

# 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 – 5
Option B — Human biochemistry	6 – 11
Option C — Chemistry in industry and technology	12 – 16
Option D — Medicines and drugs	17 – 21
Option E — Environmental chemistry	22 – 25
Option F — Food chemistry	26 – 29
Option G — Further organic chemistry	30 – 32



**Option A — Modern analytical chemistry**

1. Chemists have developed a wide variety of spectroscopic and chromatographic techniques. For each of the following analytical investigations, identify the technique that would be the most appropriate.

[5]

	Investigation	Technique
A	Determining the sodium ion concentration in bottled water	.....
B	Determining whether an organic molecule contains a C=O bond	.....
C	Determining the molecular mass of an organic molecule	.....
D	Determining the effect of changing the ligand from H <sub>2</sub> O to NH <sub>3</sub> on the difference in energy of the d orbitals of a transition metal	.....
E	Detecting the presence of dioxin as an impurity in a herbicide	.....

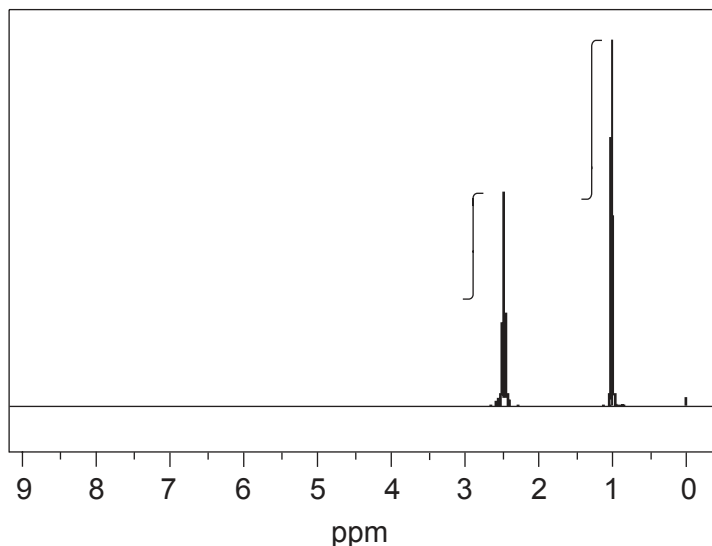
(Option A continues on the following page)



**(Option A continued)**

2. NMR spectroscopy is one of the most powerful analytical tools for determining molecular structure.

(a) The  $^1\text{H}$ NMR spectrum, including the integration trace, of a ketone with relative molecular mass 86 is shown below.



[Source: SDBS web: [www.sdb.srioddb.aist.go.jp](http://www.sdb.srioddb.aist.go.jp) (National Institute of Advanced Industrial Science and Technology, 2014)]

Deduce the structural formula of the compound, justifying your choice.

[3]

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(b) Outline why the signal at 1.0 ppm is a triplet.

[1]

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(Option A continues on the following page)



44EP03

Turn over

(Option A, question 2 continued)

- (c) Suggest why it is necessary to include an internal reference standard in a sample when its  $^1\text{H}$  NMR spectrum is being determined and why tetramethylsilane (TMS) is used for this purpose. [2]

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3. Consider the compound chloroethene,  $\text{CH}_2=\text{CHCl}$ .

- (a) Deduce **two** features you would expect to observe in its mass spectrum. [2]

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- (b) Predict **two** features you would expect to observe in its infrared (IR) spectrum. [2]

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- (c) Explain what occurs at a molecular level when a bond absorbs IR radiation. [2]

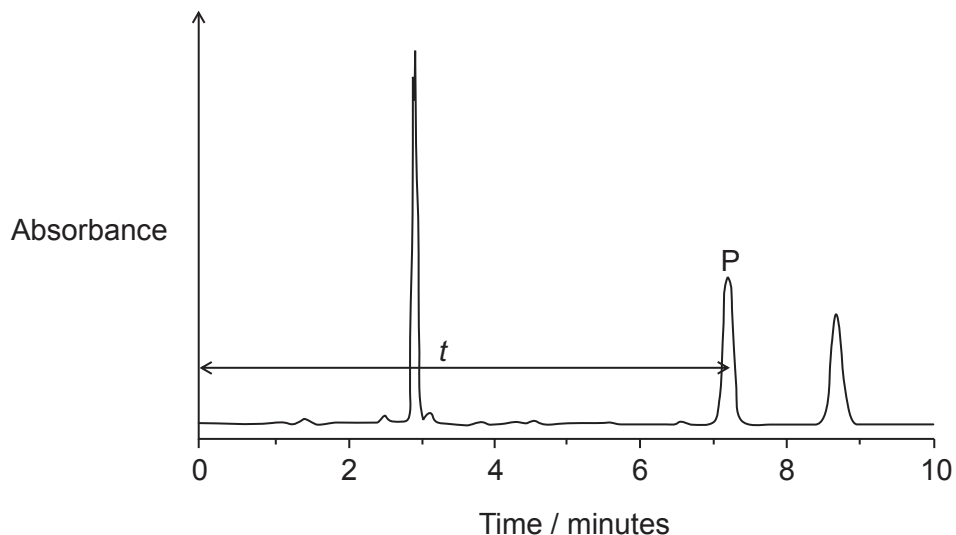
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(Option A continues on the following page)



(Option A continued)

4. High-performance liquid chromatography (HPLC) is a frequently used technique in analytical chemistry. An example of the trace obtained for the analysis of a sample by HPLC is shown below.



- (a) State what occurs at  $t = 0$ . [1]

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- (b) The peak labelled P is eluted after retention time  $t$  and has an area A. Outline what, by reference to tables or prior calibrations, can be deduced from these two values. [2]

$t$ :  
.....  
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A:  
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(Option A continues on the following page)



44EP05

Turn over

**(Option A, question 4 continued)**

- (c) A column is packed with aluminium oxide and uses hexane as the solvent. Explain why a more polar substance will generally have a longer retention time in this column. [2]

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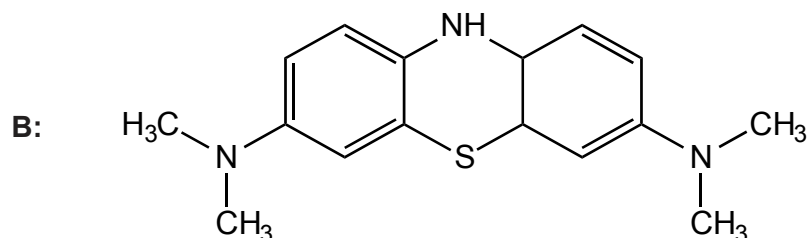
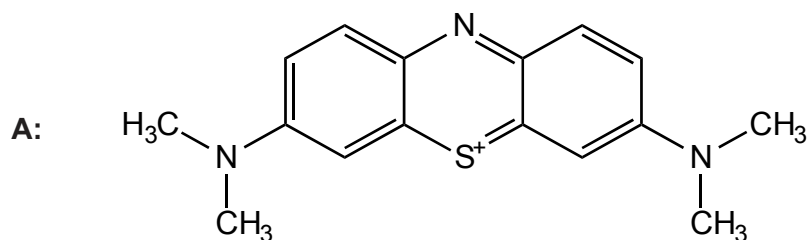
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5. Coloured substances that can be easily converted into colourless derivatives are often very useful as indicators.

- (a) The structures of two molecules, **A** and **B**, are shown below. One is a coloured compound and the other is colourless. Identify the coloured molecule, giving a reason for your choice. [1]



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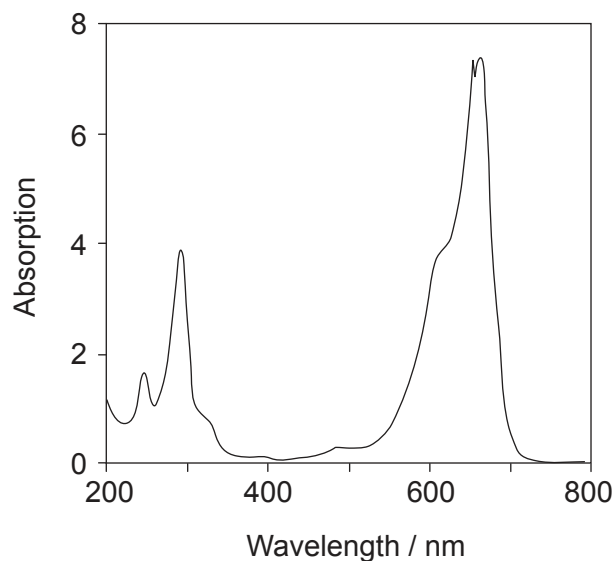
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**(Option A continues on the following page)**



**(Option A, question 5 continued)**

- (b) The UV-Vis spectrum of the coloured compound is shown below. Deduce, referring to table 3 of the data booklet, the colour of the compound, giving your reasoning. [2]



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**End of Option A**



44EP07

Turn over

**Option B — Human biochemistry**

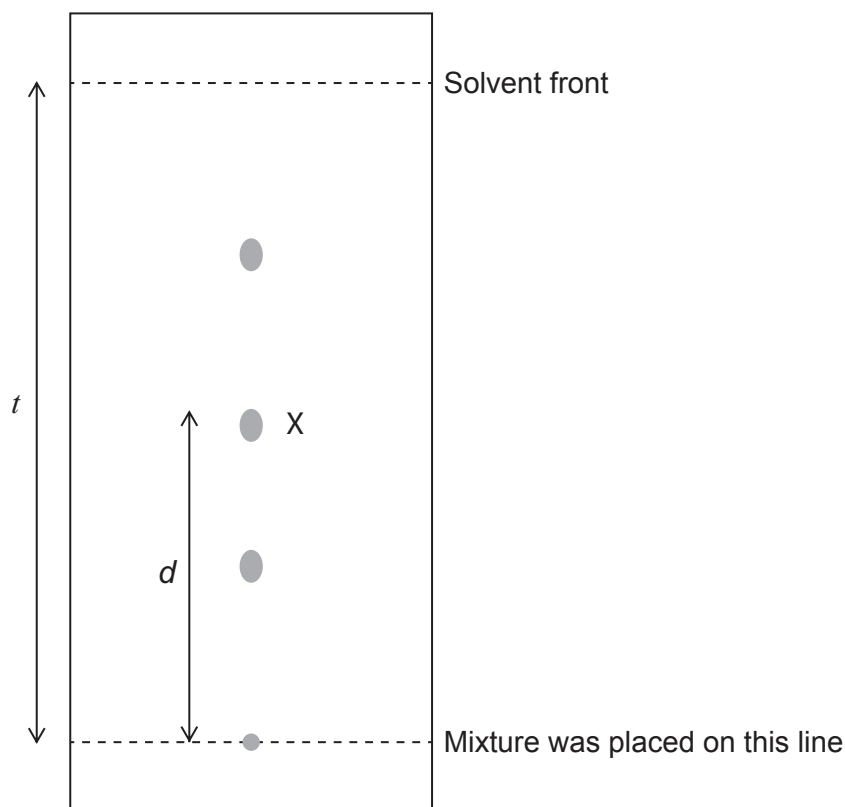
6. Proteins are made of long chains of amino acids.

- (a) (i) Explain how individual amino acids can be obtained from proteins for chromatographic separation.

[2]

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- (ii) A mixture of amino acids was spotted onto chromatography paper and eluted with a solvent mixture. The following spots were seen after the paper had been developed with ninhydrin.



Determine the  $R_f$  value of the amino acid marked as X.

[1]

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(Option B continues on the following page)



44EP08



**(Option B, question 6 continued)**

- (b) (i) Pepsin is a protein which functions as an enzyme in human stomachs. Describe the mechanism of the catalytic activity of an enzyme. [2]

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- (ii) Discuss **two** differences in the catalytic action of an enzyme such as pepsin and an inorganic catalyst such as nickel metal. [2]

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**(Option B continues on the following page)**



44EP09

Turn over

**(Option B continued)**

7. Glucose is an important monosaccharide for both plants and humans. Glucose molecules can combine to form polysaccharides such as amylose and cellulose.

(a) Compare the structures of amylose and cellulose.

[2]

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(b) Discuss how aerobic and anaerobic respiration of glucose differ in terms of the products formed and the energy released.

[2]

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**(Option B continues on the following page)**



44EP10

**(Option B continued)**

8. Linolenic acid (omega-3 fatty acid) is an essential fatty acid.

(a) List **two** benefits of linolenic acid to humans. [2]

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(b) Calculate the iodine number for linolenic acid,  $C_{17}H_{29}COOH$  ( $M_r = 278.48$ ). The condensed structural formula of linolenic acid is given in table 22 of the data booklet. [2]

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9. Nutrient deficiencies in a diet can be overcome by providing nutritional supplements or by increasing the nutrient content of foods.

Suggest **two** ways of increasing the nutrient content of foods to avoid deficiency diseases. [2]

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**(Option B continues on the following page)**



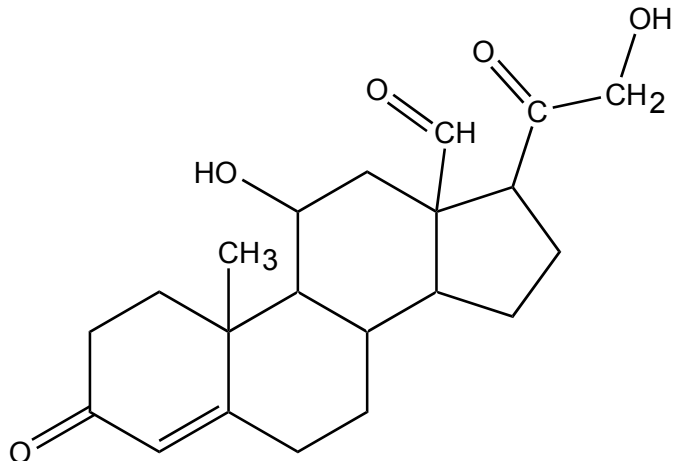
44EP11

Turn over

(Option B continued)

10. Cholesterol is in our diet and is produced in the body. It is used to produce steroid hormones and is important in membrane structures.

(a) Aldosterone is one of the steroid hormones produced in the body from cholesterol.



Aldosterone

The structure of cholesterol is shown in table 21 of the data booklet. Compare the structures of cholesterol and aldosterone by naming **two** functional groups present in both and **two** functional groups present only in aldosterone.

[2]

<p>Present in both:</p> <p>.....</p> <p>Present only in aldosterone:</p> <p>.....</p>
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(b) Identify the endocrine gland which produces aldosterone.

[1]

<p>.....</p> <p>.....</p>
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(Option B continues on the following page)



44EP12

**(Option B, question 10 continued)**

- (c) Progesterone and testosterone are other steroid hormones produced from cholesterol. Outline a function of progesterone or testosterone in the human body. [1]

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**11.** Deoxyribonucleic acid (DNA) is the genetic material that an individual inherits from both parents. DNA consists of nucleotides bonded together.

- (a) Outline the essential features of the structure of a section of one strand of DNA. [2]

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- (b) DNA profiling is used in forensic and paternity cases. Outline the steps involved in DNA profiling once the sample has been collected. [2]

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**End of Option B**



44EP13

Turn over

**Option C — Chemistry in industry and technology**

**12.** Iron is extracted from its ore by reduction in a blast furnace.

(a) State an equation for the reaction by which iron (III) oxide,  $\text{Fe}_2\text{O}_3$ , is reduced to iron in the blast furnace. [1]

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(b) Explain, using equations, how limestone removes impurities from the iron formed. [2]

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(c) Describe how quenched steel is tempered and how this changes the physical properties of the final product. [2]

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(Option C continues on the following page)



**(Option C continued)**

**13.** The chlor-alkali industry involves the large-scale electrolysis of aqueous sodium chloride.

(a) Explain why the membrane cell has almost replaced the mercury-cathode cell and the diaphragm cell. [2]

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(b) Explain, using equations, the reactions that occur at the electrodes in the membrane cell. [2]

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



44EP15

Turn over

**(Option C continued)**

**14.** There has been a shift in the use of crude oil (petroleum) away from its use as an energy source and towards its use as a chemical feedstock.

(a) Suggest **two** reasons for this shift. [2]

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(b) Outline why Kevlar<sup>®</sup> softens easily when heated whereas phenol-methanal polymers do not. [2]

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**(Option C continues on the following page)**

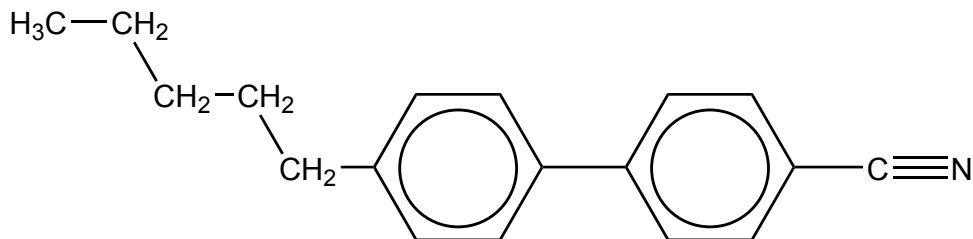


44EP16



(Option C continued)

15. Modern liquid crystals have a structure similar to this biphenyl nitrile.



(a) Explain how the structure of biphenyl nitriles makes them suitable for use in liquid-crystal devices.

[2]

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(b) Outline the principles of a liquid-crystal display (LCD) device.

[3]

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(c) One method of providing electrical energy to an LCD is to use a photovoltaic cell. Describe how the energy of sunlight interacts with a photovoltaic cell to produce electrical energy.

[2]

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(Option C continues on the following page)



44EP17

Turn over

(Option C continued)

16. Nanotechnology has expanded in the past 30 years.

(a) Define the term *nanotechnology*. [1]

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(b) Distinguish between the arrangement of carbon atoms at the sides and at the ends of carbon nanotubes. [1]

Sides:  
.....  
Ends:  
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(c) Outline why bundles of carbon nanotubes have high tensile strength. [1]

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(d) Discuss **two** concerns regarding the development of nanotechnology. [2]

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**End of Option C**



**Option D — Medicines and drugs**

17. Drug research and development is a lengthy and expensive process. Testing is required to determine the therapeutic window, tolerance and side-effects of a drug before it can be approved for use.

(a) State the meaning of the term therapeutic window. [1]

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(b) State the meaning of the term side-effects. [1]

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(c) Over-the-counter antacids have a high therapeutic window. State why some antacids contain dimethicone. [1]

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**(Option D continues on the following page)**



44EP19

Turn over

**(Option D continued)**

18. Morphine and its derivatives work by temporarily bonding to receptor sites in the brain, preventing the transmission of pain impulses.

(a) Discuss **one** advantage and **two** disadvantages of using morphine as an analgesic. [3]

Advantage:

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Disadvantages:

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(b) (i) The structures of morphine and diamorphine (heroin) are shown in table 20 of the data booklet. Describe the difference in the two structures by naming the functional groups. [1]

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(ii) Explain why the change in functional groups makes diamorphine (heroin) more potent than morphine. [2]

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**(Option D continues on the following page)**



44EP20

**(Option D continued)**

19. A variety of techniques can be used to determine the ethanol concentration of the breath, blood or urine.

- (a) (i) The breathalyser, one of the earliest tests, uses the reaction between ethanol and acidified potassium dichromate(VI). Ethanol is first oxidized to ethanal. Deduce the half-equation for the reaction of ethanol to ethanal. [1]

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- (ii) Outline why the colour changes from orange to green. [1]

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- (b) Explain how the ethanol concentration in the breath can be measured by an intoximeter using infrared absorption. [2]

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**(Option D continues on the following page)**



44EP21

Turn over

**(Option D continued)**

20. Some people believe that taking the stimulants caffeine and amphetamines improves their performance in school.

(a) Outline how caffeine and amphetamines may have this effect. [1]

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(b) Amphetamine and epinephrine (adrenaline) have similar structures based on phenylethylamine. The structures are shown in table 20 of the data booklet. Draw the structure of phenylethylamine. [1]

**(Option D continues on the following page)**



44EP22

**(Option D continued)**

**21.** Diseases may be caused by bacteria or viruses.

(a) (i) Explain how penicillins work as antibacterials. [2]

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(ii) The beta-lactam ring is highly reactive and enables penicillins to be effective antibacterials. The general structure of penicillin is given in table 20 of the data booklet. Explain, in terms of hybridization and bond angles, why the beta-lactam ring is strained. [2]

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(b) (i) Cytovaricin is an antibiotic that is produced using a chiral auxiliary. Suggest why it may be necessary to use a chiral auxiliary during its production. [1]

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**(Option D continues on the following page)**



44EP23

Turn over

(Option D, question 21 continued)

(ii) Describe how a chiral auxiliary is involved in the synthesis of a drug. [3]

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

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**End of Option D**



44EP24



**Option E — Environmental chemistry**

**22.** Climate change is a current global topic of debate.

- (a) Water and carbon dioxide are greenhouse gases present in significant quantities in the atmosphere. Identify **one** other greenhouse gas and its source. [1]

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- (b) (i) Describe on a molecular level how the greenhouse effect occurs. [3]

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- (ii) Suggest **two** factors that influence the relative greenhouse effect of a gas. [1]

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- (c) Discuss **three** effects of increasing amounts of greenhouse gases in the atmosphere and their consequences. [3]

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(Option E continues on the following page)



44EP25

Turn over

**(Option E continued)**

**23.** Another major source of concern is the depletion of ozone in the stratosphere as a result of human activity.

(a) Explain how the frequency of UV radiation absorbed by oxygen and ozone depends on the bonding in these molecules. [2]

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(b) (i) Describe, by means of equations, how nitrogen(II) oxide, NO, catalyses the depletion of ozone. [3]

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(ii) Identify and state the source of **one** other ozone-depleting pollutant. [1]

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



**(Option E continued)**

**24.** As the world's population grows, managing waste water efficiently is as important as sources of fresh drinking water.

(a) State the meaning of the term biochemical oxygen demand (BOD). [2]

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(b) Fresh water can be obtained from sea water by multi-stage distillation and by reverse osmosis. Explain the essential features of **one** of these processes. [3]

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(c) A lot of non-recyclable waste is now incinerated rather than being put into landfill. Suggest **two** economic factors that need to be considered before building a new waste incineration plant. [2]

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



44EP27

Turn over

**(Option E continued)**

**25.** The quality and composition of soil are important for the growth of healthy crops.

(a) State what is meant by the term cation-exchange capacity (CEC). [2]

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(b) Explain, including an equation, how ammonium salts in soil may be converted to nitric acid. [2]

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**End of Option E**



44EP28

**Option F — Food chemistry**

26. Olive oil is a complex mixture of triglycerides, some of which are derived from oleic acid.

(a) State the name of the compound which combines with fatty acids to form triglycerides. [1]

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(b) (i) Explain why oleic acid, *cis*-9-octadecenoic acid, has a lower melting point than its *trans* isomer, elaidic acid. [2]

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(ii) Discuss **two** effects on health of consuming *trans* fatty acids such as elaidic acid. [2]

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(Option F continues on the following page)



44EP29

Turn over

(Option F, question 26 continued)

- (c) (i) The triglycerides in olive oil may undergo oxidative rancidity. State equations for **one** initiation step, **two** propagation steps and **one** termination step of the free-radical chain mechanism that occurs during oxidative rancidity, using RH to represent any unsaturated fatty acid chain. [4]

Initiation step:  
.....

Propagation steps:  
.....  
.....

Termination step:  
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- (ii) Outline **one** method, other than adding an antioxidant, to minimize the rate of rancidity and prolong the shelf life of olive oil. [1]

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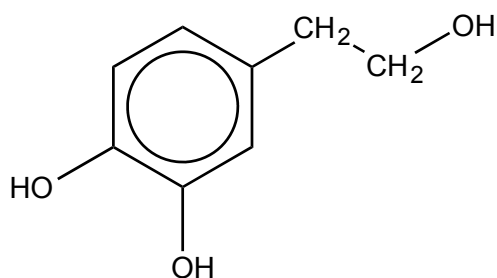
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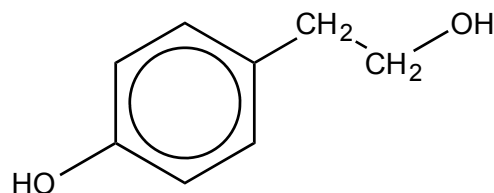
44EP30

**(Option F continued)**

27. Olive oil contains naturally occurring antioxidants such as hydroxytyrosol, tyrosol and vitamin E.



Hydroxytyrosol



Tyrosol

- (a) The structures of some synthetic antioxidants (preservatives) are shown in table 22 of the data booklet. Compare the structural features of hydroxytyrosol and tyrosol with these synthetic compounds. [3]

Similarity:

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Differences:

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- (b) Outline how vitamin E acts as an antioxidant. [1]

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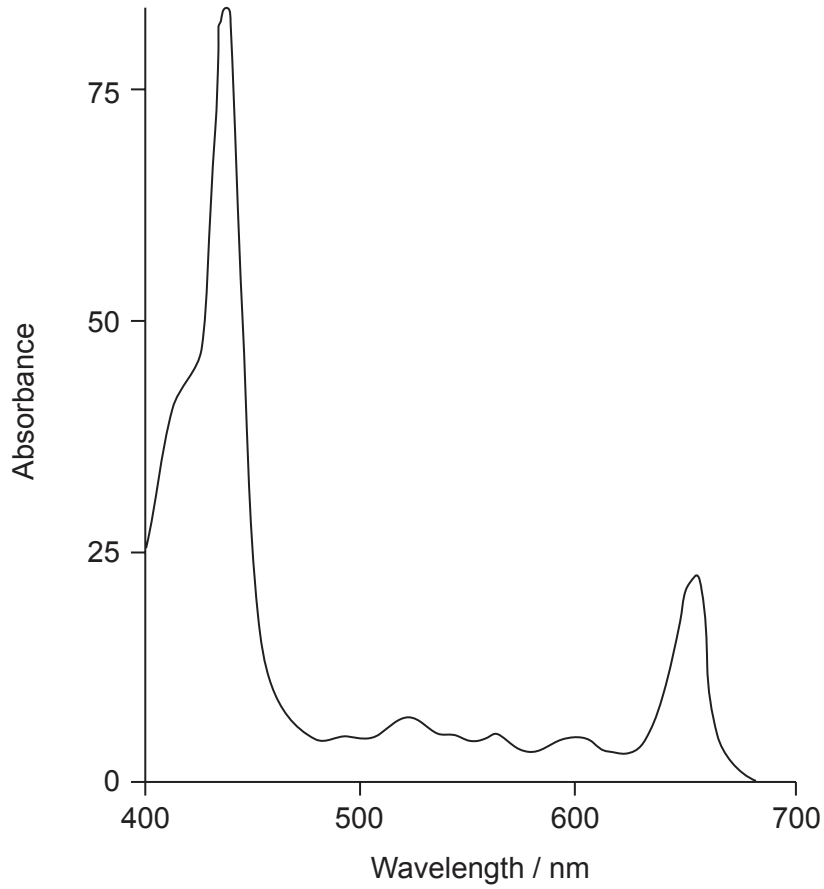
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**(Option F continues on the following page)**



(Option F continued)

28. The colour of olive oil is due to pigments such as chlorophyll, pheophytin and carotenoids. The absorption spectrum of one form of pheophytin is shown below.



- (a) (i) Explain why pheophytin is yellow-green, using the spectrum above and table 3 of the data booklet. [1]

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(Option F continues on the following page)

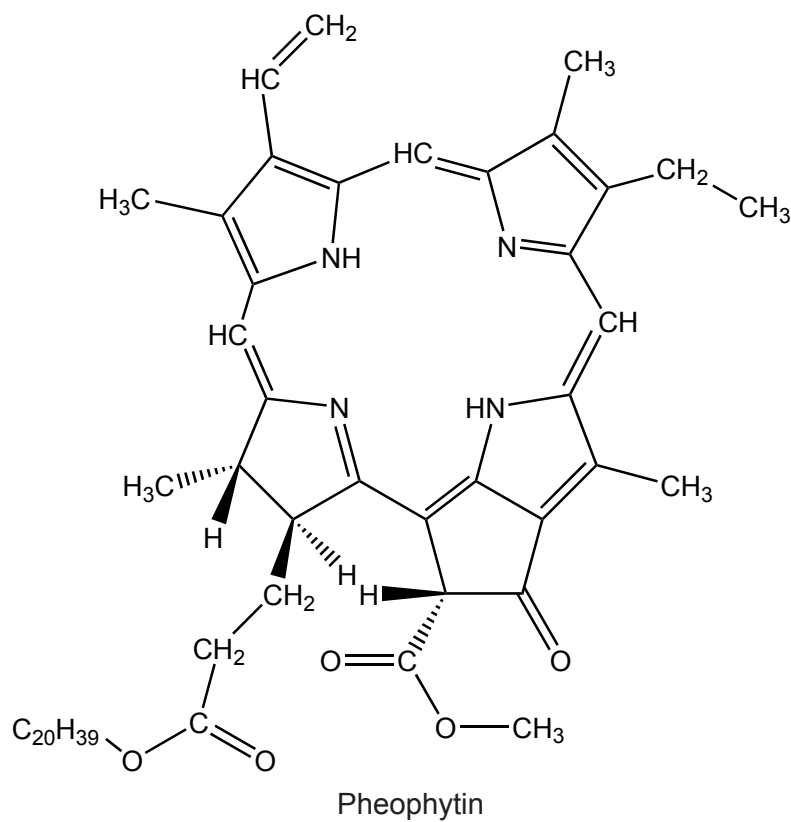




(Option F, question 28 continued)

- (ii) State the structural feature of a pheophytin molecule which allows it to absorb visible light.

[1]



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(Option F continues on the following page)



44EP33

Turn over

(Option F, question 28 continued)

- (b) (i) Carotenoids may lose their colour and develop off odours when they are oxidized. Identify, using table 22 of the data booklet, the structural feature that makes carotenoids susceptible to oxidation. [1]

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- (ii) List **two** factors which increase the rate of oxidation of carotenoids. [2]

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- (iii) Deduce, giving a reason, whether carotenoids are water-soluble or fat-soluble. [1]

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- (c) Aioli is an emulsion containing olive oil, garlic, egg yolks and lemon juice. Garlic and egg yolks contain phospholipids and are the emulsifiers in the aioli. Describe how the emulsifiers prevent the emulsion from separating. [2]

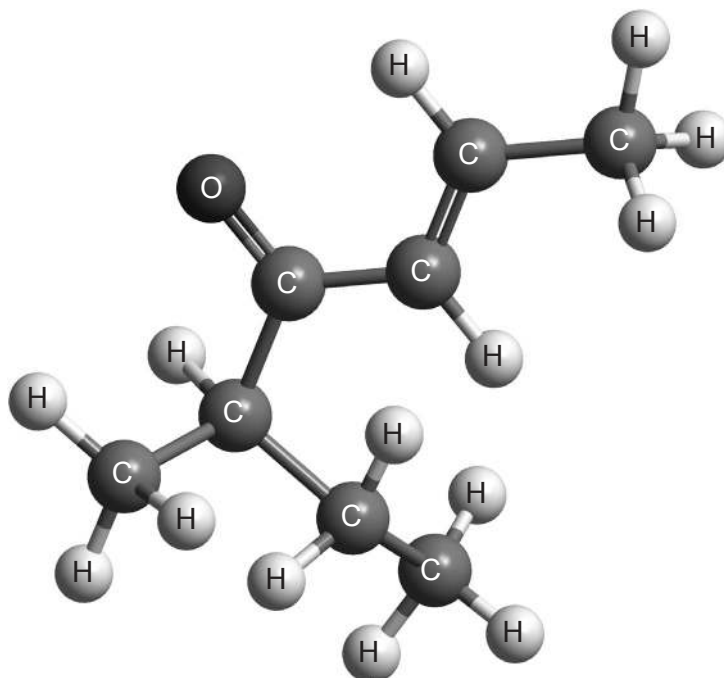
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(Option F continues on the following page)



(Option F continued)

29. Olive oil is sometimes adulterated with less expensive hazelnut oil, which contains filbertone.



Filbertone (5-methyl-2-hepten-4-one)

Explain, using the Cahn-Ingold-Prelog (CIP) convention, why the isomer of filbertone shown has the R configuration.

[3]

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**End of Option F**



44EP35

Turn over

**Option G — Further organic chemistry**

30. Benzene, C<sub>6</sub>H<sub>6</sub>, was once thought to contain alternate single and double bonds between the carbon atoms.

(a) Describe the currently accepted structure and bonding of the benzene molecule. [3]

Structure:

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Bonding:

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(b) Outline **one** piece of thermochemical evidence that provides support for the bonds in the benzene ring **not** being alternately single and double. [1]

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(c) (i) Benzene reacts when refluxed with concentrated nitric acid via the formation of the nitronium ion, NO<sub>2</sub><sup>+</sup>. Precisely identify the reagent that must be added to nitric acid to generate the nitronium ion. [1]

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(Option G continues on the following page)



(Option G, question 30 continued)

- (ii) Explain the mechanism for the nitration of benzene by the nitronium ion, using curly arrows to indicate the movement of electron pairs. [4]

- (d) Methylbenzene can be nitrated in a similar manner to benzene. Explain the relative reactivities of benzene and methylbenzene in this reaction. [2]

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- (e) State the name of **one** benzene derivative that would react with the nitronium ion less readily than benzene. [1]

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(Option G continues on page 39)



44EP37

Turn over

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Answers written on this page  
will not be marked.



44EP38

**(Option G continued)**

31. Propene,  $\text{CH}_2\text{CHCH}_3$ , is an important monomer in the production of addition polymers. It also undergoes simple addition reactions.

- (a) Explain the mechanism for the addition of hydrogen chloride,  $\text{HCl}$ , to propene that leads to the major product, using curly arrows to represent the movement of electron pairs.

[4]

- (b) Predict the structural formula of the organic product most likely to be formed when the reaction in (a) takes place in the presence of a high concentration of bromide ions.

[1]

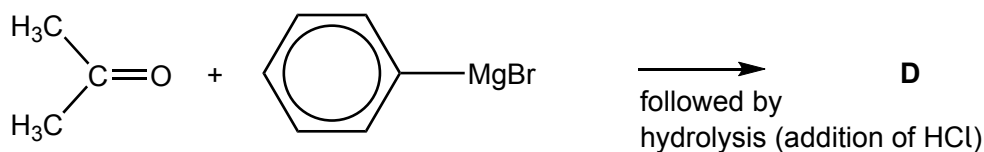
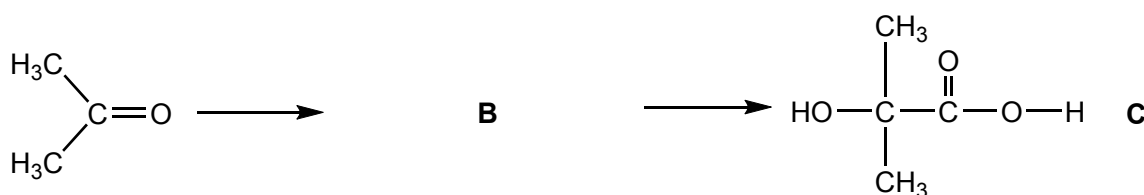
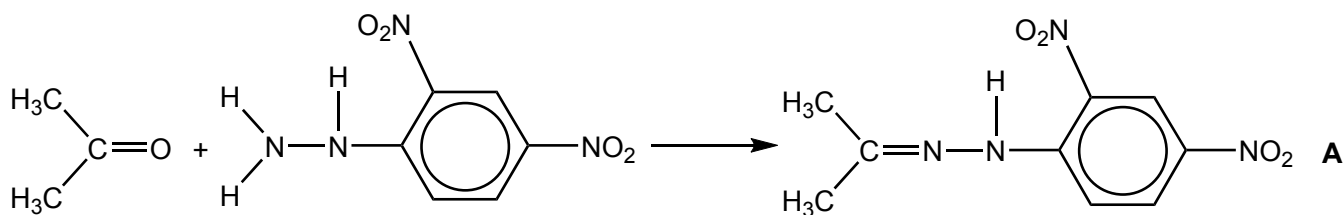
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**(Option G continues on the following page)**



(Option G continued)

32. Carbonyl compounds such as propanone,  $(\text{CH}_3)_2\text{CO}$ , are very versatile starting materials for the production of other organic molecules. Consider the schemes below.



- (a) Identify the type of reaction occurring in the conversion of propanone to **A**. [1]

.....

- (b) Deduce the structural formula of **B**. [1]

(Option G continues on the following page)





(Option G, question 32 continued)

(c) **C** reacts with ethanoyl chloride,  $\text{CH}_3\text{COCl}$ .

(i) Deduce the structural formula of the organic product. [1]

(ii) State the name of the new functional group formed. [1]

.....

(d) Explain why **C** dissociates more in aqueous solution than 2-methylpropanoic acid,  $(\text{CH}_3)_2\text{CHCOOH}$ . [2]

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

(e) (i) Deduce the structural formula of **D**. [1]

(ii) Identify the **two** substances that react together to produce  $\text{C}_6\text{H}_5\text{MgBr}$ . [1]

.....  
.....

**End of Option G**



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