5 This question is about copper(II) sulfate, $CuSO_4$, and sodium thiosulfate, $Na_2S_2O_3$.

(a) The enthalpy change of reaction, $\Delta_r H$, for converting anhydrous copper(II) sulfate to hydrated copper(II) sulfate is difficult to measure directly by experiment.

$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4 \cdot 5H_2O(s)$ $\Delta_r H$ **reaction 5.1**

The enthalpy changes of solution of anhydrous and hydrated copper(II) sulfate can be measured by experiment. The reactions are shown below.

In the equations, 'aq' represents an excess of water.

$CuSO_4(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4(s))$ **reaction 5.2**

$CuSO_4 \cdot 5H_2O(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\Delta_{sol}H(CuSO_4 \cdot 5H_2O(s))$ **reaction 5.3**

Experiment 1
A student carries out an experiment to find $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2**.

Student's method
- Weigh a bottle containing $CuSO_4(s)$ and weigh a polystyrene cup.
- Add about 50 cm^3 of water to the polystyrene cup and measure its temperature.
- Add the $CuSO_4(s)$, stir the mixture, and measure the final temperature.
- Weigh the empty bottle and weigh the polystyrene cup with final solution.

Mass readings

Mass of bottle + $CuSO_4(s)$ / g	28.04
Mass of empty bottle / g	20.06
Mass of polystyrene cup / g	23.43
Mass of polystyrene cup + final solution / g	74.13

Temperature readings

Initial temperature of water / °C	20.5
Temperature of final solution / °C	34.0

Experiment 2
The student carries out a second experiment with $CuSO_4 \cdot 5H_2O$ (**reaction 5.3**). The student uses the same method as in **Experiment 1**.

The student calculates $\Delta_{sol}H(CuSO_4 \cdot 5H_2O(s))$ as +8.43 kJ mol^{-1}.

(i)* Calculate $\Delta_{sol}H(CuSO_4(s))$ for **reaction 5.2** and determine the enthalpy change of **reaction 5.1**, $\Delta_r H$.

Assume that the specific heat capacity, *c*, of the solution is the same as for water.

Show your working, including an energy cycle linking the enthalpy changes. **[6]**

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Additional answer space if required

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(ii) The thermometer had an uncertainty in each temperature reading of ±0.1 °C.

The student calculates a 20% uncertainty in the temperature change in **Experiment 2**.

Calculate the temperature change in **Experiment 2**.

temperature change = ... °C **[1]**

(b) The standard enthalpy change of reaction, $\Delta_r H^{\ominus}$, and the standard free energy change, $\Delta G^{\ominus}$, for converting anhydrous sodium thiosulfate to hydrated sodium thiosulfate are shown below.

$Na_2S_2O_3(s) + 5H_2O(l) \rightarrow Na_2S_2O_3 \cdot 5H_2O(s)$ $\quad \Delta_r H^{\ominus} = -55.8\,kJ\,mol^{-1}$, $\Delta G^{\ominus} = -16.1\,kJ\,mol^{-1}$

Standard entropies are given in the table.

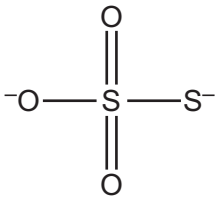
Compound	$S^{\ominus}$ / J K^{-1} mol^{-1}
$Na_2S_2O_3 \cdot 5H_2O(s)$	372.4
$H_2O(l)$	69.9

Determine the **standard** entropy, $S^{\ominus}$, of anhydrous sodium thiosulfate, $Na_2S_2O_3(s)$.

Give your answer to **3** significant figures.

$S^{\ominus}$ = ... J K^{-1} mol^{-1} **[4]**

(c) Sodium thiosulfate contains the thiosulfate ion, $S_2O_3^{2-}$.
The displayed formula of $S_2O_3^{2-}$ can be shown as below.



thiosulfate ion

(i) Predict the O–S–S bond angle and name of the shape of the thiosulfate ion.

Bond angle .....

Name of shape .....

[1]

(ii) In some of its reactions, the thiosulfate ion forms the tetrathionate ion, $S_4O_6^{2-}$.

The $S_4O_6^{2-}$ ion is a 'dimer' of $S_2O_3^{2-}$.

Draw a displayed formula for the $S_4O_6^{2-}$ ion.

[1]