



Chemistry

Higher level

Paper 3

Friday 15 May 2015 (morning)

Candidate session number

1 hour 15 minutes

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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 – 12 |
| Option D — Medicines and drugs | 13 – 16 |
| Option E — Environmental chemistry | 17 – 20 |
| Option F — Food chemistry | 21 – 24 |
| Option G — Further organic chemistry | 25 – 29 |



Option A — Modern analytical chemistry

1. Electromagnetic waves can transfer energy and carry information.

(a) State the relationship between the energy of a wave and its wavelength. [1]

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| <p>.....</p> <p>.....</p> |
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(b) Identify the region of the electromagnetic spectrum that can be used to obtain the following information. [2]

| Information | Region of the electromagnetic spectrum |
|---|--|
| Bonds present in an organic compound | |
| Concentration of Cr ³⁺ ions in industrial waste waters | |

(c) (i) Magnetic resonance imaging (MRI) is a technique in which radio waves are used to obtain an image of part or the whole of the human body.

Explain, on a molecular level, why this technique can be used to obtain information about the body. [2]

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(ii) Outline the information that MRI scans provide about the body. [1]

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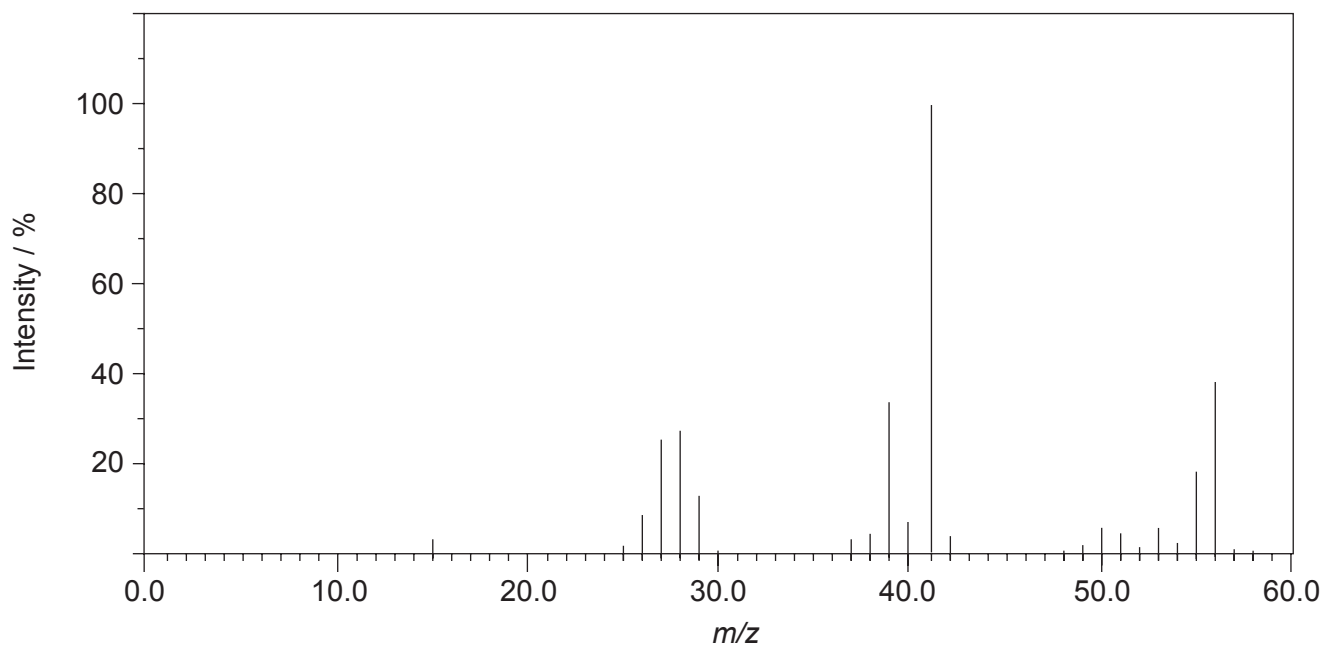
(Option A continues on the following page)



(Option A continued)

2. The structure of an unknown compound **A** with empirical formula CH_2 can be determined using information from a variety of analytical techniques.

(a) The mass spectrum of **A** is shown below.



[Source: <http://webbook.nist.gov> (2013)]

- (i) Deduce the formula of the molecular ion from the mass spectrum. [1]

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- (ii) Deduce the formulas of the fragments which give rise to peaks at $m/z = 27$ and 29. [1]

$m/z = 27$:

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$m/z = 29$:

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(Option A continues on the following page)

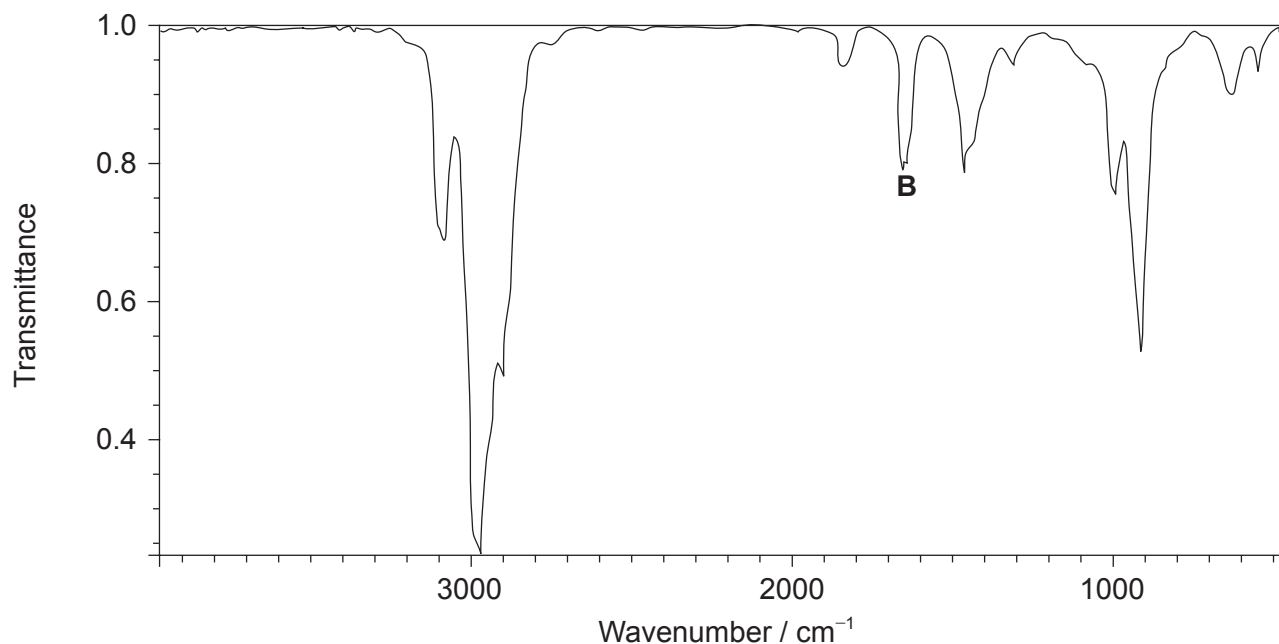


44EP03

Turn over

(Option A, question 2 continued)

(b) The infrared (IR) spectrum of **A** is shown below.



[Source: <http://webbook.nist.gov> (2013)]

(i) Identify the bond responsible for the IR absorption at **B**. [1]

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(ii) Deduce a structural formula consistent with the data. [1]

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(iii) Explain the presence of a doublet in the high-resolution proton nuclear magnetic resonance (^1H NMR) spectrum of **A**. [3]

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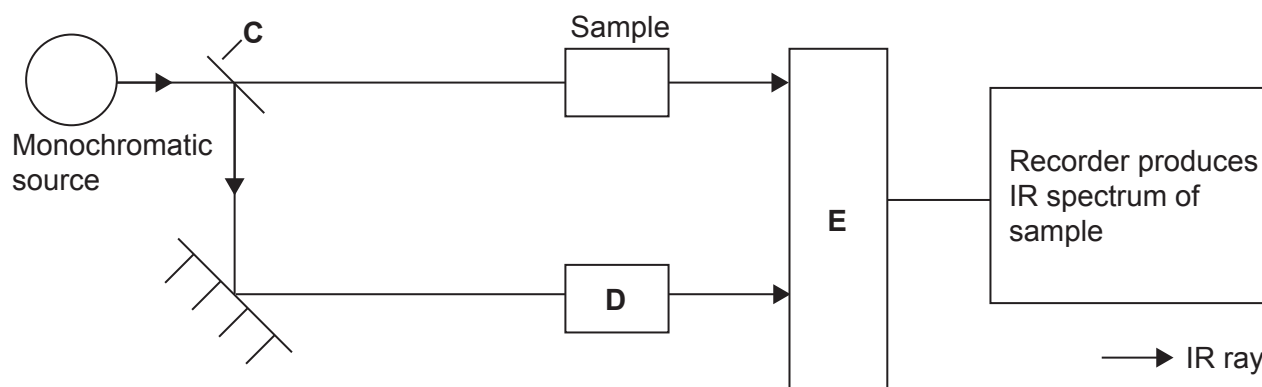
(Option A continues on the following page)



(Option A, question 2 continued)

- (iv) One isomer of **A** has only one signal in its ^1H NMR spectrum. Deduce the structural formula of this isomer. [1]

- (c) (i) The IR spectrum was obtained using a double-beam spectrometer. The principal components of the instrument are shown below.



Describe the functions of **C**, **D** and **E**.

[3]

C:

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D:

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E:

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(Option A continues on the following page)



44EP05

Turn over

(Option A, question 2 continued)

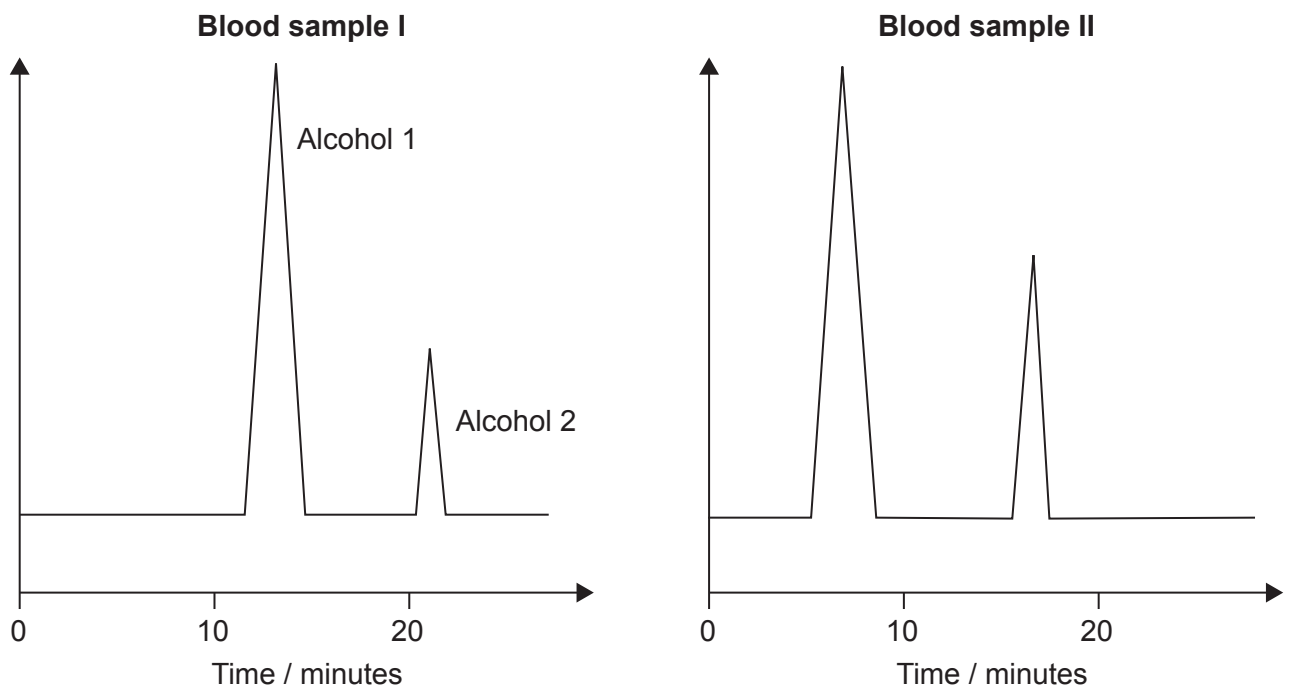
- (ii) The range of absorbances between $1500\text{--}500\text{ cm}^{-1}$ is generally called the fingerprint region. Outline what happens on a molecular level when radiation in this region is absorbed, and suggest how the region is used in chemical analysis. [2]

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3. Two blood samples are analysed for ethanol levels using gas-liquid chromatography (GLC) with a non-polar stationary phase. The same amount of propan-1-ol was added to both samples as a reference.



- (a) (i) Identify which alcohol in sample I is ethanol, justifying your choice. [1]

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(Option A continues on the following page)



(Option A, question 3 continued)

(ii) Outline which blood sample contains the most ethanol. [1]

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(b) Identify which sample is analysed at a higher temperature, justifying your choice. [1]

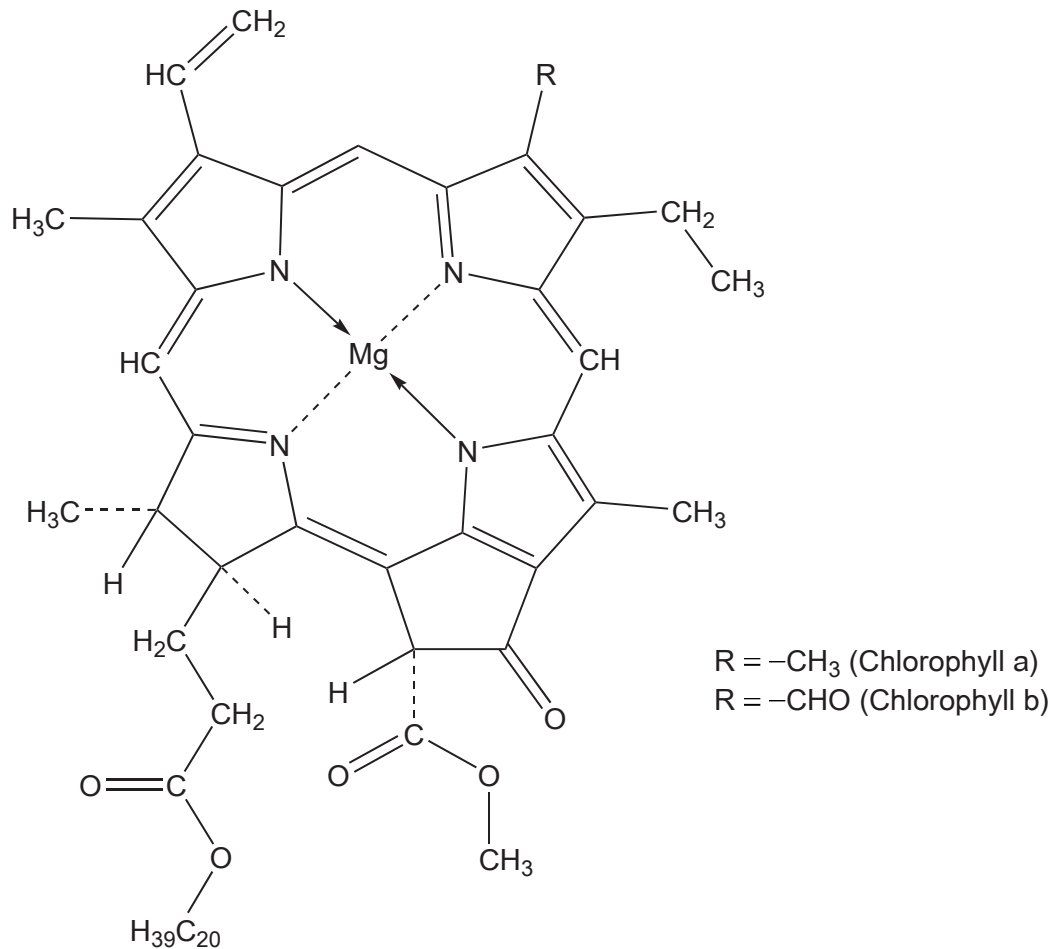
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(Option A continues on the following page)



(Option A continued)

4. The structure of chlorophyll, the pigment found in green plants, is shown below.



Explain the colour of the pigment with reference to the molecular structure.

[3]

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End of Option A



Option B — Human biochemistry

5. The building blocks of human proteins are the 2-amino acids with the general formula $\text{H}_2\text{N}-\text{CHR}-\text{COOH}$, where R represents a side-chain specific to each amino acid. A list of these amino acids and their isoelectric points is given in table 19 of the data booklet.

- (a) (i) Identify the amino acid with the empirical formula $\text{C}_3\text{H}_7\text{ON}_2$. [1]

.....

- (ii) Hydrophobic groups do not like to reside in an aqueous environment and are non-polar. Identify **two** amino acids with a hydrophobic side-chain. [1]

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- (iii) Deduce the structures of valine in a solution with a pH of 4.0. [1]

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- (b) Proteins carry out a number of important functions in the body. State the function of collagen. [1]

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(Option B continues on the following page)



(Option B continued)

6. Lipids are a diverse group of compounds found in the body.

- (a) Compare the structures and polarities of fats and phospholipids, giving **one** similarity and **one** difference in structure and **one** difference in polarity. [3]

Similarity in structure:

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.....

Difference in structure:

.....
.....

Difference in polarity:

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.....

- (b) Cholesterol is one of the most important steroids. It plays an essential role in metabolism and is the starting point for the synthesis of many important chemicals in the body.

Distinguish between **HDL** and **LDL** cholesterol in terms of their composition and their effect on health. [2]

Composition:

.....
.....

One effect on health:

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.....

(Option B continues on the following page)



(Option B, question 6 continued)

- (c) (i) Iron is an essential mineral needed in the body.

Identify **two** properties of iron ions that allow it to carry out its functions in the body. [2]

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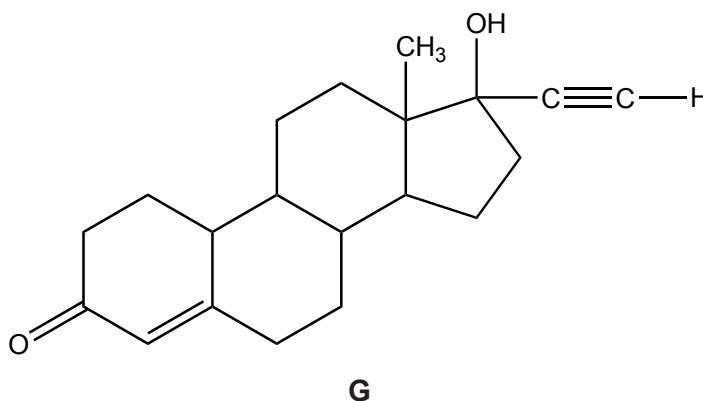
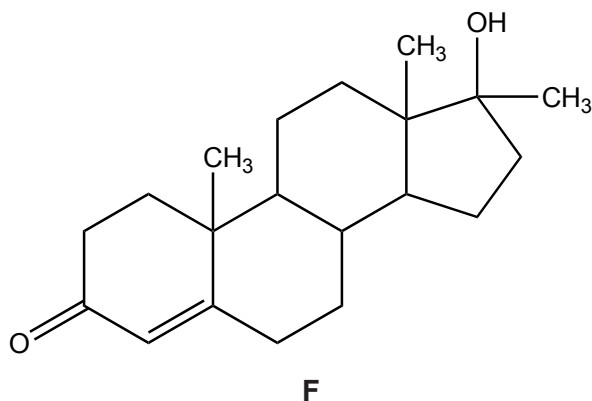
- (ii) Distinguish between the role of iron ions in oxygen transport and copper ions in electron transport with reference to the complexes and the oxidation states involved. [2]

| | Complex | Oxidation state(s) |
|---|---------|--------------------|
| Role of iron ions in oxygen transport | | |
| Role of copper ions in electron transport | | |

(Option B continues on the following page)

(Option B continued)

7. **F** and **G** are two synthetic hormones. The structures of some natural hormones are given in table 21 of the data booklet.



- (a) A number of famous athletes have been banned from competition for using hormone **F**. Explain, with reference to its structure, why hormone **F** improves performance. [2]

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- (b) **G** was first patented as a drug in 1956.

Compare the structure of **G** with that of progesterone, in terms of functional groups, by stating **one** similarity and **one** difference. [2]

Similarity in structure:

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Difference in structure:

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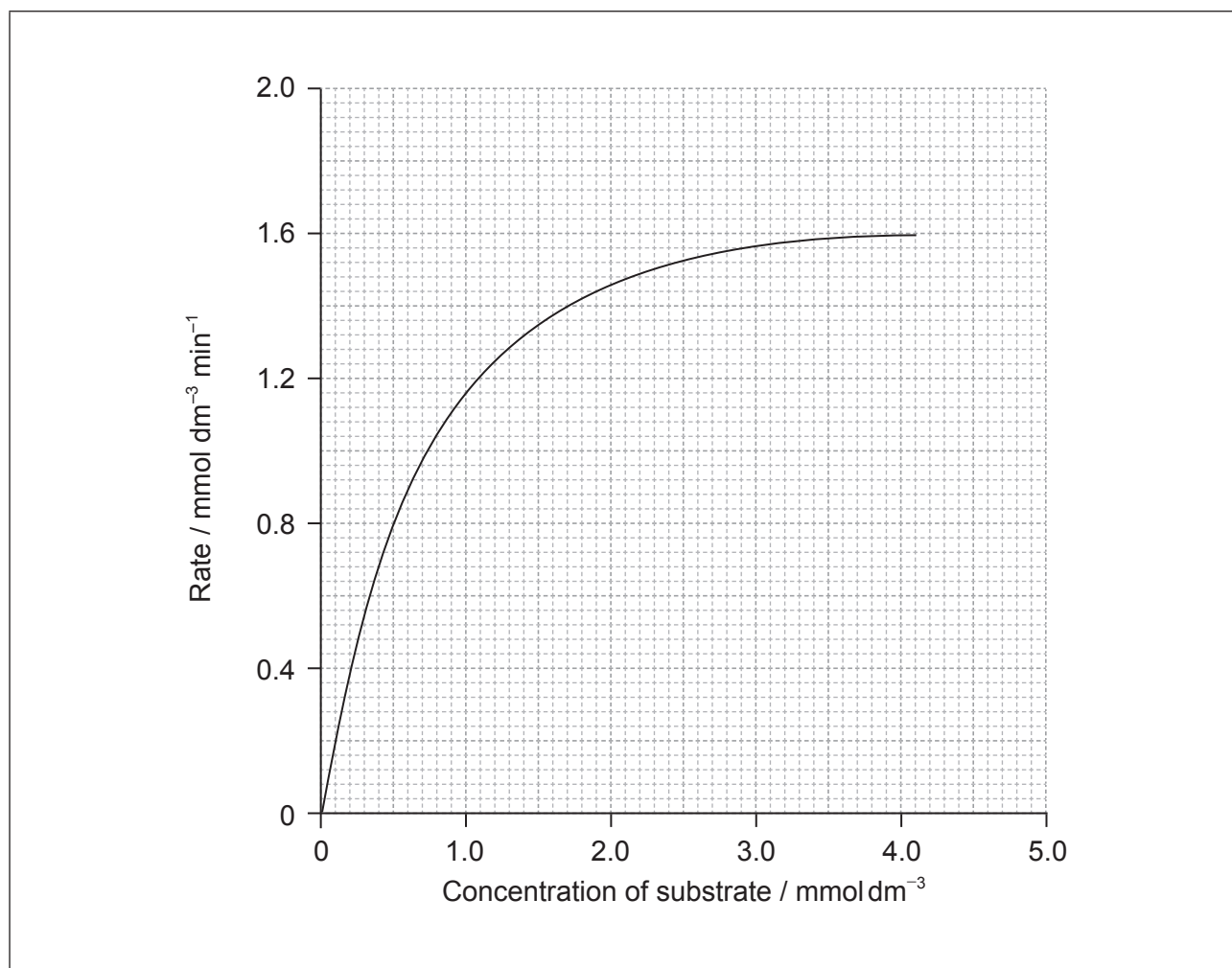
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(Option B continues on the following page)



(Option B continued)

8. The graph below shows the effect of substrate concentration on the rate of an enzyme-catalysed reaction.



- (a) Outline the relationship between enzyme activity and concentration of the substrate. [2]

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(Option B continues on the following page)



(Option B, question 8 continued)

- (b) Explain how competitive inhibition in an enzyme-catalysed reaction takes place. [2]

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- (c) Sketch, on the graph on page 13, a curve which shows competitive inhibition occurring in this reaction. [2]

- (d) Silver ions bond with sulfur atoms in an enzyme and change its tertiary structure and activity. Predict the effect of silver ions on the values of V_{\max} and K_m of this enzyme. [2]

V_{\max} :
.....

K_m :
.....

End of Option B



Option C — Chemistry in industry and technology

9. The large-scale production of iron is important for the industrial development of many countries.

- (a) (i) Magnetite, Fe_3O_4 , is a common ore of iron. Calculate the average oxidation state of iron in the compound and comment on your answer. [2]

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- (ii) State the equation for the reduction of this ore to iron with carbon monoxide. [1]

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- (b) Much of the iron produced in a blast furnace is converted into steel. The properties of the steel can be adapted for use by heat treatment. Describe the annealing process and its effect on the steel. [2]

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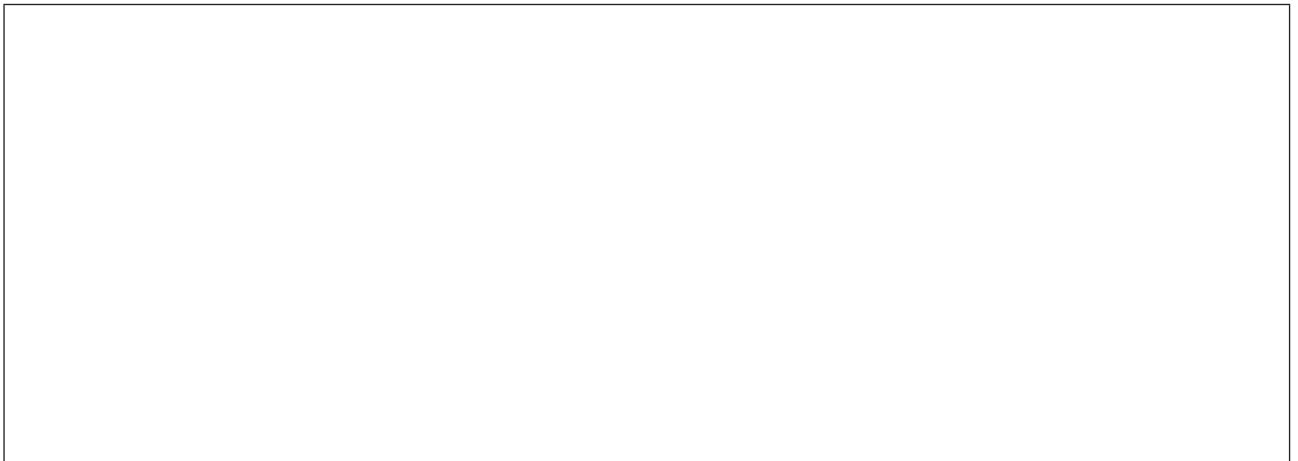
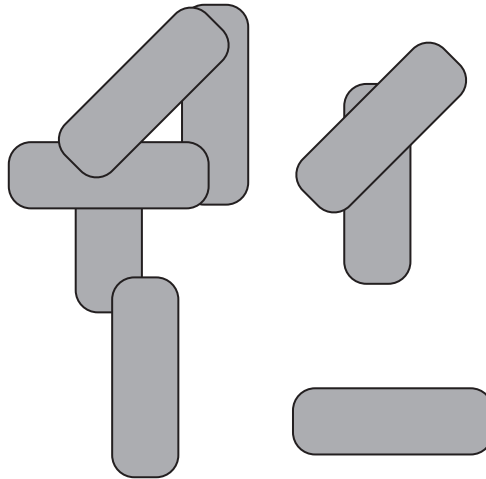
(Option C continues on the following page)



(Option C continued)

10. Thermotropic liquid crystals are widely used in display devices and sensors.

- (a) The diagram below shows eight molecules in the liquid state. Suggest, with a diagram, a possible arrangement that these rod-shaped molecules could adopt in the nematic liquid-crystal phase. [2]

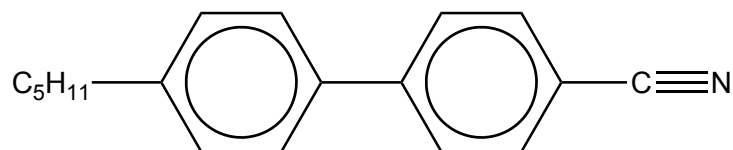


(Option C continues on the following page)



(Option C, question 10 continued)

- (b) The structure of a material used in electrical display devices is shown below.



- (i) Suggest, with reference to the structure, why the molecule is able to change orientation in an electric field. [1]

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- (ii) Explain why a liquid-crystal device may be unreliable at low temperatures. [1]

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- (c) Describe and explain, in molecular terms, the workings of a twisted nematic liquid crystal. [4]

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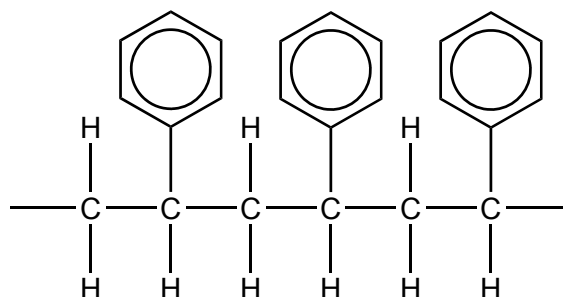
(Option C continues on the following page)



(Option C continued)

11. The development and application of plastics was one of the most important technological developments of the last century.

The diagram below represents a section of a polymer.



- (a) An expanded form of the plastic is often used in packaging. Describe how this is manufactured. [2]

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- (b) Discuss **two** advantages and **one** disadvantage of using the expanded form as a packaging material. [3]

Two advantages:

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One disadvantage:

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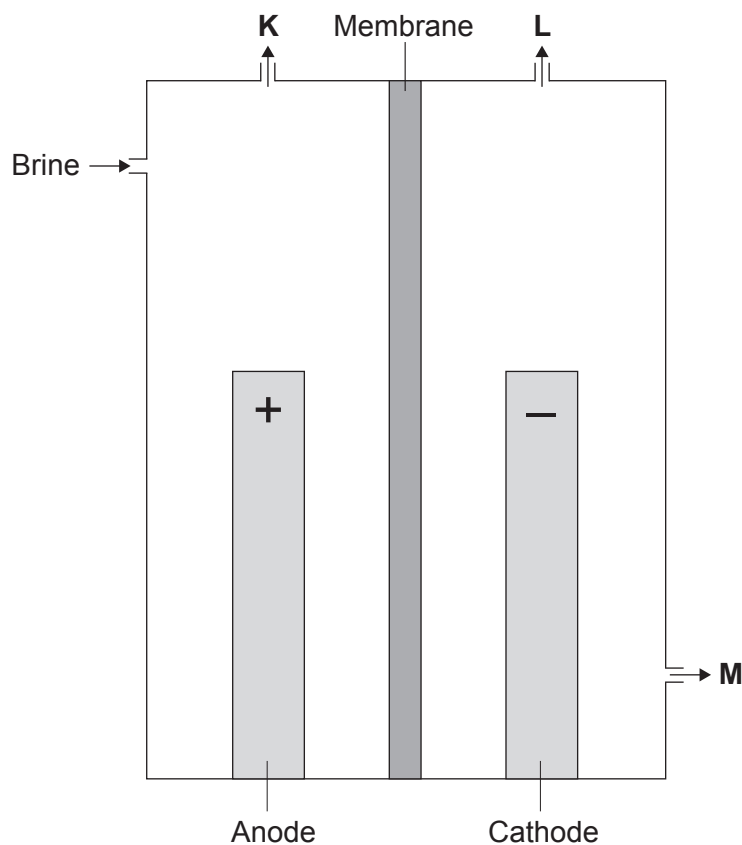
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(Option C continues on the following page)



(Option C continued)

12. The membrane chlor-alkali electrolysis cell, shown below, is increasingly used in preference to both mercury and diaphragm cells. It has greater efficiency and less impact on the environment.



- (a) Explain the function of the membrane.

[2]

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(Option C continues on the following page)



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Turn over

(Option C, question 12 continued)

- (b) Identify the products **K** and **M**. [1]

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|-------------|
| K: |
| M: |

- (c) State the half-equations for the reactions at each electrode. [2]

| |
|--|
| Negative electrode (cathode): |
| Positive electrode (anode): |

- (d) Discuss **two** differences between the membrane cell and the diaphragm cell. [2]

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End of Option C



Option D — Medicines and drugs

13. Nicotine has led to over two billion people being addicted to smoking. Its structure is shown in table 20 of the data booklet.

- (a) (i) Explain, with reference to its molecular structure, why nicotine is basic. [2]

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- (ii) Outline how nicotine passes into the bloodstream within seconds of a cigarette being smoked. [1]

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- (iii) Nicotine replacement therapy involves administering the drug in ways other than smoking. Describe **two** other methods of administering nicotine. [2]

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(Option D continues on the following page)



(Option D, question 13 continued)

(b) Cannabis is a mind-altering drug that is commonly smoked in combination with tobacco.

(i) Identify the active ingredient in cannabis. [1]

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(ii) Suggest why this active ingredient might be prescribed to some patients. [1]

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14. Many common illnesses are caused by viral infections.

(a) State the chemical composition of a virus. [2]

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(b) Acyclovir is an antiviral drug used to treat herpes infections. Outline **two** ways in which antiviral drugs work. [2]

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(Option D continues on the following page)



(Option D, question 14 continued)

- (c) Discuss **two** difficulties associated with the development of drugs for the effective treatment of AIDS. [2]

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15. Analgesics can be prescribed for treating various types of pain.

- (a) (i) The structure of aspirin is shown in table 20 of the data booklet. Suggest a suitable reagent for the conversion of aspirin to its sodium salt. [1]

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- (ii) Explain the advantage of converting aspirin into its sodium salt. [2]

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- (b) (i) Compare the structures of diamorphine (heroin) and morphine. Their structures are given in table 20 of the data booklet. [2]

Two similarities:

.....

.....

One difference:

.....

.....

(Option D continues on the following page)



(Option D, question 15 continued)

- (ii) Suggest a reagent that could be used to convert morphine into diamorphine. [1]

.....

- (c) Explain why diamorphine is a more potent drug than morphine. [2]

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16. Combinatorial chemistry uses solid-phase techniques which have increased the efficiency of drug production.

- (a) Explain how solid-phase techniques increase the productivity of a process, with reference to condensation reactions between a series of amino acids. [2]

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- (b) Describe how computers are used in drug design. [2]

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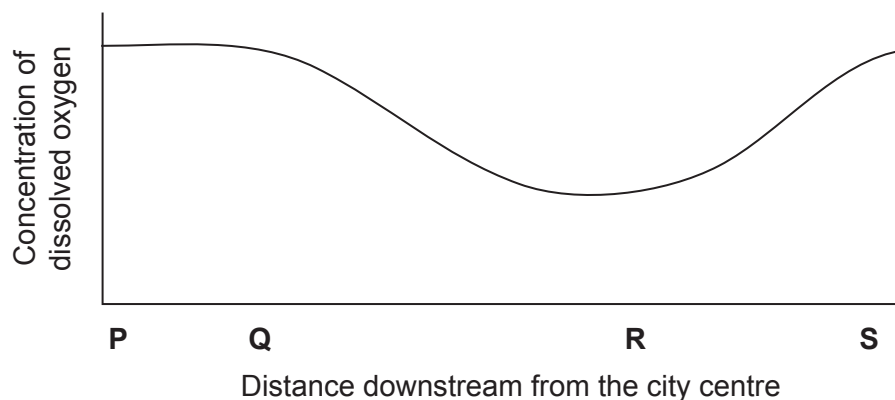
End of Option D



Option E — Environmental chemistry

17. The oxygen levels in water can change for a number of reasons.

- (a) Some organic matter is added to a river from a food processing factory near a city centre. The graph represents the variation in the concentration of dissolved oxygen along the river as it flows away from the city.



Identify which letter is the most likely location for the food processing factory, giving a reason for your choice. [2]

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- (b) The use of phosphate fertilizers can also produce changes in the oxygen concentrations in a river.

- (i) Phosphate ions can be removed from a solution by adding calcium ions. State the ionic equation for the reaction of calcium ions with phosphate ions. [1]

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- (ii) Deduce the expression for the solubility product constant, K_{sp} , of calcium phosphate. [1]

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(Option E continues on the following page)



(Option E, question 17 continued)

- (iii) The solubility product of calcium phosphate is 2.07×10^{-33} at 298 K. Determine the concentration, in mol dm^{-3} , of calcium ions, Ca^{2+} , in a saturated aqueous solution of calcium phosphate. [3]

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- (c) State a non-chemical reason for the decrease in oxygen concentration. [1]

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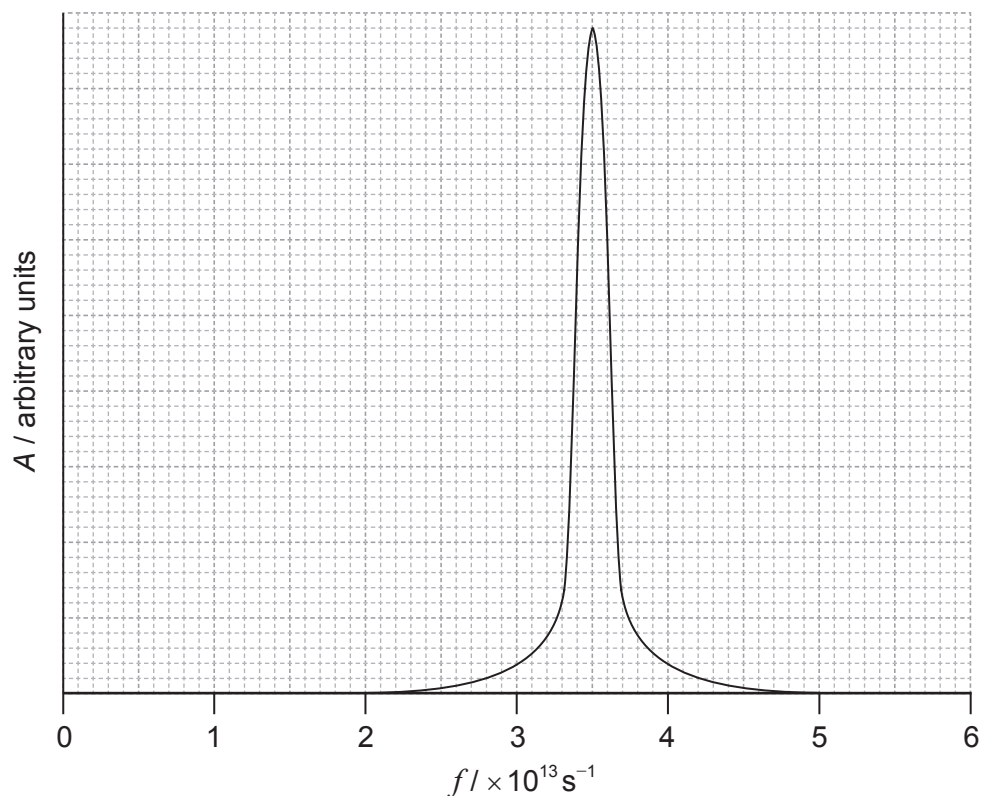
(Option E continues on the following page)



(Option E continued)

18. The atmospheric greenhouse effect is caused by several gases.

- (a) The graph shows part of the absorption spectrum of an oxide of nitrogen in which the intensity of absorbed radiation A is plotted against frequency f .



- (i) Determine the wavelength of the radiation absorbed, in m, using table 1 of the data booklet. (The speed of light, c , is 3.0×10^8 .)

[1]

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- (ii) Deduce the region of the electromagnetic spectrum to which this belongs.

[1]

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(Option E continues on the following page)



44EP27

Turn over

(Option E, question 18 continued)

(b) State the chemical formula of this oxide of nitrogen. [1]

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(c) Discuss the relative contributions of carbon dioxide and this oxide of nitrogen to global warming. [2]

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19. Intensive farming changes the composition of soils and may lead to soil degradation.

(a) Explain how agriculture removes soil nutrients and how they can be replaced. [2]

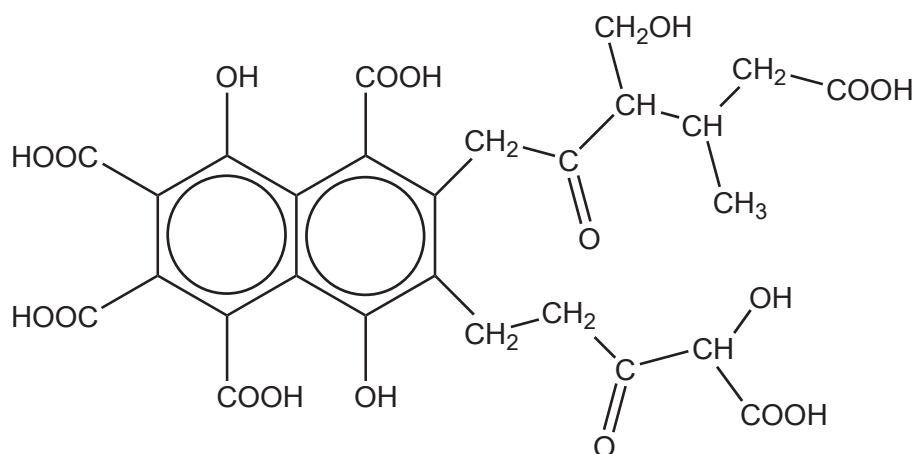
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(Option E continues on the following page)



(Option E, question 19 continued)

- (b) Fulvic acid is an important constituent of soil organic matter (SOM). A representation of its structure is shown below.



- (i) Outline how this structure of fulvic acid is able to retain water in soil. [2]

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- (ii) Describe **two** chemical functions of SOM. [2]

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- (iii) Outline how the use of pesticides and fertilizers can cause soil degradation. [2]

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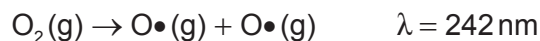
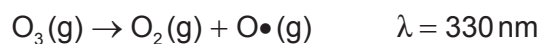
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(Option E continues on the following page)



(Option E continued)

20. Ozone and oxygen both dissociate in the ozone layer when they absorb ultraviolet light of different wavelengths.



- (a) Explain, on a molecular level, why ozone dissociates with radiation of a longer wavelength than oxygen. [2]

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- (b) Nitrogen(II) oxide, NO, is a primary pollutant that depletes the ozone layer. State **two** equations that show how this oxide catalyses the depletion of ozone in the stratosphere. [2]

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End of Option E



Option F — Food chemistry

21. Although people may consume a large amount of food, they may still not consume sufficient nutrients.

(a) Distinguish between a **food** and a **nutrient**. [2]

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|--------------------------------------|
| Food: |
| Nutrient: |

(b) (i) Describe **one** similarity and **one** difference between the structure of a saturated and an unsaturated fat. [2]

| |
|-------------------------------|
| Similarity: |
| Difference: |

(ii) Outline **one** factor that increases the melting point of oils and fats other than degree of saturation. [1]

| |
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(Option F continues on the following page)



Turn over

(Option F, question 21 continued)

- (c) State the names of **two** types of nutrient, other than lipids and water, and the purpose each serves in the body. [2]

| Nutrient | Purpose |
|---------------------------|---------------------------|
| <p>.....</p> <p>.....</p> | <p>.....</p> <p>.....</p> |
| <p>.....</p> <p>.....</p> | <p>.....</p> <p>.....</p> |

22. Many food labels now include a “best-before” expiry date to ensure that good-quality food is on sale.

- (a) Explain the meaning of the term shelf life and how it relates to the “best-before” date. [2]

| |
|---|
| <p>Shelf life:</p> <p>.....</p> <p>.....</p> <p>“Best-before” date:</p> <p>.....</p> <p>.....</p> |
|---|

(Option F continues on the following page)



(Option F, question 22 continued)

- (b) Explain, giving their names, the two types of reaction by which foods may become rancid. [2]

Reaction 1:

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Reaction 2:

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23. Mayonnaise is a thick creamy sauce made by blending oil, egg yolk and either lemon juice or vinegar.

- (a) Oil and vinegar are immiscible. Describe what you would expect to happen when oil and vinegar are shaken together and then left standing for a period of time. [2]

When shaken together:

.....
.....

After standing:

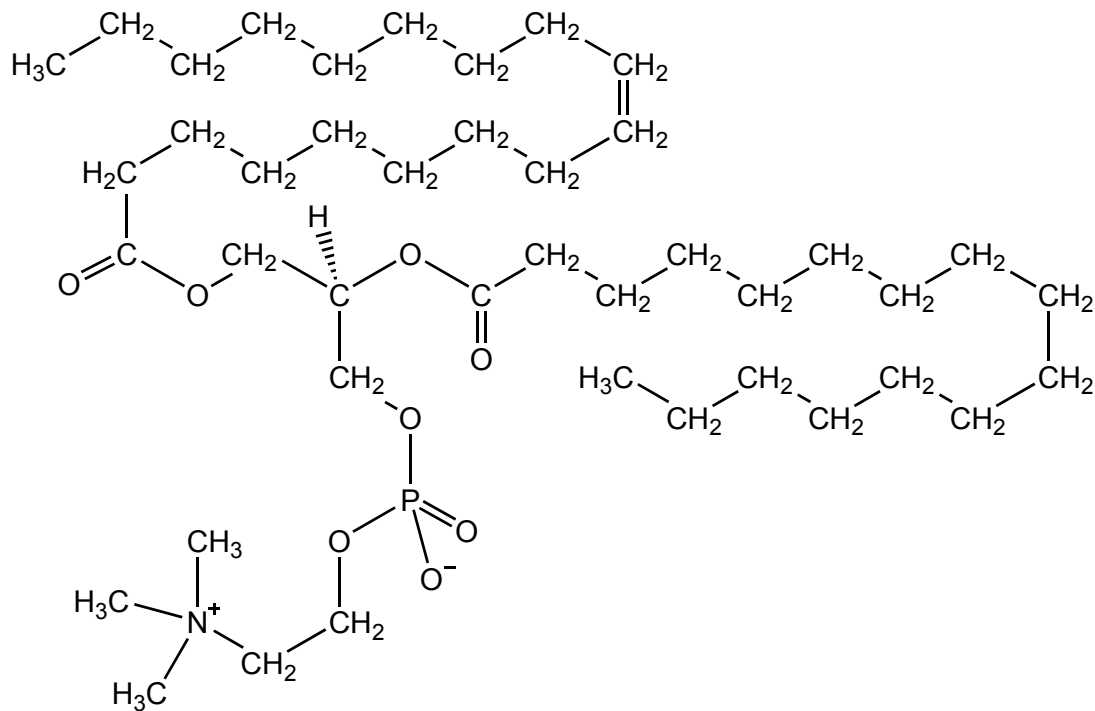
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(Option F continues on the following page)



(Option F, question 23 continued)

(b) Lecithin, found in egg yolk, contains this compound:



Explain, with reference to the structure, how lecithin acts as an emulsifier.

[2]

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24. Strawberries have a bright red colour and a distinctive smell.

(a) Ripe strawberries contain the flavylum cation, an anthocyanin. By referring to table 22 of the data booklet, explain why ripe strawberries are red.

[3]

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(Option F continues on the following page)



(Option F, question 24 continued)

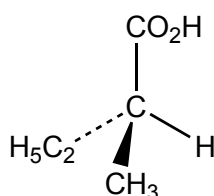
- (b) Outline the difference in solubility in water between anthocyanins and carotenes, by referring to their structures in table 22 of the data booklet. [2]

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- (c) One of the many chemicals present in the smell of strawberries is the chiral compound (S)-2-methylbutanoic acid named by the R/S convention.



Explain why the structure given is S. [3]

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- (d) Outline another convention used for specifying a molecule's spatial configuration and its relationship with the (+) and (–) notation (previously referred to as *d* and *l*). [2]

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End of Option F



Option G — Further organic chemistry

25. Halogenoalkanes can be synthesized from alkenes.

- (a) State the reagent needed and the type of reaction for converting but-1-ene to 2-bromobutane. [2]

| |
|---|
| Reagent: Type of reaction: |
|---|

- (b) (i) Explain, using curly arrows to represent the movement of electron pairs, the mechanism for converting but-1-ene to 2-bromobutane. [3]

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(Option G continues on the following page)



(Option G, question 25 continued)

- (ii) Explain why 2-bromobutane is the major product and 1-bromobutane is the minor product.

[2]

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(Option G continues on the following page)

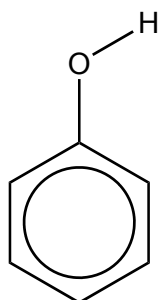


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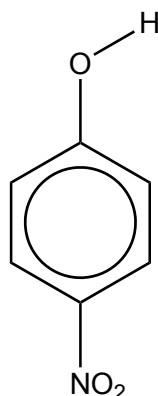
Turn over

(Option G continued)

26. Phenol and 4-nitrophenol are weak acids. Their structures are given below.



Phenol



4-nitrophenol

(a) Outline, using an equation, why phenol is more acidic than ethanol.

[3]

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(b) Explain which compound, phenol or 4-nitrophenol, is more acidic.

[3]

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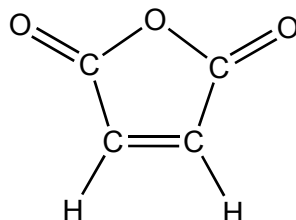
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(Option G continued)

27. Maleic anhydride is used in the production of unsaturated polyester resins for use in fibre-reinforced plastics.



Maleic anhydride

- (a) State the equation for the reaction of maleic anhydride with water. [1]

- (b) State the names of the functional groups present in the product in part (a). [1]

.....

- (c) State the type of reaction that occurs when maleic anhydride reacts with a nucleophile. [1]

.....

(Option G continues on the following page)



(Option G continued)

28. Grignard reagents are common organometallic reactants.

- (a) State the reagent and condition to form a Grignard reagent from 1-bromopropane. [2]

| |
|--|
| Reagent: Condition: |
|--|

- (b) Identify the type of alcohol formed when the Grignard reagent made in part (a) reacts with butan-2-one and then water. [1]

| |
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| |
|-------|

29. Most industrial processes involve two or more reaction stages.

- (a) (i) Describe the nitration of benzene. [2]

| |
|--|
| Type of reaction: Reagents: |
|--|

(Option G continues on the following page)



(Option G, question 29 continued)

- (ii) Predict an equation for the formation of the nitrating species. [1]

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- (b) Benzene can also be alkylated. State and explain how the products differ when nitration is carried out before or after alkylation. [3]

Nitration, then alkylation:
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Alkylation, then nitration:
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End of Option G



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