Diploma Programme
Programme du diplôme
Programa del Diploma

**Chemistry
Higher level
Paper 3**

Friday 12 May 2017 (morning)

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 – 7
Option B — Biochemistry	8 – 15
Option C — Energy	16 – 19
Option D — Medicinal chemistry	20 – 26

35 pages

36EP01

International Baccalaureate
Baccalauréat International
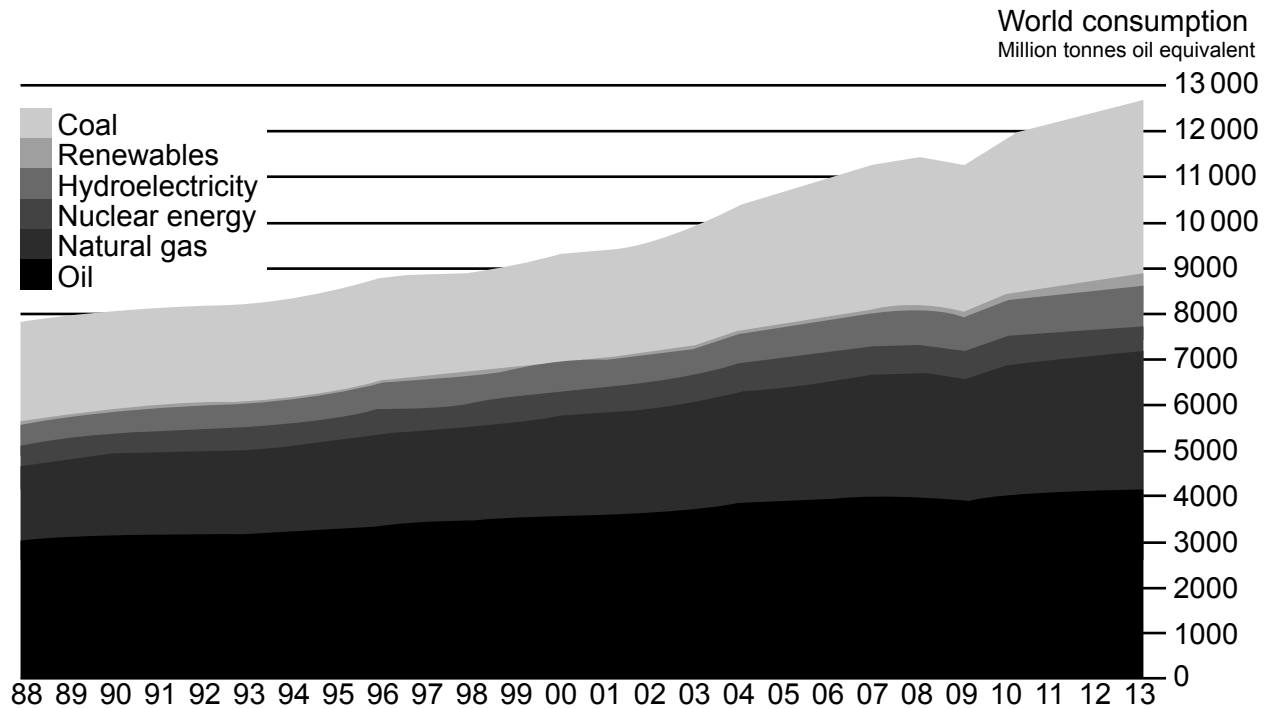Bachillerato Internacional

Section A

Answer **all** questions. Write your answers in the boxes provided.

1. There is a link between world energy consumption and carbon dioxide production.

   (a) The following graph represents world energy consumption by type for the years 1988–2013.

World consumption
Million tonnes oil equivalent

[Source: BP statistical review of world energy, www.bp.com]

Estimate the percentage of energy consumption which did **not** directly produce CO_2 in 2013. [1]

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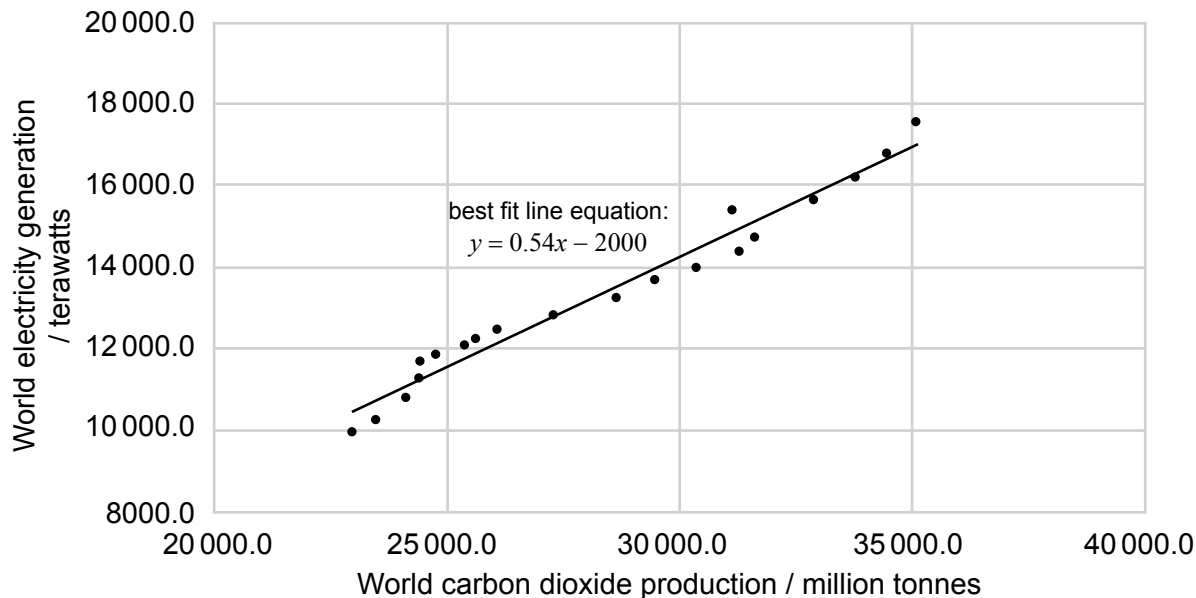
(This question continues on the following page)

(Question 1 continued)

(b) O_2 is consumed in producing CO_2 for electricity generation. The graph shows the relationship between the world's electricity generation and CO_2 production between 1994 and 2013.

best fit line equation:
$y = 0.54x - 2000$

World electricity generation / terawatts (y-axis)

World carbon dioxide production / million tonnes (x-axis)

[Source: BP statistical review of world energy, www.bp.com]

Calculate the mass, in million tonnes, of oxygen gas ultimately found in CO_2 which is consumed in generating 18 000 terawatts of electricity using the equation given for the best fit line. Give your answer to 2 significant figures.
Assume coal is the only energy source. [2]

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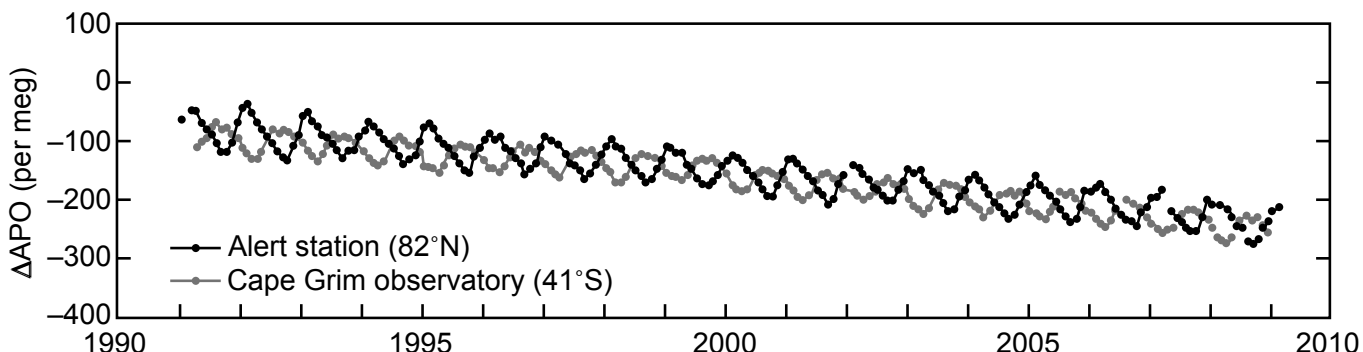
(This question continues on the following page)

(Question 1 continued)

(c)   Climate induced changes in the ocean can be studied using measurements such as the Atmospheric Potential Oxygen (APO). Trends in APO concentration from two stations, one in each hemisphere, are shown below.

Trends in atmospheric potential oxygen (APO) based on monthly averages between 1990 and 2010

[Source: www.ioos.noaa.gov]

(i)   The equilibrium expression for O_2 exchange between the atmosphere and ocean is $O_2(g) \rightleftharpoons O_2(aq)$. Identify **one** factor which shifts the equilibrium to the right.   [1]

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(ii)   Factors such as photosynthesis and respiration are excluded so that APO is influenced by oceanic changes only. Suggest why the seasonal cycles from Alert station and Cape Grim observatory are different.   [2]

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(This question continues on the following page)

(Question 1 continued)

(iii)   The change in APO O_2/N_2 ratio, per meg, is measured relative to an O_2/N_2 reference.

$$\Delta(O_2/N_2) = \left(\frac{(O_2/N_2)_{sample}}{(O_2/N_2)_{reference}} - 1 \right) \times 10^6$$

Calculate the APO $\Delta(O_2/N_2)$ value for an oxygen concentration of 209 400 ppm assuming that any change in N_2 concentration is negligible. Reference values for O_2 and N_2 are 209 460 and 790 190 ppm respectively.   [1]

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(iv)   Suggest a reason for the general negative gradient of the APO curve given in (c).   [1]

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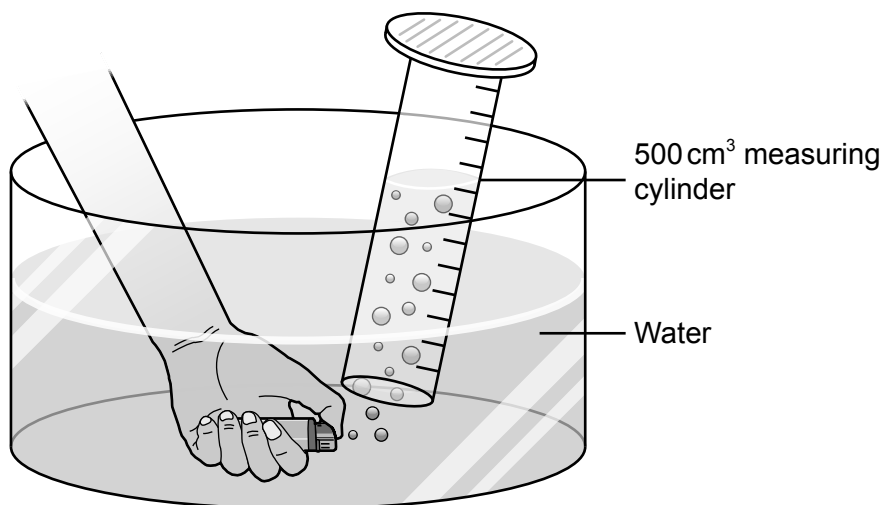..

2. Disposable plastic lighters contain butane gas. In order to determine the molar mass of butane, the gas can be collected over water as illustrated below:

500 cm^3 measuring cylinder

Water

(a) List the data the student would need to collect in this experiment. [4]

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(b) (i) Explain why this experiment might give a low result for the molar mass of butane. [2]

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(ii) Suggest **one** improvement to the investigation. [1]

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Section B

Answer **all** of the questions from **one** of the options. Write your answers in the boxes provided.

Option A — Materials

3.   Polymer nanocomposites often have better structural performance than conventional materials. Lithographic etching and metal coordination are two methods of assembling these nanocomposites.

(a)   State the two distinct phases of a composite.   [2]

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(b)   Identify the methods of assembling nanocomposites by completing the table.   [2]

	Physical or chemical	**Bottom up or top down**
Lithography	....	....
Metal coordination	....	....

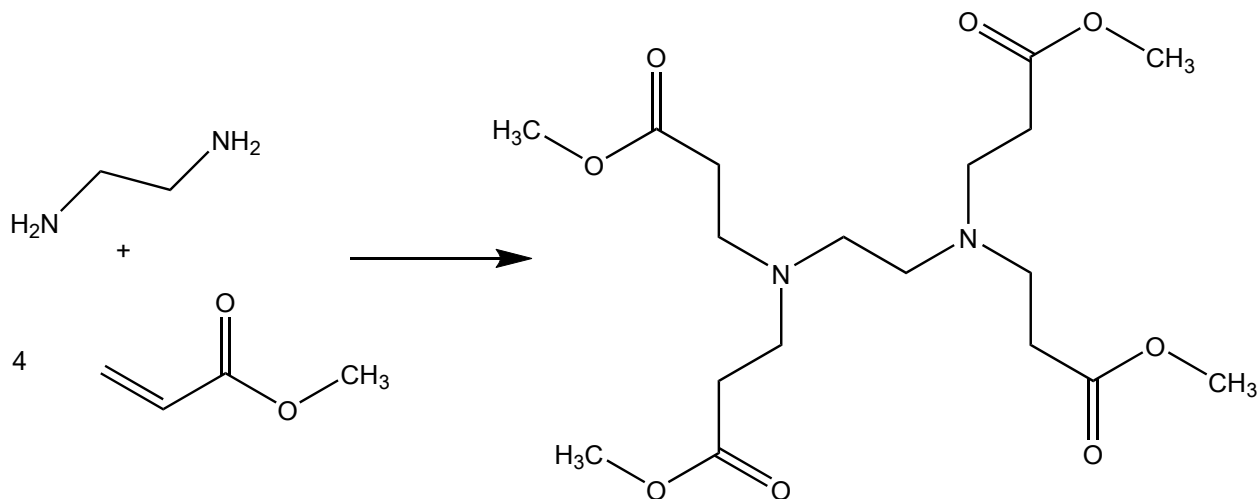**(Option A continues on the following page)**

(Option A, question 3 continued)

(c) Dendrimers are highly branched nanoparticles with a wide range of usage. One such dendrimer is PAMAM, or polyamidoamine.

Synthesized in the 1st step
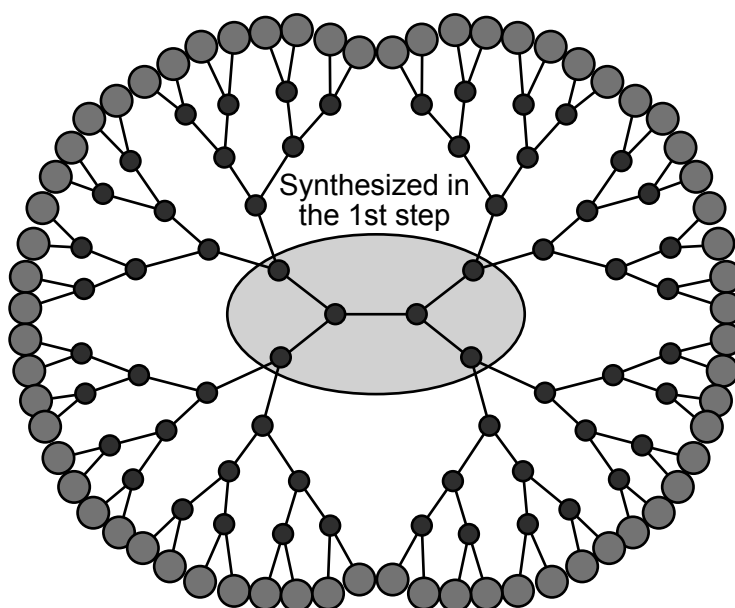
The first step in the synthesis is to make the core by reacting ethane-1,2-diamine with methylpropenoate.

(i) Estimate the atom economy of this first step. [1]

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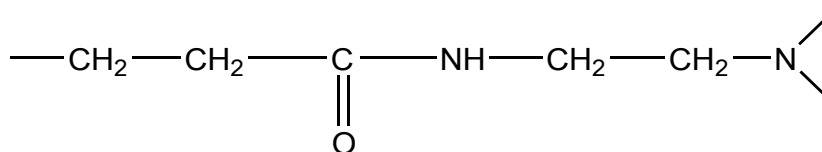
(Option A continues on the following page)

(Option A, question 3 continued)

(ii)   Suggest, giving one reason, whether this is an addition or condensation reaction.   [1]

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(iii) Subsequent steps proceed under differing conditions, forming the dendrimer polymer with the following repeating unit.

$$-CH_2-CH_2-\overset{\displaystyle C}{\underset{\displaystyle \| \atop \displaystyle O}{}}-NH-CH_2-CH_2-N\big\langle$$

State the name of **one** functional group in this repeating unit.   [1]

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4.   EDTA is produced by reacting ethane-1,2-diamine with chloroethanoic acid, $ClCH_2COOH$.
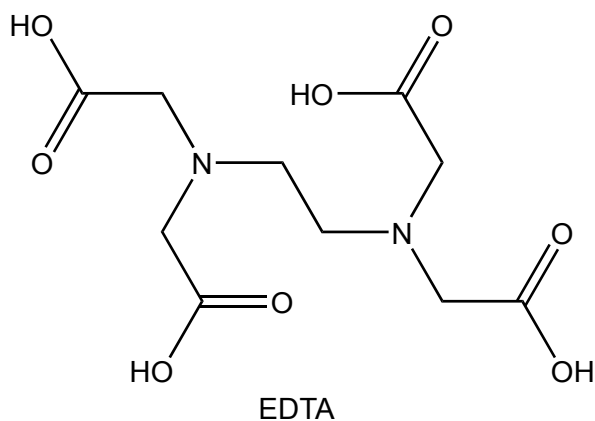
EDTA

(a)   Identify the other product formed.   [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(b) Explain why EDTA, a chelating agent, is more effective in removing heavy metal ions from solution than monodentate ligands. [3]

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5. Rhodium and palladium are often used together in catalytic converters. Rhodium is a good reduction catalyst whereas palladium is a good oxidation catalyst.

(a) In a catalytic converter carbon monoxide is converted to carbon dioxide. Outline the process for this conversion referring to the metal used. [3]

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(b) (i) Nickel is also used as a catalyst. It is processed from an ore until nickel(II) chloride solution is obtained. Identify **one** metal, using sections 24 and 25 of the data booklet, which will not react with water and can be used to extract nickel from the solution. [1]

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(Option A continues on the following page)

(Option A, question 5 continued)

  (ii) Deduce the redox equation for the reaction of nickel(II) chloride solution with the metal identified in (b)(i).   [1]

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  (iii) Nickel(II) ions are least soluble at pH 10.5. Calculate the molar solubility of nickel(II) hydroxide at this pH. $K_{sp}Ni(OH)_2 = 5.48 \times 10^{-16}$.   [2]

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(c) (i) Rhodium is paramagnetic with an electron configuration of [Kr] $5s^14d^8$.

         Explain, in terms of electron spin pairing, why paramagnetic substances are attracted to a magnetic field and diamagnetic substances are not.   [2]

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(Option A continues on the following page)
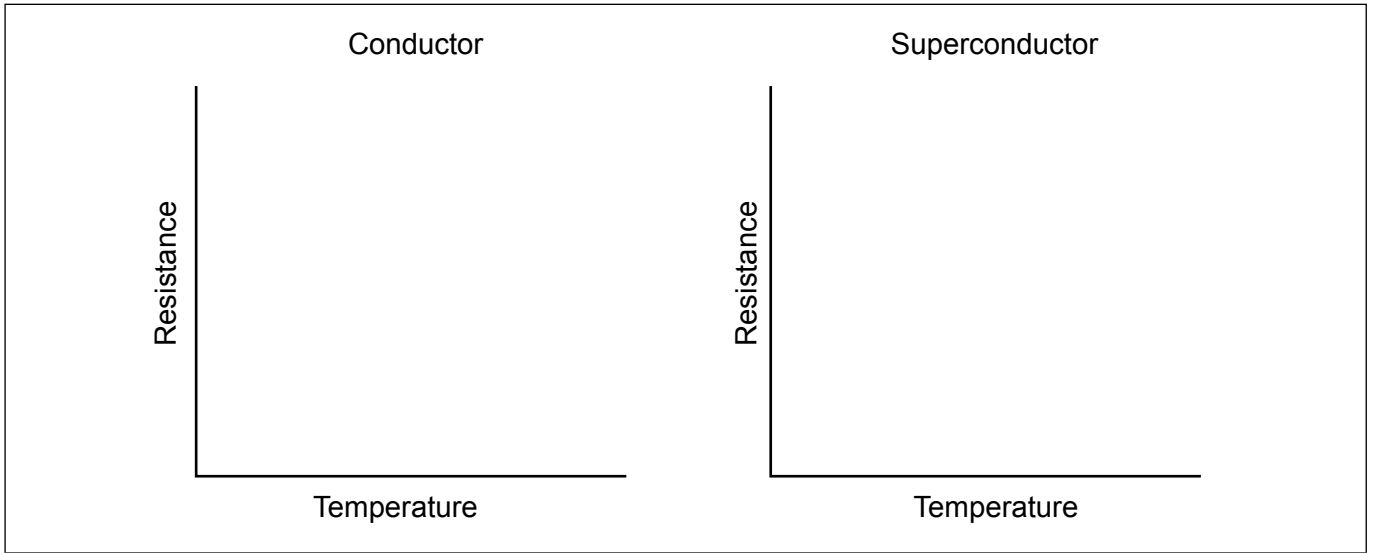
(Option A, question 5 continued)

(ii)   Rhodium is a type 1 superconductor.

Sketch graphs of resistance against temperature for a conductor and
superconductor.   [2]

Conductor	Superconductor
Resistance ↑	Resistance ↑
Temperature →	Temperature →

(iii)   Contrast type 1 and type 2 superconductors by referring to **three** differences
between them.   [3]

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(Option A continues on the following page)

(Option A continued)

6. Liquid Crystal on Silicon, LCoS, uses liquid crystals to control pixel brightness. The degree of rotation of plane polarized light is controlled by the voltage received from the silicon chip.

(a) Two important properties of a liquid crystal molecule are being a polar molecule and having a long alkyl chain. Explain why these are essential components of a liquid crystal molecule. [2]

Polar molecule:

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Long alkyl chain:

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....

(b) Metal impurities during the production of LCoS can be analysed using ICP-MS. Each metal has a detection limit below which the uncertainty of data is too high to be valid. Suggest **one** factor which might influence a detection limit in ICP-MS/ICP-OES. [1]

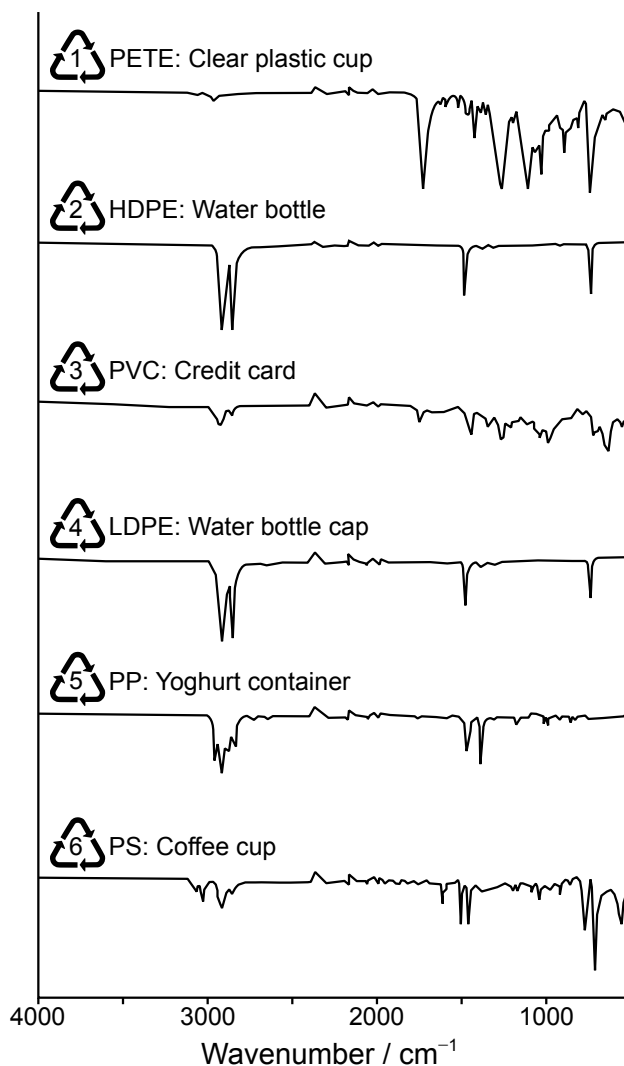..

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(Option A continues on the following page)

(Option A continued)

7.   Infrared (IR) spectra can be used to distinguish between various types of plastics.
Some simplified IR spectra are given here.

1 PETE: Clear plastic cup

2 HDPE: Water bottle

3 PVC: Credit card

4 LDPE: Water bottle cap

5 PP: Yoghurt container

6 PS: Coffee cup

Wavenumber / cm^{-1}

[Source: M Rozov, TK Valdez, L Valdez and RK Upmacis, (2013), "Teaching Green
Chemistry Principles to Undergraduate Students", *Athens Journal of Sciences*.]

Explain, with a reference to molecular structure, which two of the plastics can **not** be
distinguished by IR spectroscopy.   [2]

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End of Option A

Option B — Biochemistry

8. The structures of the amino acids cysteine, glutamine and lysine are given in section 33 of the data booklet.

(a) Deduce the structural formula of the dipeptide Cys-Lys. [2]

(b) A mixture of the three amino acids, cysteine, glutamine and lysine, was placed in the centre of a square plate covered in polyacrylamide gel. The gel was saturated with a buffer solution of pH 6.0. Electrodes were connected to opposite sides of the gel and a potential difference was applied.

Sketch lines on the diagram to show the relative positions of the three amino acids after electrophoresis. [2]

original mixture
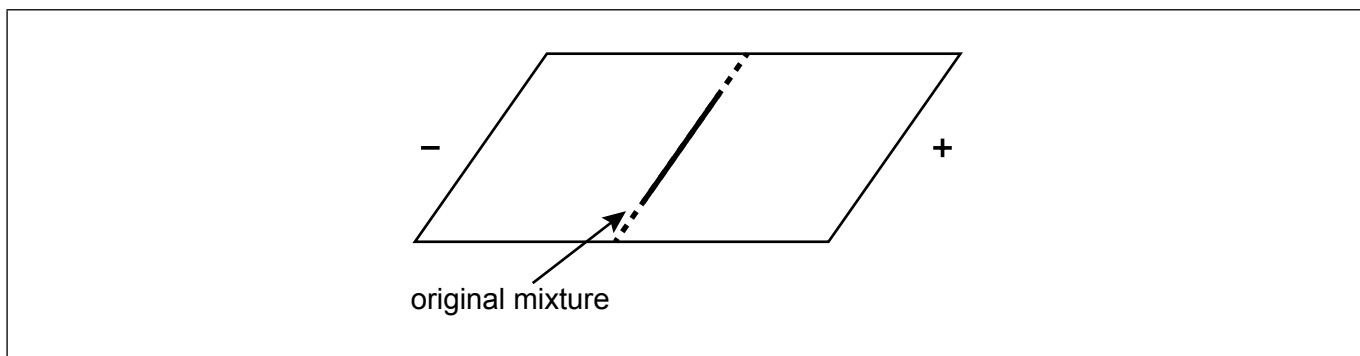
(c) (i) An aqueous buffer solution contains both the zwitterion and the anionic forms of alanine. Draw the zwitterion of alanine. [1]

(Option B continues on the following page)

Turn over

(Option B, question 8 continued)

(ii) Calculate the pH of a buffer solution which contains $0.700 \, mol \, dm^{-3}$ of the zwitterion and $0.500 \, mol \, dm^{-3}$ of the anionic form of alanine. Alanine $pK_a = 9.87$. [1]

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9. Sunflower oil contains stearic, oleic and linoleic fatty acids. The structural formulas of these acids are given in section 34 of the data booklet.

(a) Explain which one of these fatty acids has the highest boiling point. [2]

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(b) $10.0 \, g$ of sunflower oil reacts completely with $123 \, cm^3$ of $0.500 \, mol \, dm^{-3}$ iodine solution. Calculate the iodine number of sunflower oil to the nearest whole number. [3]

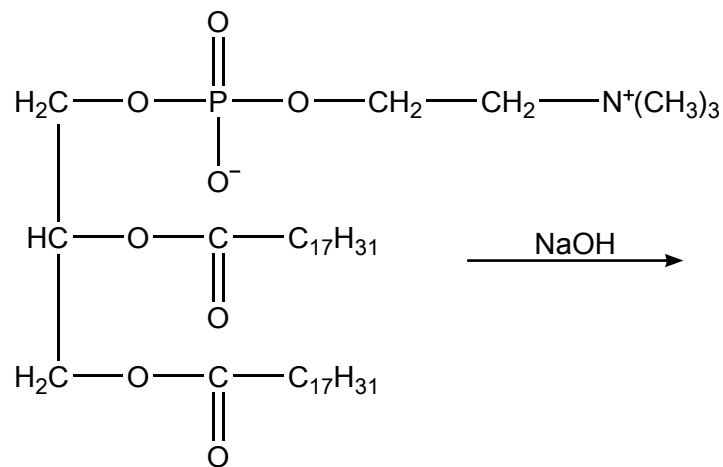..

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(Option B continues on the following page)

(Option B continued)

10. A chemical reaction occurs when a phospholipid is heated with excess sodium hydroxide.

$$H_2C-O-P(=O)(O^-)-O-CH_2-CH_2-N^+(CH_3)_3$$
$$HC-O-C(=O)-C_{17}H_{31}$$
$$H_2C-O-C(=O)-C_{17}H_{31}$$

$$\xrightarrow{\text{NaOH}}$$

(a)   Glycerol is one product of the reaction. Identify the two other organic products.   [2]

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(b)   Identify the type of reaction which occurs.   [1]

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(Option B continues on the following page)

Turn over

(Option B continued)

11. Monosaccharides can combine to form disaccharides and polysaccharides.

straight chain glucose   α-glucose   β-fructose
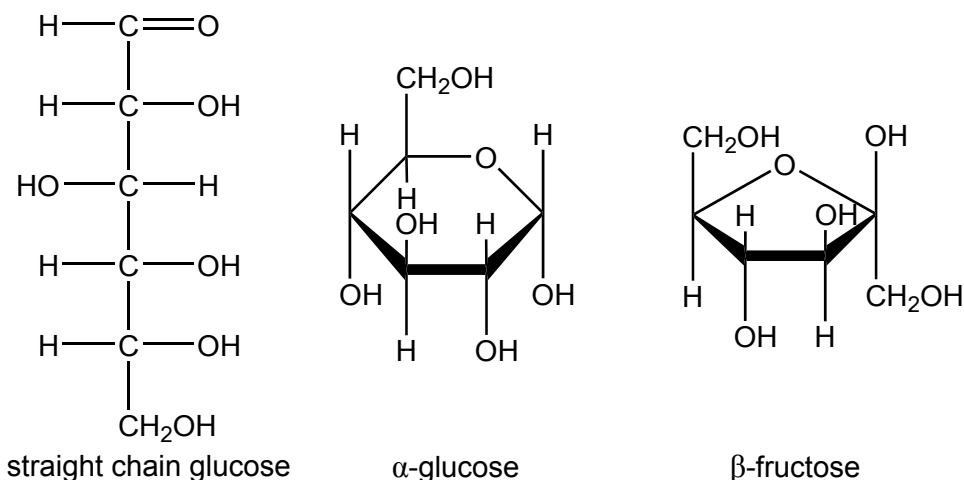
   (a)   Identify the functional groups which are present in only one structure of glucose.   [2]

Only in straight chain form:

. . . .

Only in ring structure:

. . . .

   (b)   Sucrose is a disaccharide formed from α-glucose and β-fructose.
        Deduce the structural formula of sucrose.   [1]

(Option B continues on the following page)

(Option B, question 11 continued)

(c)   Suggest **one** of the challenges scientists face when scaling up the synthesis of a new compound.   [1]

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12.   Retinal, one of the many forms of vitamin A, reacts with opsin to produce rhodopsin. Refer to section 35 of the data booklet for one structure of vitamin A.

(a)   Identify the structural feature which enables rhodopsin to absorb visible light.   [1]

....

....

(b)   Outline the change that occurs in the retinal residue during the absorption of visible light.   [1]

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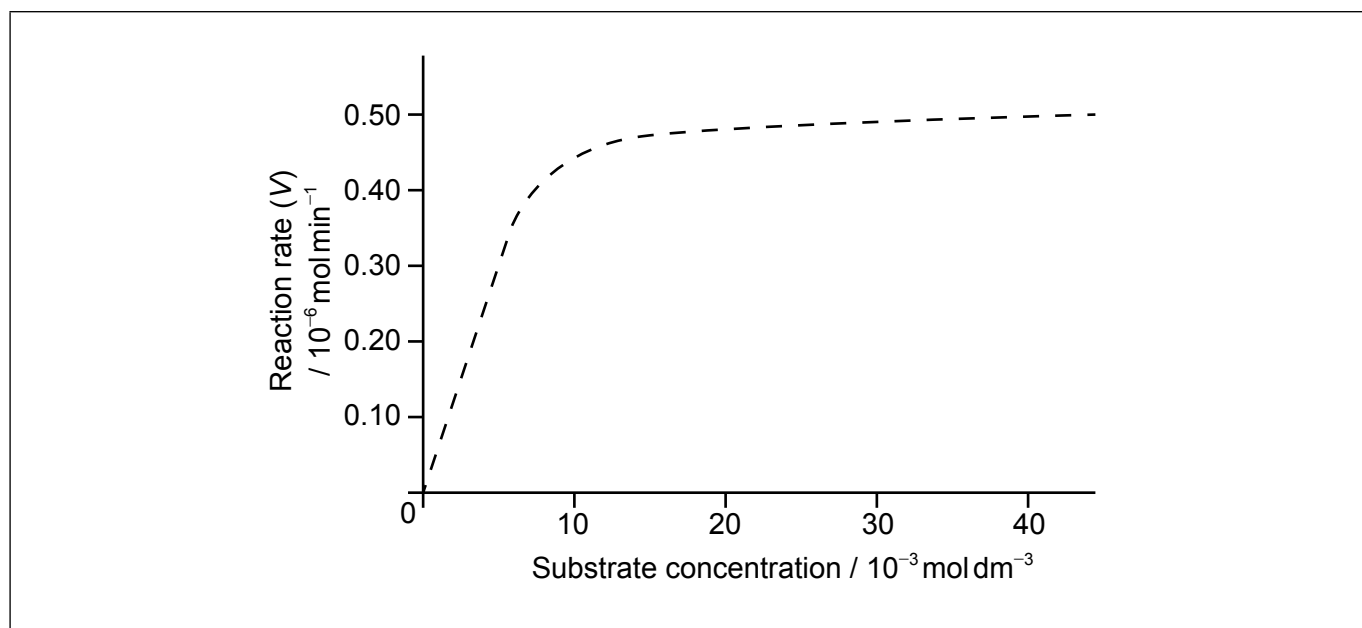...

(Option B continues on the following page)

(Option B continued)

13. The graph of the rate of an enzyme-catalyzed reaction is shown below.

(a) Determine the value of the Michaelis constant, K_m, including units, from the graph. [2]

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(b) Sketch a second graph on the same axes to show how the reaction rate varies when a competitive inhibitor is present. [1]

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

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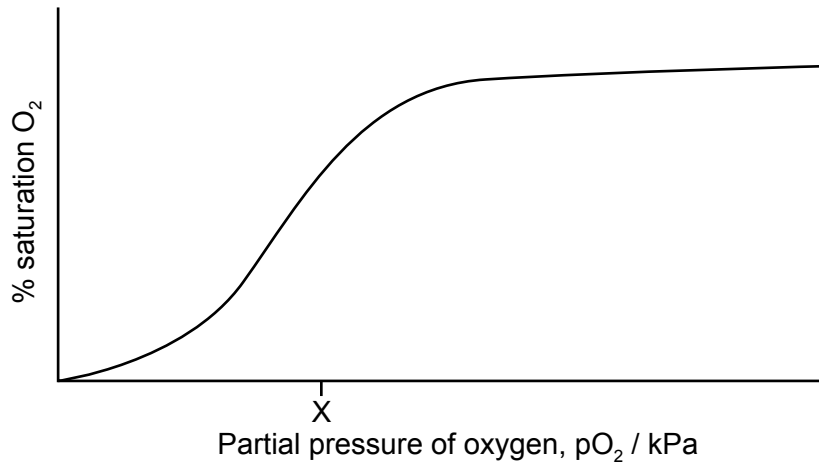...

(Option B continues on the following page)

(Option B continued)

14.   A hemoglobin-oxygen saturation curve does not follow the same model as enzyme-substrate reactions.

(a)   Explain the shape of the curve from 0 to X kPa.   [2]

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(b)   Explain why carbon monoxide is toxic to humans.   [2]

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(Option B continues on the following page)

(Option B continued)

15. DNA is a complex molecule.

(a) Outline how its structure allows it to be negatively charged in the body. [1]

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

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End of Option B

Option C — Energy

16. The sun is the main source of energy used on earth.

(a) (i) One fusion reaction occurring in the sun is the fusion of deuterium, $_1^2H$, with tritium, $_1^3H$, to form helium, $_2^4He$. State a nuclear equation for this reaction. [1]

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(ii) Explain why this fusion reaction releases energy by using section 36 of the data booklet. [2]

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(iii) Calculate the energy released, in MeV, in this reaction, using section 36 of the data booklet. [2]

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(b) State the technique used to show that the sun is mainly composed of hydrogen and helium. [1]

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(Option C continues on the following page)

(Option C continued)

17. There are many sources of energy available.

(a) State **one** advantage and **one** disadvantage for each energy source in the table. [4]

Energy Source	Advantage	Disadvantage
Biofuels	....	....
Fossil fuels	....	....

(b) (i) Calculate the specific energy of hydrogen, stating its units. Refer to sections 1, 6 and 13 of the data booklet. [2]

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(ii) Hydrogen has a higher specific energy than petrol (gasoline) but is not used as a primary fuel source in cars. Discuss the disadvantages of using hydrogen. [2]

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(Option C continues on the following page)

(Option C, question 17 continued)

(c) Methanol fuel cells provide a portable energy source. The process can be represented by the overall equation $CH_3OH(aq) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$.

(i) Deduce the half-cell equations occurring at each electrode during discharge. [2]

Anode (negative electrode):

....

Cathode (positive electrode):

....

(ii) Outline the function of the proton-exchange membrane (PEM) in the fuel cell. [1]

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(iii) Explain how the flow of ions allows for the operation of the fuel cell. [2]

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(Option C continues on the following page)

Turn over

(Option C continued)

18. The combustion of fossil fuels produces large amounts of CO_2, a greenhouse gas.
The diagram below illustrates a range of wavelengths in the electromagnetic spectrum.
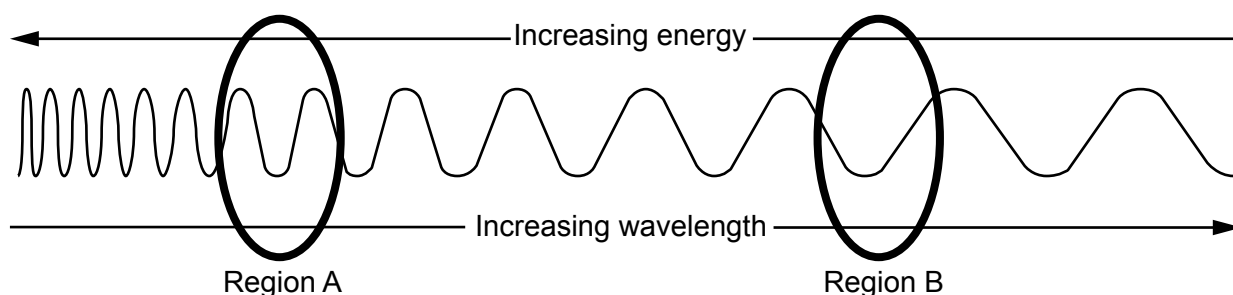
(a) (i) Identify which region, **A** or **B**, corresponds to each type of radiation by completing the table. [1]

Type of radiation	Region
Incoming radiation from sun	. . . .
Re-radiated from Earth's surface	. . . .
Absorbed by CO_2 in the atmosphere	. . . .

(ii) The structures of 11-*cis*-retinal and β-carotene are given in section 35 of the data booklet. Suggest a possible wavelength of light absorbed by each molecule using section 3 of the data booklet. [2]
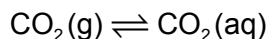
11-*cis*-retinal:

. . . .

β-carotene:

. . . .

(Option C continues on the following page)

(Option C, question 18 continued)

(b)　(i)　Oceans can act as a carbon sink, removing some $CO_2(g)$ from the atmosphere.

$$CO_2(g) \rightleftharpoons CO_2(aq)$$

Aqueous carbon dioxide, $CO_2(aq)$, quickly reacts with ocean water in a new equilibrium reaction. Construct the equilibrium equation for this reaction including state symbols.　　　　　　　　　　　[1]

　　(ii)　Describe how large amounts of CO_2 could reduce the pH of the ocean using an equation to support your answer.　　　　　　　[2]

(Option C continues on the following page)

Turn over

(Option C continued)

19. A Grätzel dye-sensitized solar cell (DSSC) and a silicon based photovoltaic cell both convert solar energy into electrical energy by producing a charge separation.

   (a) Contrast how absorption of photons and charge separation occur in each device. [4]

Type of solar cell	Absorption of photons	Charge separation
Silicon based		
DSSC		

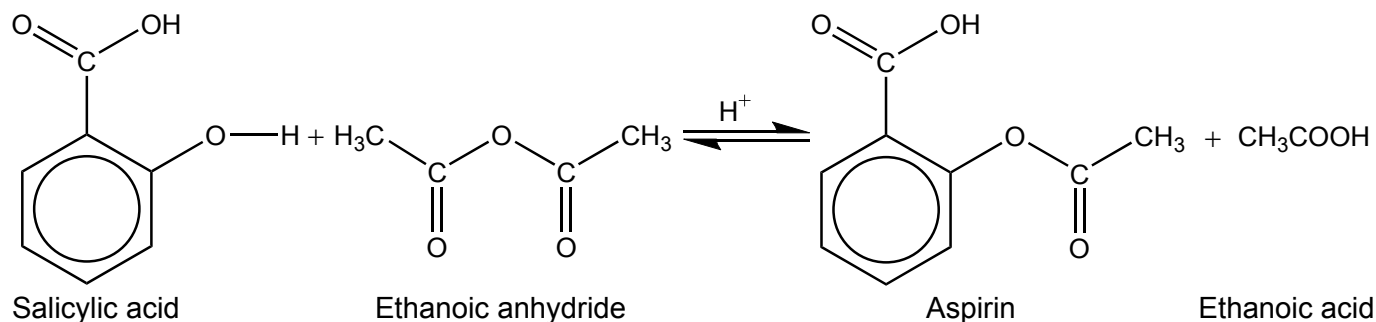   (b) Suggest one advantage a DSSC has over a silicon based photovoltaic cell. [1]

End of Option C

Option D — Medicinal chemistry

20. Aspirin is one of the most widely used drugs in the world.

(a) Aspirin was synthesized from 2.65 g of salicylic acid (2-hydroxybenzoic acid) ($M_r = 138.13$) and 2.51 g of ethanoic anhydride ($M_r = 102.10$).

Salicylic acid   Ethanoic anhydride   Aspirin   Ethanoic acid

(i) Calculate the amounts, in mol, of each reactant. [1]

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(ii) Calculate, in g, the theoretical yield of aspirin. [1]

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(iii) Suggest **two** absorbances, other than the absorbances due to the ring structure and C–H bonds, that would be present in the infrared (IR) spectrum of aspirin. [2]

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(Option D continues on the following page)

Turn over

(Option D, question 20 continued)

(iv) State **two** techniques, other than IR spectroscopy, which could be used to confirm the identity of aspirin. [2]

(b) (i) State how aspirin can be converted to water-soluble aspirin. [1]

(ii) Compare, giving a reason, the bioavailability of soluble aspirin with aspirin. [1]

21. The structures of morphine, diamorphine and codeine are given in section 37 of the data booklet.

(a) Explain why diamorphine passes more readily than morphine through the blood-brain barrier. [2]

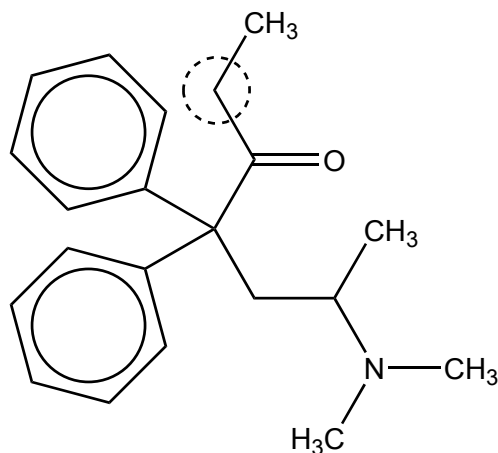**(Option D continues on the following page)**

(Option D, question 21 continued)

(b)   Suggest **one** reason why codeine is available without prescription in some countries whilst morphine is administered under strict medical supervision.   [1]

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(c)   Methadone is used to treat heroin addiction. ^1H NMR spectroscopy can be used to study its structure.

(i)   Predict the number of different hydrogen environments in the molecule ignoring the benzene rings.   [1]

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(ii)   Predict the chemical shift and the splitting pattern seen for the hydrogens on the carbon atom circled in the diagram. Use section 27 of the data booklet.   [2]

Chemical shift:

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Splitting pattern:

....

(Option D continues on the following page)

Turn over

(Option D continued)

22. A number of drugs have been developed to treat excess acidity in the stomach.

(a) Outline how ranitidine (Zantac) functions to reduce stomach acidity. [1]

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(b) 0.500 g of solid anhydrous sodium carbonate, $Na_2CO_3(s)$, is dissolved in 75.0 cm^3 of 0.100 mol dm^{-3} sodium hydrogen carbonate solution, $NaHCO_3(aq)$. Assume the volume does not change when the salt dissolves.

$$HCO_3^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H^+(aq) \qquad pK_a = 10.35.$$
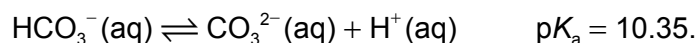
Calculate the pH of the buffer solution. [2]

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(Option D continues on the following page)

(Option D continued)

23. The structures of oseltamivir (Tamiflu) and zanamivir (Relenza) are given in section 37 of the data booklet.

    (a) Compare and contrast the structures of oseltamivir and zanamivir, stating the names of functional groups. [2]

    One similarity:

    ....

    One difference:

    ....

    ....

    (b) Suggest **one** ethical consideration faced by medical researchers when developing medications. [1]

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24. The production of many pharmaceutical drugs involves the use of solvents.

    Suggest **one** problem associated with chlorinated organic solvents as chemical waste. [1]

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(Option D continues on the following page)

(Option D continued)

25. Taxol is produced using a chiral auxiliary. Describe how the chiral auxiliary functions to produce the desired product. [3]

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26. (a) Targeted Alpha Therapy (TAT) is a technique that involves using alpha-radiation to treat leukemia and other dispersed cancers.

(i) Explain why alpha-radiation is particularly suitable for this treatment. [2]

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(ii) Outline how the alpha-radiation in TAT is directed to cancer cells. [1]

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(Option D continues on the following page)

(Option D, question 26 continued)

(b) Yttrium-90 and lutetium-177 are used in radiotherapy.

(i) Identify the type of radiation emitted by these two radioisotopes. [1]

....

(ii) State an equation for the one-step decay of yttrium-90. [1]

....

....

(iii) The half-life of lutetium-177 is 6.75 days. Calculate the percentage remaining after 27 days. [1]

....

....

End of Option D