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CHEMISTRY
HIGHER LEVEL
PAPER 3

Candidate session number

Tuesday 20 May 2014 (morning)

1 hour 15 minutes

Examination code

2	2	1	4	–	6	1	0	9

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all of the questions from two of the Options.
- Write your answers in the 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 *[50 marks]*.

Option	Questions
Option A — Modern analytical chemistry	1 – 4
Option B — Human biochemistry	5 – 8
Option C — Chemistry in industry and technology	9 – 11
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Option G — Further organic chemistry	22 – 25

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

Answers written on this page
will not be marked.

Option A — Modern analytical chemistry

1. (a) Describe the essential difference between the **emission** spectrum of sodium and the **absorption** spectrum of sodium. *[1]*

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(b) Identify the five missing components in the following table.

Type of spectroscopy	Type of atomic or molecular process	Region of electromagnetic spectrum
^{1}H NMR		
IR		infrared
	electronic transitions	

[4]

(c) Other than to identify the presence of a particular element, state **one** use of atomic absorption spectroscopy. *[1]*

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2. Organic compound **X** is 68.11 % carbon, 13.74 % hydrogen and 18.15 % oxygen by mass.

(a) Show that the empirical formula of compound **X** is $C_5H_{12}O$. *[1]*

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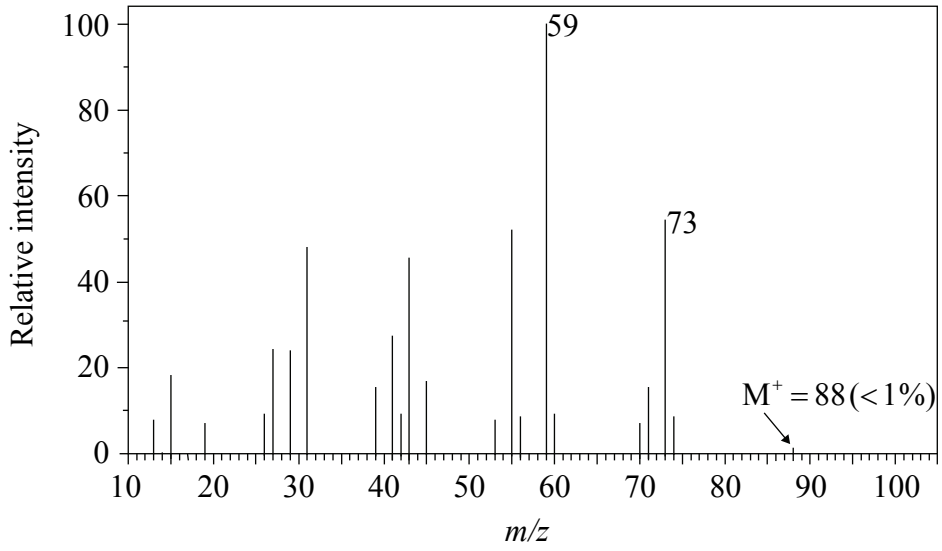
(Option A continues on the following page)

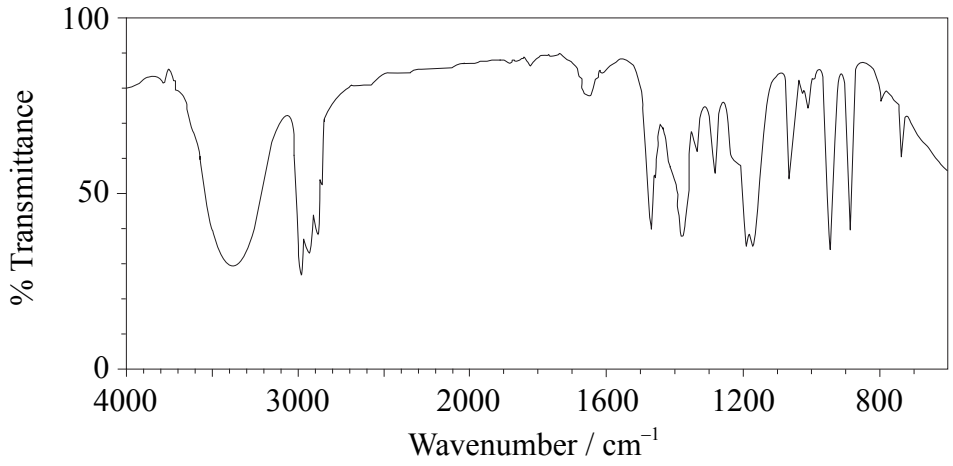
(Option A, question 2 continued)

(b) The mass spectrum, infrared spectrum and details of the ^{1}H NMR spectrum of compound **X** are given below.

Mass spectrum:



Infrared spectrum:



^{1}H NMR spectrum:

Peak with splitting	Integration trace (area under peak)
Singlet	1
Singlet	6
Triplet	3
Quartet	2

(Option A continues on the following page)

(Option A, question 2 continued)

Analyse these three spectra and, using relevant information, deduce the identity of the compound. *[11]*

Mass spectrum:

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Infrared spectrum:

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^{1}H NMR spectrum:

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Identity of **X**:

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(Option A continues on the following page)

(Option A continued)

3. A student prepared a 4.00×10^{-5} mol dm^{-3} aqueous solution of an iron(III) complex ion. She placed a sample of the solution in a cuvette (sample tube) with a path length of 1.00 cm. When light at a particular wavelength was passed through the cuvette she determined that the transmitted light was 10 % of the incident light.

(a) Calculate, using Table 1 of the Data Booklet, the value of the extinction coefficient (ε) for the iron(III) complex at this wavelength including its units. *[2]*

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(b) Outline why a solution of $Fe^{2+}(aq)$ is a different colour to a solution of $Fe^{3+}(aq)$. *[2]*

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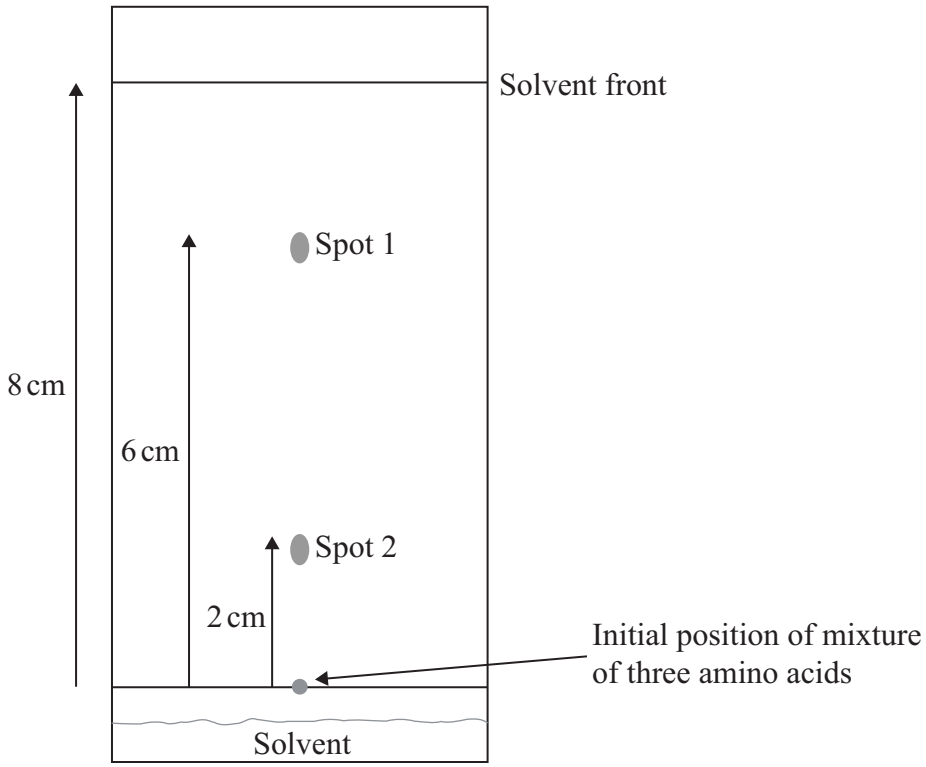
(Option A continues on the following page)

(Option A continued)

4. A sample is known to contain three different amino acids. After carrying out paper chromatography using a solvent made up of propan-1-ol, water and ammonia, the following chromatogram was obtained once the spots had been developed with ninhydrin.



(a) Calculate the R_f values for the two spots. *[1]*

Spot 1:

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Spot 2:

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(b) Suggest a reason why only two spots are present. *[1]*

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(Option A continues on the following page)

(Option A, question 4 continued)

(c) Suggest how the chromatography experiment with the same sample could be altered in order to obtain three spots. *[1]*

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End of Option A

Option B — Human biochemistry

5. Lipids are a group of molecules which includes fats, fat-soluble vitamins and triglycerides.

(a) Iodine can be used to determine the degree of unsaturation in fatty acids.

(i) Deduce the chemical equation for the reaction of oleic acid with iodine using Table 22 of the Data Booklet. *[1]*

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(ii) Calculate the volume, in cm^3, of a $1.00\,mol\,dm^{-3}$ iodine solution needed to react exactly with 1.00 g of oleic acid (molar mass = $282.52\,g\,mol^{-1}$). *[2]*

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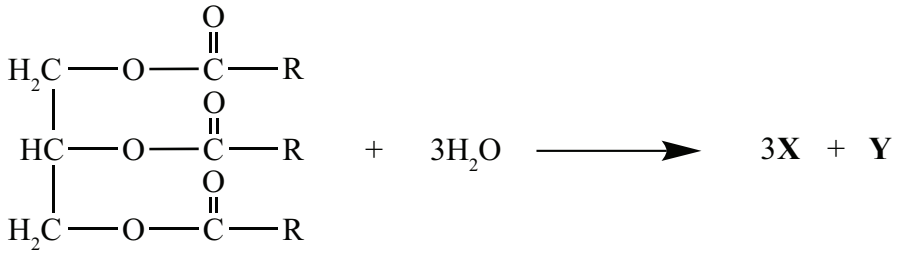
(Option B continues on the following page)

(Option B, question 5 continued)

(b) The partial equation for the enzyme-catalysed hydrolysis of a triglyceride is represented below.



(i) Deduce the named functional groups present in the two products **X** and **Y**. *[2]*

X: . . . . . .

Y: . . . . . .

(ii) Outline the factors which determine whether **X** obtained in part (i) will have a higher or lower melting point than oleic acid. *[2]*

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(c) Suggest why fats have a higher energy value than carbohydrates. *[1]*

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(Option B continues on the following page)

(Option B, question 5 continued)

(d) The two fatty acids linoleic acid and linolenic acid both have the same number of carbon atoms. Compare the structures of the two acids. *[2]*

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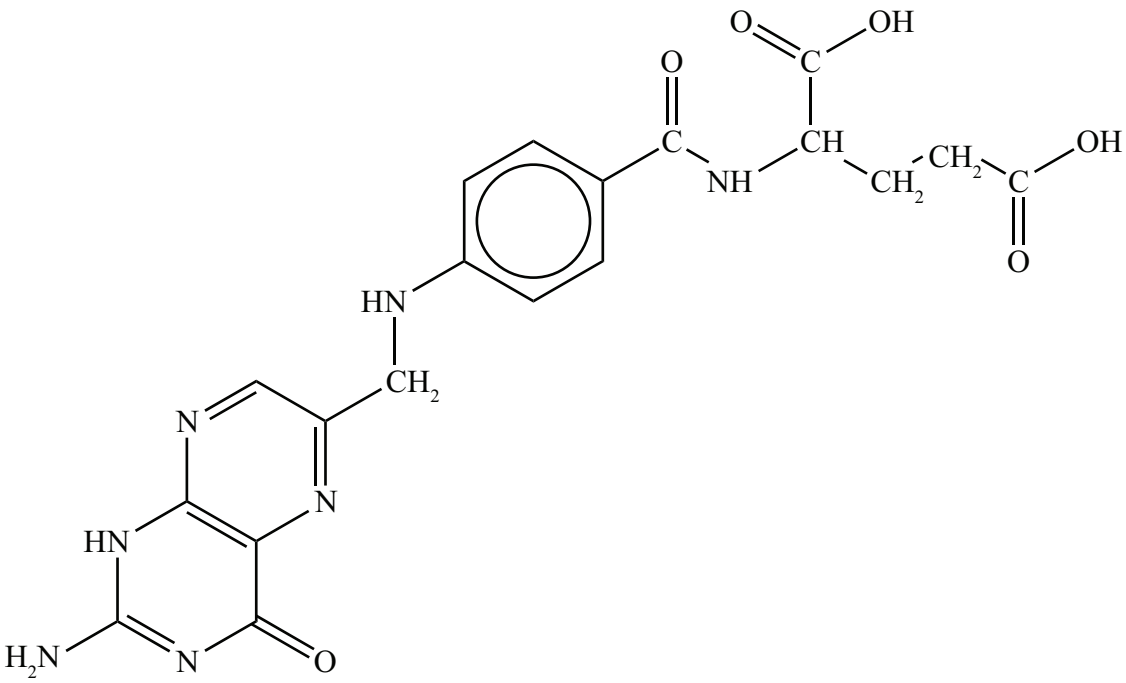
(Option B continues on the following page)

(Option B continued)

6. Vitamins are organic compounds needed in small amounts for normal metabolism in the body. Vitamins can be classified as water-soluble or fat-soluble.

(a) Vitamin B_9 is water-soluble and is important in the repair of DNA. The structure of vitamin B_9 is given below.



Suggest why this vitamin is water-soluble. *[1]*

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(Option B continues on the following page)

(Option B, question 6 continued)

(b) Vitamin A (retinol) is important for maintaining healthy skin. The structure of vitamin A (retinol) is given in Table 21 of the Data Booklet.

(i) State **one** disease caused by a deficiency of vitamin A in the body. *[1]*

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. . . . . .

(ii) The livers of polar bears and seals contain a very large amount of vitamin A. Some early explorers in the Arctic died from consuming too many livers.

Suggest an explanation for this even though males require at least 0.9 mg of the vitamin per day (females require at least 0.7 mg per day.) *[1]*

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(Option B continues on the following page)

(Option B continued)

7. The most important components of nucleotides are the nitrogeneous bases, which consist of pyrimidines and purines.

(a) Thymine (T), whose structure is given in Table 21 of the Data Booklet, is a pyrimidine. Describe how thymine forms part of a nucleotide in deoxyribonucleic acid (DNA). *[1]*

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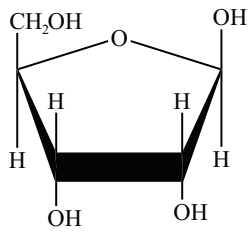
(b) Adenine, A, whose structure is also given in Table 21 of the Data Booklet, is a purine found in DNA.
Draw the structure of the organic product formed from the condensation reaction of adenine with the sugar D-ribose (whose structure is given below) and identify the other product.



[2]

Structure of organic product:

Other product:

. . . . . .

(Option B continues on the following page)

(Option B, question 7 continued)

(c) (i) Adenine (A), guanine (G), cytosine (C) and thymine (T) result in the double helix structure of DNA. Using the structures of adenine and thymine, draw a diagram to explain how thymine is able to play a role in forming a double helix. *[1]*

(ii) Compare the bonding between cytosine and guanine with the bonding between adenine and thymine. *[2]*

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(d) State **two** uses of DNA profiling. *[1]*

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(Option B continues on the following page)

(Option B continued)

8. Both aerobic and anaerobic exercise can result in the release of energy. However different pathways are used to break down glucose.

(a) Compare the aerobic and anaerobic respiration of glucose in the human body in terms of the processes of oxidation/reduction and energy release. *[4]*

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(b) State the overall chemical equation for the aerobic respiration of glucose. *[1]*

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End of Option B

Option C — Chemistry in industry and technology

9. Although fossil fuels are considered significant sources of energy, the energy conversion associated with the production of electricity is a very inefficient process, often in the region of only 40 % of total possible energy conversion.

Fuel cells provide a much more efficient process, often with a 70 % conversion factor.

(a) State the energy change conversion involved in a fuel cell. *[1]*

. . . . . .

(b) (i) Identify the two half-equations that take place at the positive electrode (cathode) and negative electrode (anode) in a hydrogen-oxygen fuel cell with an **alkaline** electrolyte. *[2]*

Positive electrode (cathode) half-equation:

. . . . . .

Negative electrode (anode) half-equation:

. . . . . .

(ii) State the overall reaction, identifying the states of all species involved. *[1]*

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(Option C continues on the following page)

(Option C, question 9 continued)

(iii) One commercial version of the hydrogen-oxygen fuel cell (with alkaline electrolyte) operates at a temperature of 353 K. The electrodes of the fuel cell are made of graphite but both are covered with a thin layer of platinum. State the function of the platinum. *[1]*

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(iv) Outline the function of the thin polymer membrane used in the corresponding hydrogen-oxygen fuel cell with an **acidic** electrolyte. *[1]*

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(v) Other than cost, state **one** disadvantage of a fuel cell. *[1]*

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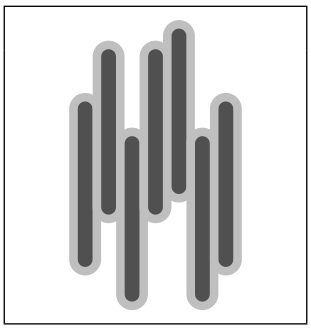
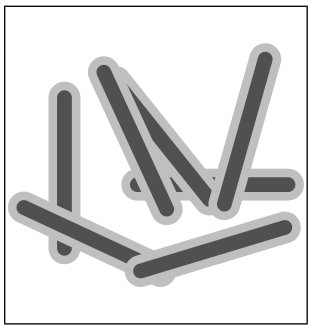
(Option C continues on the following page)

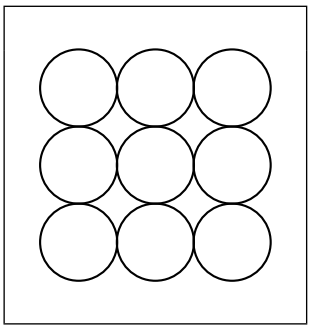
(Option C continued)

10. Liquid crystals are widely used in devices such as calculators, laptop computers and advanced optical materials.

(a) (i) Describe the meaning of the term liquid crystals and state which of the representations below (A, B or C) best describes molecules present in the liquid-crystalline phase. *[1]*

A. 

B. 

C. 

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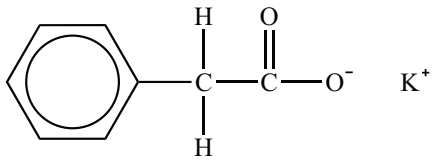
(Option C continues on the following page)

(Option C, question 10 continued)

(ii) Deduce, with reasoning, which of the following substance(s) is/are most likely to show liquid-crystalline behaviour. *[4]*

Substance I:



Liquid-crystalline behaviour (yes/no):

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Reasoning:

. . . . . .

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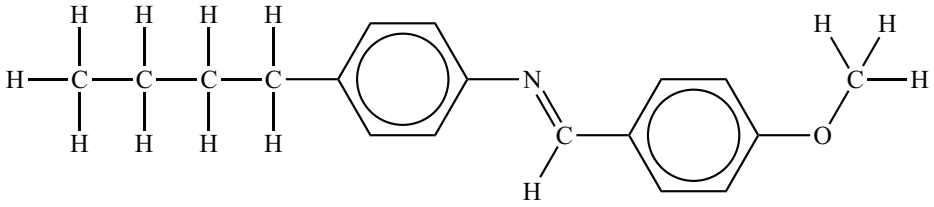
Substance II:



Liquid-crystalline behaviour (yes/no):

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Reasoning:

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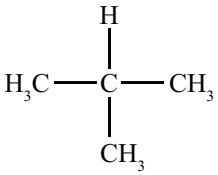
(Option C continues on the following page)

(Option C, question 10 continued)

Substance III:



Liquid-crystalline behaviour (yes/no):

. . . . . .

Reasoning:

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(iii) Suggest why octane does not show liquid-crystalline behaviour. *[1]*

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(Option C continues on the following page)

(Option C, question 10 continued)

(b) (i) State **one** difference between thermotropic and lyotropic liquid crystals. *[1]*

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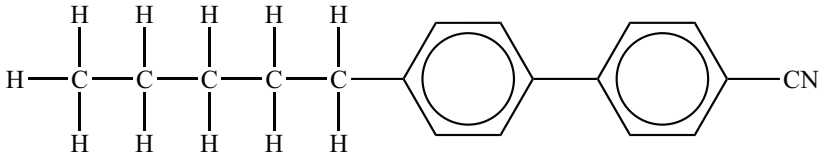
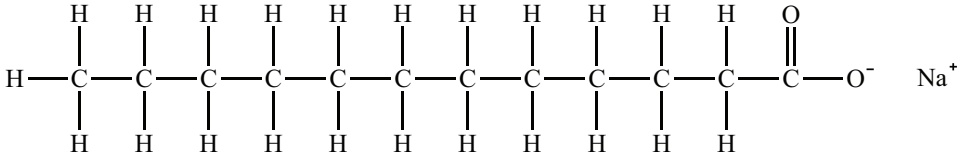
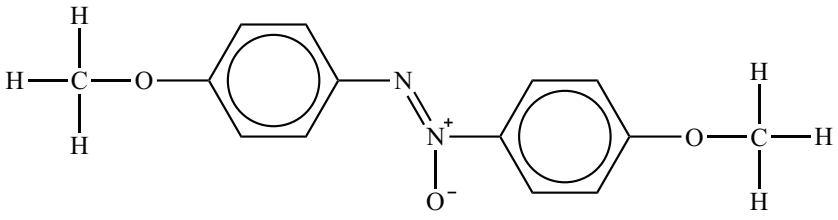
(ii) Identify, by stating yes or no, the substance(s) which show(s) thermotropic liquid-crystalline behaviour. *[1]*

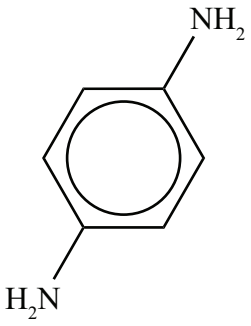
Substance	**Thermotropic liquid-crystalline behaviour**
X: 	
Y: 	
Z: 	

(Option C continues on the following page)

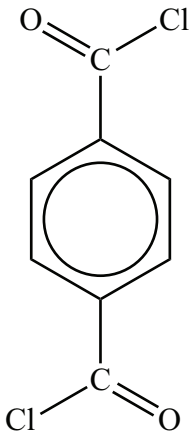
(Option C, question 10 continued)

(c) Kevlar® is a material used in bullet-proof vests.

(i) Deduce the products formed by a condensation polymerization reaction of the monomers benzene-1,4-diamine and benzene-1,4-dicarbonyl chloride to form Kevlar®. *[2]*



Benzene-1,4-diamine



Benzene-1,4-dicarbonyl chloride

(Option C continues on the following page)

(Option C, question 10 continued)

(ii) Describe the factors which account for the inherent strength of Kevlar®. *[2]*

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(iii) Outline why Kevlar® can dissolve in concentrated sulfuric acid. *[1]*

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(Option C continues on the following page)

(Option C continued)

11. Mercury cells were used in the past to produce chlorine and sodium hydroxide from sodium chloride solution. The overall reaction for this cell is:

$$2NaCl(aq) + 2H_2O(l) \rightarrow 2NaOH(aq) + Cl_2(g) + H_2(g)$$

(a) Identify the materials used for both electrodes and deduce the half-equations taking place at both the positive (anode) and negative (cathode) electrodes, including state symbols. *[4]*

Positive electrode (anode)

Material:

. . . . . .

Half-equation:

. . . . . .

Negative electrode (cathode)

Material:

. . . . . .

Half-equation:

. . . . . .

(b) State why the diaphragm cell is preferred to the mercury cell. *[1]*

. . . . . .

. . . . . .

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End of Option C

Option D — Medicines and drugs

12. Each capsule of Solpadol®, a commercial analgesic, contains 500 mg of paracetamol (acetaminophen) and 30 mg of codeine (in the form of codeine phosphate hemihydrate).

(a) Discuss the different modes of action of paracetamol (acetaminophen) and codeine in relieving pain. *[2]*

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(b) Diamorphine (heroin) is an even stronger painkiller than codeine. The structures of codeine and diamorphine are given in Table 20 of the Data Booklet. Discuss, in terms of named functional groups, how the structure of diamorphine differs from the structure of codeine. *[3]*

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(c) State **one** specific reason why many doctors recommend paracetamol rather than aspirin as a mild analgesic. *[1]*

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(Option D continues on the following page)

(Option D, question 12 continued)

(d) A normal aspirin tablet taken to relieve pain contains about 300 mg of aspirin. Certain adults who are not in pain are recommended by doctors to take a smaller 75 mg dose of aspirin each day. State **one** reason for this recommendation. *[1]*

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(e) Suggest a reason why aspirin and paracetamol are "over the counter" drugs but in many countries Solpadol® must be prescribed by a doctor. *[1]*

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(Option D continues on the following page)

(Option D continued)

13. Maalox® manufactures several different types of antacid. Maalox® Extra Strength is a suspension. One teaspoon (5.00 cm^3) contains 400 mg of magnesium hydroxide, $Mg(OH)_2$, 306 mg of aluminium hydroxide, $Al(OH)_3$, and 40.0 mg of simethicone. Maalox® Extra Strength with Anti-gas comes in tablet form. Each tablet contains 1000 mg of calcium carbonate, $CaCO_3$, and 60.0 mg of simethicone.

(a) State the equations for the reactions of magnesium hydroxide, aluminium hydroxide and calcium carbonate with hydrochloric acid. *[3]*

Magnesium hydroxide:

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Aluminium hydroxide:

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Calcium carbonate:

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(Option D continues on the following page)

(Option D, question 13 continued)

(b) Stomach acid approximates to $1.00 \times 10^{-2}\,\text{mol}\,\text{dm}^{-3}$ hydrochloric acid. Assuming that simethicone does not react with acid, determine the volume, in dm^3, of stomach acid neutralized by:

(i) one teaspoon ($5.00\ \text{cm}^3$) of Maalox® Extra Strength. *[2]*

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(ii) one tablet of Maalox® Extra Strength with Anti-gas. *[2]*

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(c) Suggest the function of the simethicone present in both antacids. *[1]*

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(Option D continues on the following page)

(Option D continued)

14. (a) In the late 1950s and early 1960s many babies were born with severe limb deformities because their mothers had taken the drug thalidomide to alleviate or prevent morning sickness. Discuss how this has affected the testing of new drugs since this time. *[2]*

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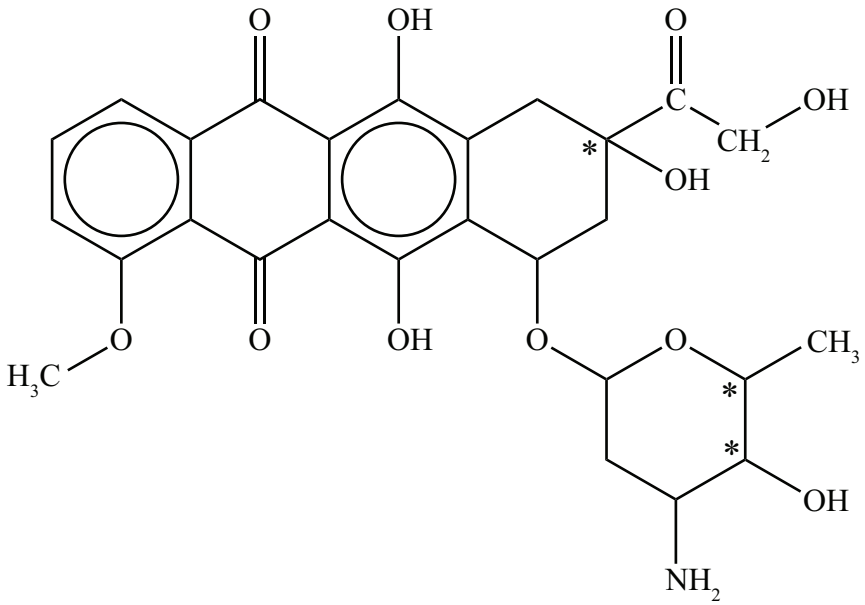
(b) Thalidomide is currently used to treat several different diseases including certain types of cancer. Research to compare its effectiveness with other cancer drugs, such as doxorubicin, is ongoing.

(i) Doxorubicin contains six different chiral carbon atoms. Three of them are identified with an asterisk, *. Identify the locations of the other three by placing circles around the relevant carbon atoms. *[3]*



Doxorubicin

(Option D continues on the following page)

(Option D, question 14 continued)

(ii) Only one of the possible enantiomers is really effective as an anti-cancer drug. Describe the general principles behind the use of chiral auxiliaries to form the desired enantiomer when several different enantiomers of a drug exist. *[2]*

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(iii) From its structure it can be seen that doxorubicin contains several polar hydroxyl groups. However, when it is given intravenously it needs to be in an ionic form to make it even more soluble in an aqueous medium. Describe how doxorubicin can be converted into a salt. *[2]*

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End of Option D

Option E — Environmental chemistry

15. Although methane is a greenhouse gas produced by anaerobic decomposition of organic matter, methane produced from landfill is now being used in New Jersey, USA, to generate electricity for homes in New York City.

(a) Evaluate the advantages and disadvantages of landfill and incineration as methods of waste disposal. *[4]*

One advantage of landfill:

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. . . . . .

One disadvantage of landfill:

. . . . . .
. . . . . .

One advantage of incineration:

. . . . . .
. . . . . .

One disadvantage of incineration:

. . . . . .
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(Option E continues on the following page)

(Option E, question 15 continued)

(b) Explain why neither landfill nor incineration are suitable methods to dispose of high-level radioactive waste. *[2]*

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(c) (i) Other than landfill, state one other source of methane produced from the decomposition of organic material. *[1]*

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(ii) State the equation, including state symbols, for the oxidation of methane in the atmosphere to produce a primary pollutant which is toxic to humans. *[1]*

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(Option E continues on the following page)

(Option E continued)

16. Ozone prevents UV radiation emitted from the Sun reaching the surface of the Earth.

(a) Describe, using chemical equations, the two-step mechanism of photochemical decomposition of ozone in the Earth's stratosphere. *[2]*

Step 1:

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Step 2:

. . . . . .

(b) The ozone layer in the stratosphere has been progressively depleted by pollutants such as chlorofluorocarbons (CFCs), which have been used as refrigerants. Compare CFCs with the alternative refrigerant hexafluoroethane, C_2F_6. *[3]*

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(Option E continues on the following page)

(Option E, question 16 continued)

(c) Two cities which experience smog on a regular basis are Santiago in Chile and Mexico City. VOCs (volatile organic compounds) are one type of primary pollutant responsible for the formation of smog in the atmosphere.

(i) State the other primary pollutant responsible for the formation of smog, its possible source and **two** conditions that make these two cities particularly susceptible to smog formation. *[2]*

Primary pollutant and source:

. . . . . .

. . . . . .

Two conditions:

. . . . . .

. . . . . .

(ii) During early morning in these cities there is a gradual build-up of these primary pollutants, but in the afternoon there is a very high concentration of the secondary pollutants, peroxyacylnitrates (PANs). Ozone is involved in this process.

Outline, stating two equations, including any essential reaction condition, how ozone is formed and identify the termination step showing the formation of PANs. *[3]*

Formation of ozone:

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. . . . . .

Termination step showing formation of PANs:

. . . . . .

(Option E continues on the following page)

(Option E, question 16 continued)

(d) Explain, with the aid of Lewis (electron-dot) structures, the difference between oxygen and ozone in terms of the energy required to dissociate both molecules. *[2]*

Oxygen: Ozone:

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(e) One CFC, Freon-13 (chlorotrifluoromethane), which can be used as a refrigerant, has been phased out by the Montreal Protocol. Describe, using equations, the mechanism of the catalysis of ozone depletion by this particular CFC. *[2]*

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(Option E continues on the following page)

(Option E continued)

17. Heavy-metal ions such as $Cu^{2+}(aq)$ are often present in waste water sewage. The $Cu^{2+}(aq)$ ions can be removed from the sewage by means of chemical precipitation.

(a) State an expression for the solubility product constant, K_{sp}, for copper(II) hydroxide. *[1]*

. . . . . .

(b) The solubility product of copper(II) hydroxide is 4.8×10^{-20} at a given temperature. Determine the concentration, in $mol\,dm^{-3}$, of $Cu^{2+}(aq)$ in the solution when copper(II) hydroxide is precipitated. *[2]*

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End of Option E

Option F — Food chemistry

18. The formula of linoleic acid is given in Table 22 of the Data Booklet.

(a) Identify the structural formula of the triglyceride formed when three molecules of linoleic acid react with one molecule of glycerol (propane-1,2,3-triol), $CH_2OHCHOHCH_2OH$. *[1]*

(b) State the other product formed during this reaction. *[1]*

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(c) Explain why the triglyceride formed from linoleic acid and glycerol is a liquid and not a solid at room temperature. *[2]*

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(Option F continues on the following page)

(Option F, question 18 continued)

(d) Describe how the triglyceride formed from linoleic acid and glycerol could be converted into a saturated fat and give any necessary conditions. *[2]*

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(e) Other than the fact that it is a solid at room temperature, discuss **two** advantages and **two** disadvantages of a saturated fat compared to an unsaturated fat or oil. *[4]*

Advantages:

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Disadvantages:

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(Option F continues on the following page)

(Option F continued)

19. Describe how the following additives can prolong the shelf life of food:

(a) sodium benzoate and benzoic acid. *[1]*

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. . . . . .

(b) potassium nitrite and potassium nitrate. *[1]*

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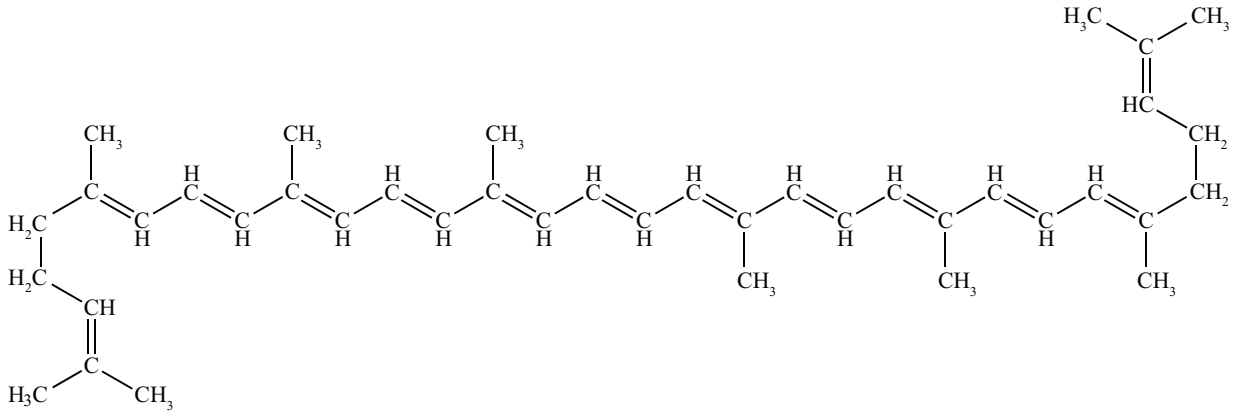
20. Lycopene occurs naturally in tomatoes and is responsible for their red colour. Lycopene is a known antioxidant and some people believe that it is effective at preventing prostate cancer. Its structure is shown below.



(a) (i) Lycopene is a hydrocarbon. State the class of naturally occurring pigments to which it belongs. *[1]*

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(Option F continues on the following page)

(Option F, question 20 continued)

(ii) Outline why lycopene is a coloured compound. *[1]*

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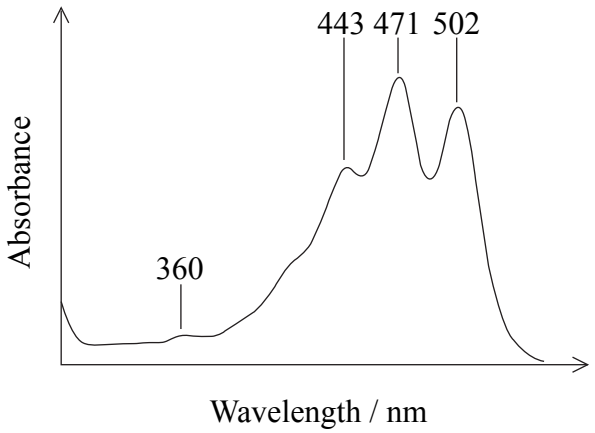
(iii) The UV/VIS spectrum of lycopene is shown below.



Explain why it is coloured red. *[1]*

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(iv) Antioxidants can be divided into three main types. Lycopene is a reducing agent and acts as an antioxidant by removing or reducing the concentration of oxygen. Others, such as BHT (3,5-di-tert-butyl-4-hydroxytoluene), inhibit the formation of free radicals or interrupt the propagation of free radicals. Explain how the third type of antioxidants functions and give **one** example. *[2]*

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(Option F continues on the following page)

(Option F, question 20 continued)

(b) (i) Describe how a fatty acid, RH, undergoes oxidative rancidity. Your answer should state the names of the **three** different steps and include **one** equation for each step. *[3]*

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(ii) Explain how an antioxidant such as BHT is able to inhibit the formation of free radicals during the oxidative rancidity of a fatty acid. *[2]*

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21. Your school is holding a debate on the benefits and concerns of genetically modified (GM) food. Several speakers have argued the benefits of GM foods and included such factors as enhanced taste, resistance to disease and increase in crop yields. Discuss three arguments you would use to highlight the concerns of using GM foods. *[3]*

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End of Option F

Option G — Further organic chemistry

22. (a) Pentanal, C_4H_9CHO, can react with hydrogen cyanide, HCN.

(i) State the equation for this reaction. *[1]*

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. . . . . .

(ii) State the name of the mechanism for this reaction. *[1]*

. . . . . .

(iii) Describe the mechanism for this reaction using curly arrows to represent the movement of electron pairs. *[3]*

(Option G continues on the following page)

(Option G, question 22 continued)

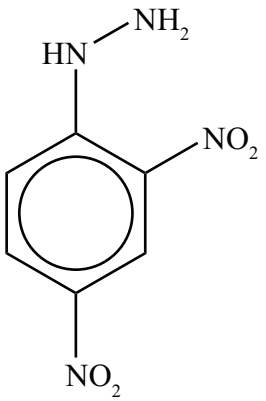
(iv) The organic product from the reaction of pentanal with hydrogen cyanide can be hydrolysed in the presence of dilute acid. Draw the structural formula and state the name of the organic product formed. *[2]*

Structure:

Name:

. . . . . .

(b) State the equation for the reaction of pentan-3-one with 2,4-dinitrophenylhydrazine. *[2]*



2,4-dinitrophenylhydrazine

(Option G continues on the following page)

(Option G continued)

23. Deduce the two-step reaction pathways for the following two syntheses. In each case state the reagents and conditions and the name of the intermediate.

(a) The formation of but-2-ene, $CH_3CH=CHCH_3$, from ethylmagnesium bromide, C_2H_5MgBr. *[3]*

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(b) The formation of butanoic acid, C_3H_7COOH, from bromopropane, C_3H_7Br. *[3]*

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24. Ethylamine, $C_2H_5NH_2$, is a weak base.

(a) Explain why ethylamine has basic properties. *[1]*

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(Option G continues on the following page)

(Option G, question 24 continued)

(b) The pK_b values at 298 K for diethylamine and triethylamine are given in Table 15 of the Data Booklet. Identify which of the two compounds is the stronger base and suggest a reason why it is stronger. *[2]*

Stronger base:

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Reason:

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25. Benzene, C_6H_6, can react with chlorine in the presence of a catalyst to form chlorobenzene.

(a) Describe the mechanism for this reaction using curly arrows to represent the movement of electron pairs. *[3]*

(Option G continues on the following page)

(Option G, question 25 continued)

(b) Explain why the chlorination of methylbenzene proceeds faster than the chlorination of benzene under the same conditions. *[2]*

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(c) Explain why the chlorination of methylbenzene produces 2-chloromethylbenzene and 4-chloromethylbenzene as the major organic products with very little 3-chloromethylbenzene being produced. *[2]*

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End of Option G

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

Answers written on this page
will not be marked.