



Rewarding Learning

ADVANCED
General Certificate of Education
2022

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



[ACH14]

ACH14

MONDAY 30 MAY, MORNING

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 fifteen** questions in **Sections A and 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 or a pencil.**

INFORMATION FOR CANDIDATES

The total mark for this paper is 110.

Quality of written communication will be assessed in Questions **11(b)** and **14(b)(ii)**.

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.

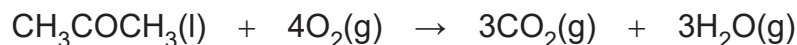


Section A

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

Select the correct response for each question and write the appropriate letter in the space provided.

- 1 Which one of the following is true for the combustion of propanone as shown below?



- A ΔS is negative and ΔH is negative
- B ΔS is negative and ΔH is positive
- C ΔS is positive and ΔH is negative
- D ΔS is positive and ΔH is positive

Answer C [1]

- 2 Which one of the following 0.1 mol dm^{-3} solutions has a pH greater than 7?

- A ammonium chloride
- B ammonium nitrate
- C sodium citrate
- D sodium sulfate

Answer C [1]



3 What volume of water must be added to 10 cm^3 of a 0.2 mol dm^{-3} solution of hydrogen peroxide to make a 0.05 mol dm^{-3} solution of hydrogen peroxide?

- A 20 cm^3
- B 30 cm^3
- C 40 cm^3
- D 50 cm^3

Answer B [1]

4 Which one of the following compounds has the greatest lattice enthalpy?

- A calcium chloride
- B calcium oxide
- C magnesium chloride
- D magnesium oxide

Answer D [1]

5 Complete combustion of 40 cm^3 of a gaseous hydrocarbon requires 240 cm^3 of oxygen. 160 cm^3 of carbon dioxide are formed at room temperature and pressure. The formula of the hydrocarbon is:

- A C_4H_8
- B C_4H_{10}
- C C_6H_{12}
- D C_6H_{14}

Answer A [1]

[Turn over]



6 Which one of the following gives the correct mechanisms for the reactions shown?

	Reaction of cyanide ions with halogenoalkanes	Reaction of hydrogen cyanide with carbonyl compounds
A	electrophilic substitution	electrophilic addition
B	electrophilic substitution	nucleophilic addition
C	nucleophilic substitution	electrophilic addition
D	nucleophilic substitution	nucleophilic addition

Answer D [1]

7 0.15 mol of a fat which is a triester, required 10.8 dm^3 of hydrogen gas at room temperature and pressure for complete hydrogenation. The average number of $\text{C}=\text{C}$ double bonds in each fatty acid chain of the fat is:

- A 1
- B 2
- C 3
- D 4

Answer A [1]

8 What is the percentage by mass of oxygen in methyl 3-nitrobenzoate?

- A 17.6 %
- B 26.5 %
- C 35.4 %
- D 44.2 %

Answer C [1]

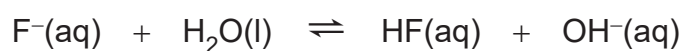


9 Which one of the following alcohols can form the ester $\text{HCOOCH}(\text{CH}_3)_2$?

- A methanol
- B 2-methylpropan-2-ol
- C propan-1-ol
- D propan-2-ol

Answer D [1]

10 Fluoride ions react with water in the following equilibrium:



Which one of the following shows the Brønsted–Lowry bases in this equilibrium?

- A F^- and HF
- B F^- and OH^-
- C H_2O and HF
- D H_2O and OH^-

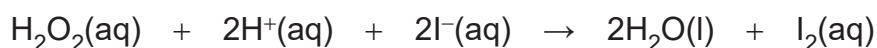
Answer B [1]



Section B

Answer **all five** questions in this section

- 11** Hydrogen peroxide reacts with iodide ions according to the equation:



- (a)** The table shows data obtained from experiments investigating the initial rate of this reaction.

Experiment number	$[\text{H}_2\text{O}_2]$ /mol dm ⁻³	$[\text{H}^+]$ /mol dm ⁻³	$[\text{I}^-]$ /mol dm ⁻³	Initial rate of reaction /mol dm ⁻³ s ⁻¹
1	0.050	0.050	0.050	1.24×10^{-6}
2	0.100	0.100	0.100	4.96×10^{-6}
3	0.100	0.200	0.075	3.72×10^{-6}
4	0.500	0.100	0.00625	1.55×10^{-6}

The rate equation for the reaction is:

$$\text{rate} = k[\text{H}_2\text{O}_2][\text{I}^-]$$

- (i)** Calculate a value for the rate constant using the results of experiment 1. State the units. Give your answer to 3 significant figures.

$$k = \text{rate} \div [\text{H}_2\text{O}_2][\text{I}^-] = 1.24 \times 10^{-6} \div (0.050 \times 0.050)$$

$$k = 4.96 \times 10^{-4} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$

[2]

- (ii)** Complete the table by inserting the missing values.

[3]



- (b) Describe how the initial rate of this reaction in $\text{mol dm}^{-3} \text{ s}^{-1}$ could be measured using colorimetry.

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

Prepare a range of standard iodine solutions of known concentration.

Select a suitable (blue) filter and calibrate the colorimeter to zero

absorbance using a blank of distilled water.

Measure and record the absorbance of each standard solution.

Plot a calibration curve of absorbance against iodine concentration.

Mix the reactants and start the timer, place the reaction mixture in

a cuvette in the colorimeter and record the absorbance at regular

time intervals.

Use the calibration curve to convert each absorbance reading into a

concentration of iodine.

Plot a graph of iodine concentration against time.

Draw a tangent to the curve at $t = 0 \text{ s}$; the gradient of this

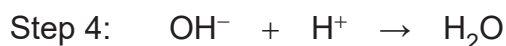
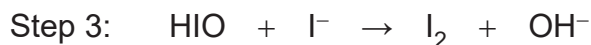
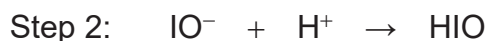
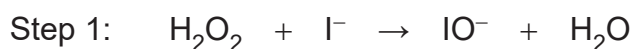
tangent is the initial rate in $\text{mol dm}^{-3} \text{ s}^{-1}$.

[6]

[Turn over]



(c) A mechanism for the reaction is shown below in 4 steps:



(i) Explain, using the rate equation, why Step 1 is the rate determining step in this mechanism.

Both H_2O_2 and I^- appear in the rate equation and they are the reactants in Step 1, whereas H^+ is not in the rate equation, so Step 1 is the slow step.

[1]

(ii) Suggest why Step 2 and Step 4 are faster than Steps 1 and 3.

Steps 2 and 4 are reactions between oppositely charged ions, which attract each other.

[1]

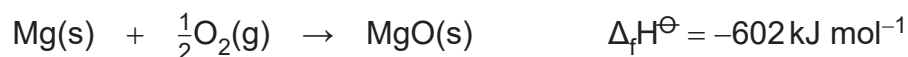
(iii) What is the systematic name for the IO^- ion?

iodate(I) ion

[1]



12 Magnesium oxide is formed from its elements as follows:



(a) (i) Use the values in the table to calculate the entropy change for the reaction.

Substance	MgO(s)	O ₂ (g)	Mg(s)
Entropy / J K ⁻¹ mol ⁻¹	26.9	205	32.7

$$\Delta S = \Sigma S(\text{products}) - \Sigma S(\text{reactants})$$

$$\Delta S = 26.9 - (32.7 + \frac{1}{2} \times 205)$$

$$= 26.9 - 135.2 = -108.3 \text{ J K}^{-1} \text{ mol}^{-1} \quad [2]$$

(ii) Write the equation for **free energy change**.

$$\Delta G = \Delta H - T\Delta S \quad [1]$$

(iii) Calculate the free energy change for the formation of magnesium oxide at 298 K. State the units. Give your answer to 3 significant figures.

$$\Delta S = -108.3 \text{ J K}^{-1} \text{ mol}^{-1} = -0.1083 \text{ kJ K}^{-1} \text{ mol}^{-1}$$

$$\Delta G = -602 - (298 \times -0.1083)$$

$$\Delta G = -602 + 32.27 = -569.7$$

$$\Delta G = -570 \text{ kJ mol}^{-1} \quad [3]$$

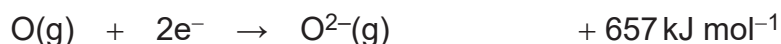
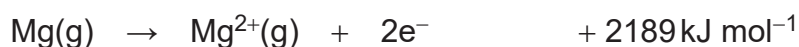
(iv) Explain why this reaction is feasible at 298 K.

$$\Delta G \text{ is negative (less than zero) at 298 K.}$$

[Turn over



- (b) The following enthalpy changes can be used to calculate the lattice enthalpy of magnesium oxide.



- (i) Define **lattice enthalpy**.

The enthalpy change when one mole of an ionic compound is converted into its gaseous ions (under standard conditions).

[2]

- (ii) Calculate the lattice enthalpy of magnesium oxide.

$$\Delta H_f = \Delta H_{at}(\text{Mg}) + 1\text{E} + \frac{1}{2}\text{BDE}(\text{O}_2) + \text{EA} - \Delta H_{latt}$$

$$-602 = 148 + 2189 + 249 + 657 - \Delta H_{latt} = 3243 - \Delta H_{latt}$$

$$\Delta H_{latt} = 3243 + 602 = +3845 \text{ kJ mol}^{-1}$$

[2]

- (iii) Write an equation for the second electron affinity of oxygen. Explain whether this process is exothermic or endothermic.

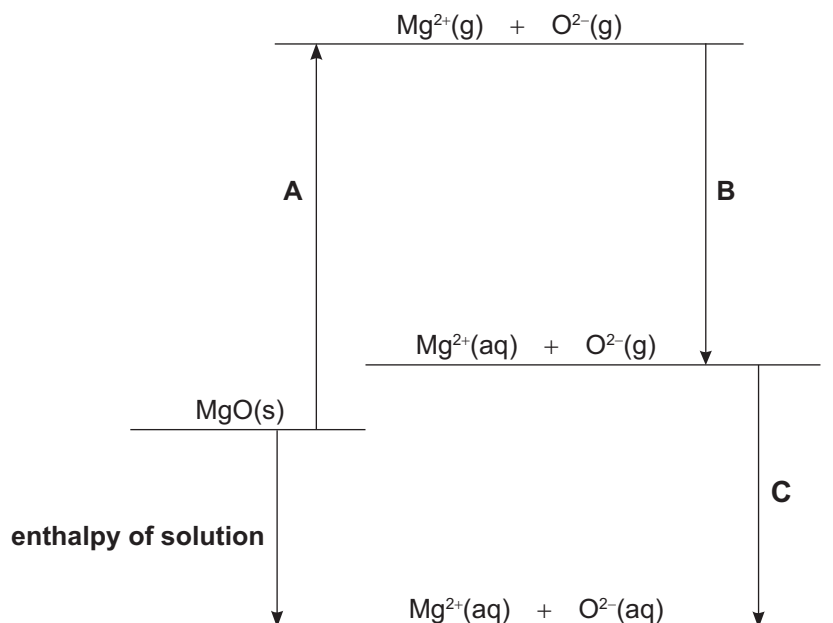


Endothermic, because energy is needed to overcome the repulsion between the negative O^{-} ion and the incoming electron.

[2]



- (c) A theoretical value for the enthalpy of solution of magnesium oxide may be calculated using a Hess's Law diagram.



- (i) Name the enthalpy changes labelled **A** and **B**.

A lattice enthalpy (of magnesium oxide)

B hydration enthalpy of the magnesium ions, Mg^{2+} [2]

- (ii) Suggest why an actual value for the enthalpy of solution of magnesium oxide is not found in any data books.

MgO is virtually insoluble in water and the oxide ion reacts with

water to form OH^- , so O^{2-} has no hydration enthalpy. [1]

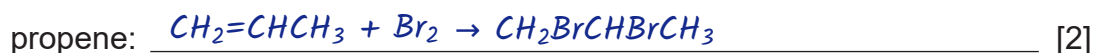
[Turn over



13 Benzene was first isolated by Faraday in 1825.

(a) Both benzene and propene will react with bromine but in different ways.

(i) Write equations for the reactions of bromine with benzene and bromine with propene.



(ii) Complete the table below.

	Reaction of bromine with benzene	Reaction of bromine with propene
Name of mechanism	<i>electrophilic substitution</i>	<i>electrophilic addition</i>
IUPAC name of product	<i>bromobenzene</i>	<i>1,2-dibromopropane</i>

[4]

(iii) Explain why the mechanisms for the reactions in (a)(ii) are different.

Benzene has a delocalised ring of π electrons which gives it

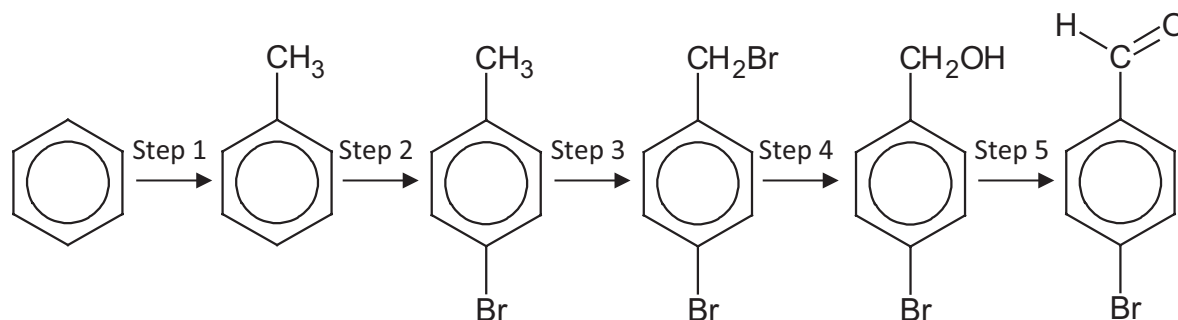
enhanced stability, so it reacts by substitution to keep this

ring; propene has a localised π bond, so it adds.

[2]



(b) (4-bromophenyl)methanal can be formed by the sequence of reactions shown below.

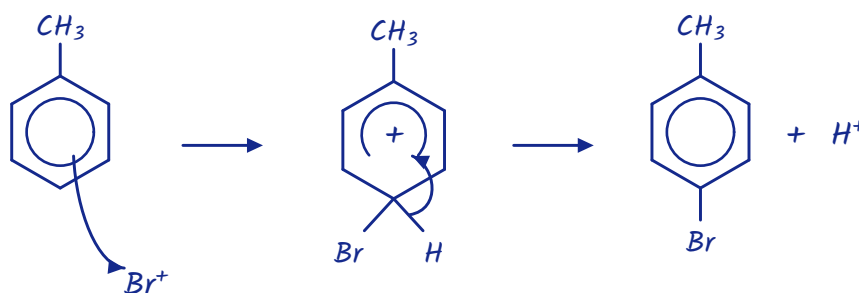


(i) Name the reagent and catalyst used in the formation of methylbenzene in Step 1.

reagent: chloromethane, CH_3Cl

catalyst: (anhydrous) aluminium chloride, AlCl_3 [2]

(ii) Methylbenzene reacts with bromine in Step 2 in the same way that benzene reacts with bromine. Including any appropriate equations, outline the mechanism for the catalysed reaction of methylbenzene and bromine in Step 2, using curly arrows.



[5]

[Turn over]



- (iii) Suggest the name for the reaction mechanism which occurs during Step 3 of the reaction sequence.

(free) radical substitution

[1]

- (iv) Name the reagent and the reaction conditions needed to carry out Step 5.

reagent: acidified potassium dichromate(VI)

conditions: heat (distil off the aldehyde as it forms)

[2]

- (v) The sample of (4-bromophenyl)methanal obtained contains an organic impurity. The relative molecular mass of the impurity was determined to be 201.

Draw the structure of this organic impurity and state its IUPAC name.

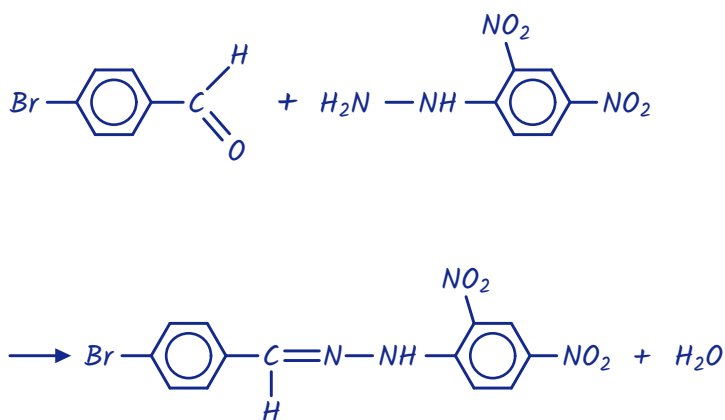


IUPAC name 4-bromobenzoic acid

[2]



- (c) (i) (4-bromophenyl)methanal reacts with 2,4-dinitrophenylhydrazine. Write an equation for this reaction.



[2]

- (ii) State how the purified organic product formed from the reaction in **c(i)** could be used to confirm the identity of (4-bromophenyl)methanal.

Measure the melting point of the purified, dry crystals and

compare it with the data book value for this derivative.

[2]

[Turn over



14 3-methylbutan-1-ol is one of eight alcohols with the molecular formula $C_5H_{12}O$.

(a) (i) Complete the table below for some of the isomers of $C_5H_{12}O$.

Structural formula	Classification	IUPAC name
$ \begin{array}{ccccccc} & H & & H & & CH_3 & H \\ & & & & & & \\ HO & -C & - & C & - & C & - & C & - & H \\ & & & & & & \\ & H & & H & & H & H \end{array} $	primary	3-methylbutan-1-ol
$ \begin{array}{ccccccc} & H & & H & & CH_3 & H \\ & & & & & & \\ H & -C & - & C & - & C & - & C & - & OH \\ & & & & & & \\ & H & & H & & H & H \end{array} $	primary	2-methylbutan-1-ol
$ \begin{array}{ccccccc} & H & & H & & H & & OH & & H \\ & & & & & & & & & \\ H & -C & - & C & - & C & - & C & - & C & - & H \\ & & & & & & & & & \\ & H & & H & & H & & H & & H \end{array} $	secondary	pentan-2-ol
$ \begin{array}{ccccccc} & H & & OH & & H & & H \\ & & & & & & & \\ H & -C & - & C & - & C & - & C & - & H \\ & & & & & & & \\ & H & & CH_3 & & H & & H \end{array} $	tertiary	2-methylbutan-2-ol
$ \begin{array}{ccccccc} & H & & H & & OH & & H \\ & & & & & & & \\ H & -C & - & C & - & C & - & C & - & H \\ & & & & & & & \\ & H & & CH_3 & & H & & H \end{array} $	secondary	3-methylbutan-2-ol

[5]



- (ii) Some of the alcohol isomers are optically active. Define the term **optically active**.

A substance which rotates the plane of plane-polarised light.

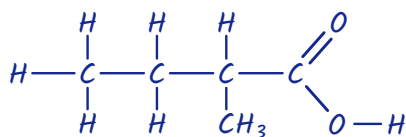
[2]

- (iii) Name the alcohols shown in the table in (a)(i) which exhibit optical activity.

2-methylbutan-1-ol, pentan-2-ol and 3-methylbutan-2-ol

[2]

- (iv) Name the alcohol shown in the table in (a)(i) which can be oxidised to produce an optically active compound. Draw the structural formula of the optically active compound.



2-methylbutanoic acid (C2 is chiral)

Name: *2-methylbutan-1-ol*

[2]

[Turn over



(b) 3-methylbutan-1-ol undergoes an esterification reaction with ethanoic acid to form 'banana oil' which is used as a food flavouring.

(i) Write an equation for this esterification reaction.



(ii) An impure sample of 'banana oil' was obtained in a round-bottomed flask by reacting 3-methylbutan-1-ol with ethanoic acid in the presence of a concentrated sulfuric acid catalyst. The impure sample of the 'banana oil' was collected by distillation. Describe how the sample could be further purified by removing acidic impurities and water.

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

Pour the impure distillate into a separating funnel.

Add sodium hydrogencarbonate solution to neutralise the acidic impurities (ethanoic acid and sulfuric acid).

Stopper the funnel and shake, inverting it and opening the tap regularly to release the pressure of carbon dioxide.

Allow the layers to separate, then run off and discard the lower aqueous layer, keeping the upper ester layer.

Transfer the ester to a dry conical flask and add anhydrous magnesium sulfate (drying agent) to remove water.

Swirl and leave until the liquid is clear and no longer cloudy.

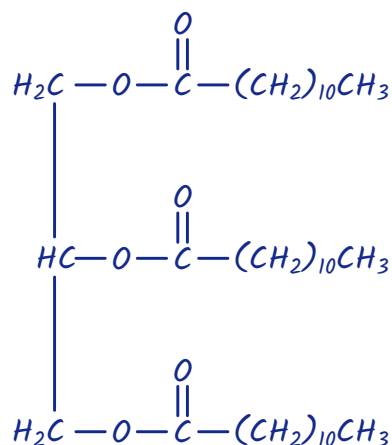
Decant (or filter) the pure ester off the solid drying agent.

[6]



- (c) Coconut oil contains a large proportion of the triglyceride, glyceryl trilaurate. The fatty acid in this triglyceride is lauric acid, $\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$.

(i) Draw the structure of glyceryl trilaurate.



[1]

(ii) Explain why glyceryl trilaurate is a solid at room temperature.

Glyceryl trilaurate has a high relative molecular mass (and
saturated chains that pack closely), so there are strong van der
Waals forces between the molecules.

[2]

(iii) Biodiesel can be produced from oils such as coconut oil by a transesterification reaction. Define the term **transesterification**.

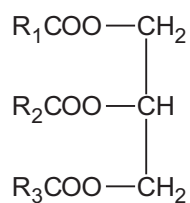
A reaction where the alkyl group of an ester is exchanged with
the alkyl group of an alcohol.

[2]

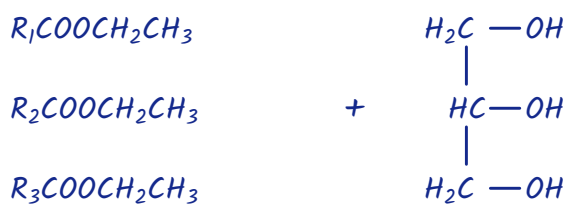
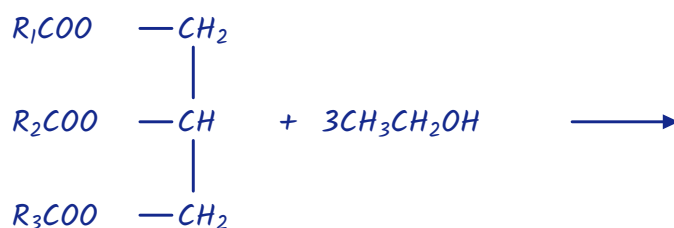
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- (iv) An oil, with the general formula shown below, can be used in the formation of biodiesel.



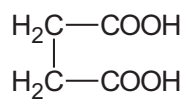
Write the equation for the formation of biodiesel by heating the oil with an excess of ethanol in the presence of a catalyst.



[2]



- 15 Succinic acid is a dicarboxylic acid. It is a white solid at room temperature and melts at 184 °C. It has a solubility in water of 0.0580 kg dm⁻³ at 20 °C.



succinic acid

- (a) (i) Explain why succinic acid has a relatively high melting point.

Succinic acid forms hydrogen bonds between the -COOH groups of adjacent molecules, which require substantial energy to break.

[2]

- (ii) Calculate the molarity of a saturated solution of succinic acid at 20 °C. Give your answer to 3 significant figures.

M_r of succinic acid, C₄H₆O₄ = 118

solubility = 0.0580 kg dm⁻³ = 58.0 g dm⁻³

molarity = 58.0 ÷ 118 = 0.492 mol dm⁻³

[2]

[Turn over]



(b) Succinic acid undergoes two successive acid ionisation reactions with $pK_{a1} = 4.30$ and $pK_{a2} = 5.60$.

(i) Write an expression for the first acid dissociation constant for succinic acid.

$$K_{a1} = \frac{[H^+][HOOCCH_2CH_2COO^-]}{[HOOCCH_2CH_2COOH]}$$

[1]

(ii) Using the pK_{a1} value, calculate the pH of a $0.100 \text{ mol dm}^{-3}$ solution of succinic acid. Give your answer to 2 decimal places.

$$K_{a1} = 10^{-4.30} = 5.012 \times 10^{-5} \text{ mol dm}^{-3}$$

$$K_{a1} = [H^+]^2 \div [\text{acid}], \text{ so } [H^+]^2 = 5.012 \times 10^{-5} \times 0.100$$

$$[H^+]^2 = 5.012 \times 10^{-6}$$

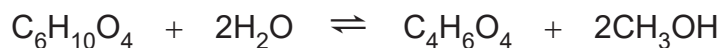
$$[H^+] = 2.239 \times 10^{-3} \text{ mol dm}^{-3}$$

$$pH = -\log_{10}(2.239 \times 10^{-3}) = 2.65$$

[3]



- (c) Dimethyl succinate ($C_6H_{10}O_4$) is a fruit-flavoured additive for ice-cream and chewing gum. It can be hydrolysed to form succinic acid and methanol.



A mixture of 2.0 moles of dimethyl succinate in 5.0 moles of water is left to reach equilibrium in the presence of an acid catalyst at 50 °C. At equilibrium 1.4 moles of dimethyl succinate are present. Calculate the value for K_c in this equilibrium at 50 °C. Give your answer to 2 significant figures.

$$\text{moles of ester reacted} = 2.0 - 1.4 = 0.6 \text{ mol}$$

$$\text{equilibrium moles: ester } 1.4, \text{ water } 5.0 - 1.2 = 3.8, \text{ succinic acid } 0.6,$$

$$\text{methanol } 1.2$$

$$K_c = [C_4H_6O_4][CH_3OH]^2 \div [C_6H_{10}O_4][H_2O]^2 \text{ (volumes cancel)}$$

$$K_c = (0.6)(1.2)^2 \div (1.4)(3.8)^2 = 0.864 \div 20.216 = 0.0427$$

$$K_c = 0.043$$

[4]

[Turn over]



- (d) Sodium ethanoate, used in the production of dimethyl succinate, can also be used in buffer solutions. Solid sodium ethanoate (relative formula mass = 82) is added to 250 cm^3 of a 0.1 mol dm^{-3} solution of ethanoic acid to form a buffer with pH 4.80. The K_a of ethanoic acid is $1.74 \times 10^{-5}\text{ mol dm}^{-3}$.

Calculate the mass of sodium ethanoate required and give your answer to 3 significant figures.

$$[H^+] = 10^{-4.80} = 1.585 \times 10^{-5}\text{ mol dm}^{-3}$$

$$K_a = [H^+][CH_3COO^-] \div [CH_3COOH]$$

$$[CH_3COO^-] = K_a[CH_3COOH] \div [H^+]$$

$$= (1.74 \times 10^{-5} \times 0.100) \div (1.585 \times 10^{-5}) = 0.1098\text{ mol dm}^{-3}$$

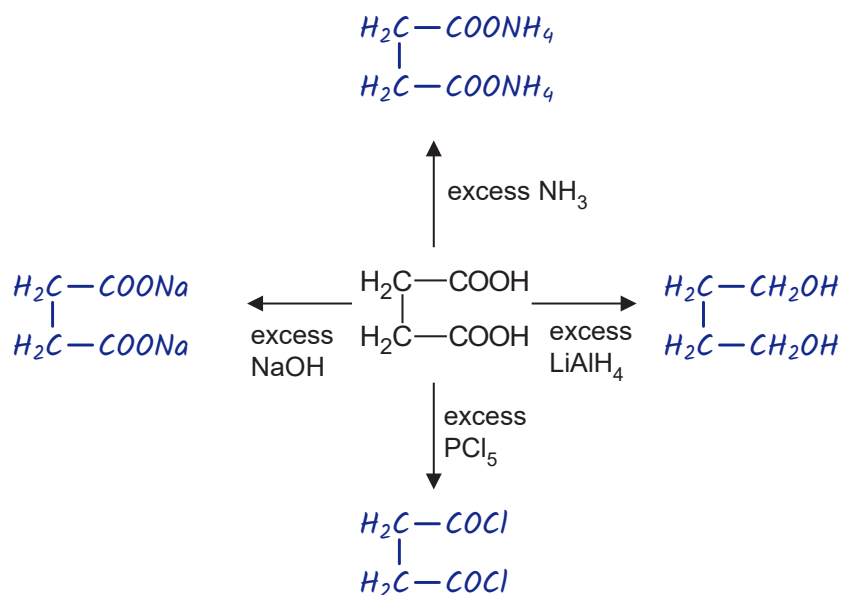
$$\text{moles of } CH_3COONa \text{ in } 250\text{ cm}^3 = 0.1098 \times 0.250 = 0.02745\text{ mol}$$

$$\text{mass of sodium ethanoate} = 0.02745 \times 82 = 2.25\text{ g}$$

[4]



- (e) Give the structures of the organic products for the reaction of succinic acid with an excess of each reagent.



[4]

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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 dm³

Avogadro Constant = 6.02×10^{23} mol⁻¹

Planck Constant = 6.63×10^{-34} Js

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

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



Characteristic absorptions in IR spectroscopy

Wavenumber/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
	C ₆ H ₅ –CH	Arene (aliphatic on ring)
2.0–4.0	X–CH	X = Cl or Br (3.0–4.0) X = I (2.0–3.0)
4.5–6.0	–C=CH	Alkenes
5.5–8.5	RCONH	Amides
6.0–8.0	–C ₆ 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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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

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 H Hydrogen																	4 He Helium
7 Li Lithium	9 Be Beryllium											11 B Boron	12 C Carbon	14 N Nitrogen	16 O Oxygen	19 F Fluorine	20 Ne Neon
23 Na Sodium	24 Mg Magnesium											27 Al Aluminium	28 Si Silicon	31 P Phosphorus	32 S Sulfur	35.5 Cl Chlorine	40 Ar Argon
39 K Potassium	40 Ca Calcium	45 Sc Scandium	48 Ti Titanium	51 V Vanadium	52 Cr Chromium	55 Mn Manganese	56 Fe Iron	59 Co Cobalt	59 Ni Nickel	64 Cu Copper	65 Zn Zinc	70 Ga Gallium	73 Ge Germanium	75 As Arsenic	79 Se Selenium	80 Br Bromine	84 Kr Krypton
85 Rb Rubidium	88 Sr Strontium	89 Y Yttrium	91 Zr Zirconium	93 Nb Niobium	96 Mo Molybdenum	98 Tc Technetium	101 Ru Ruthenium	103 Rh Rhodium	106 Pd Palladium	108 Ag Silver	112 Cd Cadmium	115 In Indium	119 Sn Tin	122 Sb Antimony	128 Te Tellurium	127 I Iodine	131 Xe Xenon
133 Cs Caesium	137 Ba Barium	139 La [*] Lanthanum	178 Hf Hafnium	181 Ta Tantalum	184 W Tungsten	186 Re Rhenium	190 Os Osmium	192 Ir Iridium	195 Pt Platinum	197 Au Gold	201 Hg Mercury	204 Tl Thallium	207 Pb Lead	209 Bi Bismuth	210 Po Polonium	210 At Astatine	222 Rn Radon
223 Fr Francium	226 Ra Radium	227 Ac [†] Actinium	261 Rf Rutherfordium	262 Db Dubnium	266 Sg Seaborgium	264 Bh Bohrium	277 Hs Hassium	268 Mt Meitnerium	271 Ds Darmstadtium	272 Rg Roentgenium	285 Cn Copernicium						
			140 Ce Cerium	141 Pr Praseodymium	144 Nd Neodymium	145 Pm Promethium	150 Sm Samarium	152 Eu Europium	157 Gd Gadolinium	159 Tb Terbium	162 Dy Dysprosium	165 Ho Holmium	167 Er Erbium	169 Tm Thulium	173 Yb Ytterbium	175 Lu Lutetium	
			232 Th Thorium	231 Pa Protactinium	238 U Uranium	237 Np Neptunium	242 Pu Plutonium	243 Am Americium	247 Cm Curium	245 Bk Berkelium	251 Cf Californium	254 Es Einsteinium	253 Fm Fermium	256 Md Mendelevium	254 No Nobelium	257 Lr Lawrencium	
			90	91	92	93	94	95	96	97	98	99	100	101	102	103	

a

X

b

a = relative atomic mass (approx)

x = atomic symbol

b = atomic number

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

$\begin{matrix} a \\ \boxed{X} \\ b \end{matrix}$ a = relative atomic mass (approx)
x = atomic symbol
b = atomic number