Cambridge International AS & A Level

Cambridge International Examinations
Cambridge International Advanced Subsidiary and Advanced Level

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

6829058285

CHEMISTRY **9701/41**

Paper 4 A Level Structured Questions **May/June 2018**

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.
You may lose marks if you do not show your working or if you do not use appropriate units.
A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

This document consists of **18** printed pages and **2** blank pages.

CAMBRIDGE International Examinations

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

1 Sodium oxide, Na_2O, is a white crystalline solid with a high melting point.

(a) Write an equation for the reaction of sodium with oxygen, forming sodium oxide. Include state symbols.

..... [2]

(b) Explain why sodium oxide has a high melting point.

.....

.....

.....

..... [2]

(c) When sodium oxide reacts with water an alkaline solution is obtained.

(i) Explain why the solution obtained is alkaline. You should use the Brønsted-Lowry theory of acids and bases in your answer.

.....

.....

.....

..... [2]

(ii) Calculate the pH of the solution obtained when 3.10 g of sodium oxide are added to 400 cm^3 of water.

pH = ... [3]

(d) Use the data below, and other suitable data from the *Data Booklet*, to calculate the lattice energy of sodium oxide, $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$.

energy change	value / kJ mol^{-1}
standard enthalpy change of formation of sodium oxide, $\Delta H^{\ominus}_{f}$ $Na_2O(s)$	–416
standard enthalpy change of atomisation of sodium, $\Delta H^{\ominus}_{at}$ Na(s)	+109
electron affinity of O(g)	–142
electron affinity of O^-(g)	+844

$\Delta H^{\ominus}_{latt}$ $Na_2O(s)$ = ... kJ mol^{-1} [4]

(e) State how $\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ differs from $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$.
Indicate this by placing a tick (✓) in the appropriate box in the table.

$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is more exothermic than $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$	$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is the same as $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$	$\Delta H^{\ominus}_{latt}$ $Na_2S(s)$ is less exothermic than $\Delta H^{\ominus}_{latt}$ $Na_2O(s)$

Explain your answer.

.....

.....

.....

[2]

[Total: 15]

2 Nitrogen monoxide, NO(g), reacts with hydrogen, $H_2(g)$, under certain conditions.

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

(a) Define the term *rate of reaction*.

.....

..... [1]

(b) Identify a change in the reaction mixture that would enable the rate of this reaction to be studied.

..... [1]

The rate equation for this reaction is given.

$$\text{rate} = k[NO]^2[H_2]$$

The result of an experiment in which NO reacted with H_2 is shown in the table.

initial [NO] / mol dm^{-3}	initial [H_2] / mol dm^{-3}	initial rate of reaction / mol dm^{-3} s^{-1}
2.50×10^{-3}	2.50×10^{-3}	1.27×10^{-3}

(c) Use the data and the rate equation to calculate a value for the rate constant *k*.
Give the units of *k*.

k = ...

units = ...
[2]

(d) A second experiment is performed at the same temperature. The initial concentration of $H_2(g)$ is 4.60×10^{-3} mol dm^{-3}. The initial rate of the reaction is 2.31×10^{-3} mol dm^{-3} s^{-1}.

Calculate the initial concentration of NO(g).

initial concentration of NO(g) = ... mol dm^{-3} [1]

(e) State the order of the reaction with respect to NO(g) and with respect to H_2(g), and the overall order of the reaction.

[NO]	
[H_2]	
overall order	

[1]

(f) The reaction is believed to proceed in three steps.

1 $2NO \rightarrow N_2O_2$

2 $N_2O_2 + H_2 \rightarrow N_2O + H_2O$

3 $N_2O + H_2 \rightarrow N_2 + H_2O$

(i) Deduce which of the three steps is the rate-determining step.

..... [1]

(ii) Explain your answer to **(i)**.

.....

.....

..... [1]

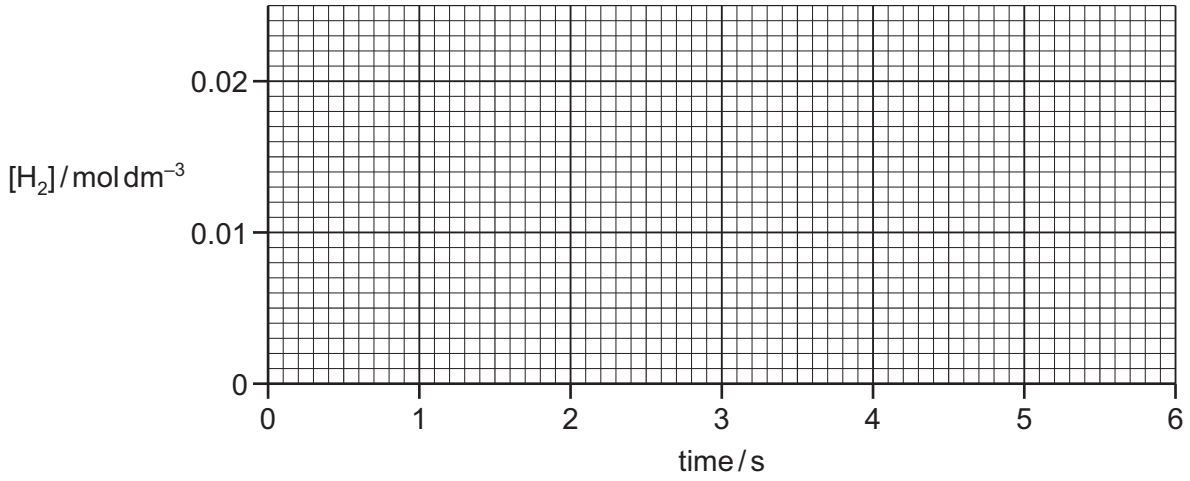
(g) A third experiment is performed under different conditions. A small amount of $H_2(g)$ of concentration $0.0200\,mol\,dm^{-3}$ is mixed with a large excess of NO(g). The concentration of $H_2(g)$ is found to have a constant half-life of 2.00 seconds under the conditions used.

(i) Define the term *half-life*.

.....

..... [1]

(ii) Use the axes below to construct a graph of the variation in the concentration of $H_2(g)$ during the first 6 seconds under the conditions used.



[2]

(h) NO(g) acts as a catalyst in the oxidation of atmospheric sulfur dioxide.

(i) Give two equations to describe how NO(g) acts as a catalyst in this process.

equation 1 .....

equation 2 .....

[1]

(ii) Explain why NO(g) can be described as a catalyst in this reaction.

.....

..... [1]

(iii) Describe, with the aid of an equation, an environmental consequence of the oxidation of atmospheric sulfur dioxide.

.....

..... [1]

[Total: 14]

3 **(a)** Complete the table, identifying the substance liberated at each electrode during electrolysis with inert electrodes.

electrolyte	substance liberated at the anode	substance liberated at the cathode
$AgNO_3(aq)$		
concentrated $NaCl(aq)$		
$CuSO_4(aq)$		

[3]

(b) Molten calcium iodide, CaI_2, is electrolysed in an inert atmosphere with inert electrodes.

(i) Write ionic equations for the reactions occurring at the electrodes.

- .....
- .....

[2]

(ii) The electrolysis of molten CaI_2 is a redox process.

Identify the ion that is oxidised and the ion that is reduced, explaining your answer by reference to oxidation numbers.

.....

.....

..... [2]

(iii) Describe **two** visual observations that would be made during this electrolysis.

1 .....

2 .....

[1]

(c) An oxide of iron dissolved in an inert solvent is electrolysed for 2.00 hours using a current of 0.800 A. The electrolysis products are iron and oxygen. The mass of iron produced is 1.11 g.

Calculate the oxidation number of Fe in the oxide of iron. Show **all** your working.

oxidation number of Fe = ... [3]

[Total: 11]

[Turn over

4 **(a)** Describe what you would see when calcium and barium are heated separately with oxygen.

calcium .....

barium .....
[2]

(b) The decomposition temperatures of the Group 2 carbonates vary down the group.

State and explain the variation in the decomposition temperatures.

.....

.....

.....

.....

.....

..... [3]

(c) Magnesium carbonate was heated in an open test-tube. It was difficult to see whether a thermal decomposition reaction took place.

Explain why.

.....

.....

..... [2]

[Total: 7]

5 Copper is a transition element with atomic number 29.

(a) Complete the electronic configurations of a Cu atom and a Cu^+ ion.

Cu atom $1s^2 2s^2 2p^6$ .....

Cu^+ ion $1s^2 2s^2 2p^6$ .....

[2]

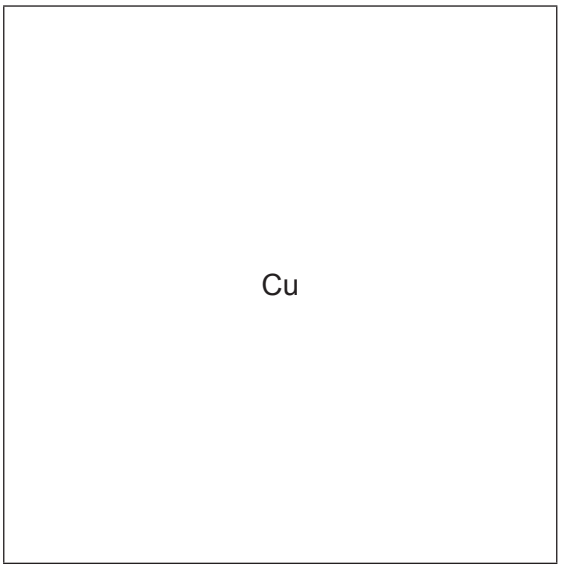
(b) Cu^+ ions form a linear complex with Cl^- ions, which are monodentate ligands.

Draw the structure of this complex and include its overall charge.

[2]

(c) Cu^{2+} ions exist as $[Cu(H_2O)_6]^{2+}$ complex ions in aqueous solution.

Complete a three-dimensional diagram to show the shape of this complex.
Name its shape.
Label and state the value of one bond angle.



name of shape .....

[2]

(d) When $NH_3(aq)$ is added to $Cu^{2+}(aq)$, dropwise at first and then in excess, two chemical reactions occur as shown.

$$[Cu(H_2O)_6]^{2+} \xrightarrow[\text{reaction 1}]{\text{dropwise } NH_3(aq)} \mathbf{A} \xrightarrow[\text{reaction 2}]{\text{excess } NH_3(aq)} \mathbf{B}$$

For each reaction, describe what you would see and write an equation.

reaction 1

observation .....

.....

equation .....

reaction 2

observation .....

.....

equation .....

[4]

(e) $EDTA^{4-}$ is a polydentate ligand. When a solution of $EDTA^{4-}$ is added to a solution containing $[Cu(H_2O)_6]^{2+}$ a new complex is formed. The formula of this complex is $[CuEDTA]^{2-}$.

(i) Name the type of reaction occurring here.

..... [1]

(ii) Write an expression for the stability constant, K_{stab}, of $[CuEDTA]^{2-}$ in this reaction.

[1]

(iii) The numerical value of the K_{stab} of $[CuEDTA]^{2-}$ is 6.3×10^{19} at 298 K.

State what this tells us about the $[CuEDTA]^{2-}$ complex ion.

..... [1]

(f) Ethanedioate ions, $C_2O_4^{2-}$, can act as a bidentate ligand.

(i) Explain what is meant by the term *bidentate ligand*.

.....

.....

.....

..... [2]

(ii) When ethanedioate ions are added to a solution of zirconium ions, Zr^{4+}, a complex ion containing four $C_2O_4^{2-}$ ions and one Zr^{4+} ion is formed. All four ethanedioate ions act as bidentate ligands in this complex.

Give the formula of this complex ion and explain why this complex is not octahedral.

.....

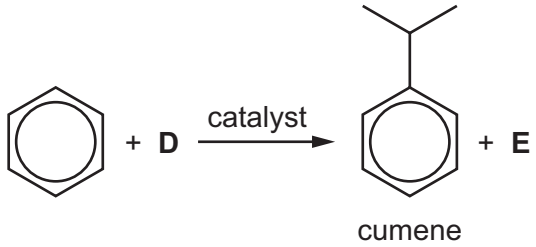
.....

.....

..... [2]

[Total: 17]

6 **(a)** Benzene reacts with **D** in the presence of a suitable catalyst to give cumene and non-organic product **E**. This is an electrophilic substitution reaction.



cumene

(i) Name the reactant **D** and the non-organic product **E**.

D .....

E .....

[2]

(ii) Give the name of the type of aromatic electrophilic substitution reaction taking place.

..... [1]

(b) Cumene undergoes substitution reactions with chlorine to give several different isomeric products with the formula $C_9H_{11}Cl$. The substitution can occur in the aromatic ring or in the side-chain of cumene.

(i) Describe the conditions that are used to ensure substitution takes place only in the **aromatic ring**.

..... [1]

(ii) Draw the structures of the **two** major isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the aromatic ring.

[1]

(iii) Describe the conditions that are used to ensure substitution takes place only in the **side-chain**.

..... [1]

(iv) Draw the structures of **two** isomeric products of the reaction, formula $C_9H_{11}Cl$, when substitution takes place in the side-chain.

[1]

(c) Complete the following table to show the structures of the organic products formed when cumene reacts with each reagent.

reagent	structure of organic product
hot $KMnO_4(aq)$	
H_2 + Ni, high pressure	

[2]

(d) Cumene can be nitrated using a mixture of concentrated nitric and sulfuric acids. The mechanism for this reaction is similar to the mechanism for the nitration of benzene.

Complete the mechanism for this reaction.

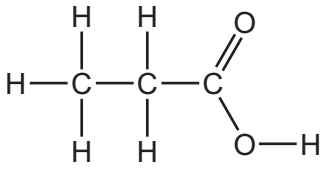
- Include all relevant charges and curly arrows showing the movement of electron pairs.
- Draw the structure of the intermediate.
- You do not need to draw the products.

cumene intermediate

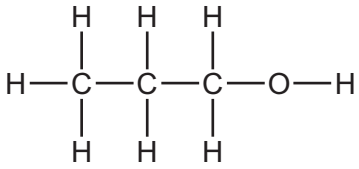
[4]

[Total: 13]

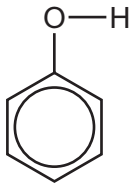
7 The three substances shown all have some acidic properties.



propanoic acid



propan-1-ol



phenol

(a) Write an equation for the reaction between propan-1-ol and sodium metal.

..... [1]

(b) **(i)** Give the order of the relative acidities of propanoic acid, propan-1-ol and phenol, stating the most acidic first.

..... [1]

(ii) Explain your answer to **(i)**.

.....

.....

.....

.....

.....

..... [2]

(c) Methanoic acid, HCO_2H, has a similar acid strength to propanoic acid.

Describe a chemical test to distinguish between these two acids. Name the acid which gives a positive result in this test and describe the observations that would be made.

.....

.....

.....

..... [2]

(d) The ester phenyl propanoate, $C_2H_5CO_2C_6H_5$, can be made from phenol and propanoic acid in a **two-step** synthesis. The first step produces an acyl chloride.

For this **two-step** synthesis,

- draw the structure of the product of the first step,
- state the reagents and conditions needed for each step of the synthesis.

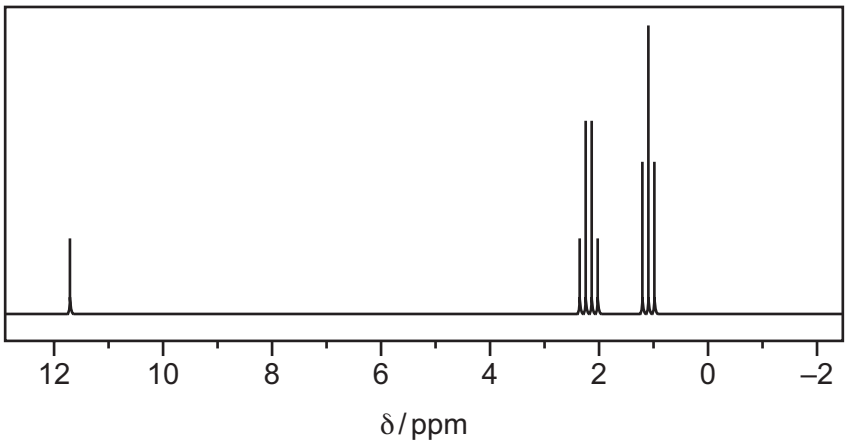
.....

.....

.....

..... [3]

(e) An unknown compound, **Z**, is propan-1-ol, propanal or propanoic acid. The proton NMR spectrum of **Z** dissolved in $CDCl_3$ is shown.



(i) From the proton NMR spectrum, identify **Z**.

..... [1]

(ii) State one feature that would be seen, and why, in the proton NMR spectra of each of the two compounds that are not **Z**.

.....

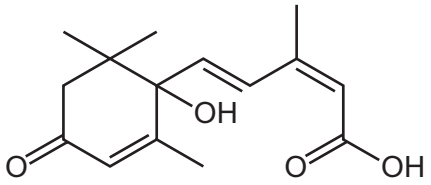
.....

.....

..... [2]

[Total: 12]

8 Abscisic acid, $C_{15}H_{20}O_4$, is a plant hormone.



abscisic acid, $C_{15}H_{20}O_4$

(a) On the diagram of abscisic acid, use an asterisk (*) to label each chiral carbon atom. [1]

(b) Abscisic acid is reacted with an excess of $NaBH_4$.

Give the molecular formula of the organic product formed.

..... [1]

(c) If abscisic acid is treated with an excess of hot, concentrated, acidified $KMnO_4$, three different carbon-containing products are formed.

(i) Draw the skeletal formula of the carbon-containing product with the **largest** molecular mass.

[1]

(ii) Identify the carbon-containing product with the **smallest** molecular mass. Explain how this product arises.

.....

.....

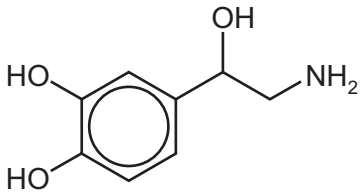
..... [2]

(iii) Identify the third carbon-containing product of this reaction by giving its displayed or structural formula.

[1]

[Total: 6]

9 Noradrenaline is a hormone found in humans.



noradrenaline

(a) Give the molecular formula of noradrenaline.

..... [1]

(b) State whether or not noradrenaline shows stereoisomerism. Explain your answer.

.....

..... [1]

(c) HNO_2(aq) is reacted at 5 °C with separate samples of noradrenaline and phenylamine.
The reaction with phenylamine produces a stable diazonium ion.
The reaction with noradrenaline produces an unstable diazonium ion.

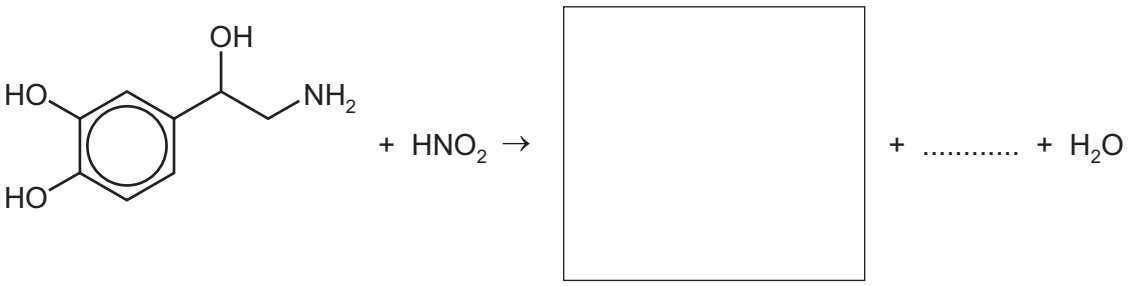
(i) Suggest why the diazonium ion produced with phenylamine is stable.

.....

..... [1]

(ii) When one noradrenaline molecule reacts with one HNO_2 molecule, the products are one water molecule, one molecule of an unreactive gas, and one molecule of an organic compound made up of carbon, hydrogen and oxygen only.

Complete the chemical equation for this reaction.



[2]

[Total: 5]

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