Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER						CANDIDATE NUMBER				

CHEMISTRY **9701/31**

Paper 3 Advanced Practical Skills 1 **May/June 2024**

2 hours

You must answer on the question paper.

You will need: The materials and apparatus listed in the confidential instructions

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 and use appropriate units.

INFORMATION

- The total mark for this paper is 40.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.
- Notes for use in qualitative analysis are provided in the question paper.

Session
Laboratory

For Examiner's Use	
1	
2	
3	
Total	

This document has **12** pages.

[Turn over

Quantitative analysis

Read through the whole method before starting any practical work. Where appropriate, prepare a table for your results in the space provided.

Show the precision of the apparatus you used in the data you record.

Show your working and appropriate significant figures in the final answer to **each** step of your calculations.

1 In this experiment you will determine the enthalpy change, ΔH_r, for the reaction shown.

$$NaOH(aq) + CO_2(g) \rightarrow NaHCO_3(aq) \qquad \text{enthalpy change} = \Delta H_r$$

You will react each of sodium hydroxide and sodium hydrogencarbonate with excess dilute sulfuric acid. You will determine the enthalpy change for each reaction, then use Hess's law to calculate ΔH_r.

(a) Reaction of sodium hydroxide with sulfuric acid

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) \qquad \text{enthalpy change} = \Delta H_1$$

FA 1 is 2.00 mol dm^{-3} sodium hydroxide, NaOH.
FA 2 is 2.00 mol dm^{-3} sulfuric acid, H_2SO_4.

Method

- Support a cup in the 250 cm^3 beaker.
- Use the 50 cm^3 measuring cylinder to transfer 30.0 cm^3 of **FA 1** into the cup.
- Place the thermometer in **FA 1** and tilt the cup, if necessary, so that the bulb of the thermometer is fully covered. Record the temperature of **FA 1**.
- Use the 25 cm^3 measuring cylinder to add 20.0 cm^3 of **FA 2** to the **FA 1** in the cup.
- Stir the mixture.
- Measure and record the maximum temperature reached.
- Calculate and record the change in temperature.

Results

I	
II	

[2]

(b) Calculations

(i) Calculate the energy change, in J, in your experiment.

energy change = ... J [1]

(ii) Calculate the amount, in mol, of sulfuric acid that reacted with **FA 1** in your experiment.

amount of H_2SO_4 = ... mol [1]

(iii) Calculate the enthalpy change of reaction, ΔH_1, in $kJ\,mol^{-1}$ of sulfuric acid, for the neutralisation of NaOH(aq) with H_2SO_4(aq).
Show your working.

ΔH_1 = ... $kJ\,mol^{-1}$ of H_2SO_4 [1]
sign *value*

(c) **Reaction of sodium hydrogencarbonate with sulfuric acid**

$2NaHCO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$ enthalpy change = ΔH_2

FA 2 is $2.00\,mol\,dm^{-3}$ sulfuric acid, H_2SO_4.
FA 3 is sodium hydrogencarbonate, $NaHCO_3$.

Method

- Support the other cup in the $250\,cm^3$ beaker.
- Use the $25\,cm^3$ measuring cylinder to transfer $25.0\,cm^3$ of **FA 2** into the cup.
- Place the thermometer in **FA 2** and tilt the cup, if necessary, so that the bulb of the thermometer is fully covered. Record the temperature of **FA 2**.
- Weigh the container with **FA 3**. Record the mass.
- Adding **small** quantities at a time, tip all the **FA 3** from the container into the **FA 2** in the cup.
- Stir the mixture.
- Measure and record the minimum temperature reached.
- Calculate and record the change in temperature.
- Weigh the container with any residual **FA 3**. Record the mass.
- Calculate and record the mass of **FA 3** added.

Results

I	
II	
III	

[3]

(d) **Calculations**

Use your data to calculate the enthalpy change, ΔH_2, in kJ mol^{-1} of sulfuric acid, for the reaction of $NaHCO_3(s)$ with $H_2SO_4(aq)$.
Show your working.

ΔH_2 = ... kJ mol^{-1} of H_2SO_4 [3]
sign *value*

(e) The enthalpy change when one mole of sodium hydrogencarbonate dissolves in water is ΔH_3.

$NaHCO_3(s) + aq \rightarrow NaHCO_3(aq)$ enthalpy change = ΔH_3

Using the symbols ΔH_1, ΔH_2 and ΔH_3 in your answer, use Hess's law to deduce an expression for ΔH_r.

$NaOH(aq) + CO_2(g) \rightarrow NaHCO_3(aq)$ enthalpy change = ΔH_r

ΔH_r = ... kJ mol^{-1} [1]

(f) A student suggested that the experiment in **(c)** would be more accurate if $25.0\,cm^3$ of $3.00\,mol\,dm^{-3}$ sulfuric acid was used instead of $25.0\,cm^3$ of $2.00\,mol\,dm^{-3}$ sulfuric acid.

State whether the student's suggestion is correct.

Explain your answer.

....

....

.... [1]

[Total: 13]

2 Sodium sulfite is oxidised when it reacts with excess iodine.

$$Na_2SO_3(aq) + I_2(aq) + H_2O(l) \rightarrow Na_2SO_4(aq) + 2HI(aq)$$

The remaining iodine is then titrated using aqueous sodium thiosulfate.

$$I_2(aq) + 2Na_2S_2O_3(aq) \rightarrow Na_2S_4O_6(aq) + 2NaI(aq)$$

You will determine the integer value of *x* in the formula of hydrated sodium sulfite, $Na_2SO_3 \bullet xH_2O$, by titration.

FA 4 is aqueous sodium thiosulfate containing 14.24 g of $Na_2S_2O_3$ in 1.00 dm^3.

FA 5 is aqueous iodine, prepared as shown.
- 5.00 g of hydrated sodium sulfite is added to 600 cm^3 of 0.100 mol dm^{-3} aqueous iodine.
- The mixture is allowed to stand to ensure that all the sodium sulfite has been oxidised.
- The mixture containing the remaining iodine is made up to 1.00 dm^3 with distilled water.

FA 6 is starch indicator.

(a) Method

- Fill the burette with **FA 4**.
- Pipette 25.0 cm^3 of **FA 5** into a conical flask.
- Add **FA 4** from the burette into the conical flask until the colour of the solution changes to yellow.
- Add 10 drops of **FA 6** to the conical flask. Continue titrating until the blue-black colour just disappears.
- Perform a rough titration and record your burette readings in the space below.

The rough titre is .... cm^3.

- Carry out as many accurate titrations as you think necessary to obtain consistent results.
- Make sure any recorded results show the precision of your practical work.
- Record, in a suitable form in the space below, all your burette readings and the volume of **FA 4** added in each accurate titration.

I	
II	
III	
IV	
V	
VI	
VII	

[7]

(b) From your accurate titration results, calculate a suitable mean value to use in your calculations. Show clearly how you obtain the mean value.

25.0 cm^3 of **FA 5** required .... cm^3 of **FA 4**. [1]

(c) **Calculations**

(i) Give your answers to **(c)(ii)**, **(c)(iii)**, **(c)(iv)** and **(c)(v)** to an appropriate number of significant figures. [1]

(ii) Calculate the amount, in mol, of sodium thiosulfate present in the volume of **FA 4** in **(b)**.

amount of $Na_2S_2O_3$ = ... mol [1]

(iii) Calculate the amount, in mol, of iodine in 1.00 dm^3 of **FA 5**.

amount of I_2 in 1.00 dm^3 = ... mol [1]

(iv) Use the information given and your answer to **(c)(iii)** to calculate the amount, in mol, of iodine that reacted with sodium sulfite when solution **FA 5** was prepared.

amount of I_2 reacted with sodium sulfite = ... mol [1]

(v) Use your answer to **(c)(iv)** to calculate the relative formula mass, M_r, of hydrated sodium sulfite.

M_r of $Na_2SO_3 \bullet xH_2O$ = ... [1]

(vi) Calculate the value of *x*.

Show your working.

x = ... [1]

[Total: 14]

Qualitative analysis

For each test you should record all your observations in the spaces provided.

Examples of observations include:

- colour changes seen
- the formation of any precipitate and its solubility (where appropriate) in an excess of the reagent added
- the formation of any gas and its identification (where appropriate) by a suitable test.

You should record clearly at what stage in a test an observation is made.

Where no change is observed, you should write ‘no change’.

Where reagents are selected for use in a test, the name or correct formula of the element or compound must be given.

If any solution is warmed, a boiling tube must be used. If a solid is heated, a hard-glass test-tube must be used.

Rinse and reuse test-tubes and boiling tubes where possible.

No additional tests should be attempted.

3 **(a)** **FA 7**, **FA 8** and **FA 9** are dilute ethanoic acid, dilute hydrochloric acid and aqueous silver nitrate but **not** necessarily in that order. The solutions of acids have equal concentrations.

(i) You are supplied with strips of magnesium ribbon.
You must **not** use any other reagents in this part of the question.

Carry out tests to identify each of the three solutions, **FA 7**, **FA 8** and **FA 9**.
Obtain as much evidence as you can for your identifications.
Use a 1 cm depth of solution in a test-tube for each test you carry out.

Record all your observations.

FA 7 is .... **FA 8** is .... **FA 9** is ....
[5]

(ii) Give the ionic equation for the reaction of magnesium with **FA 8**. Include state symbols.

.... [1]

(b) **FA 10** and **FA 11** are both aqueous solutions of salts, each of which contains one cation and one anion listed in the Qualitative analysis notes.

(i) Carry out the following tests and record your observations in Table 3.1.

For Tests 1 and 2, use a 1 cm depth of **FA 10** or **FA 11** in a test-tube.
For Test 3, use a 1 cm depth of **FA 10** or **FA 11** in a boiling tube.

Table 3.1

test	*observations*	
	FA 10	**FA 11**
Test 1 Add aqueous ammonia.		
Test 2 Add a few drops of aqueous barium chloride or aqueous barium nitrate, then		
add dilute hydrochloric acid.		
Test 3 Add aqueous sodium hydroxide, then		
warm the mixture carefully, then		
add one piece of aluminium foil.		

[5]

(ii) Use your observations in **(b)(i)** to complete Table 3.2 by identifying the formulae of the ions present in **FA 10** and **FA 11**.
If you cannot identify an ion write ‘unknown’.

Table 3.2

	cation	anion
FA 10		
FA 11		

[2]

[Total: 13]

Qualitative analysis notes

1 Reactions of cations

cation	reaction with	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	no ppt. ammonia produced on warming	–
barium, Ba^{2+}(aq)	faint white ppt. is observed unless [Ba^{2+}(aq)] is very low	no ppt.
calcium, Ca^{2+}(aq)	white ppt. unless [Ca^{2+}(aq)] is very low	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	pale blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

2 Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^-(aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^-(aq)	gives cream / off-white ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^-(aq)	gives pale yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^-(aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; decolourises acidified aqueous $KMnO_4$
sulfate, SO_4^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids); gives white ppt. with high [Ca^{2+}(aq)]
sulfite, SO_3^{2-}(aq)	gives white ppt. with Ba^{2+}(aq) (soluble in excess dilute strong acids); decolourises acidified aqueous $KMnO_4$
thiosulfate, $S_2O_3^{2-}$(aq)	gives off-white / pale yellow ppt. slowly with H^+

3 Tests for gases

gas	**test and test result**
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater
hydrogen, H_2	‘pops’ with a lighted splint
oxygen, O_2	relights a glowing splint

4 Tests for elements

element	**test and test result**
iodine, I_2	gives blue-black colour on addition of starch solution

Important values, constants and standards

molar gas constant	$R = 8.31\,J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^4\,C\,mol^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23}\,mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,C$
molar volume of gas	$V_m = 22.4\,dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,kJ\,kg^{-1}\,K^{-1}$ ($4.18\,J\,g^{-1}\,K^{-1}$)

The Periodic Table of Elements

Key

atomic number atomic symbol name relative atomic mass

Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –
