Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME									
CENTRE NUMBER						CANDIDATE NUMBER				

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 [ ].

This document has **24** pages. Blank pages are indicated.

[Turn over

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

1 Nitrogen monoxide, NO, reacts with oxygen to form nitrogen dioxide, NO_2.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

The rate equation for the forward reaction is shown.

$$\text{rate} = k[NO]^2[O_2]$$

(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 = ... units = ...
[2]

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

[NO] = ... mol dm^{-3} [1]

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

..... [1]

(d) Peroxodisulfate ions, $S_2O_8^{2-}$, react with iodide ions, I^-.

$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2$$

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

$$\text{rate} = k[S_2O_8^{2-}][I^-]$$

(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, $[I^-] = 0.00780\,\text{mol}\,\text{dm}^{-3}$. Under the conditions used, the half-life of $[I^-]$ is 48 seconds.

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

iodide ion concentration = ... $\text{mol}\,\text{dm}^{-3}$ [1]

[Total: 8]

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.

ΔH_{latt}MgO(s) = ... kJ mol^{-1}

ΔH_{latt}BaO(s) = ... 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]

(c) Use the following data and relevant data from the *Data Booklet* to calculate a value for the lattice energy of magnesium fluoride, $MgF_2(s)$.

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

electron affinity of F(g)	$= -348\,kJ\,mol^{-1}$
enthalpy change of atomisation of Mg(s)	$= +147\,kJ\,mol^{-1}$
enthalpy change of formation of $MgF_2(s)$	$= -1102\,kJ\,mol^{-1}$

$\Delta H_{latt} MgF_2(s)$ = ... [3]

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

.....

..... [2]

(ii) The electron affinity of carbon, C(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]

3 **(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, $Na_2SO_4(aq)$.

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 4.50 A.

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]

(c) The equation representing the standard electrode potential, $E^{\ominus}$, for the reduction of $MnO_4^-(aq)$ to $Mn^{2+}(aq)$ in acid solution is given.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l) \qquad E^{\ominus} = +1.52\,V$$

(i) Draw a diagram of the apparatus that would be used to measure the $E^{\ominus}$ 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]

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 mol dm^{-3} NaOH(aq).

pH = ... [1]

(b) The K_a value of chloric(I) acid, HC*l*O, is 3.72×10^{-8} mol dm^{-3}.

Calculate the pH of 0.010 mol dm^{-3} HC*l*O(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 $CuSO_4 \cdot 5H_2O$ in an excess of aqueous ammonia. This solution contains the copper complex $[Cu(NH_3)_4]^{2+}$.

(a) (i) Write an expression for the K_{stab} of $[Cu(NH_3)_4]^{2+}$.

K_{stab} =

[1]

(ii) State the colour of the solution of $[Cu(NH_3)_4]^{2+}$.

..... [1]

The solution of $[Cu(NH_3)_4]^{2+}$ 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 $Cu(OH)_2$ forms and is collected.

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

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

$[Cu(NH_3)_4]^{2+}$, **Y** and **Z** are different colours.

(b) Suggest an equation for the reaction of $[Cu(NH_3)_4]^{2+}$ to form $Cu(OH)_2$ as the aqueous solution of $[Cu(NH_3)_4]^{2+}$ is heated.

..... [1]

(c) Suggest an equation for the reaction of $Cu(OH)_2$ 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]

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

.....

.....

.....

.....

.....

.....

.....

..... [5]

[Total: 12]

6 **(a)** When 1.0 mol dm^{-3} $Na_2S_2O_3$(aq) is added to a solution containing Ag^+(aq) ions, a linear complex, **P**, is formed. $S_2O_3^{2-}$ 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 mol dm^{-3} NaCN(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 NaCN(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]

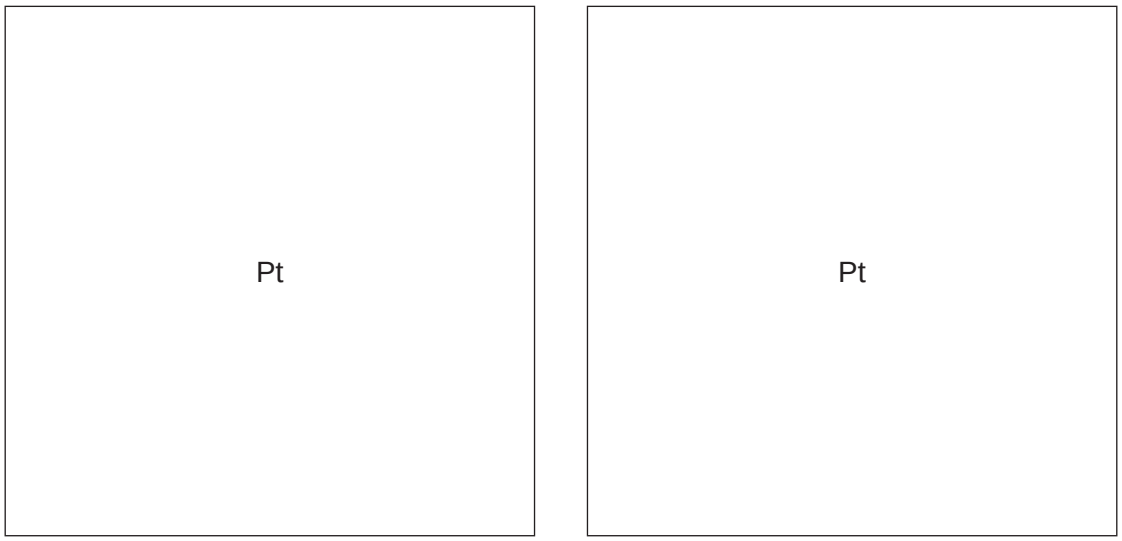
(iii) Name the type of reaction in which **P** forms **Q**.

..... [1]

(c) Platinum forms a complex ion with the formula $[Pt(CN)_2Cl_2]^{2-}$. 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 $[Pt(CN)_2Cl_2]^{2-}$.

..... [1]

(iii) Name the type of stereoisomerism shown by $[Pt(CN)_2Cl_2]^{2-}$.

..... [1]

[Total: 9]

7 Phenol, C_6H_5OH, is a weak acid.

(a) Phenol can be made from phenylamine, $C_6H_5NH_2$.

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 $C_6H_5NO_3$.

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]

(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]

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

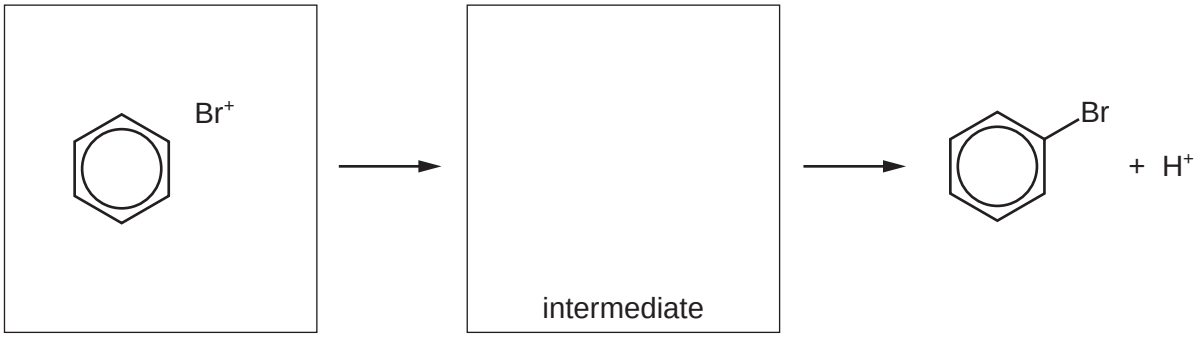
(a) Benzene reacts with bromine, in the presence of a suitable catalyst, forming bromobenzene as one product.

(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.

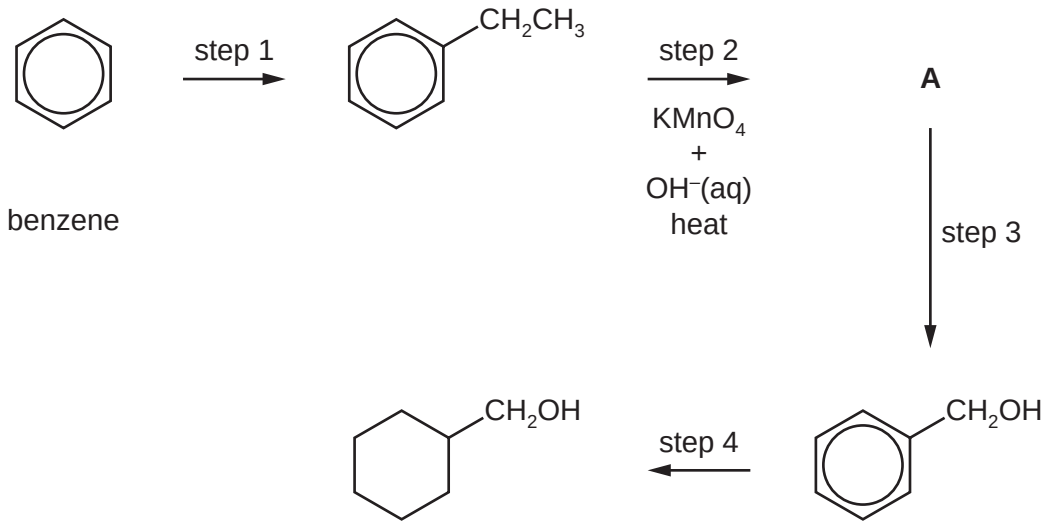


[2]

(iii) Name this mechanism.

..... [1]

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



cyclohexylmethanol

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

reagent .....

catalyst .....

[2]

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

A

[1]

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

step 3 .....

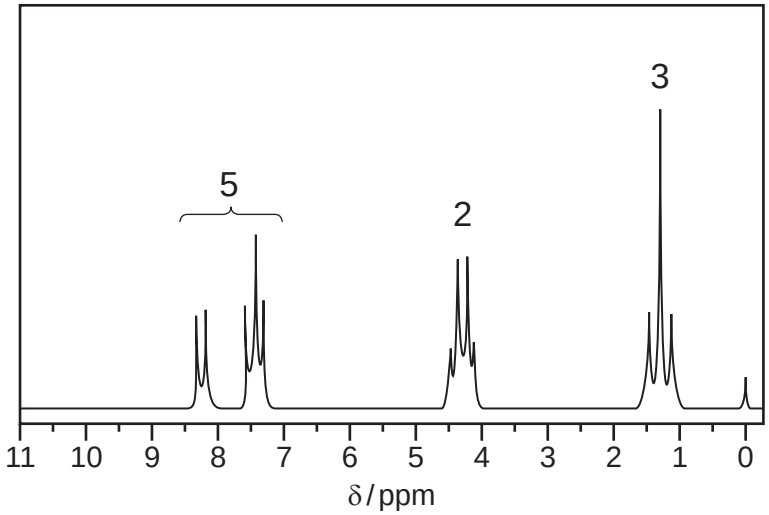
step 4 .....
[2]

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

..... [1]

[Total: 10]

9 The proton NMR spectrum of compound **E** in the solvent $CDCl_3$ is shown. The molecular formula of compound **E** is $C_9H_{10}O_2$.



(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]

(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 .....

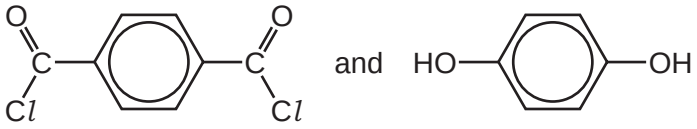
fragment ion with *m*/*e* = 77 .....

[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
$HOCH_2CH_2OH$ and $HO_2CCH_2CO_2H$	
	
CH_3CHCF_2 and CH_3CHCH_2	

[1]

(b) 2-aminopropanoic acid, $CH_3CH(NH_2)CO_2H$, 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]

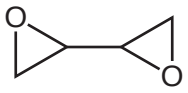
(ii) 2-aminopropanoic acid, $CH_3CH(NH_2)CO_2H$, exists as two stereoisomers.

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

type of stereoisomerism .....

[2]

(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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