Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Friday 6 November 2020 (morning)

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 – 14
Option D — Medicinal chemistry	15 – 19

8820 – 6103

Section A

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

1. In order to determine the oil content of different types of potato crisps (chips), a student weighed 5.00 g of crushed crisps and mixed them with 20.0 cm^3 of non-polar solvent.

She assumed all the oil in the crisps dissolved in the solvent.

The student then filtered the mixture to remove any solids, and gently heated the solution on a hot plate to evaporate the solvent.

She measured the mass of the oil that remained from each type of crisps.

(a) Suggest why a non-polar solvent was needed. [1]

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(b) State one reason why the mixture was not heated strongly. [1]

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(c) Non-polar solvents can be toxic. Suggest a modification to the experiment which allows the evaporated solvent to be collected. [1]

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(This question continues on the following page)

(Question 1 continued)

(d) Suggest one source of error in the experiment, excluding faulty apparatus and human error, that would lead to the following: [2]

Experimental mass greater than actual mass of oil in crisps:

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Experimental mass lower than actual mass of oil in crisps:

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2. An investigation was carried out to determine the effect of chain length of the alcohol on the equilibrium constant, K_c, for the reversible reaction:

$$ROH + CH_3COOH \overset{H^+(aq)}{\rightleftharpoons} CH_3COOR + H_2O$$

The reactants, products and the catalyst form a homogeneous mixture.

Fixed volumes of each alcohol, the ethanoic acid and the sulfuric acid catalyst were placed in sealed conical flasks.

At equilibrium, the flasks were placed in an ice bath, and samples of each flask titrated with NaOH (aq) to determine the ethanoic acid concentration present in the equilibrium mixture.

The following processed results were obtained.

ROH	**Chain length / number of carbons**	**Experimentally determined K_c**	**Literature value of K_c**
Methanol	1	6.5 ± 0.4	5.3
Ethanol	2	5.1 ± 0.3	4.0
Propan-1-ol	3	5.0 ± 0.3	4.1
Butan-1-ol	4	5.6 ± 0.5	4.2
Pentan-1-ol	5	3.2 ± 0.3	Not available

(a) Identify the independent and dependent variables in this experiment. [1]

Independent variable:

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Dependent variable:

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(This question continues on the following page)

(Question 2 continued)

(b) The ice bath is used at equilibrium to slow down the forward and reverse reactions. Explain why adding a large amount of water to the reaction mixture would also slow down **both** reactions. [2]

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(c) Suggest why the titration must be conducted quickly even though a low temperature is maintained. [1]

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(d) An additional experiment was conducted in which only the sulfuric acid catalyst was titrated with NaOH(aq). Outline why this experiment was necessary. [1]

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(This question continues on the following page)

(Question 2 continued)

(e) Calculate the percentage uncertainty and percentage error in the experimentally determined value of K_c for methanol. [2]

Percentage uncertainty:

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Percentage error:

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(f) Comment on the magnitudes of random and systematic errors in this experiment using the answers in (e). [2]

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(g) Suggest a risk of using sulfuric acid as the catalyst. [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. Carbon fibre reinforced plastic (CFRP) is a useful composite. Epoxy is a thermoset polymer that is used as a binding polymer when making CFRP.

(a) Outline the **two** distinct phases of this composite. [2]

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(b) (i) Thermoplastic composites are increasingly replacing thermosets.

Suggest **one** advantage of thermoplastic polymers over thermosets. [1]

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(ii) Explain how thermoplastics, such as polyvinylchloride, PVC, can be made more flexible by the addition of phthalate ester plasticizers. [3]

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(Option A continues on the following page)

(Option A, question 3 continued)

(iii) Explain why phthalates are replaced by other plasticizers in the production of plastics. [2]

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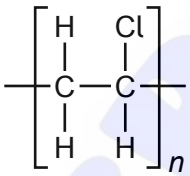
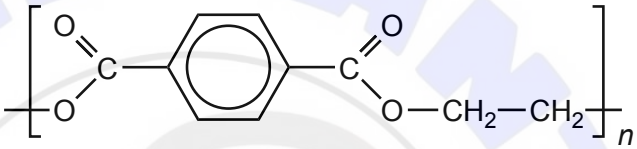
(c) Classify PVC and polyethene terephthalate, PET, as addition or condensation polymers and deduce the structural formulas. [3]



PVC



PET

Polymer	Classification	Structure of monomer(s)
PVC	. . . . .	
PET	. . . . .	

(Option A continues on the following page)

(Option A continued)

4. There has been significant growth in the use of carbon nanotubes, CNT.

(a) Explain these properties of carbon nanotubes. [2]

Excellent strength:

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Excellent conductivity:

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(b) (i) CNT can act as Type 2 superconductors. Outline why Type 2 superconductors are generally more useful than Type 1. [2]

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(ii) Explain the role of electrons in superconducting materials in terms of the Bardeen–Cooper–Schrieffer (BCS) theory. [3]

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(Option A continues on the following page)

(Option A, question 4 continued)

(c) (i) Alloying metals changes their properties. Suggest **one** property of magnesium that could be improved by making a magnesium–CNT alloy. [1]

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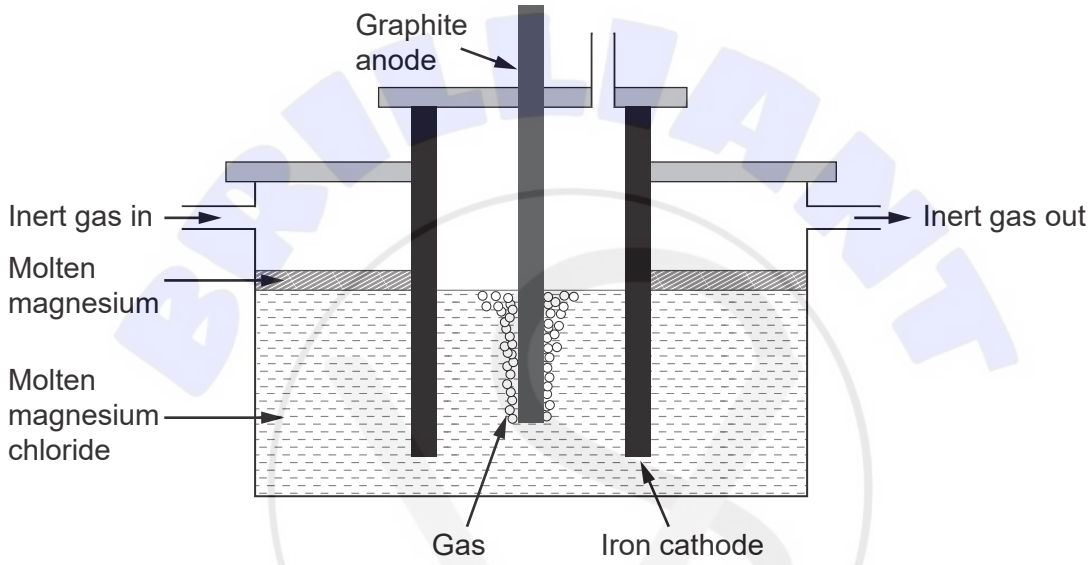
(ii) Pure magnesium needed for making alloys can be obtained by electrolysis of molten magnesium chloride.



Calculate the theoretical mass of magnesium obtained if a current of 3.00A is used for 10.0 hours. Use charge (Q) = *current* (I) × *time* (t) and section 2 of the data booklet. [3]

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(Option A continues on the following page)

(Option A, question 4 continued)

(iii) Suggest a gas which should be continuously passed over the molten magnesium in the electrolytic cell. [1]

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(d) Zeolites can be used as catalysts in the manufacture of CNT. Explain, with reference to their structure, the high selectivity of zeolites. [2]

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(e) Experiments have been done to explore the nematic liquid crystal behaviour of CNT. Justify how CNT molecules could be classified as **nematic**. [1]

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(Option A continues on page 13)

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will not be marked.

(Option A continued)

5. Precipitation is one method used to treat waste water.

(a) Phosphates, PO_4^{3-}, in waste water can be removed by precipitation with magnesium ions. K_{sp} of magnesium phosphate is 1.04×10^{-24}.

$$3Mg^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Mg_3(PO_4)_2(s)$$

Calculate the maximum solubility of phosphate ions in a solution containing $0.0100\,mol\,dm^{-3}$ magnesium ions. [2]

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(b) Zinc, cadmium, nickel, and lead are metal ions which can be removed by precipitation. Explain why waste water is adjusted to a pH of 9–10 to remove these ions by referring to section 32 of the data booklet. [2]

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End of Option A

Option B — Biochemistry

6. Proteins are polymers of amino acids.

(a) (i) A paper chromatogram of two amino acids, A1 and A2, is obtained using a non-polar solvent.

Determine the R_f value of A1. [1]

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(Option B continues on the following page)

(Option B, question 6 continued)

(ii) The mixture is composed of glycine, Gly, and isoleucine, Ile. Their structures can be found in section 33 of the data booklet.

Deduce, referring to relative affinities and R_f, the identity of A1. [2]

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(b) Glycine is one of the amino acids in the primary structure of hemoglobin.

State the type of bonding responsible for the α-helix in the secondary structure. [1]

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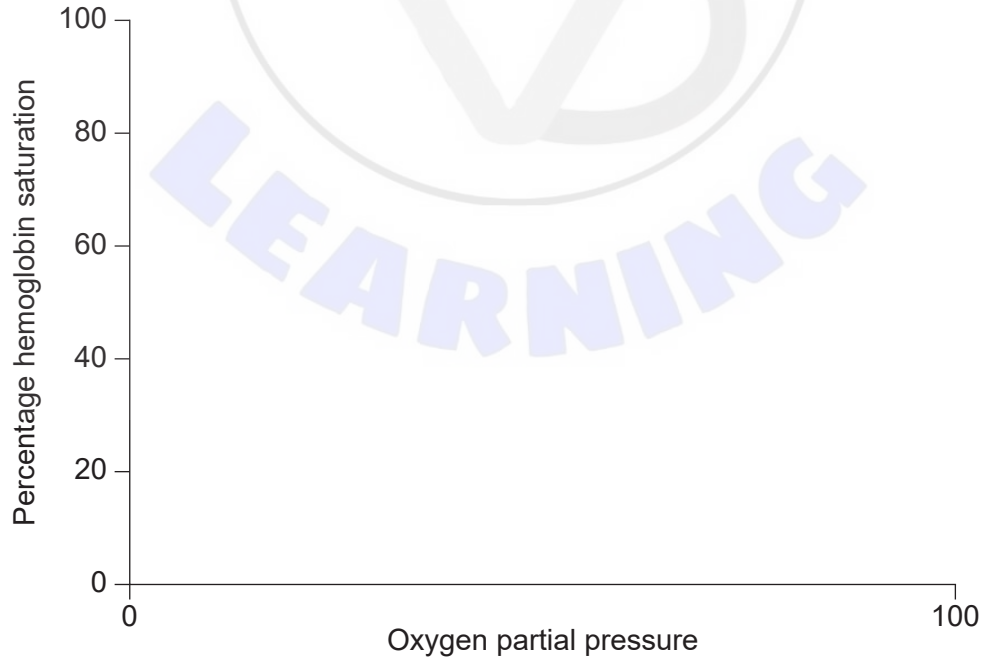
(c) (i) Sketch and label **two** oxygen dissociation curves, one for adult hemoglobin and one for foetal hemoglobin. [2]



(Option B continues on the following page)

(Option B, question 6 continued)

(ii) Explain why the affinity for oxygen of foetal hemoglobin differs from that of adult hemoglobin. [2]

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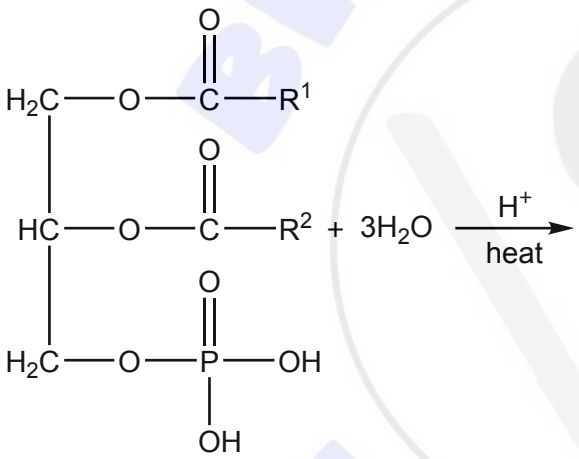
7. Phospholipids are a main component of cell membranes.

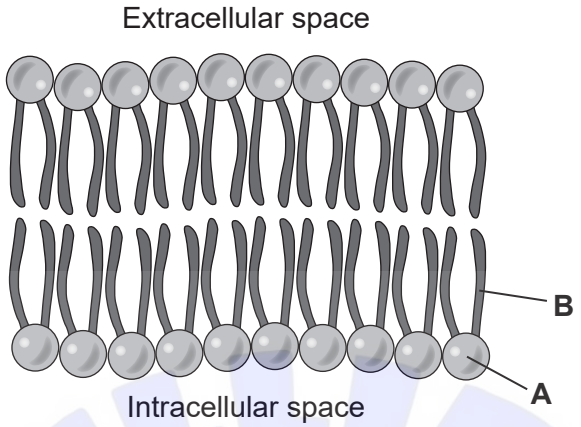
(a) Deduce the products of the hydrolysis of a non-substituted phospholipid, where R^1 and R^2 represent long alkyl chains. [2]



(Option B continues on the following page)

(Option B, question 7 continued)

(b) (i) A representation of a phospholipid bilayer cell membrane is shown:



Identify the components of the phospholipid labelled **A** and **B**. [1]

A:

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B:

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(ii) State the most significant intermolecular forces in the phospholipid in b(i). [2]

Forces occurring between components labelled **A**:

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Forces occurring between components labelled **B**:

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(Option B continues on the following page)

(Option B, question 7 continued)

(c) Phospholipids help maintain cellular environments while fatty acid lipids have important roles in energy storage and electrical insulation. Discuss the structural properties of saturated fats needed for these roles. [2]

Energy storage:

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Electrical insulator:

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8. The diverse functions of biological molecules depend on their structure and shape.

(a) Classify vitamins A, C and D as either mainly fat- or water-soluble, using section 35 of the data booklet. [1]

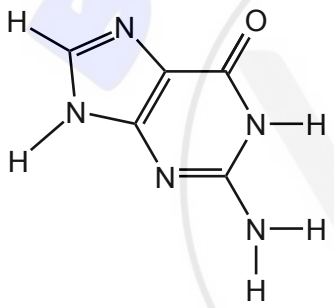
Vitamin	Soluble in
A	. . . . .
C	. . . . .
D	. . . . .

(Option B continues on the following page)

(Option B, question 8 continued)

(b) (i) Deduce the straight chain structure of deoxyribose from its ring structure drawn in section 34 of the data booklet. [1]

(ii) Draw the nitrogenous base that is paired with guanine in DNA, showing the hydrogen bonds between the bases. Use section 34 of the data booklet. [2]



Guanine

(c) Retinal is the key molecule involved in vision. Explain the roles of *cis*- and *trans*-retinal in vision and how the isomers are formed in the visual cycle. [3]

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(Option B continues on page 21)

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will not be marked.

(Option B continued)

9. Biomagnification factor, BMF, can be defined as the concentration of a chemical, X, in a predator, relative to the concentration found in its prey.

$$BMF = \frac{[X]_{predator}}{[X]_{prey}}$$, where [X] = (μg X per kg body weight)

(a) Calculate the BMF if a 120 kg shark consumes 1000 mackerel in **one** year. Each mackerel weighs 1 kg on average. The $[X]_{mackerel}$ = 0.3 μg X per kg body weight. Assume chemical X remains in the shark's body for **two** years. [2]

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(b) Suggest, with a reason, if fat-soluble or water-soluble xenobiotics would have a larger BMF. [1]

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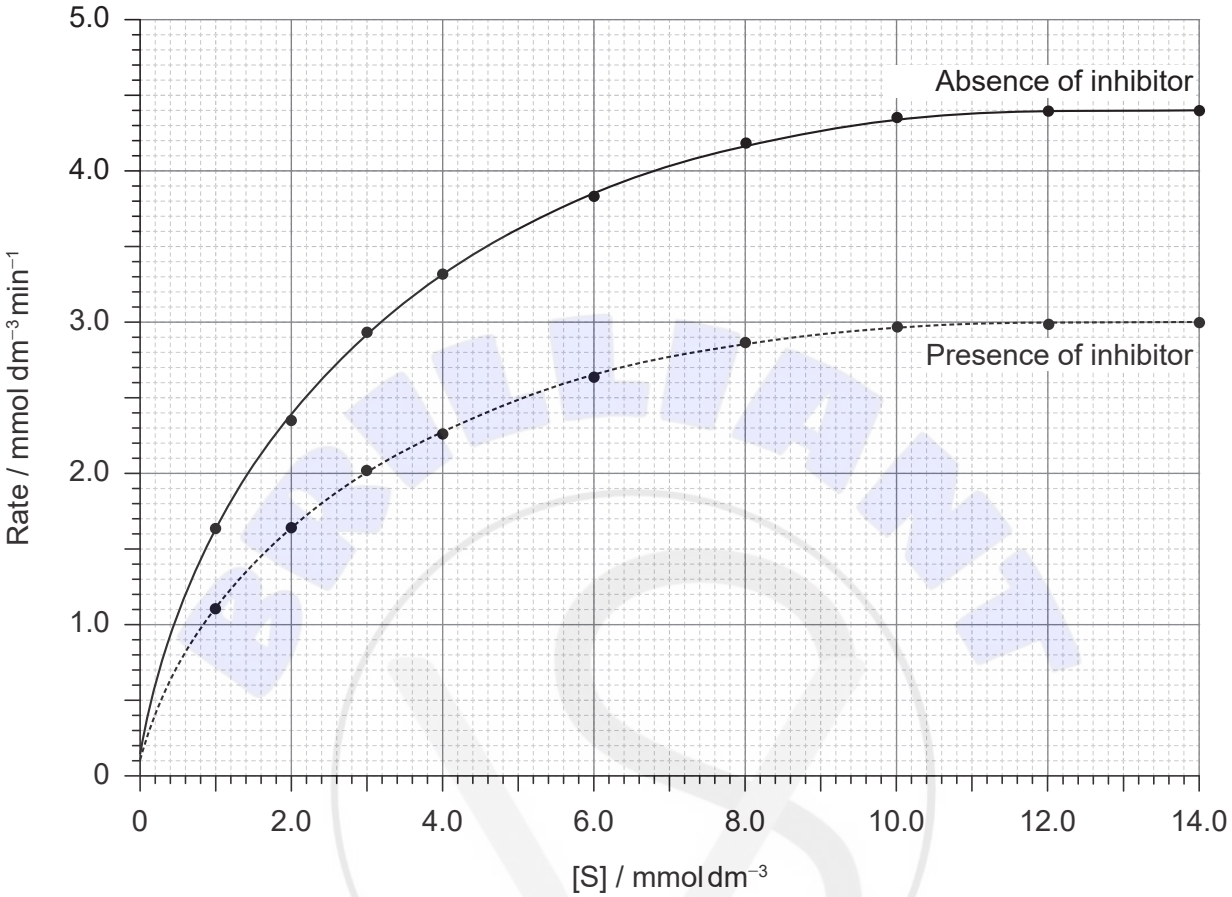
(Option B continues on the following page)

(Option B continued)

10. The kinetics of an enzyme-catalysed reaction are studied in the absence and presence of an inhibitor. The graph represents the initial rate as a function of substrate concentration.



(a) Identify the type of inhibition shown in the graph. [1]

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(Option B continues on the following page)

(Option B, question 10 continued)

(b) (i) Determine the value of V_{max} and K_m in the absence and presence of the inhibitor. [3]

	V_{max}	K_m
Absence of the inhibitor	. . . .	. . . .
Presence of the inhibitor	. . . .	. . . .

(ii) Outline the significance of the value of the Michaelis constant, K_m. [1]

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End of Option B

Option C — Energy

11. Gasoline (petrol), biodiesel and ethanol are fuels.

	Gasoline (petrol)	**Biodiesel**	**Ethanol**
Chemical structure	Mainly hydrocarbons of chain length C_4–C_{12}	Methyl esters of fatty acids of chain lengths C_{12}–C_{22}	CH_3CH_2OH
Energy density / kJ dm^{-3}	31 800	33 400	21 200

(a) Calculate the energy released, in kJ, from the complete combustion of 5.00 dm^3 of ethanol. [1]

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(b) State a class of organic compounds found in gasoline. [1]

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(c) Outline the advantages and disadvantages of using biodiesel instead of gasoline as fuel for a car. Exclude any discussion of cost. [4]

Advantages:

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Disadvantages:

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(Option C continues on the following page)

(Option C, question 11 continued)

(d) A mixture of gasoline and ethanol is often used as a fuel. Suggest an advantage of such a mixture over the use of pure gasoline. Exclude any discussion of cost. [1]

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(e) (i) When combusted, all three fuels can release carbon dioxide, a greenhouse gas, as well as particulates. Contrast how carbon dioxide and particulates interact with sunlight. [1]

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(ii) Methane is another greenhouse gas. Contrast the reasons why methane and carbon dioxide are considered significant greenhouse gases. [2]

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(iii) Suggest a wavenumber absorbed by methane gas. [1]

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(Option C continues on the following page)

(Option C, question 11 continued)

(iv) Determine the relative rate of effusion of methane ($M_r = 16.05$) to carbon dioxide ($M_r = 44.01$), under the same conditions of temperature and pressure. Use section 1 of the data booklet. [1]

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12. 1.57 % of the mass of a rock weighing 46.5 kg is uranium(IV) oxide, UO_2. 99.28 % of the uranium atoms in the rock are uranium-238, ^{238}U.

(a) Show that the mass of the ^{238}U isotope in the rock is 0.639 kg. [2]

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(b) The half-life of ^{238}U is 4.46×10^9 years. Calculate the mass of ^{238}U that remains after 0.639 kg has decayed for 2.23×10^{10} years. [2]

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(c) Outline a health risk produced by exposure to radioactive decay. [1]

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(Option C continues on the following page)

(Option C, question 12 continued)

(d) Deduce the nuclear equation for the decay of uranium-238 to thorium-234. [1]

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(e) Thorium-234 has a higher binding energy per nucleon than uranium-238. Outline what is meant by the binding energy of a nucleus. [1]

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(f) Determine the nuclear binding energy, in J, of ^{238}U using sections 2 and 4 of the data booklet.

The mass of the ^{238}U nucleus is 238.050786 amu. [3]

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(Option C continues on the following page)

(Option C continued)

13. A voltaic cell is made up of nickel and magnesium half-cells.

$$Mg\ (s)\ |\ Mg^{2+}(aq)\ |\ |\ Ni^{2+}(aq)\ |\ Ni\ (s)$$

(a) Write the balanced equation for the reaction in this voltaic cell. [1]

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(b) Calculate the cell potential for $0.0100\,mol\,dm^{-3}$ $Mg^{2+}(aq)$ and $0.800\,mol\,dm^{-3}$ $Ni^{2+}(aq)$ at 298 K. Use sections 1, 2 and 24 of the data booklet. [3]

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(c) Predict, giving a reason, how an increase in temperature affects the potential of this cell. [1]

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(Option C continues on the following page)

(Option C continued)

14. Doping of silicon increases the conductivity in semiconductors.

(a) Describe the doping in p-type and n-type semiconductors. [2]

p-type:

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n-type:

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(b) Explain how doping improves the conductivity of silicon. [1]

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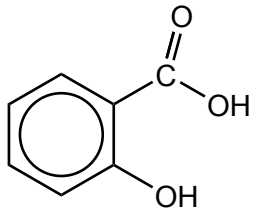
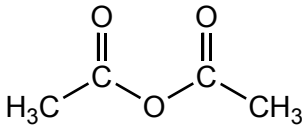
End of Option C

Option D — Medicinal chemistry

15. Aspirin is formed by reacting salicylic acid with ethanoic anhydride. The structure of aspirin is given in section 37 of the data booklet.



Salicylic acid



Ethanoic anhydride

(a) Deduce the structural formula of the by-product of this reaction. [1]

(b) Aspirin crystals are rinsed with water after recrystallization to remove impurities. Suggest why **cold** water is used. [1]

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(c) The solubility of aspirin is increased by converting it to an ionic form. Draw the structure of the ionic form of aspirin. [1]

(Option D continues on the following page)

(Option D, question 15 continued)

(d) Comment on the risk of overdose when taking aspirin as an analgesic, referring to the following values, for a person weighing 70 kg:

Minimum therapeutic dose = 0.5 g

Estimated minimum lethal dose = 15 g [1]

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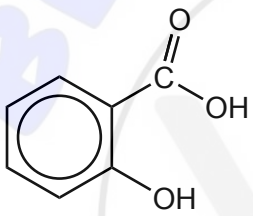
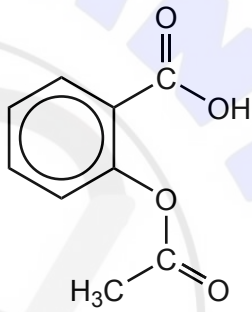
(e) Explain how IR spectroscopy can be used to distinguish aspirin from salicylic acid. [2]



Salicylic acid



Aspirin

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(Option D continues on the following page)

(Option D continued)

16. Consider the following antacids:

	Antacid X	**Antacid Y**
Active substance	Magnesium hydroxide ($M_r = 58.32$)	Calcium carbonate ($M_r = 100.09$)
Mass of active substance in tablet / g	0.200	0.220

Show that antacid **X** is more effective, per tablet, than antacid **Y**. [3]

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17. Technetium-99m is the most commonly used isotope for diagnostic medicine.

(a) State the type of radiation technetium-99m emits. [1]

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(b) Discuss the properties that make a radioisotope suitable for **diagnosis**. [3]

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(Option D continues on the following page)

(Option D, question 17 continued)

(c) Describe the proper disposal of low-level radioactive waste in hospitals. [2]

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(d) Technetium-99m has a half-life of 6.03 hours. Calculate the amount of 1.00×10^{-11} mol of technetium-99m remaining after 48.0 hours. [2]

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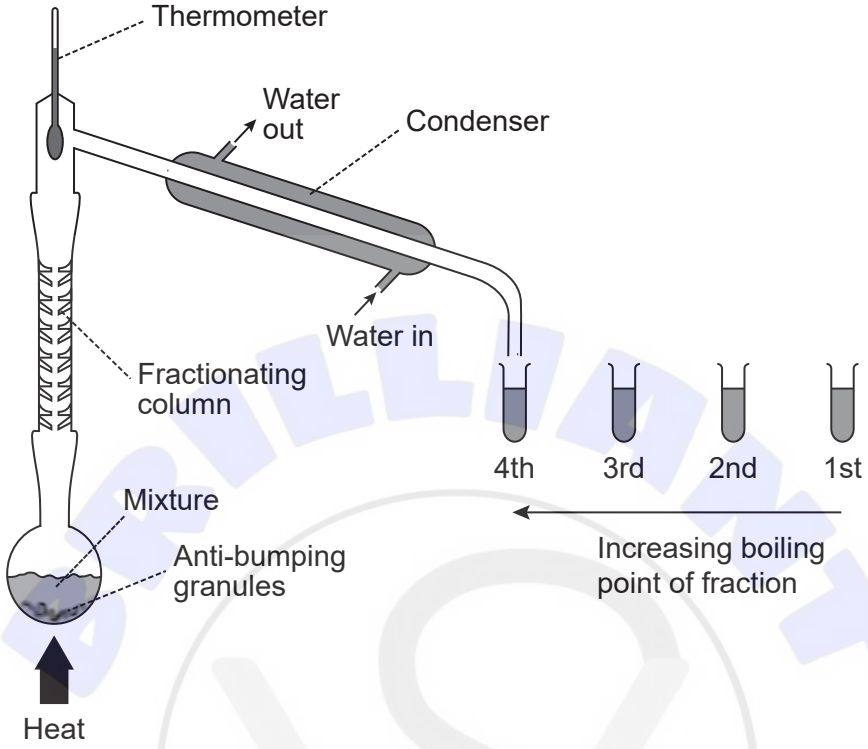
(Option D continues on the following page)

(Option D continued)

18. A mixture of 0.100 mol ethanal, 0.100 mol ethanol and 0.200 mol ethanoic acid is fractionally distilled.



(a) (i) Calculate the mole fraction of ethanal in the mixture. [1]

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(ii) The vapour pressure of pure ethanal at 20 °C is 101 kPa.

Calculate the vapour pressure of ethanal above the liquid mixture at 20 °C. [1]

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(Option D continues on the following page)

(Option D, question 18 continued)

(b) Describe how this mixture is separated by fractional distillation. [2]

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19. Consider the structures of medicinal molecules in section 37 of the data booklet.

(a) Explain how zanamivir works as a preventative agent against flu viruses. [2]

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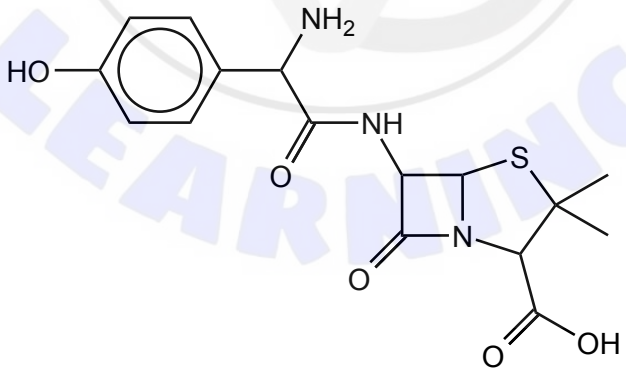
(b) (i) Circle the side-chain in penicillin on the structure below. [1]



(Option D continues on the following page)

(Option D, question 19 continued)

(ii) Explain, with reference to the action of penicillin, why new penicillins with different side-chains need to be produced. [2]

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(c) (i) State and explain the relative solubility of codeine in water compared to morphine and diamorphine. [2]

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(ii) State the natural source from which codeine, morphine and diamorphine are obtained. [1]

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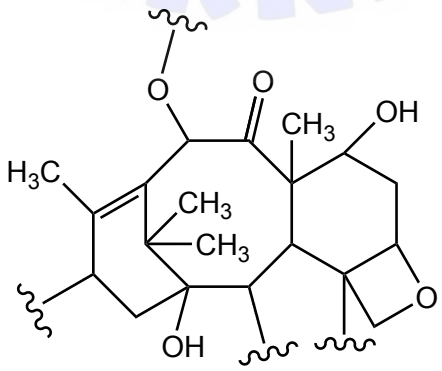
(d) Circle **two** chiral carbons in the section of the Taxol structure below. [1]



References:

2. © International Baccalaureate Organization 2020.

4.(c)(ii) © International Baccalaureate Organization 2020.

6.(a)(i) © International Baccalaureate Organization 2020.

7.(b)(i) © International Baccalaureate Organization 2020.

9. Franklin, J., 2015. *How reliable are field-derived biomagnification factors and trophic magnification factors as indicators of bioaccumulation potential? Conclusions from a case study on per- and polyfluoroalkyl substances.* Available at: https://setac.onlinelibrary.wiley.com/doi/full/10.1002/ieam.1642.

11. U.S. Department of Energy. https://afdc.energy.gov/.

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