

Chemistry

Higher level

Paper 3

Monday 16 November 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 – 5
Option B — Human biochemistry	6 – 11
Option C — Chemistry in industry and technology	12 – 16
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Option E — Environmental chemistry	23 – 26
Option F — Food chemistry	27 – 32
Option G — Further organic chemistry	33 – 37



Option A — Modern analytical chemistry

1. Infrared (IR) spectroscopy is a powerful analytical technique.

(a) Describe how information from an IR spectrum can be used to identify the bonds in a molecule. [2]

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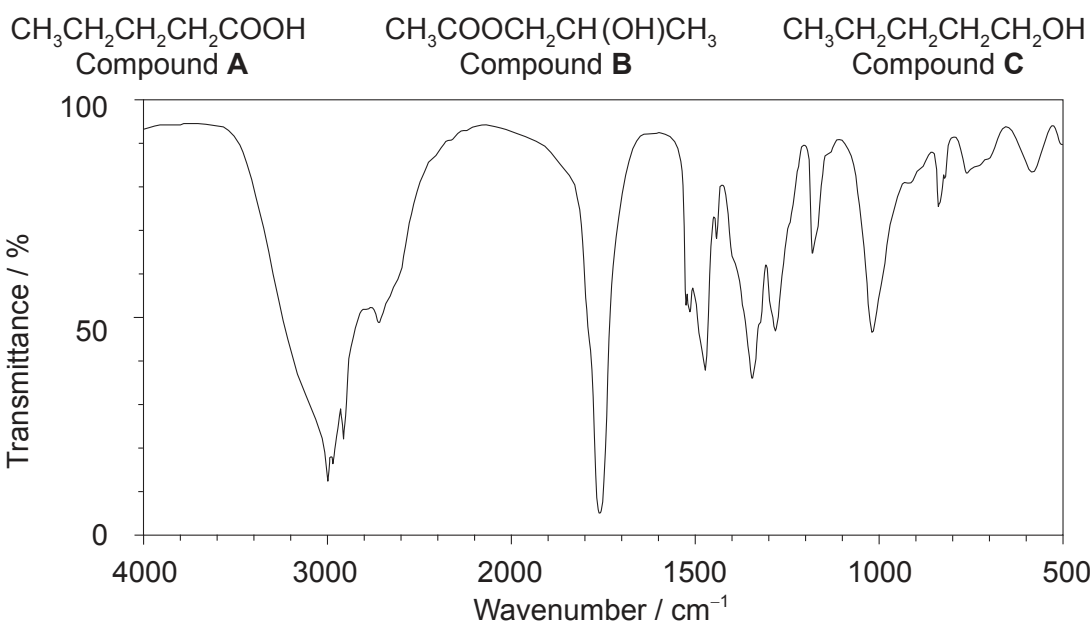
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(b) Explain which of the following compounds would produce the IR spectrum below by referring to the wavenumbers of the relevant peaks found in table 17 of the data booklet. [3]



[Source SDBSWeb, <http://sdb.s.db.aist.go.jp> (National Institute of Advanced Industrial Science and Technology)]

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(Option A continues on the following page)



44EP02

(Option A, question 1 continued)

- (c) Explain how the low resolution ^1H NMR spectra of the three compounds in part (b) can be used to distinguish between them. Ignore chemical shifts. [3]

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2. Atomic absorption (AA) spectroscopy is used to detect very low concentrations of metal ions.

- (a) State **one** application of AA spectroscopy. [1]

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- (b) Describe the uses of the fuel and the monochromatic detector in the AA spectrophotometer. [2]

Fuel:
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Monochromatic detector:
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(Option A continues on the following page)



44EP03

Turn over

(Option A continued)

3. Absorption and emission spectra can be used to identify elements.

(a) Distinguish between the processes within the atom that give rise to absorption and emission spectra. [2]

Absorption spectra:

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Emission spectra:

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(b) Outline how the **emission** spectrum of a sample of gaseous element is produced. [2]

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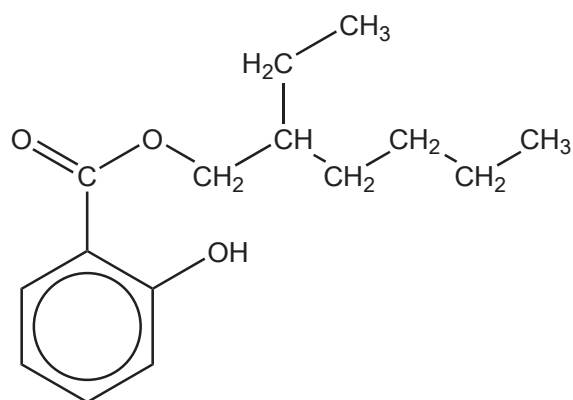
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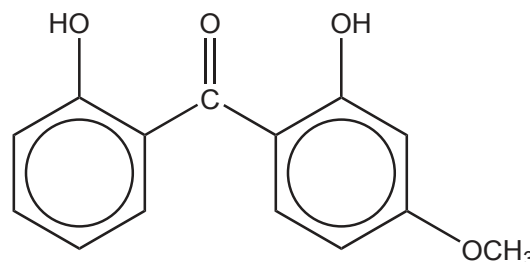


(Option A continued)

4. Octyl salicylate and dioxybenzone are compounds used in sunscreens to absorb high energy ultraviolet (UV) radiation from the sun.



Octyl salicylate



Dioxybenzone

- (a) State the structural feature of the molecules that absorbs high energy UV radiation. [1]

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- (b) Predict which of the two molecules provides better protection against high energy UV radiation. Explain your reasoning. [3]

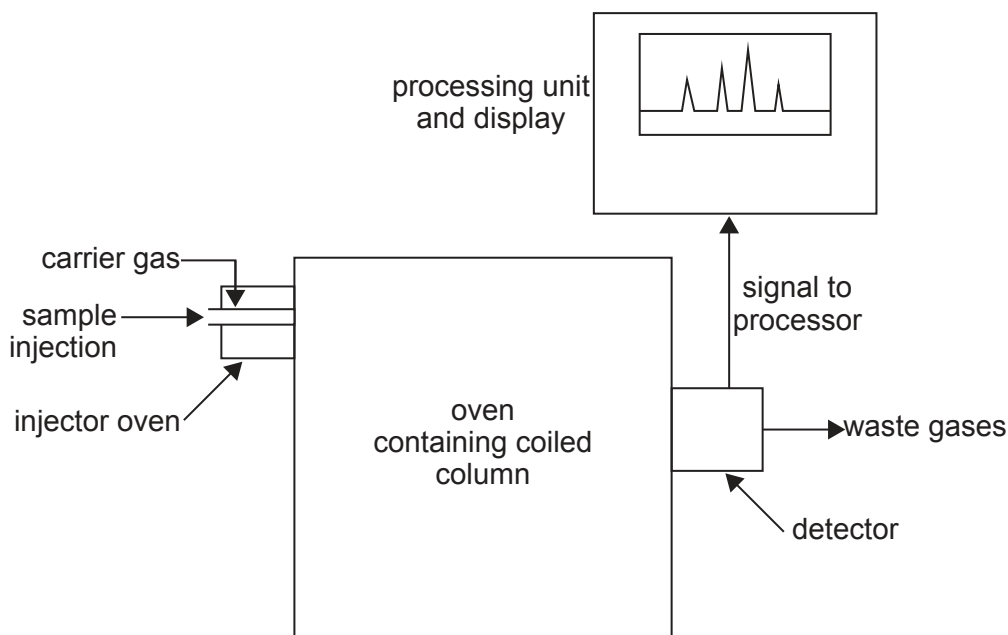
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(Option A continues on the following page)



(Option A continued)

5. Gas-liquid chromatography (GLC) can be used to determine the concentration of alcohol in a sample of blood. A simplified diagram of the apparatus is shown.



[Source: Adapted from www.chemguide.co.uk (2014)]

- (a) State suitable materials for the stationary and mobile phases in GLC. [2]

Stationary phase:
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Mobile phase:
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- (b) Explain how the substances in the blood sample are separated by GLC. [2]

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(Option A continues on the following page)



44EP06

(Option A, question 5 continued)

- (c) Outline how the concentration of alcohol is obtained from the GLC processing unit. [1]

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- (d) Suggest why GLC might not be suitable for determining the concentration of sugar in the blood. [1]

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End of Option A

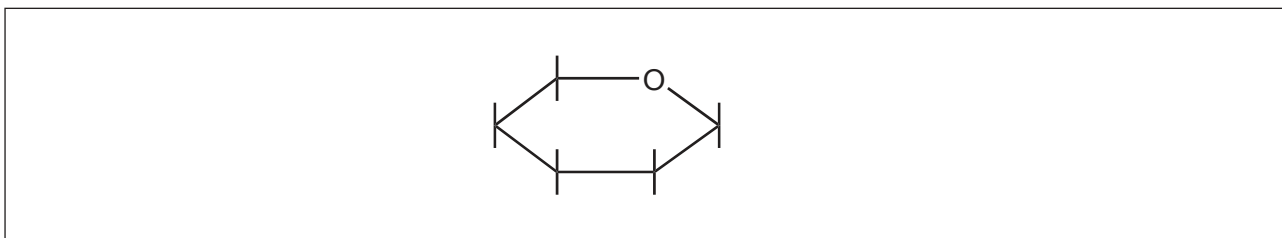


44EP07

Turn over

Option B — Human biochemistry

6. Glucose is a carbohydrate. A skeletal structure is shown for one of the ring structures of glucose.



- (a) (i) Draw the structure of β -glucose by adding the constituent atoms and groups to the diagram. [1]
- (ii) State how the α -glucose would differ from the β -glucose. [1]

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- (b) β -glucose polymerizes by condensation to form cellulose. State the specific type of linkage formed between the monomer units. [1]

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7. (a) Vitamins are micronutrients which are vital for good health.

Deduce the relative solubilities of vitamins C and D in water by referring to the structures shown in table 21 of the data booklet. [2]

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(Option B continues on the following page)



(Option B, question 7 continued)

- (b) The absence of micronutrients from the diet can cause significant health problems. Suggest **three** ways in which these problems could be solved. [3]

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8. Insulin is a globular protein which controls cellular uptake of glucose. Glucose test strips impregnated with an enzyme can be used to detect glucose in urine.

- (a) (i) Describe the mechanism of enzyme action by reference to its three-dimensional structure. [2]

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- (ii) Explain, with reference to the enzyme structure, why it is important to store the test strips below 40 °C. [2]

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(Option B continues on the following page)



44EP09

Turn over

(Option B, question 8 continued)

- (b) Lysine is one of the amino acids found in the polypeptide chain in insulin and its structure is shown in table 19 of the data booklet. It can exist in different structural forms depending on the pH of its solution.

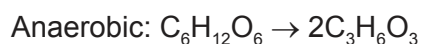
Draw the structure of the most abundant form of lysine present under the following conditions.

[2]

At its isoelectric point:

At a pH well below its isoelectric point:

9. (a) Aerobic and anaerobic respiration in human beings can be represented by the following overall equations.



Identify the process which:

[1]

(i) releases most energy per mole of glucose.
.....

(ii) is not shown by a redox equation.
.....

(Option B continues on the following page)



44EP10

(Option B, question 9 continued)

- (b) Cytochromes and hemoglobin are both involved in the process of respiration. Outline the role of each metal complex in respiration. [2]

Cytochromes:
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Hemoglobin:
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10. Hormones are regulatory substances produced in the body.

- (a) Deduce the differences between progesterone and estradiol by naming their specific functional groups. The structures are given in table 21 of the data booklet. [2]

Two functional groups in progesterone:
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.....

Two functional groups in estradiol:
.....
.....

(Option B continues on the following page)



44EP11

Turn over

(Option B, question 10 continued)

- (b) Anabolic steroids are closely related to testosterone. State **one** medical use of anabolic steroids and **one** example of abuse of these compounds. [2]

Medical use:

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.....

Example of abuse:

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11. The discovery of the DNA double helix has led to many advances in our understanding of life processes. DNA profiling allows an individual to be identified by DNA analysis.

- (a) Explain the key features of the double helical structure of DNA. [3]

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- (b) State one application of DNA profiling. [1]

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End of Option B

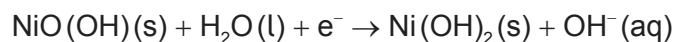
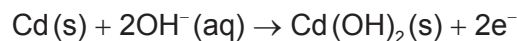


44EP12

Option C — Chemistry in industry and technology

12. The nickel–cadmium (NiCad) battery is rechargeable.

During discharge, the following half-reactions take place:



(a) State the name of the substance used as the negative electrode (anode) during discharge and the name of the substance used as the electrolyte. [2]

Negative electrode (anode): Electrolyte:

(b) When the NiCad battery is recharged, the electrodes are connected to a power supply and electrolysis occurs. State the half-equations for the chemical reactions during recharging. [1]

Negative electrode (cathode): Positive electrode (anode):
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(Option C continues on the following page)



44EP13

Turn over

(Option C, question 12 continued)

(c) Compare rechargeable batteries and fuel cells.

[3]

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13. Nanotechnology manipulates the properties of substances by positioning individual atoms or molecules in specific ways. Carbon nanotubes are a product of nanotechnology.

(a) Outline how the bonding in carbon nanotubes causes them to be much stronger than graphite.

[2]

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(b) Suggest **two** health concerns that arise due to the small size of the substances used in nanotechnology.

[2]

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(Option C continues on the following page)



44EP14

(Option C continued)

14. Steel is formed by blowing oxygen into a mixture of iron and lime in the basic oxygen converter.

(a) State the equations for **two** reactions that occur in the basic oxygen converter. [2]

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(b) Low-carbon and high-carbon steels are produced in the basic oxygen converter. Distinguish between these **two** alloys in terms of their properties. [2]

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(Option C continues on the following page)

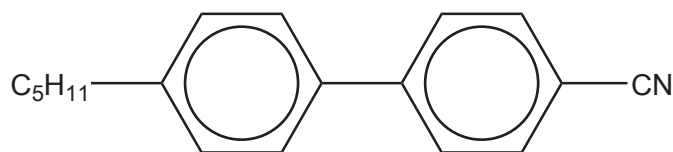


44EP15

Turn over

(Option C continued)

15. Biphenyl nitriles are thermotropic liquid-crystal materials. An example of a biphenyl nitrile is shown below.



4'-pentyl-4-biphenylcarbonitrile

- (a) Explain thermotropic behaviour in terms of the arrangement of molecules. [2]

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- (b) Explain the roles of the following groups in the thermotropic behaviour of biphenyl nitriles. [3]

Biphenyl group:

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Nitrile group:

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Long alkyl group:

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(Option C continues on page 18)



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will not be marked.

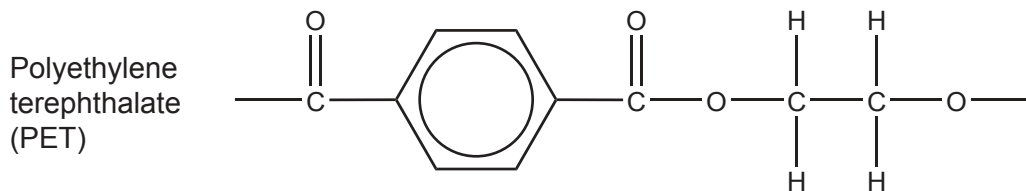
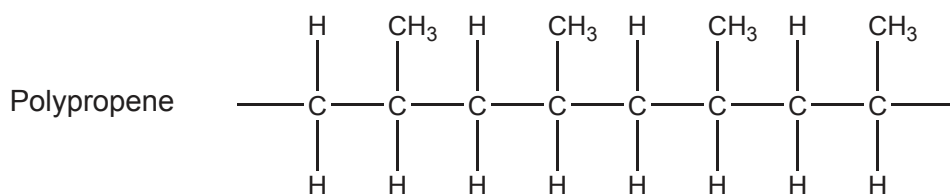
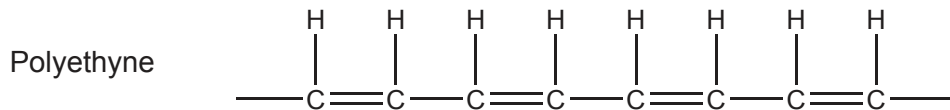
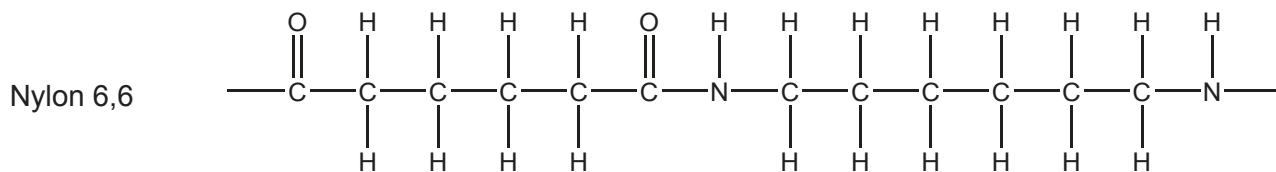


44EP17

Turn over

(Option C continued)

16. Consider the following polymers.



(Option C continues on the following page)



(Option C, question 16 continued)

- (a) Identify an addition polymer and a condensation polymer from the four polymers and the structural formulas of their monomers.

[3]

	Addition polymer
Name of polymer
Structural formula of monomer(s)	

	Condensation polymer
Name of polymer
Structural formula of monomer(s)	

(Option C continues on the following page)



44EP19

Turn over

(Option C, question 16 continued)

- (b) Outline how the properties of the *trans* isomer of polyethyne change when iodine is added to its monomer during polymerization.

[1]

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- (c) Discuss the environmental implications of the use of polyethylene terephthalate (PET).

[2]

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End of Option C



44EP20

Option D — Medicines and drugs

17. During the drug development process, clinical trials are carried out on humans to evaluate the effectiveness and safety of a new drug.

Explain the terms therapeutic window and tolerance. [2]

Therapeutic window:

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.....

Tolerance:

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18. Diamorphine is a strong analgesic which is synthesized from morphine. Both structures are given in table 20 of the data booklet.

(a) Identify the type of reaction which takes place when morphine is converted to diamorphine. [1]

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(b) Explain how the function of diamorphine differs from that of mild analgesics in the relief of pain. [2]

Diamorphine:

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Mild analgesics:

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(Option D continues on the following page)

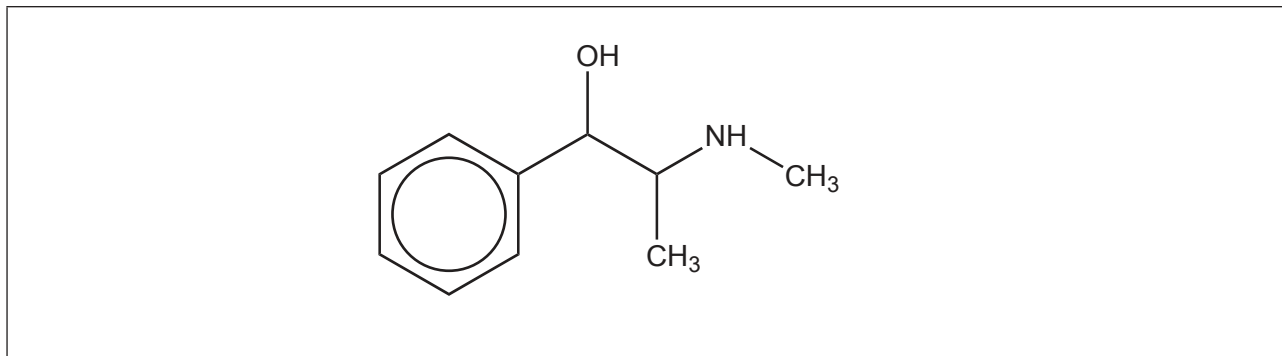


44EP21

Turn over

(Option D continued)

19. Pseudoephedrine is a sympathomimetic drug used as a stimulant and a decongestant.



(a) (i) Identify the chiral carbons in the molecule of pseudoephedrine by means of asterisks (*). [1]

(ii) Discuss the significance of chirality in drug action with reference to an example. [2]

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(b) Describe how chiral auxiliaries are used to synthesize the desired enantiomer of a drug. [2]

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(Option D continues on the following page)



(Option D, question 19 continued)

- (c) (i) State **two** physiological effects of stimulants. [2]

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- (ii) Outline the meaning of the term sympathomimetic drug. [1]

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- (iii) Explain why the drug is administered as the hydrochloride salt of pseudoephedrine. [2]

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(Option D continues on the following page)



44EP23

Turn over

(Option D continued)

20. The development of new antiviral and antibacterial drugs has become a focus for the pharmaceutical industry owing to significant global health threats from infections.

(a) Describe **two** ways in which antiviral drugs work. [2]

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(b) Discuss **two** effects of the overuse of antibiotics. [2]

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21. Ethanol consumption by drivers causes motor vehicle accidents. The presence of ethanol in the breath may be detected by using a breathalyser containing acidified potassium dichromate(VI).

(a) State the colour change and the type of reaction occurring when the test detects ethanol. [2]

Colour change:
.....
Type of reaction:
.....

(Option D continues on the following page)



(Option D, question 20 continued)

- (b) Blood ethanol levels can also be measured using an intoximeter which is either a fuel cell or an infrared (IR) spectrometer. Explain how the amount of ethanol can be determined using **one** of these techniques. [2]

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- 22.** The structures of the mind-altering drugs lysergic acid diethylamide (LSD) and psilocybin are shown in table 20 in the data booklet.

State the names of **two** functional groups which are present in both LSD and psilocybin. [2]

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End of Option D



44EP25

Turn over

Option E — Environmental chemistry

23. Lowering air pollutant emissions is a major concern for car manufacturers.

(a) Catalytic converters are used in car exhausts to lower the amounts of harmful gases released into the atmosphere.

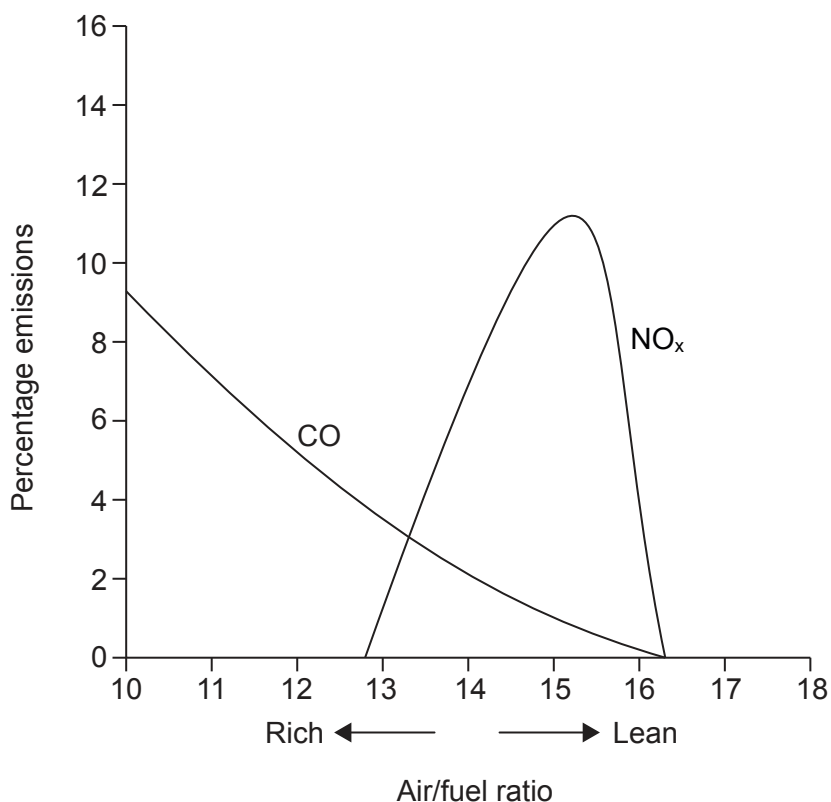
(i) State an equation for a reaction occurring in the catalytic converter. [1]

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(ii) Suggest why the palladium-based catalyst is spread into a very thin layer. [1]

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(b) A car manufacturer conducted tests in which the air/fuel ratio in the engine was altered and the amounts of pollutants released measured. The results are represented below.



(Option E continues on the following page)



(Option E, question 23 continued)

- (i) State and explain the effect of increasing the air/fuel ratio on CO emissions. [2]

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- (ii) Explain the changes in nitrogen oxide (NO_x) emissions as the air/fuel ratio increases. [4]

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- (iii) NO_x contributes to the formation of photochemical smog. Outline the formation of peroxyacetyl nitrates (PANs) in photochemical smog. [3]

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(Option E continues on the following page)



44EP27

Turn over

(Option E continued)

24. Soil degradation is an agricultural concern.

(a) Explain how soil salinization occurs. [2]

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(b) Describe the chemical functions of soil organic matter (SOM). [3]

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25. Chlorofluorocarbons (CFCs) play an important role in the depletion of ozone in the atmosphere.

(a) State equations for the stepwise mechanism of ozone depletion catalyzed by the CFC compound dichlorodifluoromethane, CCl_2F_2 . [3]

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(Option E continues on the following page)



(Option E, question 25 continued)

- (b) Discuss one advantage and one disadvantage of using hydrofluorocarbons (HFCs) as alternatives to CFCs.

[2]

<p>Advantage:</p> <p>.....</p> <p>.....</p> <p>Disadvantage:</p> <p>.....</p> <p>.....</p>
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(Option E continues on the following page)



44EP29

Turn over

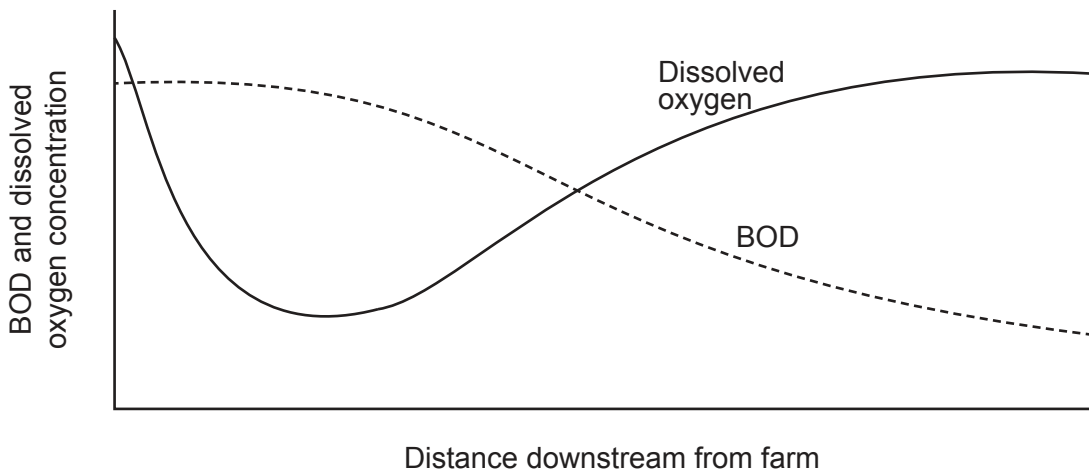
(Option E continued)

26. Biochemical oxygen demand (BOD) is a measure of oxygen-demanding wastes in water.

(a) State **two** examples of oxygen-demanding wastes. [1]

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(b) A student monitored BOD and the concentration of dissolved oxygen downstream along a river starting at a farm. Her results are represented below.



Outline the reasons for the variation in the BOD and the concentration of dissolved oxygen. [3]

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End of Option E



Option F — Food chemistry

27. Most fats contain fatty acids which can vary in their health benefits. Some information about three fatty acids is given in the table.

Name of fatty acid	Molecular formula	Structural formula	Melting point / °C
Stearic acid	$C_{18}H_{36}O_2$		70
Oleic acid	$C_{18}H_{34}O_2$		13
Elaidic acid	$C_{18}H_{34}O_2$		44

(a) State the name of the unsaturated *trans* fatty acid in the table. [1]

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(b) Explain why elaidic acid has a higher melting point than oleic acid. [2]

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(Option F continues on the following page)



(Option F continued)

28. Nutrients are obtained from food and are essential for maintaining a healthy body. Identify a nutrient with each given characteristic. [3]

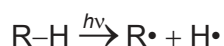
Characteristic	Nutrient
Contains an ester group
Made up of monosaccharides
Essential for healthy bones

29. The shelf life of a food depends on many factors.

- (a) (i) Oily fish may become rancid as the oils present contain a high proportion of polyunsaturated fatty acids. Outline how a customer would observe that food is rancid. [1]

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.....

- (ii) Oxidative rancidity in oily fish occurs when fatty acids react with oxygen to form hydroperoxides. The initiation step involves the homolytic fission of the C-H bond in the fatty acid which is represented as RH.



State equations for the **two** propagation steps which result in the formation of the hydroperoxide. [2]

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(Option F continues on the following page)

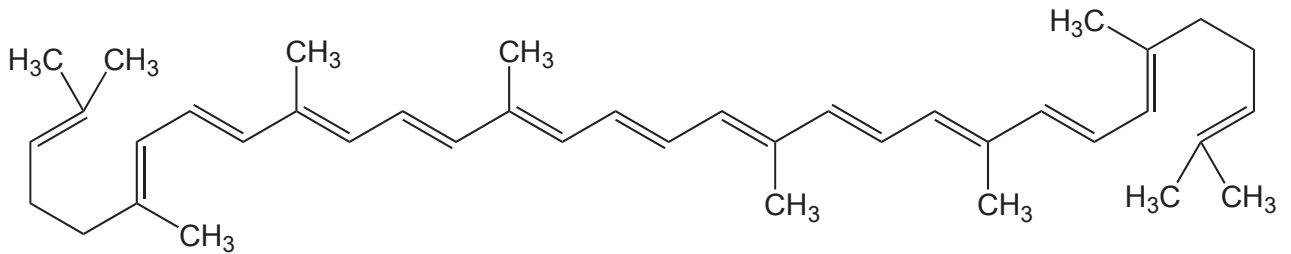


(Option F, question 29 continued)

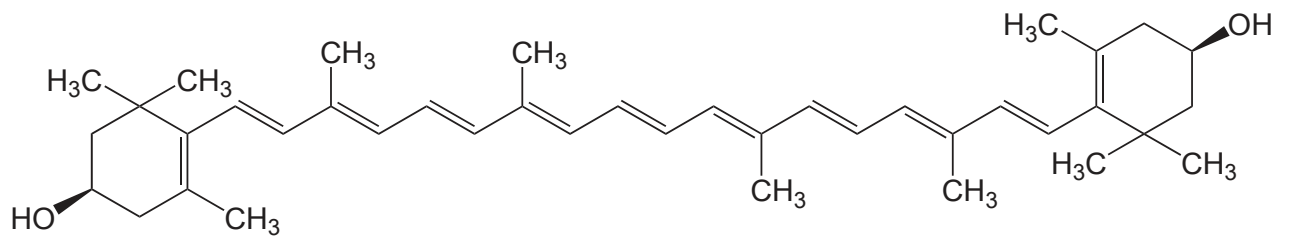
- (b) Many cheeses contain high levels of salt. Suggest why lowering the salt content may lead to a shorter shelf life. [2]

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30. Lycopene gives tomatoes their red colour and zeaxanthin gives some peppers their orange colour.



Lycopene



Zeaxanthin

- (a) Identify the class of pigments to which lycopene and zeaxanthin belong. [1]

.....

(Option F continues on the following page)



(Option F, question 30 continued)

- (b) (i) With reference to their interaction with light, explain why these pigments are coloured. [2]

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- (ii) Explain, by referring to the bonding in the molecule, why the colour of lycopene gradually changes from red to yellow on addition of bromine. [2]

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31. Salad dressings are examples of food products which consist of stable dispersed systems.

- (a) Define the term dispersed system. [1]

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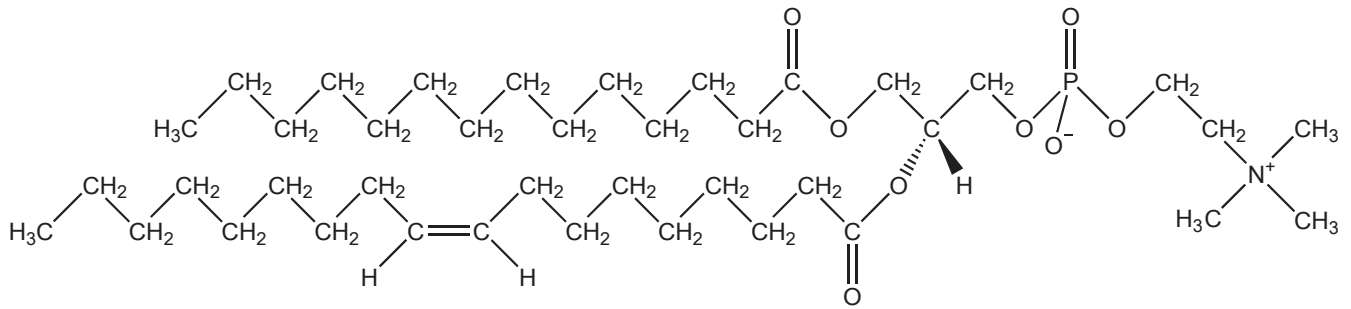
(Option F continues on the following page)



(Option F, question 31 continued)

- (b) Lecithin is an emulsifier which is an essential ingredient of salad dressings. By referring to its structure, describe the role of lecithin in salad dressings.

[2]



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- (c) Salad dressings often contain the antioxidant calcium disodium EDTA which acts as a chelating agent. There are two other types of antioxidant.

Explain the mode of action of the three types of antioxidant.

[3]

Chelating agents:
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Free-radical quenchers:
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Reducing agents (electron donors):
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(Option F continues on the following page)

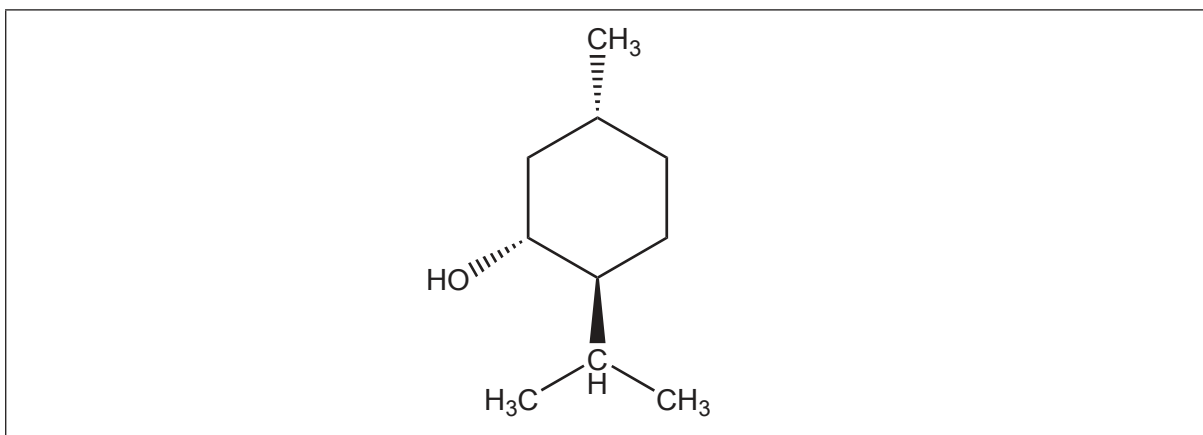


44EP35

Turn over

(Option F continued)

32. Mint leaves have been used for both medicinal and culinary purposes for many centuries. The strong mint flavour is due to the enantiomer, L-(–)-menthol.



- (a) Identify the chiral centres in the structure of L-(–)-menthol by means of asterisks (*). [1]
- (b) Chiral molecules such as L-(–)-menthol can be differentiated from other enantiomers using either the R, S or the (+) (previously represented by d) and (–) (previously represented by l) system of notation.

Explain the difference between the R, S notation and the (+) and (–) notation for enantiomers. [2]

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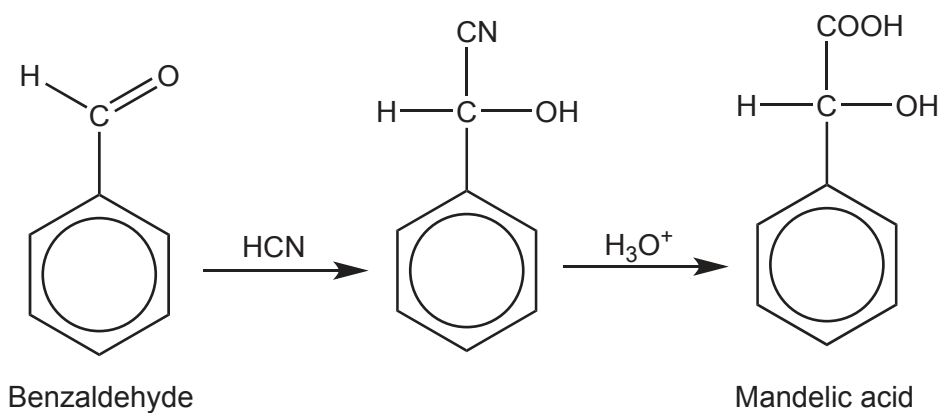
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End of Option F



Option G — Further organic chemistry

33. Mandelic acid is used in antibacterial agents. One possible route for its formation is shown below.



The first stage involves nucleophilic addition of hydrogen cyanide, HCN, to the aldehyde group in benzaldehyde.

- (a) Explain the mechanism for the reaction of benzaldehyde with HCN using curly arrows to show the movement of electron pairs. [3]

(Option G continues on the following page)



(Option G, question 33 continued)

(b) Benzaldehyde can also be used to synthesize 1-phenylethanol, $C_6H_5CH(OH)CH_3$. This reaction involves the use of a Grignard reagent.

(i) State the formula of a Grignard reagent which could be used in this reaction. [1]

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.....

(ii) Identify the reagents and conditions for the formation of the Grignard reagent given in (b) (i). [2]

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(c) 1-phenylethanol, $C_6H_5CH(OH)CH_3$, can be converted to phenylethene, $C_6H_5CH=CH_2$, which is used in the polymer industry. [3]

Identify the following for the conversion of 1-phenylethanol to phenylethene.

Type of reaction:
.....

Reagent:
.....

Condition:
.....

(Option G continues on the following page)



(Option G continued)

34. 2-methylbut-2-ene, $(\text{CH}_3)_2\text{C}=\text{CHCH}_3$, reacts readily with HBr by an electrophilic addition reaction. The products are found to consist of two structural isomers with the molecular formula $\text{C}_5\text{H}_{11}\text{Br}$.

(a) Deduce the structural formula of the **major** product. [1]

(b) Explain why this isomer is the major product. [3]

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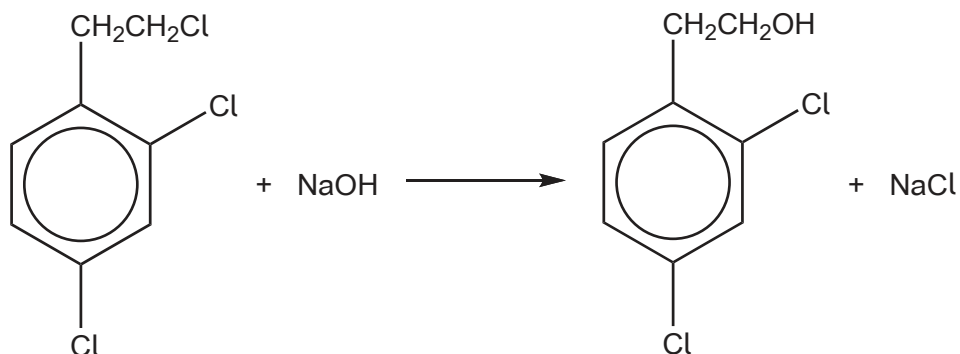
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(Option G continues on the following page)



(Option G continued)

35. A halogenated arene is reacted with warm sodium hydroxide solution as shown in the equation below.



Explain why only **one** of the three chlorine atoms is substituted by a hydroxyl group.

[2]

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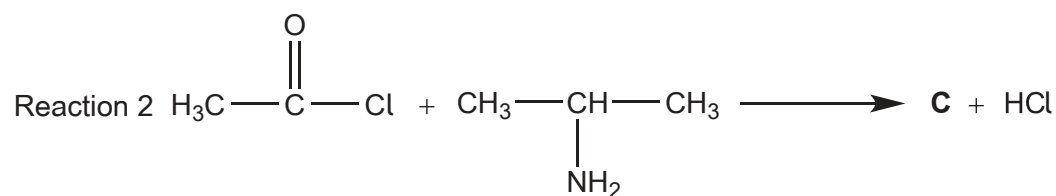
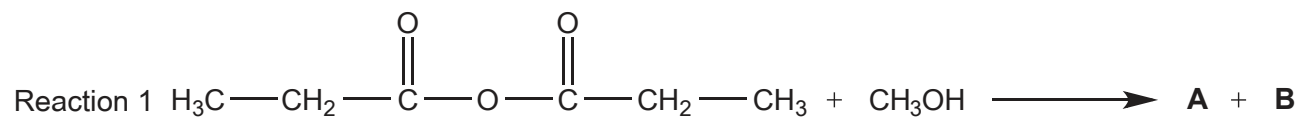
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44EP40

(Option G continued)

36. Draw the structures of products **A**, **B** and **C** in the following addition–elimination reactions. [3]**A:****B:****C:**

(Option G continues on the following page)



(Option G continued)

37. Benzene, C_6H_6 , undergoes electrophilic substitution in the presence of a mixture of concentrated nitric and sulfuric acids to form nitrobenzene, $C_6H_5NO_2$.

(a) Outline, using an equation, the formation of the electrophile NO_2^+ from the two acids. [1]

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(b) Describe the mechanism for the reaction of benzene with the electrophile to form nitrobenzene using curly arrows to represent the movement of electron pairs. [3]

(c) Nitrobenzene can be nitrated further to form 1,3-dinitrobenzene. Suggest why this further nitration of nitrobenzene is more difficult. [1]

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(Option G continues on the following page)



(Option G, question 37 continued)

- (d) The nitration of methylbenzene, $C_6H_5CH_3$, results in the formation of 2- and 4-isomers. Explain why the presence of a methyl group leads to the formation of these two isomers. [2]

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End of Option G



44EP43

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Answers written on this page
will not be marked.



44EP44