



Cambridge International AS & A Level

CANDIDATE
NAME
CENTRE
NUMBER

--	--	--	--	--

CANDIDATE
NUMBER

--	--	--	--

**CHEMISTRY****9701/41**

Paper 4 A Level Structured Questions

May/June 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 **20** pages. Blank pages are indicated.

2

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

- 1 (a) An aqueous solution of cobalt(II) contains the $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ion.

- (i) Define the term *complex ion*.

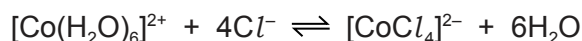
.....
 [1]

- (ii) Samples of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with aqueous sodium hydroxide and with an excess of aqueous ammonia.

Give the following information about these reactions.

- the reaction of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ with aqueous sodium hydroxide
 colour and state of the cobalt-containing species
 ionic equation
 type of reaction
- the reaction of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous ammonia
 colour and state of the cobalt-containing species
 ionic equation
 type of reaction [6]

- (b) When concentrated hydrochloric acid is added to a solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$, a blue solution of $[\text{CoCl}_4]^{2-}$ is formed and the following equilibrium is established.



Use Le Chatelier's principle to suggest the expected observations when silver nitrate solution is added dropwise to the blue solution of $[\text{CoCl}_4]^{2-}$. Explain your answer.

.....

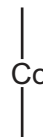
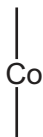
 [2]

3

(c) The $[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$ complex shows stereoisomerism.

Complete the three-dimensional diagrams to show the two isomers of $[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$.

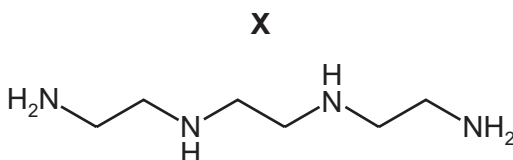
Suggest the type of stereoisomerism.



type of stereoisomerism

[2]

(d) Compound **X**, $\text{C}_6\text{H}_{18}\text{N}_4$, is a tetradentate ligand.



(i) Suggest why one molecule of **X** can form four dative bonds.

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

(ii) $\text{C}_6\text{H}_{18}\text{N}_4$ reacts with aqueous cobalt(II) ions, $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$, in a 1:1 ratio to form a new complex ion.

Construct an equation for this reaction.

..... [1]

[Total: 13]

4

- 2 (a) (i) Describe and explain the trend in the solubility of the Group 2 hydroxides down the group.

.....

.....

.....

.....

.....

..... [4]

Group 2 hydroxides decompose on heating to give the corresponding metal oxide and water vapour.

- (ii) Suggest which of $\text{Mg}(\text{OH})_2$ and $\text{Sr}(\text{OH})_2$ will decompose at a **lower** temperature.

Explain your answer.

.....

.....

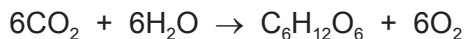
.....

..... [2]

[Total: 6]

5

- 3 The overall reaction for photosynthesis is shown.



Water is oxidised in this process according to the following half-equation.



- (a) (i) Use these equations to deduce the half-equation for the reduction of carbon dioxide in this process.

[2]

- (ii) Draw a fully labelled diagram of the apparatus that should be used to measure the standard electrode potential, E° , of $\text{O}_2(\text{g})$ in half-equation 1 under standard conditions. Include all necessary chemicals.

[4]

- (iii) For the cell drawn in (a)(ii), use the *Data Booklet* to calculate the E°_{cell} and deduce which electrode is positive.

$$E^\circ_{\text{cell}} = \dots\dots\dots \text{V}$$

identity of the positive electrode =
[1]

[Total: 7]

6

- 4 (a) The molecular formulae of three nitrogen-containing compounds are given.

S $\text{C}_6\text{H}_5\text{CONH}_2$

T $\text{C}_6\text{H}_5\text{NH}_2$

U $\text{C}_6\text{H}_5\text{CH}_2\text{NH}_2$

Describe and explain the relative basicities of **S**, **T** and **U**.

..... > >
 most basic least basic

.....

.....

.....

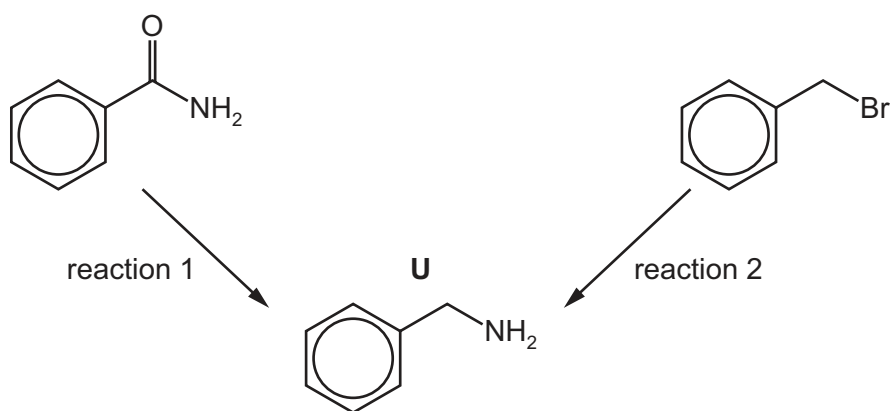
.....

.....

.....

[3]

- (b) Compound **U** can be prepared by two different methods as shown.



- (i) Suggest reagents and conditions for reaction 1 and for reaction 2.

reaction 1

reaction 2

[2]

- (ii) State the type of reaction in reaction 1 and name the mechanism in reaction 2.

type of reaction in reaction 1

mechanism of reaction 2

[2]

[Total: 7]

7

- 5 (a)** Benzene reacts with bromine in the presence of an aluminium bromide catalyst, AlBr_3 , to form bromobenzene. This is a substitution reaction. No addition reaction takes place.

(i) Explain why no addition reaction takes place.

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

AlBr_3 reacts with bromine to generate an electrophile, Br^+ .

(ii) Draw the mechanism of the reaction between benzene and Br^+ ions. Include all relevant arrows and charges.

[3]

(iii) Write an equation to show how the AlBr_3 catalyst is reformed.

..... [1]

(b) Suggest why bromination of phenol occurs more readily than bromination of benzene.

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

8

- (c) (i) There are four different carbocations with the same formula, $C_4H_9^+$. One structure is given in the table.

Suggest the structural formulae of the three other carbocations.

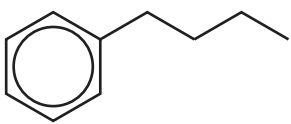
structure 1	structure 2	structure 3	structure 4
$CH_3CH_2CH_2CH_2^+$			

[3]

- (ii) Benzene reacts with each of these carbocations in separate Friedel-Crafts alkylation reactions.

In each reaction an organic compound with formula $C_{10}H_{14}$ is formed. The number of peaks observed in the carbon-13 NMR spectrum of each compound is given.

Suggest the structures for the three other compounds.

	
number of peaks in carbon-13 NMR = 8	number of peaks in carbon-13 NMR = 6
number of peaks in carbon-13 NMR = 7	number of peaks in carbon-13 NMR = 8

[4]

[Total: 14]

9

- 6 (a) Compare and explain the relative acidities of 2-chloropropanoic acid, 3-chloropropanoic acid, and propanoic acid. Explain your answer.

..... > >
 most acidic least acidic

explanation

.....

.....

.....

.....

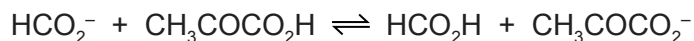
.....

[3]

- (b) (i) The numerical values of K_a for methanoic acid, HCO_2H , and pyruvic acid, $\text{CH}_3\text{COCO}_2\text{H}$, are given.

acid	K_a
HCO_2H	1.78×10^{-4}
$\text{CH}_3\text{COCO}_2\text{H}$	4.07×10^{-3}

An equilibrium mixture containing the two acid-base pairs is formed.



Use the K_a values to calculate the equilibrium constant, K_{eq} , for this equilibrium.

$K_{\text{eq}} = \dots\dots\dots$ [1]

- (ii) Use your value of K_{eq} to predict the position of this equilibrium. Indicate this by placing a tick (✓) in the appropriate box in the table. Explain your answer.

equilibrium lies to the left	equilibrium lies in the middle	equilibrium lies to the right

.....

.....

[1]

10

- (iii) Ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$, has two dissociation constants, $K_{\text{a}1}$ and $K_{\text{a}2}$, whose $\text{p}K_{\text{a}}$ values are 1.23 and 4.19.

Suggest equations to show the two dissociations that give rise to these $\text{p}K_{\text{a}}$ values.

$\text{p}K_{\text{a}1}$ 1.23

$\text{p}K_{\text{a}2}$ 4.19

[2]

- (iv) State the mathematical relationship between $\text{p}K_{\text{a}}$ and the acid dissociation constant K_{a} .

..... [1]

- (c) Three tests were carried out on separate samples of the organic acids shown in the table. The following results were obtained.

✓ = observed change

x = no observed reaction

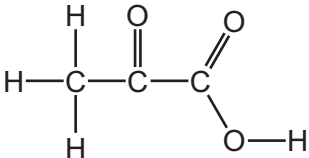
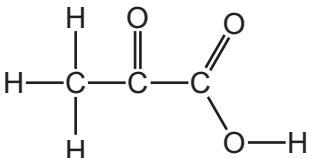
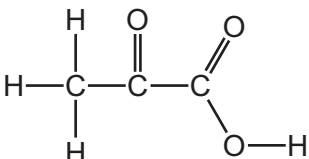
test	reagent(s) and conditions	HCO_2H	$\text{CH}_3\text{COCO}_2\text{H}$	$\text{HO}_2\text{CCO}_2\text{H}$	observed change
1		✓	x	x	
2		x	✓	x	
3		✓	x	✓	

Complete the table with the reagent(s) and conditions and the observed change for each test. Assume these organic acids all have a similar acid strength. [5]

- (d) A sample of pyruvic acid, $\text{CH}_3\text{COCO}_2\text{H}$, is analysed by carbon-13 NMR spectroscopy. Three peaks are observed.

Complete the table by:

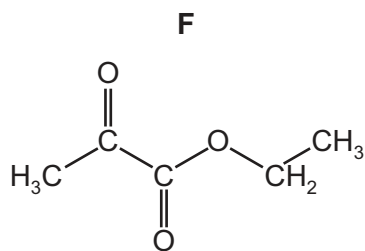
- circling the carbon atom responsible for the chemical shift
- stating the hybridisation of the circled carbon atom.

chemical shift (δ)	carbon atom responsible for chemical shift	hybridisation of the circled carbon atom
27		
163		
192		

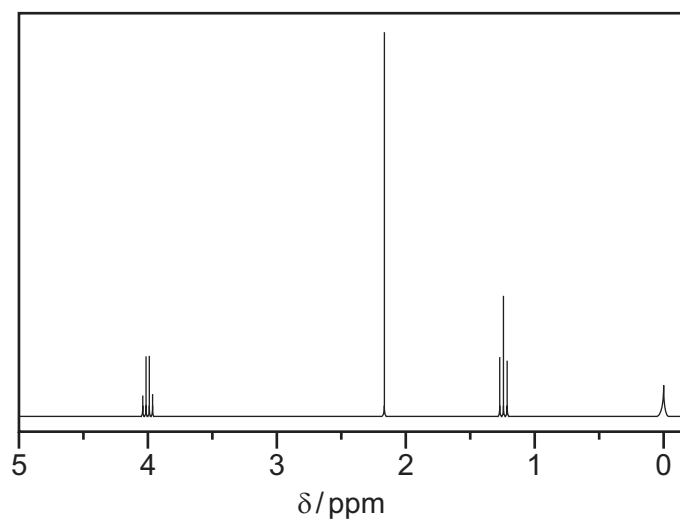
[2]

12

(e) An ester of pyruvic acid, **F**, is dissolved in CDCl_3 and analysed by proton NMR spectroscopy.



The proton NMR spectrum of **F** is shown.



Use the proton NMR spectrum of **F** to complete the table.

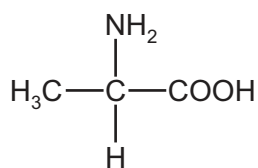
chemical shift (δ)	group responsible for the peak	splitting pattern	number of ^1H atoms responsible for the peak
1.3			
2.2			
4.0			

[3]

13

- (f) Deuterium oxide, D_2O , where D is 2H , can be used as a solvent in proton NMR spectroscopy. The proton NMR spectrum of alanine in $CDCl_3$ has 4 peaks. The proton NMR spectrum of alanine in D_2O has 2 peaks.

alanine



On the diagram of alanine, circle the protons that show peaks in **both** NMR spectra. Explain your answer.

.....

 [2]

- (g) The ionic product, K_w , for D_2O has a value of $1.35 \times 10^{-15} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K.

- (i) Write the expression for the K_w of D_2O .

$$K_w =$$

[1]

- (ii) Calculate the pH of pure, neutral D_2O at 298 K. Assume $[D^+]$ is equivalent to $[H^+]$ for pH calculations.

pH = [2]

[Total: 23]

14

- 7 (a) Silver carbonate, Ag_2CO_3 , is sparingly soluble in water. The numerical value of the solubility product, K_{sp} , for silver carbonate is 6.3×10^{-12} at 25°C .

(i) Write an expression for the solubility product, K_{sp} , of Ag_2CO_3 , and state its units.

$$K_{\text{sp}} =$$

units =

[2]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2CO_3 at 25°C .

$$[\text{Ag}^+] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

(iii) Solid Ag_2CO_3 is stirred at 25°C with $0.050 \text{ mol dm}^{-3} \text{ AgNO}_3$ until no more Ag_2CO_3 dissolves.

Calculate the concentration of carbonate ions, $[\text{CO}_3^{2-}]$, in this solution.

$$[\text{CO}_3^{2-}] = \dots\dots\dots \text{mol dm}^{-3} \quad [1]$$

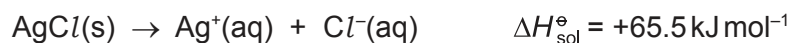
(iv) An electrochemical cell is set up to measure the electrode potential, E , for the Ag^+/Ag half-cell using the saturated $\text{Ag}_2\text{CO}_3(\text{aq})$ with a standard hydrogen electrode.

Use the *Data Booklet*, your answer to (a)(ii), and the Nernst equation to calculate the electrode potential, E , for this Ag^+/Ag half-cell.

$$E \text{ for } \text{Ag}^+/\text{Ag} \text{ half-cell} = \dots\dots\dots \text{V} \quad [2]$$

15

- (b) Silver chloride, AgCl , is sparingly soluble in water. The equation for the enthalpy change of solution is shown.



Standard entropies are shown in the table.

species	AgCl(s)	$\text{Ag}^+(\text{aq})$	$\text{Cl}^-(\text{aq})$
$S^{\circ} / \text{JK}^{-1} \text{mol}^{-1}$	+96.2	+72.7	+56.5

- (i) Calculate the standard entropy change of solution, ΔS° .

$$\Delta S^{\circ} = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1} \quad [1]$$

- (ii) Explain, with the aid of a calculation, why AgCl is insoluble in water at 25°C .

You should use data from this question and your answer to (b)(i).

.....
 [3]

[Total: 10]

16

- 8 (a) Explain what is meant by the term *buffer solution*.

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

- (b) (i) Write an expression for the acid dissociation constant, K_a , for ammonium ions, $\text{NH}_4^+(\text{aq})$.

$$K_a =$$

[1]

- (ii) Write **two** equations to describe how a solution containing ammonium ions, $\text{NH}_4^+(\text{aq})$, and ammonia, $\text{NH}_3(\text{aq})$, can act as a buffer.

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

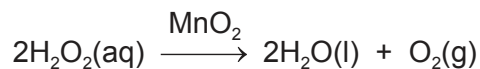
- (iii) The numerical value of K_a for $\text{NH}_4^+(\text{aq})$ is 5.6×10^{-10} at 298 K.
A buffer solution was prepared by adding 0.80 dm^3 of 0.25 mol dm^{-3} ammonia, an excess, to 0.20 dm^3 of 0.20 mol dm^{-3} hydrochloric acid.

Calculate the pH of the buffer solution formed at 298 K.

pH = [3]

[Total: 8]

- 9 (a) Manganese(IV) oxide, MnO_2 , catalyses the decomposition of hydrogen peroxide, H_2O_2 , as shown.



The mechanism involves the formation of the intermediate species, Mn^{2+} , in the first step which is subsequently used up in the second step.

State and use relevant electrode potentials, $E^\ominus$, to construct **two** equations to show how MnO_2 can catalyse this reaction.

.....

.....

.....

.....

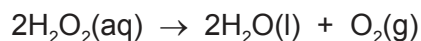
.....

equation 1

equation 2

[3]

- (b) The equation for the decomposition of hydrogen peroxide without a catalyst is shown.

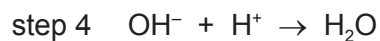
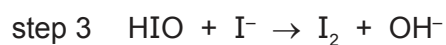
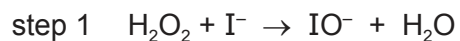


Under certain conditions this reaction is found to be first order with respect to hydrogen peroxide, with a rate constant, k , of $2.0 \times 10^{-6} \text{ s}^{-1}$ at 298 K.

Calculate the initial rate of decomposition of a 0.75 mol dm^{-3} hydrogen peroxide solution at 298 K.

initial rate = $\text{mol dm}^{-3} \text{ s}^{-1}$ [1]

- (c) A four-step mechanism is suggested for the reaction between hydrogen peroxide and iodide ions in an acidic solution.



Step 1 is the rate-determining step.

- (i) State what is meant by the term *rate-determining step*.

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

- (ii) Use this mechanism to construct a balanced equation for this reaction.

..... [1]

- (iii) Deduce the order of reaction with respect to each of the following.

$\text{H}_2\text{O}_2 =$ $\text{I}^- =$ $\text{H}^+ =$ [1]

[Total: 7]

19

10 (a) The electronic configuration of transition element **Q** is $[\text{Ar}] 3d^2 4s^2$.

Predict the likely oxidation states of element **Q** in compounds.

..... [1]

(b) Suggest why transition elements often show variable oxidation states in their compounds, but typical s-block elements such as calcium do not.

.....

..... [1]

(c) Many enzymes contain transition element complexes.

Describe, with the aid of a suitably labelled diagram, how an enzyme catalyses the breakdown of a substrate molecule.

.....

.....

.....

..... [3]

[Total: 5]

BLANK PAGE

Permission to reproduce items where third-party owned material protected by copyright is included has been sought and cleared where possible. Every reasonable effort has been made by the publisher (UCLES) to trace copyright holders, but if any items requiring clearance have unwittingly been included, the publisher will be pleased to make amends at the earliest possible opportunity.

To avoid the issue of disclosure of answer-related information to candidates, all copyright acknowledgements are reproduced online in the Cambridge Assessment International Education Copyright Acknowledgements Booklet. This is produced for each series of examinations and is freely available to download at www.cambridgeinternational.org after the live examination series.

Cambridge Assessment International Education is part of the Cambridge Assessment Group. Cambridge Assessment is the brand name of the University of Cambridge Local Examinations Syndicate (UCLES), which itself is a department of the University of Cambridge.