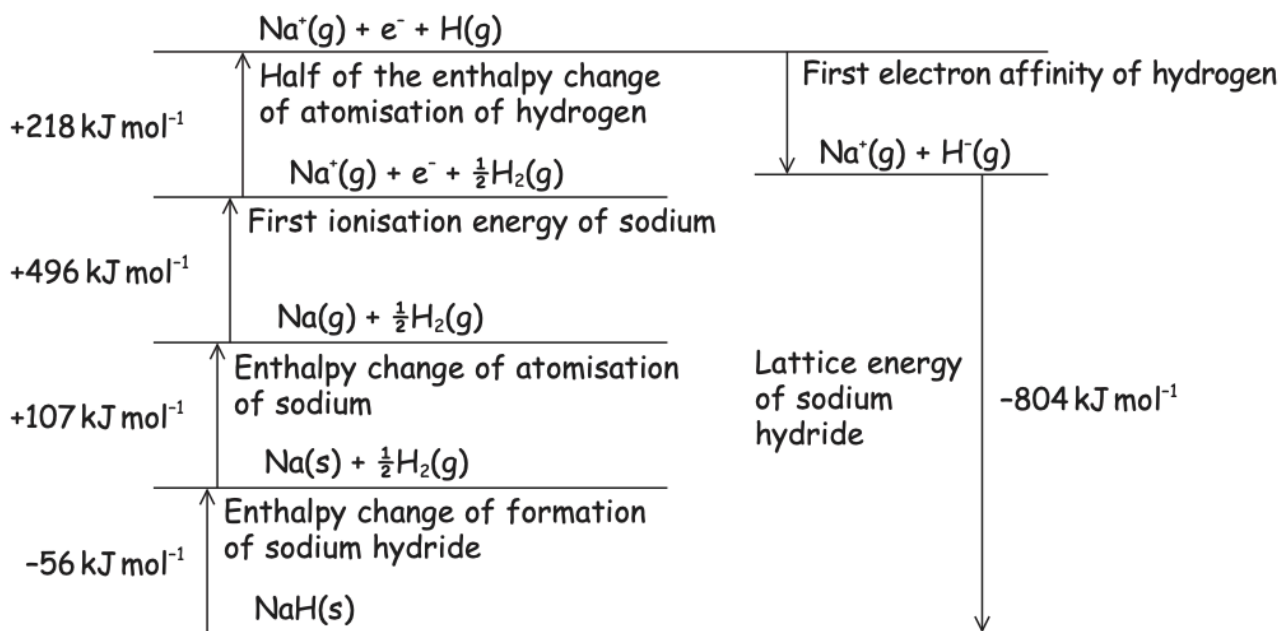**8** Sodium hydride, NaH, can be used to generate hydrogen for fuel cells.

    (a) In order to calculate the first electron affinity of hydrogen, a student was asked to draw a Born-Haber cycle for sodium hydride.

        The cycle had **two** errors but the numerical data were correct.

$Na^+(g) + e^- + H(g)$

Half of the enthalpy change of atomisation of hydrogen

First electron affinity of hydrogen

$+218 \, kJ \, mol^{-1}$

$Na^+(g) + e^- + \frac{1}{2}H_2(g)$

$Na^+(g) + H^-(g)$

First ionisation energy of sodium

$+496 \, kJ \, mol^{-1}$

$Na(g) + \frac{1}{2}H_2(g)$

Enthalpy change of atomisation of sodium

Lattice energy of sodium hydride

$-804 \, kJ \, mol^{-1}$

$+107 \, kJ \, mol^{-1}$

$Na(s) + \frac{1}{2}H_2(g)$

Enthalpy change of formation of sodium hydride

$-56 \, kJ \, mol^{-1}$

$NaH(s)$

    (i) Identify and correct the **two** errors in this Born-Haber cycle.

        (2)

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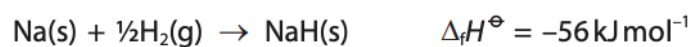
    (ii) Calculate the first electron affinity, in $kJ \, mol^{-1}$, of hydrogen, using the values given in the cycle.

        (1)

(b) The equation for the formation of sodium hydride is

$$Na(s) + \tfrac{1}{2}H_2(g) \rightarrow NaH(s) \qquad \Delta_f H^\ominus = -56\,kJ\,mol^{-1}$$

The standard entropy change of the system, $\Delta S^\ominus_{system}$, for this reaction is $-76.5\,J\,K^{-1}\,mol^{-1}$.

(i) Deduce the feasibility of this reaction at 298 K by calculating the free energy change, ΔG.

(2)

(ii) Calculate the temperature at which $\Delta G = 0$.

(1)

| 0 | 1 |.| 1 | Define the term enthalpy of lattice formation.

[2 marks]

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| 0 | 1 |.| 2 | Some enthalpy change data are shown in **Table 1**.

Table 1

	Enthalpy change / kJ mol^{-1}
$AgI(s) \rightarrow Ag^+(aq) + I^-(aq)$	+112
$Ag^+(g) \rightarrow Ag^+(aq)$	−464
$I^-(g) \rightarrow I^-(aq)$	−293

Use the data in **Table 1** to calculate the enthalpy of lattice formation of silver iodide.
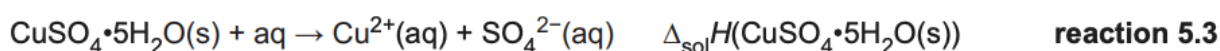
[2 marks]

Enthalpy of lattice formation _____ kJ mol^{-1}
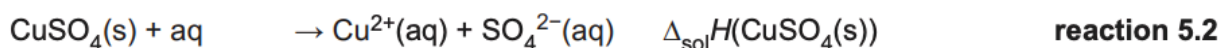
5 This question is about copper(II) sulfate, $CuSO_4$, and sodium thiosulfate, $Na_2S_2O_3$.

(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.

$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4 \cdot 5H_2O(s)$ $\qquad$ $\Delta_r H$ $\qquad$ **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.

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

$CuSO_4 \cdot 5H_2O(s) + aq \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$ $\quad$ $\Delta_{sol}H(CuSO_4 \cdot 5H_2O(s))$ $\qquad$ **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 $+8.43\,kJ\,mol^{-1}$.

13

(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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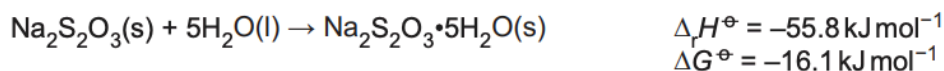
(ii) The thermometer had an uncertainty in each temperature reading of $\pm 0.1\,°C$.

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.

$$Na_2S_2O_3(s) + 5H_2O(l) \rightarrow Na_2S_2O_3 \cdot 5H_2O(s)$$

$$\Delta_r H^\ominus = -55.8\,kJ\,mol^{-1}$$
$$\Delta G^\ominus = -16.1\,kJ\,mol^{-1}$$

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]**

Question Number	Answer	Additional Guidance	Mark
8(a)(i)	An answer that makes reference to the following points: • identification and correction of the first error **(1)** • identification and correction of the second error **(1)**	Allow corrections to be made on the diagram Error 1 – arrow for enthalpy change of formation should go down/be reversed Error 2 – the word 'half' should be deleted from the enthalpy change of atomisation of hydrogen	**(2)**

Question Number	Answer	Additional Guidance	Mark
8(a)(ii)	• calculation of first electron affinity of hydrogen	<u>Example of calculation</u> 1st EA= −(218+496+107)−56 +804 = −73 (kJ mol⁻¹) Allow a TE 1st EA = +39(kJ mol⁻¹) if the first arrow reversed direction is not identified	**(1)**

Question Number	Answer	Additional Guidance	Mark
		Penalise incorrect or missing units in (b)(i) and (b)(ii) once only	

8(b)(i)	• calculation of ΔG **(1)**
	
	 • ΔG is negative/ <0 and so reaction is feasible **(1)**
		<u>Example of calculation</u>
		 ΔG = −56 −(298 x <u>−76.5</u>)
		            1000
		    =−33.203 (kJ mol⁻¹)
		 or
		 ΔG = −56000 −(298 x −76.5)
		     = −33203 (J mol⁻¹)
		
		 Ignore SF except 1
		
		 Allow ≤0 and so reaction is feasible
		 Standalone mark
		 Allow TE on own ΔG calculated value
			(2)

Question Number	Answer	Additional Guidance	Mark
8(b)(ii)	• calculation of T	<u>Example of calculation</u> ΔG = 0, so $\Delta H = T\Delta S_{(system)}$ or $T = \Delta H/\Delta S_{(system)}$ T = 56/0.0765 = 732 K **or** T = 56000/76.5 = 732 K **or** T = 459°C Ignore SF except 1 SF Do not award −732K TE on incorrect values penalised already in (b)(i)	**(1)**

| 01.1 | Enthalpy change or heat energy change when 1 mol of solid ionic compound/substance or 1 mol of ionic lattice | 1 | Allow: enthalpy change for: M^+ (g) + X^- (g) → MX (s) or Ag^+ (g) + I^- (g) → AgI (s) |
| | is formed from its gaseous ions. | 1 | CE=0/2 if describing wrong process (eg ΔH of lattice dissociation or ΔH of formation/ or heat energy required) Ignore heat energy released |

| 01.2 | lattice dissociation energy= (112 + 464 + 293) = + 869 (kJmol^{-1}) | 1 | |
| | lattice formation energy = − 869 (kJ mol^{-1}) | 1 | (+)869 = 1 mark |

Question			Answer	Marks	AO element	Guidance

5	(a)	(i)*	*Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.*
			
			Level 3 (5–6 marks)
			Calculates **CORRECT** enthalpy change with correct – signs for
			$\Delta_{sol}H$ ($CuSO_4(s)$) for **reaction 5.2**
			AND
			Δ_rH, for **reaction 5.1**.
			
			There is a well-developed line of reasoning which is clear and logically structured.
			The information presented is relevant and substantiated.
			
			Level 2 (3–4 marks)
			Calculates a value of $\Delta_{sol}H$ ($CuSO_4(s)$) for **reaction 5.2** from the:
			Energy change
			AND
			Amount in mol of $CuSO_4$.
			
			There is a line of reasoning presented with some structure.
			The information presented is relevant and supported by some evidence.
			
			Level 1 (1–2 marks)
			Processes experimental data to obtain the:
			Energy change from $mc\Delta T$
			OR
			Amount in mol of $CuSO_4$.
			
			There is an attempt at a logical structure with a line of reasoning.
			The information is in the most part relevant.
				6	AO3.1 ×4
					
					AO3.2 ×2
						Indicative scientific points may include:
						1. Processing experimental data
						Energy change from $mc\Delta T$
						• Energy in J OR kJ
						  Using 50.70 g, 50.0 g
						  = **50.70** × 4.18 × 13.5 = **2861** (J) **OR 2.861** (kJ)
						    3SF or more (2.861001 unrounded)
						OR 50.0 × 4.18 × 13.5 = **2821.5** (J) **OR 2.8215** (kJ)
						Amount in mol of $CuSO_4$
						• $n(CuSO_4) = \dfrac{7.98}{159.6}$ = 0.0500 (mol)
						--- 	
						2. ± value of $\Delta_{sol}H(CuSO_4(s))$ for reaction 5.2
						From m = 50.70 g = ± $\dfrac{2.861}{0.0500}$ = **±57.22** (kJ mol^{-1})
						(−57.22002 unrounded)
						From m = 50.0 g = ± $\dfrac{2.8215}{0.0500}$ = **±56.43** (kJ mol^{-1})
						--- 	
						3. CORRECT enthalpy changes for reactions 5.2 and 5.1 with signs (using 50.70 g ONLY)
						Reaction 5.2 = **−57.22** (kJ mol^{-1})
						       3SF or more with correct – sign
						Reaction 5.1
						$\Delta_rH = \Delta_{sol}H(CuSO_4(s)) - \Delta_{sol}H(CuSO_4 \cdot 5H_2O(s))$
						    = −57.22 − 8.43 = **−65.65** (kJ mol^{-1})
						       3SF or more with correct – sign
						NOTE: *A clear and logically structured response would include an energy cycle*
						ALLOW omission of trailing zeroes
						ALLOW minor slips

Question			Answer	Marks	AO element	Guidance
			0 marks – No response or no response worthy of credit.			
	(a)	(ii)	Temperature change = 0.2 × $\dfrac{100}{20}$ = **1**(.0)°C ✓	1	AO2.8	**IGNORE** direction of temperature change Working **NOT** required

	(b)		**FIRST CHECK THE ANSWER IN ON ANSWER LINE**
			If answer = (+)156 (J K^{-1} mol^{-1}) award 4 marks
			--- 	
			Part 1: Calc of Δ_rS
			Use of 298 K (seen anywhere) **1 mark** ✓
			• e.g. −16.1 = −55.8 − 298 × ΔS
			
			CORRECT use of Gibbs' equation **1 mark**
			• using candidate's temperature (e.g. 298)
			• with −16.1 **AND** −55.8
			• to calculate ΔS in kJ **OR** J ✓
			
			-- 	
			Part 2: Calc of $S(Na_2S_2O_3)$ **1 mark**
			CORRECT use of standard S data in question ✓
			Seen anywhere (could be within an expression) e.g.
			• 372.4 − [$S(Na_2S_2O_3)$ + (5 × 69.9)]
			• **OR** 372.4 − (5 × 69.9)
			• **OR** 372.4 − 349.5
			• **OR** 22.9
			
			IGNORE sign, i.e. **ALLOW** −22.9, etc
			
			CORRECT calculation of $S(Na_2S_2O_3)$ using candidate's calculated ΔS in Part 1 **to 3 SF** **1 mark** ✓
				4	AO2.4 ×4	Using 298 K, ΔS = $\dfrac{-55.8-(-16.1)}{298}$ = $\dfrac{-39.7}{298}$
						    = −0.133…(kJ K^{-1}mol^{-1})
						       OR −133… (J K^{-1}mol^{-1})
						       Sign required IGNORE units
						Calculator:
						  −0.133221 (kJ K^{-1} mol^{-1})
						  −133.221 (J K^{-1} mol^{-1})
						
						ALLOW ECF from incorrect temperature.
						
						Using −133:
						  $S(Na_2S_2O_3)$ = 372.4− 349.5 − (−133)
						    = 22.9 + 133
						    = (+)**156** (J K^{-1} mol^{-1})
						       3 SF required
						
						ALLOW ECF from incorrect Δ_rS (Part 1)