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S4 New Curriculum chemistry

Theme: Thermochemistry

Chapter 4 – Energy changes during chemical reactions



Bond and energy changes

Chemical substance contains chemical energy stored in their bond. Formation of a bond releases energy while breaking a bond requires energy. Chemical reaction often involves energy changes due to the breaking of bonds in the reactants and formation of bonds in the products. If energy required to break the bonds in reactants is lower than the energy released in formation of bonds in the products, there is a net loss of heat from the reaction to the surrounding. And if energy required to break the bonds in reactants is higher than the energy released in formation of bonds in the products, there is a net gain of heat to the reaction from the surrounding.

Definitions

- Exothermic reactions** are reactions that release heat to the surrounding e.g. as burning fire. Temperature rises.
- Endothermic reactions are reactions that absorb heat from the surrounding such as dissolution of ammonium chloride in water. Temperature drops.

Uses of exothermic reactions

(i) Energy Production

- **Combustion reactions** (e.g., burning fuels like coal, natural gas, and gasoline) generate heat for electricity, vehicles, and heating systems.
- **Nuclear reactions** (e.g., nuclear fission) produce large amounts of energy in power plants.

(ii) Manufacturing & Industrial Processes

- **Metal extraction** (e.g., iron from ore in a blast furnace).
- **Cement and glass production** relies on exothermic chemical reactions for processing.

(iii) Everyday Applications

- **Self-heating cans** (used for food and beverages) contain exothermic chemicals to warm contents.
- **Hand warmers** use iron oxidation or crystallization of sodium acetate to generate heat.

(iv) Explosives & Fireworks

- **Combustion reactions** in gunpowder and explosives provide energy for propulsion and pyrotechnics.
- **Fireworks** rely on exothermic decomposition to release heat, light, and sound.

(v) Biological Processes

- **Respiration in living organisms** (glucose breakdown releases heat and energy for body functions).
- **Decomposition** (microbial breakdown of organic matter generates warmth, aiding composting).

(vi) Cooking & Heating

- **Burning wood, gas, or charcoal** releases heat for cooking and warmth.
- **Self-heating meals** use exothermic chemical packs to heat food.

(vii) Chemical & Laboratory Applications

- **Neutralization reactions** (acid-base reactions) often produce heat.
- **Polymerization reactions** in materials like epoxy resin generate heat during curing.

Uses of endothermic reactions

(i) Cooling & Refrigeration

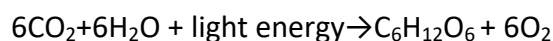
- **Ice packs** (used in sports injuries) rely on endothermic reactions to provide cooling.
- **Refrigeration and air conditioning** systems use heat absorption to regulate temperature.

(ii) Cooking & Food Processing

- **Melting ice** and **boiling water** are endothermic processes necessary for cooking.
- **Evaporation** helps food preservation (drying fruits or meats).

(iii) Photosynthesis in Plants

- Plants absorb **sunlight energy** to convert carbon dioxide and water into glucose and oxygen:



- Essential for oxygen production and food chains.

(iv) 4. Medical & Biological Applications

- **Sweating** helps the body cool down by absorbing heat during evaporation.
- **Cold therapy** uses endothermic reactions to reduce swelling and pain.

(v) Chemical & Industrial Processes

- **Electrolysis** (splitting water into hydrogen and oxygen) is endothermic.
- **Cooking reactions** (baking bread or cakes) absorb heat to transform food.

(vi) Climate & Natural Phenomena

- **Cloud formation** occurs as water vapor absorbs heat and condenses.
- **Glacier melting** is an endothermic reaction affecting global climate.

Amount of heat liberated by a reaction

The amount of heat absorbed or released in a reaction depend on

- Amounts of the reactants
- Temperature and
- Pressure at which a reaction is carried out.

When molar quantities are involved at 298K and 1 atmosphere the resultant heat changes are referred to as standard **heat/enthalpy** changes given a symbol a symbol ΔH (delta H).

Enthalpy changes (ΔH) (for exothermic reactions carry a negative sign because heat is lost from the system while enthalpy changes (ΔH) for endothermic reaction carry a positive sign because heat is gained by the system.

Heat is measured in joules (J)

Each heat change is identified by names; the common ones are:

1. Enthalpy of solution is the amount of heat liberated or absorbed when 1 mole a substance dissolves in excess water at 298K and 1 atmosphere.

When a substance dissolves exothermically/with liberation of heat, the temperature of the solution rises while when a substance dissolves endothermically/with absorption heat the final temperature of the solution drops.

Examples of salts that dissolve with liberation of heat are NaOH, CaCl₂, MgCl₂, AlCl₃.
Examples of salts that dissolve with absorption of heat are NH₄Cl, KCl, Na₂CO₃ and KNO₃.

2. Heat of combustion or enthalpy of combustion of a substance is the heat change when 1 mole of substance is burnt completely in oxygen.

Experiment to determine enthalpy of combustion

A given mass (M_1 g) of a substance of molecular mass, M_r , is burnt completely in excess oxygen. Heat liberated raises the temperature of (M_w g) of water through a temperature change of θ° .

Assumption

Heat liberated by a burning substance = heat absorbed by water
= $M_w C \theta$ (where C = specific heat capacity of water)

$\Rightarrow M_1$ g of the substance produce = $M_w C \theta$ J

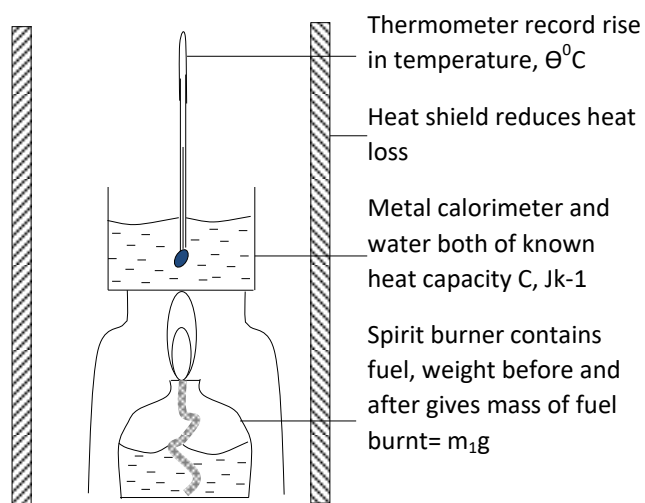
$\Rightarrow Mr$ g of substance produce = $\frac{M_w C \theta \times Mr}{M_1}$ Jmol⁻¹.

Therefore, enthalpy of combustion of the substance = $\frac{M_w C \theta \times Mr}{M_1}$ Jmol⁻¹

Experimental method for finding enthalpy of combustion a liquid fuel

The figure below shows a simple method for obtaining approximate value for the enthalpy of combustion of a fuel for example ethanol.

Setup



Calculations

Assumption

Heat produced by combusting fuel = Heat gained by calorimeter and water

Heat gained by calorimeter and water = $C\theta$ joules

It implies that

$m_1\text{g}$ of the fuel produce = $C\theta$ joules

M_r (mass equivalent to 1 mole of fuel) produces = $\frac{MrC\theta}{m_1}$ joules mol^{-1}

Example 1

When 23g of ethanol completely burnt, 13600KJ of heat was produced.

Calculate the molar heat of combustion of ethanol ($\text{C} = 12, \text{H} = 1, \text{O} = 16$)

solution

Formula mass of ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) = $12 \times 2 + 6 + 16 = 46$

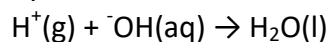
23g of ethanol liberate 13600KJ

Then, 46g of ethanol liberate $\frac{13600 \times 46}{23} = 27200\text{kJ}$

Therefore, the enthalpy of combustion of ethanol = 27200kJmol^{-1} .

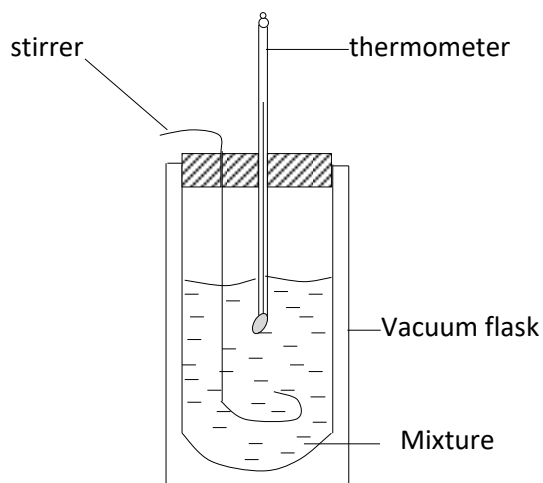
3. Enthalpy of neutralization

This refers to enthalpy change for the formation 1 mole of water from hydrogen and hydroxide ions



Measurement of standard enthalpy of neutralization

The heat released when a known amount of water is formed is found by measuring the temperature produced in a calorimeter and its contents.



NB. A vacuum flask is used to minimize heat losses

Known volume of standard acid (V_1) and alkali (V_2) are added to calorimeter, and temperature change $\theta^\circ\text{C}$ is noted. The number of moles of water formed, M_w , is calculated

Calculations

Heat given out = Heat received by
By water calorimeter of capacity, C.

$$\text{Total volume} = (V_1 + V_2)\text{cm}^3$$

Given that the density of solution = density of water (or 1gcm^{-3})

$$\text{Mass of water, } m = (V_1 + V_2)\text{g}$$

Heat = $mc\theta$ J (where c is the specific heat capacity)

Amount of water formed = m_w moles

The standard enthalpy of neutralization is $(mc\theta)/m_w \text{Jmol}^{-1}$.

Example 2

250 cm³ of 0.40M NaOH were added to 250cm³ of 0.40M HCl in the calorimeter. The temperature of the two solutions was 17.5⁰C and rose to 20.1⁰C

Calculate the enthalpy of neutralization assuming that the specific heat capacities of solution are the same as that of water = 4180J kg⁻¹ K⁻¹.

Solution

$$\text{Temperature rise} = 20.1 - 17.5 = 2.6^{\circ}\text{C}$$

$$\begin{aligned}\text{Mass of solution} &= \text{total volume of solution} \\ &= (250 + 250) = 500\text{g}\end{aligned}$$

$$\begin{aligned}\text{Heat liberated} &= mc\theta \\ &= 500 \times 4.180 \times 2.6 \\ &= 5434\text{J}\end{aligned}$$

Mole of water produced = moles of NaOH or moles of HCl

$$= \frac{250 \times 0.4}{1000} = 0.1\text{mole}$$

0.1mole of water require = 5434J

$$1 \text{ mole of water require} = \frac{5434 \times 1}{0.1} = 54340 \text{ J}$$

Therefore, enthalpy of neutralization of water = 54340Jmol⁻¹

Energy profile of a reaction

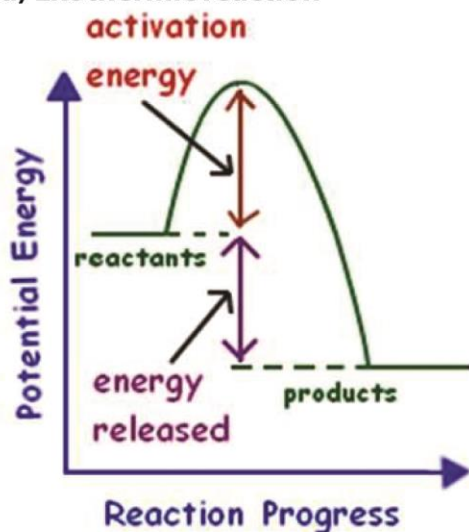
An **energy profile of a reaction** is a graphical representation showing how the energy of the reactants and products changes during the course of a chemical reaction. It helps visualize the energy required to start a reaction and whether it releases or absorbs energy.

Key Features of an Energy Profile:

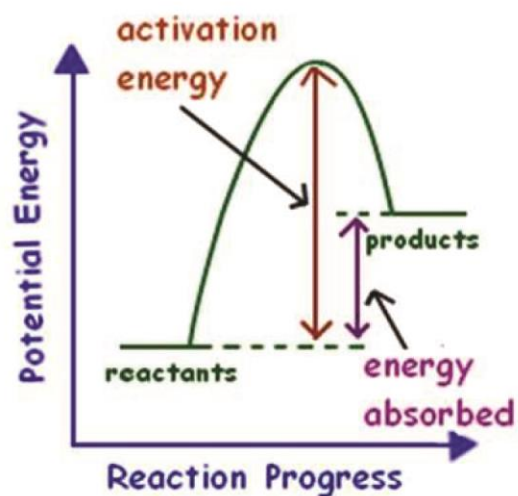
1. **Reactants** – The starting substances, usually at a certain energy level.
2. **Activation Energy (E_a)** – The minimum energy needed for the reaction to proceed. This forms a peak in the graph.
3. **Transition State** – The highest energy point where old bonds are breaking and new bonds are forming.
4. **Products** – The final substances formed, which can be at a higher or lower energy level compared to the reactants.
5. **Enthalpy Change (ΔH)** – This indicates whether the reaction is **exothermic** (releasing heat) or **endothermic** (absorbing heat).

Energy profiles for:

(a) Exothermic reaction



(b) Endothermic reaction



(a) **Exothermic reactions** (e.g., combustion) have a **downward slope**, meaning the products have lower energy than the reactants, and heat is released.

(b) **Energy Profile of Endothermic reactions** (e.g., photosynthesis) have an **upward slope**, meaning the products have higher energy than the reactants, and heat is absorbed.

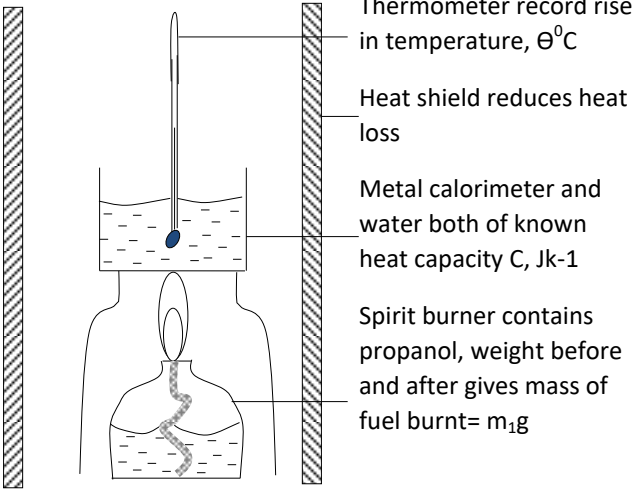
Revision Question

1.	(a)	What is meant by enthalpy of neutralization? (02marks)
	(b)	When 50.0cm ³ of 1M sulphuric acid was added to 50cm ³ of 2M sodium hydroxide, the temperature rose by 13.6 ^o C. (i) Write ionic equation for the reaction that took place (01 mark) (ii) Calculate the enthalpy of neutralization of sodium hydroxide. (specific heat capacity of water = 4.2Jmol ⁻¹ , density of water 1g/cm ³ (3marks)
2		Biogas contain mainly methane.
	(a)	Name two raw materials that can be used to produce biogas
	(b)	Methane burns in oxygen according to the following equation $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \quad \Delta\text{H} = -890\text{kJmol}^{-1}$ Calculate the volume of methane at s.t.p that will produce 2670kJ.
3	(a)	50cm ³ of 2M HCl and 50cm ³ of 2M NaOH each at 22 ^o C were mixed in a plastic beaker. The mixture was stirred and its maximum temperature was 35 ^o C. [heat capacity of solution is 4.2kJkg ⁻¹ ^o C, density of water = 1gcm ⁻³] (i) Write ionic equation for the reaction. (ii) Calculate the heat of reaction
	(b)	50cm ³ of 2M ammonia was used instead of 2M NaOH in (a). State whether the heat of the reaction was greater than, equal to or less than the value obtained in (a)(ii) above. Explain your answer.
4	(a)	Write equation for complete combustion of methane
	(b)	A litre of methane gas costs 600/=. Calculate the cost of methane required to produce 1746 x 10 ³ J of heat. (1mole of a gas occupies 24dm ³ at room temperature, heat of combustion of methane is -882kJmol ⁻¹)
5	(a)	Define the term enthalpy of combustion (02marks)
	(b)	With the aid of a diagram describe an experiment you would carry out in a laboratory to determine the enthalpy of combustion of propanol (9marks)
	(c)	In an experiment to determine the enthalpy of combustion of propanol, 0.54g of propanol was burnt and the heat evolved caused the temperature of 150cm ³ of water to rise by 21.5 ^o C (molar mass of propanol = 60, density of water is 1gcm ⁻³ , specific heat capacity of water = 4.1Jg ⁻¹) Calculate heat capacity experiment value of enthalpy of combustion of propanol (3 ½ marks)

6		<p>Ethane burns in oxygen according to the following equation</p> $2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \longrightarrow 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$ <p>When 2.0g of ethane was burnt in excess oxygen, 104kJ of heat was produced.</p> <p>Calculate</p>
	(a)	Mass of water formed (03marks)
	(b)	Molar heat of combustion of ethane (02marks)
7	(a)	What is meant by the term enthalpy of combustion? (02mark)
	(b)	<p>Ethanol burns in oxygen according to the following equation</p> $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l}) \quad \Delta H = -1360\text{kJmol}^{-1}$ <p>Calculate the mass of ethanol that is required to raise the temperature of 1000cm³ of water by 10.0°C (03marks) (specific heat capacity of water = 4.2Jg⁻¹K⁻¹)</p>

Suggested answers

1.	(a)	Enthalpy of neutralization is enthalpy change when 1 mole of water is formed from aqueous hydrogen and hydroxyl ions.
	(b)	<p>(i) $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$</p> <p>(ii) total volume of water = $50 + 50 = 100\text{cm}^3$</p> <p>Mass of water = $100 \times 1 = 100\text{g}$</p> <p>Heat liberated = $mc\theta = 100 \times 4.2 \times 13.6 = 5712\text{J}$</p> <p>Mole of water formed = moles NaOH = $\frac{50 \times 2}{1000} = 0.1 \text{ mole}$</p> <p>Production of 0.1mole of water produce 5712J</p> <p>1mole of water produced $\frac{5712 \times 1}{0.1} 57120\text{J} = 57.12\text{kJmol}^{-1}$</p>
2	(a)	Cow dung, water, plant remaining
	(b)	<p>Formula mass of $\text{CH}_4 = 12 + 4 = 16$</p> <p>890kJ are produced by 16g of methane</p> <p>2670kJ are produced by $\frac{16 \times 2670}{890} = 48\text{g}$</p>
3	(a)	$\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
	(b)	<p>total volume of water = $50 + 50 = 100\text{cm}^3$</p> <p>Mass of water = $100 \times 1 = 100\text{g}$</p> <p>Temperature change = $35 - 22 = 13^\circ\text{C}$</p> <p>Heat liberated = $mc\theta = 100 \times 4.2 \times 13 = 5460\text{J}$</p> <p>Mole of water formed = moles NaOH = $\frac{50 \times 2}{1000} = 0.1 \text{ mole}$</p> <p>Production of 0.1mole of water produce 5460J</p> <p>1mole of water produced $\frac{5460 \times 1}{0.1} 54600\text{J} = 54.6\text{kJmol}^{-1}$</p>
	(b)	It would be less because ammonia is a weak base

4	(a) $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \longrightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$
	(b) Formula mass of $\text{CH}_4 = 12 + 4 = 16$ 882kJ are produce by 24 l 1746kJ require $\frac{1746 \times 24}{882} = 47.5\text{l}$ Cost of 47.5l of methane = $47.5 \times 600 = 28500/=$
5	Ethnalpy of combustion is entalpy change when 1 mole of a substance is completely burnt in oxygen.
	<p>Experimental method for finding enthalpy of combustion a liquid fuel</p> <p>The figure below shows a simple method for obtaining approximate value for the enthalpy of combustion of a propanol.</p>  <p>Calculations</p> <p>Assumption</p> <p>Heat produced by combusting fuel = Heat gained by calorimeter and water</p> <p>Heat gained by calorimeter and water = $C\theta$ joules</p> <p>It implies that</p> <p>$m_1\text{g}$ of fuel produce = $C\theta$ joules</p> <p>Mr (mass equivalent to 1 mole of fuel) produces = $\frac{MrC\theta}{m_1}$ joulesmol⁻¹</p>
	(b) Mass of water = $150 \times 1 = 150\text{g}$ Heat = $mc\theta = 150 \times 4.2 \times 21.5 = 13545\text{J}$ 0.54gof propanol produce 13545J 60g of propanol produce $\frac{13545 \times 60}{0.54} = 1505\text{kJ}$

6	(a)	Formula mass of ethane $C_2H_6 = 2 \times 12 + 6 \times 1 = 30$ Formula mass of water, $H_2O = 1 \times 2 + 16 = 18$ (2 x 30) g of ethane produce (6 x 18) g of water 2g of ethane produce $\frac{2 \times 6 \times 18}{2 \times 30} = 3.6 \text{ g of water}$
	(b)	2g of ethane produce 104kJ 30g (1mole) of ethane produce $\frac{30 \times 104}{2} = 1560 \text{ kJ}$
7.	(a)	Enthalpy of combustion is the enthalpy change when 1 mole of a substance is burnt completely in oxygen.
	(b)	Formula mass of ethanol $C_2H_5OH = 2 \times 12 + 6 + 16 = 46$ Mass of water = volume of water = 1000g Heat = $mc\theta = 1000 \times 10 \times 4.2 = 42000 \text{ J}$ 2g of ethanol produce 42000 30g of ethanol produce $\frac{42000 \times 30}{2} = 630 \text{ kJ}$

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Thanks

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