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CHEMISTRY
HIGHER LEVEL
PAPER 3

Candidate session number

Tuesday 20 May 2014 (morning)

1 hour 15 minutes

Examination code

2	2	1	4	–	6	1	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	Questions
Option A — Modern analytical chemistry	1 – 4
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Option A — Modern analytical chemistry

1. Modern analytical techniques are used widely for different purposes in everyday life.

(a) State which analytical technique or combination of techniques would be most suitable for the following purposes. *[2]*

Purpose	Analytical technique(s)
Determining the level of ethanol in the breath of a driver of a vehicle	. . . . .
Determining the concentration of chromium in seawater	. . . . .
Body scanning to diagnose the autoimmune disease, multiple sclerosis	. . . . .
Testing for the presence of volatile performance-enhancing drugs such as nandrolone	. . . . .

(b) Two types of spectroscopy are absorption and emission. Distinguish between each type of spectra, including how each is produced. *[4]*

Absorption spectra:

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Emission spectra:

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(Option A continues on the following page)

(Option A continued)

2. Thin-layer chromatography (TLC) is an example of adsorption chromatography. Gas-liquid chromatography (GLC) can be used to separate and identify small samples of gases and volatile liquids.

(a) A mixture of two organic compounds was separated by TLC using a non-polar solvent.

Compound	Distance travelled / mm
A	22
B	65
Solvent	80

(i) Calculate the R_f values of A and B. *[1]*

Compound	R_f value
A	
B	

(ii) Outline why compound B has travelled the greater distance. *[1]*

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. . . . . .

(b) Describe the technique of gas-liquid chromatography (GLC). *[4]*

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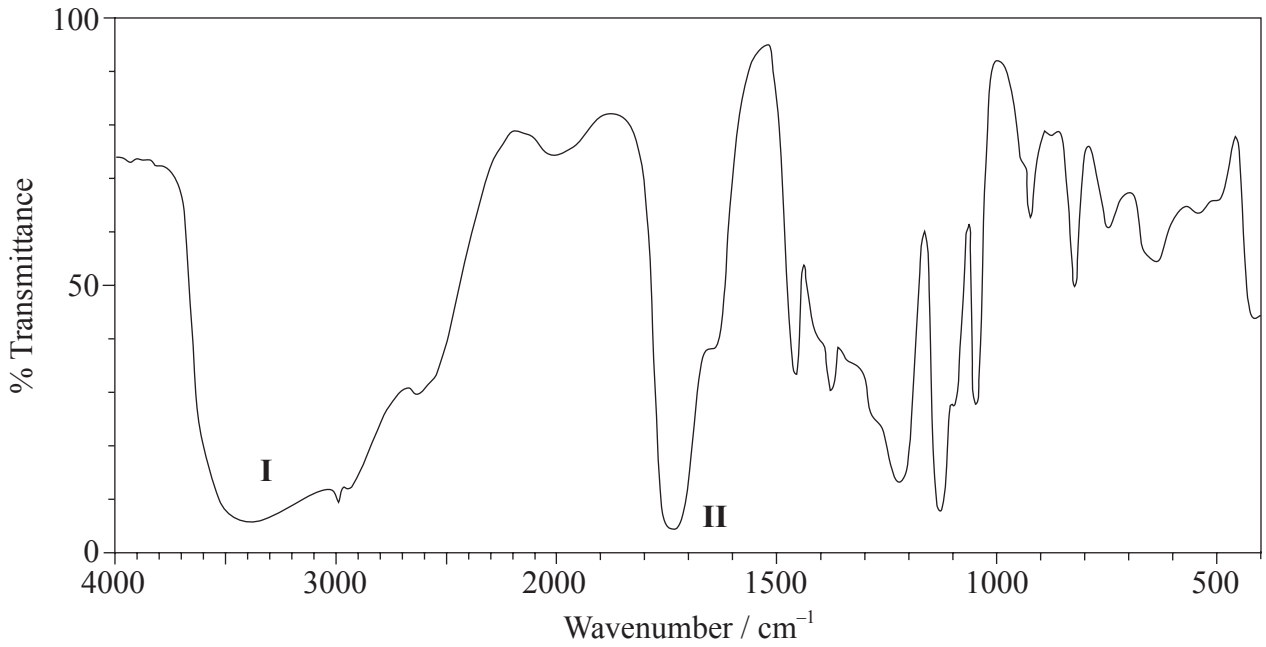
(Option A continues on the following page)

(Option A continued)

3. Compound **X** has the molecular formula $C_3H_6O_3$ and is found in human perspiration.

(a) Its infrared (IR) spectrum is represented below.



[Source: SDBS web: www.sdbs.riodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2013)]

Deduce the bonds responsible for the absorptions labelled **I** and **II**. *[1]*

I:

. . . . . .

II:

. . . . . .

(Option A continues on the following page)

(Option A, question 3 continued)

(b) The ^{1}H NMR spectrum recorded showed four peaks with the following chemical shift values (in ppm):

Peaks	Chemical shift / ppm
A	12.4
B	4.0
C	3.4
D	1.2

The integration trace for A:B:C:D was found to be 1:1:1:3.

Deduce what information can be obtained about the hydrogen atoms responsible for peak D at 1.2 ppm from the integration trace in the ^{1}H NMR spectrum of **X**. *[1]*

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

(c) Deduce the fragments in the mass spectrum which correspond to the following *m/z* values. *[2]*

$m/z = 45$:

. . . . . .

$m/z = 17$:

. . . . . .

$m/z = 15$:

. . . . . .

(Option A continues on the following page)

(Option A, question 3 continued)

(d) Deduce the structural formula of **X**. *[1]*

(e) **Y** is an isomer of **X**, which contains the same functional groups. Deduce the structural formula of **Y**. *[1]*

(f) (i) Like **X**, 3-methylbutanoic acid is also a source of body odour. Deduce the *m*/*z* value for the molecular ion peak on the mass spectrum of this compound. *[1]*

. . . . . .

. . . . . .

(ii) Ethyl propanoate (ethyl propionate) is an isomer of 3-methylbutanoic acid. Its ^{1}H NMR spectrum consists of four peaks.

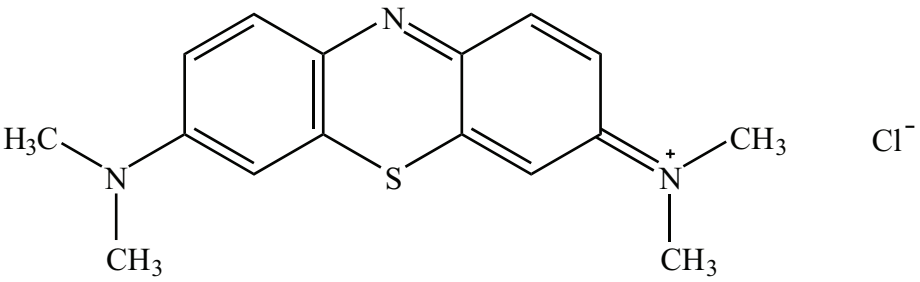
Deduce the ratios of the areas under each peak in the ^{1}H NMR spectrum of ethyl propanoate. For each peak, deduce the range of chemical shift values (in ppm), using Table 18 of the Data Booklet, and predict the splitting pattern. *[3]*

Ratio under each peak	Range of chemical shift values / ppm	Splitting pattern

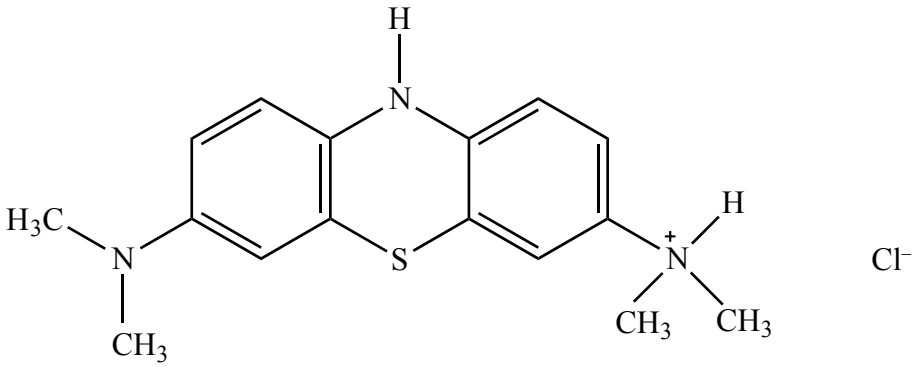
(Option A continues on the following page)

(Option A continued)

4. Methylene blue can be used as an indicator.



I



II

(a) Explain which of the two structures would be coloured. *[2]*

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(b) In terms of the wavelength of the visible light absorbed, suggest why the coloured form is blue. *[1]*

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End of Option A

Option B — Human biochemistry

5. Foods such as pasta are rich in carbohydrates.

(a) State why a professional cyclist would eat pasta before a race. *[1]*

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

(b) Monosaccharides are a type of carbohydrate.

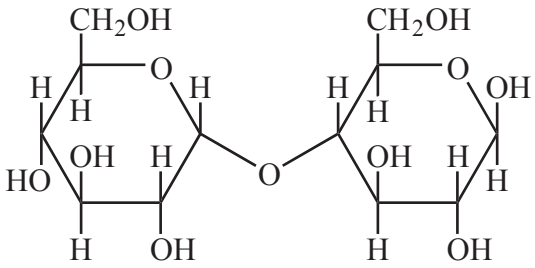
(i) Fructose, a monosaccharide, is found in honey. Draw the straight-chain structure of fructose. *[1]*

(ii) Draw the five-membered ring structure of β-fructose. *[1]*

(Option B continues on the following page)

(Option B, question 5 continued)

(c) The structure of maltose is shown below. The structure of sucrose is given in Table 21 of the Data Booklet.



Maltose

(i) Draw a circle around the 1,4 glycosidic link in maltose. *[1]*

(ii) Identify which sugar other than fructose is involved in these two structures. *[1]*

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

(iii) The structure of lactose is also given in Table 21 of the Data Booklet. Outline how the structure of lactose differs from that of maltose. *[2]*

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(Option B continues on the following page)

(Option B continued)

6. Lipids are a group of naturally occurring largely non-polar biomolecules.

(a) (i) Draw the structure of glycerol (propane-1,2,3-triol). *[1]*

(ii) Glycerol can react with three molecules of lauric acid to form a triglyceride. The structure of lauric acid is given in Table 22 of the Data Booklet. State the name of the functional group of the triglyceride and identify the other product formed. *[1]*

Name of functional group of triglyceride:

. . . . . .

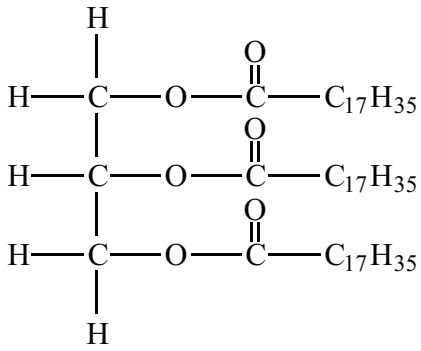
Other product formed:

. . . . . .

(Option B continues on the following page)

(Option B, question 6 continued)

(b) The hydrolysis of tristearin, whose structure is shown below, can be catalysed by the enzyme lipase.



Tristearin

Successive hydrolysis of tristearin results in the formation of distearin and monostearin. Deduce the structure of the diglyceride, distearin, and state the name of the other product formed from this reaction. *[2]*

Structure of diglyceride, distearin:

Name of other product:

. . . . . .

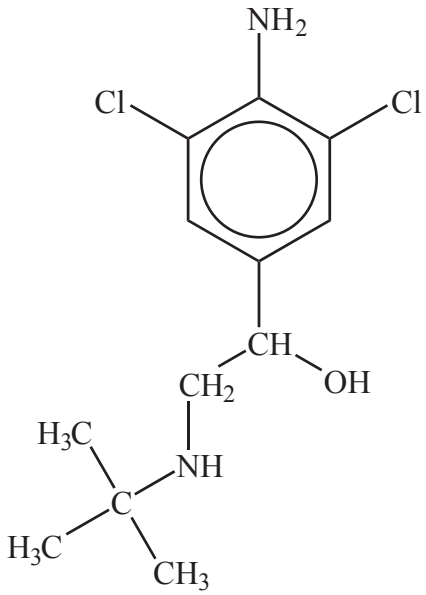
(Option B continues on the following page)

(Option B continued)

7. Anabolic androgenic steroids mimic the effect of testosterone in the body. The structures of testosterone and other hormones are given in Table 21 of the Data Booklet.

(a) The use of anabolic steroids is prohibited by UCI (*Union Cycliste Internationale*) – the governing body of world cycling, based in Switzerland.

Since 2010, a number of professional cyclists have tested positive to traces of the substance clenbuterol, known to enhance the aerobic capacity of high-performance cyclists. The structure of clenbuterol is given below.



Some sections of the media have described clenbuterol as an anabolic steroid. Suggest why this is incorrect. *[1]*

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

(b) Compare the functional groups present in the structures of the male sex hormone, testosterone, and the female sex hormone, progesterone. *[2]*

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(Option B continues on the following page)

(Option B continued)

8. Nucleic acids, which are polynucleotides present in cells, transmit essential genetic information.

(a) Explain the double helical structure of DNA, including the importance of hydrogen bonding. *[4]*

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(b) Outline the steps used in DNA profiling. *[3]*

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(Option B continues on the following page)

(Option B continued)

9. Hemoglobin is often described as a carrier of diatomic oxygen.

(a) Describe the structure of hemoglobin. *[2]*

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(b) Outline the role of hemoglobin in transporting diatomic oxygen. *[2]*

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End of Option B

Option C — Chemistry in industry and technology

10. Both chlorine and sodium hydroxide are important intermediates in the modern chemical industry.

(a) Outline the process used to produce these substances. *[1]*

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

(b) State equations for the reactions taking place at the positive electrode (anode) and the negative electrode (cathode), for the process outlined in (a). *[2]*

Positive electrode (anode):

. . . . . .

Negative electrode (cathode):

. . . . . .

(c) State the name of the process used in modern factories and outline **one** reason why this process is preferred to earlier processes. *[2]*

Name of process:

. . . . . .

Reason:

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

(Option C continues on the following page)

(Option C continued)

11. Modern society is very dependent on electrical power for portable devices.

(a) Two common rechargeable batteries are lead-acid and nickel-cadmium (NiCad) batteries.

(i) State equations for the reactions that occur at each electrode in a **lead-acid battery** when it delivers a current. *[2]*

Positive electrode (cathode):

. . . . . .

Negative electrode (anode):

. . . . . .

(ii) State equations for the reactions that occur at each electrode in a **nickel-cadmium (NiCad) battery** when it delivers a current. *[2]*

Positive electrode (cathode):

. . . . . .

Negative electrode (anode):

. . . . . .

(Option C continues on the following page)

(Option C, question 11 continued)

(b) Another source of power for portable devices is the fuel cell. Compare fuel cells with **lead-acid** rechargeable batteries, stating **one** similarity and **two** differences. *[3]*

Similarity:

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. . . . . .

Differences:

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(Option C continues on the following page)

(Option C continued)

12. Ethene can be polymerized to form poly(ethene) and, depending on the conditions used, either high-density poly(ethene) (HDPE) or low-density poly(ethene) (LDPE) is formed.

(a) (i) Other than density, state **two** differences in the physical properties of HDPE and LDPE. *[1]*

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

(ii) Outline how the differences in (a)(i) relate to differences in their chemical structure. *[1]*

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. . . . . .

(b) State the conditions required to produce HDPE and LDPE and the name of each type of mechanism involved. *[4]*

	HDPE	**LDPE**
Condition	. . . .	. . . .
Mechanism	. . . .	. . . .

(Option C continues on the following page)

(Option C continued)

13. Liquid crystals are an important component in many devices considered essential in modern life, such as smartphones.

(a) Describe the meaning of the term liquid crystal. *[1]*

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

(b) List **two** properties needed for a substance to be used in a liquid-crystal display. *[2]*

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(c) (i) Describe the nature of a pixel. *[1]*

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. . . . . .

(ii) Explain how it responds to the application of a voltage across it. *[3]*

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End of Option C

Option D — Medicines and drugs

14. Adults can produce approximately 2 dm^3 of gastric juice daily in the stomach.

(a) The pH of gastric juice is 1.5. Identify the compound responsible for its acidity and state whether it is a strong or weak acid. *[2]*

Compound:

. . . . . .

Strong or weak acid:

. . . . . .

(b) Antacid tablets are often taken for an upset stomach. Identify the reaction involved in this treatment and state the general ionic equation for this reaction type. *[2]*

Type of reaction:

. . . . . .

Ionic equation:

. . . . . .

(Option D continues on the following page)

(Option D, question 14 continued)

(c) One active ingredient in a commercial brand of antacid tablets is a complex of aluminium hydroxide and sodium carbonate, dihydroxyaluminium sodium carbonate, $Al(OH)_2NaCO_3(s)$.

Deduce the balanced equation, including state symbols, for the reaction of $Al(OH)_2NaCO_3(s)$ with the acid present in gastric juice. *[2]*

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. . . . . .

(d) (i) Explain why anti-foaming agents are often added to the formulation in antacids. *[1]*

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. . . . . .

(ii) State the name of **one** such agent. *[1]*

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. . . . . .

(Option D continues on the following page)

(Option D continued)

15. A commonly used mild analgesic is aspirin, 2-acetoxybenzoic acid, whose structure is given in Table 20 of the Data Booklet.

(a) Describe how mild analgesics function. *[1]*

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

(b) One form of soluble aspirin is $Ca(C_9H_7O_4)_2$.

(i) Outline why this substance is more soluble than standard aspirin in water. *[1]*

. . . . . .

(ii) Deduce the balanced ionic equation for the reaction that occurs between soluble aspirin and the acid in the stomach. *[1]*

. . . . . .

(Option D continues on the following page)

(Option D, question 15 continued)

(c) Morphine, codeine and diamorphine (heroin) are examples of strong analgesics. Their structures are given in Table 20 of the Data Booklet.

(i) Deduce **two** named functional groups present in both aspirin and diamorphine. *[2]*

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

(ii) Deduce **one** named functional group present in morphine but not in diamorphine. *[1]*

. . . . . .

(iii) State **two** short-term advantages and **two** long-term disadvantages of using codeine as a strong analgesic. *[2]*

Short-term advantages:

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

Long-term disadvantages:

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

(Option D, question 15 continued)

(iv) Explain the increased potency of diamorphine compared to morphine. *[3]*

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(Option D continues on the following page)

(Option D continued)

16. Lysergic acid diethylamide (LSD), mescaline, psilocybin and tetrahydrocannabinol (THC) are mind-altering drugs.

(a) State **one** different effect for each of the drugs, LSD and THC. *[2]*

Mind-altering drug	Effect
LSD	. . . . .
THC	. . . . .

(b) Discuss the structural similarities and differences between mescaline and psilocybin. Their structures are given in Table 20 of the Data Booklet. *[4]*

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End of Option D

Option E — Environmental chemistry

17. Motor vehicles are very convenient but can be a major source of air pollution.

(a) (i) In some countries there has been a recent shift from petrol (gasoline) to diesel as a fuel for motor vehicles. State **one** primary pollutant produced by both of these fuels. *[1]*

. . . . . .

(ii) Outline **one** method that has been developed for each fuel to reduce polluting emissions. *[2]*

Fuel	Method to decrease emissions
Diesel	. . . . .
Petrol (gasoline)	. . . . .

(iii) Sulfur dioxide is generated from the sulfur present in diesel fuel. State **two** other manufactured (anthropogenic or sometimes termed man-made) sources of sulfur dioxide. *[2]*

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. . . . . .

(Option E continues on the following page)

(Option E, question 17 continued)

(b) Motor vehicle emissions contribute to the formation of photochemical smog.

(i) State how location affects the formation of smog. *[1]*

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(ii) Outline, using relevant equations, how pollutants from motor vehicles form secondary pollutants in photochemical smog. *[3]*

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(Option E continues on the following page)

(Option E continued)

18. Acid deposition is a consequence of industrial processes.

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

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

(b) Describe, using equations, the mechanism of acid deposition caused by the oxides of nitrogen, including their initial formation. *[3]*

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(c) All shellfish have a calcium carbonate shell. Discuss, including a balanced equation, the long-term effect of acid deposition on these organisms. *[2]*

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

Balanced equation:

. . . . . .

(Option E continues on the following page)

(Option E continued)

19. One method of removing heavy metal ions from a solution is by precipitation.

(a) State an ionic equation, including state symbols, for the reaction taking place when an aqueous solution containing chloride ions is added to an aqueous solution containing lead(II) ions. *[2]*

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(b) The solubility product, K_{sp}, of lead(II) chloride is 1.7×10^{-5} at 298 K. Determine the concentration of lead(II) ions, in $mol\,dm^{-3}$, when equal volumes of $1.0\,mol\,dm^{-3}$ aqueous potassium chloride and a solution of $0.50\,mol\,dm^{-3}$ lead(II) ions are mixed. State any assumption used. *[4]*

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(Option E continues on the following page)

(Option E continued)

20. The health of soils is important for feeding the world's population.

(a) (i) Describe how nutrient depletion occurs. *[1]*

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

(ii) State **one** way of minimizing nutrient depletion. *[1]*

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

(b) Explain why the soil becomes salty in areas where soil is constantly irrigated. *[2]*

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. . . . . .

End of Option E

Option F — Food chemistry

21. Food chemistry and nutritional science are two important scientific fields to which the general public relate.

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

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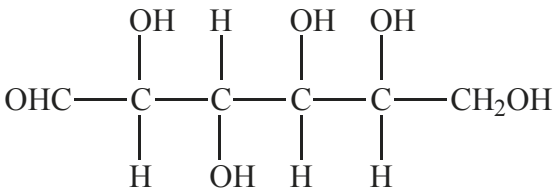
. . . . . .
. . . . . .
. . . . . .
. . . . . .
. . . . . .

(b) State **two** named functional groups present in each of the following molecules found in two different food products (honey and sardines). Identify each molecule as a protein, a carbohydrate or a fatty acid. *[3]*

Molecule		$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$
Present in food	honey	sardines
Two named functional groups	. . . .	. . . .
Protein, carbohydrate or fatty acid	. . . . .	. . . . .

(Option F continues on the following page)

(Option F, question 21 continued)

(c) Butter is an example of a saturated fat and olive oil is an example of an unsaturated fat. Describe the main structural difference between these two types of fat. *[1]*

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

(d) (i) Linoleic acid, whose structure is given in Table 22 of the Data Booklet, is present in peanut oil. The oil can be converted to a semi-solid using hydrogen gas. Predict the structural formula of the compound formed from the **partial** hydrogenation reaction of linoleic acid, and state a suitable catalyst for this reaction. *[2]*

Structural formula:

Catalyst:

. . . . . .

(ii) State **one** food product that may be obtained by careful control of the extent of the reaction in (d)(i). *[1]*

. . . . . .

(Option F continues on the following page)

(Option F, question 21 continued)

(iii) Partial hydrogenation can sometimes produce *trans* fats. Suggest why *trans* fats are considered unhealthy. *[1]*

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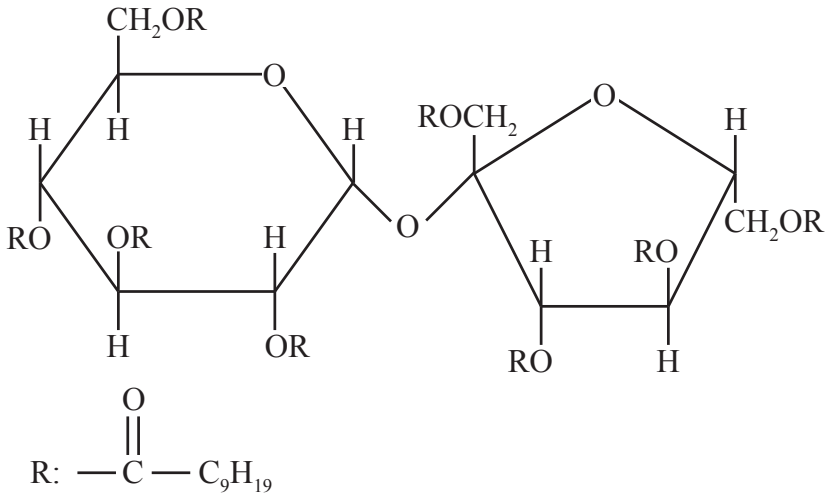
. . . . . .

(iv) Olestra, with one of its structures shown below, has been used to prepare snacks such as crisps (potato chips). Deduce the type of compound that can undergo an esterification reaction involving carboxylic acid to produce olestra. *[1]*



Olestra

. . . . . .

(Option F continues on the following page)

(Option F continued)

22. Food can be coloured by natural or artificial means.

(a) Distinguish between a *dye* and a *pigment* in terms of their solubility. *[1]*

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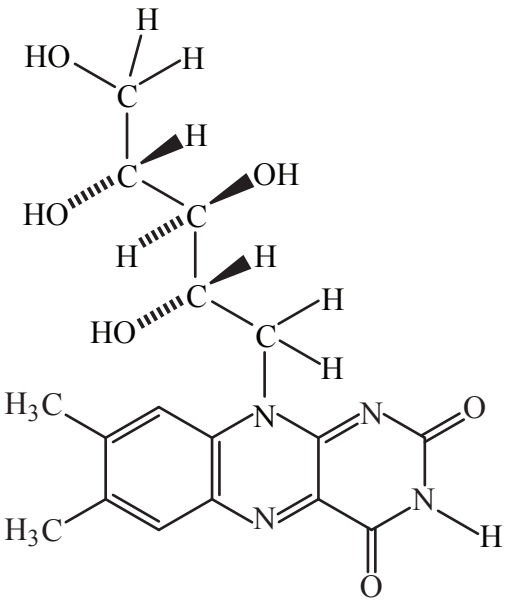
. . . . . .
. . . . . .

(b) (i) Many vegetables contain the pigment β-carotene. After ingestion, β-carotene is oxidized by enzymes forming vitamin A (retinol), whose structure is given in Table 21 of the Data Booklet.

Suggest why taking large doses of vitamin B_2 (riboflavin), which is found in eggs, can be safer than taking large doses of vitamin A (retinol). *[1]*



Vitamin B_2 (riboflavin)

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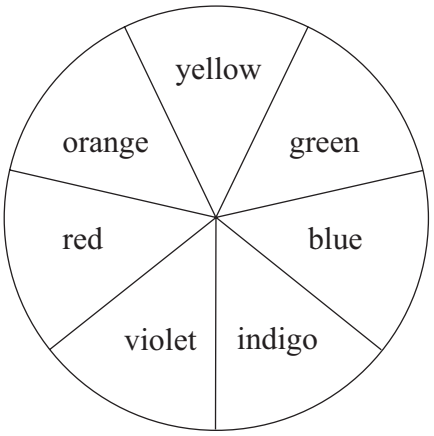
(Option F continues on the following page)

(Option F, question 22 continued)

(ii) Extraction of the vegetable spinach produces β-carotene and chlorophyll. These have different colours due to their different ultraviolet-visible (UV-Vis) absorption spectra. The λ_{max} values for β-carotene and chlorophyll are 425 nm and 662 nm respectively.

Using the λ_{max} values corresponding to the colours of the visible region of the electromagnetic spectrum, explain the colours of the two compounds. *[2]*

Colour	**λ / nm**
Violet	380–450
Indigo	450–475
Blue	475–495
Green	495–570
Yellow	570–590
Orange	590–620
Red	620–750



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(Option F continues on the following page)

(Option F continued)

23. Antioxidants in food slow down the rate of oxidation.

(a) Describe, using equations, the steps in the free-radical chain mechanism that occurs in oxidative rancidity. Only one equation is required for each step. *[3]*

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(b) Distinguish between the **three** main types of antioxidants. *[3]*

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(Option F continues on the following page)

(Option F continued)

24. Stereochemistry plays a key role in food.

(a) State what is meant by the + and – notations often used for naming different enantiomeric forms. *[1]*

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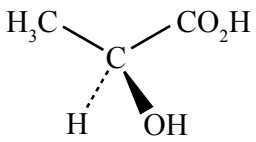
(b) Lactic acid is found in sour milk.



Lactic acid

(i) Identify the chiral centre in the structure with an asterisk (*). *[1]*

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(ii) Deduce whether the enantiomer shown is R or S. Your answer should include the method of assignment used. *[2]*

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End of Option F

Option G — Further organic chemistry

25. Both phenol, C_6H_5OH, and butan-1-ol, $CH_3CH_2CH_2CH_2OH$, contain the hydroxyl group.

(a) (i) State the structural formula of the organic product formed by heating butan-1-ol with concentrated phosphoric acid, H_3PO_4. *[1]*

(ii) Identify the type of reaction in (a)(i). *[1]*

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(iii) Suggest why concentrated phosphoric acid is a more effective reagent than concentrated sulfuric acid, H_2SO_4, for the reaction in (a)(i). *[1]*

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(b) State whether phenol is a stronger or a weaker acid than butan-1-ol and explain your answer. *[2]*

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(Option G continues on the following page)

(Option G continued)

26. Consider the following reaction pathway starting with the reaction of hex-1-ene with hydrogen iodide.

Stage 1: $H_2C{=}CH(CH_2CH_2CH_2CH_3) + HI \rightarrow \mathbf{X}$ (Major) + **Y** (Minor)

Stage 2: $\mathbf{X} + Mg \rightarrow \mathbf{Z}$

(a) (i) In Stage 1 two isomers form. Deduce the **full** structural formula of each isomer, showing all the bonds. *[2]*

X (Major):

Y (Minor):

(ii) Explain the mechanism of the reaction of hex-1-ene with hydrogen iodide to form **X**, using curly arrows to represent the movement of electron pairs. *[3]*

(Option G continues on the following page)

(Option G, question 26 continued)

(iii) Suggest why the intermediate involved in forming isomer **X** is more stable than the one required to form **Y**. *[1]*

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(b) **Z** is a Grignard reagent.

(i) State the structural formula of **Z**. *[1]*

(ii) State an important condition for the Stage 2 reaction to occur. *[1]*

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(Option G continues on the following page)

(Option G, question 26 continued)

(iii) Deduce the structural formula of the organic product formed from the reaction of **Z** with propanone, $(CH_3)_2CO$, and subsequent hydrolysis with dilute aqueous acid, H_3O^+. Identify the class of compound to which the organic product formed belongs. *[2]*

Structural formula:

Class of compound:

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(iv) Identify the reagent that would be required to react with **Z** to produce a carboxylic acid. *[1]*

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(Option G continues on the following page)

(Option G continued)

27. (a) (i) Identify the **two** reagents used to form the electrophile in the nitration of benzene. *[1]*

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(ii) Explain, using curly arrows to represent the movement of electrons, the mechanism for this reaction. *[4]*

(b) State how the compound 1-methyl-2-nitrobenzene could be synthesized from benzene. *[3]*

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(Option G continues on the following page)

(Option G, question 27 continued)

(c) Predict what change would be required if you wanted to synthesize the other isomer, 1-methyl-3-nitrobenzene. *[1]*

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End of Option G

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

Answers written on this page
will not be marked.