



Rewarding Learning

**ADVANCED**  
**General Certificate of Education**  
**2019**

Centre Number

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Candidate Number

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# Chemistry

*StemUp Model Solution*

Assessment Unit A2 1

*assessing*

Further Physical and  
Organic Chemistry



**[ACH12]**

\*ACH12\*

**TUESDAY 4 JUNE, AFTERNOON**

## TIME

2 hours.

## INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

Answer **all twenty-one** questions.

Answer **all ten** questions in **Section A**. Record your answers by marking the appropriate letter on the answer sheet provided. Use only the spaces numbered 1 to 10. Keep in sequence when answering.

Answer **all eleven** questions in **Section B**.

**You must answer the questions in the spaces provided.**

**Do not write outside the boxed area on each page or on blank pages.**

Complete in black ink only. **Do not write with a gel pen.**

## INFORMATION FOR CANDIDATES

The total mark for this paper is 110.

Quality of written communication will be assessed in Questions **12(a)(ii)** and **20(a)(ii)**.

In Section A all questions carry equal marks, i.e. **one** mark for each question.

In Section B the figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.

A Periodic Table of Elements, containing some data, is included with this question paper.

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## Section A

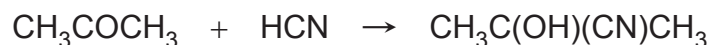
For each of the following questions only **one** of the lettered responses (A–D) is correct.

**Select the correct response in each case and mark its code letter by connecting the dots as illustrated on the answer sheet.**

- 1 How many sigma bonds are there in benzene?  
A 3  
B 6  
☒ C 12  
D 24
  
- 2 Which compound has the highest boiling point?  
A Methanal  
B Methanol  
☒ C Methanoic acid  
D Methyl methanoate
  
- 3 Which reagent will distinguish between the molecules  $\text{C}_6\text{H}_5\text{CHO}$  and  $\text{C}_6\text{H}_5\text{COCH}_3$ ?  
A Aqueous bromine  
☒ B Aqueous diammine silver(I) ions  
C Lithium tetrahydridoaluminate(III)  
D Sodium



- 4 The following reaction is an intermediate stage in the manufacture of the polymer perspex.



What type of reaction is this?

- A Electrophilic addition
  - ☒ B Nucleophilic addition
  - C Nucleophilic substitution
  - D Radical substitution
- 5 For which compound is it possible to construct a Born–Haber cycle?
- A Boron trichloride
  - B Hydrogen chloride
  - ☒ C Lead(II) chloride
  - D Phosphorus(III) chloride
- 6 What is the name of the  $\text{NO}_2^+$  ion?
- A Nitrate cation
  - B Nitrite cation
  - ☒ C Nitronium ion
  - D Nitrosonium ion

[Turn over



- 7 What is the percentage of carbon in dimethylbenzene?
- A 88.9 %  
B 89.7 %  
C 90.3 %  
☒ D 90.6 %
- 8 Vegetable oils are hardened to
- A convert to unsaturated fats.  
☒ B increase the melting temperature.  
C prevent oxidation.  
D reduce viscosity.
- 9 What is the conjugate base of the acid  $\text{HCO}_3^-$ ?
- A  $\text{CO}_3^-$   
☒ B  $\text{CO}_3^{2-}$   
C  $\text{H}_2\text{CO}_3$   
D  $\text{OH}^-$
- 10 Which pair of reactants would produce the ester  $\text{C}_3\text{H}_7\text{CO}_2\text{C}_2\text{H}_5$ ?
- A  $\text{C}_2\text{H}_5\text{Cl}$  and  $\text{C}_3\text{H}_7\text{CO}_2\text{H}$   
B  $\text{C}_3\text{H}_7\text{OH}$  and  $\text{C}_2\text{H}_5\text{COCl}$   
☒ C  $\text{C}_2\text{H}_5\text{OH}$  and  $\text{C}_3\text{H}_7\text{COCl}$   
D  $\text{C}_3\text{H}_7\text{Cl}$  and  $\text{C}_2\text{H}_5\text{CO}_2\text{H}$





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**(Questions continue overleaf)**

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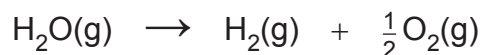


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## Section B

Answer **all eleven** questions in this section

- 11 The splitting of water into hydrogen and oxygen becomes feasible at 5440 K.



| molecule                              | $\text{H}_2\text{O}(\text{g})$ | $\text{H}_2(\text{g})$ | $\text{O}_2(\text{g})$ |
|---------------------------------------|--------------------------------|------------------------|------------------------|
| $S / \text{J K}^{-1} \text{mol}^{-1}$ | 189                            | 131                    | 205                    |

- (a) Define the term **entropy**.

*Entropy is a measure of the disorder (randomness) of a system.*

[1]

- (b) Using the data in the table, calculate the molar entropy change for this reaction.

$$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants}) = (131 + \frac{1}{2} \times 205) - 189$$

$$\Delta S = 233.5 - 189 = +44.5 \text{ J K}^{-1} \text{ mol}^{-1}$$

[1]

- (c) Suggest, and explain, the effect upon the entropy change if liquid water was split instead of gaseous water.

*The entropy change would be larger (more positive), because liquid*

*water has a lower entropy than gaseous water as it is less disordered.*

[2]



(d) Define the term **feasible**.

*A feasible reaction is one for which  $\Delta G < 0$  ( $\Delta G$  is negative).*

[1]

(e) Calculate the value for the molar enthalpy change for the splitting of gaseous water at 5440 K.

*At 5440 K,  $\Delta G = 0$  so  $\Delta H = T\Delta S = 5440 \times 44.5 \div 1000$*

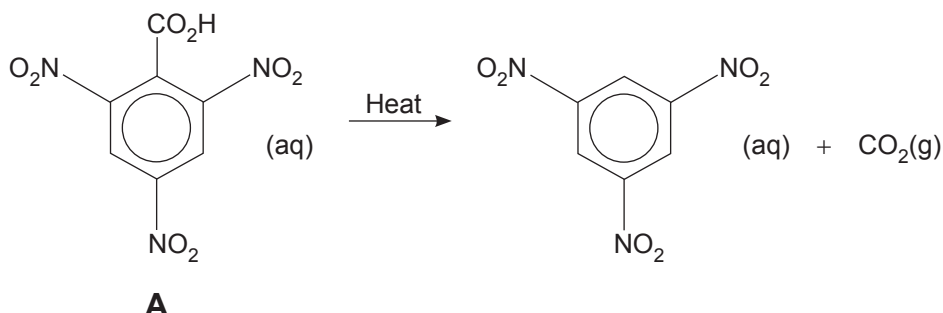
*$\Delta H = 242.08 = +242 \text{ kJ mol}^{-1}$*

[2]

[Turn over]



- 12 In 1931 Moelwyn-Hughes and Hinshelwood monitored the decarboxylation of the strong acid **A**:



- (a) (i) Suggest an IUPAC name for the organic product.

1,3,5-trinitrobenzene

[1]

- (ii) Moelwyn-Hughes and Hinshelwood followed the kinetics of the reaction by titration. Explain how they could have determined the rate of reaction. Include in your answer the names of an alkali and an indicator which could be used. Indicate what steps and graphs would be needed to determine the order of reaction with respect to **A**.

**In this question you will be assessed on using your written communication skills including the use of specialist scientific terms.**

Pipette samples from the reaction mixture at regular time

intervals and quench each one with ice to stop the reaction.

Titrate each sample against standard sodium hydroxide solution

using phenolphthalein indicator to find [A] remaining.

Plot a graph of [A] against time, draw tangents at several

points; each gradient gives the rate.

Plot a graph of rate against [A] and determine the order from

its shape: a straight line through the origin shows first order



*with respect to A.*

[6]

- (b) Moelwyn-Hughes and Hinshelwood obtained the following data from their experiments.

| experiment | $[A] \times 10^{-4} / \text{mol dm}^{-3}$ | initial rate $\times 10^{-6} / \text{mol dm}^{-3}\text{min}^{-1}$ |
|------------|-------------------------------------------|-------------------------------------------------------------------|
| 1          | 2.50                                      | 2.40                                                              |
| 2          | 1.67                                      | 1.64                                                              |
| 3          | 1.04                                      | 1.02                                                              |

- (i) State the order of the reaction.

*First order*

[1]

- (ii) Using the results from experiment 1 calculate the rate constant, stating its units.

$$k = \text{rate} \div [A] = 2.40 \times 10^{-6} \div 2.50 \times 10^{-4}$$

$$k = 9.60 \times 10^{-3} \text{ min}^{-1}$$

[2]

- (iii) Explain why the rate constant would increase if the experiment was repeated at a higher temperature.

*A greater proportion of collisions are successful because a greater*

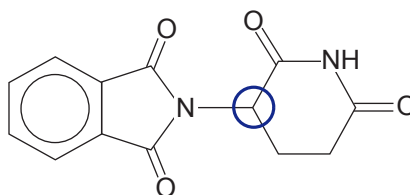
*fraction of molecules have energy greater than or equal to  $E_a$ .*

[1]

[Turn over]



- 13 Thalidomide was first marketed in 1957 as a sedative to reduce morning sickness during pregnancy. It contains a chiral centre and exists as two optical isomers.



thalidomide

- (a) Circle the chiral centre in the structure above. [1]

- (b) Define the term **optical isomers**.

*Molecules with the same structural formula which are*

*non-superimposable mirror images of each other.*

[1]

- (c) The original use of thalidomide led to babies being born with deformed limbs. It was found that one optical isomer of thalidomide caused these birth defects. Suggest how the drug action may be determined by the stereochemistry of the drug.

*The receptor sites in the body are stereospecific, so only one optical*

*isomer fits the receptor site.*

[1]

- (d) Thalidomide, in the sedative, was used as a racemic mixture. Define the term **racemic mixture** and explain why a racemic mixture would be optically inactive.

*A racemic mixture is a 50:50 mixture of the two optical isomers.*

*Each isomer rotates plane-polarised light equally in opposite directions,*

*so the effects cancel out.*

[2]



14 The titration curve for a strong acid with a strong alkali can be determined by measuring pH using specialised pH paper or a pH meter.

- (a) Suggest an advantage and a disadvantage of using the pH meter compared to pH paper.

*Advantage: the pH meter gives a more precise, quantitative pH value which is easier to read.*

*Disadvantage: the pH meter is more expensive, takes time to set up and calibrate and must be stored properly.* [2]

- (b) Explain, using your knowledge of titration curves, why both methyl orange and phenolphthalein are suitable indicators for this titration.

*The vertical section of the curve passes through the pH ranges in which both indicators change colour.* [1]

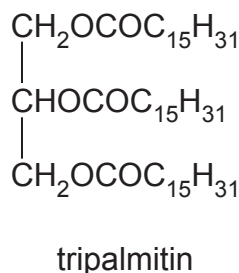
- (c) Explain whether the salt solution formed from the reaction between sulfuric acid and sodium hydroxide is neutral or not.

*Neutral, as sodium sulfate is the salt of a strong acid and a strong base.* [1]

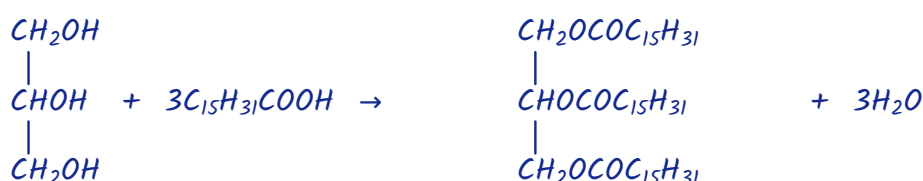
[Turn over]



- 15 The ester tripalmitin can be used to make biodiesel using transesterification. Tripalmitin is formed when glycerol reacts with palmitic acid.



- (a) Write an equation for the formation of tripalmitin from glycerol and palmitic acid.



[2]

- (b) Use the structure of tripalmitin to explain whether tripalmitin is a saturated or unsaturated fat.

*Saturated: each  $\text{C}_{15}\text{H}_{31}$  group fits the formula  $\text{C}_n\text{H}_{2n+1}$ , so there are no  $\text{C}=\text{C}$  double bonds.*

[2]

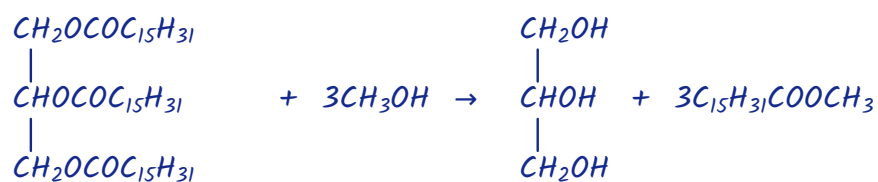
- (c) Explain the term **transesterification**.

*A reaction in which the alkyl group of an ester is exchanged with the alkyl group of an alcohol, forming a new ester.*

[2]



- (d) Write the equation for the reaction between tripalmitin and methanol forming molecules, some of which are used in biodiesel.



[1]

- (e) From the equation written in (d), write the formula of the product that could be used as biodiesel.

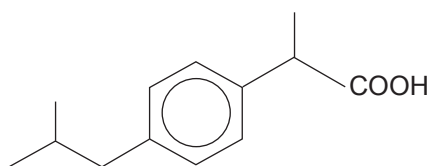


[1]

[Turn over

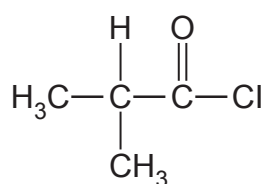


- 16 Benzene is used to synthesise the analgesic, ibuprofen. This occurs using a multi-step reaction involving both Friedel–Crafts acylation and alkylation.



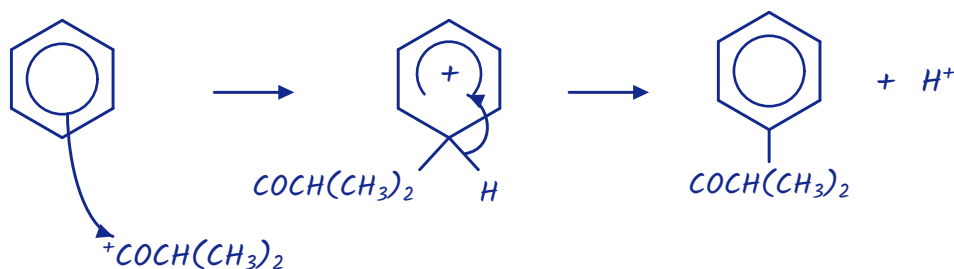
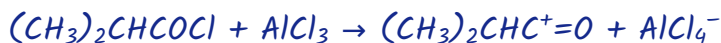
ibuprofen

- (a) The first step in this reaction is the acylation of benzene with 2-methylpropanoyl chloride. The structure of 2-methylpropanoyl chloride is shown below.



2-methylpropanoyl chloride

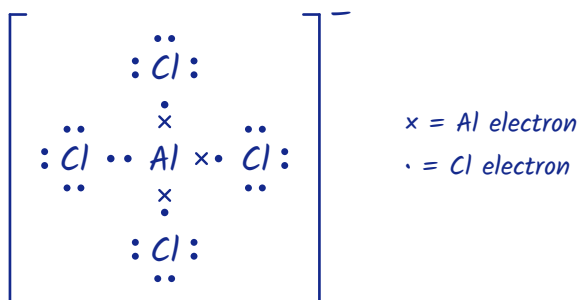
Show the mechanism for the catalysed reaction between 2-methylpropanoyl chloride and benzene, using aluminium chloride as a catalyst.



[5]

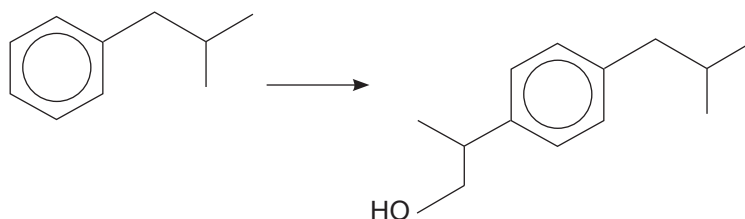


- (b) Draw a dot and cross diagram for the aluminium-containing intermediate species formed by the catalyst during this reaction.

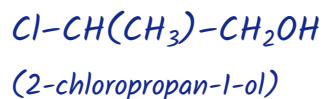


[1]

- (c) A later step in the synthesis is shown below.



Suggest the structure of the organic reagent used for the step shown.



[1]

- (d) The acylation and alkylation reactions of benzene are substitution reactions. Explain why benzene undergoes substitution reactions rather than addition reactions.

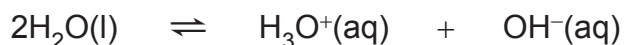
Addition would destroy the delocalised  $\pi$  electron ring, so the extra  
stability of benzene would be lost; substitution keeps it.

[1]

[Turn over]



- 17 The dissociation of water is an endothermic process. At 60 °C the ionic product of water,  $K_w$ , has a value of  $9.3 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ .



- (a) (i) Write the expression for  $K_w$ .

$K_w = [\text{H}_3\text{O}^+(\text{aq})][\text{OH}^-(\text{aq})]$  [1]

- (ii) Explain why the expression for  $K_w$  does not include the concentration of water.

$[\text{H}_2\text{O}]$  is effectively constant, so it is incorporated into the value of  $K_w$ . [1]

- (b) (i) Calculate the pH of water at 60 °C. Give your answer to two decimal places.

$[\text{H}^+]^2 = 9.3 \times 10^{-14}$ , so  $[\text{H}^+] = 3.05 \times 10^{-7} \text{ mol dm}^{-3}$

$\text{pH} = -\log(3.05 \times 10^{-7}) = 6.52$

\_\_\_\_\_ [2]

- (ii) Explain whether water at 60 °C is neutral, acidic or alkaline.

Neutral, because  $\text{H}_3\text{O}^+$  and  $\text{OH}^-$  ions are formed in equal amounts, so  $[\text{H}_3\text{O}^+] = [\text{OH}^-]$ . [2]



- (iii) Calculate the pH of a solution containing 256.5 g of barium hydroxide dissolved in 500 cm<sup>3</sup> of water at 60 °C. Give your answer to two decimal places.

$$M_r \text{Ba(OH)}_2 = 137 + 2(16 + 1) = 171$$

$$\text{moles} = 256.5 \div 171 = 1.50 \text{ mol}$$

$$[\text{OH}^-] = 2 \times 1.50 \div 0.500 = 6.00 \text{ mol dm}^{-3}$$

$$[\text{H}^+] = 9.3 \times 10^{-14} \div 6.00 = 1.55 \times 10^{-14} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(1.55 \times 10^{-14}) = 13.81 \quad [4]$$

- (c) (i) An acidic buffer is formed when 10.0 cm<sup>3</sup> of 0.12 mol dm<sup>-3</sup> aqueous sodium hydroxide is added to 25.0 cm<sup>3</sup> of 0.18 mol dm<sup>-3</sup> ethanoic acid. Calculate the pH of this buffer. The pK<sub>a</sub> of ethanoic acid is 4.76. Give your answer to two decimal places.



$$\text{moles of acid} = 25.0 \div 1000 \times 0.18 = 0.0045$$

$$\text{moles of NaOH} = 10.0 \div 1000 \times 0.12 = 0.0012$$

$$\text{acid left} = 0.0045 - 0.0012 = 0.0033 \text{ mol; salt} = 0.0012 \text{ mol}$$

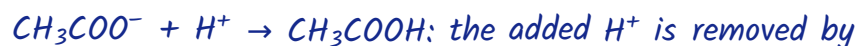
$$K_a = 10^{-4.76} = 1.74 \times 10^{-5} \text{ mol dm}^{-3}$$

$$[\text{H}^+] = K_a[\text{acid}] \div [\text{salt}] = 1.74 \times 10^{-5} \times 0.0033 \div 0.0012$$

$$[\text{H}^+] = 4.78 \times 10^{-5} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log(4.78 \times 10^{-5}) = 4.32 \quad [4]$$

- (ii) Explain, using an equation, the effect of adding small amounts of acid to the buffer.



ethanoate ions so  $[\text{H}^+]$  stays constant and the pH is unchanged. [2]

[Turn over



- 18 Sulfur dioxide is reacted with oxygen to form sulfur trioxide in the manufacture of sulfuric acid in the Contact Process.



- (a) State the pressure and catalyst used in this reaction.

*Pressure: 1 to 2 atm*

*Catalyst: vanadium(V) oxide,  $\text{V}_2\text{O}_5$*

[2]

- (b) Explain why the temperature chosen for this reaction,  $450^\circ\text{C}$ , can be described as a compromise temperature.

*A lower temperature gives a better equilibrium yield of  $\text{SO}_3$  (forward reaction is exothermic) but the rate is too slow.*

*$450^\circ\text{C}$  is a compromise between a good yield and a fast enough rate.*

[2]

- (c) Write an expression for  $K_c$  for the above reaction.

$$K_c = \frac{[\text{SO}_3]^2}{[\text{SO}_2]^2[\text{O}_2]}$$

[1]



- (d) Sulfur dioxide, oxygen and sulfur trioxide were mixed and allowed to reach equilibrium in a 20 dm<sup>3</sup> container. At equilibrium, 8.0 moles of sulfur dioxide and 10.0 moles of sulfur trioxide were present. Calculate the number of moles of oxygen present if the numerical value of  $K_c$  is 27.9 mol<sup>-1</sup> dm<sup>3</sup>.

$$[SO_2] = 8.0 \div 20 = 0.40, [SO_3] = 10.0 \div 20 = 0.50, [O_2] = x \div 20$$

$$= 0.05x \text{ mol dm}^{-3}$$

$$K_c = 0.50^2 \div (0.40^2 \times 0.05x) = 0.25 \div 0.008x = 27.9$$

$$0.25 = 27.9 \times 0.008x = 0.2232x$$

$$x = 1.12, \text{ so } 1.1 \text{ mol of oxygen}$$

[4]



19 The lattice enthalpy of magnesium chloride is  $2493 \text{ kJ mol}^{-1}$  and that of calcium chloride is  $2237 \text{ kJ mol}^{-1}$ .

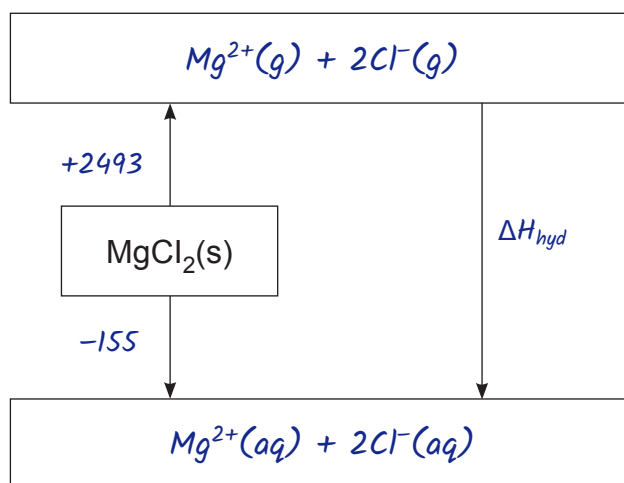
- (a) (i) Write an equation, including state symbols, for the lattice enthalpy of calcium chloride.



- (ii) Explain why the lattice enthalpy of magnesium chloride is greater than that of calcium chloride.

$\text{Mg}^{2+}$  is a smaller ion than  $\text{Ca}^{2+}$  with the same charge, so it has a higher charge density. [1]

- (b) (i) The enthalpy of solution of magnesium chloride is  $-155 \text{ kJ mol}^{-1}$ . Complete the following enthalpy diagram for dissolving magnesium chloride.



[2]



- (ii) Calculate the enthalpy of hydration of magnesium ions. The enthalpy of hydration of chloride ions is  $-364 \text{ kJ mol}^{-1}$ .

$$-155 = 2493 + \Delta H_{\text{hyd}}(\text{Mg}^{2+}) + 2(-364)$$

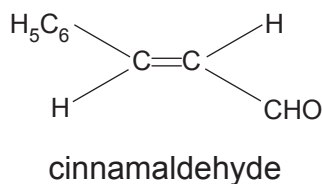
$$\Delta H_{\text{hyd}}(\text{Mg}^{2+}) = -155 - 2493 + 728 = -1920 \text{ kJ mol}^{-1}$$

[2]

[Turn over]



- 20 Cinnamaldehyde is a pale yellow liquid that can be obtained from the bark of cinnamon trees.



- (a) (i) Cinnamaldehyde is a geometric isomer. State and explain which geometric isomer cinnamaldehyde is.

*E isomer, because the higher priority groups ( $C_6H_5$  and  $CHO$ ) are on opposite sides of the  $C=C$  bond.*

[2]

- (ii) Explain how a pale yellow oil suspected as being cinnamaldehyde, could be identified using 2,4-dinitrophenylhydrazine. Include in your answer experimental details of the preparation of cinnamaldehyde-2,4-dinitrophenylhydrazone.

**In this question you will be assessed on using your written communication skills including the use of specialist scientific terms.**

*Place 5 cm<sup>3</sup> of 2,4-dinitrophenylhydrazine solution in a test tube and add a few drops of the pale yellow oil.*

*An orange precipitate forms (carbonyl present). Cool the mixture in iced water.*

*Filter off the crystals by suction filtration using a Buchner funnel, then recrystallise from the minimum volume of hot ethanol.*

*Dry the crystals by sucking air through them in the Buchner funnel or in a desiccator.*



*Determine the melting point of the dry crystals and compare it with the data book value for the derivative; a match identifies the oil.*

[6]

- (b) Write an equation for the reduction of cinnamaldehyde with lithal using [H] to represent the reducing agent.



[1]

- (c) Oxidation of cinnamaldehyde produces cinnamic acid which is a solid at room temperature with a melting point of 132–133 °C. Explain why cinnamic acid has a higher melting point than cinnamaldehyde.

*Cinnamic acid has van der Waals' forces and hydrogen bonds between molecules. Cinnamaldehyde has van der Waals' and permanent dipole-dipole forces only. More energy is needed to break hydrogen bonds.*

[3]

[Turn over



- 21 Ethanoyl chloride can be used in the preparation of esters. It reacts readily with moisture in the air.

(a) Write an equation for the reaction of ethanoyl chloride with water.



(b) Describe a chemical test for the inorganic product of the reaction, indicating a positive result for this test.

Hold a glass rod dipped in concentrated ammonia solution in the HCl

gas: white smoke forms. [2]

(c) (i) Write an equation for the reaction of excess ethanoyl chloride with ethane-1,2-diol to produce an ester.



[2]

(ii) Calculate the percentage yield if 31 g of ethane-1,2-diol produces 49 g of the ester.

$moles\ of\ diol = 31 \div 62 = 0.50; M_r\ of\ C_6H_{10}O_4 = 146$

$theoretical\ yield = 0.50 \times 146 = 73\ g$

$\% \ yield = 49 \div 73 \times 100 = 67\%$

[3]



- (d) State **three** advantages of using ethanoyl chloride instead of ethanoic acid in esterification reactions.

*No catalyst is needed.*

*The reaction goes to completion, giving a higher yield.*

*Less purification is needed (the reaction is fast and not reversible).* [3]

- (e) Give the formula and the IUPAC name of a reagent that could convert ethanoic acid into ethanoyl chloride.

*PCl<sub>5</sub>, phosphorus(V) chloride* [2]

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## General Information

1 tonne =  $10^6$  g

1 metre =  $10^9$  nm

One mole of any gas at 293 K and a pressure of 1 atmosphere ( $10^5$  Pa) occupies a volume of  $24 \text{ dm}^3$

Avogadro Constant =  $6.02 \times 10^{23} \text{ mol}^{-1}$

Planck Constant =  $6.63 \times 10^{-34} \text{ Js}$

Specific Heat Capacity of water =  $4.2 \text{ J g}^{-1} \text{ K}^{-1}$

Speed of Light =  $3 \times 10^8 \text{ ms}^{-1}$

## Characteristic absorptions in IR spectroscopy

| Wavenumber/ $\text{cm}^{-1}$ | Bond                | Compound                                                             |
|------------------------------|---------------------|----------------------------------------------------------------------|
| 550–850                      | C–X (X = Cl, Br, I) | Haloalkanes                                                          |
| 750–1100                     | C–C                 | Alkanes, alkyl groups                                                |
| 1000–1300                    | C–O                 | Alcohols, esters, carboxylic acids                                   |
| 1450–1650                    | C=C                 | Arenes                                                               |
| 1600–1700                    | C=C                 | Alkenes                                                              |
| 1650–1800                    | C=O                 | Carboxylic acids, esters, aldehydes, ketones, amides, acyl chlorides |
| 2200–2300                    | C≡N                 | Nitriles                                                             |
| 2500–3200                    | O–H                 | Carboxylic acids                                                     |
| 2750–2850                    | C–H                 | Aldehydes                                                            |
| 2850–3000                    | C–H                 | Alkanes, alkyl groups, alkenes, arenes                               |
| 3200–3600                    | O–H                 | Alcohols                                                             |
| 3300–3500                    | N–H                 | Amines, amides                                                       |

## Proton Chemical Shifts in Nuclear Magnetic Resonance Spectroscopy (relative to TMS)

| Chemical Shift | Structure                        |                                           |
|----------------|----------------------------------|-------------------------------------------|
| 0.5–2.0        | –CH                              | Saturated alkanes                         |
| 0.5–5.5        | –OH                              | Alcohols                                  |
| 1.0–3.0        | –NH                              | Amines                                    |
| 2.0–3.0        | –CO–CH                           | Ketones                                   |
|                | –N–CH                            | Amines                                    |
|                | $\text{C}_6\text{H}_5\text{–CH}$ | Arene (aliphatic on ring)                 |
| 2.0–4.0        | X–CH                             | X = Cl or Br (3.0–4.0)<br>X = I (2.0–3.0) |
| 4.5–6.0        | –C=CH                            | Alkenes                                   |
| 5.5–8.5        | RCONH                            | Amides                                    |
| 6.0–8.0        | – $\text{C}_6\text{H}_5$         | Arenes (on ring)                          |
| 9.0–10.0       | –CHO                             | Aldehydes                                 |
| 10.0–12.0      | –COOH                            | Carboxylic acids                          |

These chemical shifts are concentration and temperature dependent and may be outside the ranges indicated above.

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New  
Specification



# Data Leaflet

## Including the Periodic Table of the Elements

For the use of candidates taking  
Advanced Subsidiary and  
Advanced Level Examinations

**Copies must be free from notes or additions of any kind. No other type of data booklet or information sheet is authorised for use in the examinations**

# gce a/as examinations chemistry

For first teaching from September 2016  
For first award of AS Level in Summer 2017  
For first award of A Level in Summer 2018  
Subject Code: 1110

IIIIVVVIVII0

THE PERIODIC TABLE OF ELEMENTS

Group

| 1                                  | 2                                  | 3                                                | 4                                        | 5                                  | 6                                     | 7                                   | 8                                   | 9                                     | 10                                      | 11                                     | 12                                     | 13                                 | 14                                 | 15                                 | 16                                  | 17                                  | 18                               |
|------------------------------------|------------------------------------|--------------------------------------------------|------------------------------------------|------------------------------------|---------------------------------------|-------------------------------------|-------------------------------------|---------------------------------------|-----------------------------------------|----------------------------------------|----------------------------------------|------------------------------------|------------------------------------|------------------------------------|-------------------------------------|-------------------------------------|----------------------------------|
| 1<br><b>H</b><br>Hydrogen<br>1     |                                    |                                                  |                                          |                                    |                                       |                                     |                                     |                                       |                                         |                                        |                                        |                                    |                                    |                                    |                                     |                                     | 4<br><b>He</b><br>Helium<br>2    |
| 7<br><b>Li</b><br>Lithium<br>3     | 9<br><b>Be</b><br>Beryllium<br>4   |                                                  |                                          |                                    |                                       |                                     |                                     |                                       |                                         |                                        |                                        | 11<br><b>B</b><br>Boron<br>5       | 12<br><b>C</b><br>Carbon<br>6      | 14<br><b>N</b><br>Nitrogen<br>7    | 16<br><b>O</b><br>Oxygen<br>8       | 19<br><b>F</b><br>Fluorine<br>9     | 20<br><b>Ne</b><br>Neon<br>10    |
| 23<br><b>Na</b><br>Sodium<br>11    | 24<br><b>Mg</b><br>Magnesium<br>12 |                                                  |                                          |                                    |                                       |                                     |                                     |                                       |                                         |                                        |                                        | 27<br><b>Al</b><br>Aluminium<br>13 | 28<br><b>Si</b><br>Silicon<br>14   | 31<br><b>P</b><br>Phosphorus<br>15 | 32<br><b>S</b><br>Sulfur<br>16      | 35.5<br><b>Cl</b><br>Chlorine<br>17 | 40<br><b>Ar</b><br>Argon<br>18   |
| 39<br><b>K</b><br>Potassium<br>19  | 40<br><b>Ca</b><br>Calcium<br>20   | 45<br><b>Sc</b><br>Scandium<br>21                | 48<br><b>Ti</b><br>Titanium<br>22        | 51<br><b>V</b><br>Vanadium<br>23   | 52<br><b>Cr</b><br>Chromium<br>24     | 55<br><b>Mn</b><br>Manganese<br>25  | 56<br><b>Fe</b><br>Iron<br>26       | 59<br><b>Co</b><br>Cobalt<br>27       | 59<br><b>Ni</b><br>Nickel<br>28         | 64<br><b>Cu</b><br>Copper<br>29        | 65<br><b>Zn</b><br>Zinc<br>30          | 70<br><b>Ga</b><br>Gallium<br>31   | 73<br><b>Ge</b><br>Germanium<br>32 | 75<br><b>As</b><br>Arsenic<br>33   | 79<br><b>Se</b><br>Selenium<br>34   | 80<br><b>Br</b><br>Bromine<br>35    | 84<br><b>Kr</b><br>Krypton<br>36 |
| 85<br><b>Rb</b><br>Rubidium<br>37  | 88<br><b>Sr</b><br>Strontium<br>38 | 89<br><b>Y</b><br>Yttrium<br>39                  | 91<br><b>Zr</b><br>Zirconium<br>40       | 93<br><b>Nb</b><br>Niobium<br>41   | 96<br><b>Mo</b><br>Molybdenum<br>42   | 98<br><b>Tc</b><br>Technetium<br>43 | 101<br><b>Ru</b><br>Ruthenium<br>44 | 103<br><b>Rh</b><br>Rhodium<br>45     | 106<br><b>Pd</b><br>Palladium<br>46     | 108<br><b>Ag</b><br>Silver<br>47       | 112<br><b>Cd</b><br>Cadmium<br>48      | 115<br><b>In</b><br>Indium<br>49   | 119<br><b>Sn</b><br>Tin<br>50      | 122<br><b>Sb</b><br>Antimony<br>51 | 128<br><b>Te</b><br>Tellurium<br>52 | 127<br><b>I</b><br>Iodine<br>53     | 131<br><b>Xe</b><br>Xenon<br>54  |
| 133<br><b>Cs</b><br>Caesium<br>55  | 137<br><b>Ba</b><br>Barium<br>56   | 139<br><b>La</b> <sup>*</sup><br>Lanthanum<br>57 | 178<br><b>Hf</b><br>Hafnium<br>72        | 181<br><b>Ta</b><br>Tantalum<br>73 | 184<br><b>W</b><br>Tungsten<br>74     | 186<br><b>Re</b><br>Rhenium<br>75   | 190<br><b>Os</b><br>Osmium<br>76    | 192<br><b>Ir</b><br>Iridium<br>77     | 195<br><b>Pt</b><br>Platinum<br>78      | 197<br><b>Au</b><br>Gold<br>79         | 201<br><b>Hg</b><br>Mercury<br>80      | 204<br><b>Tl</b><br>Thallium<br>81 | 207<br><b>Pb</b><br>Lead<br>82     | 209<br><b>Bi</b><br>Bismuth<br>83  | 210<br><b>Po</b><br>Polonium<br>84  | 210<br><b>At</b><br>Astatine<br>85  | 222<br><b>Rn</b><br>Radon<br>86  |
| 223<br><b>Fr</b><br>Francium<br>87 | 226<br><b>Ra</b><br>Radium<br>88   | 227<br><b>Ac</b> <sup>†</sup><br>Actinium<br>89  | 261<br><b>Rf</b><br>Rutherfordium<br>104 | 262<br><b>Db</b><br>Dubnium<br>105 | 266<br><b>Sg</b><br>Seaborgium<br>106 | 264<br><b>Bh</b><br>Bohrium<br>107  | 277<br><b>Hs</b><br>Hassium<br>108  | 268<br><b>Mt</b><br>Meitnerium<br>109 | 271<br><b>Ds</b><br>Darmstadtium<br>110 | 272<br><b>Rg</b><br>Roentgenium<br>111 | 285<br><b>Cn</b><br>Copernicium<br>112 |                                    |                                    |                                    |                                     |                                     |                                  |

\* 58 – 71 Lanthanum series  
† 90 – 103 Actinium series

aXb

a = relative atomic mass (approx)  
x = atomic symbol  
b = atomic number

|                                   |                                        |                                     |                                      |                                     |                                     |                                      |                                     |                                       |                                       |                                    |                                        |                                     |                                       |
|-----------------------------------|----------------------------------------|-------------------------------------|--------------------------------------|-------------------------------------|-------------------------------------|--------------------------------------|-------------------------------------|---------------------------------------|---------------------------------------|------------------------------------|----------------------------------------|-------------------------------------|---------------------------------------|
| 140<br><b>Ce</b><br>Cerium<br>58  | 141<br><b>Pr</b><br>Praseodymium<br>59 | 144<br><b>Nd</b><br>Neodymium<br>60 | 145<br><b>Pm</b><br>Promethium<br>61 | 150<br><b>Sm</b><br>Samarium<br>62  | 152<br><b>Eu</b><br>Europium<br>63  | 157<br><b>Gd</b><br>Gadolinium<br>64 | 159<br><b>Tb</b><br>Terbium<br>65   | 162<br><b>Dy</b><br>Dysprosium<br>66  | 165<br><b>Ho</b><br>Holmium<br>67     | 167<br><b>Er</b><br>Erbium<br>68   | 169<br><b>Tm</b><br>Thulium<br>69      | 173<br><b>Yb</b><br>Ytterbium<br>70 | 175<br><b>Lu</b><br>Lutetium<br>71    |
| 232<br><b>Th</b><br>Thorium<br>90 | 231<br><b>Pa</b><br>Protactinium<br>91 | 238<br><b>U</b><br>Uranium<br>92    | 237<br><b>Np</b><br>Neptunium<br>93  | 242<br><b>Pu</b><br>Plutonium<br>94 | 243<br><b>Am</b><br>Americium<br>95 | 247<br><b>Cm</b><br>Curium<br>96     | 245<br><b>Bk</b><br>Berkelium<br>97 | 251<br><b>Cf</b><br>Californium<br>98 | 254<br><b>Es</b><br>Einsteinium<br>99 | 253<br><b>Fm</b><br>Fermium<br>100 | 256<br><b>Md</b><br>Mendelevium<br>101 | 254<br><b>No</b><br>Nobelium<br>102 | 257<br><b>Lr</b><br>Lawrencium<br>103 |