



Cambridge International AS & A Level

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CHEMISTRY

9701/41

Paper 4 A Level Structured Questions

October/November 2020

2 hours

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.
- 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.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

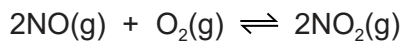
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2

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

- 1 Nitrogen monoxide, NO, reacts with oxygen to form nitrogen dioxide, NO₂.



The rate equation for the forward reaction is shown.

$$\text{rate} = k[\text{NO}]^2[\text{O}_2]$$

- (a) Complete the following table.

the order of reaction with respect to [NO]	
the order of reaction with respect to [O ₂]	
the overall order of reaction	

[1]

- (b) Two separate experiments are carried out at 30 °C to determine the rate of the forward reaction.

experiment	[NO]/mol dm ⁻³	[O ₂]/mol dm ⁻³	rate/mol dm ⁻³ s ⁻¹
1	0.00300	0.00200	1.51×10^{-4}
2		0.00500	6.05×10^{-5}

- (i) Use the data for experiment 1 to calculate the value of the rate constant, *k*. State the units of *k*.

$$k = \dots\dots\dots \text{ units} = \dots\dots\dots$$

[2]

- (ii) Calculate the value of [NO] in experiment 2.

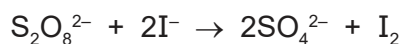
$$[\text{NO}] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

- (c) Define the term *rate-determining step*.

..... [1]

3

- (d) Peroxodisulfate ions, $\text{S}_2\text{O}_8^{2-}$, react with iodide ions, I^- .



The rate equation for the reaction in the absence of any catalyst is shown.

$$\text{rate} = k[\text{S}_2\text{O}_8^{2-}][\text{I}^-]$$

- (i) Suggest equations for a two-step mechanism for this reaction, stating which of the two steps is the rate-determining step.

step 1

step 2

rate-determining step =

[2]

- (ii) A large excess of peroxodisulfate ions is mixed with iodide ions. Immediately after mixing, $[\text{I}^-] = 0.00780 \text{ mol dm}^{-3}$. Under the conditions used, the half-life of $[\text{I}^-]$ is 48 seconds.

Calculate the iodide ion concentration 192 seconds after the peroxodisulfate and iodide ions are mixed.

iodide ion concentration = mol dm^{-3} [1]

[Total: 8]

4

- 2 (a) The lattice energies of three ionic compounds are given.

compound	lattice energy / kJ mol^{-1}
LiF(s)	−1022
CaO(s)	−3513
SrO(s)	−3310

- (i) Define the term *lattice energy*.

.....

 [2]

- (ii) Explain why the lattice energy of CaO is more exothermic than the lattice energy of LiF.

.....

 [1]

- (iii) Use the data in the table to estimate approximate values for the lattice energies of magnesium oxide and barium oxide.

$$\Delta H_{\text{latt}} \text{MgO(s)} = \dots\dots\dots \text{kJ mol}^{-1}$$

$$\Delta H_{\text{latt}} \text{BaO(s)} = \dots\dots\dots \text{kJ mol}^{-1}$$

[1]

- (b) (i) Write an equation for the reaction between BaO and H_2O .
 Include state symbols.

..... [1]

- (ii) State and explain how the solubilities of the hydroxides of the Group 2 elements vary down the group.

.....

 [4]

5

- (c) Use the following data and relevant data from the *Data Booklet* to calculate a value for the lattice energy of magnesium fluoride, $\text{MgF}_2(\text{s})$.

You might find it helpful to construct an energy cycle.
Show your working.

electron affinity of $\text{F}(\text{g})$ $= -348 \text{ kJ mol}^{-1}$
enthalpy change of atomisation of $\text{Mg}(\text{s})$ $= +147 \text{ kJ mol}^{-1}$
enthalpy change of formation of $\text{MgF}_2(\text{s})$ $= -1102 \text{ kJ mol}^{-1}$

$\Delta H_{\text{latt}} \text{MgF}_2(\text{s}) = \dots\dots\dots$ [3]

- (d) (i) Define the term *electron affinity*.

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

- (ii) The electron affinity of carbon, $\text{C}(\text{g})$, is -120 kJ mol^{-1} .

Suggest an explanation for the difference between the electron affinity of fluorine and the electron affinity of carbon.

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

[Total: 15]

6

- 3 (a) Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, $\text{Na}_2\text{SO}_4(\text{aq})$.

anode

cathode

[1]

- (b) When molten sodium chloride is electrolysed, chlorine is liberated at the anode and sodium is liberated at the cathode.

A sample of molten sodium chloride is electrolysed for 1.50 hours using a current of 4.50A.

Calculate the volume of chlorine and the mass of sodium that are liberated under room conditions.

volume of chlorine = dm^3

mass of sodium = g
[4]

7

- (c) The equation representing the standard electrode potential, E° , for the reduction of $\text{MnO}_4^-(\text{aq})$ to $\text{Mn}^{2+}(\text{aq})$ in acid solution is given.



- (i) Draw a diagram of the apparatus that would be used to measure the E° value of this half-cell. Your diagram should be fully labelled to identify all apparatus, substances and conditions.

[4]

- (ii) Use the *Data Booklet* to identify a substance that could be used to oxidise Mn^{2+} ions to MnO_4^- ions under standard conditions.

Write an equation for the reaction.

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

[Total: 11]

8

- 4 (a) (i) Give the mathematical expression for each of the terms pH and K_w .

pH =

K_w =

[2]

- (ii) Calculate the pH of $0.027 \text{ mol dm}^{-3} \text{ NaOH(aq)}$.

pH = [1]

- (b) The K_a value of chloric(I) acid, HClO , is $3.72 \times 10^{-8} \text{ mol dm}^{-3}$.

Calculate the pH of $0.010 \text{ mol dm}^{-3} \text{ HClO(aq)}$.

pH = [1]

- (c) Water and octan-1-ol form two layers when mixed.

Ethanamide is more soluble in water than it is in octan-1-ol. When 1.00 g of ethanamide is added to 50.0 cm^3 of water and this is then shaken with 50.0 cm^3 of octan-1-ol, it is found that the water layer contains 0.935 g of ethanamide at equilibrium.

- (i) Calculate the partition coefficient, K_{pc} , for ethanamide in water and octan-1-ol.

K_{pc} = [1]

- (ii) The 50.0 cm^3 of water containing 0.935 g of ethanamide is then shaken with 100.0 cm^3 of pure octan-1-ol under the same conditions.

Calculate the mass of ethanamide that is dissolved in the 100.0 cm^3 of octan-1-ol at equilibrium.

mass of ethanamide = g
[2]

[Total: 7]

- 5 A solution is made by dissolving $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in an excess of aqueous ammonia. This solution contains the copper complex $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

(a) (i) Write an expression for the K_{stab} of $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

$$K_{\text{stab}} =$$

[1]

(ii) State the colour of the solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$.

..... [1]

The solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ is heated gently in a fume cupboard so that NH_3 is released. Some NH_3 remains in solution and some forms NH_3 gas. The colour of the solution changes; a precipitate of $\text{Cu}(\text{OH})_2$ forms and is collected.

A sample of $\text{Cu}(\text{OH})_2$ is added to concentrated hydrochloric acid. A reaction takes place forming a coloured copper complex, **Y**.

A sample of $\text{Cu}(\text{OH})_2$ is added to dilute sulfuric acid. A reaction takes place forming a coloured copper complex, **Z**.

$[\text{Cu}(\text{NH}_3)_4]^{2+}$, **Y** and **Z** are different colours.

(b) Suggest an equation for the reaction of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ to form $\text{Cu}(\text{OH})_2$ as the aqueous solution of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ is heated.

..... [1]

(c) Suggest an equation for the reaction of $\text{Cu}(\text{OH})_2$ with concentrated hydrochloric acid, forming **Y**.

..... [2]

(d) Complete the table with the colour and geometry of complex **Y** and the colour, geometry and formula of complex **Z**.

	Y	Z
colour of complex		
geometry of complex		
formula of complex		

[2]

10

(e) Explain why complexes **Y** and **Z** are coloured and why their colours are different.

.....

.....

.....

.....

.....

.....

.....

..... [5]

[Total: 12]

- 6 (a) When $1.0 \text{ mol dm}^{-3} \text{ Na}_2\text{S}_2\text{O}_3(\text{aq})$ is added to a solution containing $\text{Ag}^+(\text{aq})$ ions, a linear complex, **P**, is formed. $\text{S}_2\text{O}_3^{2-}$ ions are present in **P** as monodentate ligands.

(i) Define the term *monodentate ligand*.

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

(ii) Give the formula of **P**, including its charge.

..... [1]

- (b) When $1.0 \text{ mol dm}^{-3} \text{ NaCN}(\text{aq})$ is added to a solution of **P**, a mixture which includes a second linear complex, **Q**, is formed. In this mixture the concentration of **Q** is much greater than the concentration of **P**.

(i) Write an equation for the reaction that occurs when $\text{NaCN}(\text{aq})$ is added to a solution of **P**.

..... [1]

(ii) Suggest a reason why the concentration of **Q** is much greater than the concentration of **P** in the mixture.

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

(iii) Name the type of reaction in which **P** forms **Q**.

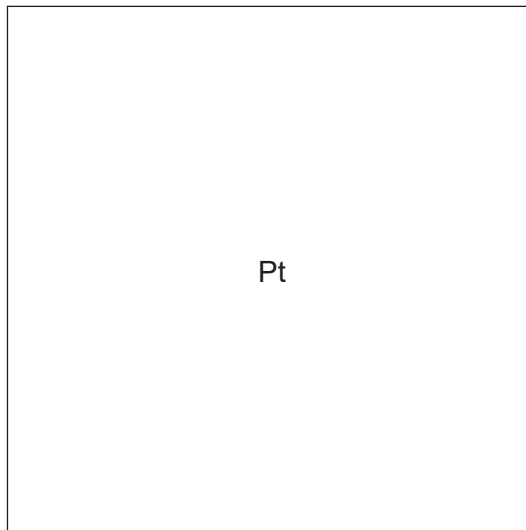
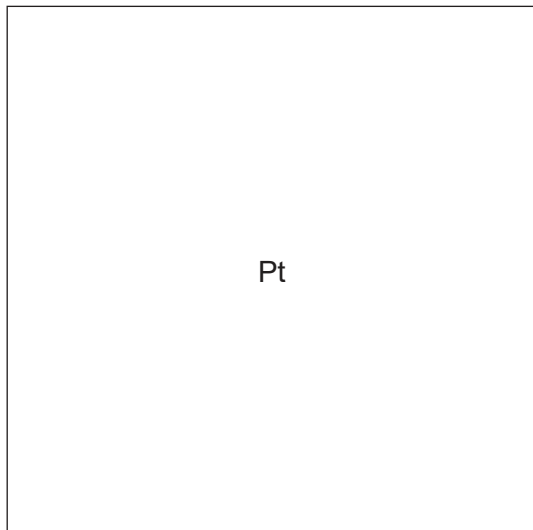
..... [1]

12

(c) Platinum forms a complex ion with the formula $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$. In this complex ion the carbon atom of each CN^- ligand bonds to the platinum ion. This complex shows stereoisomerism.

(i) There are only two isomers of this complex.

Draw structures of these two isomers in the boxes below.



[1]

(ii) Describe the geometry of $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$.

..... [1]

(iii) Name the type of stereoisomerism shown by $[\text{Pt}(\text{CN})_2\text{Cl}_2]^{2-}$.

..... [1]

[Total: 9]

13

7 Phenol, $\text{C}_6\text{H}_5\text{OH}$, is a weak acid.

(a) Phenol can be made from phenylamine, $\text{C}_6\text{H}_5\text{NH}_2$.

Give the reagents and conditions for this reaction.

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

(b) Phenol reacts with dilute aqueous nitric acid under room conditions to give a mixture of two isomeric products with molecular formula $\text{C}_6\text{H}_5\text{NO}_3$.

Use the *Data Booklet* to draw the structural formulae of these two products in the boxes and name each product.

name

name

[2]

(c) Phenol reacts with an excess of aqueous bromine.

(i) Draw and name the organic product of this reaction in the box.

name

[2]

14

- (ii) Describe **two** visual observations that can be made when phenol reacts with an excess of aqueous bromine.

observation 1

observation 2

[1]

- (d) Write an equation for a neutralisation reaction in which phenol behaves as an acid.

..... [1]

- (e) Water, phenol and ethanol can all behave as acids.

Place these three compounds in order of acidity, starting with the **most** acidic.
Explain your answer.

..... > >
most acidic least acidic

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

[3]

[Total: 11]

15

8 Benzene, C_6H_6 , can be obtained from crude oil.

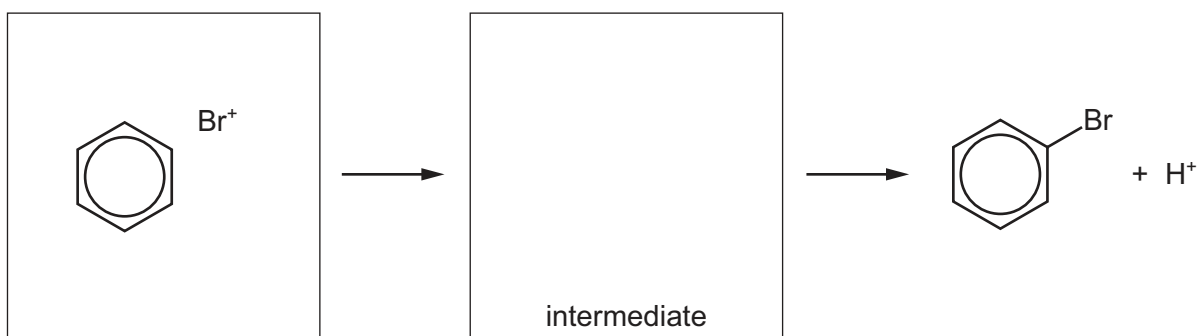
(a) Benzene reacts with bromine, in the presence of a suitable catalyst, forming bromobenzene as one product.

(i) Give the name or formula of the other product of this reaction.

..... [1]

(ii) In the presence of the catalyst, bromine can be considered to form the electrophile Br^+ .

Complete the mechanism by which benzene reacts with Br^+ , using curly arrows to show the movement of electron pairs.



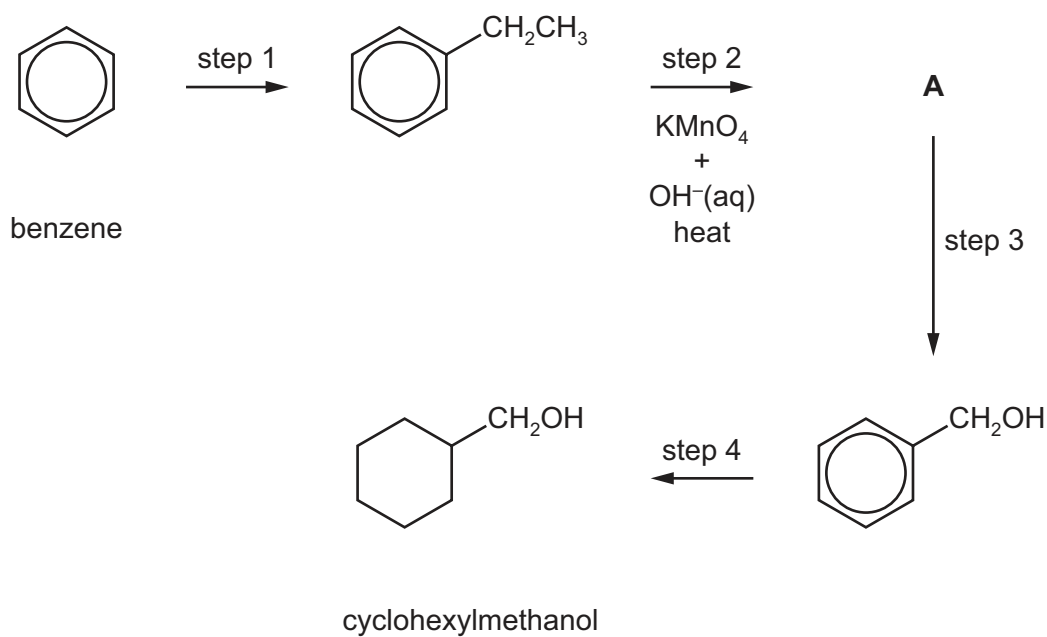
[2]

(iii) Name this mechanism.

..... [1]

16

- (b) Benzene can be used as a starting material in the synthesis of cyclohexylmethanol, $C_6H_{11}CH_2OH$, as outlined below.



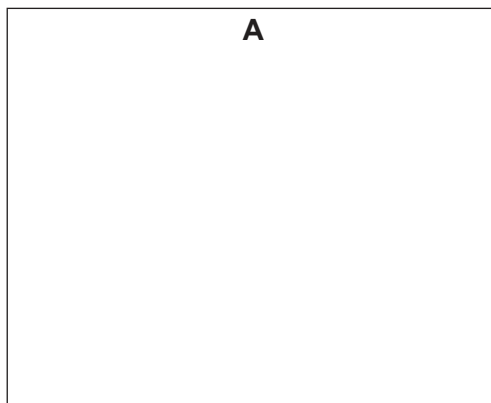
- (i) Identify a suitable reagent and a suitable catalyst for step 1.

reagent

catalyst

[2]

- (ii) Draw the structure of **A**.



[1]

17

(iii) Identify suitable reagents for steps 3 and 4.

step 3

step 4

[2]

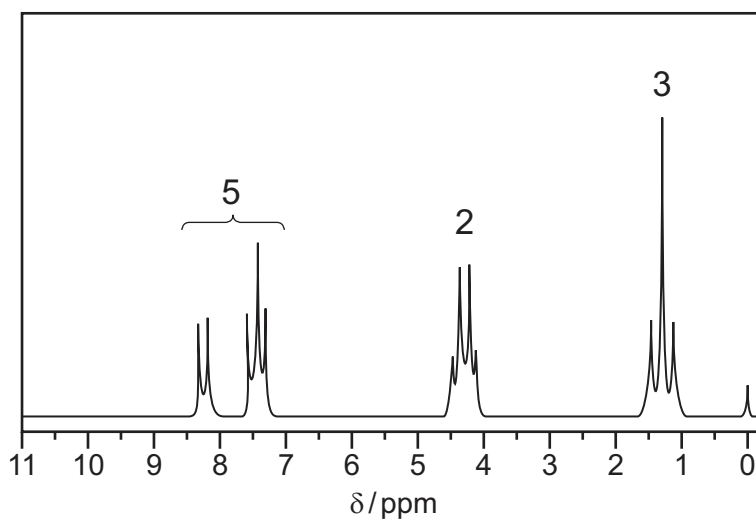
(iv) Deduce the number of peaks in the carbon-13 NMR spectrum of cyclohexylmethanol.

..... [1]

[Total: 10]

18

- 9 The proton NMR spectrum of compound **E** in the solvent CDCl_3 is shown. The molecular formula of compound **E** is $\text{C}_9\text{H}_{10}\text{O}_2$.



- (a) Explain why CDCl_3 is used as a solvent instead of CHCl_3 .

..... [1]

- (b) Explain why TMS is added to give the small peak at chemical shift $\delta = 0$.

..... [1]

- (c) Compound **E** is hydrolysed by hot NaOH(aq) , giving two organic products only. One of these products is ethanol.

Name the functional group in compound **E** that is hydrolysed by hot NaOH(aq) .

..... [1]

- (d) (i) Describe and explain the splitting patterns of the peaks at $\delta = 1.4$ and $\delta = 4.3$.

splitting pattern at $\delta = 1.4$

reason for splitting pattern at $\delta = 1.4$

splitting pattern at $\delta = 4.3$

reason for splitting pattern at $\delta = 4.3$

[2]

- (ii) Each molecule of compound **E** contains five protons which give rise to the peaks between $\delta = 7.0$ and $\delta = 8.5$.

Identify the functional group in compound **E** which contains these protons.

..... [1]

19

(iii) Give the structural formula of compound **E**.

[1]

(e) The mass spectrum of compound **E** includes fragment ions with m/e values of 29 and 77.

Give the formulae of these fragment ions.

fragment ion with $m/e = 29$

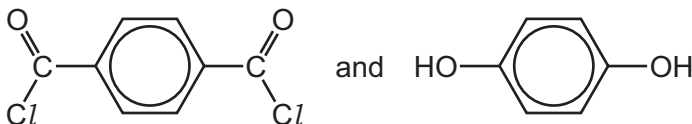
fragment ion with $m/e = 77$

[2]

[Total: 9]

- 10 (a)** The table shows three pairs of monomers that are capable of polymerisation.

Complete the table by identifying each type of polymerisation.

pair of monomers	type of polymerisation
$\text{HOCH}_2\text{CH}_2\text{OH}$ and $\text{HO}_2\text{CCH}_2\text{CO}_2\text{H}$	
	
CH_3CHCF_2 and CH_3CHCH_2	

[1]

- (b)** 2-aminopropanoic acid, $\text{CH}_3\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, can polymerise under suitable conditions. No other monomer is involved in this reaction.

- (i)** Draw a section of the polymer chain formed including **three** monomer residues. Clearly identify **one** repeat unit on your diagram.

[3]

- (ii)** 2-aminopropanoic acid, $\text{CH}_3\text{CH}(\text{NH}_2)\text{CO}_2\text{H}$, exists as two stereoisomers.

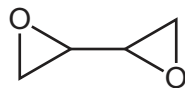
Draw three-dimensional diagrams to show the two stereoisomers of 2-aminopropanoic acid. State the type of stereoisomerism shown.

type of stereoisomerism

[2]

21

(c) The skeletal formula of compound **W** is shown.



When **W** is mixed with a second compound, called a hardener, a polymerisation reaction occurs, producing a non-solvent-based adhesive.

(i) Give the name of this type of non-solvent-based adhesive.

..... [1]

(ii) The hardener is a diamine. A diamine has an alkyl chain with two amine groups which are not bonded to the same carbon atom.

Draw the structural formula of a compound that would make a suitable hardener.

[1]

[Total: 8]

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