Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Thursday 23 May 2019 (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 – 7
Option B — Biochemistry	8 – 14
Option C — Energy	15 – 18
Option D — Medicinal chemistry	19 – 25

2219 – 6109

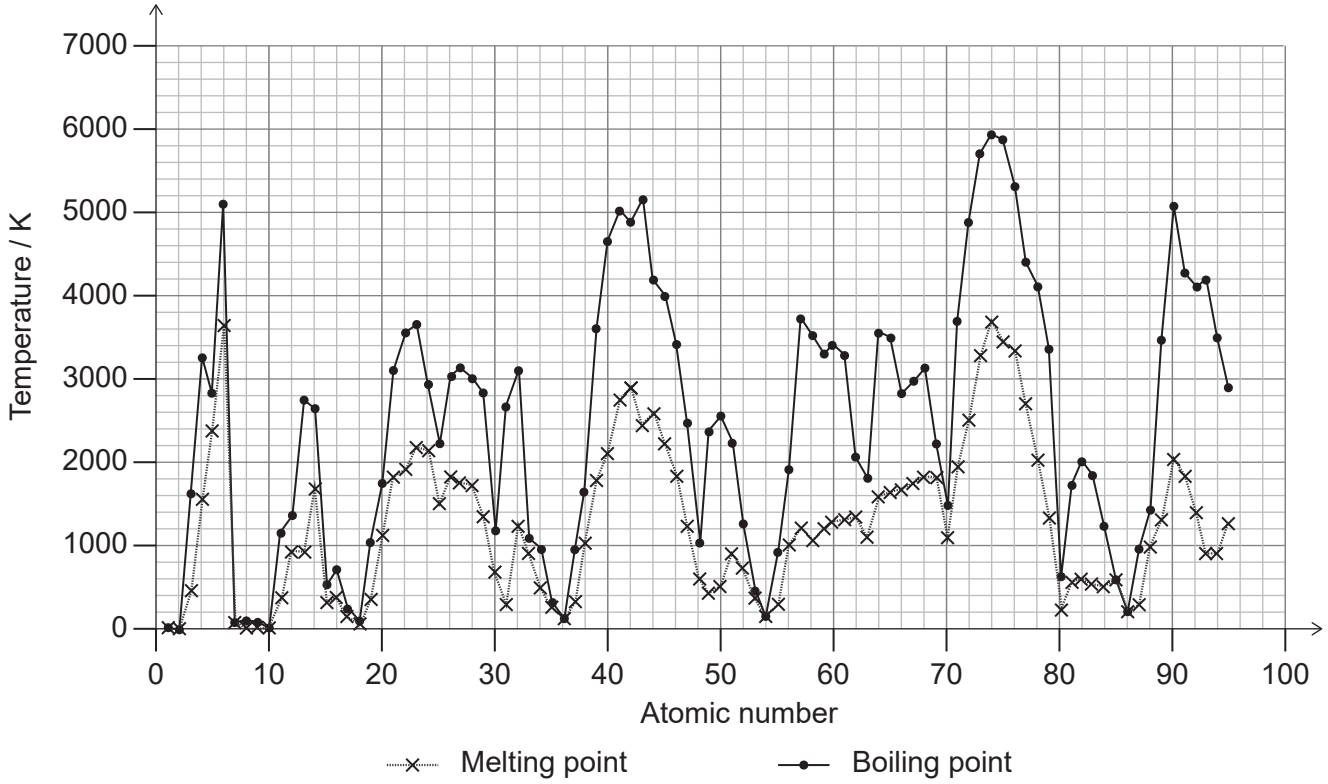
38 pages

Section A

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

1. Physical properties of elements vary according to atomic number. Sections 6 to 9 of the data booklet list some of these properties.

Melting points and boiling points of elements 1 to 95



[Source: www.mrbigler.com/documents/Periodic-Table.xls, used with the kind permission of Jeff Bigler]

(a) Deduce, giving a reason, the group of elements in the periodic table most likely to undergo sublimation. [2]

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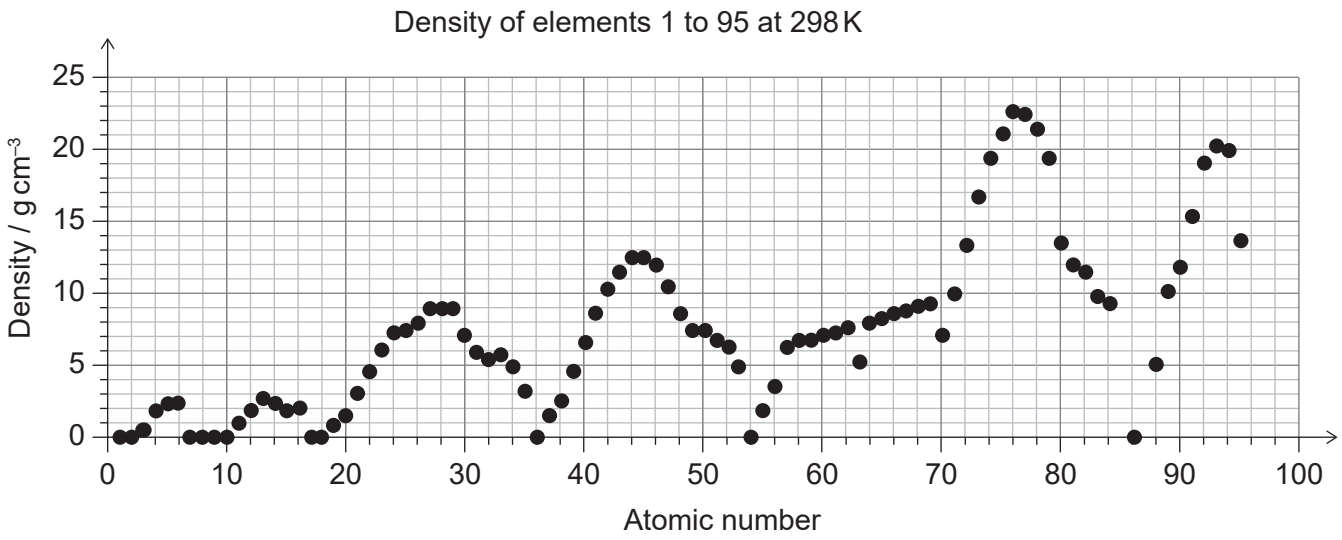
(Question 1 continued)

(b) (i) Describe the density trend across periods 4 and 5 of the periodic table. [1]



[Source: © International Baccalaureate Organization 2019]

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(ii) Suggest, with a reason, whether the lanthanoids or actinoids of the f-block would have the higher density. [1]

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(iii) Compare the ease of oxidation of s-block and d-block metals to their melting points **and** densities. Use section 25 of the data booklet. [2]

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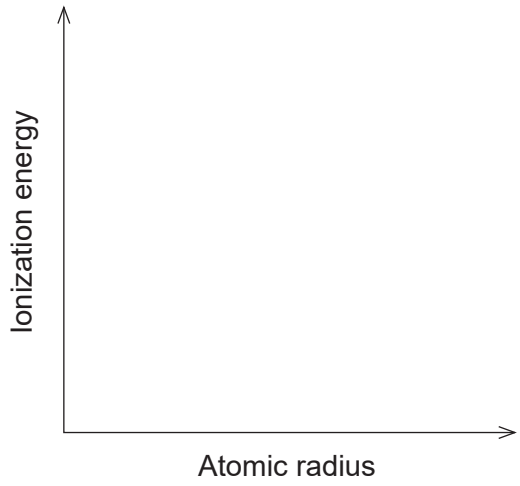
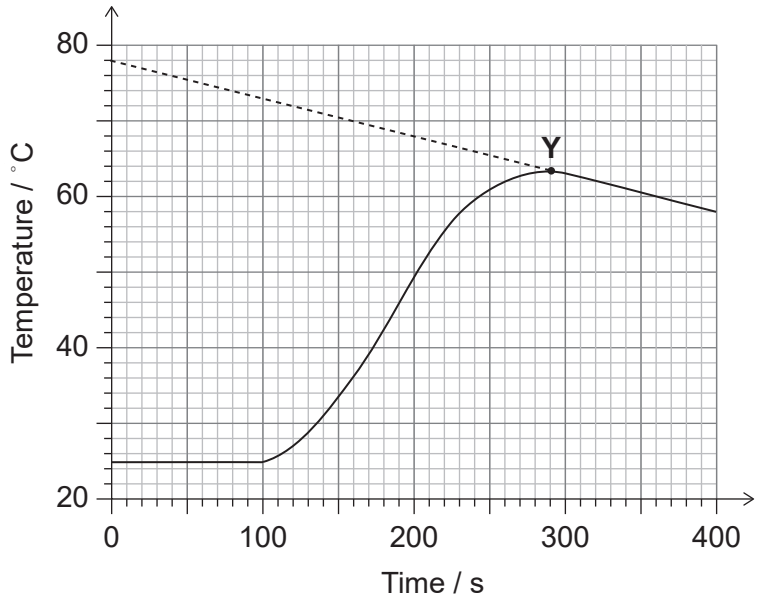
(Question 1 continued)

(iv) Sketch how the first ionization energies of elements vary with their atomic radius. [1]



2. Powdered zinc was reacted with 25.00 cm^3 of 1.000 mol dm^{-3} copper(II) sulfate solution in an insulated beaker. Temperature was plotted against time.



[Source: © International Baccalaureate Organization 2019]

(a) (i) Estimate the time at which the powdered zinc was placed in the beaker. [1]

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(This question continues on the following page)

(Question 2 continued)

(ii) State what point **Y** on the graph represents. [1]

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(b) (i) The maximum temperature used to calculate the enthalpy of reaction was chosen at a point on the extrapolated (dotted) line.

State the maximum temperature which should be used and outline **one** assumption made in choosing this temperature on the extrapolated line. [2]

Maximum temperature:

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Assumption:

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(ii) To determine the enthalpy of reaction the experiment was carried out five times. The same volume and concentration of copper(II) sulfate was used but the mass of zinc was different each time. Suggest, with a reason, if zinc or copper(II) sulfate should be in excess for each trial. [1]

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(This question continues on the following page)

(Question 2 continued)

(iii) The formula $q = mc\Delta T$ was used to calculate the energy released. The values used in the calculation were $m = 25.00\,g$, $c = 4.18\,J\,g^{-1}\,K^{-1}$.

State an assumption made when using these values for *m* and *c*. [2]

Value	Assumption
$m = 25.00\,g$	. . . .
$c = 4.18\,J\,g^{-1}\,K^{-1}$	. . . .

(iv) Predict, giving a reason, how the final enthalpy of reaction calculated from this experiment would compare with the theoretical value. [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. Lithium has many uses.

(a) Identify the type of bonding in lithium hydride, using sections 8 and 29 of the data booklet. [1]

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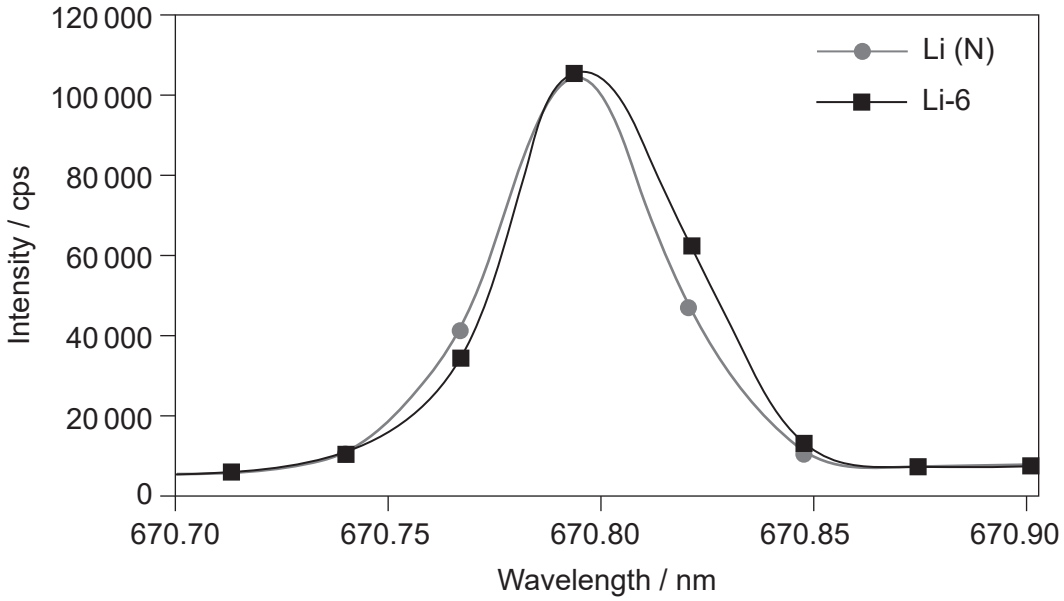
(b) The emission spectra obtained by ICP-OES for a mixture containing the isotope ^{6}Li (Li-6) and naturally occurring lithium (Li (N)) is shown.



[Source: *J. Anal. At. Spectrom.*, 2015, **30**, 2003–2009, https://doi.org/10.1039/C5JA00181A – Reproduced by permission of The Royal Society of Chemistry. https://pubs.rsc.org/en/content/articlelanding/2015/JA/C5JA00181A#!divAbstract]

(i) Identify the colour of the emission spectrum of lithium using section 17 of the data booklet. [1]

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(Option A continues on the following page)

(Option A, question 3 continued)

(ii) Suggest why ICP-OES does not give good quantitative results for distinguishing ^{6}Li from naturally occurring lithium. [1]

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(iii) Suggest a better method. [1]

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(c) Lithium is obtained by electrolysis of molten lithium chloride. Calculate the time, in seconds, taken to deposit 0.694 g Li using a current of 2.00 A.

$$Q \text{ (charge)} = I \text{ (current)} \times t \text{ (time)}$$ [2]

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(d) (i) Lithium has shown some superconductive properties when doped into graphene or when under high pressure. Under high pressure, however, the Meissner effect is absent.

Describe the Meissner effect. [1]

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(Option A continues on the following page)

(Option A, question 3 continued)

(ii) At very low temperatures, lithium atoms enhance the phonon binding of electrons in graphene suggesting the formation of Cooper pairs.

Explain how Cooper pairs are formed. [3]

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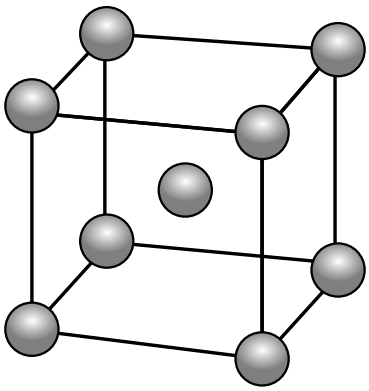
(e) Lithium forms a crystalline lattice with the unit cell structure shown below.



X-ray diffraction shows that the length of the edge of the unit cell is 3.51×10^{-8} cm.

Determine the density of lithium, in g cm^{-3}, using sections 2 and 6 of the data booklet. [3]

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(Option A continues on the following page)

(Option A continued)

4. Polybutadiene, used in truck tyres, is a polymer of buta-1,3-diene. The spatial arrangement of atoms in the polymer depends on the type of catalyst used.

(a) Outline **two** differences between heterogeneous and homogeneous catalysts. [2]

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(b) Suggest, giving a reason, how elastomers used for the tyre tread can increase the traction between the tyre and the road. [2]

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(c) Tyre fires emit trace quantities of polychlorinated dibenzofurans and polychlorinated dibenzo-*p*-dioxin.

Outline, using section 31 of the data booklet, why polychlorinated dibenzofuran is not classed chemically as a dioxin but considered “dioxin-like”. [2]

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(Option A continues on the following page)

(Option A, question 4 continued)

(d) Classify polybutadiene as either an addition or condensation polymer, giving a reason. [1]

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(e) State **one** factor considered when making green chemistry polymers. [1]

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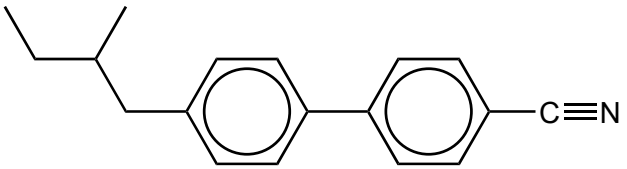
5. Liquid-crystal displays (LCDs) have many uses.

A molecule which acts as a chiral nematic thermotropic liquid-crystal is given.



(a) Label with an asterisk, *, the chiral carbon atom. [1]

(b) Explain the effects of very low and high temperatures on the liquid-crystal behaviour of this molecule. [2]

Low temperature:

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High temperature:

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(Option A continues on the following page)

(Option A continued)

6. Nanotechnology has allowed the manipulation of materials on the atomic level.

(a) Describe the structure and bonding of a carbon nanotube. [2]

Structure:

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Bonding:

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(b) Suggest **one** application for carbon nanotubes. [1]

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7. EDTA chelates with $Ni^{2+}(aq)$.

$$[Ni(H_2O)_6]^{2+}(aq) + EDTA^{4-}(aq) \rightleftharpoons [Ni(EDTA)]^{2-}(aq) + 6H_2O(l)$$

(a) Explain how entropy affects this equilibrium. [2]

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(b) State the number of coordinate covalent bonds EDTA forms with Ni^{2+}. [1]

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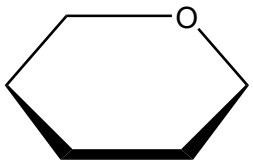
End of Option A

Option B — Biochemistry

8. Starch is a natural polymer of glucose.

(a) Draw the structure of the repeating unit of starch and state the type of linkage formed between these units. [2]



Type of linkage:

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(b) Formulate the equation for the complete hydrolysis of a starch molecule, $(C_6H_{10}O_5)_n$. [1]

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(c) Calculate the energy released, in $kJ\,g^{-1}$, when 3.49 g of starch are completely combusted in a calorimeter, increasing the temperature of 975 g of water from 21.0 °C to 36.0 °C. Use section 1 of the data booklet. [2]

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(Option B continues on the following page)

(Option B, question 8 continued)

(d) Explain how the inclusion of starch in plastics makes them biodegradable. [2]

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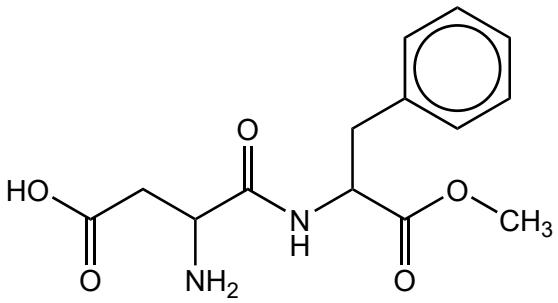
9. Aspartame is a derivative of a dipeptide formed between two amino acids, phenylalanine (Phe) and aspartic acid (Asp).

(a) Draw a circle around the functional group formed between the amino acids and state its name. [2]



Name:

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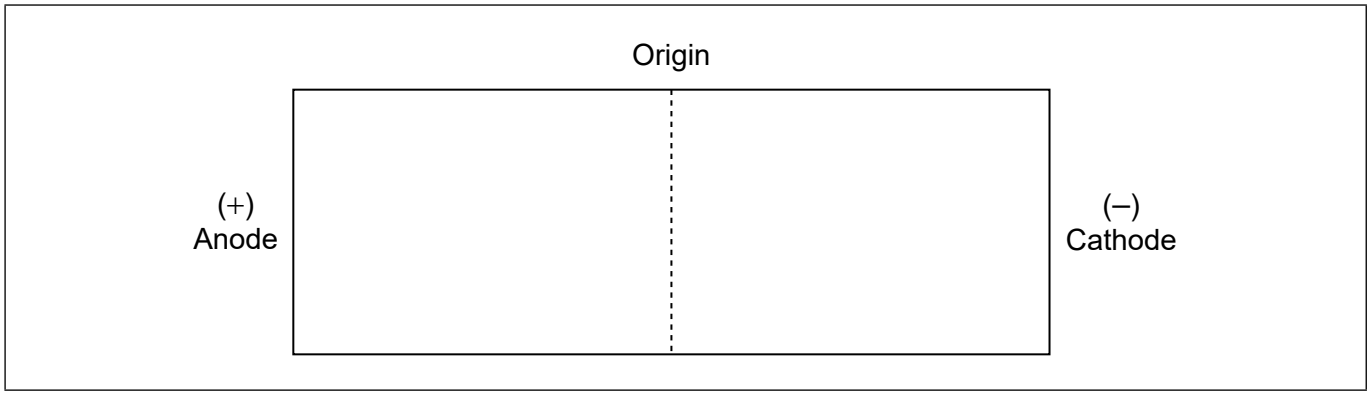
(Option B continues on the following page)

(Option B, question 9 continued)

(b) A mixture of phenylalanine and aspartic acid is separated by gel electrophoresis with a buffer of pH = 5.5.

Deduce their relative positions after electrophoresis, annotating them on the diagram. Use section 33 of the data booklet. [2]



(c) Aspartic acid is obtained synthetically as a racemic mixture. Draw the three-dimensional shape of each isomer showing their spatial relationship to each other. Use section 33 of the data booklet. [1]

(Option B continues on page 17)

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

Answers written on this page
will not be marked.

(Option B continued)

10. The main fatty acid composition of cocoa butter and coconut oil is detailed below.

Source	**Saturated fatty acids / %**						**Mono-unsaturated / %**	**Poly-unsaturated / %**
	Octanoic ($C_8H_{16}O_2$)	Lauric ($C_{12}H_{24}O_2$)	Myristic ($C_{14}H_{28}O_2$)	Palmitic ($C_{16}H_{32}O_2$)	Stearic ($C_{18}H_{36}O_2$)	Others	Oleic ($C_{18}H_{34}O_2$)	Total
Cocoa butter	0.0	0.0	0.1	26.9	35.2	0.0	34.6	3.3
Coconut oil	7.5	46.2	18.4	9.4	2.8	6.8	7.0	1.9

[Source: U.S. Department of Agriculture, Agricultural Research Service. FoodData Central, 2019. fdc.nal.usda.gov.]

(a) The melting points of cocoa butter and coconut oil are 34 °C and 25 °C respectively.

Explain this in terms of their saturated fatty acid composition. [3]

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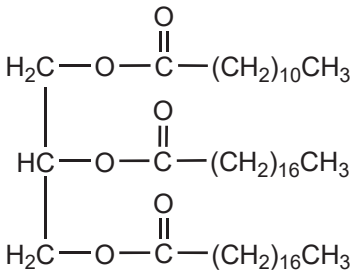
(b) Fats contain triglycerides that are esters of glycerol and fatty acids. Deduce an equation for the acid hydrolysis of the following triglyceride. [2]



(Option B continues on the following page)

(Option B, question 10 continued)

(c) The addition of partially hydrogenated cocoa butter to chocolate increases its melting point and the content of *trans*-fatty acids (*trans*-fats).

Outline **one** effect of *trans*-fatty acids on health. [1]

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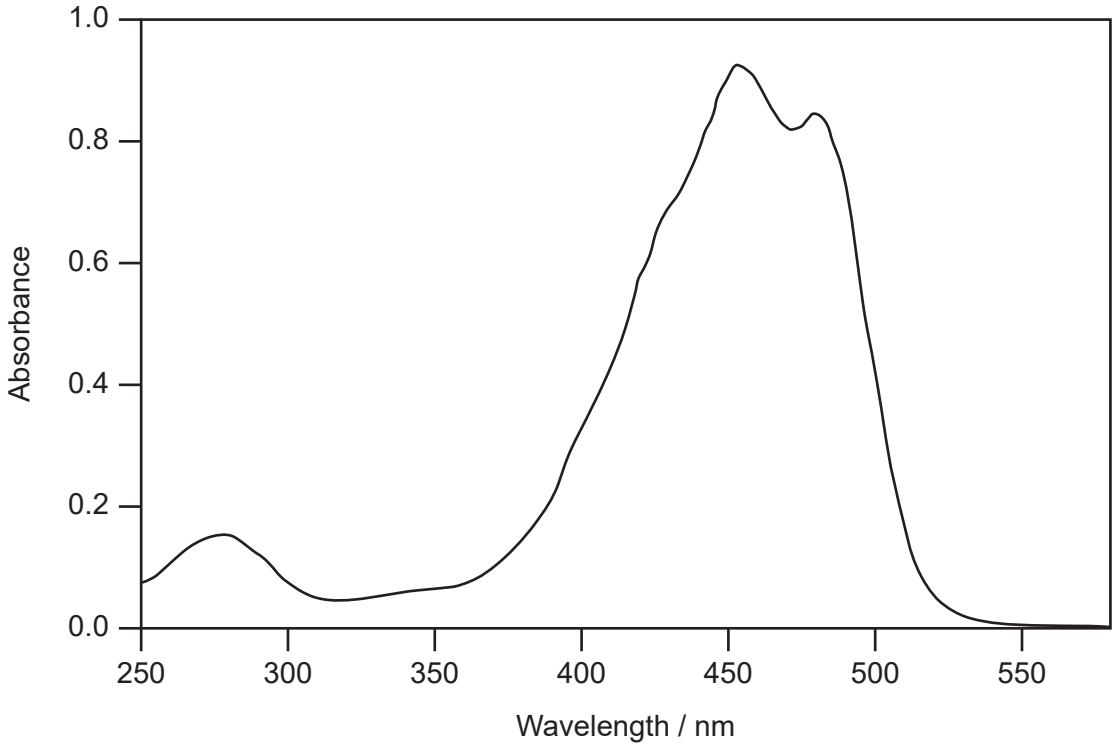
11. Carotenoids are pigments found in leaves.

(a) The absorption spectrum of β-carotene is shown below.



[Source: The plot was created by Takaichi Shinichi]

Explain its colour in terms of its absorption bands. Use section 17 of the data booklet. [2]

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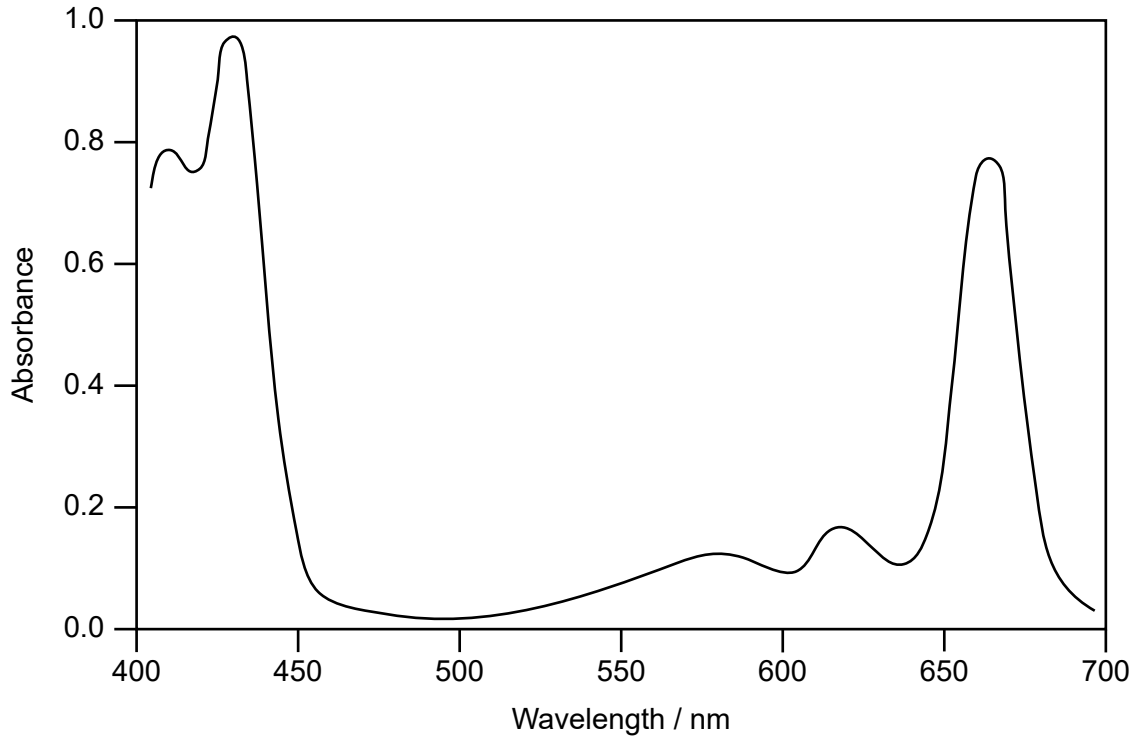
(Option B continues on the following page)

(Option B, question 11 continued)

(b) The absorption spectrum of chlorophyll *a* is shown below.



Suggest how the combination of chlorophyll *a* and carotenoids is beneficial for photosynthesis. [1]

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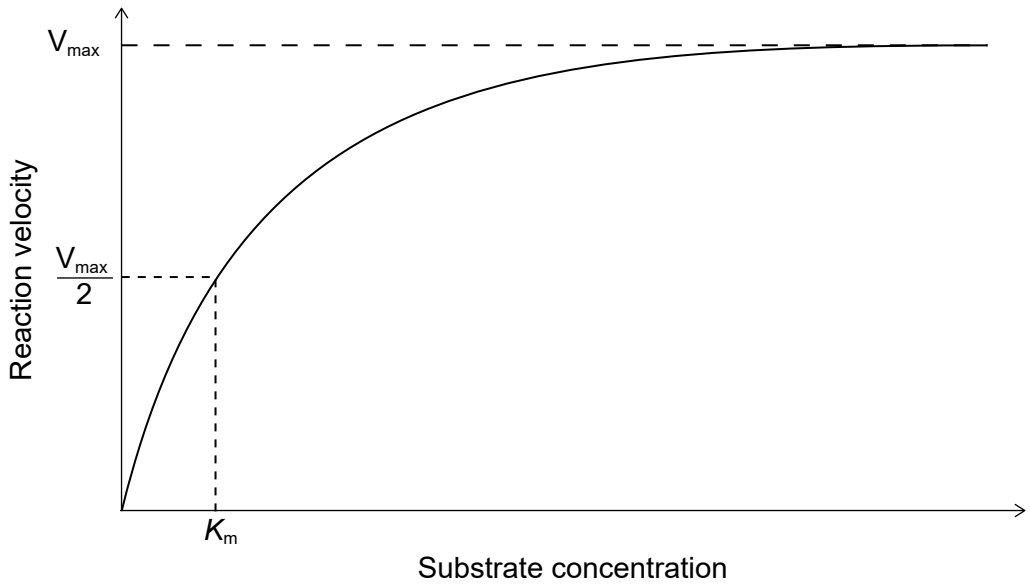
(Option B continues on the following page)

(Option B continued)

12. Alcohol dehydrogenase (ADH) catalyses the oxidation of methanol. The products of oxidation, methanal and methanoic acid, are toxic.

(a) (i) A Michaelis–Menten plot for an enzyme-catalysed reaction is shown.

Sketch a curve to show the effect of a competitive inhibitor. [1]



(ii) Suggest, based on the Michaelis–Menten plot, how a competitive inhibitor such as ethanol reduces the toxicity of methanol. [2]

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(Option B continues on the following page)

(Option B, question 12 continued)

(b) Enzymatic activity is studied in buffered aqueous solutions.

Calculate the ratio in which 0.1 mol dm^{-3} NaH_2PO_4(aq) and 0.1 mol dm^{-3} Na_2HPO_4(aq) should be mixed to obtain a buffer with pH = 6.10. Use section 1 of the data booklet.

pK_a (NaH_2PO_4) = 7.20 [2]

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13. Ascorbic acid and retinol are two important vitamins.

Explain why ascorbic acid is soluble in water and retinol is not. Use section 35 of the data booklet. [2]

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(Option B continues on the following page)

(Option B continued)

14. New genetically modified organisms (GMO), especially plants, are continually being developed in research laboratories.

(a) Outline what is meant by genetically modified organisms. [1]

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(b) Outline **one** benefit of the use of these products. [1]

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End of Option B

Option C — Energy

15. Natural gas is an energy source composed mainly of methane.

(a) Calculate the specific energy of methane, in MJ kg^{-1}, using sections 1, 6 and 13 of the data booklet. [1]

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(b) Natural gas is burned to produce steam which turns turbines in an electricity generating power plant.

The efficiency of several sources for power plants is given below.

Type of power plant	Maximum efficiency
Natural gas	up to 58 %
Coal	up to 47 %
Nuclear	up to 36 %
Hydroelectric	up to 95 %

[Source: Eurelectric]

(i) Calculate the maximum electric energy output, in MJ, which can be obtained from burning 1.00 kg of methane by using your answer from (a). [1]

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(Option C continues on the following page)

(Option C, question 15 continued)

(ii) Hydroelectric power plants produced 16 % of the world's energy in 2015, down from 21 % in 1971.

Suggest why hydroelectric power production has a higher efficiency than the other sources given in (b) and why its relative use has decreased despite the high efficiency. [2]

Reason for higher efficiency:

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Reason for decreased use:

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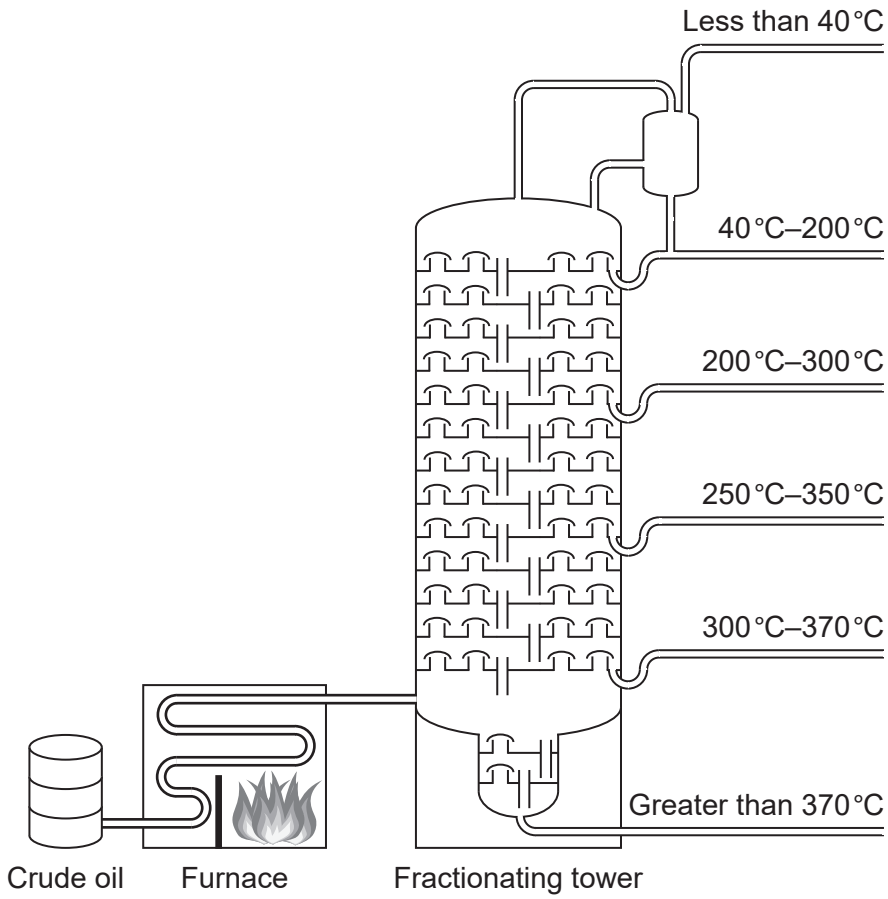
(Option C continues on the following page)

(Option C, question 15 continued)

(c) (i) Methane can also be obtained by fractional distillation of crude oil.



[Source: Image used with kind permission of science-resources.co.uk]

Draw a circle on the diagram to show where the methane fraction is withdrawn. [1]

(ii) List the following products, which are also obtained by fractional distillation, according to **decreasing** volatility: asphalt, diesel, gasoline, lubricating motor oil. [1]

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(Option C continues on the following page)

(Option C, question 15 continued)

(d) (i) Explain how methane absorbs infrared (IR) radiation by referring to its molecular geometry and dipole moment. [3]

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(ii) Compare methane's atmospheric abundance and greenhouse effect to that of carbon dioxide. [1]

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16. Uranium-235, ^{235}U, is bombarded with a neutron causing a fission reaction.

(a) Two products of the fission of ^{235}U are ^{144}Ba and ^{89}Kr.

(i) Write the nuclear equation for this fission reaction. [1]

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(ii) Outline why the reaction releases energy. [1]

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(Option C continues on the following page)

(Option C, question 16 continued)

(iii) The masses of the particles involved in this fission reaction are shown below.

Mass of neutron	=	1.00867 amu
Mass of U-235 nucleus	=	234.99346 amu
Mass of Ba-144 nucleus	=	143.89223 amu
Mass of Kr-89 nucleus	=	88.89788 amu

Determine the energy released, in J, when one uranium-235 nucleus undergoes fission. Use this data and information from sections 1 and 2 of the data booklet. [3]

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(b) The critical mass for weapons-grade uranium can be as small as 15 kg. Outline what is meant by critical mass by referring to the equation in (a)(i). [2]

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(c) The daughter product, ^{89}Kr, has a half-life of 3.15 min.

Calculate the time required, in minutes, for its radioactivity to fall to 10 % of its initial value, using section 1 of the data booklet. [2]

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(Option C continues on the following page)

(Option C continued)

17. E10 is composed of 10 % ethanol and 90 % normal unleaded fuel.

(a) Ethanol has a Research Octane Number (RON) of 108.6.

Outline how higher octane fuels affect engine performance. [1]

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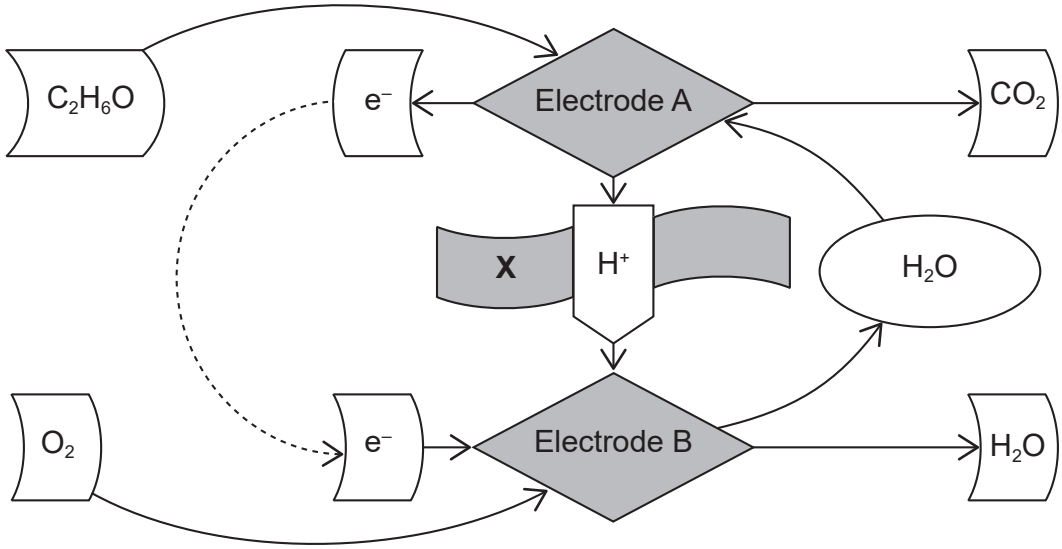
(b) (i) Ethanol can be used in a direct-ethanol fuel cell (DEFC) as illustrated by the flow chart.



[Source: https://commons.wikimedia.org/wiki/File:Direct_Ethanol_Fuel_Cell.svg, by Fordi]

Deduce the half-equations occurring at electrodes A and B. [2]

Electrode A:

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Electrode B:

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(Option C continues on the following page)

(Option C, question 17 continued)

(ii) State the name and function of **X** in the diagram in (b)(i). [2]

Name:

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Function:

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(iii) Outline why aqueous ethanol, rather than pure ethanol, is used in a DEFC. [1]

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(c) Biodiesel containing ethanol can be made from renewable resources.

Suggest **one** environmental disadvantage of producing biodiesel from renewable resources. [1]

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(Option C continues on page 31)

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(Option C continued)

18. This question is about solar cells.

(a) Some solar cells use photovoltaic semi-conductors. Compare, giving reasons, the electrical conductivity of metals and semi-conductors as temperature increases. [3]

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(b) Suggest **one** advantage of a dye-sensitized solar cell (DSSC) over a silicon based photovoltaic cell. [1]

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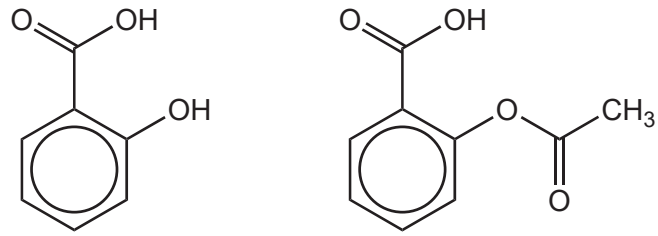
End of Option C

Option D — Medicinal chemistry

19. Aspirin can be obtained from salicylic acid.

(a) Unreacted salicylic acid may be present as an impurity in aspirin and can be detected in the infrared (IR) spectrum.



Salicylic acid Aspirin

Name the functional group and identify the absorption band that differentiates salicylic acid from aspirin. Use section 26 of the data booklet. [2]

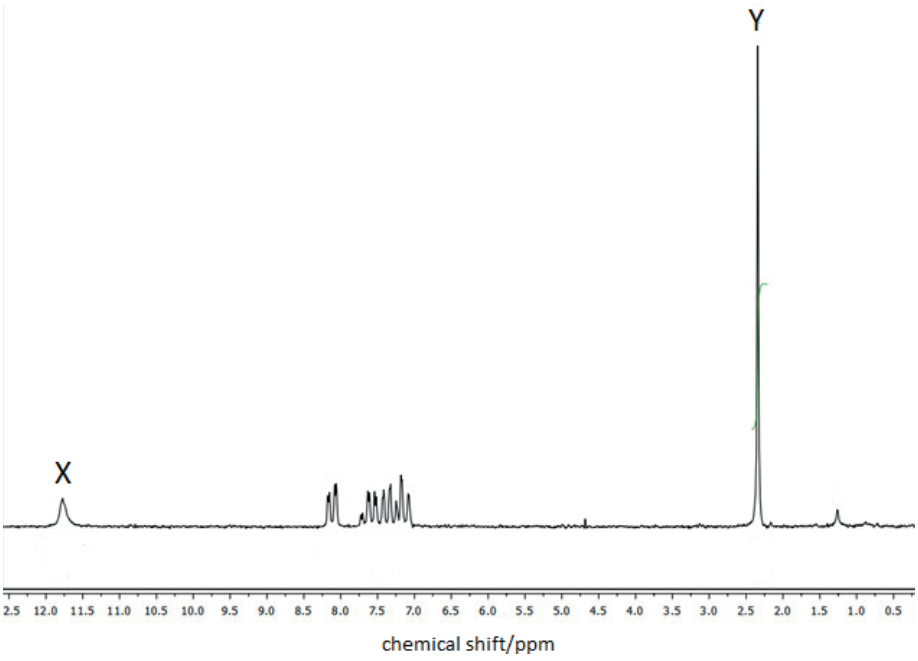
Name:

. . . . . .

Absorption band:

. . . . . .

(b) Additional information can be obtained from the ^{1}H NMR spectrum of aspirin.



[Source: image courtesy of Thermo Fisher Scientific]

(i) Deduce the protons responsible for signals **X** and **Y** by marking them on the structure of aspirin in (a). Use section 27 of the data booklet. [2]

(Option D continues on the following page)

(Option D, question 19 continued)

(ii) Identify the splitting pattern of signals **X** and **Y**. [1]

X:

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Y:

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20. *Staphylococcus aureus* (*S. aureus*) infections have been successfully treated with penicillin and penicillin derivatives.

(a) Identify the feature in penicillin responsible for its antibiotic activity. [1]

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(b) (i) The widespread use of penicillin and its derivatives has led to the appearance of resistant *S. aureus* strains.

Outline how these bacteria inactivate the antibiotics. [1]

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(ii) Outline how the structure of penicillin has been modified to overcome this resistance. [1]

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(Option D continues on the following page)

(Option D continued)

21. Mild heartburn is treated with antacids such as calcium carbonate.

(a) Formulate an equation for the neutralization of stomach acid with calcium carbonate, $CaCO_3(s)$. [1]

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(b) Acid secretion can be regulated by other types of drugs such as omeprazole and ranitidine. Outline how each of these drugs acts to reduce excess stomach acid. [2]

Omeprazole:

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Ranitidine:

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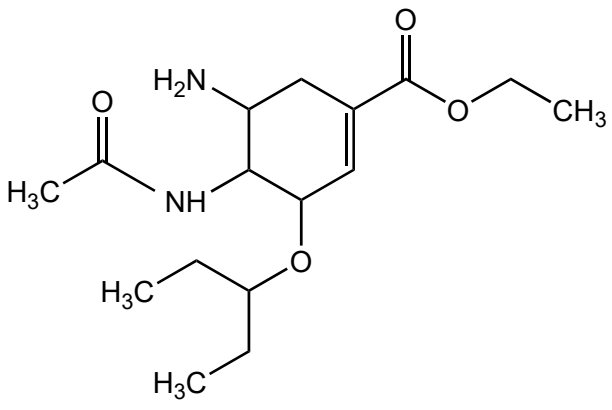
22. This question is about antiviral drugs.

(a) Oseltamivir, used for the treatment of severe flu, is inactive until converted in the liver to its active carboxylate form.

(i) Draw a circle around the functional group that can be converted to the carboxylate by hydrolysis. [1]



(Option D continues on the following page)

(Option D, question 22 continued)

(ii) The resulting active metabolite of oseltamivir can be detected by mass spectrometry (MS) analysis.

Deduce the mass of the expected carboxylate ion.

M_r oseltamivir = 312 [1]

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(b) Suggest a reason for using a phosphate salt of oseltamivir in oral tablets. [1]

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(c) Anti-HIV drugs, such as zidovudine, often become less effective over time.

Explain the development of resistant virus strains in the presence of antiviral drugs. [2]

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(Option D continues on the following page)

(Option D continued)

23. Opium and its derivatives have been used for thousands of years as strong analgesics.

(a) Explain how opiates act to provide pain relief. [2]

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(b) Discuss how the difference in structure of two opiates, codeine and morphine, affect their ability to cross the blood–brain barrier. Use section 37 of the data booklet. [2]

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24. Technetium-99m, a widely used radionuclide, has a half-life of 6.0 hours and undergoes gamma decay to technetium-99.

(a) (i) Determine the percentage of technetium-99m remaining after 24.0 hours. [2]

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(ii) Technetium-99 decays further, emitting beta radiation. Formulate the equation for the decay of technetium-99. [2]

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(Option D continues on the following page)

(Option D, question 24 continued)

(b) Most of the nuclear waste generated in a hospital is low-level waste (LLW).

(i) Outline what is meant by low-level waste. [1]

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(ii) Outline the disposal of LLW. [1]

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(c) Magnetic resonance imaging (MRI) is an application of NMR technology using radiowaves.

Suggest why MRI is much less dangerous than imaging techniques such as X-rays and radiotracers. Use section 3 of the data booklet. [1]

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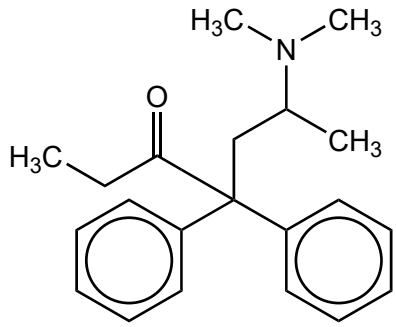
(Option D continues on the following page)

(Option D continued)

25. Methadone is a synthetic opiate administered as a racemic mixture to treat strong pain and morphine or heroin dependence.



(a) Identify the chiral carbon atom using an asterisk, *. [1]

(b) Enantiomers can be identified using a polarimeter. Outline how this instrument differentiates the enantiomers. [2]

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End of Option D

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