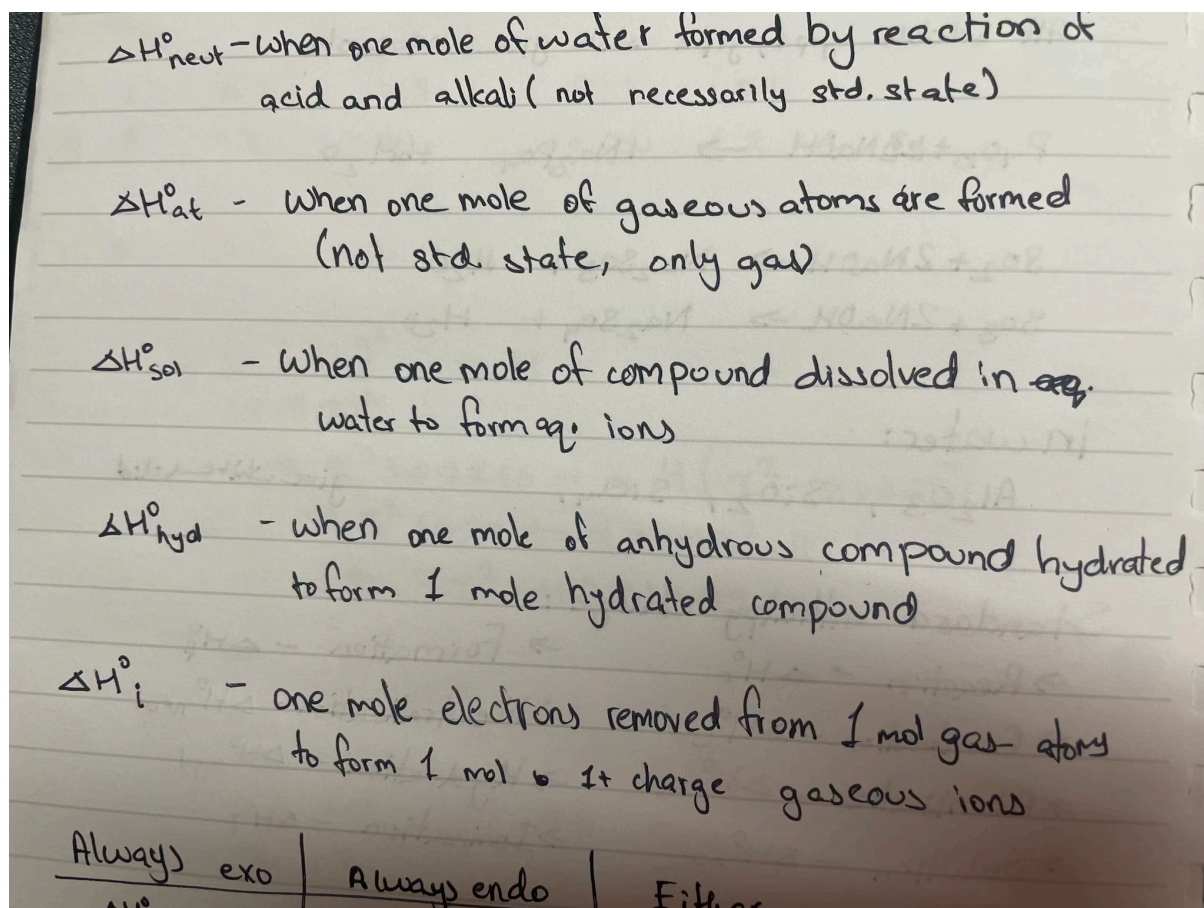


Exothermic	Endothermic
Combustion, Neutralisation	Thermal decomposition

NOTE: precipitation reactions can be either endothermic/ exothermic.



- Define enthalpy change of formation
 - enthalpy change / energy change when one mole of a compound / substance is formed
 - from its elements in their standard states
- Define enthalpy change of neutralisation
 - enthalpy change / energy change when one mole of water is formed
 - from an (aqueous) acid and an alkali / (aqueous) base
- Define enthalpy change of combustion
 - enthalpy change / energy change when one mole of a compound burns in excess of oxygen

4.

When 3.645 g of Mg(s) burns in excess N₂(g) to form Mg₃N₂(s), 23.05 kJ of energy is released.

Calculate the enthalpy change of formation, ΔH_f , of Mg₃N₂. Show your working.

M1 correct method to find amount Mg₃N₂ formed in reaction

3.645 ÷ 24.3 mol Mg produces 0.15 ÷ 3 mol of Mg₃N₂ **OR** 0.05 mol of Mg₃N₂

M2 use M1 in correct expression to find energy released by 1 mol Mg₃N₂

23.05 ÷ **M1** **OR** 23.05 ÷ mol Mg₃N₂

OR 23 050 ÷ **M1** **OR** 23 050 ÷ Mg₃N₂

M3 calculate value from M2 expression correctly

$\Delta H = -(M2) = -461(.0) \text{ kJ mol}^{-1}$ **OR** $-461\ 000 \text{ J mol}^{-1}$

NOTE: question states that energy is released! So enthalpy change must be negative!! Read the question thoroughly.

5.

A neutralisation reaction occurs when NaOH(aq) is added to H₂SO₄(aq).

equation 1 $2\text{NaOH(aq)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{Na}_2\text{SO}_4\text{(aq)} + 2\text{H}_2\text{O(l)}$

An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and H₂SO₄(aq).

100 cm³ of 1.00 mol dm⁻³ NaOH(aq) is added to 75 cm³ of 1.00 mol dm⁻³ H₂SO₄(aq) in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq)/°C	20.0
initial temperature of H ₂ SO ₄ (aq)/°C	20.0
maximum temperature of mixture/°C	27.8

(i) Use equation 1 to calculate the amount, in mol, of H₂SO₄(aq) that is neutralised in the experiment.

- No of mol of NaOH = $\frac{100}{1000} \times 1 = 0.1$
- No of mol of H₂SO₄ = $\frac{0.1}{2} = 0.05$

(ii) Calculate ΔH_{neut} using the results in Table 2.1. Include units in your answer.

Assume that:

- the specific heat capacity of the final solution is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$
- 1.00 cm^3 of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- full dissociation of $\text{H}_2\text{SO}_4(\text{aq})$ occurs
- the experiment takes place at constant pressure.

Show your working.

$$Q = -mc\Delta T$$

$$\Delta T = 27.8 - 20.0 = 7.8$$

NOTE: only change in temperature is required, so °C or K doesn't matter!!

$$m = 100 + 75 = 175 \text{ g}$$

$$c = 4.18$$

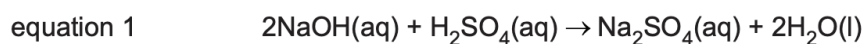
$$Q, \text{ for } 0.1 \text{ moles of H}_2\text{O} = -175 \times 4.18 \times 7.8 = -5705.7 \text{ J mol}^{-1}$$

$$Q, \text{ for } 1 \text{ moles of H}_2\text{O} = (-5705.7) / 0.1 = -57057 \text{ J mol}^{-1} = -57.1 \text{ kJ mol}^{-1}$$

6. Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

- The precipitation of BaSO_4 also involves an energy change.

7.



(b) In an experiment, 50.0 cm^3 of 2.00 mol dm^{-3} $\text{NaOH}(\text{aq})$ is added to 60.0 cm^3 of 1.00 mol dm^{-3} $\text{H}_2\text{SO}_4(\text{aq})$ in a polystyrene cup and stirred. Both solutions have a temperature of 21.4°C before mixing. The maximum temperature of the mixture is measured.

(i) Use equation 1 to calculate the amount, in mol, of $\text{H}_2\text{SO}_4(\text{aq})$ that is neutralised in the experiment.

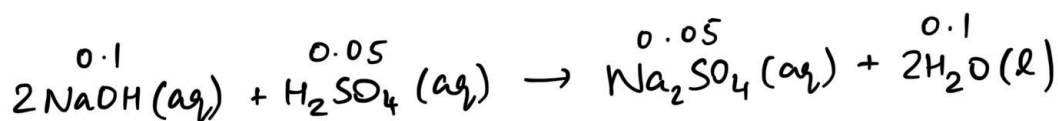
amount of H_2SO_4 neutralised = mol [1]

(ii) Calculate the theoretical maximum temperature of the mixture in this experiment.

Assume that:

- enthalpy change of neutralisation, ΔH_{neut} , of $\text{NaOH}(\text{aq})$ and $\text{H}_2\text{SO}_4(\text{aq})$ is -57.1 kJ mol^{-1}
- full dissociation of $\text{H}_2\text{SO}_4(\text{aq})$ occurs
- the specific heat capacity of the final solution is $4.18\text{ J g}^{-1}\text{ K}^{-1}$
- 1.00 cm^3 of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- the experiment takes place at constant pressure.

Show your working.



$$\text{i) mol of NaOH} = \frac{50}{1000} \times 2 = 0.1$$

$$\text{mol of H}_2\text{SO}_4 \text{ neutralised} = 0.05$$

$$\text{ii) } \Delta H_r = 0.1 \times -57.1 = -5.71\text{ kJ mol}^{-1} = -5710\text{ J mol}^{-1}$$

$$m = 50 + 60 = 110$$

$$Q = -mc\Delta T$$

$$\Rightarrow \Delta T = \frac{-5710}{-110 \times 4.18} = 12.4$$

$$\therefore \text{max temp} = 21.4 + 12.4 = 33.8^\circ\text{C}$$

8.

Values for the enthalpy change of neutralisation, ΔH_{neut} , are shown in Table 3.1.

Table 3.1

reagents	$\Delta H_{\text{neut}}/\text{kJ mol}^{-1}$
NaOH + HCl	-57.1
NaOH + CH ₃ COOH	-55.2

Suggest why the value for ΔH_{neut} of the weak acid, CH₃COOH, reacting with NaOH is different to the value obtained using the strong acid, HCl. Assume that the values are determined under the same conditions.

- additional energy is involved / required to fully ionise / dissociate the weak ethanoic acid OR additional energy is involved / required to donate/ release H⁺ ions

9.

Separate samples of Na₂CO₃ and NaHCO₃ react with HCl(aq) to produce the same products, as shown in Table 2.1.

Table 2.1

reaction	equation	$\Delta H/\text{kJ mol}^{-1}$
1	$\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	ΔH_1
2	$\text{NaHCO}_3 + \text{HCl} \rightarrow \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$	$\Delta H_2 = +27.2$

The value for ΔH_1 is determined by experiment using the following method.

- 50.0 cm³ of 2.00 mol dm⁻³ HCl(aq) is added to a polystyrene cup.
- The initial temperature of the acid is recorded as 19.6 °C.
- 0.0400 mol of Na₂CO₃ is added and the mixture is stirred.
- All the solid Na₂CO₃ disappears and a colourless solution is produced.

The maximum temperature recorded during the reaction is 26.2 °C.

a.

Calculate the value of ΔH_1 in kJ mol⁻¹.

Assume the specific heat capacity of the reaction mixture is the same as for water and no heat is lost to the surroundings.

Show your working.

M1 calculate Q from $= 50 \times 4.18 \times (26.2 - 19.6) = 1379.4$

M2 Use M1 to find energy change when 1 mol Na_2CO_3 / 2 mol HCl reacts

M1 $\div 0.04 = 34485$

M3 express Q as $\Delta H_{(1)}$ in $\text{kJ mol}^{-1} = -(\text{value for M2}) \div 1000$
 $= -34.5 \text{ kJ mol}^{-1}$

Alternative method

M1 evidence of use $Q = mc\Delta T = 50 \times 4.18 / 1000 \times (26.2 - 19.6) = 1.3794$

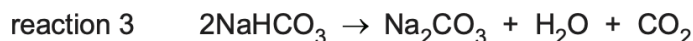
M2 Use M1 to find energy change when 1 mol Na_2CO_3 / 2 mol HCl reacts

M1 $\div 0.04 = 34.485$

M3 express Q as $\Delta H_{(1)}$ in $\text{kJ mol}^{-1} = -(\text{value for M2})$ (expressed in kJ)
 $= -34.5 \text{ kJ mol}^{-1}$

b.

Thermal decomposition occurs when NaHCO_3 is heated.



Calculate the enthalpy change for reaction 3, ΔH_r , using the data in Table 2.1 and the value of ΔH_1 calculated in **(b)(ii)**.

(If you were unable to calculate a value for ΔH_1 in **(b)(ii)**, assume the enthalpy change is $-38.4 \text{ kJ mol}^{-1}$. This is **not** the correct value.)

Using answer from 2(b)(ii)

(=) $2\Delta H_2 - (\Delta H_1)$

(=) $2 \times 27.2 - (2\text{b(ii)})$

$2 \times 27.2 - (-34.50) = (+) 88.9 \text{ kJ mol}^{-1}$

All three correct (2 marks) or two correct (1 mark):

- $(27.2) - (-34.5)$ OR $(27.2) - (2\text{b(ii)})$
- 2×27.2 and $1 \times 2\text{b(ii)}$
- calculate correctly their expression

Using **alternative** value of $\Delta H_1 = -38.4 \text{ kJ mol}^{-1}$

$\Delta H_r = (+)92.8 \text{ kJ mol}^{-1} = 2 \text{ marks}$

- c. All the solid Na_2CO_3 disappears and a colourless solution is produced.
Describe one other observation that shows the reaction is complete.
- no more fizzing / effervescence stops

10.

(e) $\text{POCl}_3(\text{g})$ forms when $\text{PCl}_3(\text{g})$ reacts with $\text{O}_2(\text{g})$.

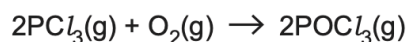


Table 1.3 gives some relevant data.

Table 1.3

process	value/ kJ mol^{-1}
enthalpy change of formation of $\text{PCl}_3(\text{g})$	-289
enthalpy change of formation of $\text{POCl}_3(\text{g})$	-592
$\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$	+496

Calculate the bond energy of $\text{P}=\text{O}$ in POCl_3 using the data in Table 1.3.

Show your working.

$$2(-592) = 2(-289) + (496) - 2(\text{P}=\text{O})$$

OR

$$(2) \text{P}=\text{O} = 2(-289) + (496) + 2(592)$$

$$E_{\text{P}=\text{O}} = \frac{1}{2}(1102) = +551 \text{ (kJ mol}^{-1}\text{)}$$

NOTE: when labelling energy level diagrams, be careful when labelling E_a . E_a is only from reactants to the hump!!! Careful especially for exothermic reactions!