READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Give details of the practical session and laboratory where appropriate, in the boxes provided.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO NOT WRITE IN ANY BARCODES.

Answer all questions.
You are advised to show all working in calculations.
Use of a Data Booklet is unnecessary.

Qualitative Analysis Notes are printed on pages 11 and 12.

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.
You are provided with the following reagents.

- two weighing bottles labelled **FA 1**, each containing between 2.90 g and 3.00 g of zinc powder
- **FA 2**, 0.80 mol dm⁻³ copper sulfate, CuSO₄

You are to determine the enthalpy change, \( \Delta H \), for the following reaction.

\[
\text{Zn(s) + CuSO}_4(\text{aq}) \rightarrow \text{Cu(s) + ZnSO}_4(\text{aq})
\]

You will carry out the experimental procedure twice.

**Read through the instructions below before starting the experiment.**

(a) You will weigh each bottle and later in the experiment weigh it again after the zinc powder has been tipped into copper sulfate solution.

In the space below prepare a table to record the weighings and the mass of zinc powder used in each experiment.

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<table>
<thead>
<tr>
<th>Bottle</th>
<th>Mass Before Zinc</th>
<th>Mass After Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FA 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weigh accurately, to at least one decimal place, one of the weighing bottles labelled **FA 1**.

Record this mass in the table you have prepared.  

[1]

(b) **Procedure**

- Support the plastic cup in the 250 cm³ beaker and, using a pipette, place 25.0 cm³ of **FA 2** into the plastic cup.

- Stir gently, taking a temperature reading every ½ minute until a steady temperature has been obtained for a period of at least 2 minutes. You may need to tilt the beaker in order to cover the bulb of the thermometer with solution.

- On a precise minute reading tip the zinc powder from the weighing bottle into the plastic cup.

  **Do not read the temperature at this time or at the following ½ minute.**

- Continue to stir the mixture thoroughly. Starting 1 minute after the addition of the zinc powder, record the temperature every ½ minute until the temperature has reached a maximum value and then decreased steadily for at least 5 minutes.

- Reweigh the empty weighing bottle. Record the mass of the bottle + any residual zinc powder and the mass of zinc powder used in the experiment in the table you prepared in (a).

- Record your results in an appropriate form in the space on the following page.

Repeat the experiment using the contents of the second weighing bottle and 25.0 cm³ copper sulfate solution pipetted into a clean plastic cup.
(b) continued

**Results** Make certain your readings of temperature display the precision of the apparatus used.

(c) Plot your temperature and time readings separately for each experiment on the grids on the next page. Your temperature axis should extend 10°C **above** the highest temperature you recorded. Draw lines as instructed below.

On each graph draw a horizontal straight line through the steady initial temperature.

Extrapolate the cooling section of each graph back to the time when you added the zinc powder. Draw construction lines on the graphs to deduce the “theoretical” temperature rise at the moment of mixing the reagents.
(d) The “theoretical” temperature rises are .................. °C and .................. °C.

The mean “theoretical” temperature rise is .................. °C. [1]

Calculations

Show working and appropriate significant figures in all of your calculations. [2]

(e) Calculate how many moles of copper sulfate, CuSO\textsubscript{4}, were pipetted into the plastic cup.

\[ \text{mol of CuSO}_4 \text{ were pipetted into the cup} \]

For each experiment calculate how many moles of zinc powder were added to the plastic cup. [A\textsubscript{i}: Zn, 65.4]

<table>
<thead>
<tr>
<th>1\textsuperscript{st} experiment</th>
<th>2\textsuperscript{nd} experiment</th>
</tr>
</thead>
</table>

In the 1\textsuperscript{st} experiment .................. mol of zinc powder were added to the plastic cup.

In the 2\textsuperscript{nd} experiment .................. mol of zinc powder were added to the plastic cup. [1]

(f) Use your answers to (e) and the equation for the reaction to determine which reagent was in excess and which was the limiting reagent. Explain your answer.

\[
\text{Zn(s) + CuSO}_4\text{(aq) } \rightarrow \text{Cu(s) + ZnSO}_4\text{(aq)}
\]

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

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

..................................................................................................................................... [1]
(g) From your mean “theoretical” temperature rise at the time of mixing, calculate the heat energy released in the plastic cup by the reaction of zinc powder with copper sulfate solution.
[You may assume that 4.3 J are required to raise the temperature of 1 cm$^3$ of any solution by 1 °C and that the mass of any solid may be ignored.]

……………… of heat energy are released. [1]

(h) Calculate, correct to 3 significant figures, the enthalpy change in kJ mol$^{-1}$ for the following reaction.

\[
\text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{Cu}(s) + \text{ZnSO}_4(aq)
\]

\[
\Delta H = \text{\hspace{1cm}} \text{kJ mol}^{-1}
\]

[2]

(i) Identify and explain one source of error in the experiment you have carried out.

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

(j) Suggest a way in which the experimental method you used could be improved in a school or college laboratory in order to minimise this error.

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

[Total: 26]
The three boiling-tubes, labelled FA 3, FA 4, and FA 5, each contain a solid with one cation and one anion from those listed on pages 11 and 12.

You will carry out specified tests to deduce the cations and anions present in FA 3, FA 4 and FA 5.

At each stage of any test you are to record details of the following.
- colour changes seen
- the formation of any precipitate
- the solubility of such precipitates in an excess of the reagent added

Where gases are released they should be identified by a test, described in the appropriate place in your observations.

You should indicate clearly at what stage in a test a change occurs. Marks are not given for chemical equations.

**No additional tests for ions present should be attempted.**

If any solution is warmed a boiling-tube MUST be used.

(a) Heat the boiling-tube containing FA 5 gently at first then more strongly. Record your observations in the space below.

(b) In their boiling-tubes, dissolve FA 3, FA 4 and the cold residue after heating FA 5 in a minimum of dilute nitric acid and then add distilled water so that each boiling-tube is approximately ⅔ full. Warm to dissolve if necessary. Record your observations in the space below. Use these solutions for tests (d), (e) and (f).
(c) Which anion can be identified from your observations in (a) and (b)? Explain your answer.

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

(d) The cations present in FA 3, FA 4 and FA 5 can be identified by reaction of each solution with aqueous sodium hydroxide and with aqueous ammonia. React 1 cm depth of each of the solutions prepared in (b) with each of these two reagents.

Record, in an appropriate form in the space below, your observations for these reactions.

Conclusions

Using your observations you should be able to identify the cation present in two of the solutions. For the remaining solution you should be able to identify two possible cations.

FA 3 contains the cation(s) ...........................................

FA 4 contains the cation(s) ...........................................

FA 5 contains the cation(s) ........................................... [6]
(e) Use the information on pages 11 and 12 to select a reagent to distinguish between the two possible cations identified as present in one of the solutions in (d).

Carry out the test with the selected reagent.

reagent ............................................................................................................................
observation ......................................................................................................................
conclusion ........................................................................................................................

(f) Carry out the following tests.

<table>
<thead>
<tr>
<th>test</th>
<th>observations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FA 3</td>
</tr>
<tr>
<td>To 1 cm depth of solution in a test-tube, add 1 cm depth of aqueous barium nitrate, then add 2 cm depth of dilute nitric acid.</td>
<td></td>
</tr>
<tr>
<td>To 1 cm depth of solution in a test-tube, add 1 cm depth of aqueous silver nitrate, then allow any precipitate formed to settle, pour off the solution and add aqueous ammonia to the precipitate.</td>
<td></td>
</tr>
</tbody>
</table>

What conclusions can be made from the observations above?

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

[Total: 14]
Qualitative Analysis Notes

Key: [ppt. = precipitate]

## 1 Reactions of aqueous cations

<table>
<thead>
<tr>
<th>Cation</th>
<th>Reaction with NaOH(aq)</th>
<th>Reaction with NH₃(aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aluminium, Al³⁺(aq)</td>
<td>white ppt. soluble in excess</td>
<td>white ppt. insoluble in excess</td>
</tr>
<tr>
<td>ammonium, NH₄⁺(aq)</td>
<td>no ppt. ammonia produced on heating</td>
<td></td>
</tr>
<tr>
<td>barium, Ba²⁺(aq)</td>
<td>no ppt. (if reagents are pure)</td>
<td>no ppt.</td>
</tr>
<tr>
<td>calcium, Ca²⁺(aq)</td>
<td>white ppt. with high [Ca²⁺(aq)]</td>
<td>no ppt.</td>
</tr>
<tr>
<td>chromium(III), Cr³⁺(aq)</td>
<td>grey-green ppt. soluble in excess giving dark green solution</td>
<td>grey-green ppt. insoluble in excess</td>
</tr>
<tr>
<td>copper(II), Cu²⁺(aq)</td>
<td>pale blue ppt. insoluble in excess giving dark blue solution</td>
<td>blue ppt. soluble in excess giving dark blue solution</td>
</tr>
<tr>
<td>iron(II), Fe²⁺(aq)</td>
<td>green ppt. turning brown on contact with air insoluble in excess</td>
<td>green ppt. turning brown on contact with air insoluble in excess</td>
</tr>
<tr>
<td>iron(III), Fe³⁺(aq)</td>
<td>red-brown ppt. insoluble in excess</td>
<td>red-brown ppt. insoluble in excess</td>
</tr>
<tr>
<td>lead(II), Pb²⁺(aq)</td>
<td>white ppt. soluble in excess</td>
<td>white ppt. insoluble in excess</td>
</tr>
<tr>
<td>magnesium, Mg²⁺(aq)</td>
<td>white ppt. insoluble in excess</td>
<td>white ppt. insoluble in excess</td>
</tr>
<tr>
<td>manganese(II), Mn²⁺(aq)</td>
<td>off-white ppt. rapidly turning brown on contact with air insoluble in excess</td>
<td>off-white ppt. rapidly turning brown on contact with air insoluble in excess</td>
</tr>
<tr>
<td>zinc, Zn²⁺(aq)</td>
<td>white ppt. soluble in excess</td>
<td>white ppt. soluble in excess</td>
</tr>
</tbody>
</table>

[Lead(II) ions can be distinguished from aluminium ions by the insolubility of lead(II) chloride.]
## 2 Reactions of anions

<table>
<thead>
<tr>
<th>ion</th>
<th>reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbonate, $\text{CO}_3^{2-}$</td>
<td>$\text{CO}_2$ liberated by dilute acids</td>
</tr>
<tr>
<td>chromate(VI), $\text{CrO}_4^{2-}$ (aq)</td>
<td>yellow solution turns orange with $\text{H}^+(aq)$; gives yellow ppt. with $\text{Ba}^{2+}(aq)$; gives bright yellow ppt. with $\text{Pb}^{2+}(aq)$</td>
</tr>
<tr>
<td>chloride, $\text{Cl}^-$ (aq)</td>
<td>gives white ppt. with $\text{Ag}^+(aq)$ (soluble in $\text{NH}_3(aq)$); gives white ppt. with $\text{Pb}^{2+}(aq)$</td>
</tr>
<tr>
<td>bromide, $\text{Br}^-$ (aq)</td>
<td>gives pale cream ppt. with $\text{Ag}^+(aq)$ (partially soluble in $\text{NH}_3(aq)$); gives white ppt. with $\text{Pb}^{2+}(aq)$</td>
</tr>
<tr>
<td>iodide, $\text{I}^-$ (aq)</td>
<td>gives yellow ppt. with $\text{Ag}^+(aq)$ (insoluble in $\text{NH}_3(aq)$); gives yellow ppt. with $\text{Pb}^{2+}(aq)$</td>
</tr>
<tr>
<td>nitrate, $\text{NO}_3^-$ (aq)</td>
<td>$\text{NH}_3$ liberated on heating with $\text{OH}^-(aq)$ and $\text{Al}$ foil</td>
</tr>
<tr>
<td>nitrite, $\text{NO}_2^-$ (aq)</td>
<td>$\text{NH}_3$ liberated on heating with $\text{OH}^-(aq)$ and $\text{Al}$ foil, $\text{NO}$ liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown $\text{NO}_2$ in air)</td>
</tr>
<tr>
<td>sulfate, $\text{SO}_4^{2-}$ (aq)</td>
<td>gives white ppt. with $\text{Ba}^{2+}(aq)$ or with $\text{Pb}^{2+}(aq)$ (insoluble in excess dilute strong acid)</td>
</tr>
<tr>
<td>sulfite, $\text{SO}_3^{2-}$ (aq)</td>
<td>$\text{SO}_2$ liberated with dilute acids; gives white ppt. with $\text{Ba}^{2+}(aq)$ (soluble in excess dilute strong acid)</td>
</tr>
</tbody>
</table>

## 3 Tests for gases

<table>
<thead>
<tr>
<th>gas</th>
<th>test and test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>ammonia, $\text{NH}_3$</td>
<td>turns damp red litmus paper blue</td>
</tr>
<tr>
<td>carbon dioxide, $\text{CO}_2$</td>
<td>gives a white ppt. with limewater (ppt. dissolves with excess $\text{CO}_2$)</td>
</tr>
<tr>
<td>chlorine, $\text{Cl}_2$</td>
<td>bleaches damp litmus paper</td>
</tr>
<tr>
<td>hydrogen, $\text{H}_2$</td>
<td>&quot;pops&quot; with a lighted splint</td>
</tr>
<tr>
<td>oxygen, $\text{O}_2$</td>
<td>relights a glowing splint</td>
</tr>
<tr>
<td>sulfur dioxide, $\text{SO}_2$</td>
<td>turns acidified aqueous potassium dichromate(VI) (aq) from orange to green</td>
</tr>
</tbody>
</table>