

CANDIDATE
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CENTRE
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CANDIDATE
NUMBER

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9701/21

May/June 2020

1 hour 15 minutes

You must answer on the question paper.

You will need: Data booklet

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working, use appropriate units and use an appropriate number of significant figures.

- The total mark for this paper is 60.
- The number of marks for each question or part question is shown in brackets [].

This document has **12** pages. Blank pages are indicated.

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

1 Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga .

(i) State, with reference to subatomic particles, how the isotopes ^{69}Ga and ^{71}Ga differ from each other.

.....
..... [1]

(ii) State what further information is needed to calculate the relative atomic mass of gallium.

..... [1]

(b) Gallium and its compounds show similar properties to aluminium and its compounds.
Gallium reacts with excess chlorine to form gallium trichloride.

(i) At 500°C , gallium trichloride is a gas.

Suggest the type of attraction that exists at 500°C

- between atoms within a gallium trichloride molecule

.....

- between gallium trichloride molecules.

.....

[2]

(ii) When gallium trichloride is cooled a solid, Ga_2Cl_6 , forms.

Suggest the name of the attraction formed between two gallium trichloride molecules to form Ga_2Cl_6 .

..... [1]

(c) Gallium metal reacts rapidly when exposed to air. A white solid layer is formed on its surface.

- (i) Suggest an equation to describe the reaction occurring when gallium metal is exposed to air.

..... [2]

- (ii) The table gives the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and hot aqueous sodium hydroxide.

	formula of gallium-containing product
hot aqueous hydrochloric acid	GaCl_3
hot aqueous sodium hydroxide	$\text{NaGa}(\text{OH})_4$

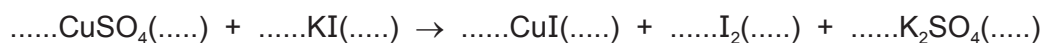
Give the name of the type of behaviour shown by gallium oxide in these reactions.

..... [1]

[Total: 8]

- 2 (a) The equation shown in (a)(i) describes the reaction which occurs when aqueous potassium iodide is added to aqueous copper(II) sulfate. A white precipitate of copper(I) iodide forms in a brown solution of iodine and potassium sulfate.

(i) Balance the equation and include state symbols.



[2]

The table gives the oxidation numbers of iodine in the different species in the equation.

iodine-containing species	oxidation number of iodine
KI	−1
CuI	−1
I ₂	0

(ii) Deduce the oxidation number of copper in CuSO₄ and CuI.

- oxidation number of copper in CuSO₄
- oxidation number of copper in CuI

[1]

(iii) Describe the type of reaction shown by the equation in (a)(i). Explain your answer in terms of electron transfer.

.....

 [2]

- (b) In the reaction described in (a)(i), a student uses 17.43 g of CuSO₄•yH₂O. By further titration of the reaction products the student concludes that the total amount of CuSO₄ in the sample is 0.0982 mol.

Use the *Data Booklet* to complete the table to calculate the value of **y**, where **y** is an integer. Show your working.

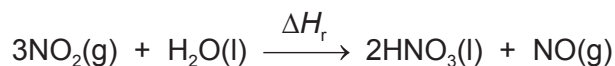
mass of 0.0982 mol CuSO ₄	 g
amount of H ₂ O in 17.43 g of CuSO ₄ •yH ₂ O	 mol H ₂ O
value of y	y = ...

[4]

[Total: 9]

- 3 Nitric acid, HNO_3 , can be made by reacting nitrogen dioxide with water.

The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.



- (a) Explain what is meant by the term *enthalpy change of formation*.

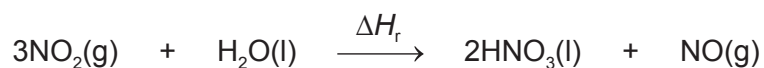
.....

 [2]

- (b) Complete the Hess' cycle using the values given in the table and hence calculate the enthalpy change, ΔH_r , for this reaction.

Show your working.

substance	$\Delta H_f / \text{kJ mol}^{-1}$
$\text{NO}_2(\text{g})$	34.0
$\text{H}_2\text{O}(\text{l})$	-286
$\text{HNO}_3(\text{l})$	-173
$\text{NO}(\text{g})$	91.1



$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$
 [3]

- (c) Nitrogen and oxygen do not react at normal atmospheric temperatures.

Explain why.

.....

.....

.....

..... [2]

Nitrogen oxides can be formed naturally in the Earth's atmosphere from nitrogen and oxygen in the air.

- (d) State **one** way that nitrogen oxides are produced naturally.

..... [1]

- (e) Nitrogen dioxide, NO_2 , acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide.

- (i) Explain why NO_2 is described as a homogeneous catalyst.

.....

.....

.....

..... [3]

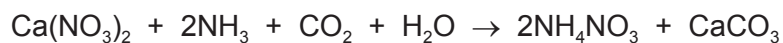
- (ii) Write equations which describe the two reactions occurring when NO_2 acts as a catalyst in the formation of sulfur trioxide from sulfur dioxide.

.....

..... [2]

[Total: 13]

- 4 Calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.



- (a) Explain why ammonia is described as a Brønsted-Lowry base in this reaction.

..... [1]

The product mixture can then be added to soil.

- (b) State **two** reasons why this mixture of products is added to some soils.

1

2 [2]

- (c) Complete the table to name the shape and give the bond angle of each species.

	name of shape	bond angle / °
CO_2		
NH_3		
H_2O		

[3]

[Total: 6]

5 (a) Below is a list of species which can react with organic compounds.



(i) From the list, identify a species which can react with ethane.

..... [1]

(ii) From the list, identify **two** species which can attack the π bond in ethene.

..... [1]

(iii) From the list, identify a species which can be used to distinguish between solutions of propanoic acid and propan-1-ol. Describe any relevant observations.

.....

.....

..... [2]

(b) Cl(g) can be made from $\text{Cl}_2(\text{g})$.

(i) Describe the conditions required for this process.

..... [1]

(ii) Name this process.

..... [1]

(c) (i) Name an organic functional group which reacts with a nucleophile in an addition reaction.

..... [1]

(ii) Name an organic functional group which tends to react with a nucleophile in an $\text{S}_{\text{N}}1$ substitution mechanism.

..... [1]

- (d) But-1-ene reacts with steam in the presence of concentrated phosphoric acid to form two isomers of molecular formula $C_4H_{10}O$.

Each reaction occurs via a different intermediate ion.

- (i) Draw the structure of both intermediate ions.

[2]

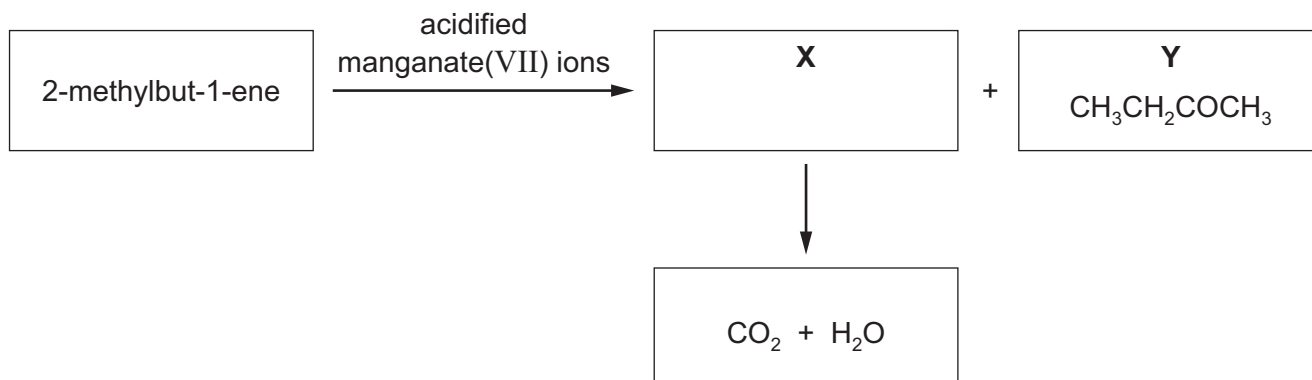
- (ii) Circle the more stable intermediate ion drawn in (d)(i). Explain your answer.

.....
.....
..... [2]

[Total: 12]

- 6 2-methylbut-1-ene reacts with acidified manganate(VII) ions, under specific conditions, to produce two organic compounds **X** and **Y**.

X immediately reacts with the acidified manganate(VII) ions to form carbon dioxide and water. **Y** has the structural formula $\text{CH}_3\text{CH}_2\text{COCH}_3$.



- (a) Draw the skeletal formula of 2-methylbut-1-ene.

[1]

- (b) (i) State the specific conditions required for the acidified manganate(VII) ions to react with 2-methylbut-1-ene in this way.

..... [1]

- (ii) Name the type of reaction occurring to the functional group in 2-methylbut-1-ene in the reaction in (b)(i).

..... [1]

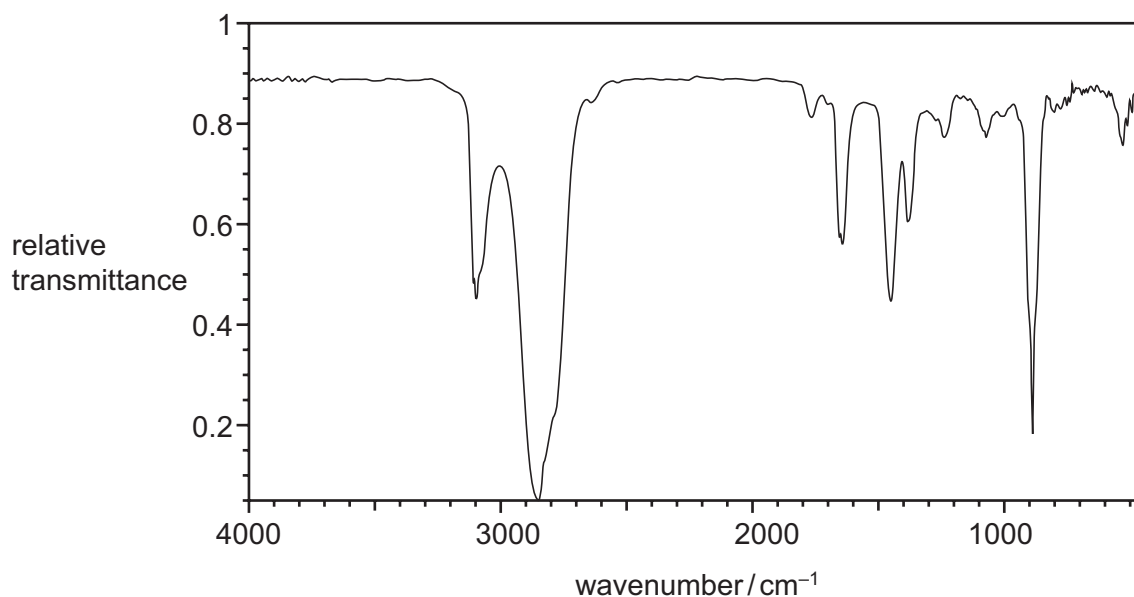
- (c) Draw the structural formula of **X**.

..... [1]

- (d) Describe a chemical test and the expected observation(s) to confirm the presence of the carbonyl functional group in **Y**.

.....
 [2]

(e) The infra-red spectrum of 2-methylbut-1-ene is shown.



Predict two main differences that would be seen between the spectra of **Y**, $\text{CH}_3\text{CH}_2\text{COCH}_3$, and of 2-methylbut-1-ene. Give reasons for your predictions.

Your answer should refer only to the region of each spectrum **above 1500 cm^{-1}** .

.....

.....

.....

.....

..... [2]

(f) Propanoic acid, $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$, is reduced by LiAlH_4 .

(i) Write an equation to show this reaction. Use $[\text{H}]$ to represent an atom of hydrogen from the reducing agent.

..... [1]

(ii) Name the organic product formed in this reaction.

..... [1]

(g) Organic compound **W** is an ester which is a structural isomer of propanoic acid.

(i) State the molecular formula of **W**.

..... [1]

(ii) Draw a possible structure of **W**.

[1]

[Total: 12]

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Cambridge International AS & A Level

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CHEMISTRY

9701/22

Paper 2 AS Level Structured Questions

May/June 2020

1 hour 15 minutes

You must answer on the question paper.

You will need: Data booklet

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
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INFORMATION

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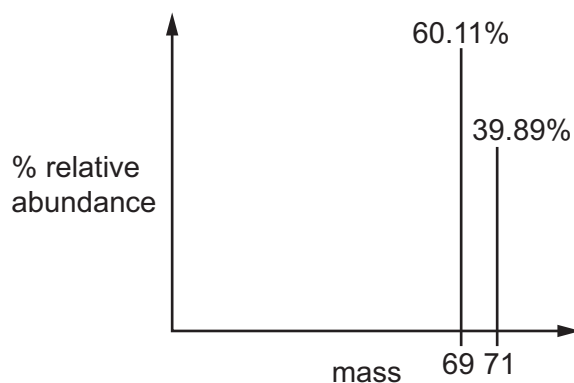
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Answer **all** the questions in the spaces provided.

- 1 Gallium is an element in Group 13.

A sample of gallium is analysed using a mass spectrometer. The mass spectrum produced is shown.



- (a) Explain what is meant by the term *relative atomic mass*.

.....
 [2]

- (b) Calculate the relative atomic mass of gallium in this sample. Give your answer to 4 significant figures.

Show your working.

relative atomic mass = ... [2]

- (c) Complete the table which describes a gaseous atom of gallium.

isotope	nucleon number	total number of electrons in lowest energy level	type of orbital which contains the electron in the highest energy level
^{71}Ga			

[3]

- (d) When gallium is heated in excess chlorine, gallium trichloride, GaCl_3 , is made.

Draw the shape of the gallium trichloride molecule and suggest the Cl-Ga-Cl bond angle.

shape of molecule

bond angle

[2]

- (e) Gallium oxide, Ga_2O_3 , and aluminium oxide react in the same way with $\text{HCl}(\text{aq})$ and with $\text{NaOH}(\text{aq})$.

- (i) Suggest the equation for the reaction between Ga_2O_3 and $\text{HCl}(\text{aq})$.

..... [1]

- (ii) Suggest an equation for the reaction between gallium oxide and $\text{NaOH}(\text{aq})$.

..... [2]

[Total: 12]

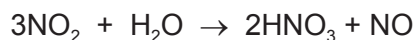
2 Nitric acid can be made in a 3-stage process.

Stage 1 Ammonia is oxidised by oxygen from the air, to form nitrogen monoxide and water. This reaction is carried out at 10–13 atmospheres pressure and 900 °C in the presence of a platinum catalyst.

Stage 2 Nitrogen monoxide reacts with more oxygen to form nitrogen dioxide.



Stage 3 Nitrogen dioxide reacts with water to make nitric acid and nitrogen monoxide.



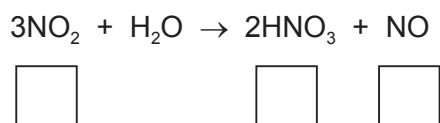
(a) Write an equation to show the reaction occurring in stage 1.

..... [1]

(b) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons in a molecule of ammonia.

[1]

(c) (i) In the boxes, give the oxidation numbers of nitrogen in the nitrogen-containing species for the reaction in stage 3.



[2]

(ii) Explain why the reaction in stage 3 is described as a disproportionation reaction. Include reference to transfer of electrons in your answer.

.....

.....

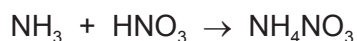
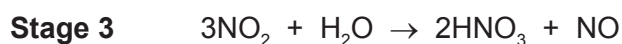
..... [2]

- (d) The release of nitrogen monoxide into the atmosphere causes atmospheric pollution.

State and explain the effect of nitrogen monoxide gas in contact with moist air.

.....
 [2]

- (e) The nitric acid made in stage 3 can then be reacted with ammonia to form ammonium nitrate.



Calculate the volume of nitrogen dioxide, measured at room temperature and pressure, required to make 40 tonnes of ammonium nitrate.

[1 tonne = 1000 kg]

Show your working.

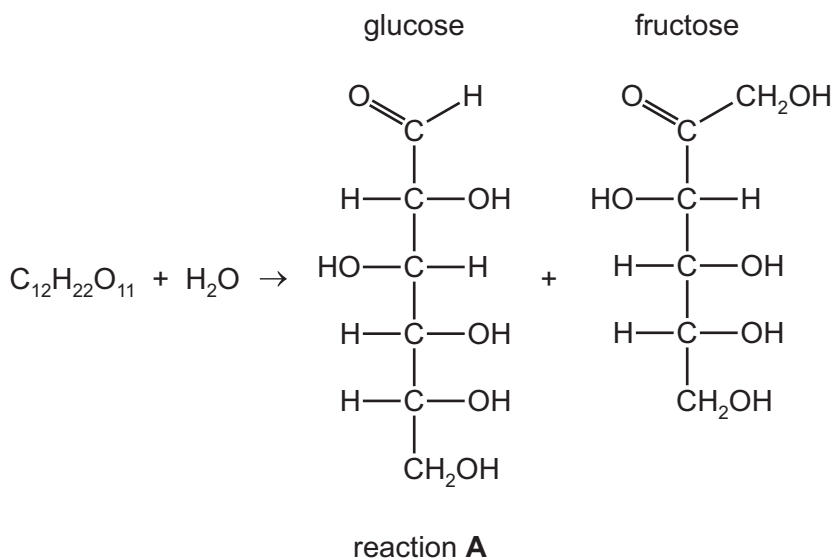
volume of nitrogen dioxide = ... [3]

- (f) State **one** use of ammonium nitrate.

..... [1]

[Total: 12]

- 3 Sucrose, $C_{12}H_{22}O_{11}$, reacts with water to form glucose and fructose in reaction **A**.



- (a) Suggest a name for this type of reaction.

..... [1]

- (b) Explain in detail, why glucose and fructose are a pair of structural isomers. Your answer should refer specifically to these two molecules.

.....

.....

..... [2]

- (c) Reaction **A** occurs faster in the presence of an enzyme. This is reaction **B**.

- (i) The activation energy for reaction **B** is $+29 \text{ kJ mol}^{-1}$.

Predict a value for the activation energy of reaction **A**.

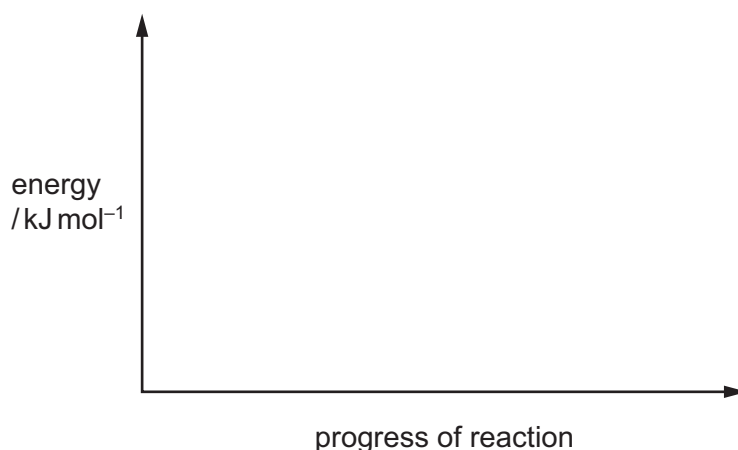
..... [1]

- (ii) The enthalpy change for reaction **A** is -14 kJ mol^{-1} .

Predict a value for the enthalpy change for reaction **B**.

..... [1]

- (iii) Sketch a labelled energy level diagram for reaction **B**. Use relevant values from (c)(i) and (c)(ii).



[2]

- (d) 1.00 g of sucrose, $C_{12}H_{22}O_{11}$, is completely combusted. The heat energy produced is used to increase the temperature of 250 g of water inside a calorimeter from 25.0 °C to 40.7 °C.

These data can be used to calculate the enthalpy change of combustion of sucrose.

- (i) Explain what is meant by the term *enthalpy change of combustion of sucrose*.

.....

 [2]

- (ii) Use the *Data Booklet* to calculate the enthalpy change, in kJ mol^{-1} , for the combustion of sucrose.

Assume that all of the heat energy produced is transferred to the water.

Show your working.

enthalpy change of combustion of sucrose = ... kJ mol^{-1}
 [3]

[Total: 12]

- 4 (a) An unlabelled bottle contains a straight-chain halogenoalkane, **Q**. The molecular formula of **Q** is $C_5H_{11}X$, where **X** is a halogen; bromine, chlorine or iodine.

A test is carried out to identify the halogen present in **Q**.

A sample of **Q** is added to $NaOH(aq)$ and warmed. Dilute nitric acid is then added followed by a few drops of aqueous silver nitrate. A cream precipitate is observed.

- (i) Suggest the identity of **X**.

..... [1]

- (ii) Write an ionic equation to describe the formation of the cream precipitate. Include state symbols.

..... [1]

- (iii) Describe a further test which would confirm the identity of **X**.

test

expected result

[2]

- (b) The reaction of **Q** with $NaOH(aq)$ tends to proceed via an S_N2 mechanism.

- (i) Suggest the structural formula of the straight-chain halogenoalkane **Q**.

[1]

- (ii) Explain why the reaction tends to proceed via an S_N2 mechanism rather than an S_N1 mechanism.

.....

.....

..... [2]

- (c) Two different halogenoalkanes, **P** and **R**, both with the molecular formula C_4H_9Cl , are separately dissolved in ethanol and heated under reflux with sodium hydroxide.

The major organic product of each of these reactions is methylpropene.

- (i) Name the type of reaction occurring.

..... [1]

- (ii) Write an equation, using molecular formulae, to represent the reaction occurring.

..... [1]

- (iii) Draw the skeletal formula of methylpropene.

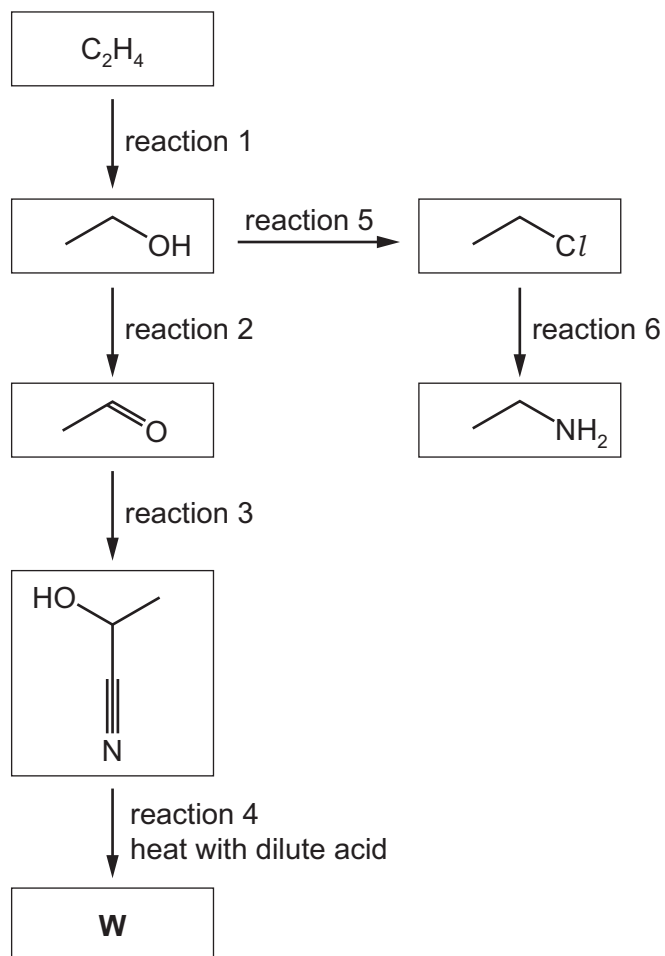
[1]

- (iv) Give the names of **P** and **R**.

..... [2]

[Total: 12]

5 The reaction sequence shows how ethene, C_2H_4 , can be converted into other organic molecules.



(a) Complete the table to give

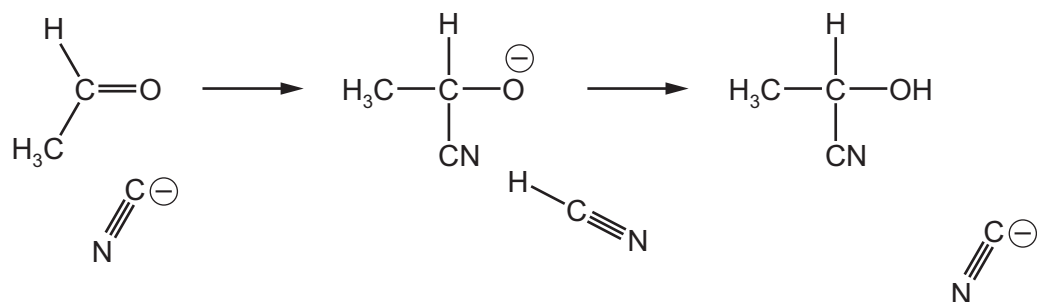
- the name of the reaction mechanisms of reactions 1 and 6
- the reagents and conditions required for reactions 1, 2 and 6.

reaction	name of mechanism	name of reagents and conditions
1		
2		
6		

[6]

(b) In reaction 3 the organic molecule reacts with HCN and a KCN catalyst.

- (i) Complete the diagram to show the mechanism of the reaction occurring. Include all relevant dipoles, lone pairs and curly arrows in your answer.



[3]

- (ii) Name the functional groups present in the product of reaction 3.

..... [2]

(c) Draw the structure of the organic molecule **W** formed in reaction 4.

[1]

[Total: 12]

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9701/23

May/June 2020

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1 (a) A sample of barium is heated in oxygen.

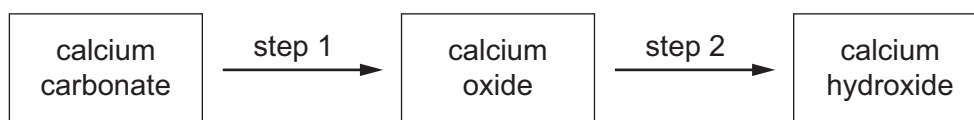
(i) Describe **two** observations for this reaction.

.....
..... [2]

(ii) Write an equation for this reaction. Include state symbols.

..... [1]

(b) Calcium carbonate can be converted into calcium hydroxide in a two-step process.



(i) Describe how the two-step process is carried out to convert calcium carbonate into calcium hydroxide. Include relevant equations.

.....
.....
.....
..... [3]

(ii) Name the type of reaction occurring when calcium carbonate is converted into calcium oxide.

..... [1]

(iii) State **one** common use for both calcium carbonate and calcium hydroxide.

..... [1]

(c) Gallium is a silver-grey solid. Aluminium and gallium share many similar chemical properties.

- (i) Construct an equation for the reaction of gallium when heated in oxygen to form gallium oxide, Ga_2O_3 .

..... [1]

- (ii) Deduce the oxidation number of gallium in Ga_2O_3 .

..... [1]

- (iii) Complete the table by predicting the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and with hot concentrated sodium hydroxide.

reagents and conditions	formula of gallium-containing product
gallium oxide + hot $\text{HCl}(\text{aq})$	
gallium oxide + hot concentrated $\text{NaOH}(\text{aq})$	

[2]

[Total: 12]

- 2 (a) Explain what is meant by the term *relative isotopic mass*.

.....

 [2]

- (b) A sample of copper contains two isotopes, ^{63}Cu and ^{65}Cu . The relative atomic mass of the copper in this sample is 63.55.

Calculate the percentage abundance of each of these isotopes. Show your working.

percentage abundance of ^{63}Cu = ... %

percentage abundance of ^{65}Cu = ... %
 [2]

- (c) (i) Name the type of bonding within a sample of solid copper.

..... [1]

- (ii) Draw a labelled diagram to show the bonding within a sample of solid copper.

[2]

- (iii) State the electronic configuration of a copper atom.

$1s^2$ [1]

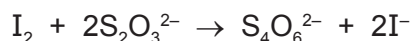
- (d) A student is provided with a sample of hydrated copper(II) sulfate, $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$, and is asked to determine the value of x .

The student dissolves a sample of the hydrated copper(II) sulfate in water and adds it to an excess of aqueous potassium iodide to make a total volume of 250.0 cm^3 of solution.



The amount of iodine produced during this reaction is found by titrating a sample of this solution with sodium thiosulfate solution.

25.0 cm^3 of the iodine-containing solution requires 20.0 cm^3 of 0.10 mol dm^{-3} sodium thiosulfate solution.



- (i) Calculate the amount, in mol, of copper(II) sulfate present in the original sample of hydrated copper(II) sulfate.

Show your working.

amount of copper(II) sulfate = ... mol [2]

- (ii) A total of 7.98 g of CuSO_4 is present in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$.

Complete each row of the table to calculate the value of x , where x is an integer.

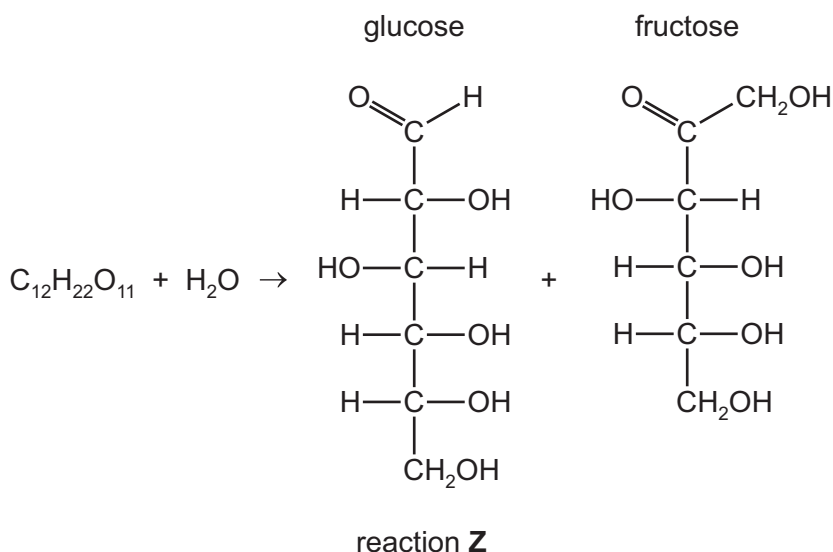
$[M_r: \text{CuSO}_4, 159.6]$

amount of CuSO_4 in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$	 mol
amount of H_2O in 10.68 g of $\text{CuSO}_4 \cdot x\text{H}_2\text{O}$	 mol
value of x	$x = \dots\dots\dots$

[3]

[Total: 13]

- 3 Sucrose is a white crystalline solid, $C_{12}H_{22}O_{11}$. In reaction **Z**, sucrose reacts with water in the presence of a catalyst, aqueous hydrochloric acid, to form glucose and fructose.

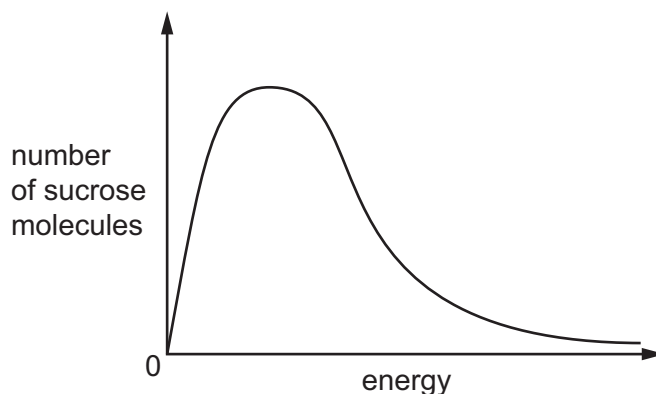


- (a) (i) Suggest a name for the reaction that occurs when sucrose reacts with water to form glucose and fructose.

..... [1]

- (ii) If no catalyst is added in reaction **Z**, the reaction is very slow.

Label the Boltzmann distribution to show the effect of adding a catalyst to the sample of sucrose and water molecules at constant temperature.



Explain your labelled diagram.

.....

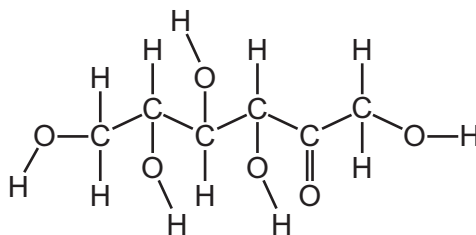
[3]

- (b) Both fructose and glucose contain chiral centres.

- (i) Explain what is meant by the term *chiral centre*.

..... [1]

- (ii) On the diagram of the fructose molecule, label all the chiral centres with an asterisk (*).



[1]

- (iii) Determine the empirical formula of fructose.

..... [1]

- (c) (i) Explain what is meant by the term *enthalpy change of combustion*.

.....

..... [2]

- (ii) Write the equation for the complete combustion of sucrose.

..... [1]

The enthalpy change of reaction **Z**, ΔH_r , can be calculated using the enthalpy change of combustion data given in the table.

substance	enthalpy change of combustion, $\Delta H_c / \text{kJ mol}^{-1}$
sucrose	-5643
glucose	-2805
fructose	-2810

- (iii) Use the data in the table to calculate the enthalpy change for the reaction occurring when sucrose reacts with water, ΔH_r . You should draw a labelled Hess' cycle to show your working.

$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1}$ [2]

[Total: 12]

- 4 Hexane, C_6H_{14} , is a colourless liquid. Two test-tubes contain equal amounts of hexane. 1 cm^3 of bromine, $\text{Br}_2(\text{aq})$, is added to both test-tubes. One test-tube is kept in the dark and the other is exposed to sunlight.

The table describes the appearance of each test-tube after one hour.

test-tube conditions	observations
in the dark	no change, mixture remains orange
in sunlight	colour of mixture fades to pale yellow

- (a) The test-tube in the dark is kept cool and is not exposed to ultraviolet light.

Explain the observations for the test-tube kept in the dark.

.....
 [2]

- (b) In sunlight, bromine reacts with hexane by a mechanism which occurs via a series of steps.

- (i) State the name of the mechanism of the reaction that occurs.

..... [1]

- (ii) Give an equation which shows a propagation step in this reaction in which hexane produces $\cdot\text{C}_6\text{H}_{13}$.

..... [1]

- (iii) Give an equation which shows a propagation step in this reaction that produces 1-bromohexane.

..... [1]

- (iv) Give an equation which shows a termination step in this reaction that produces 1-bromohexane.

..... [1]

(c) **A** and **B** are different straight chain alkenes with molecular formula, C_6H_{12} .

A does not show stereoisomerism.

A reacts with potassium manganate(VII) to form hexane-1,2-diol.

(i) Draw the structural formula of **A**.

[1]

(ii) State the conditions needed for this reaction of **A**.

..... [2]

(d) **B** reacts with hydrogen gas in the presence of a platinum catalyst to produce hexane.

(i) Name the type of reaction occurring.

..... [1]

(ii) In terms of σ and π bonds, describe any similarities and differences in the type of carbon-carbon bonds in **B** and the type of carbon-carbon bonds in hexane.

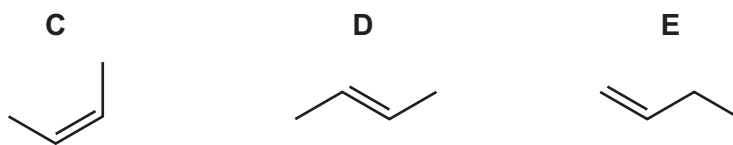
.....

.....

..... [2]

[Total: 12]

- 5 **C**, **D** and **E** are isomers of each other.
They are made by passing an alcohol vapour over an aluminium oxide catalyst.



- (a) (i) Name the type of reaction occurring.

..... [1]

- (ii) Draw the displayed formula of the alcohol used in this reaction.

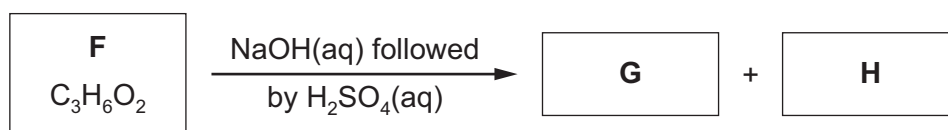
[2]

- (iii) Name the isomers **C**, **D** and **E**.

isomer	name
C	
D	
E	

[2]

- (b) **F** is an organic molecule which has the molecular formula $C_3H_6O_2$.
When **F** is heated with $NaOH(aq)$ followed by $H_2SO_4(aq)$ the products **G** and **H** are made.



Separate samples of **G** and **H** are added to

- $Na_2CO_3(aq)$
- sodium metal
- alkaline aqueous iodine.

The observations are described in the table.

reagent(s)	G	H
$Na_2CO_3(aq)$	colourless bubbles of gas produced	no visible reaction
$Na(s)$	colourless bubbles of gas produced	colourless bubbles of gas produced
alkaline aqueous iodine	no visible reaction	yellow precipitate forms

- (i) Complete the table to identify the functional groups present in **F**, **G** and **H**.

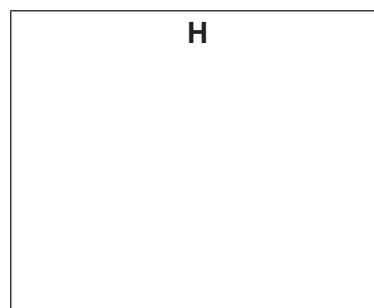
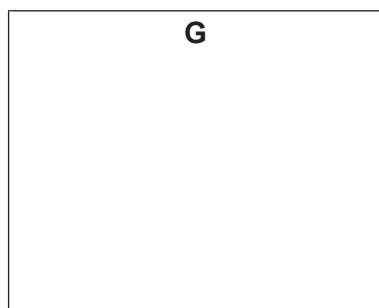
	functional group
F	
G	
H	

[3]

- (ii) Name the yellow precipitate formed when alkaline aqueous iodine reacts with **H**.

..... [1]

- (iii) Draw the structures of **G** and **H**.



[2]

[Total: 11]

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