Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 3

Thursday 9 November 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 – 3

Section B	Questions
Answer all of the questions from one of the options.	
Option A — Materials	4 – 9
Option B — Biochemistry	10 – 15
Option C — Energy	16 – 20
Option D — Medicinal chemistry	21 – 27

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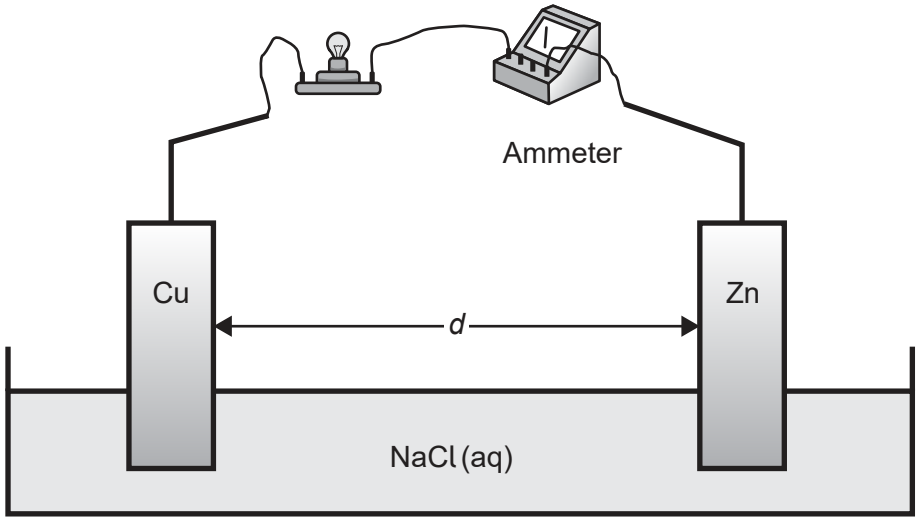
Please **do not** write on this page.

Answers written on this page
will not be marked.

Section A

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

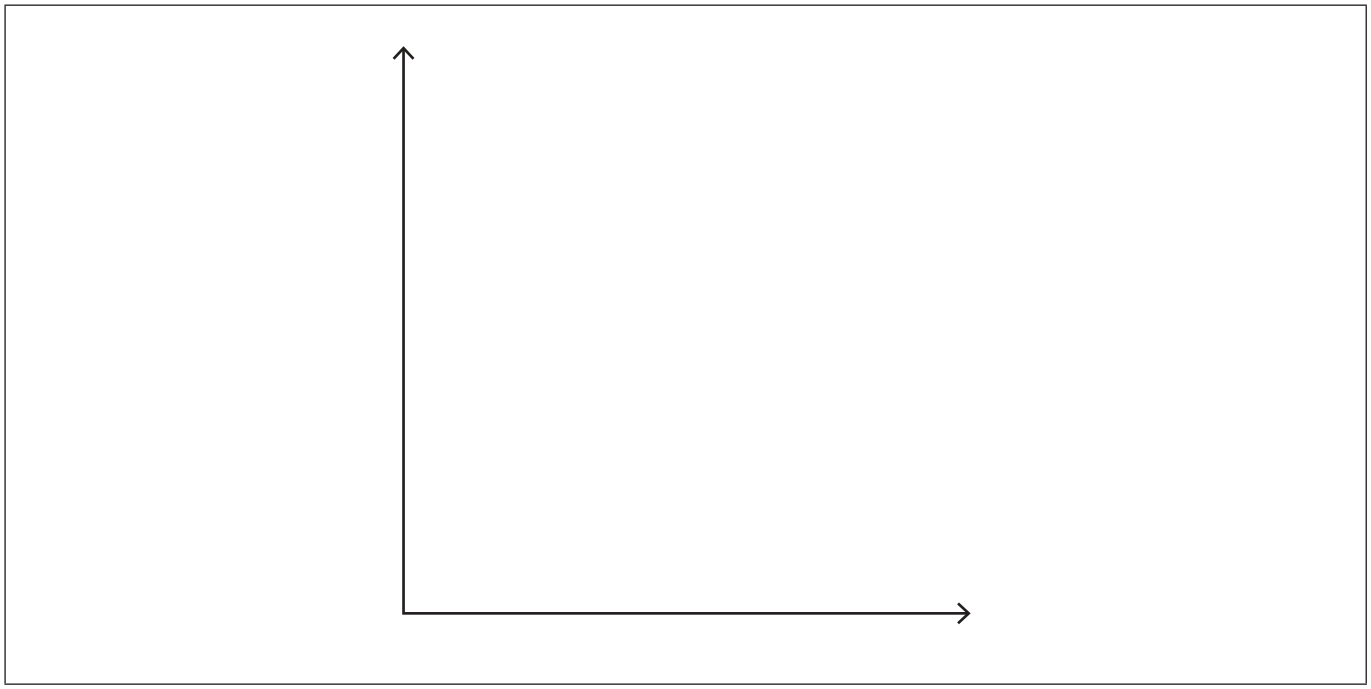
1. A student set up a simple voltaic cell consisting of a copper electrode and a zinc electrode dipped in sodium chloride solution.



The student gradually increased the distance, *d*, between the electrodes to study the effect on the initial current, I, passing through the light bulb.

The student hypothesized that the initial current would be inversely proportional to the distance between the electrodes.

(a) Sketch a graph that would support the student's hypothesis. [1]



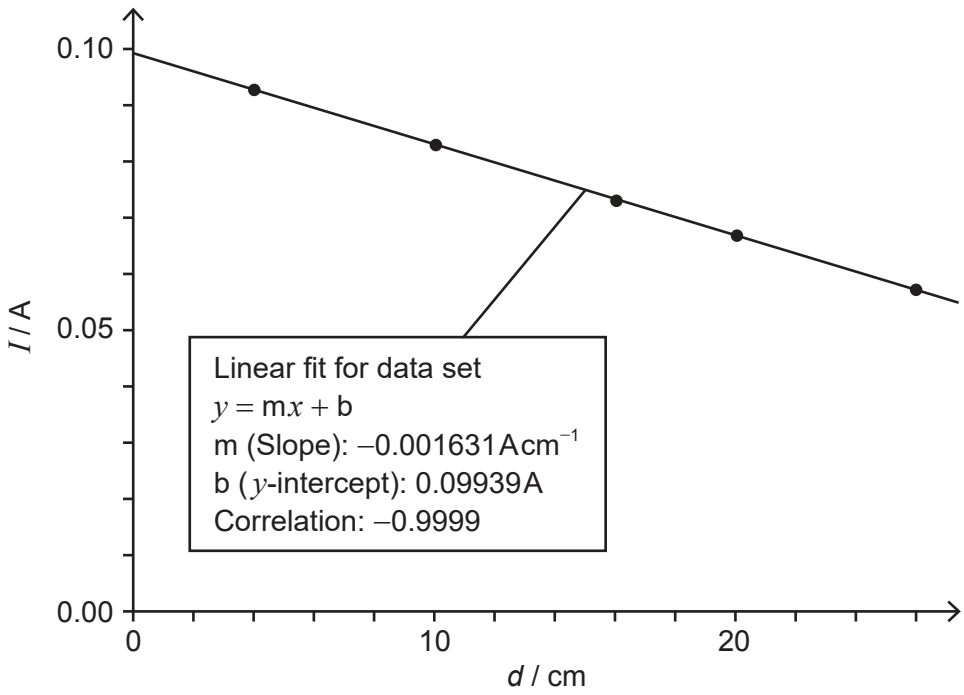
(This question continues on the following page)

(Question 1 continued)

(b) The following data was collected over five trials.

***d* / ±0.1 cm**	**Average I / ±0.04 A**
4.0	0.093
10.0	0.083
16.0	0.073
20.0	0.067
26.0	0.057

The data did not support the student's hypothesis. He investigated other possible relationships by plotting a graph of the average current against the distance between the electrodes. He obtained the following best-fit line with a correlation coefficient (r) of –0.9999.



(i) Suggest what the correlation coefficient of –0.9999 indicates. [1]

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(This question continues on the following page)

(Question 1 continued)

(ii) State the equation of the straight line obtained using the data. [1]

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(iii) Outline how current flows in the sodium chloride solution. [1]

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2. Antacids react with hydrochloric acid in the stomach to relieve indigestion. A student investigated different brands of antacid to see which caused the largest increase in pH in a given time. She added the antacids to hydrochloric acid, and recorded the change in pH over five minutes.

Antacid brand	Active ingredient(s)	Recommended dosage	Dose used	Initial pH ±0.02	Final pH ±0.02	Change in pH
A	magnesium hydroxide aluminium hydroxide	2–3 tablets	2 tablets	1.68	4.53	+2.85
B	sodium hydrogen carbonate calcium carbonate	2–4 tablets	2 tablets	1.70	5.31	+3.61
C	calcium carbonate	1–2 tablets	1 tablet	1.70	4.52	+2.82
D	magnesium hydroxide aluminium oxide aluminium hydroxide	1–2 tablets	1 tablet	1.69	2.21	+0.52

(a) State an equation for the reaction of magnesium hydroxide with hydrochloric acid. [1]

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(This question continues on the following page)

(Question 2 continued)

(b) Suggest two variables, besides the time of reaction, which the student should have controlled in the experiment to ensure a fair comparison of the antacids. [2]

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(c) Calculate the uncertainty in the change in pH. [1]

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(d) The student concluded that antacid **B** was the most effective, followed by **A** then **C** and finally **D**. Discuss two arguments that reduce the validity of the conclusion. [2]

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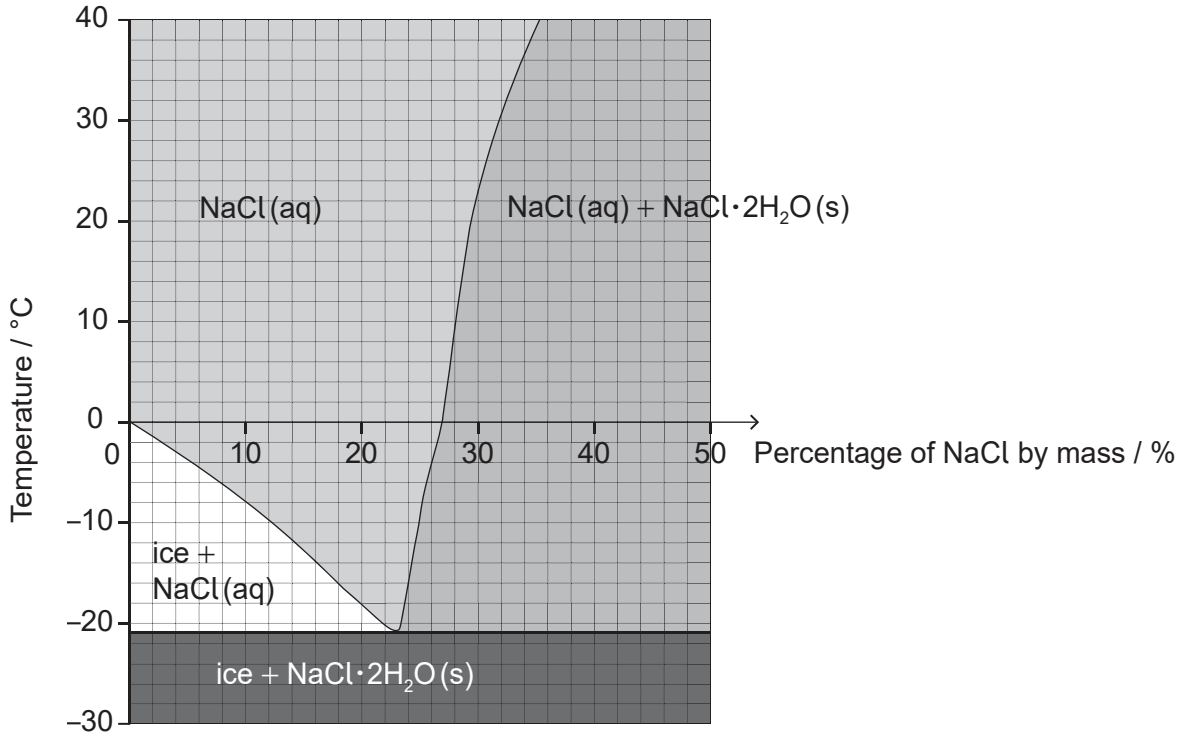
3. Sodium chloride, NaCl, can be spread on icy roads to lower the freezing point of water. The diagram shows the effects of temperature and percentage by mass of NaCl on the composition of a mixture of NaCl and H_2O.



(a) Estimate the lowest freezing point of water that can be reached by adding sodium chloride. [1]

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(b) Estimate the percentage by mass of NaCl dissolved in a saturated sodium chloride solution at +10 °C. [1]

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(This question continues on the following page)

(Question 3 continued)

(c) Calculate the percentage of water by mass in the $NaCl \cdot 2H_2O$ crystals. Use the data from section 6 of the data booklet and give your answer to two decimal places. [2]

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(d) Suggest a concern about spreading sodium chloride on roads. [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

4. It is wise to fill dental cavities before irreversible tooth decay sets in. An amalgam (alloy of mercury, silver, and other metals) is often used although many prefer a white composite material.

(a) Outline the composition of an alloy and a composite. [2]

Alloy:

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Composite:

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(b) Outline why an alloy is usually harder than its components by referring to its structure. [1]

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(Option A continues on the following page)

(Option A, question 4 continued)

(c) Explain how Inductively Coupled Plasma (ICP) Spectroscopy could be used to determine the concentration of mercury in a sample of dental filling. [3]

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5. Catalysts can take many forms and are used in many industrial processes.

Suggest two reasons why it might be worth using a more expensive catalyst to increase the rate of a reaction. [2]

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(Option A continues on the following page)

(Option A continued)

6. The development of materials with unique properties is critical to advances in industry.

(a) Outline two properties a substance should have to be used as liquid-crystal in a liquid-crystal display. [2]

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(b) Explain why Type 2 superconductors are generally more useful than Type 1. [2]

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(c) Nanotechnology has many applications.

(i) State equations for the formation of iron nanoparticles and carbon atoms from $Fe(CO)_5$ in the HIPCO process. [2]

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(Option A continues on the following page)

(Option A, question 6 continued)

(ii) Outline why the iron nanoparticle catalysts produced by the HIPCO process are more efficient than solid iron catalysts. [1]

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7. Low density polyethene (LDPE) and high density polyethene (HDPE) are both addition polymers.

(a) Describe how the structures of LDPE and HDPE affect one mechanical property of the plastics. [2]

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(b) Describe how the monomers of addition polymers and of condensation polymers differ. [1]

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(c) Identify the type of intermolecular bonding that is responsible for Kevlar®'s strength. [1]

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(Option A continues on the following page)

(Option A, question 7 continued)

(d) One of the two infrared (IR) spectra is that of polyethene and the other of polytetrafluoroethene (PTFE).

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(Option A continues on the following page)

(Option A, question 7 continued)

Deduce, with a reason, which spectrum is that of PTFE. Infrared data is given in section 26 of the data booklet. [1]

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(e) Many plastics used to be incinerated. Deduce an equation for the complete combustion of two repeating units of PVC, $(–C_2H_3Cl–)_2$. [2]

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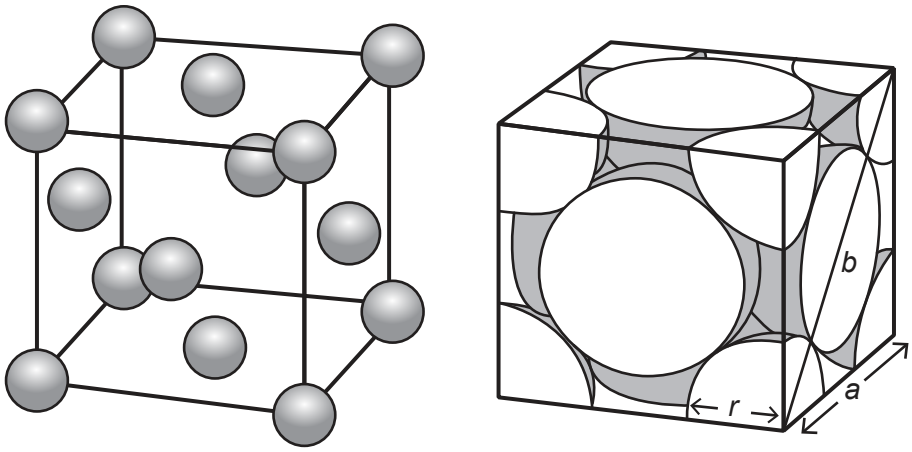
(Option A continues on the following page)

(Option A continued)

8. Metals have various crystal structures. Cobalt forms a face-centred cubic (FCC) lattice. Two representations of FCC are shown.



(a) Calculate the total number of cobalt atoms within its unit cell. [1]

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(b) (i) The atomic radius, r, of cobalt is 1.18×10^{-8} cm. Determine the edge length, in cm, of the unit cell, a, using the second diagram. [1]

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(Option A continues on the following page)

(Option A, question 8 continued)

(ii) Determine a value for the density of cobalt, in $g\,cm^{-3}$, using data from sections 2 and 6 of the data booklet and your answers from (a) and (b) (i).

If you did not obtain an answer to (b) (i), use 3.00×10^{-8} cm but this is not the correct answer. [2]

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(Option A continues on the following page)

(Option A continued)

9. Heavy metal ions are an important environmental concern.

(a) State the name of one method, other than precipitation, of removing heavy metal ions from solution in water. [1]

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(b) The solubility product, K_{sp}, of cadmium sulfide, CdS, is 8.0×10^{-27}. Determine the concentration of cadmium ions in 1.0 dm^3 of a saturated solution of cadmium sulfide to which 0.10 mol of solid sodium sulfide has been added, stating any assumption you make. [3]

Calculation:

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Assumption:

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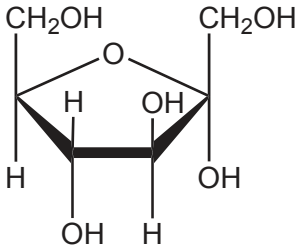
End of Option A

Option B — Biochemistry

10. Consider the following lipid and carbohydrate.

$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$

Linoleic acid, $M_r = 280.50$



Fructose, $M_r = 180.18$

(a) (i) Determine the empirical formula of linoleic acid. [1]

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(ii) The empirical formula of fructose is CH_2O. Suggest why linoleic acid releases more energy per gram than fructose. [1]

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(b) In order to determine the number of carbon-carbon double bonds in a molecule of linoleic acid, 1.24 g of the lipid were dissolved in 10.0 cm^3 of non-polar solvent. The solution was titrated with a 0.300 mol dm^{-3} solution of iodine, I_2.

Calculate the volume of iodine solution used to reach the end-point. [3]

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(Option B continues on the following page)

(Option B, question 10 continued)

(c) Outline the importance of linoleic acid for human health. [2]

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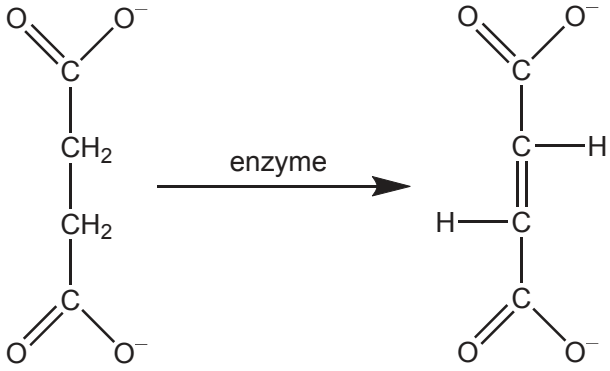
(Option B continues on the following page)

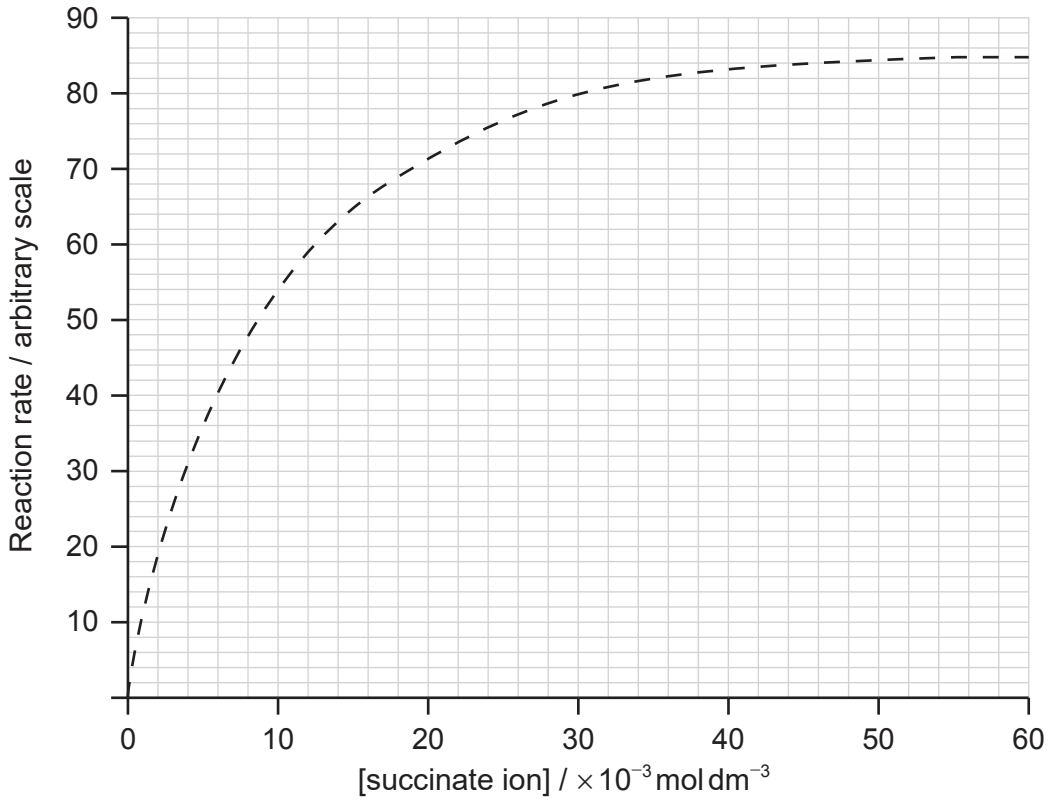
(Option B continued)

11. An enzyme catalyses the conversion of succinate to fumarate ions in a cell, as part of the process of respiration.



Succinate ion Fumarate ion

The rate of the reaction was monitored and the following graph was plotted.



(a) Determine the value of the Michaelis constant, K_m, by annotating the graph. [2]

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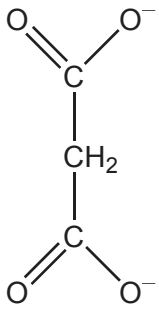
(Option B continues on the following page)

(Option B, question 11 continued)

(b) (i) The malonate ion acts as an inhibitor for the enzyme.



Malonate ion

Suggest, on the molecular level, how the malonate ion is able to inhibit the enzyme. [2]

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(ii) Draw a curve on the graph on page 21 showing the effect of the presence of the malonate ion inhibitor on the rate of reaction. [1]

(c) Enzyme activity depends on many factors. Explain how pH change causes loss of activity of an enzyme. [4]

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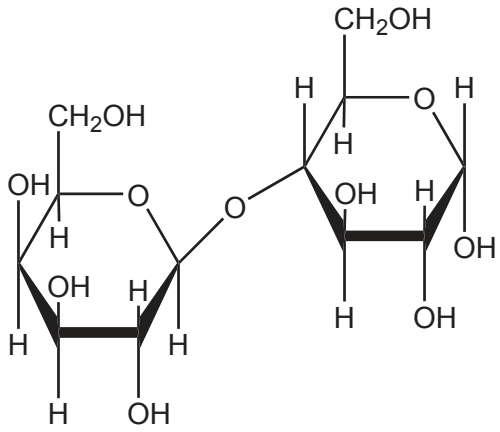
(Option B continues on the following page)

(Option B continued)

12. Lactose is a disaccharide formed by the condensation reaction of the monosaccharides galactose and glucose.



Lactose

(a) Describe what is meant by a condensation reaction. [2]

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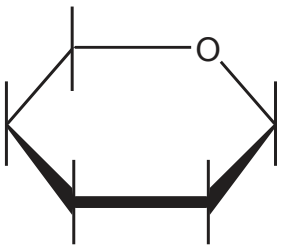
(b) Draw the structure of galactose on the skeleton provided. [1]



(Option B continues on the following page)

(Option B, question 12 continued)

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

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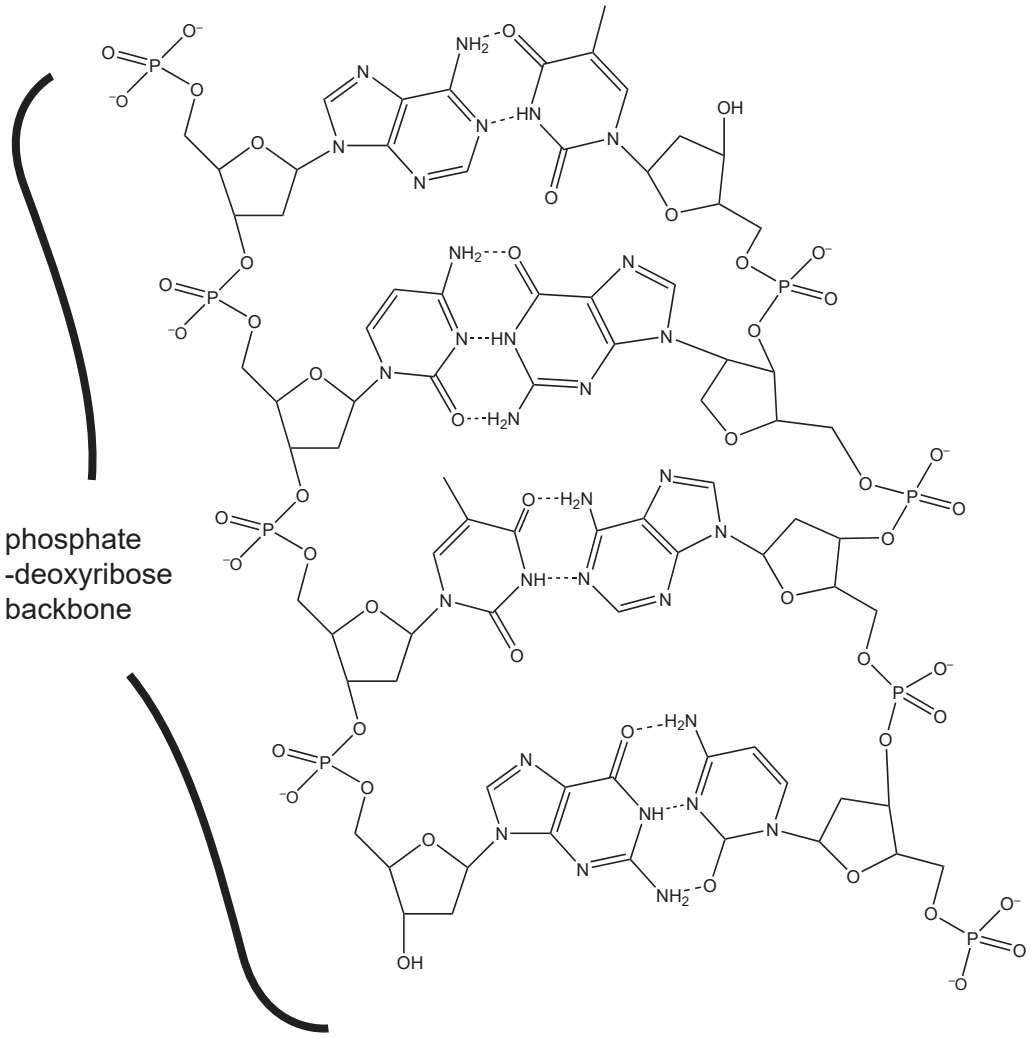
(Option B continues on the following page)

(Option B continued)

13. The stability of DNA is due to interactions of its hydrophilic and hydrophobic components.



Outline the interactions of the phosphate groups in DNA with water and with surrounding proteins (histones). [2]

Water:

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Proteins:

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(Option B continues on the following page)

(Option B continued)

14. The heme groups in cytochromes contain iron ions that are involved in the reduction of molecular oxygen.

(a) State the half-equation for the reduction of molecular oxygen to water in acidic conditions. [1]

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(b) Outline the change in oxidation state of the iron ions in heme groups that occurs when molecular oxygen is converted to water. [1]

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15. Vitamins can be water-soluble or fat-soluble.

(a) Explain, at the molecular level, why vitamin D is soluble in fats. Use section 35 of the data booklet. [2]

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(Option B continues on the following page)

(Option B, question 15 continued)

(b) 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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End of Option B

Option C — Energy

16. One method of comparing fuels is by considering their specific energies.

(a) Calculate the specific energy of octane, C_8H_{18}, in $kJ\,kg^{-1}$ using sections 1, 6 and 13 of the data booklet. [2]

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(b) A typical wood has a specific energy of $17 \times 10^3\,kJ\,kg^{-1}$. Comment on the usefulness of octane and wood for powering a moving vehicle, using your answer to (a).
If you did not work out an answer for (a), use $45 \times 10^3\,kJ\,kg^{-1}$ but this is not the correct answer. [1]

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(c) State the name of **one** renewable source of energy other than wood. [1]

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(Option C continues on the following page)

(Option C continued)

17. Much of our energy needs are still provided by the refined products of crude oil.

(a) "Knocking" in an automobile (car) engine can be prevented by increasing the octane number of the fuel. Explain, including an equation with structural formulas, how heptane, C_7H_{16}, could be chemically converted to increase its octane number. [3]

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(b) Many like to refer to our "carbon footprint". Outline one difficulty in quantifying such a concept. [1]

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(c) Climate change or global warming is a consequence of increased levels of carbon dioxide in the atmosphere. Explain how the greenhouse effect warms the surface of the earth. [3]

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(Option C continues on the following page)

(Option C continued)

18. In the 20th Century, both fission and fusion were considered as sources of energy but fusion was economically and technically unattainable.

(a) (i) Compare and contrast fission and fusion in terms of binding energy and the types of nuclei involved. [2]

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(ii) Suggest **two** advantages that fusion has over fission. [2]

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(b) The amount of ^{228}Ac in a sample decreases to one eighth $\left(\frac{1}{8}\right)$ of its original value in about 18 hours due to β-decay. Estimate the half-life of ^{228}Ac. [1]

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(Option C continues on the following page)

(Option C, question 18 continued)

(c) (i) Calculate the loss in mass, in kg, and the energy released, in J, when 0.00100 mol of ^{228}Ac decays, each atom losing an electron. Use section 2 of the data booklet and $E = mc^2$. [2]

$$^{228}Ac \rightarrow {}^{0}_{-1}e + {}^{228}Th$$

Particle	^{228}Ac	$^{0}_{-1}e$	^{228}Th
Mass / kg	3.78532×10^{-25}	9.109383×10^{-31}	3.78528×10^{-25}

Loss in mass:

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Energy released:

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(ii) Determine the energy released, in J, by 0.00100 mol of ^{228}Ac over the course of 18 hours. [1]

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(Option C continues on the following page)

(Option C, question 18 continued)

(d) Outline how nuclear ionising radiation can damage DNA and enzymes in living cells. [1]

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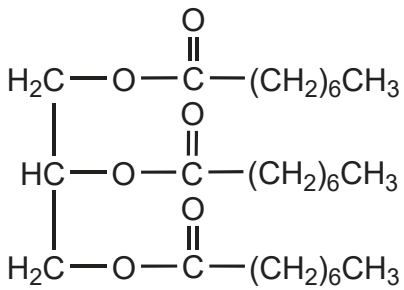
19. Vegetable oils and the sun can be used as sources of energy.

(a) Vegetable oils are too viscous for use as liquid fuels. Describe, using an equation, how a vegetable oil, such as that shown, is converted to oils with lower viscosity by reaction with methanol, CH_3OH. [2]



(Option C continues on the following page)

(Option C, question 19 continued)

(b) The natural absorption of light by chlorophyll has been copied by those developing dye-sensitized solar cells (DSSCs). Outline how a DSSC works. [3]

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20. A fuel cell converts chemical energy directly to electrical energy.

(a) Deduce the half-equations and the overall equation for the reactions taking place in a direct methanol fuel cell (DMFC) under acidic conditions. [3]

Negative electrode (anode):

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Positive electrode (cathode):

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Overall equation:

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(Option C continues on the following page)

(Option C, question 20 continued)

(b) Outline **one** advantage and **one** disadvantage of the methanol cell (DMFC) compared with a hydrogen-oxygen fuel cell. [2]

Advantage:

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Disadvantage:

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End of Option C

Option D — Medicinal chemistry

21. Lutetium-177 is used in radiotherapy. It emits beta radiation when it decays.

(a) State a nuclear equation to show the decay of lutetium-177. [2]

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(b) The half-life of lutetium-177 is 6.73 days. Determine the percentage of a sample of lutetium-177 remaining after 14.0 days. [2]

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(c) Explain the low environmental impact of most medical nuclear waste. [2]

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(Option D continues on the following page)

(Option D continued)

22. Ibuprofen and paracetamol are mild analgesics. One of the IR spectra below belongs to ibuprofen and the other to paracetamol. The structures of both compounds are given in section 37 of the data booklet.

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(Option D continues on the following page)

(Option D, question 22 continued)

(a) (i) Both spectra show a peak at wavenumber 1700 cm^{-1}. Identify the bond responsible for this peak. [1]

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(ii) Deduce which spectrum belongs to paracetamol, giving two reasons for your choice. Use section 26 of the data booklet. [2]

X or **Y**:

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Reason 1:

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Reason 2:

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(b) Describe how mild analgesics function. [2]

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(c) (i) The strong analgesics morphine and codeine are opiates. Outline how codeine can be synthesized from morphine. The structures of morphine and codeine are in section 37 of the data booklet. [1]

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(Option D continues on the following page)

(Option D, question 22 continued)

(ii) Explain why opiates are addictive. [2]

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23. Some drugs are extracted from natural sources and others are synthetic.

(a) New drugs undergo thorough clinical trials before they are approved. Outline the difference between the therapeutic index in animal studies and the therapeutic index in humans. [1]

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(b) Explain the role of the chiral auxiliary in the synthesis of Taxol. [3]

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(c) State the method of drug administration that gives the maximum bioavailability. [1]

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(Option D continues on the following page)

(Option D continued)

24. Oseltamivir (Tamiflu) and zanamivir (Relenza) are antiviral drugs used to prevent flu. State the names of **two** functional groups that **both** compounds contain, using section 37 of the data booklet. [2]

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25. Excess acid in the stomach can cause discomfort and more serious health issues.

(a) Explain how ranitidine (Zantac) reduces stomach acid production. [2]

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(b) The pH is maintained in different fluids in the body by the use of buffers.

Calculate the pH of a buffer solution of $0.0200\,mol\,dm^{-3}$ carbonic acid, H_2CO_3, and $0.400\,mol\,dm^{-3}$ sodium hydrogen carbonate, $NaHCO_3$. The pK_a of carbonic acid is 6.35. [2]

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(Option D continues on the following page)

(Option D continued)

26. Molecules of antibiotics often contain a beta-lactam ring. Explain the importance of the beta-lactam ring in the action of penicillin, using section 37 of the data booklet. [3]

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27. Ethanol slows down the reaction time of a driver leading to traffic accidents. Explain how the concentration of ethanol in a sample of breath can be determined using a fuel cell breathalyser. [2]

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End of Option D