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CHEMISTRY
HIGHER LEVEL
PAPER 3

Candidate session number

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Friday 17 May 2013 (morning)

1 hour 15 minutes

Examination code

2	2	1	3	–	6	1	1	5

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 A — Modern analytical chemistry

A1. Paper chromatography is a simple method used to separate and identify the components in a mixture. To aid identification, the retention factor, R_f, of an unknown component can be compared with the R_f values of pure samples of the possible components.

(a) State the meaning of the term *retention factor*. *[1]*

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(b) Explain why the value of the retention factor for the same component can be very different if different solvents (eluents) are used for the mobile phase. *[2]*

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(c) If the components of the mixture are coloured then they can be seen with the naked eye. Describe **two** different ways in which a chromatogram can be developed if the components are colourless. *[2]*

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A2. (a) Describe the function of the following components during the operation of a double-beam infrared spectrometer.

(i) Monochromator. *[1]*

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(ii) Rotating mirrors. *[1]*

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(iii) Photomultiplier (photodiode). *[1]*

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(This question continues on the following page)

(Question A2 continued)

(b) Organic compounds containing a carbon–carbon double bond, (C=C), absorb infrared radiation in the region 1610 – 1680 cm^{-1}.

(i) Outline the reasons why compounds containing C=C bonds absorb infrared radiation. *[2]*

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(ii) Explain why different compounds containing C=C bonds absorb infrared radiation at slightly different wavenumbers. *[1]*

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A3. The structures of some natural pigments and three preservatives are given in Table 22 of the Data Booklet.

(a) Explain why all the natural pigments listed (anthocyanins, carotenes and porphyrins) are coloured whereas the three preservatives (2-BHA, 3-BHA and BHT) are not coloured. *[3]*

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(b) When the flavylium cation is placed in alkaline solution the structure changes to the quinoidal base. Explain why the colour changes from red to blue. *[1]*

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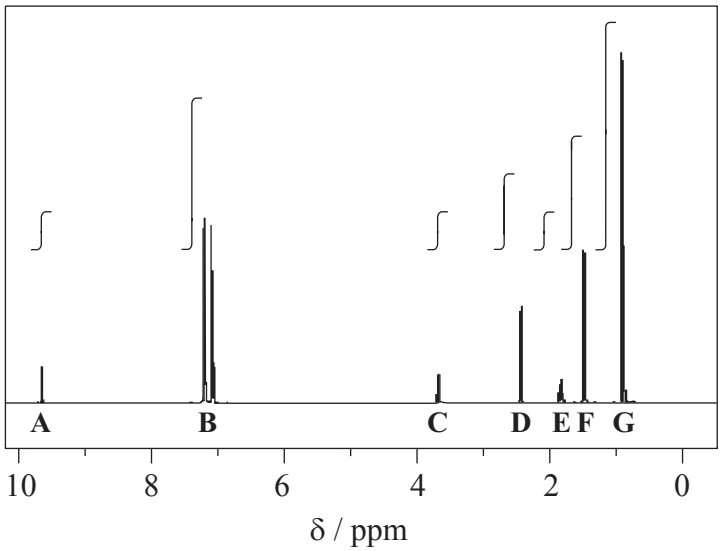
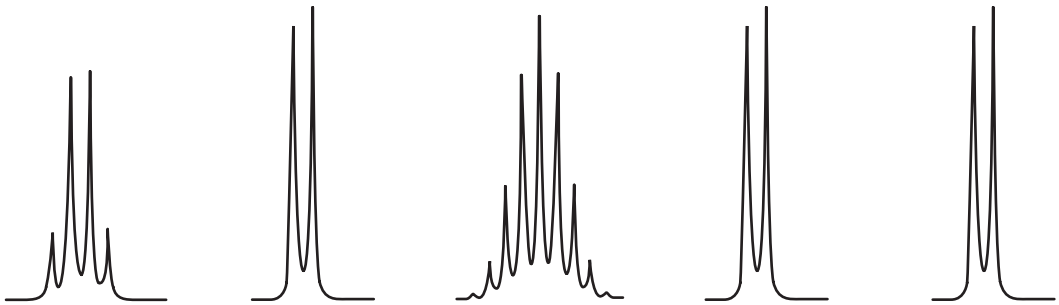
A4. (a) The ^{1}H NMR spectrum of one of the intermediate compounds formed during the synthesis of the painkiller ibuprofen is shown below. The peaks labelled **A** to **G** are not fully expanded to show the splitting but the integration trace for each peak is included.



The peak labelled **A** is a singlet. The two peaks labelled **B** centred at 7.1 ppm are due to the four hydrogen atoms on the benzene ring. The expansions to show the splitting for the other five peaks are shown below.



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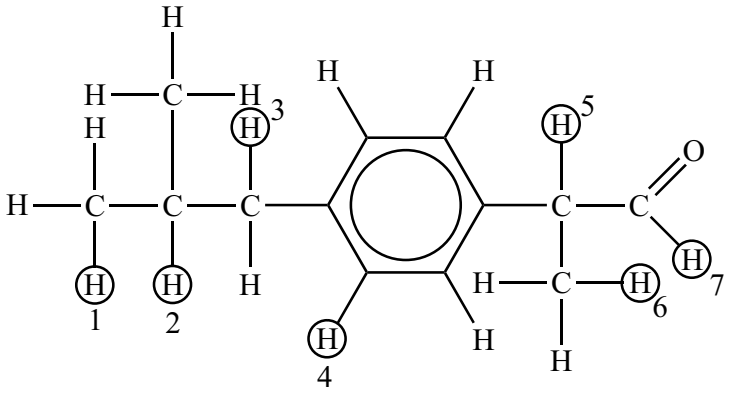
(Question A4 continued)

The structure of the intermediate compound is given below, with seven of the hydrogen atoms labelled.



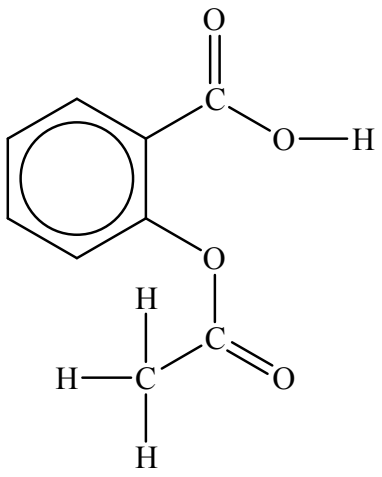
Deduce which labelled hydrogen atoms are responsible (wholly or in part) for each of the peaks and complete the table. *[6]*

Peak	Hydrogen atom responsible
A	
B	4
C	
D	
E	
F	
G	

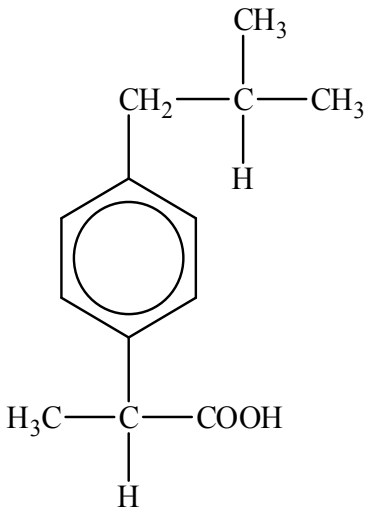
(This question continues on the following page)

(Question A4 continued)

(b) Another painkiller is aspirin. The structures of aspirin and ibuprofen are:



Aspirin



Ibuprofen

(i) State the number of peaks in the ^{1}H NMR spectrum of aspirin (**ignore** the peaks due to the hydrogen atoms on the benzene ring and the reference sample). *[1]*

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(ii) Describe the splitting pattern for each of the peaks given in (b) (i). *[1]*

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(This question continues on the following page)

(Question A4 continued)

(iii) State how the infrared spectra of aspirin and ibuprofen will differ in the region 1700 – 1750 cm^{-1}. *[2]*

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Option B — Human biochemistry

B1. Lipids play a significant role in human nutrition and have many important biological functions. The triglycerides are one type of lipid.

Table 22 of the Data Booklet shows the formulas of some fatty acids.

(a) (i) Olive oil contains a triglyceride (glyceryl trioleate) which, on hydrolysis, yields propane-1,2,3-triol (glycerol) and oleic acid.

Deduce the equation for this reaction. You may use the letter R to represent the hydrocarbon chains. *[3]*

(ii) Calculate the iodine number for oleic acid (M_r of oleic acid $= 282.52$). *[2]*

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(Question B1 continued)

(b) (i) Linoleic acid and stearic acid have similar molecular masses. Explain why linoleic acid has a much lower melting point than stearic acid. *[2]*

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(ii) Linoleic acid and linolenic acid are classed as essential fatty acids. State the importance of these fatty acids in the human diet. *[1]*

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B2. Papain is a globular protein which is present in papaya fruit. Part of the sequence of its polypeptide chain is Gly–Cys–Val–Gly.

(a) Proteins such as papain are formed by the condensation reactions of 2-amino acids.

By referring to Table 19 of the Data Booklet, draw the structural formulas of the **two** dipeptides formed by the reaction of glycine with cysteine. *[2]*

(b) In the analysis of proteins, mixtures of amino acids with different isoelectric points can be separated using electrophoresis.

(i) Describe the essential features of electrophoresis. *[3]*

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(This question continues on the following page)

(Question B2 continued)

(ii) Arginine, cysteine and glycine undergo electrophoresis at pH 6.0. Deduce which amino acid moves towards the positive electrode (anode). *[1]*

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B3. (a) Respiration is the process by which energy-rich molecules such as glucose are broken down to release energy to cells. Glucose is converted to pyruvate ions which can then break down aerobically or anaerobically.

(i) Compare aerobic and anaerobic respiration in the human body in terms of the products formed and the redox nature of the pyruvate ion reaction. *[3]*

	Products formed	**Redox nature of the pyruvate ion reaction (oxidation or reduction)**
Aerobic respiration		
Anaerobic respiration		

(ii) State whether aerobic or anaerobic respiration has the greater energy yield. *[1]*

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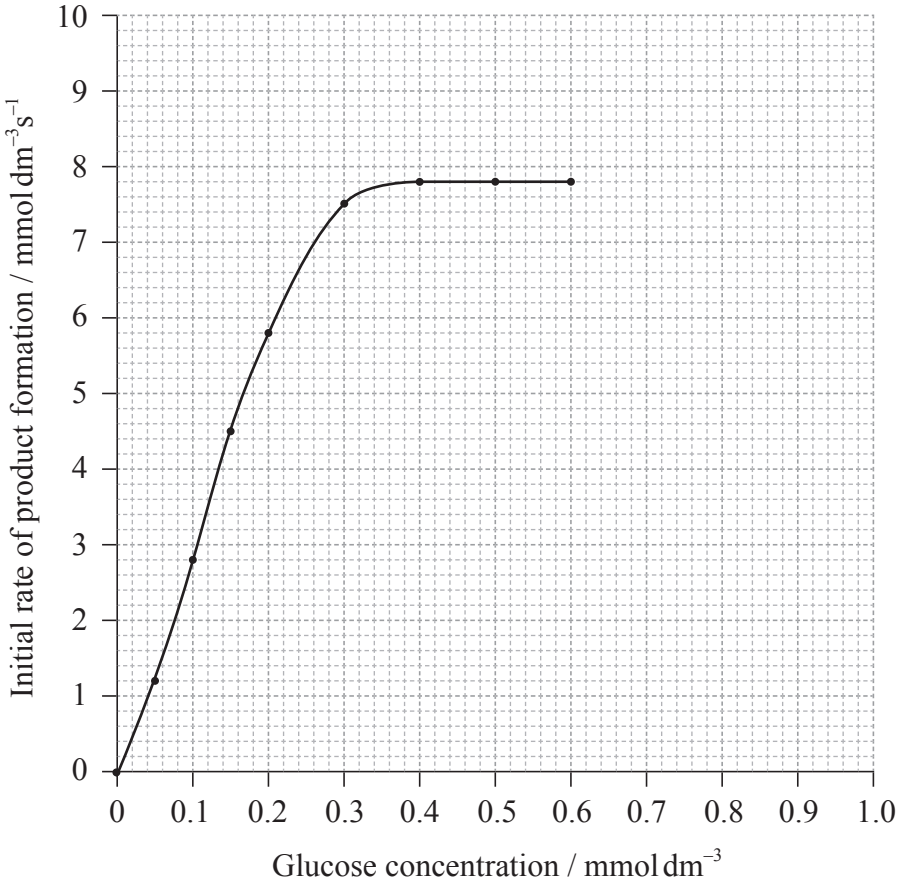
(This question continues on the following page)

(Question B3 continued)

(b) The enzyme hexokinase catalyses one of the initial reactions between glucose and adenosine triphosphate (ATP) during the process of glycolysis.

The graph below shows how the rate of this enzyme-catalysed reaction changes as the glucose concentration is increased.



(i) From the graph, determine V_{max} and the Michaelis constant, K_m. *[2]*

V_{max}: . . . . . .

K_m: . . . . . .

(This question continues on the following page)

(Question B3 continued)

(ii) Explain why a **low** value of K_m is significant. *[2]*

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(iii) State and explain the effect of a competitive inhibitor on the value of K_m. *[3]*

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Option C — Chemistry in industry and technology

C1. (a) The main ore used to produce aluminium by electrolysis is bauxite. Bauxite is mainly aluminium hydroxide, and contains iron(III) oxide and titanium(IV) oxide as impurities.

(i) Explain how pure aluminium oxide is obtained from bauxite. *[3]*

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(ii) Explain why sodium hexafluoroaluminate, Na_3AlF_6, (cryolite) is added to the aluminium oxide before electrolysis takes place to produce aluminium. *[1]*

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(iii) State the half-equations for the reactions taking place at the positive and negative electrodes during the production of aluminium by electrolysis. *[2]*

Positive electrode (anode):

. . . . . .

Negative electrode (cathode):

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(This question continues on the following page)

(Question C1 continued)

(b) Before the introduction of the electrolytic method by Hall and Héroult in the 1880s it was very difficult to obtain aluminium metal from its ores. Suggest **one** way in which it was achieved. *[1]*

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(c) The worldwide production of aluminium by electrolysis makes a significant impact on global warming. Suggest **two** different ways in which the process increases the amount of carbon dioxide in the atmosphere. *[2]*

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C2. (a) Distinguish between a *homogeneous* and a *heterogeneous* catalyst. *[1]*

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. . . . . .

(b) Other than cost, state **one** advantage and **one** disadvantage of using a homogeneous catalyst rather than a heterogeneous catalyst. *[2]*

Advantage:

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. . . . . .

Disadvantage:

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

(c) Other than selectivity and cost, list **three** factors which should be considered when choosing a catalyst for a particular industrial process. *[3]*

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C3. (a) Phenol and methanal can react in the presence of acid or alkali to form a phenol-methanal plastic. The first step is the reaction of one molecule of phenol with one molecule of methanal.

(i) Draw the structures of the **two** different organic products that can be formed in the first step of this reaction. *[2]*

(ii) State the equation for the reaction of **one** of the organic products identified in (a) (i) with another molecule of phenol. *[2]*

(This question continues on the following page)

(Question C3 continued)

(iii) Explain how cross-linking is able to occur to form a three-dimensional structure in phenol-methanal plastics. *[2]*

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(b) Another polymer that has cross-linking is Kevlar. Kevlar can be made by reacting 1,4-diaminobenzene with benzene-1,4-dicarboxylic acid.

(i) Draw the structural formula of the repeating unit in Kevlar. *[2]*

(ii) Explain how the long rigid chains in Kevlar are able to form cross-links to build up a three-dimensional structure. *[2]*

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Option D — Medicines and drugs

D1. The structures of aspirin and diamorphine (heroin) are given in Table 20 of the Data Booklet.

(a) Other than the benzene (aromatic) ring, state the name of the functional group that is common to both aspirin and diamorphine. *[1]*

. . . . . .

(b) Describe the different ways in which aspirin and diamorphine function when they relieve or prevent pain. *[2]*

Aspirin:

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. . . . . .

Diamorphine:

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(This question continues on the following page)

(Question D1 continued)

(c) Other than the prevention of pain and/or the reduction of fever, state **one** reason why aspirin is often prescribed or recommended to some people for daily use. *[1]*

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(d) Discuss **one** advantage and **one** disadvantage of taking diamorphine rather than morphine to relieve pain. *[2]*

Advantage:

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

Disadvantage:

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

D2. Ethanol is a depressant.

(a) Describe the effects of depressants when taken in moderate doses and in higher doses. *[2]*

Moderate doses:

. . . . . .

Higher doses:

. . . . . .

(b) The presence of ethanol in the breath can be detected by blowing into a "bag" through a tube containing acidified potassium dichromate(VI). The half-equation for the dichromate reaction is:

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

(i) Describe the colour change observed when the dichromate ion reacts with the ethanol. *[1]*

. . . . . .

(ii) State the name of the organic product formed during the reaction. *[1]*

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(This question continues on the following page)

(Question D2 continued)

(c) In order to quantify exactly how much ethanol is present in the blood, a person may be required to give a blood sample or may be asked to blow into an intoximeter. Explain the chemistry behind the techniques for determining the ethanol content in a blood sample and by using an intoximeter. *[4]*

Blood sample:

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

Intoximeter:

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(d) Ethanol may exert a synergistic effect when taken with other medicines. State the meaning of the term *synergistic effect*. *[1]*

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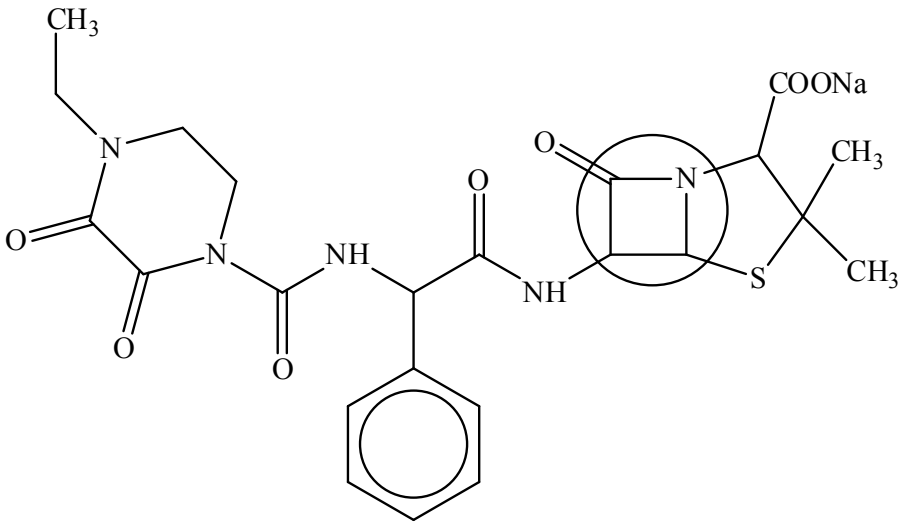
D3. (a) The structure of a drug is shown below:



(i) Identify the class of drugs to which this particular drug belongs. *[1]*

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(ii) Explain the high reactivity of the part of the drug that is enclosed in the circle. *[2]*

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(iii) Suggest why the drug is administered as its sodium salt. *[2]*

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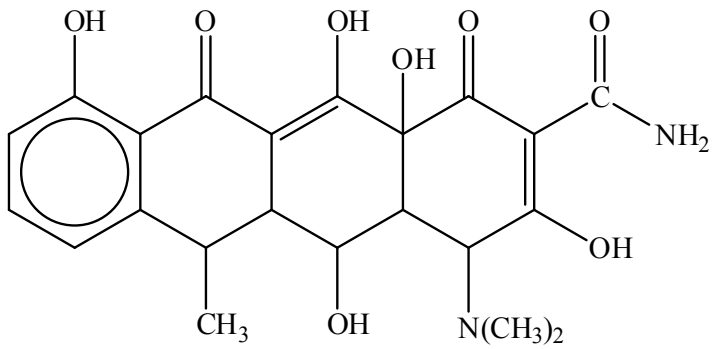
(Question D3 continued)

(b) Another drug that can have a similar effect to the one shown in (a) is doxycycline, shown below.



(i) Because it contains several –OH groups and an amine group, doxycycline is slightly polar. Identify the amine group by drawing a circle around it on the structure above **and** state whether it is a primary, secondary or tertiary amine. *[2]*

. . . . . .

(ii) Suggest **one** way in which the polarity of doxycycline could be substantially increased. *[1]*

. . . . . .

(iii) Deduce the number of chiral carbon atoms in doxycycline **and** explain why chirality is important when considering its action in the body. *[2]*

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Option E — Environmental chemistry

E1. Acid deposition can have a significant impact on aquatic environments such as lakes or wetlands.

(a) (i) State what is meant by the term *acid deposition*. *[1]*

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(ii) Identify **one** oxide which causes acid deposition **and** state the balanced chemical equation to show how it reacts with water. *[2]*

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(iii) One effect of acid deposition is to decrease the pH of lake water. Suggest how this effect could be reversed. *[1]*

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. . . . . .

(b) State **two** ways in which the emissions of the oxide identified in (a) (ii) can be decreased. *[2]*

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E2. Emissions of ozone-depleting substances such as CFCs have decreased extensively as a result of the Montreal Protocol. In the most recent assessment of ozone depletion by the United Nations Environmental Programme, scientists predict a substantial recovery of the ozone layer by 2050.

(a) Using equations, explain the natural formation and depletion of ozone in the upper atmosphere. *[2]*

Formation:

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

Depletion:

. . . . . .
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(b) (i) Although the use of harmful CFCs is being phased out, suggest why these compounds are expected to remain in the atmosphere for the next 80–100 years. *[1]*

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(This question continues on the following page)

(Question E2 continued)

(ii) Discuss **one** advantage and **two** disadvantages of using hydrocarbons as alternatives to CFCs. *[3]*

Advantage:

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Disadvantages:

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E3. Photochemical smog is an environmental problem in Los Angeles and Mexico City.

(a) Describe the conditions which favour the formation of photochemical smog in the presence of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in sunlight. *[3]*

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(b) Photochemical smog contains a number of secondary pollutants such as O_3 and NO_2.

(i) Identify **two** secondary pollutants other than O_3 and NO_2. *[2]*

1. . . . . .

2. . . . . .

(ii) State **one** equation for the production of **each** of the two pollutants identified in your answer to (b) (i). *[2]*

1. . . . . .
. . . . . .

2. . . . . .
. . . . . .

E4. In order to make waste water acceptable for drinking, it is treated in a series of steps to remove hazardous substances.

Tertiary treatment removes phosphates, nitrates and heavy metal ions from water.

(a) State an ionic equation, including the state symbols, to show how hydrogen sulfide gas, $H_2S(g)$, is able to remove mercury(II) ions, $Hg^{2+}(aq)$, when it is bubbled through a water sample. *[2]*

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(b) (i) The solubility product constant, K_{sp}, of cadmium(II) sulfide, CdS, is 8.00×10^{-28} at 298 K. Determine the concentration of cadmium(II) ions, $Cd^{2+}(aq)$, in a saturated solution of cadmium(II) sulfide. *[2]*

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(ii) Explain how the addition of hydrogen sulfide gas can decrease the concentration of cadmium(II) ions in a saturated solution. *[2]*

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Option F — Food chemistry

F1. Antioxidants are often used to extend the shelf life of food.

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

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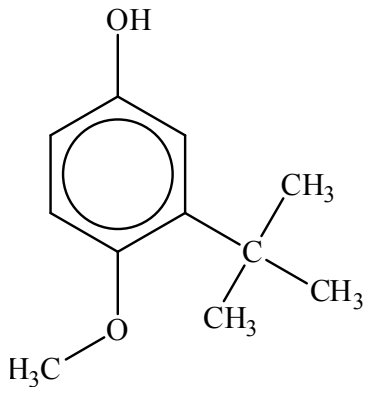
(b) The structure of a synthetic antioxidant, 2-BHA (2-*tert*-butyl-4-hydroxyanisole) is shown below.



Draw a circle around the part of the 2-BHA molecule which corresponds to:

(i) the phenolic group, and label it A. *[1]*

(ii) the tertiary butyl group, and label it B. *[1]*

(c) State **two** examples of naturally occurring antioxidants. *[2]*

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(This question continues on the following page)

(Question F1 continued)

(d) Antioxidants can be classified into three groups: free-radical inhibitors, chelating agents and reducing agents.

(i) Compare the modes of action of each type of antioxidant. *[3]*

Free-radical inhibitors:

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

Chelating agents:

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

Reducing agents:

. . . . . .
. . . . . .
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(ii) Identify **one** natural antioxidant which behaves as a chelating agent. *[1]*

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F2. Naturally occurring pigments give many foods their distinctive colours.

(a) List **two** factors which may affect the colour stability of a pigment. *[2]*

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(b) Chlorophyll is a pigment found in green vegetables.

A student decided to investigate the effect of sodium hydrogencarbonate, $NaHCO_3$, and vinegar on the colour of cooked green peas. Her results are shown below:

Experiment	Colour of peas before cooking	Colour of peas after cooking
Peas heated in water containing $NaHCO_3$	Green	Green
Peas heated in water containing vinegar	Green	Olive-brown

(i) State how the sodium hydrogencarbonate maintains the green colour of the peas. *[1]*

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(This question continues on the following page)

(Question F2 continued)

(ii) The structure of chlorophyll is shown in Table 22 of the Data Booklet. Describe what happens to the structure of chlorophyll when the peas are heated in water containing vinegar. *[1]*

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(iii) State the substance responsible for the olive-brown colour. *[1]*

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(c) The brown colour of roast meat is mainly due to the products of the Maillard reactions. Explain the chemistry of these non-enzymatic browning reactions. *[3]*

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F3. In recent years, the use of soybean oil by the food industry has increased. A significant proportion of this oil is produced from genetically modified soybeans.

Discuss **two** benefits and **two** concerns of using genetically modified foods. *[4]*

Benefits:

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Concerns:

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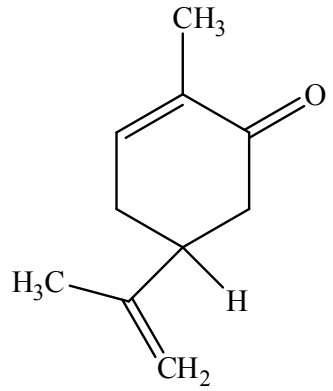
F4. Enantiomers can have different biological effects in the human body. Caraway seeds and spearmint have different smells as they contain different enantiomers of the compound carvone.

The structure of one of the enantiomers is shown below.



(a) Identify the chiral carbon in this enantiomer with an asterisk, *. *[1]*

(b) The enantiomer *d*-carvone is present in caraway seeds and *l*-carvone is found in spearmint. State the meaning of the symbol *d* used in this convention. *[1]*

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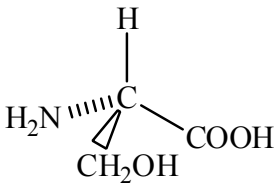
(This question continues on the following page)

(Question F4 continued)

(c) Another convention used for naming different enantiomers is the R, S notation.

An enantiomer of the amino acid serine is shown below.



Determine whether the enantiomer shown is R or S. Explain your answer. *[2]*

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Option G — Further organic chemistry

G1. (a) When 2-methylbut-1-ene, $H_2C=C(CH_3)CH_2CH_3$, reacts with hydrogen bromide the major organic product is 2-bromo-2-methylbutane, $(CH_3)_2C(Br)CH_2CH_3$.

(i) State the name of the mechanism which describes this type of reaction. *[1]*

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(ii) Describe the mechanism of this reaction using structural formulas and curly arrows to represent the movement of electron pairs. *[3]*

(iii) Explain why the major organic product is 2-bromo-2-methylbutane and not 1-bromo-2-methylbutane. *[2]*

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(Question G1 continued)

(b) Outline **one** way in which 2-bromo-2-methylbutane could be converted into 2-methylbutan-2-ol. *[1]*

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(c) 2-methylbutan-2-ol can also be synthesized starting with bromoethane and propanone via an organometallic intermediate. State the reagents and conditions necessary to prepare the organometallic reagent from the bromoethane. *[2]*

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G2. (a) Discuss **three** separate pieces of evidence (physical or chemical) to show that the bonding between the carbon atoms in benzene is not simply alternate double and single carbon–carbon covalent bonds. *[3]*

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(b) Describe and explain the reactivities of iodobenzene and (iodomethyl)benzene with a warm aqueous solution of sodium hydroxide. *[4]*

Iodobenzene:

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(Iodomethyl)benzene:

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G3. (a) The structure of paracetamol (acetaminophen) is given in Table 20 of the Data Booklet. It can be synthesized by reacting 4-aminophenol with ethanoic anhydride. State the equation for this reaction using structural formulas and state the name of the other organic product. *[2]*

(b) Paracetamol can also be prepared by reacting ethanoyl chloride with 4-aminophenol.

Explain the mechanism of this reaction using structural formulas and curly arrows to represent the movement of electron pairs. *[3]*

(This question continues on the following page)

(Question G3 continued)

(c) The structural formula of aspirin is also given in Table 20 of the Data Booklet. Deduce the structural formula of the compound which could be used to prepare aspirin by reacting it in one step with ethanoic anhydride. *[1]*

(d) The structure of ibuprofen, another common painkiller, is also given in Table 20. It contains a benzene ring substituted in the 1- and 4- positions. One of the substituted groups is an alkyl group. Suggest how the alkylation of benzene by the $–CH_2–CH(CH_3)_2$ group to give $C_6H_5–CH_2–CH(CH_3)_2$ could be achieved. Your answer should include the reagents and conditions and the name of the mechanism. *[3]*

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

Answers written on this page
will not be marked.