page)

(Question 2 continued)

(b) (i) There are two methods of producing benzamide from bromobenzene. Scheme 1 is shown below.



Scheme 1 has a yield of 82 %, requires a nitrogen atmosphere and is activated via microwave radiation.

The MSDS safety codes for the affected reagents are:
Bromobenzene (N), Formamide (T), KO *t*-Bu (F), dppf (T)

Eco-Scale = 100 – penalty points.

Penalty point deductions based on Eco-Scale:

Parameter	**Penalty points**
N (dangerous for environment)	5
T (toxic)	5
F (highly flammable)	5
F+ (extremely flammable)	10
Yield	$\frac{(100 - \%\text{yield})}{2}$
Unconventional/electromagnetic activation technique	2
(Inert) gas atmosphere	1
Heating < 1 hour	2
Heating > 1 hour	3

(This question continues on the following page)

(Question 2 continued)

Determine the Eco-Scale for Scheme 1, ignoring $Pd(OAc)_2$ and imidazole. [2]

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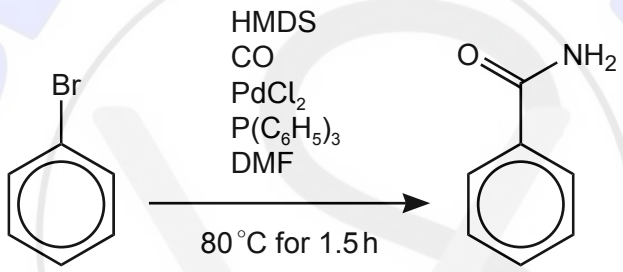
(ii) Scheme 2 is shown below.



Scheme 2 has a yield of 76 % and is carried out under a CO atmosphere.

The MSDS safety codes for the affected reagents are:
Bromobenzene (N), CO (T, F+), HMDS (F), DMF (T), $P(C_6H_5)_3$ (N)

Suggest **one** reason why Scheme 2 has a lower Eco-Scale score than Scheme 1. [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

3. Nitinol, NiTi, is a shape memory alloy composed of 50 % nickel atoms and 50 % titanium atoms.

(a) State **two** differences between alloys and composites. [2]

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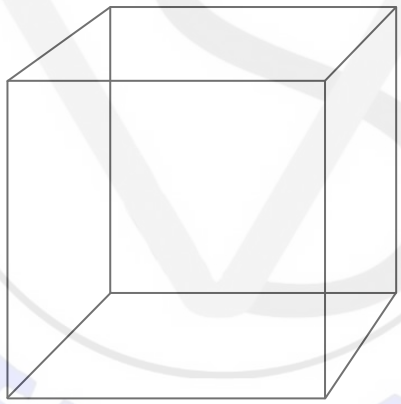
(b) (i) Nitinol has a body-centred cubic (BCC) lattice.

Sketch a BCC unit cell on the diagram identifying the BCC coordination number. [2]



Coordination number:

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(Option A continues on the following page)

(Option A, question 3 continued)

(ii) X-ray diffraction measurements of nitinol using a wavelength, λ, of 0.1789 nm produced a primary diffraction peak at an angle of 17.25°.

Calculate the lattice spacing distance, *d*, in nm, in the crystal, using section 1 of the data booklet. [1]

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(iii) Nitinol has a density of 6.45 g cm^{-3}. Determine the average relative molar mass, M_r, of nitinol, NiTi. [2]

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(iv) Titanium, unlike nitinol, exhibits the Meissner effect at very low temperatures. Explain the Meissner effect. [2]

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(Option A continues on the following page)

(Option A, question 3 continued)

(c) Titanium is highly reactive and the production of pure nitinol is difficult. One method of producing high-grade nitinol is by plasma arc melting.

(i) Outline the nature of the plasma state. [1]

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(ii) The plasma torch used is similar to that used in inductively coupled plasma (ICP).

Identify a gas used to produce the plasma. [1]

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(iii) Explain the significance of this plasma in the production of pure nitinol. [2]

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(d) Chemical vapour deposition (CVD) can be used to produce nitinol or graphene.

Outline the production of graphene nanotubes using CVD. [3]

Source of carbon:

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Conditions:

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(Option A continues on the following page)

(Option A, question 3 continued)

(e) Nickel and its compounds can be used as a homogenous or heterogeneous catalyst.

State **one** advantage and **one** disadvantage of a homogenous metal catalyst. [2]

Advantage:

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Disadvantage:

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4. Polystyrene is a thermoplastic polymer.

(a) One method of producing the monomer, styrene, is by oxidation of ethylbenzene.

$$C_6H_5CH_2CH_3\,(l) + \frac{1}{2}O_2\,(g) \rightleftharpoons C_6H_5C_2H_3\,(l) + H_2O\,(l)$$

Calculate the percent atom economy for the production of the monomer by this route. Use sections 1 and 6 of the data booklet. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(b) Kevlar®, a thermoplastic polymer, is a lyotropic liquid crystal.

Outline what is meant by lyotropic liquid crystal. [2]

Liquid crystal:

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Lyotropic:

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(c) Explain the strength of Kevlar® and its solubility in concentrated sulfuric acid. [2]

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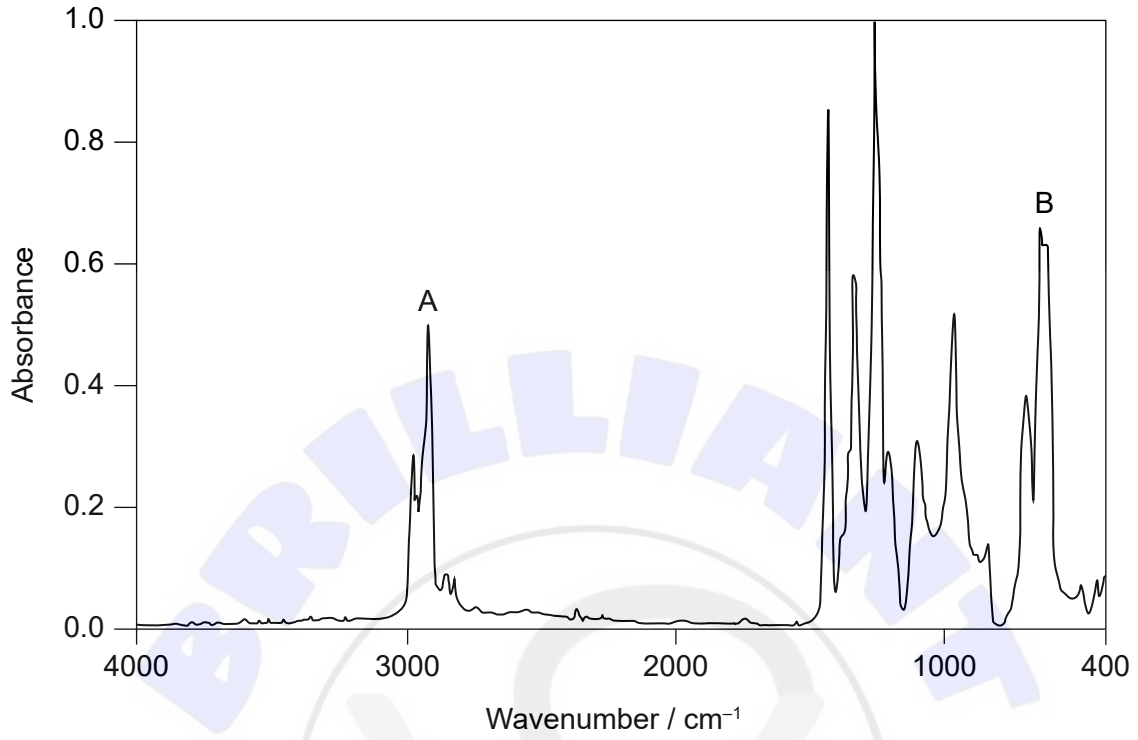
(Option A continues on the following page)

(Option A, question 4 continued)

(d) An IR spectrum of a recyclable plastic is given.



Deduce the bonds in the polymer responsible for the peaks at A and B and the Resin Identification Code (RIC), using sections 26 and 30 of the data booklet. [2]

Bond causing peak A:

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Bond causing peak B:

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RIC:

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(Option A continues on the following page)

(Option A continued)

5. Heavy metals have many uses, but they can also produce toxic effects.

(a) Discuss the causes of toxic effects of heavy metals. [3]

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(b) Describe **one** method of removing heavy metals. [2]

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End of Option A

Option B — Biochemistry

6. Amino acids combine to form proteins.

(a) (i) Identify the bond responsible for the primary structure of proteins. [1]

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(ii) Identify the type of metabolic process that occurs during synthesis of proteins. [1]

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(iii) Outline how DNA determines the primary structure of proteins. [2]

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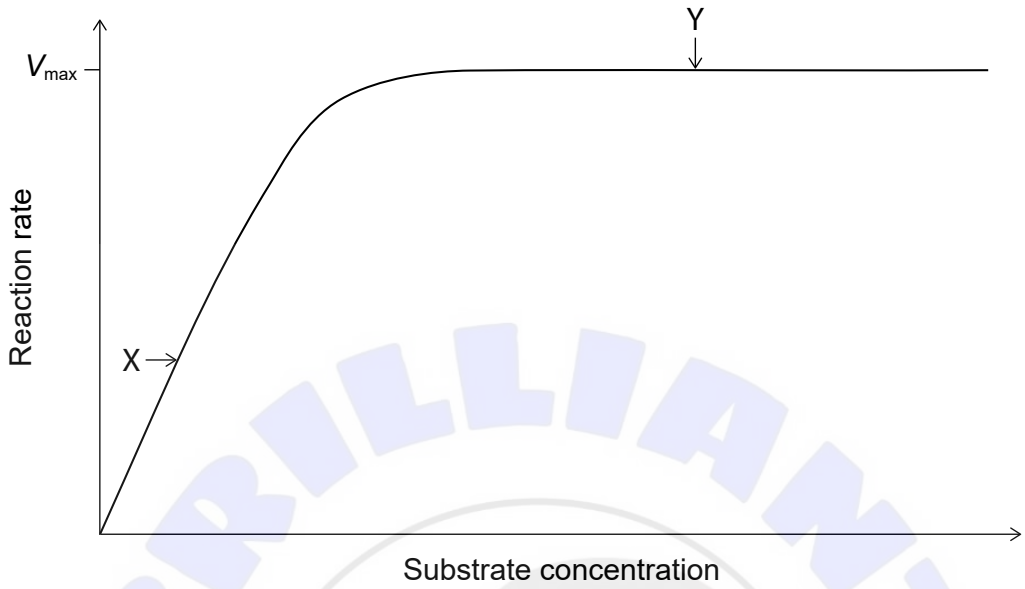
(Option B continues on the following page)

(Option B, question 6 continued)

(b) Some proteins act as enzymes, which catalyse biological reactions.



(i) Explain the shape of the graph at points X and Y. [4]

Point X:

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Point Y:

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(Option B continues on the following page)

(Option B, question 6 continued)

(ii) Show on the graph how a value for the Michaelis constant, K_m, can be determined. [1]

(iii) Outline the significance of the value of K_m. [1]

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(iv) Explain the effect of a competitive inhibitor on the maximum rate, V_{max}, of an enzyme–substrate reaction. [2]

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7. Eicosadienoic acid, $M_r = 308.56$, is a fatty acid found in human milk.

(a) (i) Eicosadienoic acid has an iodine number of 164.5.

Determine the number of C=C double bonds in each molecule of eicosadienoic acid, showing your working. [2]

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(Option B continues on the following page)

(Option B, question 7 continued)

(ii) Eicosanoic acid is a saturated fatty acid with the same number of carbon atoms as eicosadienoic acid.

Explain why eicosadienoic acid has a lower melting point than eicosanoic acid. [2]

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(b) *Trans*-fats can be formed during food processing.

Outline **two** disadvantages of *trans*-fats in the human diet. [2]

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(c) (i) Eicosadienoic acid may undergo rancidity.

Identify **two** conditions that favour the rancidity reaction. [2]

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(ii) State the name of **one** class of organic compound produced by the rancidity reaction. [1]

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(Option B continues on the following page)

(Option B, question 7 continued)

(d) Ascorbic acid (vitamin C) may be added to foods to prevent rancidity.

Predict, giving **one** reason, whether ascorbic acid is soluble in oil. Use section 35 of the data booklet. [1]

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8. Retinol (vitamin A) plays an important role in human vision. Its structure is similar to that of carotene.

(a) Explain why retinol is coloured, using section 35 of the data booklet. [2]

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(b) Suggest why carotene increases the efficiency of photosynthesis. [1]

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(Option B continues on the following page)

(Option B continued)

9. Monosaccharides and polysaccharides have different properties and functions that are related to their structures.

(a) Identify the monomer in cellulose. [1]

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(b) Glucose or starch can be mixed with active ingredients to produce tablets such as aspirin. The carbohydrate molecules break away to release the drug.

Suggest why a drug made with starch is released more slowly in the stomach than one made with glucose. [1]

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10. Heavy metal toxicity is a problem in the environment.

(a) Suggest **one** source of cadmium pollution. [1]

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(b) Explain how host–guest chemistry can remove cadmium from contaminated waterways. [2]

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End of Option B

Option C — Energy

11. Nuclear fission is an important source of energy.

(a) Outline why only heavy nuclei are capable of spontaneous fission reactions. [1]

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(b) (i) Write the equation for the spontaneous fission of ^{254}Cf into the two smaller nuclei, ^{118}Pd and ^{132}Te. [1]

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(ii) ^{254}Cf has a relative atomic mass of 254.087323.

Calculate the mass defect, in kg, of ^{254}Cf, using section 4 of the data booklet.

1 amu = 1.660540×10^{-27} kg [3]

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(iii) Determine the binding energy, in kJ per nucleon, of a ^{254}Cf nucleus. Use your answer to (b)(ii), $E = mc^2$ and section 2 of the data booklet.

(If you have no answer to (b)(ii), use 5.00×10^{-27} kg, although this is not the correct answer.) [1]

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(Option C continues on the following page)

(Option C, question 11 continued)

(c) Explain the storage and disposal of spent fuel rods from nuclear reactors, which are classified as high-level nuclear waste. [3]

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(d) Fusion reactions can run on abundant cheap fuel and produce minimum radioactive waste. Suggest **one** reason why, despite these advantages, energy is provided from fission rather than fusion reactors. [1]

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12. Energy from the sun can interact with molecules in various ways.

(a) Describe global dimming and its causes. [3]

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(Option C continues on the following page)

(Option C, question 12 continued)

(b) (i) Identify the feature of chlorophyll that allows it to absorb sunlight. [1]

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(ii) Write the summary equation for photosynthesis. [1]

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(c) (i) Dye-sensitized solar cells (DSSCs) mimic the way plants use sunlight.

Explain how the dye in a Grätzel DSSC converts sunlight into electrical energy. [2]

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(ii) Explain the role of the electrolyte solution containing iodide ions, I^-, and triiodide ions, I_3^-, in the DSSC. [2]

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(Option C continues on the following page)

(Option C continued)

13. Batteries and fuels provide portable sources of energy.

(a) Suggest, with a reason, if specific energy or energy density is a better measure of a fuel's usefulness as an everyday portable energy source. [1]

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(b) (i) Ethylbenzene, $C_6H_5CH_2CH_3$, is an aromatic compound that is used to increase the octane rating in petrol (gasoline). It has a specific energy of $4.135 \times 10^7\,J\,kg^{-1}$.

Calculate the enthalpy of combustion of ethylbenzene, in $kJ\,mol^{-1}$, using section 6 of the data booklet. [2]

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(ii) Distillation of crude oil does not yield enough aromatic compounds for addition to petrol. Explain how aromatic compounds are formed from alkanes. [3]

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(Option C continues on the following page)

(Option C, question 13 continued)

(c) (i) Lithium ion and lead acid are both types of rechargeable batteries.

Outline the mass and voltage advantages of a lithium-ion battery, using sections 6 and 24 of the data booklet. [2]

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(ii) Graphite and a lithium cobalt oxide complex, $LiCoO_2$ (s), are the electrodes used in a lithium-ion cell.

Deduce the half-equations for the reactions occurring at each electrode during the charging of a lithium-ion cell. [2]

Graphite:

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$LiCoO_2$ (s):

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(iii) State **one** disadvantage of the lithium-ion battery. [1]

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End of Option C

Option D — Medicinal chemistry

14. Antibiotics and antivirals are important in the fight against disease.

(a) Describe how penicillin acts against bacteria. [2]

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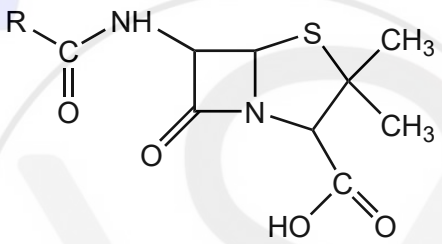
(b) (i) Draw a circle around the section of the penicillin structure that is primarily responsible for its activity. [1]



(ii) Explain, with reference to its structure, why this section of penicillin is reactive. [1]

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(c) Oseltamivir (Tamiflu) and zanamivir (Relenza) are antiviral drugs. Their structures are given in section 37 of the data booklet.

Deduce the name of **one** functional group that is in both structures and the name of **one** functional group that is present only in zanamivir. [2]

Functional group in both structures:

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Functional group in zanamivir only:

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(Option D continues on the following page)

(Option D continued)

15. Aspirin and codeine are used as pain relievers.

(a) (i) Describe how a strong analgesic, such as codeine, works. [2]

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(ii) Explain why long-term codeine usage is addictive. [2]

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(b) People can develop tolerance to codeine. Outline the meaning of tolerance. [1]

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(c) State **one** use of aspirin other than for pain relief. [1]

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(Option D continues on the following page)

(Option D, question 15 continued)

(d) Suggest **one** reason why consuming alcohol with aspirin may be harmful. [1]

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16. Excess acid in the stomach can cause the breakdown of the stomach lining.

(a) A single dose of an antacid contains 2.320 g of sodium hydrogencarbonate, $NaHCO_3$, and 0.500 g of sodium carbonate, Na_2CO_3.

$$M_r(NaHCO_3) = 84.01 \text{ and } M_r(Na_2CO_3) = 105.99$$

Determine the amount of stomach acid, in mol, neutralized by this medication. [2]

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(b) Outline how ranitidine (Zantac) inhibits stomach acid production. [2]

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(Option D continues on the following page)

(Option D continued)

17. Many medical procedures involve the use of radioisotopes.

(a) Justify why protective clothing and instruments used in nuclear medicine may be classified as low-level waste. [1]

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(b) Suggest **one** suitable disposal method for this low-level waste. [1]

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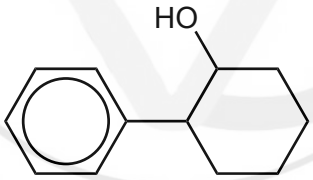
18. The optically active chiral auxiliary used to produce Taxol is *trans*-2-phenylcyclohexanol.

(a) Draw circles around the chiral carbon centres on this diagram of *trans*-2-phenylcyclohexanol. [1]



(Option D continues on the following page)

(Option D, question 18 continued)

(b) Describe how the use of *trans*-2-phenylcyclohexanol forms only the desired enantiomer of Taxol. [2]

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19. Radium-223 has a half-life of 11.4 days.

(a) Write an equation for the alpha decay of radium-223. [1]

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(b) Determine the percentage of radium-223 remaining after 30 days, using section 1 of the data booklet. [2]

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(c) Targeted Alpha Therapy (TAT) uses alpha emitters to treat dispersed cancers.

Explain why alpha radiation is suitable for this purpose. [2]

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(Option D continues on the following page)

(Option D continued)

20. A redox breathalyser involves oxidizing ethanol in the breath to ethanal or ethanoic acid.

(a) Identify **one** absorption range in the IR spectrum of ethanoic acid that is not in the IR spectrum of ethanol. Use section 26 of the data booklet. [1]

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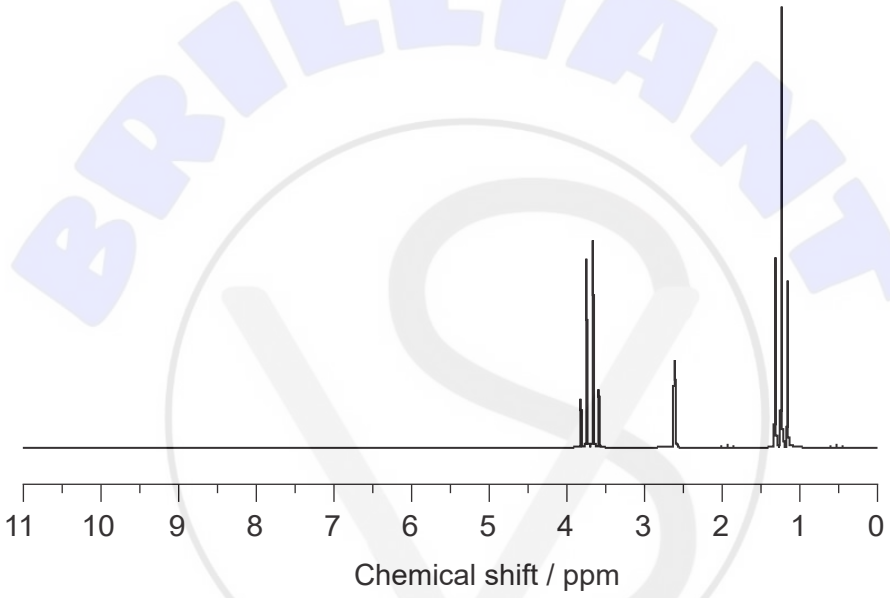
(b) (i) Deduce, giving a reason, whether the following ^{1}H NMR spectrum is of ethanol or ethanoic acid. Use section 27 of the data booklet. [1]



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

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(ii) Predict, giving a reason, the splitting pattern of the signal produced by the hydrogen atoms in the methyl group of ethanal. [1]

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End of Option D

References:

1.(b)(i) With permission from Alex Sullivan (www.scienceskool.co.uk).

4.(d) With permission from NICODOM Ltd. www-ir-spectra.com.

20.(b)(i) SDBS, National Institute of Advanced Industrial Science and Technology.