

GCE A LEVEL – CHEMISTRY UNIT 4 QUESTION PACK

1095-01 (Legacy CH4) · New spec Unit 4 Topic 2 · A2 unit, first sat 2017, 80 marks, 1h 45min paper

REVISE.wales**CHEMISTRY – UNIT 4 · Carbonyl Compounds & Carboxylic Acid Derivatives**

Topics 4.3 & 4.4 – Aldehydes, ketones, carboxylic acids and their derivatives (esters, acyl chlorides, amides)

Nucleophilic addition to C=O (HCN, NaBH₄), distinguishing aldehydes from ketones (Tollens' / Fehling's / 2,4-DNPH), the triiodomethane test, esterification, acid-chloride reactivity, amide hydrolysis and the iodoform reaction.

Legacy 2008 specification

Estimated time for entire question pack: ~4 h*Derived from the legacy CH4 paper's pace of ~1.3 min/mark, padded for long-prose and synthesis answers (150 marks over 10 questions).**You are advised to **not** attempt to complete all of this in one sitting.***ABOUT THIS QUESTION PACK**This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC CH4 papers (2008 modular spec, Jan 2010 – Jun 2016) that maps onto the new-spec A2 Unit 4 Topic 4.3 & 4.4.

Questions are ordered by source paper date.

INSTRUCTIONS

Use black ink or black ball-point pen. Show all working – quality of written communication will affect marks. A calculator is allowed. You will need the WJEC Periodic Table / Data Booklet.

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Q	Source	Max	Mark
1	Jun 10 Q2	15	
2	Jun 11 Q2	15	
3	Jan 12 Q4	20	
4	Jun 12 Q4	20	
5	Jan 13 Q1	12	

Q	Source	Max	Mark
6	Jun 13 Q1	12	
7	Jun 13 Q3	15	
8	Jan 14 Q1	13	
9	Jun 16 Q2	13	
10	Jun 16 Q3	15	
Total		150	

Carbonyl Compounds & Carboxylic Acid Derivatives – what the new spec asks

WJEC GCE A Level Chemistry (from 2015) · Unit 4: Organic Chemistry & Analysis · Topic 4.3 & 4.4.

Carbonyl reactivity

- C=O is polar (δ^+ on C, δ^- on O).
- Aldehydes RCHO more reactive than ketones R₂CO (less steric, less inductive).
- Nucleophiles attack C; H⁺ adds to O.
- C=O resists addition more than C=C (need stronger nucleophiles).

Distinguishing tests

- Tollens': Ag⁺(NH₃) reagent → silver mirror with aldehydes only.
- Fehling's: Cu²⁺ complex → brick-red Cu₂O with aliphatic aldehydes only.
- 2,4-DNPH: both aldehydes and ketones give orange/red precipitate (mp confirms identity).
- Triiodomethane test: I₂/NaOH with methyl ketones (or CH₃CH(OH)R) → yellow CHI₃.

Esters

- Esterification: RCOOH + R'OH → RCOOR' + H₂O (conc. H₂SO₄ catalyst, reflux).
- Equilibrium – remove water or use excess to drive forward.
- Acid hydrolysis: heat with dilute H₂SO₄ → reverse of esterification.
- Alkaline hydrolysis (saponification): NaOH → RCOO⁻Na⁺ + R'OH; not reversible.

Nucleophilic addition

- HCN: adds across C=O → 2-hydroxynitrile. Use NaCN + dilute H₂SO₄ (HCN toxic).
- Mechanism: CN⁻ attacks Cδ⁺, alkoxide intermediate protonated.
- Product racemic (planar C=O attacked from either face).
- NaBH₄ reduces RCHO → RCH₂OH, R₂CO → R₂CHOH.

Carboxylic acids

- RCOOH weakly acidic: K_a 10⁻⁴-10⁻⁵.
- -COO⁻ stabilised by resonance (charge delocalised over both O).
- Electron-withdrawing groups (e.g. -Cl) increase acidity; +I groups decrease it.
- React with carbonates/hydrogencarbonates → CO₂ (test).

Acyl chlorides & amides

- RCOCl: most reactive carboxylic acid derivative; SOCl₂ + RCOOH → RCOCl.
- RCOCl + R'OH → ester; + R'NH₂ → amide; + H₂O → carboxylic acid (vigorous).
- Amides: RCONHR'; planar around N (partial C-N double bond character).
- Amide hydrolysis: acidic → RCOOH + R'NH₃⁺; basic → RCOO⁻ + R'NH₂.

Carbonyl Compounds & Carboxylic Acid Derivatives in one page

Quick-reference notes – revisit before each question.

Carbonyl polarity

O is more electronegative \Rightarrow $C\delta^+$, $O\delta^-$.
Nucleophiles (CN^- , H^- , NH_3) attack the C.

$NaBH_4$ vs $LiAlH_4$

$NaBH_4$ (in water/ethanol): reduces $RCHO$ & R_2CO to alcohols. Doesn't touch $RCOOH/RCOOR'$.
 $LiAlH_4$ (dry ether): reduces everything including $RCOOH \rightarrow RCH_2OH$ and $RCN \rightarrow RCH_2NH_2$.

Tollens' / Fehling's

Both reduced by $RCHO$, not by R_2CO .
Tollens': silver mirror. Fehling's: brick-red Cu_2O . Aromatic aldehydes don't reduce Fehling's (only Tollens').

Iodoform test

$I_2/NaOH(aq)$ gives yellow CHI_3 precipitate with CH_3CO-R or $CH_3CH(OH)-R$ groups. Positive for ethanol, propan-2-ol, propanone, ethanal, but NOT methanol.

Esterification

$RCOOH + R'OH \rightarrow RCOOR' + H_2O$.
Reversible. Use conc. H_2SO_4 catalyst + heat. Use excess alcohol or remove water to drive forward.

Acyl chlorides

$RCOCl$ most reactive carboxylic derivative. + $ROH \rightarrow$ ester; + $R'NH_2 \rightarrow$ amide; + $H_2O \rightarrow$ acid (steamy fumes of HCl).

Examiner
only

2. (a) Explain the difference in structure between *primary* and *secondary* alcohols. [1]

.....
.....

- (b) Quantitative analysis of an alcohol shows that its percentage composition by mass is C 68.1%, H 13.7% and O 18.2%. It has a relative molecular mass of 88.1.

Calculate the empirical formula of the alcohol and show that its molecular formula is the same as the empirical formula. [3]

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

- (c) The following compounds have the same molecular formula, C₅H₁₀O.



- (i) Draw the structure of an isomer of **B** that is also an aldehyde. [1]

- (ii) I. State which **one** of the compounds **A–D** exhibits E-Z (trans-cis) isomerism. [1]

.....

- II. Draw the structures of **both** isomers. [1]

Examiner
only

- (iii) Give one test, including reagents and expected observations, which would distinguish between **A** and **B**. [2]

.....

.....

.....

.....

- (iv) Give one test, including reagents and expected observations, which would distinguish between **C** and **D**. [2]

.....

.....

.....

.....

- (d) Ketones such as propanone react with hydrogen cyanide.

- (i) Classify the type of reaction taking place. [1]

.....

- (ii) Draw, with the aid of curly arrows, the mechanism for this reaction. [3]

Total [15]

Examiner
only

2. (a) Butan-1-ol can be produced by the reduction of butanal.

(i) State the name of a reducing agent that can be used for this reaction. [1]

.....

(ii) The infrared spectrum of butanal shows an absorption at 1731 cm^{-1} . State which bond in butanal is responsible for this absorption and explain how the intensity of this absorption changes as the reduction proceeds. [2]

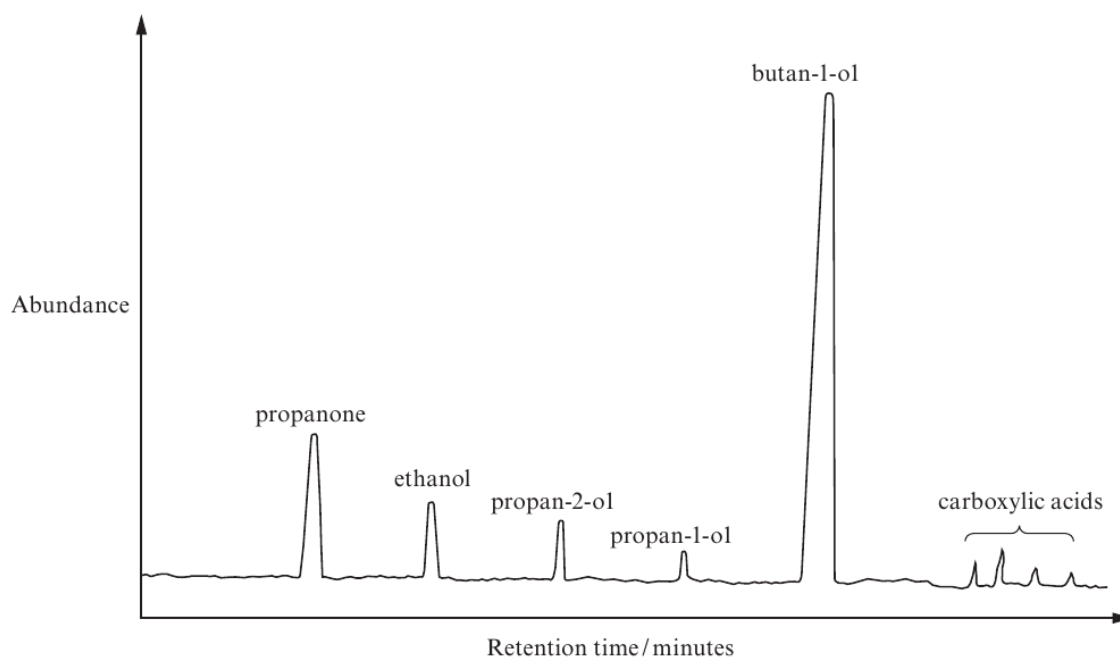
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(b) A traditional route for making butan-1-ol is by the fermentation of sugar cane residues and other starch-containing materials. One problem with this method is that a number of other products are also obtained.

The gas chromatogram shows the major products from a typical fermentation of starch.



Use the chromatogram to help you answer the questions below and opposite.

(i) State, in **decreasing** order of abundance, the three main products of this fermentation. [1]

.....

Examiner
only

(ii) State which **one** of the products in (i) **cannot** normally be oxidised to a carboxylic acid. [1]

(iii) Select **two** compounds, from the chromatogram, that will give a positive result in the triiodomethane (iodoform) reaction giving an explanation for your answer. [2]

Compounds and

Explanation

(iv) Since there is a plentiful supply of cellulose from plants, scientists are using a new bacterium to ferment cellulose rather than starch. The first results of this research have been promising.
If this new method is to be tested by other research groups why is it essential that the conditions are kept exactly the same? [1]

(c) There is interest in developing butan-1-ol as a fuel to replace petrol and diesel as this would be a carbon neutral fuel.
Suggest why this fuel is described as carbon neutral, giving a reason for your answer. [2]

(d) A large proportion of the butan-1-ol produced is used to react with ethanoic acid to produce 1-butyl ethanoate.

(i) Give the equation for this reaction. [1]

(ii) State the name of the catalyst that is used. [1]

Total [12]

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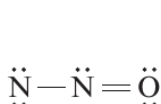
Read the passage below and then answer parts (a)-(g) in the spaces provided.

3.

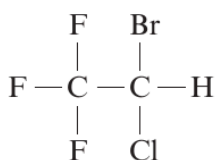
Anaesthetics

It is difficult to believe, in these days of modern medicine, that only 100 years ago tooth extractions were still being carried out without any form of anaesthetic. Modern anaesthetics are of two types – general anaesthetics, which have a whole body effect and local anaesthetics, which remove pain at the site of surgery.

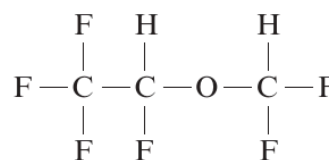
- 5 The first demonstrations of anaesthesia were in the late 1840s when Morton, in the USA, used ethoxyethane, and Simpson, in Scotland, used chloroform (trichloromethane). Later that century nitrous oxide, N_2O , was successfully used. In more recent times, up to about 1960, the most commonly used anaesthetics were cyclopropane and ethoxyethane. In the 21st century a number of safer general anaesthetics are in use, the choice depending on the condition for which they are being used. The formulae of some general anaesthetics are shown below, together with their common names.



nitrous oxide



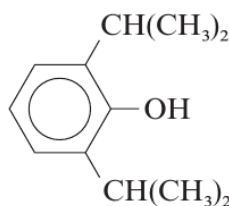
halothane



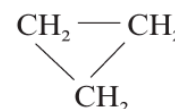
desflurane



ethoxyethane

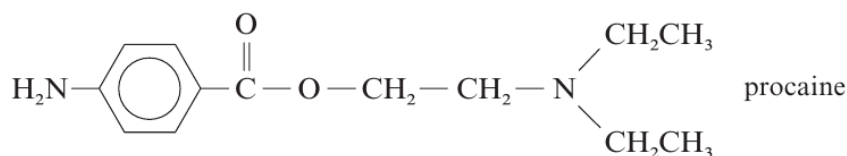


propofol



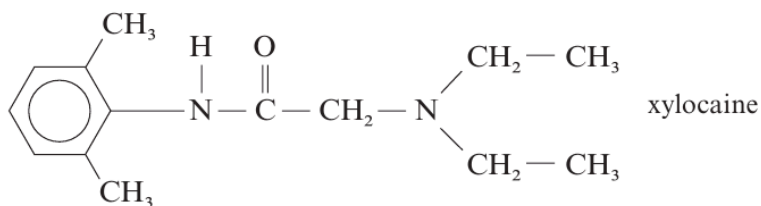
cyclopropane

- 15 In the twentieth century, the general anaesthetic nitrous oxide was still being used for routine dental extractions but in recent years the use of local anaesthetics has become the norm. A popular choice for dentists is the ester procaine, although a number of other compounds are available; their use depending on the anaesthetic effect required and its duration of action. The formulae and common names of some local anaesthetics are shown below.

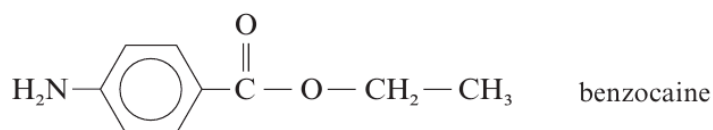


procaine

20



Benzocaine, for external use only, has uses in skin creams for which a numbing action is required.



25 The relative safety of the anaesthetic itself is an important factor in deciding which anaesthetic to use for each situation. However, another factor to be considered is the method by which the body metabolises the anaesthetic and the nature of the compounds that are produced.

– End of passage –

Examiner
only

- (a) In the upper atmosphere nitrous oxide (dinitrogen oxide), N_2O , decomposes to nitrogen and nitrogen monoxide.



Nitrogen monoxide is a reactive molecule that contains an unpaired electron.

State the general name for species that contain an unpaired electron.

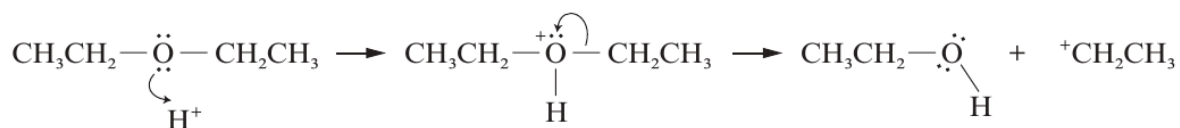
[1]

- (b) The use of cyclopropane as an anaesthetic causes concern because of its extreme flammability. Give the balanced equation for the complete combustion of cyclopropane, C_3H_6 .

[1]

- (c) Ethoxyethane, $CH_3CH_2OCH_2CH_3$, reacts with some aqueous acids to give ethanol as one of the products.

One stage of this reaction can be represented as follows:



- (i) State why ethoxyethane is behaving as a nucleophile in this reaction stage.

[1]

- (ii) I To reduce the danger of fire when carrying out this reaction, the reactants are heated together under reflux.

State what is meant by the term *heating under reflux*.

[1]

- II The reactants need to be refluxed at a temperature of $130^\circ C$.

Suggest how this mixture could be safely heated at this temperature in a laboratory fume cupboard.

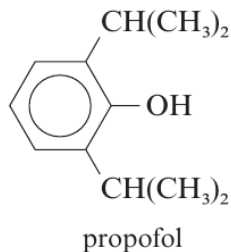
[1]

- (d) The article mentions the use of halothane (*line 12*) and desflurane (*line 12*) as general anaesthetics. State and explain which of these two compounds could cause more damage to the ozone layer.

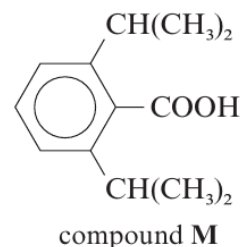
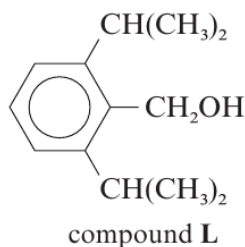
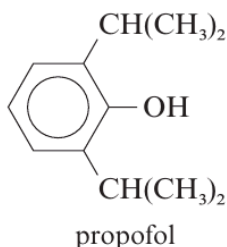
[2]

Examiner
only

- (e) Propofol, which allegedly caused the death of Michael Jackson in 2009, is an important intravenous anaesthetic.
- (i) State what would be seen if a few drops of iron(III) chloride solution were added to a solution of propofol in a suitable solvent. [1]



- (ii) The formulae of propofol, compound **L** and compound **M** are shown below.



- I The three compounds are dissolved separately in a suitable solvent and each solution tested with universal indicator paper and with sodium hydrogencarbonate solution. Complete the table below giving any **observations** or writing 'no reaction' as appropriate.

Compound	Colour given with universal indicator paper	Observation with sodium hydrogencarbonate solution
propofol		
compound L	green	no reaction
compound M		

[2]

- II Give the test for any gas produced with sodium hydrogencarbonate solution. [1]

Examiner
only

- (f) The article describes procaine (*line 19*) as an ester.
- (i) Draw the section of the formula that identifies procaine as an ester. [1]
- (ii) Use the formula of procaine to help you draw the structural formula of the nitrogen-containing alcohol that will react with a suitable acid to give procaine. [1]
- (g) Pure benzocaine has a melting temperature of 89°C. A melting temperature determination shows that a sample of benzocaine is impure. State **two** observations that would indicate that this sample is impure. [2]

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.....

.....

Total [15]

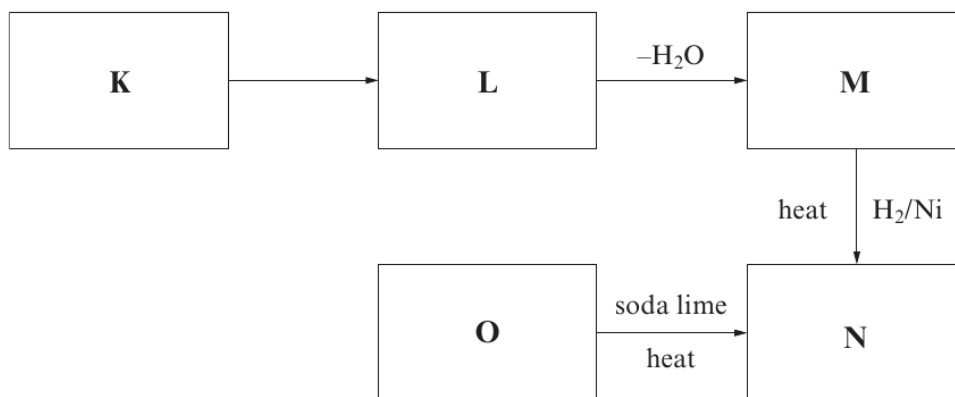
Total Section A [40]

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SECTION B

Answer **both** questions in the separate answer book provided.

4. (a) Study the reaction scheme shown below and the other information about compounds **K–O** that follows:



Compound **K** has a relative molecular mass of 58.06. It gives an orange-yellow solid with 2, 4-dinitrophenylhydrazine and gives a positive triiodomethane (iodoform) test.

0.500 g of compound **O** in aqueous solution requires 56.75 cm³ of sodium hydroxide solution of concentration 0.100 mol dm⁻³ for complete neutralisation. Compound **O** reacts with sodium hydroxide in a 1:1 molar ratio.

Compound **L** cannot be oxidised to compound **O**.

- Calculate the relative molecular mass of compound **O**. [2]
 - Identify compounds **K** and **O**, giving your full reasoning. [5]
 - Identify compounds **L**, **M** and **N**. [3]
 - State the reagent(s) needed for the conversion of **L** to **M**. [1]
- (b) Rhodri prepared benzenecarboxylic acid, C₆H₅COOH, by hydrolysing ethyl benzenecarboxylate, C₆H₅COOC₂H₅.

The overall equation for this hydrolysis is:



He used the following method.

- Dissolve 3.20 g of sodium hydroxide in water and make up to 40.0 cm³.
- Add the aqueous sodium hydroxide to 2.90 cm³ of ethyl benzenecarboxylate in a round bottomed flask and reflux for 30 minutes.
- Transfer the mixture into a beaker and add dilute sulfuric acid until the solution is acidic.
- Filter the crystals obtained and recrystallise the benzenecarboxylic acid by dissolving in the minimum amount of hot water.

At the end of the experiment Rhodri's yield of benzenecarboxylic acid was 1.45 g.

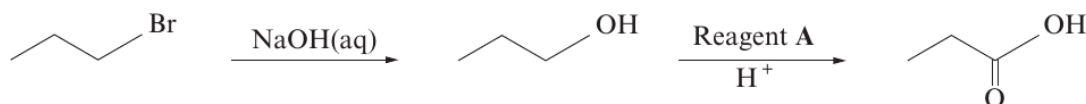
- (i) Suggest why Rhodri had to add sulfuric acid before recrystallising. [1]
- (ii) State why water is a suitable solvent for the recrystallisation. [1]
- (iii) Calculate the concentration, in mol dm^{-3} , of the aqueous sodium hydroxide used. [2]
- (iv) The density of ethyl benzenecarboxylate is 1.06 g cm^{-3} . Calculate how many moles of ethyl benzenecarboxylate were used. [2]
- (v) Calculate the percentage yield obtained by Rhodri. [2]
- (vi) Give a reason why the percentage yield was substantially lower than 100%. [1]

Total [20]

SECTION B

Answer **both** questions in the separate answer book provided.

4. (a) 1-bromopropane can be used to prepare propanoic acid in a two-stage process shown below.



- (i) Classify the reaction occurring in the first stage of this process. [1]
- (ii) The first stage uses aqueous sodium hydroxide. Under alternative conditions, 1-bromopropane produces a different product when it reacts with sodium hydroxide. Give the alternative conditions required, and the product that would be formed from 1-bromopropane under these conditions. [2]
- (iii) For the second stage, state the **full name** of reagent **A** and classify the reaction occurring. [2]
- (iv) Reagent **A** can also be used to produce propanal from propan-1-ol. State how you would isolate propanal from this reaction. [1]
- (b) (i) 1-bromopropane can also be used to prepare butanoic acid in a different two-stage process. For **each** of these two stages, give reagents and conditions required, and draw the **displayed** formula (showing all bonds) of the intermediate. [3]
- (ii) Butanoic acid is used to prepare esters used in the flavouring and perfume industries. It may be prepared from 1-bromopropane in a two-stage process as in (b)(i) above or from butan-1-ol or butanal in a one-stage process.
- Suggest **two** factors that a scientist would consider in choosing between these different routes to produce butanoic acid on a bulk scale. [2]
- (c) Compound **B** is an isomer of formula $\text{C}_4\text{H}_8\text{O}_2$ which exists as a sweet-smelling liquid at room temperature.
- (i) Elemental analysis of compound **B** shows that it has a composition of 54.5% carbon, 9.1% hydrogen and 36.4% oxygen, by mass. Show that this composition is consistent with the formula above. [2]

- (ii) Compound **B** shows three resonances in its ^1H nuclear magnetic resonance spectrum.
- A triplet at 1.0 ppm with an area of 3
 - A singlet at 2.1 ppm with an area of 3
 - A quartet at 4.0 ppm with an area of 2

The infrared spectrum of compound **B** shows absorptions at 2981 cm^{-1} and 1750 cm^{-1} .

These are the only significant absorptions above 1500 cm^{-1} .

Using **all** the information supplied, deduce the structure of compound **B**.

Give **reasons** in support of your answer.

[5]
(QWC) [2]

Total [20]

SECTION A

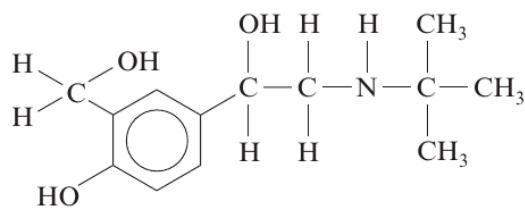
Answer **all** questions in the spaces provided.

Examiner
only

1. (a) From the information given, draw the displayed formula of each compound.
In parts (i)-(iii) the compounds consist of molecules that have **three** carbon atoms.
In part (iv) the compound has **four** carbon atoms.
- (i) A compound that is oxidised to a ketone [1]
- (ii) A neutral sweet-smelling compound [1]
- (iii) An α -amino acid [1]
- (iv) A hydrocarbon that exhibits E-Z isomerism [1]

Examiner
only

- (b) The active compound in Ventolin[®] inhalers used by asthma sufferers is salbutamol, which shows optical isomerism.



salbutamol

- (i) Indicate a chiral centre in this molecule by labelling it with an asterisk (*). [1]
- (ii) State how the optical isomers of salbutamol could be distinguished from each other. [1]
-
-
- (iii) Suggest a reason why only one optical isomer of salbutamol is used as a pharmaceutical. [1]
-
- (iv) Draw the displayed formula of the likely organic product formed when salbutamol is refluxed with acidified $K_2Cr_2O_7$. [2]

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(c) (i) Arrange the following molecules in order of **increasing** acidity. [1]

ethanoic acid ethanol ethylamine phenol

least most
acidic acidic

(ii) Explain the difference in acid-base properties of ethylamine and phenol. [4]

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.....

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.....

.....

Total [14]

Examiner
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Examiner
only

2. (a) 2,4-Dinitrophenylhydrazine reagent (2,4-DNP), Tollens' reagent and iodine in sodium hydroxide solution can all be used in the laboratory to identify unknown compounds. Complete the table below by giving any observations made (or writing 'no reaction' as appropriate) when these reagents are added to the compounds listed. [4]

	butan-2-ol	ethanal	ethanol	propanone
2,4-DNP	no reaction			
Tollens' reagent			no reaction	
I ₂ /NaOH				

- (b) Under certain conditions ethanol can be formed from ethene and water. A possible mechanism for this reaction is shown below.



- (i) Classify this type of mechanism. [1]
.....
- (ii) State the name given to species such as the intermediate ion CH_3CH_2^+ . [1]
.....
- (iii) Give another reaction of ethene that follows this type of mechanism. [1]
.....
- (iv) Give a reason why the main product of the reaction between propene and water under similar conditions is propan-2-ol. [1]
.....
.....

(c) Propanone can react with hydrogen cyanide.

(i) Classify the type of reaction taking place when propanone reacts in this way. [1]

.....

(ii) Draw the mechanism for this reaction. [3]

Total [12]

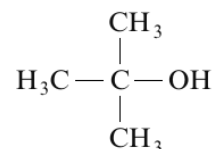
Examiner
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SECTION A

Answer **all** questions in the spaces provided.

1. (a) In 2012 an off-licence in Derby was prosecuted for selling fake vodka.
- (i) A report in the local paper stated that this 'vodka' was contaminated by 'tertiary butanol', the formula of which is shown below.



State the **systematic** name of this compound. [1]

-
- (ii) Analysis showed that the total alcohol content of a bottle of the fake vodka was 35%.
A gas-liquid chromatogram showed a mixture of alcohols to be present in the following proportions:

tertiary butanol	6 parts
methanol	8 parts
ethanol	86 parts

Calculate the percentage of ethanol by volume in the fake vodka. [1]

..... %

- (iii) Tertiary butanol can be dehydrated in an elimination reaction to produce 2-methylpropene. Suggest a suitable dehydrating agent for this reaction. [1]

.....

- (iv) 2-Methylpropene can be polymerised to give poly(2-methylpropene). Draw the repeating unit of the polymer.

[1]

Examiner
only

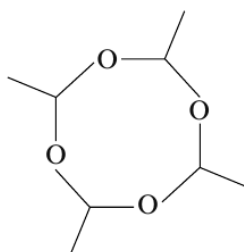
- (v) Write the displayed formula of any isomer of tertiary butanol that contains a chiral centre. Identify the chiral centre by an asterisk (*).

[2]

- (vi) The main alcoholic compound of the fake vodka is ethanol. This can be oxidised to give ethanal.

I State the reagent(s) used to oxidise ethanol to ethanal in the laboratory. [1]

II Ethanal can be polymerised to 'metaldehyde', $(\text{CH}_3\text{CHO})_4$, which is used to kill slugs.



Use the Data Sheet to describe how the infrared spectrum of 'metaldehyde' will differ from the infrared spectrum of its monomer, ethanal, giving the absorption values and the bonds involved. Reference to C—H bonds is not required. [2]

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.....

.....

Examiner
only

(b) The oxidation of tertiary alcohols is different from those of primary and secondary alcohols. ‘Tertiary butanol’ is oxidised to propanone and methanoic acid.

(i) State a test that will give a positive result for propanone but not methanoic acid. [2]

Reagent

Observation

.....

(ii) State a test, other than the use of an acid-base indicator, that will give a positive result for methanoic acid but not propanone. [2]

Reagent

Observation

.....

Total [13]

13

Examiner
only

2. (a) You are given two aqueous solutions in unlabelled bottles. One is methyl propenoate, $\text{CH}_2=\text{CHCOOCH}_3$, and the other is phenol, $\text{C}_6\text{H}_5\text{OH}$.
Give a chemical test, other than the use of an acid-base indicator, which you could use to distinguish between these two compounds, giving the result of the test for **each** compound. [2]

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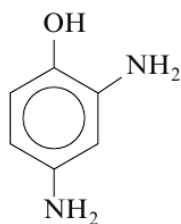
- (b) 2,4-Dinitrophenol is a yellow solid that is an inhibitor of ATP production in cells. As a result it has been sold as an aid to slimming, in spite of it being a dangerous and unlicensed product.

- (i) State why this compound is seen as yellow in white light. [1]

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- (ii) Reduction of 2,4-dinitrophenol, using the same reducing agent that is used for the reduction of nitrobenzene, gives the photographic developer 'amidol'.



amidol

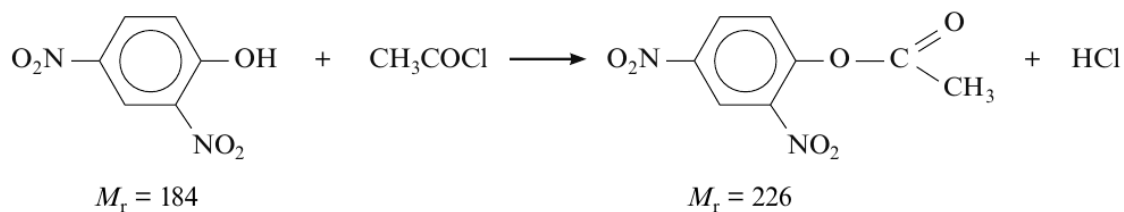
- State the reagent(s) used for this reduction. [1]

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1094
010005

Examiner
only

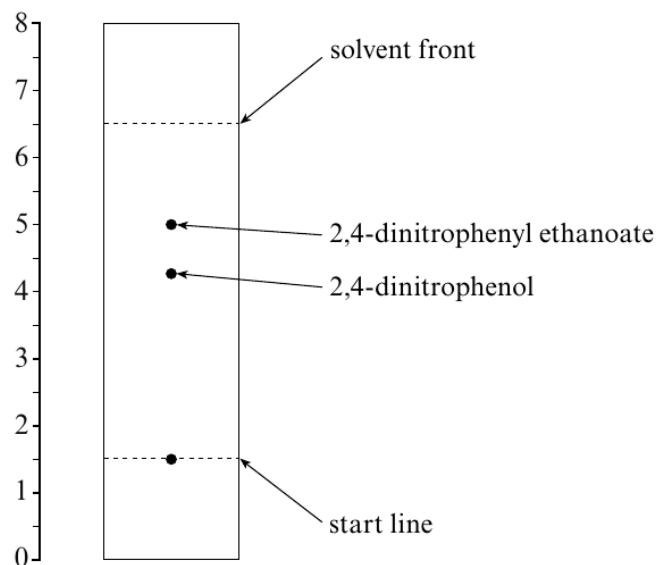
- (c) (i) 2,4-Dinitrophenol reacts with ethanoyl chloride to produce 2,4-dinitrophenyl ethanoate.



In an experiment 7.36 g of 2,4-dinitrophenol produced 7.91 g of 2,4-dinitrophenyl ethanoate. Calculate the percentage yield of 2,4-dinitrophenyl ethanoate. [3]

Percentage yield = %

- (ii) The 2,4-dinitrophenyl ethanoate obtained in (c)(i) was impure and contained some unreacted 2,4-dinitrophenol. The presence of this phenol was detected using thin layer chromatography.



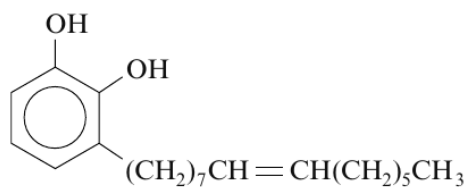
Calculate the R_f value of 2,4-dinitrophenol from this chromatogram. [2]

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- (d) 'Urushiol' is a yellow liquid that is found in the plant poison ivy. It causes an allergic skin rash. Urushiol is not a single compound but a mixture of phenolic compounds that have long saturated or unsaturated alkyl groups bonded to the benzene ring. It contains, for example, the following compound.



- (i) Suggest a catalyst that could be used in the hydrogenation of the unsaturated alkyl side chain. [1]
-
- (ii) By analogy with carboxylic acids, explain why 1,2-dihydroxybenzene is soluble in water but urushiol is not. [2]
-
-
-

Total [12]

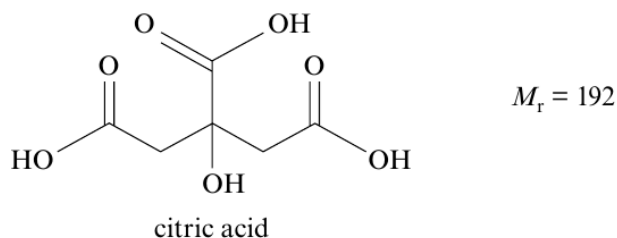
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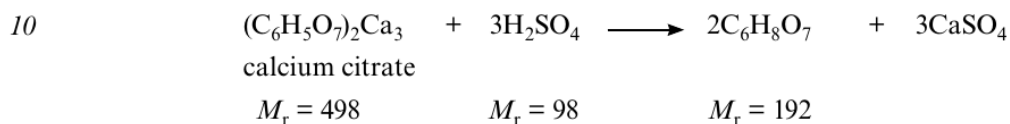
3. Read the passage below and then answer the questions in the spaces provided.

Citric acid – its production and chemistry

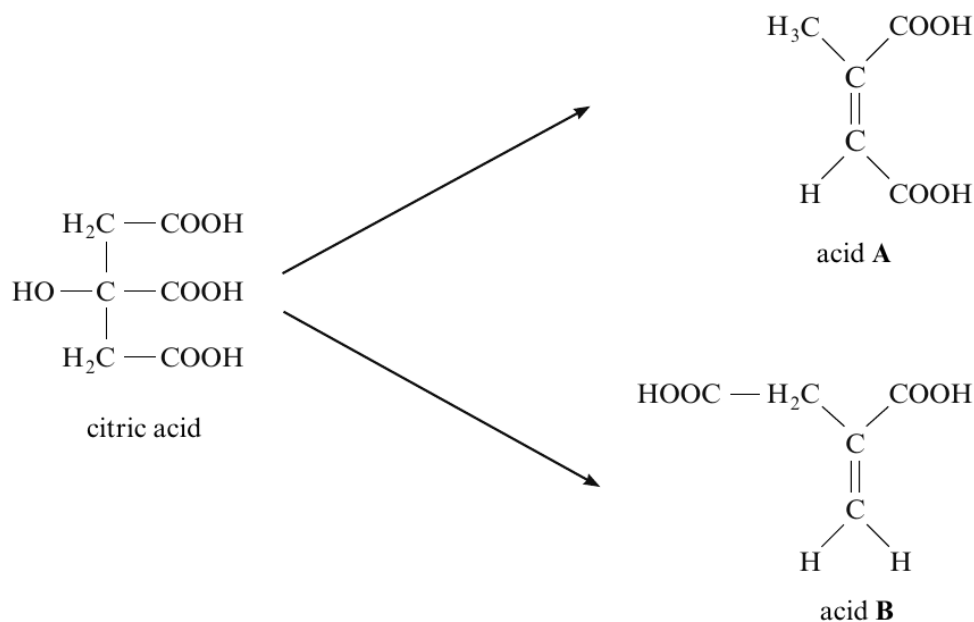
Citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid) is a weak organic acid that occurs naturally in many fruits.



- 5 This acid has been known since the 8th century and from about 1890 it began to be isolated from citrus fruits. The concentration of citric acid in the juices of these fruits varies from about $0.005 \text{ mol dm}^{-3}$ for oranges to $0.300 \text{ mol dm}^{-3}$ for lemons. However, most citric acid is now made from sugars by the use of a fungus. After treatment with this material the mixture is filtered and then reacted with calcium hydroxide, to precipitate insoluble calcium citrate. This is then treated with sulfuric acid to produce citric acid and calcium sulfate.

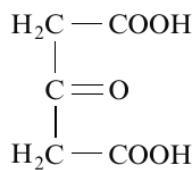


On heating, citric acid gives two unsaturated acids by the loss of water and subsequent decarboxylation.



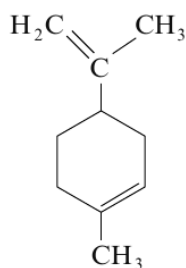
When citric acid is treated with concentrated sulfuric acid, acid C is formed.

15

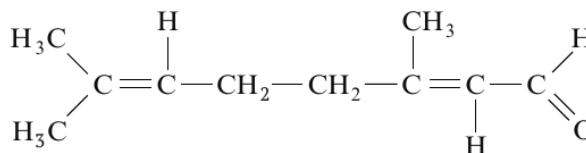


acid C

Lemons, from which citric acid was formerly extracted, contain a number of other compounds. Lemon oil is obtained by crushing the peel of lemons. This oil contains about 90% limonene and 5% citral.



limonene



citral

- 20 Citric acid remains a very important material today with extensive uses for soft drinks and other important uses in the food and detergent industries.

– End of passage –

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- (a) (i) Calculate the atom economy when citric acid is made by the acidification of calcium citrate (*line 10*). [1]

Atom economy = %

- (ii) Suggest a way in which this stage of the process could be made more cost effective. [1]
-
-

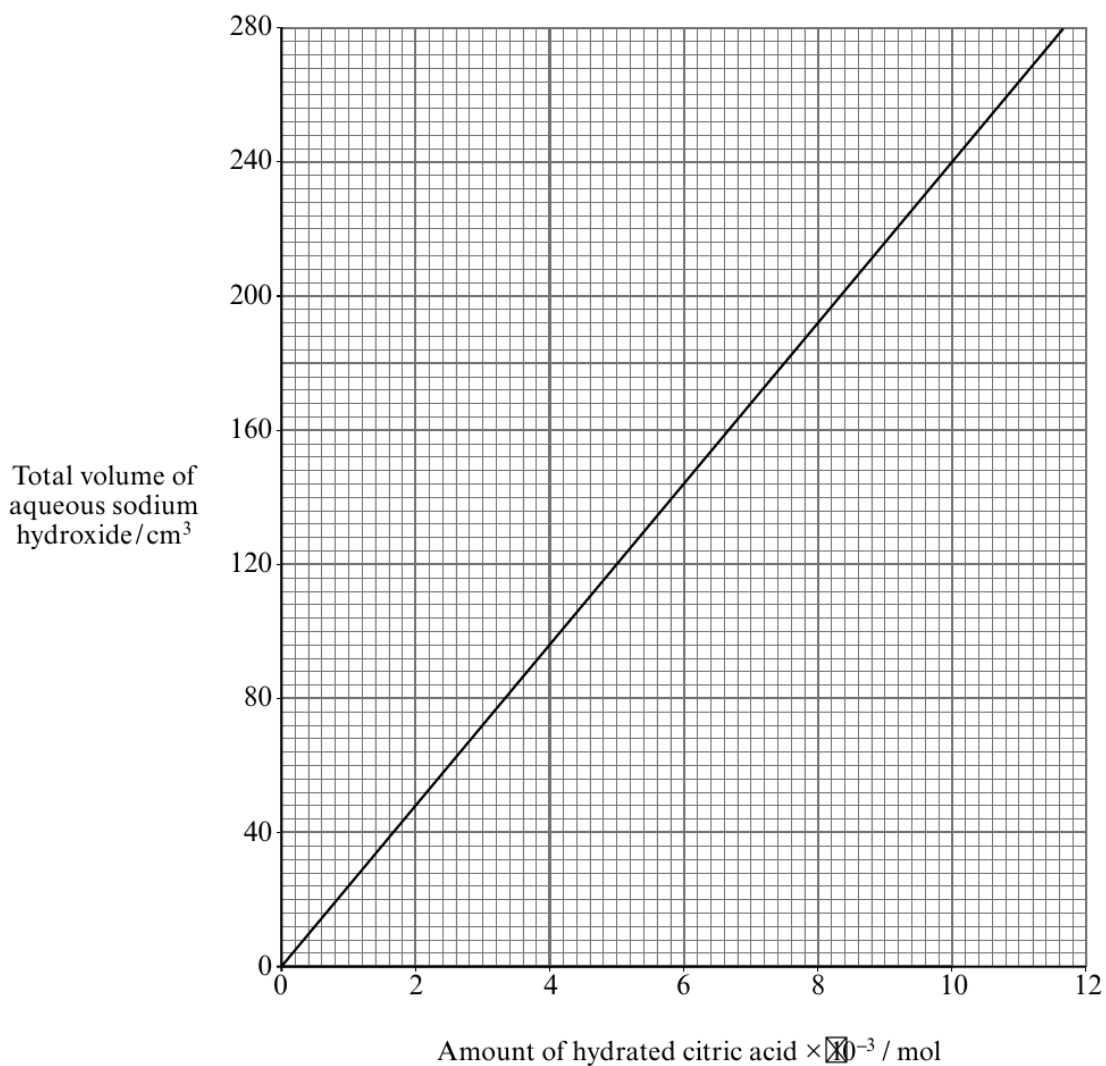
- (b) Citric acid occurs in two forms – an anhydrous form and a hydrate. Some students were given samples of the **hydrated** form of this tribasic acid and were asked to find its relative molecular mass by a titration with aqueous sodium hydroxide, using a suitable indicator to monitor complete neutralisation of the acid.

2.31 g of the hydrated acid was dissolved and made up to 250 cm³ with distilled water. A 25.00 cm³ sample of this solution needed 26.40 cm³ of a sodium hydroxide solution for complete neutralisation.

Calculate the total volume of sodium hydroxide solution needed to neutralise all of the acid and then use the graph opposite to help you calculate the relative molecular mass of the hydrated citric acid. Use your answer to calculate the value of *n* in hydrated citric acid, C₆H₈O₇·*n*H₂O. You are required to show your working in this calculation.

[5]

n =

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- (c) Explain why acids **A** and **B** (line 13) are **not** *E*- and *Z*- isomers of each other. [1]

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- (d) Acids **A** and **B** are formed by dehydration and by decarboxylation (where the compound is heated with sodalime). Give any other decarboxylation reaction of your choice, stating the organic starting material and the organic product of your chosen reaction. [2]
-
-

- (e) On heating to 130°C, acid **C** (*line 15*) decomposes to give only propanone and carbon dioxide. Give the equation for this reaction. [1]
-

- (f) Give the **displayed** formula of the product formed when acid **C** is reduced by lithium tetrahydridoaluminate(III) (lithium aluminium hydride). [1]

- (g) The boiling temperatures of limonene and citral, both present in lemon oil, are 177°C and 228°C respectively. State a method by which these two liquids can be separated. [1]
-

- (h) Limonene occurs in some substances as a single enantiomer and in others as a racemic mixture.

- (i) State what is meant by the term *enantiomer*. [1]
-
-

- (ii) State what is meant by the term *racemic mixture*. [1]
-
-

Total [15]

Total Section A [40]

15

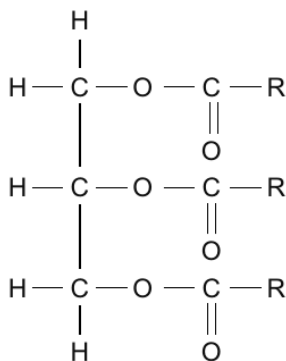
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SECTION A

Answer **all** questions in the spaces provided.

1. Fats and oils found in living things are esters of fatty acids and glycerol (propan-1,2,3-triol). Fatty acids are carboxylic acids with one —COOH group and a long hydrocarbon chain, often shown as R.

(a) The general structure of a fat is shown below.



The three ester groups in this molecule can be hydrolysed in the same way as other esters. Give the reagent(s) and condition(s) needed for the hydrolysis of this fat, and write a balanced equation for the reaction. [3]

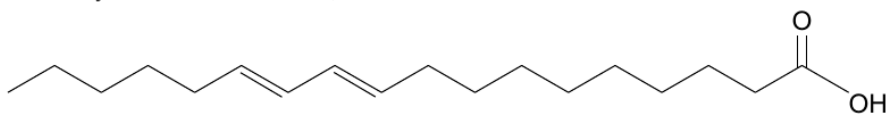
Reagent(s)

Condition(s)

Equation

Examiner
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- (b) One fatty acid is linoleic acid, whose structure is shown below.



- (i) This molecule is an unsaturated fatty acid because it contains carbon-carbon double bonds. Give a chemical test to show that a molecule contains carbon-carbon double bonds. [2]

Reagent(s)

Observation(s)

- (ii) Unsaturated fatty acids may be converted into saturated fatty acids by reaction with hydrogen gas in an addition reaction. Give the catalyst required for this reaction. [1]

- (iii) The hydrogenation of a sample of linoleic acid to the saturated fatty acid stearic acid ($M_r = 284$) required exactly 1.15 dm^3 of hydrogen gas for complete reaction. Calculate the maximum mass of stearic acid that could be formed in this reaction. [3]

[1 mol of a gas occupies 24.0 dm^3 at 298K and 1 atm pressure.
Assume all gas volumes are measured under these conditions.]

Maximum mass = g

QUESTION CONTINUES ON PAGE 4

Examiner
only

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(c) Another fatty acid with one carboxylic acid group was found to contain 69.7% carbon, 11.7% hydrogen and 18.6% oxygen by mass.

(i) Calculate the **empirical** formula of this fatty acid. [2]

Empirical formula

(ii) Give the **molecular** formula of this fatty acid. [1]

(d) There has been great interest in converting fats and oils into biodiesel as an alternative to fossil fuels produced from crude oil. Give **one** advantage of using biodiesel as an alternative to fossil fuels. [1]

Total [13]

Examiner
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13

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2. Students in an A level chemistry group were discussing topics that they had studied. They decided that each of the following statements was incorrect.

For each statement:

- identify the error and explain why the statement is incorrect,
- discuss the chemical principles involved, naming the products of any reaction.

(a) Ethanol and propanone can be distinguished from each other because only propanone forms a yellow solid when warmed with iodine and aqueous sodium hydroxide. [4]

QWC [1]

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(b) Bubbles are formed when carboxylic acids or phenols are added to aqueous sodium carbonate. [4]

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(c) α -amino acids are solids at room temperature whereas small carboxylic acids and small amines are liquids. The higher than expected melting temperatures of the α -amino acids is due to the presence of hydrogen bonds. [4]

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Total [13]

13

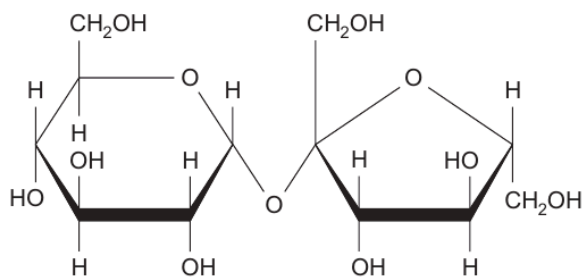
3. Read the passage below and then answer the questions in the spaces provided.

Stereoisomerism in organic compounds

Stereoisomerism in organic compounds often involves the presence of a chiral centre but this is not always the reason for different isomers being possible. The existence of stereoisomers can be useful but it can have serious effects in biological systems.

Sucrose is a sugar with the formula below.

5



10

Sucrose can be hydrolysed to produce two simpler sugars – glucose and fructose. The hydrolysis of sucrose can be carried out by merely heating the sugar with water but it is much quicker if an enzyme or an acid is used as a catalyst. The extent to which hydrolysis has occurred can be followed using the fact that sucrose does not contain an aldehyde group but glucose and fructose both exist in a form that includes this functional group.

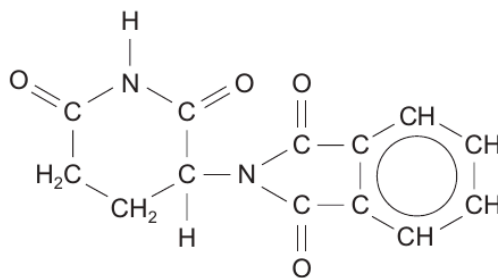
The hydrolysis can also be monitored by using the fact that sucrose, glucose and fructose all exist in forms that are optically active. The table shows data for this optical activity.

Sugar	Angle of rotation for 1 mol dm ⁻³ solution
sucrose	+66.5°
glucose	+52.8°
fructose	-92.0°

The solution that is formed after the complete hydrolysis of sucrose is called invert sugar.

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- 15 Thalidomide is a drug that has a wide range of valuable medical uses. Its formula is below.



This molecule contains a chiral centre and therefore has two optical isomers. One of the isomers is safe but the other one is dangerous to the foetus if taken by pregnant women. It is possible to prepare only the safe isomer but, in the body, a racemic mixture is produced.

- End of passage -

- (a) What is *stereoisomerism*? (line 1) [1]

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- (b) Suggest a chemical method by which an analytical chemist could identify that sucrose has been hydrolysed. (line 8) [2]

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- (c) (i) Explain what is meant by *optical activity* and the significance of the sign in the table of data. (line 12) [2]

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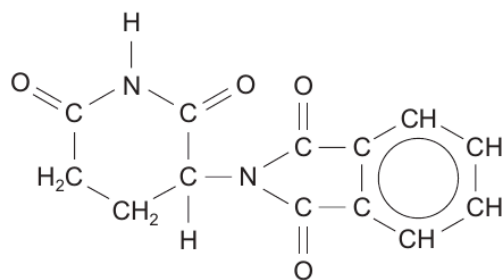
- (ii) Use the data to explain why a rotation of -39.2° is seen when the hydrolysis of sucrose is complete. [2]

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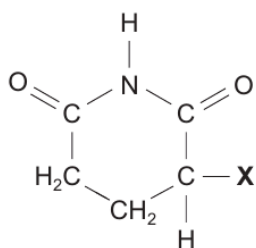
- (d) Mark with an asterisk (*) the chiral centre on the thalidomide molecule below. [1]



- (e) State what happens when a racemic mixture is formed from a sample containing only one isomer. (*lines 17-19*)

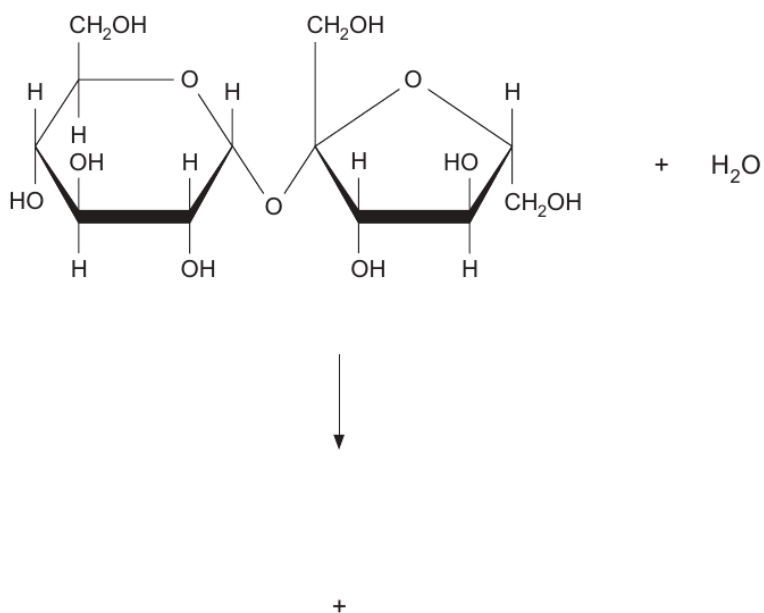
You should include suitable diagrams of a simple molecule of your choice. [2]

- (f) The formula below shows part of the thalidomide molecule (with the other part being replaced by the letter **X**). Draw the structural formula of a product formed when this molecule is heated with dilute aqueous hydrochloric acid. [2]



- (g) (i) Complete the equation to show clearly the difference in structure between glucose and fructose. You do **not** need to state which structure is which isomer. (line 6) [1]

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- (ii) Explain why sucrose, glucose and fructose are all very soluble in water. [2]

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Total [15]

15

Total Section A [40]

END OF QUESTION PACK

10 questions · 150 marks · ~4 h

Source: WJEC CH4 (2008 modular spec, Jan 2010 – Jun 2016)

Curated for WJEC Chemistry 2015 spec A2 Unit 4 – Topic 2 (4.3 & 4.4)

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