Chemistry
Higher level
Paper 3

11 May 2023

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

1 hour 15 minutes

Candidate session number

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 – 11
Option C — Energy	12 – 15
Option D — Medicinal chemistry	16 – 21

41 pages

44EP01

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Answers written on this page
will not be marked.

Section A

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

1. Graphs showing the first ionization energy and first electron affinity of the elements in period 2 of the periodic table are shown.

First ionization energy
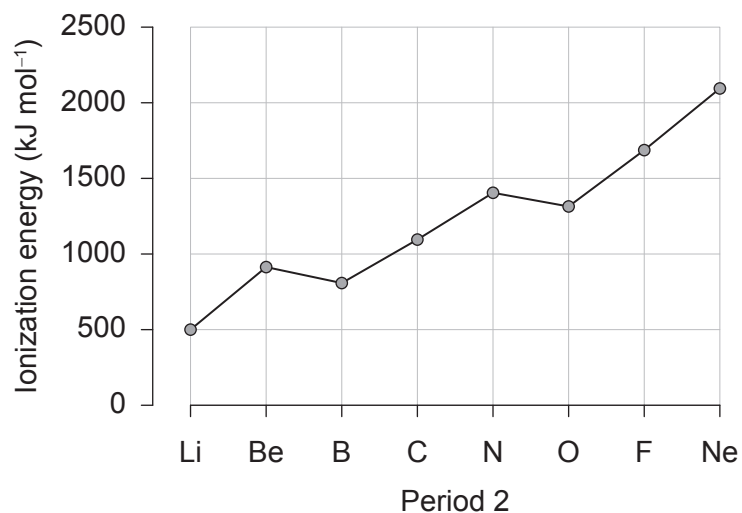
First electron affinity
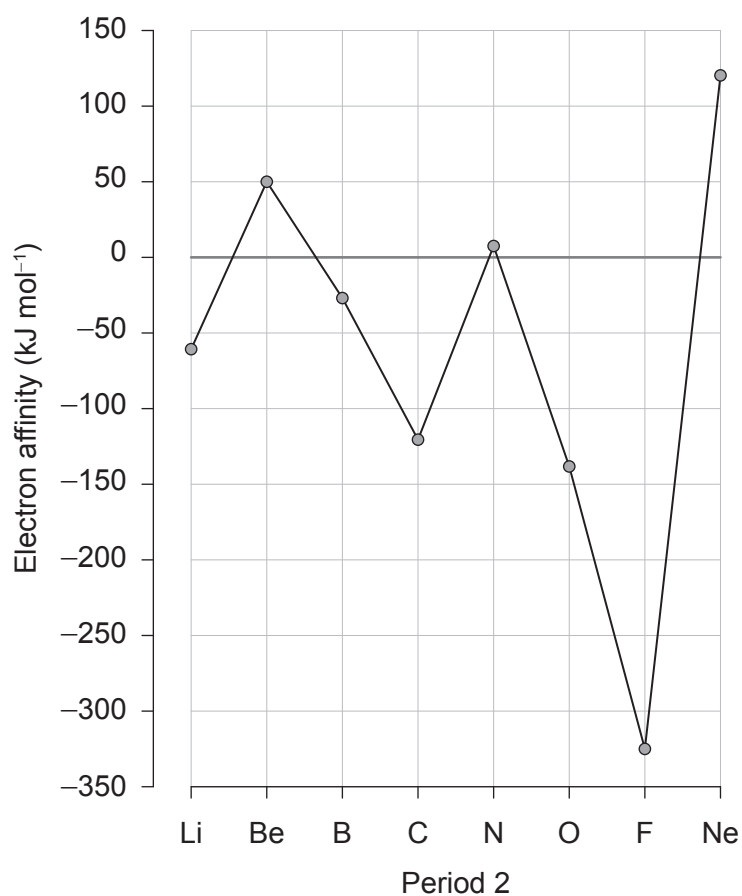
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Turn over

(Question 1 continued)

(a) Outline why ionization energies have positive values but most electron affinities have negative values. [1]

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(b) First ionization energy tends to increase across the period. Explain the decrease in first ionization energy from beryllium to boron. [2]

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(c) The electron affinity of nitrogen is $6.8\,kJ\,mol^{-1}$. Sketch the 2s and 2p orbital filling diagram that represents the electron arrangement of the species produced. [1]

2s   2p
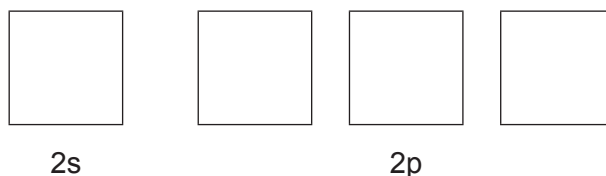
(d) Suggest **one** reason for a positive value for the first electron affinity for nitrogen. [1]

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(This question continues on the following page)

(Question 1 continued)

(e) Suggest reasons why noble gases have the largest first ionization energy and largest positive first electron affinity in their period. [2]

Largest first ionization energy: ....

....

Largest positive first electron affinity: ....

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(f) Suggest, giving **one** reason, how the first electron affinity of xenon compares with that of neon. [1]

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2. Metals A, B, C, D, and E were placed in sulfate solutions.

(a) The results are given where $\checkmark$ = reaction occurred and $\times$ = no reaction.

Metal	$ASO_4(aq)$	$BSO_4(aq)$	$CSO_4(aq)$	$DSO_4(aq)$	$ESO_4(aq)$
A	—	$\checkmark$	$\times$	$\checkmark$	$\checkmark$
B	$\times$	—	$\times$	$\checkmark$	$\checkmark$
C	$\checkmark$	$\checkmark$	—	$\checkmark$	$\checkmark$
D	$\times$	$\times$	$\times$	—	$\checkmark$
E	$\times$	$\times$	$\times$	$\times$	—

(i) Identify the oxidation state of metal A in ASO_4. [1]

....

....

(ii) Deduce the activity series of the metals. [1]

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(This question continues on the following page)

(Question 2 continued)

    (b)   Sketch the voltaic cell that produces the greatest electromotive force, EMF, using the information in part (a). Label the direction of electron flow, salt bridge, anode, cathode, the metals (A–E) and solutions used in each half-cell. [4]

    (c)   Deduce **one** metal that could be electroplated, with high efficiency, on to a metal key using an aqueous salt of the metal. Use section 24 of the data booklet. [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. New materials have brought many benefits to society but come with associated risks.

   (a) High-pressure carbon monoxide disproportionation (HiPco) produces carbon atoms that react with nano catalysts to produce carbon nanotubes.

   (i) Write the equation for the disproportionation of carbon monoxide to produce carbon atoms. [1]

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   ....

   (ii) Calculate the percent atom economy of producing carbon using this method. Use section 1 of the data booklet. [1]

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   (iii) Outline how a metal functions as a heterogeneous catalyst. [2]

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   (iv) Explain whether the production of carbon nanotubes using HiPco is a bottom up or top down nanotechnology technique. [1]

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(Option A continues on the following page)

(Option A, question 3 continued)

       (v)   Suggest **one** health risk of using nanoparticles.   [1]

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   (b)   Kevlar® is a recyclable polyamide polymer and a liquid crystal. One repeating unit of the polyamide is shown.
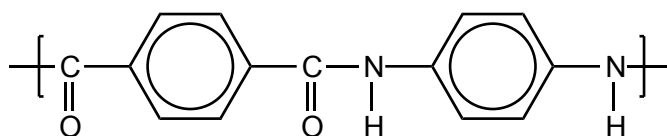
       (i)   Outline what is meant by a *liquid crystal.*   [1]

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       (ii)   Some liquid crystal displays (LCD) use liquid crystals between two polarizing filters. The display appears black until a small voltage is applied. Outline how the liquid crystals allow polarized light to pass through the filters.   [2]

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       (iii)   Identify the resin identification code (RIC) that applies to Kevlar®. Use section 30 of the data booklet.   [1]

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(Option A continues on the following page)

(Option A, question 3 continued)

The IR spectrum of Kevlar® is shown.

IR spectrum of Kevlar®

Wavenumber (cm^{-1})
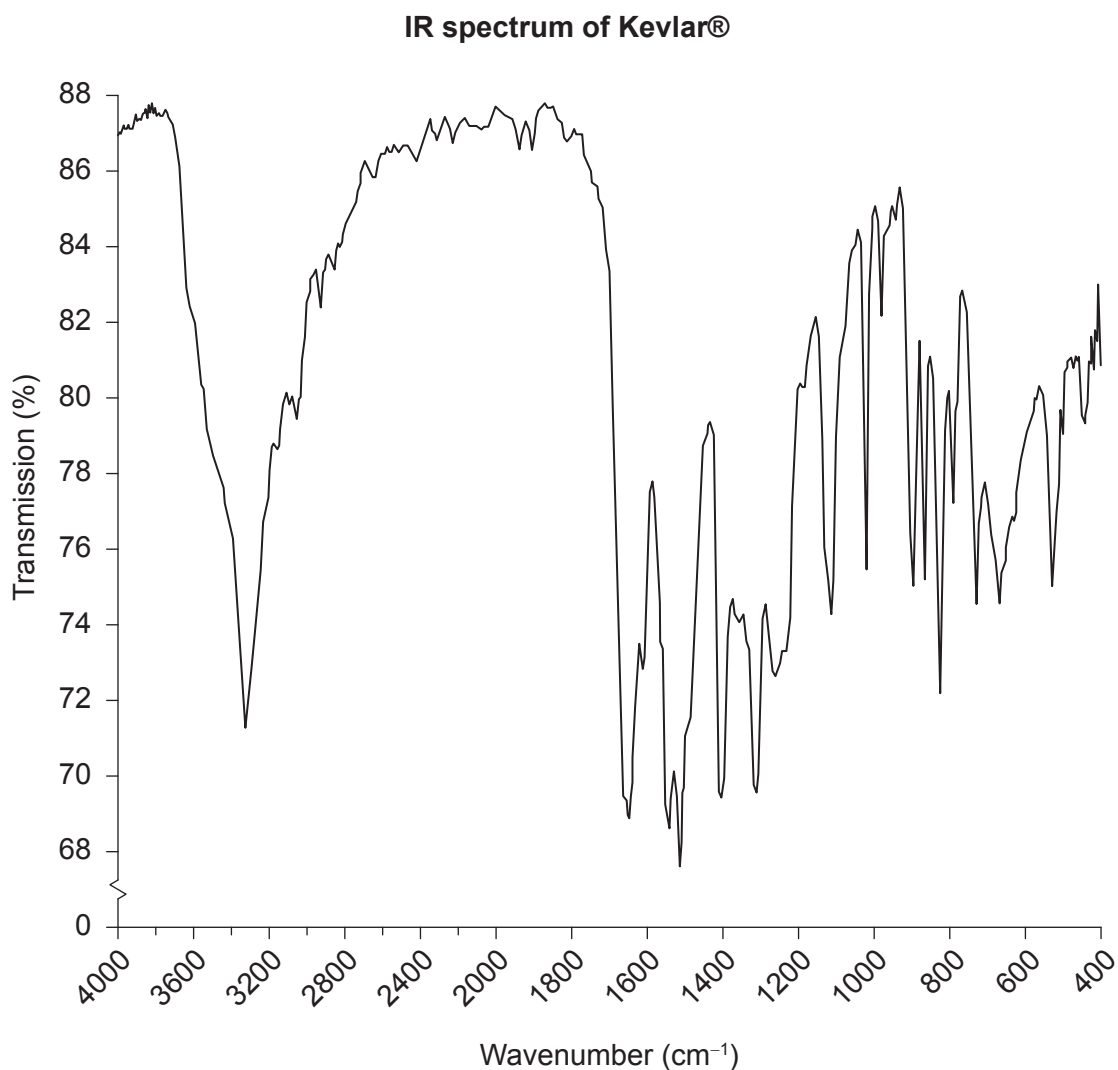
(iv) Deduce the peak in the Kevlar® IR spectrum which would not be found in compounds with any other RIC code. Use Sections 26 and 30 of the data booklet.   [1]

. . . .

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(Option A continues on the following page)

(Option A, question 3 continued)

(v)   Kevlar® is a condensation polymer. Distinguish between addition and
condensation polymerization, in terms of monomers and products.   [3]

Monomers: . . . .

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Products: . . . .

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Turn over

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(Option A continued)

4. Metals are often alloyed for desired characteristics.

    (a) Explain why metals alloyed with another metal are usually harder and stronger but poorer conductors than the pure metal. [3]

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    (b) Bronze is one of the oldest known alloys. Inductively coupled plasma spectroscopy can be combined with mass spectrometry (ICP–MS) or optical emission spectroscopy (ICP–OES) to analyse the structure and composition of alloys.

    Sketch a typical calibration curve for ICP–OES. [1]
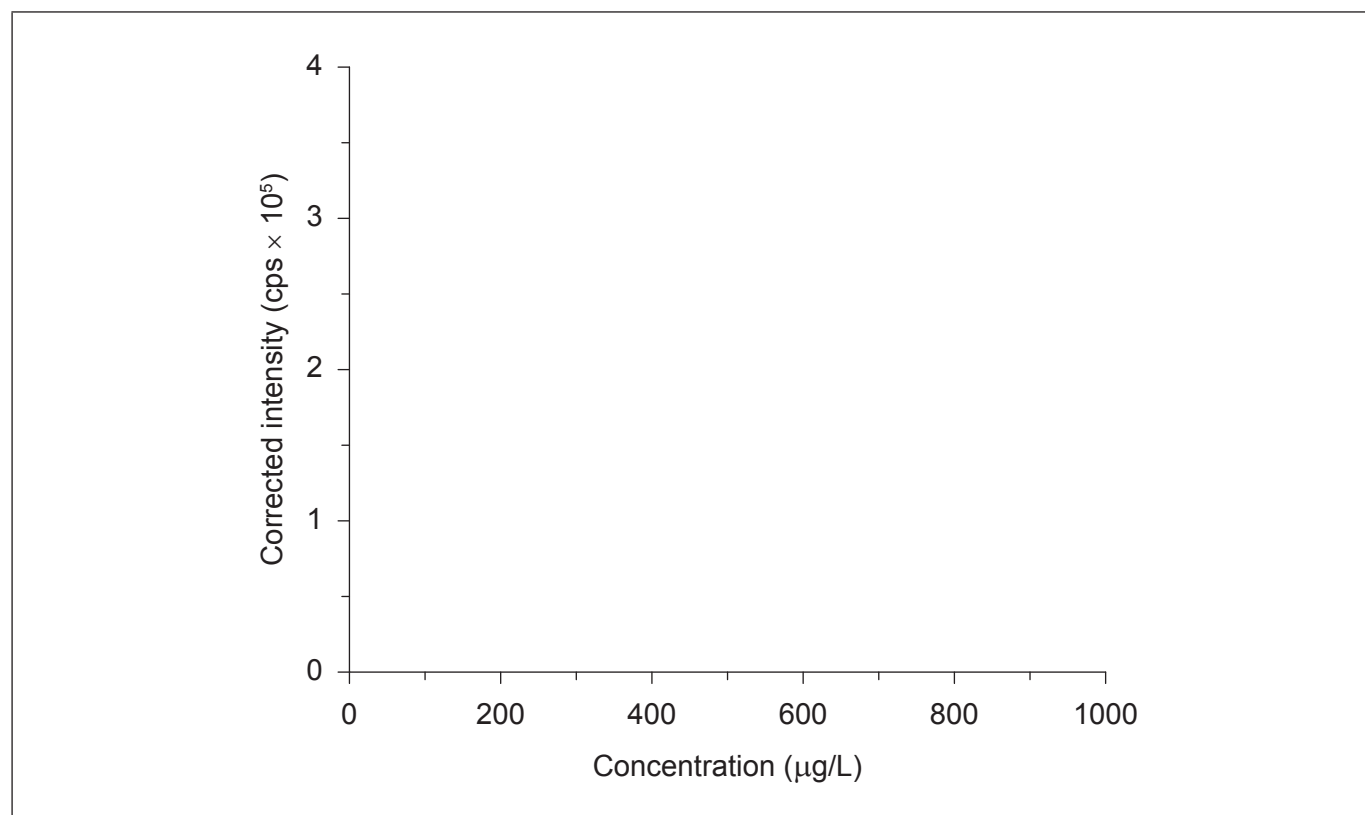
(Option A continues on the following page)

(Option A, question 4 continued)

(c) Various bronze shields from Ayanis fortress in Turkey, dated 670 BCE, were analysed using ICP–MS.

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</div>

(i) Draw the expected mass spectrum produced by shield EHR for the range given on the graph. Use relative atomic mass, ignoring isotopes.   [1]

Mass spectrum for elements in shield EHR
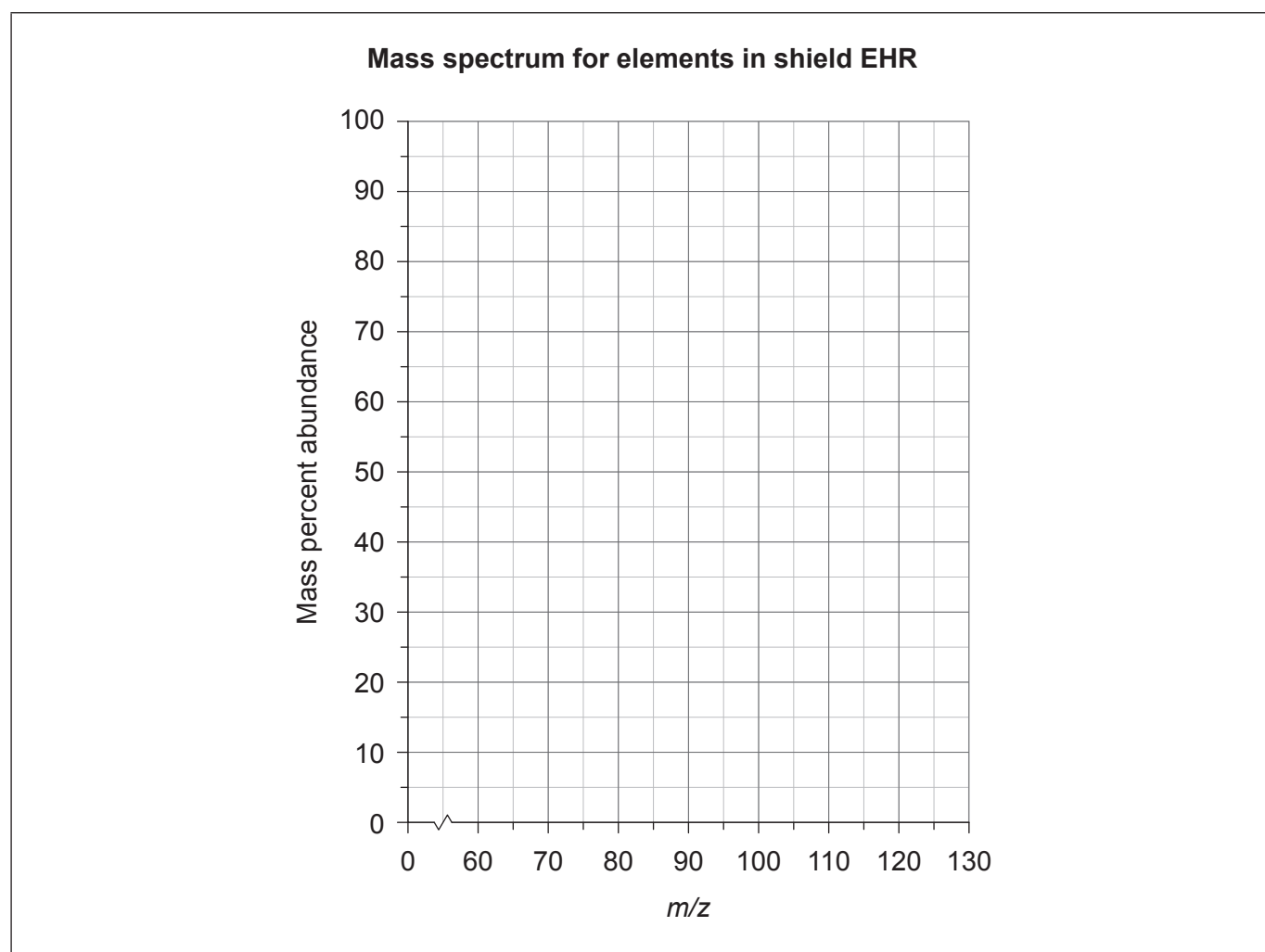
(Option A continues on the following page)

(Option A, question 4 continued)

    (ii)   Explain the role of the inductively coupled plasma (ICP) torch in allowing the sample to be injected into the mass spectrometer for analysis. [2]

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(Option A continues on the following page)

(Option A continued)

5. Copper forms a face-centred cubic structure:

(a) (i) Identify the coordination number and number of atoms per unit cell for this structure. [2]

Coordination number: . . . .

. . . .

Number of atoms per unit cell: . . . .

. . . .
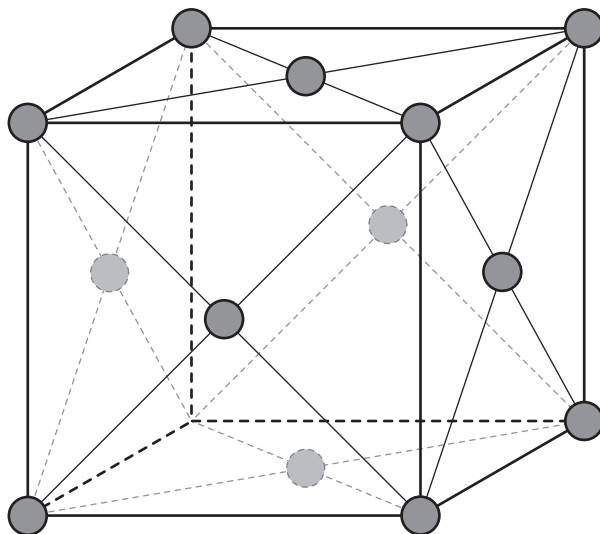
(ii) The edge length of a unit cell of copper is 3.61×10^{-8} cm. Determine the density of copper, in g cm^{-3}, using your answer to part (a)(i) and sections 2 and 6 of the data booklet. [3]

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(Option A continues on the following page)

(Option A, question 5 continued)

(b) The K_{sp} of copper(II) hydroxide is 2.2×10^{-20}. Calculate the molar solubility of Cu^{2+}(aq) ions in a solution of pH 9. [2]

The Haber–Weiss reaction produces hydroxyl radicals.

$$H_2O_2 + \bullet O_2^{-} \rightarrow O_2 + OH^{-} + \bullet OH$$
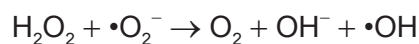
(c) Show the two-step mechanism by which Cu^{2+} ions can catalyse this reaction by reacting with the superoxide ion, $\bullet O_2^{-}$, in the first step. [2]

End of Option A

Option B — Biochemistry

6.   Vitamins are micronutrients necessary for the correct functioning of the body.

   (a)   Outline why vitamins usually need to be obtained from food sources.   [1]

   ....

   ....

   (b)   State **two** factors, other than concentration, that must be controlled for correct
         metabolic functioning in the cytoplasm of a cell.   [1]

   ....

   ....

7.   Lipids and carbohydrates play an essential role in the body.

   (a)   (i)   State the general formula of a carbohydrate.   [1]

   ....

   (ii)   Fructose is a carbohydrate. Determine the energy, in kJ, released by
          the respiration of 10.5 g of fructose, $C_6H_{12}O_6$.   [2]

   Enthalpy of ($\Delta H_c^{\ominus}$) of fructose $= -2810 \, kJ \, mol^{-1}$

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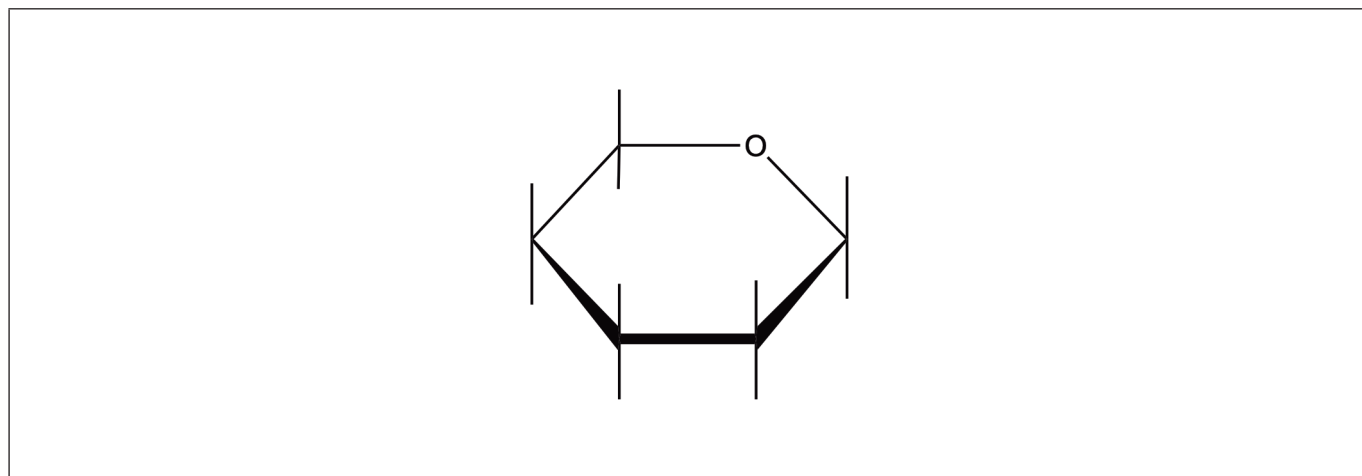   ....

(Option B continues on the following page)

(Option B, question 7 continued)

(b) Glucose, an isomer of fructose, exists as two isomeric ring forms. Annotate the diagram below to complete the structure of β-glucose. Use section 34 of the data booklet. [1]

(c) Cellulose is a polymer of β-glucose. Describe the importance of cellulose in the human diet. [1]

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....

(d) Lipids and carbohydrates both release energy in the body.

(i) Write balanced equations for the complete oxidation of fructose, $C_6H_{12}O_6$, and the triglyceride tristearin, $C_{57}H_{110}O_6$. [2]

$C_6H_{12}O_6$: ....

....

$C_{57}H_{110}O_6$: ....

....

(ii) Predict, giving **one** reason, whether 10.5 g of the triglyceride tristearin would release more or less energy than 10.5 g of fructose when completely oxidized. [1]

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(Option B continues on the following page)

Turn over

(Option B, question 7 continued)

    (e)   Describe the chemical composition of phospholipids and their function in the body, other than as energy storage. [2]

Chemical composition: . . . .

. . . .

Function: . . . .

. . . .

8.   The amino acids in a protein can be separated using paper chromatography. The R_f values using a solvent of butanol and ethanoic acid are given.

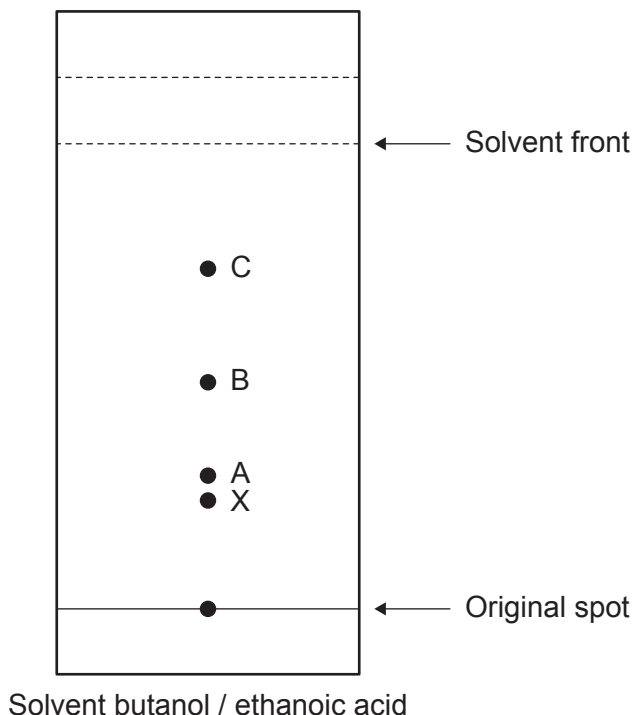| Amino acid	R_f value
Lysine	0.14
Glutamic acid	0.30
Threonine	0.35
Tyrosine	0.45
Asparagine	0.5
Methionine	0.55
Valine	0.61
Tryptophan	0.66
Leucine	0.73

(Option B continues on the following page)

(Option B, question 8 continued)

(a) The following diagram shows a chromatogram.

Solvent butanol / ethanoic acid

(i) Determine the identity of the amino acid creating spot C by calculating the R_f value from the chromatogram. [1]

Identity of spot C: . . . .

(ii) Predict, referring to the structure of the amino acids, whether spot X on the chromatogram in part (a)(i) is more likely to be serine or phenylalanine. Use the table of R_f values and section 33 of the data booklet. [2]

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(Option B continues on page 23)

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will not be marked.

(Option B, question 8 continued)

(b) One role of proteins in the body is to catalyse reactions. Describe how enzymes catalyse reactions in the body. [2]

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....

(c) State **one** industrial use of enzymes. [1]

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....

(d) Explain how a non-competitive inhibitor affects the Michaelis constant, K_m, and V_{max} of a reaction. Refer to the reaction between the inhibitor and the enzyme in your answer. [3]

Effect on K_m: ....

Effect on V_{max}: ....

Explanation for K_m: ....

....

....

Explanation for V_{max}: ....

....

....

(e) Determine the concentration, in mol dm^{-3}, for a protein sample with absorbance of 0.50 at 240 nm. Use section 1 of the data booklet. [2]

Molar extinction coefficient = 0.75 dm^3 cm^{-1} mol^{-1}
Path length = 1.0 cm

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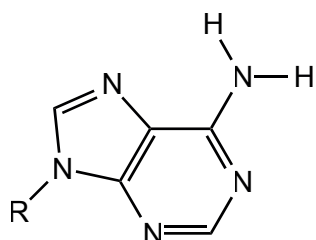**(Option B continues on the following page)**

(Option B continued)

9. DNA is an essential biological molecule.

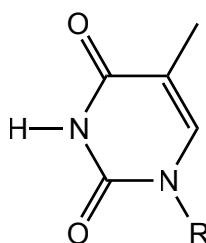(a) State the **three** components of a monomer of DNA (a nucleotide). [1]

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(b) Draw the hydrogen bonds between adenine and thymine. [1]

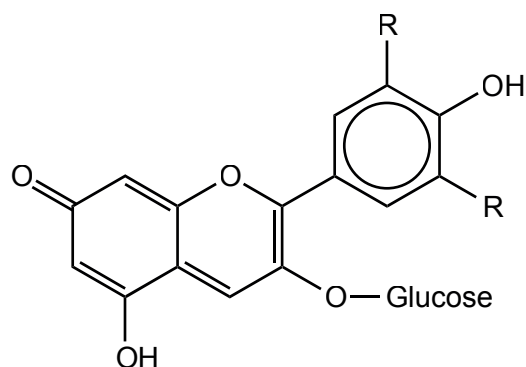**Adenine**   **Thymine**
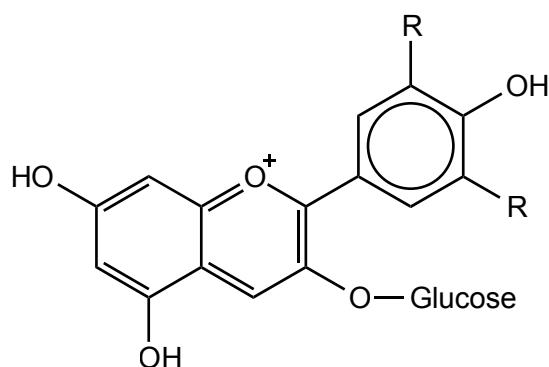
10. There are many biological pigments.

Anthocyanins are pigments that can be used as pH indicators.

Anthocyanin X   **Anthocyanin Y**

(Option B continues on the following page)

(Option B, question 10 continued)

(a) Explain which form of the anthocyanin, **X** or **Y**, predominates at a pH of 12. [1]

....

....

(b) State **one** factor, other than pH, that can affect the stability of anthocyanins. [1]

....

(c) Outline **one** structural similarity **and one** structural difference between hemoglobin
and myoglobin. [2]

Similarity: ....

....

Difference: ....

....

11. Outline the meaning of the term *xenobiotic*. [1]

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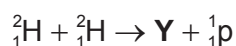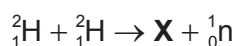# End of Option B

Option C — Energy

12. Energy is often converted into more usable forms.

    (a)   The efficiency of a nuclear power plant is approximately 33 %.

        (i)   Outline the meaning of the above statement in terms of energy conversion.   [1]

        (ii)   The fusion of two deuterium nuclei, ^2_1H, can occur in two ways:

$$^2_1\text{H} + {}^2_1\text{H} \rightarrow \mathbf{X} + {}^1_0\text{n}$$

$$^2_1\text{H} + {}^2_1\text{H} \rightarrow \mathbf{Y} + {}^1_1\text{p}$$

        Deduce the nuclear symbols for **X** and **Y** using the correct notation.   [1]

    X: ....

    Y: ....

        (iii)   Explain which fusion reaction of deuterium releases more energy. Use section 36 of the data booklet.   [1]

(Option C continues on the following page)

(Option C, question 12 continued)

      (iv)   The mass of deuteron, the nucleus of a deuterium atom, is 2.013553 amu. Determine the binding energy, in J, of deuteron. Use sections 2 and 4 of the data booklet and 1 amu = 1.660540×10^{-27} kg.   [3]

      (v)   Suggest why the specific energy of deuterium in fusion is higher than that of uranium-235 in fission, yet the energy density of uranium is significantly greater than that of deuterium. Use section 1 of the data booklet.   [4]

      (vi)   Uranium needs to be enriched from its natural isotope, ^{238}U, to the more fissile ^{235}U for use in nuclear reactors. Explain how the proportion of ^{235}U in natural uranium is increased.   [2]

(Option C continues on the following page)

(Option C, question 12 continued)

(b) Catalytic reforming and cracking can produce more efficient fuel.

(i) Deduce the equation for the conversion of heptane to methylbenzene. [1]

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(ii) Identify **two** products that can be formed from cracking heptane. [1]

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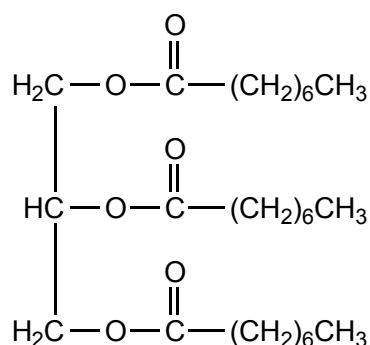
(Option C continues on the following page)

(Option C continued)

13. Biofuels can be synthesized or converted to make them more usable.

(a) Write the equation for the fermentation of glucose, $C_6H_{12}O_6$, to produce ethanol. [1]

....

....

(b) Deduce the equation for the reaction of the triglyceride shown with methanol. [2]

(c) Outline the essential feature needed for a molecule to convert light energy into chemical energy. [1]

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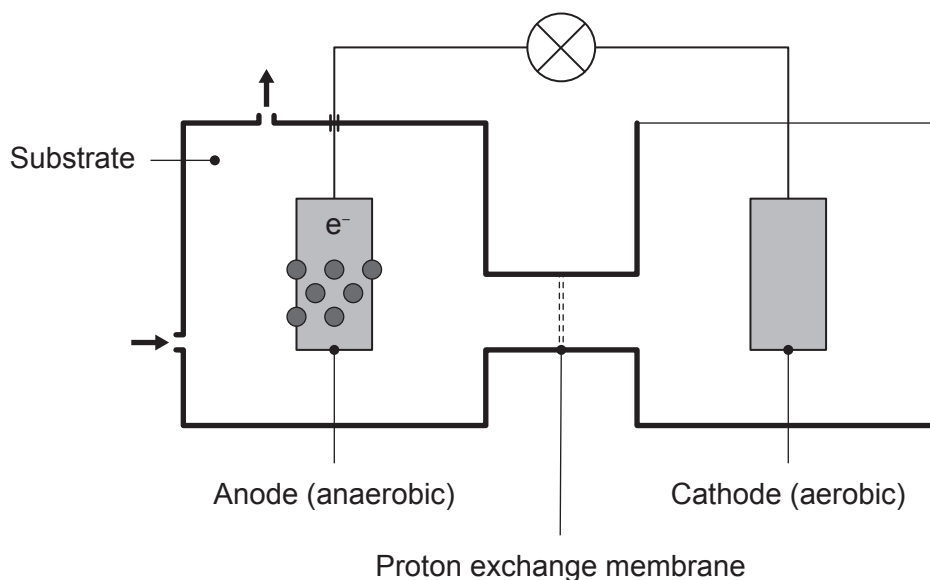..

(Option C continues on the following page)

Turn over

(Option C, question 13 continued)

(d) The Geobacter bacterium anaerobically oxidizes substances present in the substrate of microbial fuel cells. For example, ethanoate ions, CH_3COO^- (aq), are oxidized to carbon dioxide gas.

Anode (anaerobic)   Cathode (aerobic)

Proton exchange membrane

(i) Outline the function of the proton exchange membrane. [1]

....

....

(ii) Write equations for the reactions occurring at the anode and cathode, and an overall equation for a microbial fuel cell containing ethanoate ions. [3]

Anode: ....

....

Cathode: ....

....

Overall equation: ....

....

(Option C continues on the following page)

(Option C, question 13 continued)

      (iii)   Suggest **one** reason why microbial fuel cells might be a sustainable energy source. [1]

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14. Energy production often has associated costs. Global warming potential (GWP) is a measure of heat absorbed by a greenhouse gas relative to the heat absorbed by the same mass of carbon dioxide.

    (a)   Suggest **one** piece of evidence, other than temperature rise, that shows correlation between greenhouse gas emission and global warming. [1]

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....

    (b)   Outline how greenhouse gas molecules absorb infrared radiation. [1]

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    (c)   The GWP of methane is approximately 21. Estimate the heat absorbed by one mole of methane relative to a mole of carbon dioxide. [2]

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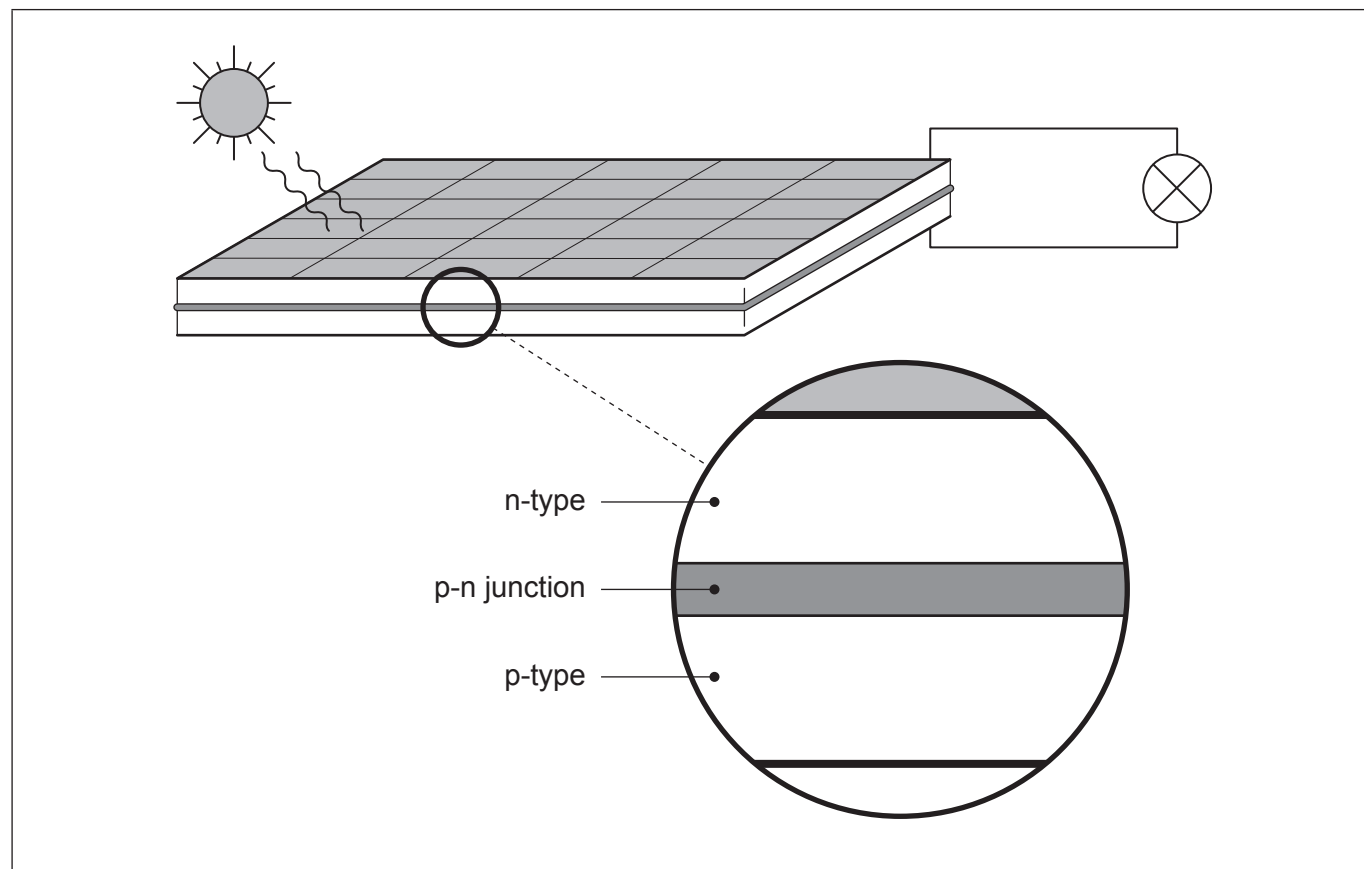
(Option C continues on page 33)

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(Option C continued)

15. Photovoltaic cells often contain p- and n-type materials on either side of a p-n junction.

(a) Annotate the diagram to show the charge separation at the p-n junction and flow of electrons through the external circuit. [2]

(b) Identify **one** element that could be used as the material for the p-n junction. [1]

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End of Option C

Option D — Medicinal chemistry

16. Drugs are commonly prescribed by medical professionals to treat illness.

(a)   State **two** different drug administration methods.   [1]

. . . .

. . . .

(b)   Explain how aspirin works as a mild analgesic.   [2]

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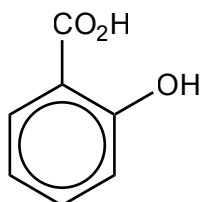. . . . .

(c)   Deduce the structural formulae of the missing reactant **A** and product **B** in the
synthesis of aspirin from salicylic acid.   [2]
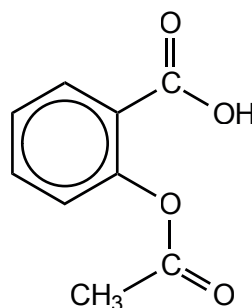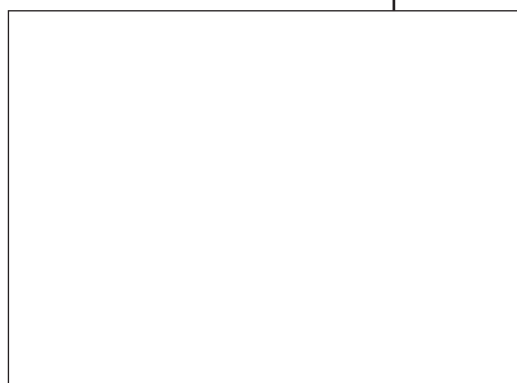
Salicylic acid   **Aspirin**

(Option D continues on the following page)

(Option D, question 16 continued)

(d) State **one** advantage **and one** disadvantage of prescribing opiates to patients. [2]

Advantage: . . . .

. . . .

Disadvantage: . . . .

. . . .

17. Magnesium carbonate and aluminium hydroxide are two antacids.

(a) Write **two** equations showing how these antacids neutralize excess hydrochloric acid. [1]

Magnesium carbonate: . . . .

. . . .

Aluminium hydroxide: . . . .

. . . .

(b) Show by calculation that a 2.00 g tablet of aluminium hydroxide would neutralize more hydrochloric acid than a 2.00 g tablet of magnesium carbonate. [2]

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(Option D continues on the following page)

(Option D continued)

18. Many illnesses are caused by bacteria and viruses.

(a) Explain **two** ways antiviral medications prevent the replication of viruses. [2]

(b) Bacterial infections are treated using antibiotics such as penicillin. Suggest how penicillin can be modified and the reasons for the modification. [2]

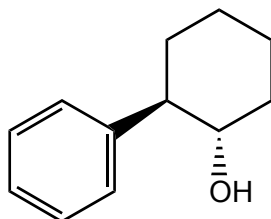**(Option D continues on the following page)**

(Option D continued)

19. The chemotherapy drug Taxol is now manufactured using a chiral auxiliary and 10-deacetybaccatin III instead of the bark of Pacific yew trees.

(a) A chiral auxiliary used in the synthesis of Taxol is trans-2-phenylcyclohexanol. Deduce and label with asterisks (*) the positions of the **two** chiral carbon atoms in the molecule.   [2]

(b) State **one** natural source of 10-deacetylbaccatin III now used to synthesize Taxol.   [1]

....

(c) State **two** principles of green (sustainable) chemistry in drug manufacturing, other than using less hazardous or toxic reactants.   [2]

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(Option D continues on the following page)

Turn over

(Option D continued)

20. Two radiation treatments for cancer are Targeted Alpha Therapy, TAT, and Boron Neutron Capture Therapy, BNCT.

   (a)   Describe which cancers are treated by TAT and BNCT and the particles used in
         each treatment.   [2]

   TAT: . . . .

   . . . .

   BNCT: . . . .

   . . . .

   (b)   Suggest **two** reasons why technetium-99m is the most commonly used radioisotope in
         nuclear medicine.   [2]

   (c)   A freshly prepared solution for radiodiagnostics contains 1.0×10^{-7} mol dm^{-3} of
         technetium-99m. Determine the concentration, in mol dm^{-3}, of technetium-99m
         remaining in the solution 22.00 hours later. Use section 1 of the data booklet.   [2]

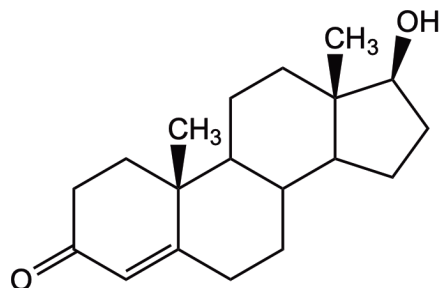   Half-life of technetium-99m $= 6.01$ h

(Option D continues on the following page)

(Option D continued)

21. Analytical chemistry is very important in drug detection.

(a) An example of a steroid is testosterone.

(i) State the technique used to separate steroids, such as testosterone, from biological fluids. [1]
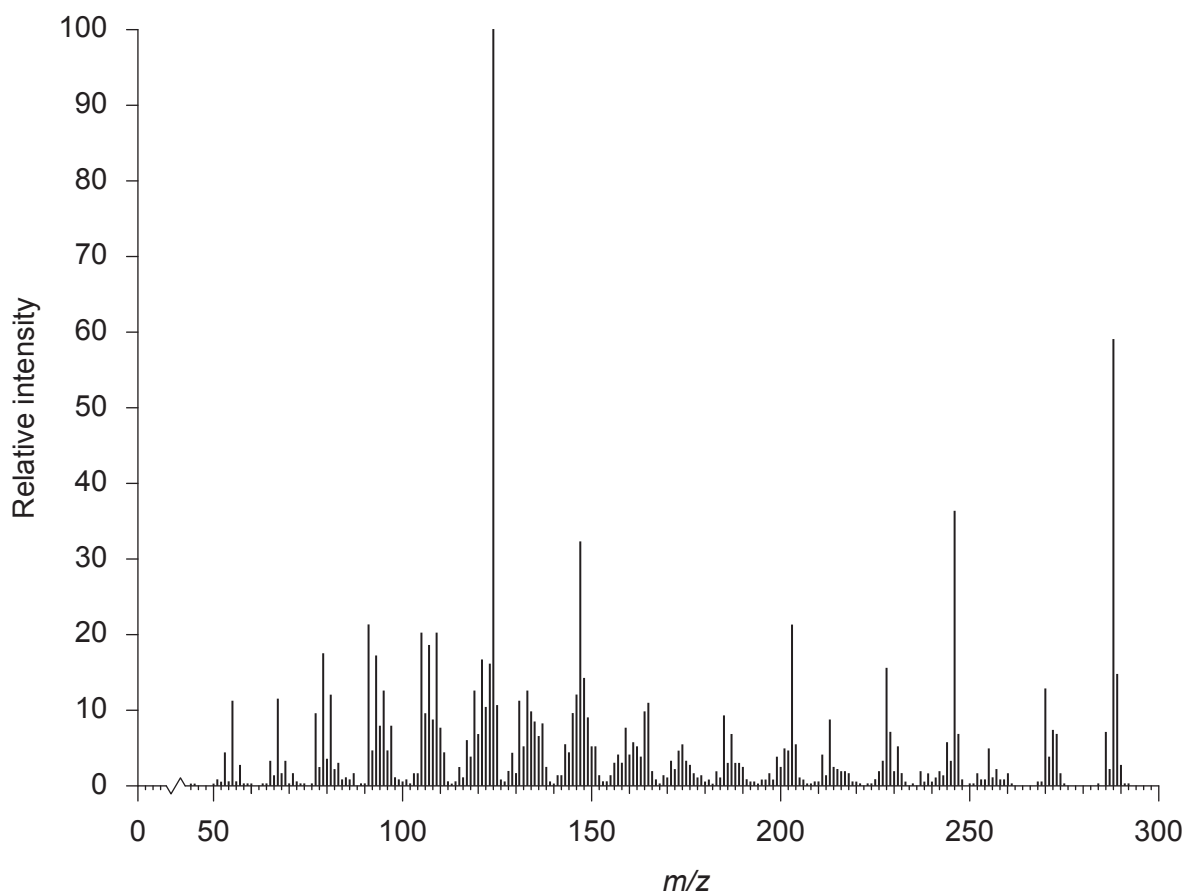
....

....

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(Option D, question 21 continued)

Once separation has been completed, the components can be identified using mass spectrometry. The following mass spectrum is of testosterone:

(ii)   Explain how the fragments at *m/z* 288 and 273 can be used to show that it is testosterone, $C_{19}H_{28}O_2$, M_r 288.   [2]

m/z 288: . . . .

. . . .

m/z 273: . . . .

. . . .

(Option D continues on the following page)

(Option D, question 21 continued)

(b) One breathalyser technique is to measure the change in colour when the dichromate ion is reduced to the chromium (III) ion:

Orange   **Green**

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

Deduce the half-equation for the oxidation of ethanol and the overall redox equation occurring in the breathalyser. [2]

Half-equation for oxidation of ethanol: . . . .

. . . .

Overall balanced redox equation: . . . .

. . . .

End of Option D

References:

1.   Wikipedia, n.d. *Electron affinity*. [online] Available at: https://en.wikipedia.org/wiki/Electron_affinity [Accessed 22 June 2021]. Source adapted.

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8.   BioTopics. n.d. *Chromatography of amino acids*. [online] Available at: https://www.biotopics.co.uk/as/amino_acid_chromatography.html [Accessed 20 May 2021]. Source adapted.

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13.(d)   Belafi-Bako, K., Vajda, B., Bakonyi, P., Nemestothy, N., 2014. *Removal of COD by Two-Chamber Microbial Fuel Cells*. The scheme of a two-chamber microbial fuel cell [image online]. Available at: https://www.intechopen.com/books/technology-and-application-of-microbial-fuel-cells/removal-of-cod-by-two-chamber-microbial-fuel-cells [Accessed 20 May 2021]. Source adapted.

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21.(a)(ii)   SDBS, National Institute of Advanced Industrial Science and Technology.

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Answers written on this page
will not be marked.