Diploma Programme
Programme du diplôme
Programa del Diploma

# Chemistry
# Higher level
# Paper 3

11 May 2023

**Zone A** afternoon | **Zone B** morning | **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 – 14 |
| Option C — Energy | 15 – 17 |
| Option D — Medicinal chemistry | 18 – 28 |

2223 – 6115

36 pages

## Section A

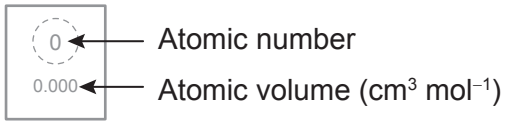
Answer **all** questions. Answers must be written within the answer boxes provided.

**1.** One definition of atomic volume is given by the formula:

$$\text{Atomic volume} = \frac{\text{atomic mass (g mol}^{-1})}{\text{density (g cm}^{-3})}$$

The table gives the atomic volumes of the first nineteen elements, in the form in which they occur at STP.

**Key:**




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1<br>11 240 | | | | | | | 2<br>22 400 |
| 3<br>13.00 | 4<br>4.870 | 5<br>4.620 | 6<br>5.459<br>(3.419) | 7<br>11 200 | 8<br>11 200<br>(7460) | 9<br>11 200 | 10<br>22 420 |
| 11<br>23.70 | 12<br>13.97 | 13<br>9.993 | 14<br>12.06 | 15<br>16.99<br>(13.24) | 16<br>15.49<br>(16.36) | 17<br>11 080 | 18<br>22 390 |
| 19<br>43.93 | 20<br>? | | | | | | |

(a) Outline why many elements have atomic volumes greater than 10 000 $cm^3$ $mol^{-1}$. [1]

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(b) Outline why some of those with larger atomic volumes have values ~11 000 $cm^3$ $mol^{-1}$ and others ~22 000 $cm^3$ $mol^{-1}$. [1]

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**(This question continues on the following page)**

**(Question 1 continued)**

(c) Suggest why some elements, such as carbon and oxygen, have more than one value for their atomic volume. [1]

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(d) Explain why the atomic volumes of elements 11, 12 and 13 show a steady decrease. [2]

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(e) Estimate the atomic volume, in $cm^3\ mol^{-1}$, of element 20. [1]

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(f) Suggest, giving **one** reason, whether you could ever know the actual volume of a single atom. [1]

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**2.** To investigate how much kale would supply the daily recommended intake of iron a student:

1. weighed 79.6 g of kale leaves and blended with 500 $cm^3$ of water
2. boiled, filtered and cooled
3. pipetted 10.0 $cm^3$ of the filtrate into 20.0 $cm^3$ of 2.00 mol $dm^{-3}$ sulfuric acid in a flask
4. titrated with 0.00100 mol $dm^{-3}$ potassium manganate (VII).

The reaction taking place is:

$$5Fe^{2+}(aq) + MnO_4^-(aq) + 8H^+(aq) \rightarrow 5Fe^{3+}(aq) + Mn^{2+}(aq) + 4H_2O(l)$$

(a) All species are almost colourless except for $MnO_4^-$, which has an intense purple colour, though the kale extract is coloured by the chlorophyll present.

(i) State the colour change at the end point. [1]

From: . . . . . .

To: . . . . . .

(ii) Outline how the addition of distilled water to the 10.0 $cm^3$ aliquot before titration will affect the titrant volume at the end point. [1]

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(b) State the class of errors that always affect results in a particular direction. [1]

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**(This question continues on the following page)**

**(Question 2 continued)**

(c) The end point occurred when $3.1 \pm 0.1\,cm^3$ of the titrant had been added.

(i) Calculate the percentage uncertainty associated with the titre. [1]

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(ii) Suggest **one** procedural modification which would reduce the percentage uncertainty for a single titration, other than using a burette with greater precision. [1]

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(iii) The solution in the titration flask contained $8.66 \times 10^{-4}$ g of iron. Determine, to three significant figures, the percentage of iron, by mass, in the kale leaves. [2]

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(d) The value obtained is about 30 times greater than published values for the percentage of iron in kale. Suggest **one** reason, other than human error, why there might be such a large discrepancy. [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.** Most metals have to be extracted from an ore. The way in which this is carried out depends on the reactivity of the metal.

(a) Identify a metal produced by reacting its oxide with carbon or carbon monoxide. Use section 25 of the data booklet. [1]

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(b) Aluminium is produced by electrolytic reduction of a solution of aluminium oxide, $Al_2O_3$, in molten cryolite, $Na_3AlF_6$.

(i) Write the half equation for the reaction at the electrode where aluminium is formed. [1]

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(ii) Calculate the atom economy for the production of aluminium from its oxide, assuming the products do not react with the electrodes. Use section 1 of the data booklet. [1]

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(iii) Suggest **one** factor, other than atom economy, that indicates the production of aluminium from its ore has a significant environmental impact. [1]

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

**(Option A, question 3 continued)**

(iv) Deduce why pure molten aluminium oxide is a poor conductor of electricity. Use sections 8 and 29 of the data booklet. [2]

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(c) Inductively coupled plasma (ICP) techniques can be used to estimate the concentration of other metals in the aluminium produced.

(i) Describe the plasma state. [1]

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(ii) Explain how different metals are identified, and their concentrations determined, if ICP is coupled with Optical Emission Spectroscopy (OES). [2]

Identification: . . . . . .

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Concentration: . . . . . .

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**(Option A continues on page 9)**

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

Answers written on this page
will not be marked.

**(Option A, question 3 continued)**

(d) An aluminium matrix can be reinforced with carbon nanotubes. Outline why carbon nanotubes are so strong and rigid. [1]

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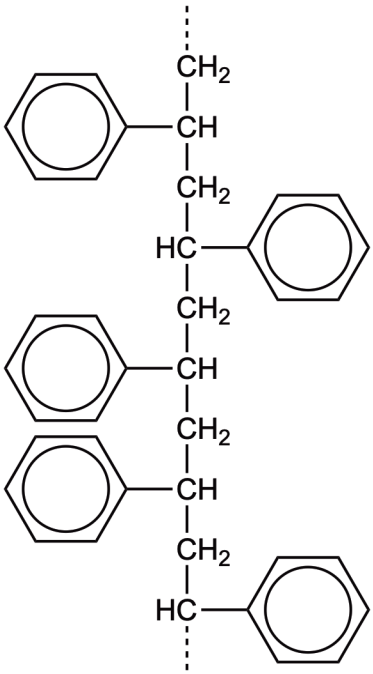
**(Option A continues on the following page)**

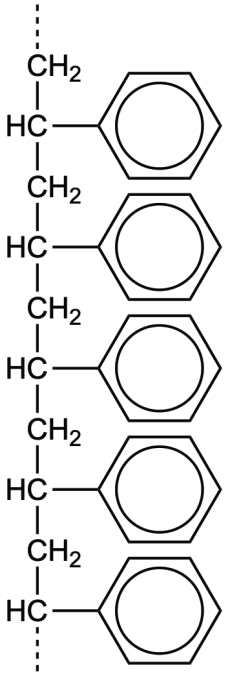
**(Option A continued)**

**4.** Sections of two forms of polystyrene are shown:

**Polystyrene A**



**Polystyrene B**



(a) (i) Draw the structural formula of the monomer from which they were formed. [1]

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

**(Option A, question 4 continued)**

(ii) Identify, giving **one** reason, the form with the higher melting point. [1]

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(b) Explain how a substance in the same phase as the reactants can reduce the activation energy and act as a catalyst. [2]

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(c) Solutions of substituted polystyrenes can form lyotropic liquid crystals. Outline how lyotropic liquid crystals differ from other liquid crystals. [1]

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

**(Option A, question 4 continued)**

(d) Expanded polystyrene (EPS) is a useful material.

(i) Explain how polystyrene is converted to EPS. [2]

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(ii) State **one** property of EPS that makes it a useful material. [1]

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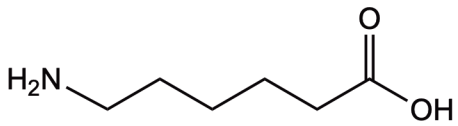
Nylon-6 is a polymer that can be formed from the monomer:




(e) State the type of polymerization reaction that occurs and the structural characteristic of the monomer that allows this type of polymerization to occur. [2]

Type of polymerization: . . . . . .
. . . . . .
Structural characteristic: . . . . . .
. . . . . .

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

**(Option A, question 4 continued)**

(f) Outline why plastics do not break down easily in the environment. [1]

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(g) State the RIC number for polyamide plastic (nylon). Use section 30 of the data booklet. [1]

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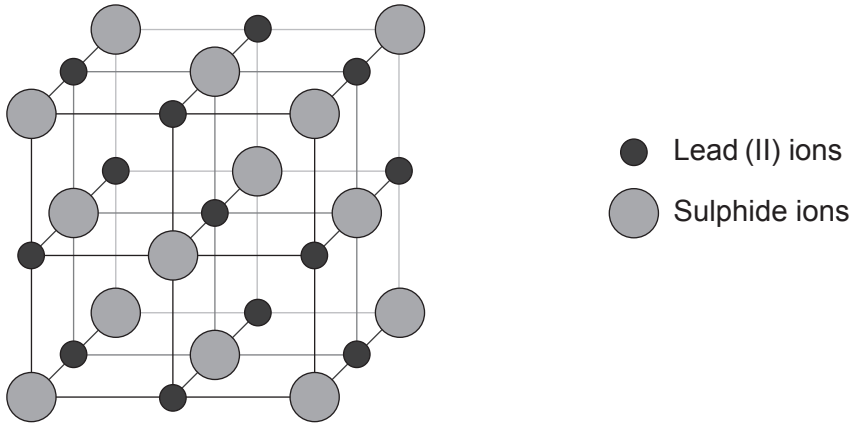
**(Option A continues on the following page)**

**(Option A continued)**

**5.** Lead can be removed from waste water by precipitation, for example as lead (II) sulfide, PbS, or lead (II) hydroxide, $Pb(OH)_2$.

(a) The unit cell of lead (II) sulfide is shown:




(i) State the coordination number of the lead (II) ion. [1]

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(ii) There are 14 sulfide ions shown in the diagram. Explain why the unit cell is only considered to contain 4 sulfide ions. [2]

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(iii) Identify **one** technique that could be used to determine the structure of lead (II) sulfide. [1]

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

**(Option A, question 5 continued)**

(b) Lead hydroxide is best precipitated at pH 9. Determine the concentration of lead(II) ions present in an aqueous solution of a lead(II) salt at pH 9. Use section 32 of the data booklet. [3]

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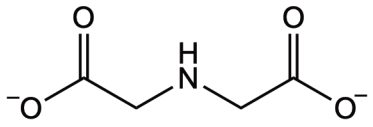
(c) An alternative method of removing lead(II) ions from aqueous solutions is chelation. A possible ligand for this is the anion of iminodiacetic acid.

Draw circles around the atoms on the following ligand, that would bond to the lead(II) ion when it forms a complex ion. [1]

**Anion of iminodiacetic acid**




## End of Option A

**Option B — Biochemistry**

**6.** State an equation for aerobic respiration. [1]

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**7.** Proteins are large polymers of 2-amino acids.

(a) Describe the interactions between amino acids occurring at the primary, secondary and tertiary levels within a protein. [3]

| Structure Level | Interactions between amino acids |
|---|---|
| Primary | . . . . . |
| Secondary | . . . . . |
| Tertiary | . . . . . |

(b) Explain how paper chromatography can separate and identify mixtures of amino acids. [2]

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

**(Option B, question 7 continued)**

(c) Explain the concept of product inhibition in metabolic pathways. [2]

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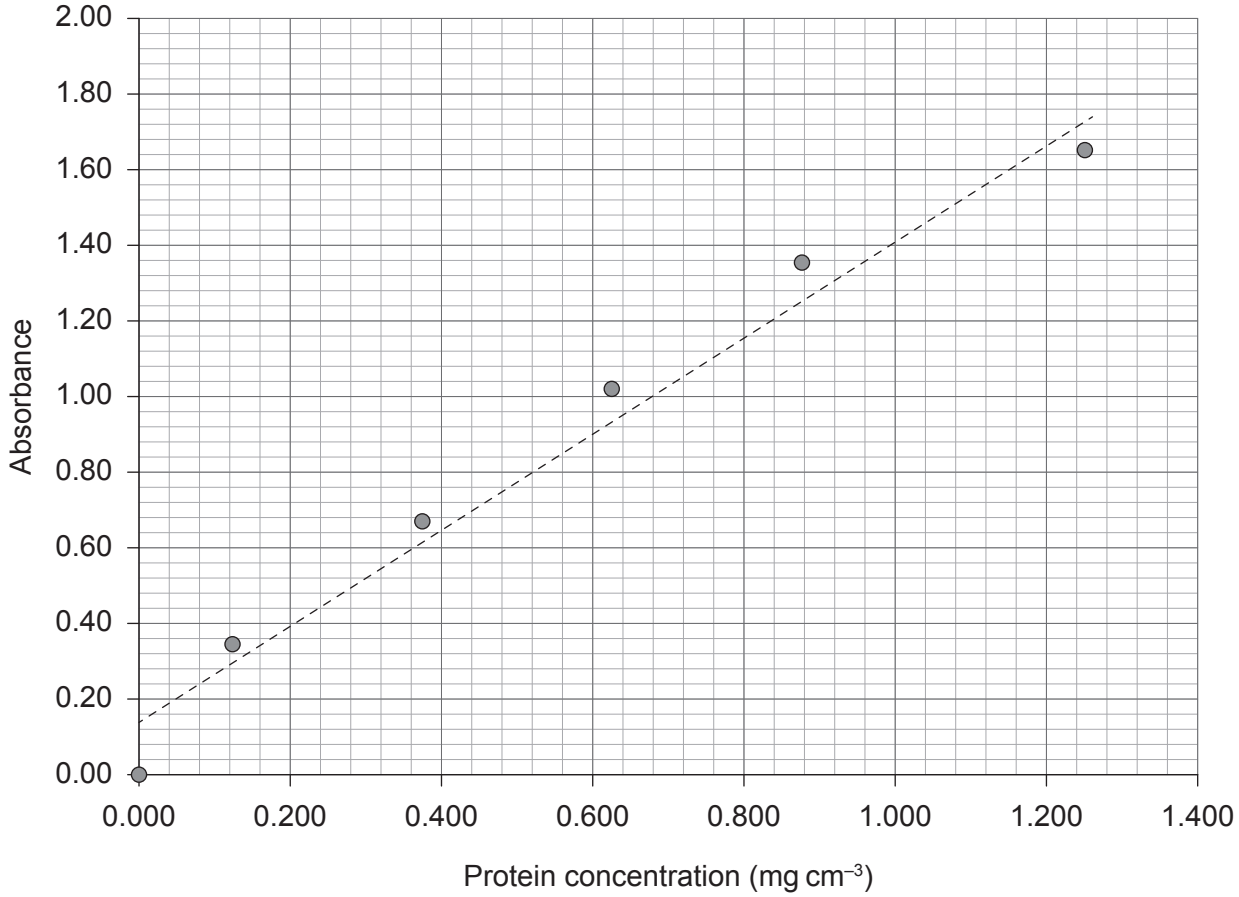
**(Option B continues on the following page)**

**(Option B, question 7 continued)**

The following diagram shows a protein calibration curve.

**Protein calibration curve**




(d) State the concentration, in mg $cm^{-3}$, of a protein sample with an absorbance of 0.80. [1]

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

**(Option B continued)**

**8.** Lipids are another group of biomolecules.

(a) Compare the hydrolytic and oxidative rancidity and contrast the site where the chemical changes occur. [2]

Compare rancidity: . . . . . .

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Contrast reaction site: . . . . . .

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(b) Calculate the iodine number for ozubondo acid, $C_{21}H_{33}COOH$. [2]

$M_r = 330.56$

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(c) Explain **two** ways in which carbohydrates and lipids differ as sources of energy. [2]

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

**(Option B continued)**

**9.** Identify the type of bond and by-product when monosaccharides combine. [2]

Bond: . . . . . .

By-product: . . . . . .

**10.** Outline why we need vitamins/micronutrients in our diets. [1]

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**11.** Outline how host–guest chemistry mimics enzymes in the removal of xenobiotics. [2]

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

**(Option B continued)**

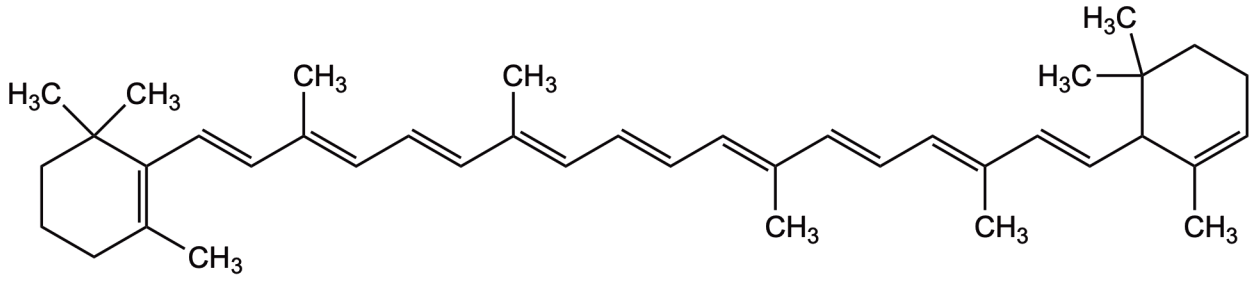
**12.** Identify **three** structural differences between DNA and RNA. Use section 34 of the data booklet. [3]

| DNA | RNA |
|---|---|
| . . . . . | . . . . . |
| . . . . . | . . . . . |
| . . . . . | . . . . . |

**13.** Biological pigments are coloured compounds.

The following structure is the β-carotene:

**β-carotene**




(a) Explain in terms of its structure, why β-carotene appears orange in visible white light. Refer to section 17 of the data booklet. [2]

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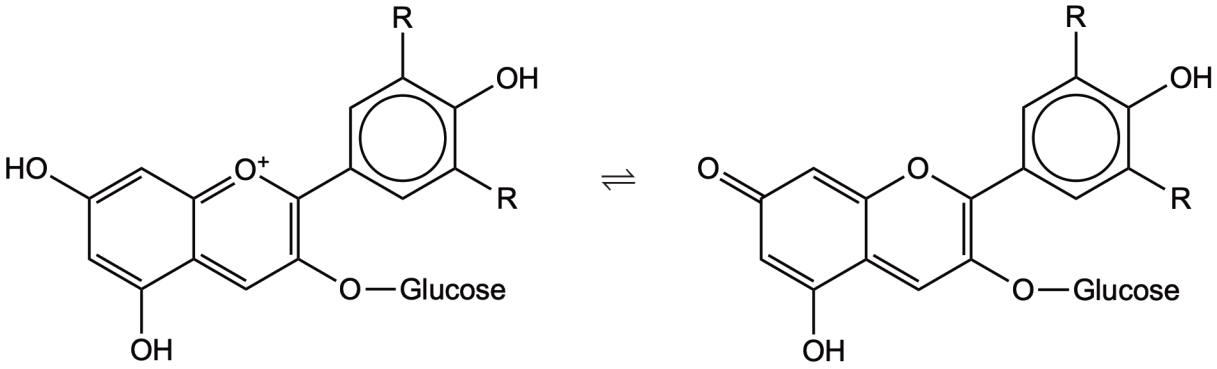
**(Option B continues on the following page)**

**(Option B, question 13 continued)**

Anthocyanins can act as acid-base indicators. The two examples shown, are the flavylium cation and the quinoidal base.

**Flavylium cation (red)** **Quinoidal base (blue)**




(b) Explain how these anthocyanins can act as acid-base indicators as pH increases. [2]

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

**(Option B continued)**

**14.** Monosaccharides combine to form polymers.

(a) Identify **one** similarity and **one** difference between the structures of starch and cellulose. [2]

Similarity: . . . . . .

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Difference: . . . . . .

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(b) Outline why humans cannot digest cellulose. [1]

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## End of Option B

**Option C — Energy**

**15.** (a) Photosynthesis enables green plants to store energy from sunlight as glucose.

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

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(ii) Identify the structural feature that allows chlorophyll to absorb light.
Use section 35 of the data booklet. [1]

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(iii) Explain how photosynthesis is being employed to control global warming. [2]

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

**(Option C, question 15 continued)**

(b) Photovoltaic cells also convert sunlight into energy.

(i) State the form of energy produced by photosynthesis and photovoltaic cells. [1]

Photosynthesis: . . . . . .

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Photovoltaic: . . . . . .

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(ii) Explain how a silicon-based photovoltaic cell brings about this conversion. [3]

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

**(Option C, question 15 continued)**

(c) Glucose can be converted to ethanol through fermentation:

$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

(i) Determine the energy efficiency of this conversion in terms of the enthalpies of combustion of the reactants and products. Use section 13 of the data booklet. [1]

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(ii) Suggest **one** reason, other than energy density and specific energy, why ethanol may be considered a more useful fuel than glucose. [1]

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(d) Both ethanol and glucose can be used to generate energy through fuel cells.

(i) Outline **one** way fuel cells differ from primary cells. [1]

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(ii) State **one** way to increase the maximum current of a voltaic cell. [1]

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

**(Option C continued)**

**16.** Geological transformations produce fossil fuels.

(a) Combustion of coal emits particulates into the atmosphere.

(i) Outline why this affects global warming. [1]

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(ii) State the major form of energy produced by the combustion of coal. [1]

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(b) Conversion of petroleum to petrol (gasoline) involves fractional distillation and cracking.

Distinguish between these processes. [2]

Fractional distillation: . . . . . .
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Cracking: . . . . . .
. . . . . .
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**(Option C continues on the following page)**

**(Option C, question 16 continued)**

(c) The equation for the combustion of octane is:

$$C_8H_{18}(l) + 12\frac{1}{2}O_2 \rightarrow 8CO_2(g) + 9H_2O(l)$$

(i) Determine the mass of carbon dioxide, in g, produced when 1 kJ of energy is produced. Use section 13 of the data booklet. [3]

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(ii) Suggest a piece of evidence that leads some people to not accept a causal link between the industrial emission of greenhouse gases, such as $CO_2$, and global warming. [1]

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

**(Option C continued)**

**17.** Both fission and fusion reactions are potential sources of nuclear energy.

(a) Compare and contrast the nuclear changes and products formed in these processes giving **one** similarity and **one** difference. [2]

Similarity: . . . . . .

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Difference: . . . . . .

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

**(Option C, question 17 continued)**

(b) Uranium is converted into a gaseous compound for enrichment.

(i) Identify the gaseous compound. [1]

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(ii) Determine the percentage difference in the rate of diffusion of molecules containing $^{235}U$ compared to those containing $^{238}U$. The molar masses of these molecules are 349 and 352 respectively. Use section 1 of the data booklet. [2]

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(iii) Show how the dependence of the rate of diffusion on molar mass arises from kinetic theory. Use section 1 of the data booklet and:

$$E = \frac{1}{2} mv^2,$$

where E is energy of the particle, m its mass and v its velocity. [2]

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

**(Option C, question 17 continued)**

(c) Some reactors convert $^{238}U$ into another nucleus that can also undergo fission.

(i) Complete the equation for this process by identifying the reacting particle, **X**, and the isotope formed, **Y**. [2]

$$^{238}U + \mathbf{X} \rightarrow {}^{239}U \rightarrow \mathbf{Y} + 2\,{}^{0}\beta^{-}$$

**X:** . . . . . .

**Y:** . . . . . .

(ii) The intermediate, $^{239}U$, has a half-life of 23 minutes. Outline what is meant by half-life. [1]

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## End of Option C

**Option D — Medicinal chemistry**

**18.** Outline how these drug administration methods affect bioavailability. [2]

Oral: . . . . . .

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Intravenous: . . . . . .

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**19.** Aspirin is most commonly used as a mild analgesic. State **two** other common medical uses for aspirin. [2]

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**20.** Suggest **two** reasons why the penicillin side-chain is modified. [2]

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

**(Option D continued)**

**21.** Explain how strong analgesics like morphine work. [2]

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**22.** Aluminium hydroxide and ranitidine can be used to relieve indigestion.

(a) (i) Write an equation for the reaction of aluminium hydroxide with stomach acid. [1]

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(ii) Calculate the mass, in g, of aluminium hydroxide needed to neutralize 100.0 $cm^3$ of $5.00 \times 10^{-3}$ mol $dm^{-3}$ stomach acid. [2]

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

**(Option D, question 22 continued)**

(b) Explain how ranitidine (Zantac®) can also relieve excess stomach acid. [2]

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**23.** Explain **two** different ways antiviral medications work. [2]

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**24.** Distinguish between the hazards of high-level and low-level nuclear waste. [2]

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**25.** Describe the original source of Taxol and the disadvantages of obtaining the medication from this source. [2]

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

**(Option D continued)**

**26.** Nuclear medicine can be used to diagnose and treat diseases.

(a) Deduce the nuclear equation for the beta decay of cobalt-60. [1]

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(b) Explain how Targeted Alpha Therapy (TAT) works and why it is used for treating cancers that have spread throughout the body. [3]

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**27.** Ethanol can be identified by a variety of analytical techniques.

(a) Predict the structures of **three** possible fragments you would expect from the mass spectrum of ethanol. [3]

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(b) Identify the **two** products formed when acidified potassium dichromate (VI), $K_2Cr_2O_7$, is used in a breathalyser test. [2]

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

**(Option D continued)**

**28.** The production of many pharmaceutical drugs involves the use of solvents.

(a) State **one** problem associated with chlorinated organic solvents as chemical waste. [1]

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(b) Suggest how the principles of green chemistry can be used to overcome the environmental problems caused by organic solvents. [1]

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## End of Option D

**References:**