ENERGY CHANGES IN PHYSICAL AND CHEMICAL PROCESSES.

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Organizer

Objectives

By the end of this topic, the learner should be able to:

(a) Define endothermic and exothermic reactions using the ΔH notation.

(b) Draw energy level and energy cycle diagrams.

(c) Explain fusion and vaporisation as evidence of inter-particle forces.

(d) Explain that energy changes in chemical reactions are due to bond breaking and bond formation.

(e) Define and explain various types of heat changes.

(f) Carry out some experiments to determine enthalpy changes for some reactions.

(g) Write correct simple thermochemical equations.

(h) State Hess's Law and carry out related calculations.

(i) State and explain the factors that influence the choice of a fuel.

(j) Explain the environmental effects of fuels.

ENERGY CHANGES IN PHYSICAL AND CHEMICAL PROCESSES.

Energy is the ability to do work. There are many forms of energy such as chemical, electrical, heat, kinetic and potential energy.

Energy can neither be created nor destroyed but can only be converted from one form to another. For example, heat energy to kinetic energy.

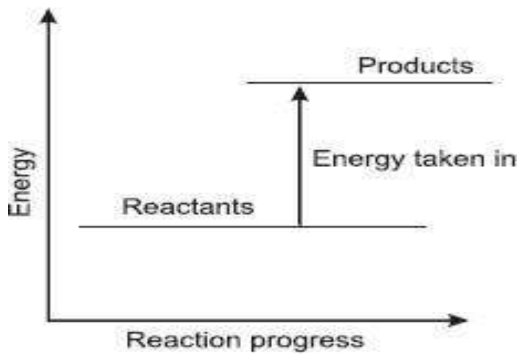
Many physical and chemical changes are accompanied by energy changes.

Endothermic and Exothermic Reactions

A process that is accompanied by **absorption of heat** is called an **endothermic reaction,** for example dissolving of ammonium nitrate in water.

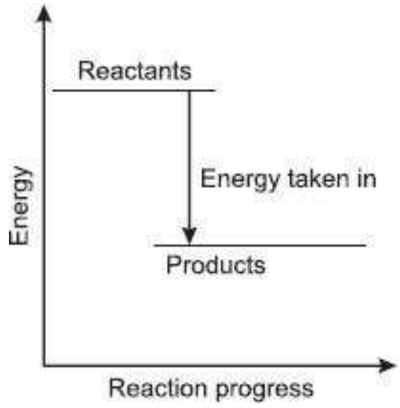
The reactants and products in a reaction form a system.

In an endothermic reaction, the system **absorbs heat energy from the surrounding. Therefore, the products**



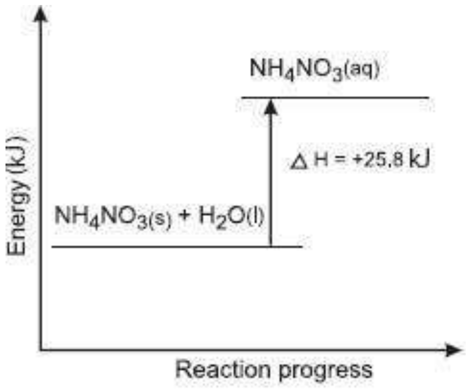
have a higher energy compared to the reactants as shown below:

A process that is accompanied by production of heat is called an **exothermic reaction,** for example dissolving of sodium hydroxide in water. In an exothermic reaction, heat is **lost from the system.** The products therefore have a **lower energy content compared to the reactants** as shown below.

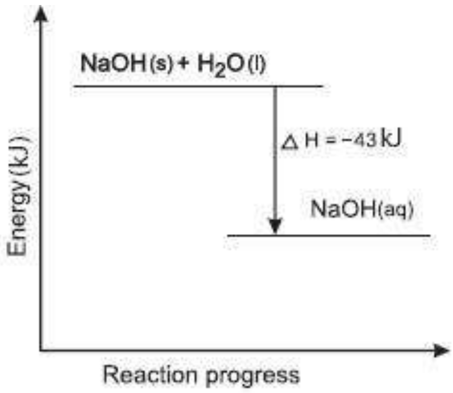


Illustrations which show the relative energies of the products and reactants in a reaction are called **energy level diagrams**.

The energy level diagrams for ammonium nitrate and sodium hydroxide dissolving in water respectively are:



(a) Ammonium nitrate



(b) Sodium nitrate

Enthalpy Notation

The **heat content** in a chemical is called its **enthalpy**. It is assigned the symbol **H**.

Enthalpy change is a **change in heat content** and is denoted by the symbol **ΔH**.

The enthalpy change during a reaction is given by the expression:

Enthalpy change (ΔH) = Enthalpy of products – Enthalpy of reactants.

In an **endothermic reaction**, the enthalpy of products is **higher** than that of the reactants. The **enthalpy change** is therefore **positive**.

In an **exothermic reaction**, the products have **lower** enthalpy compared to the reactants. The **enthalpy change is** therefore **negative.**

The energy change associated with a chemical change is usually shown **at the end** of the balanced chemical equation. For example,

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g)\ \Delta H = -728\ kJ\ mol^{-1}$$

$$NaNO_3(s) + (aq) \xrightarrow{H_2O} NaNO_3(aq)\quad \Delta H = +21\ kJ\ mol^{-1}$$

Such a chemical equation is called a **thermochemical equation**.

Bond Breaking and Bond Formation in Physical and Chemical Processes

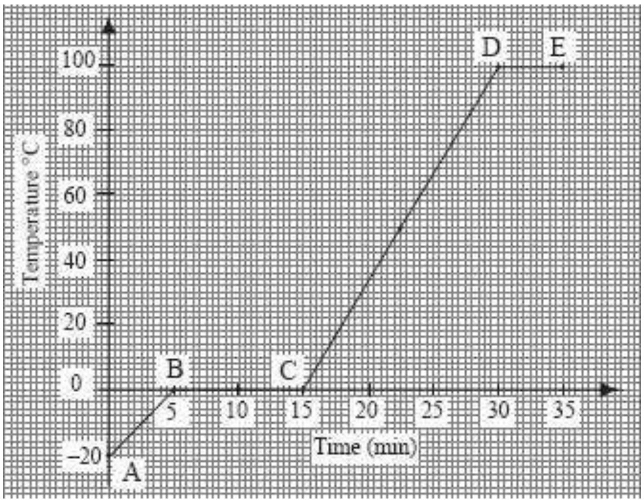
During a physical change such as melting and evaporation, energy changes are involved.

For pure substances, temperature remains constant at the melting and boiling points respectively. The heat energy supplied during melting and boiling is only used to overcome the forces holding the solid lattice together and the forces of attraction between the liquid molecules respectively. It does not therefore result in temperature rise.

The amount of heat energy required to convert a given amount of a solid substance to a liquid at its melting point is called **latent heat of fusion.**

The amount of heat energy required to convert one mole of a solid substance at its melting point to a liquid and vise versa is called **molar heat of fusion**.

The heat absorbed by a substance when changing from the liquid state to the gaseous state at constant temperature is known as **latent heat of vaporisation**. The amount of heat energy required to convert one mole of a liquid substance at its boiling point to its gaseous state is called **molar heat of vaporisation**



Heating curve of pure ice

If the forces holding the particles together in the solid structure are strong, then the molar heat of fusion is high. This is reflected in the high melting point of the substance. Similarly, when the forces holding the particles in the liquid are strong, the molar heat of vaporisation is high. This is reflected in the high boiling point of the substance.

The atoms in elements or compounds are held together by chemical bonds. For reactions to occur between substances, the bonds must be broken and new bonds formed as the constituent atoms recombine to form new substances.

Bond breaking and bond formation involve energy changes in the substances involved. For example, methane reacts with chlorine as shown below:

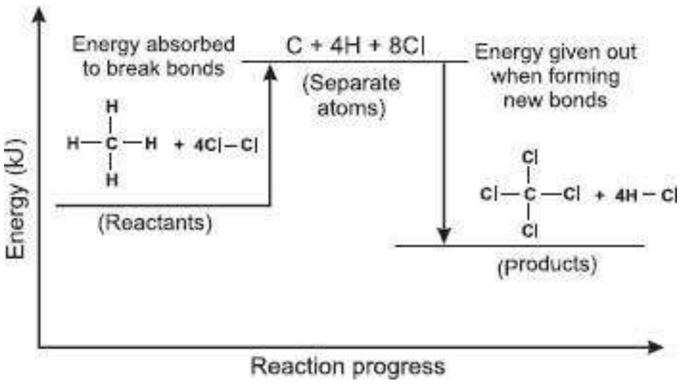
$$CH_4(g) + 4Cl_2(g) \longrightarrow CCl_{4+} 4HCl(g).$$

For a reaction to occur, the covalent bonds in both methane and chlorine **must be broken** to obtain separate atoms. Energy is **required** to break these bonds. Thus **bond breaking is an endothermic process.**

Once the bonds are broken, the atoms **rearrange themselves** and **new bonds are formed** in the products. In the process of bond formation, **energy is given out**. Therefore, **bond formation is an exothermic process.**

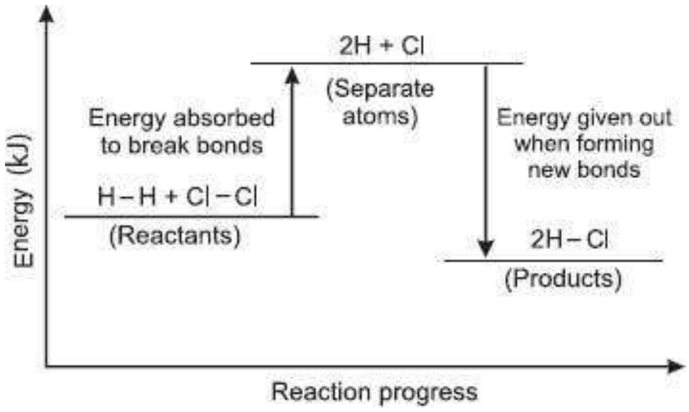
The energy **spent in breaking the bonds** in the methane and chlorine molecules is **less** than the energy **given out when the products are formed.** Overall, the reaction therefore **gives out energy.**

These changes can be illustrated using the energy level diagram shown below for the reaction between methane and chlorine.



Energy level diagram for the reaction between methane and chlorine

The reaction between hydrogen gas and chlorine gas to form hydrogen chloride can be similarly illustrated as shown below:



Energy level diagram for the reaction between hydrogen and chlorine

In reactions where **more energy is spent in breaking the bonds** in the reactants **than** is given out when **new bonds are formed** in the products, the overall process is **endothermic**.

If the bond strengths in reactants and products are known, then the enthalpy change for the reaction can be determined as follows:

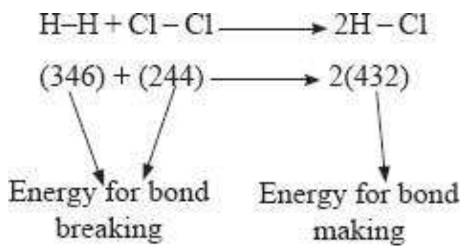
Example

Use the following bond energies to determine whether the reaction below is exothermic or endothermic:

$$H_2(g) + Cl_2(g) \longrightarrow 2HCl(g).$$

Bond	Energy in kJ mol^{-1}
H–H	+436
Cl–Cl	+244
H–Cl	+432

Working



Heat of reaction = Bond breaking energy + Bond formation energy

= 680 kJ + – 864 kJ

= –184 kJ

Since the overall energy is negative (–) the formation of hydrogen chloride (HCl) gas from hydrogen gas and chlorine gas is an **exothermic reaction**.

Determination of Enthalpy Changes

Enthalpy of solution.

The enthalpy change that occurs when a substance is dissolved in a solvent to give an infinitely dilute solution is called the **enthalpy of solution**.

The molar heat of solution is the enthalpy change that occurs one mole of a substance is dissolved in a solvent to give an infinitely dilute solution.

Ammonium nitrate

To determine the molar enthalpy of solution of ammonium nitrate:

Measure 100 ml distilled water into a clean 250 ml plastic beaker. Note the temperature of the water. Weigh accurately 2.0 g of ammonium nitrate. Add all the ammonium nitrate at once into the water in the beaker. Stir gently using the thermometer to dissolve the ammonium nitrate. Note and record the steady temperature of the resulting solution.

Discussion Questions

1. **State whether the changes in the experiment are exothermic or endothermic.**

Ammonium nitrate dissolves in water with the **absorption of heat (a drop in temperature).** This change is **endothermic**.

2. **Calculate the enthalpy change in each experiment.**

When 2 g of ammonium nitrate is dissolved in 100 ml distilled water, a temperature change of about 1.5°C (1.5 K) is noted. The enthalpy change is calculated using the formula:

Enthalpy change = Mass of solution × Specific heat capacity × Temperature change

$\Delta H = MC\Delta T$ where M = Mass

C = Specific capacity

ΔT = Change in temperature in Kelvin

In this case, it is **assumed** that the **mass of the solution is equal to that of a similar amount for water, i.e., 100 g (0.1 kg). The specific heat capacity of water is used in the calculation.** Therefore:

$$\text{Heat absorbed} = 0.1\text{kg} \times 4.2\ \text{kJ Kg}^{-1}\ \text{K}^{-1} \times 1.5\ \text{K}$$

$$= 0.63\ \text{kJ}$$

3. **Calculate the number of moles of solute dissolved in each experiment.**

The number of moles of ammonium nitrate is calculated as follows:

$$\text{Number of moles} = \frac{\text{Mass}}{\text{Molar mass}} = \frac{2.0\ \text{g}}{80\ \text{g mol}^{-1}} = 0.025\ \text{mol}$$

4. **Calculate the enthalpy change that would occur if one mole of each solute is dissolved.**

when 0.025 mol/ of ammonium nitrate dissolves, 0.63 kJ of heat is absorbed. Therefore the enthalpy change when 1 mol of ammonium nitrate dissolves is:

$$= \frac{1\ \text{mol} \times 0.63\ \text{kJ}}{0.025\ \text{mol}}$$

$$= 25.2\ \text{kJ}$$

Thus when 1 mol of ammonium nitrate dissolves 25.2 kJ of heat is absorbed

5. **Write the equation for each reaction. Include the energy change.**

The equation for the reaction including the enthalpy change is:

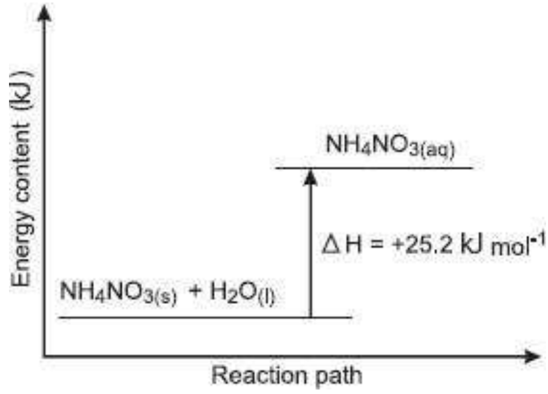
$$NH_4NO_3(s) \longrightarrow NH_4NO_3\ (aq)\ \Delta H = +\ 25.2\ kJ\ mol^{-1}$$

This value: + 25.22 kJ mol^{-1} is called the **molar heat of solution** of ammonium nitrate.

NB: A mole of solute should be dissolved in a sufficient amount of solvent to ensure complete dissolution.

A chemical equation which shows the enthalpy change during reaction is called a **thermochemical equation**.

A thermochemical equation is illustrated on an energy level diagram as shown below:



Energy level diagram for dissolving ammonium nitrate

Sodium hydroxide

Sodium hydroxide dissolves in water with the **evolution of heat**. A temperature **rise** of about **5°C** is recorded when 2 g of sodium hydroxide dissolves in 100 ml distilled water.

Heat evolved = Mass × Specific heat capacity × Temperature change

$= 0.1\ Kg \times 4.2\ kJ\ Kg^1\ K^1 \times 5\ K$

$= 2.1\ kJ$

Moles of sodium hydroxide used is given by:

$$\text{No. of moles} = \frac{\text{Mass}}{\text{Molar mass}}$$

$$= \frac{2.0\ g}{40\ g\ mol^{-1}}$$

$$= 0.05\ mol$$

Therefore, 0.05 mol liberates 2.1 kJ of heat.

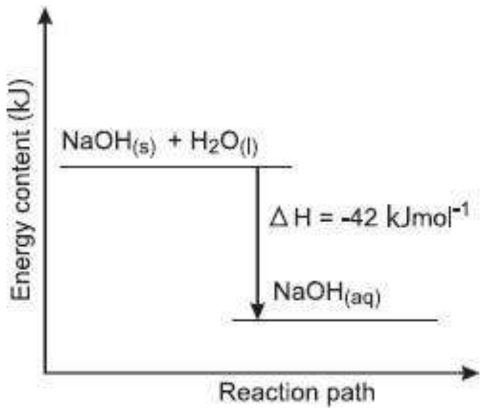
$$1\ \text{mol liberates:}\ \frac{1.0 \times 2.1}{0.05}\ \text{kJ of heat} = 42\ kJ$$

The thermochemical equation for the reaction is:

$$NaOH(s) \longrightarrow NaOH(aq)\ \Delta H = -42\ kJ\ mol^{-1}$$

This (i.e., – 42 kJ mol^{-1}) is the **molar heat of solution of sodium hydroxide.**

The thermochemical equation can be illustrated on an energy level diagram.



Energy level diagram for dissolving sodium hydroxide.

Concentrated sulphuric(VI) acid?

Wrap a clean 250 ml plastic beaker with tissue paper. Secure the tissue paper with a rubber band. Measure exactly 98 cm^3 of distilled water into the beaker. Note the steady temperature of the water. Measure 2 cm^3 of concentrated sulphuric(VI) acid. Hold the beaker containing distilled water in a tilted position and carefully pour the 2 cm^3 of concentrated sulphuric(VI) acid into the beaker.

Discussion Questions

1. **State whether the change is exothermic or endothermic.**

Concentrated sulphuric(VI) acid dissolves in water with the evolution of heat. The reaction is exothermic.

2. **Determine the temperature change for the reaction.**

When 2cm^3 of concentrated sulphuric(VI) acid is dissolved in 98 cm^3 of water, a temperature rise of 4.5°C is recorded.

3. **Calculate the enthalpy change for the reaction.**

The total volume of the solution = (2 + 98) cm^3 = 100 cm^3

The mass of solution is given by = Volume × Density

= 100 cm^3× 1.0 g cm^{-3}

= 100g (0.1g)

Heat evolved = Mass × Specific heat capacity × Temperature change

= 0.1 Kg × 4.2 kJ Kg^{-1} K^{-1} × 4.5 K = 1.89 kJ

4. **Determine the mass of the concentrated acid used hence the moles of sulphuric(VI) acid. (Concentrated sulphuric(VI) acid is 98% pure and has a specific density of 1.84 (cm^{-3}).**

The mass of the concentrated acid is calculated from the formula:

Mass = Specific density × Volume

= 1.84g cm^{-3} × 2 cm^3 = 3.68 g

Thus the 2 cm^3 of concentrated sulphuric(VI) acid has a mass of 3.68 g. But since the acid is 98% pure, the actual mass of sulphuric(VI) acid is calculated by:

Mass of acid = Mass of conc. acid × percentage purity

$$= 3.68 \text{ g} \times \frac{98}{100} = 3.6064 \text{ g}$$

The moles of the acid is given by:

$$= \frac{3.6064 \text{ g}}{98 \text{ g mol}^{-1}}$$

$$= 0.0368 \text{ mol}$$

5. **Calculate the enthalpy change when one mole of concentrated sulphuric(VI) acid dissolves.**

when 0.0368 mol of sulphuric(VI) acid dissolves, 1.89 kJ of heat is evolved.

When 1 mol of the sulphuric(VI) acid dissolves, $\frac{1.0 \times 1.89 \text{ kJ}}{0.0368}$ of heat is evolved.

= 51.358 kJ of heat.

Thus the molar heat of solution of sulphuric(VI) acid

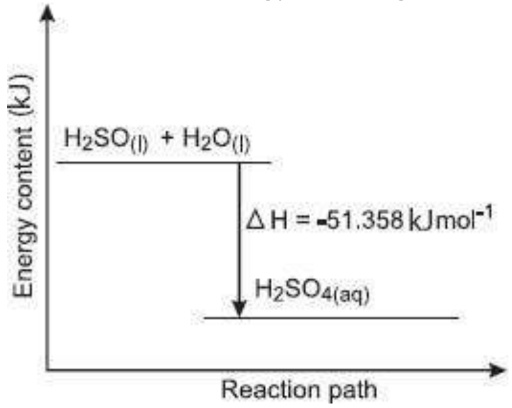
= –51.358 kJ mol^{-1}

The negative sign is added to show that the process is exothermic.

6. **Write down the thermochemical equation for the reaction**.

$$H_2SO_4\,(l) \xrightarrow{H_2O} H_2SO_4(aq) \qquad \Delta H = -51.358 \text{ kJ mol}^{-1}$$

The thermochemical equation is illustrated on an energy level diagram as shown.



Energy level diagram for dissolving concentrated sulphuric(VI) acid.

NB:The **experimental values** of molar heat of solution obtained in experiments are **usually lower than those quoted in data books**, since the **heat gained by the apparatus** and that **lost to the surrounding** during an experiment is **not accounted for in the calculations.**

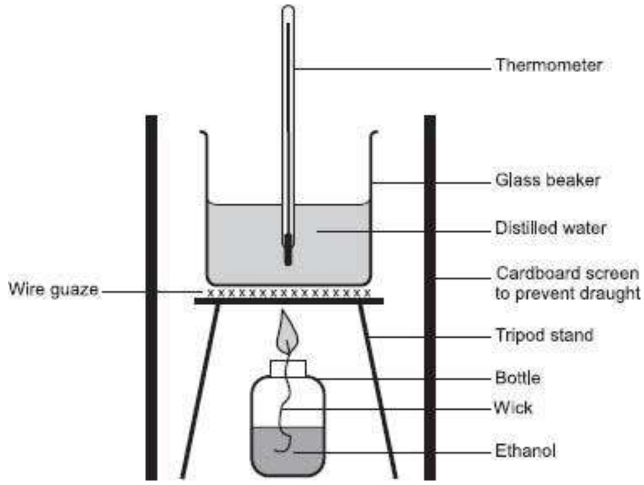
Enthalpy of combustion.

Enthalpy of combustion is the enthalpy change that occurs when a substance burns completely in oxygen.

Molar heat of combustion is the enthalpy change that occurs when one mole of a substance is completely burned in oxygen.

To determine the molar heat of combustion of ethanol,

Pour exactly 100 cm^3 of distilled water into a 250 ml glass beaker. Record the temperature of the water. Half fill a small bottle with ethanol and close the bottle with a lid fitted with a clean wick.



Weigh the bottle and its contents and arrange the apparatus as shown.

Light the wick to start heating the water. Stir the water carefully with the thermometer and extinguish the flame when the temperature of the water has risen by 15°C. Record the temperature of the water. Weigh the bottle and its contents again. Record the results obtained.

The following results were obtained in a similar experiment.

Initial mass of bottle + contents = 28.25 g

Final mass of bottle + contents = 28.02 g

Mass of ethanol burnt = 0.23 g

Final temperature of water = 43.0°C

Initial temperature of water = 28.0°C

Rise in temperature of water = 15°C (15 K)

QUESTIONs

1. **Determine the number of moles of the ethanol burned.**

Formula mass of ethanol, CH_3CH_2OH = (12 × 2) + 16 + 6 = 46 g

$$\text{Moles of ethanol burned} = \frac{0.23 \text{ g}}{46 \text{ g mol}^{-1}}$$

= 0.005 mol

2. **Determine the amount of heat given out.**

The heat evolved by the burning ethanol is absorbed by the water. It is this heat that raises the temperature of water. Therefore, the heat evolved is determined thus:

Heat evolved = Mass of solution × Specific heat capacity × Temperature change

= 0.1 kg × 4.2 kJ g^{-1} K^{-1} × 15 k = 6.3 kJ

3. **Using your answers to questions 1 and 2, calculate the molar enthalpy of combustion of ethanol.**

0.005 moles of ethanol liberate 6.3 kJ of heat.

Therefore 1 mol of ethanol will liberate:

$$\frac{6.3 \text{ kJ} \times 1.0 \text{ mol}}{0.005 \text{ mol}}$$

= 1260 Kg of heat

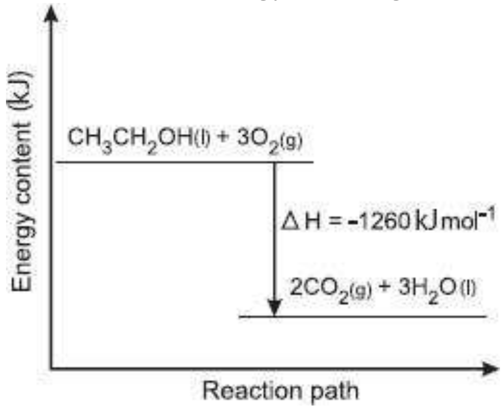
4. **The theoretical enthalpy of combustion of ethanol is –1368 kJ mol^{-1}, why does the value calculated from experimental results differ from this?**

Experimentally determined heats of combustion are usually lower than the theoretical values because the heat lost to the surrounding is not accounted for in the calculations (experimental error).

5. **Write the thermochemical equation for the reaction.**

$$CH_3CH_2OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l) \quad \Delta H = -1260 \text{ kJ mol}^{-1}$$

The thermochemical equation is illustrated on an energy level diagram as shown.



Energy level diagram for the combustion of ethanol

The negative sign is added to show that the process is exothermic.

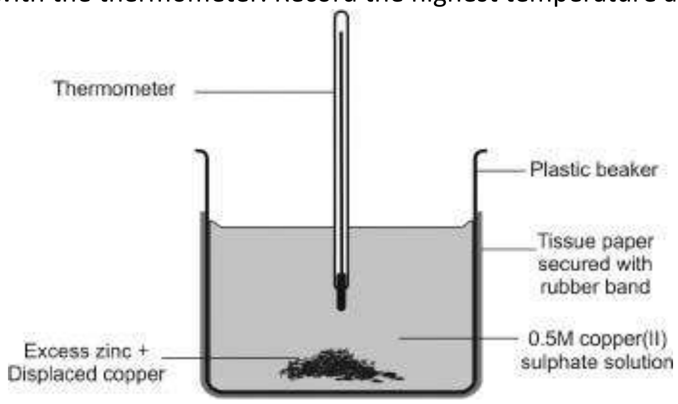
3.Enthalpy of Displacement

The enthalpy of displacement is the enthalpy change that occurs when a substance is displaced from a solution of its ions.

The Molar heat of displacement *is the enthalpy change that occurs when one mole of a subtance is diplaced from a solution of its ions.*

To determine the enthalpy of displacement of copper,

Wrap a 250 cm^3 plastic beaker with tissue paper. Measure 100 cm^3 of 0.5 M copper (II) sulphate into the beaker. Note the steady temperature of the solution. Carefully, transfer 4.0 g of zinc powder into the plastic beaker and stir carefully with the thermometer. Record the highest temperature attained by the solution.



Questions

1. **State whether the reaction is exothermic or endothermic**.

When zinc is added to copper(II) sulphate solution, an **exothermic** reaction occurs.

2. **What other observations were made? Explain.**

The **blue colour of the solution fades** as a **brown solid is deposited**.

During the reaction, the blue copper(II) ions in the solution are **reduced to copper metal** which is the **brown solid** deposited at the bottom of the beaker.The zinc atoms are **oxidised to zinc ions which are colourless**

3. **Write the equation for the reaction that takes place.**

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$

4. **Determine the temperature change for the reaction.**

The expected change in temperature for this experiment is 24.5°C (24.5 K).

5. **Calculate the number of moles of zinc used.**

$$\text{Moles of zinc used} = \frac{4\ \text{g}}{65\ \text{g mol}^{-1}}$$
$$= 0.062\ \text{mol}$$

6. **Calculate the number of moles of copper.**

$$\text{Moles of copper (II) ions} = \frac{0.5\ \text{mol} \times 100\ \text{cm}^3}{1000\ \text{cm}^3}$$
$$= 0.05\ \text{mol}$$

7. **Why is it necessary to use excess zinc powder, magnesium or iron filings in this reaction?**

Excess zinc is used in this experiment in order to ensure that all the copper(II) ions are changed to copper metal.

8. **Calculate the molar heat of displacement of copper(II) ions with zinc. Given that:**

(a) Density of solution is 1 g cm^{-3}

(b) The volume of the solution remains unchanged after the reaction.

(c) The specific heat capacity of the solution is 4.2 kJ g^{-1} K^{-1} (Cu= 63.5, S=32.0, O =16.0, Zn = 65.0)

From the equation the reaction ratio between metal and copper(II) ions is 1:1.

Heat evolved = Mass × Specific heat capacity × Temperature change

= 0.1 kg × 4.2 kJ Kg^{1} K^{1} ×24.5 K

= 10.29 kJ

Thus, when 0.05 mol of copper(II) ions are displaced from solution by zinc, 10.29 kJ of heat is evolved.

When 1 mol of Copper (II)ions are displaced, $\frac{10.29 \times 1}{0.05}$ = 205.8 kJ of heat is evolved.

The molar heat of displacement of copper by zinc therefore, is –205.8 kJ mol^{-1}

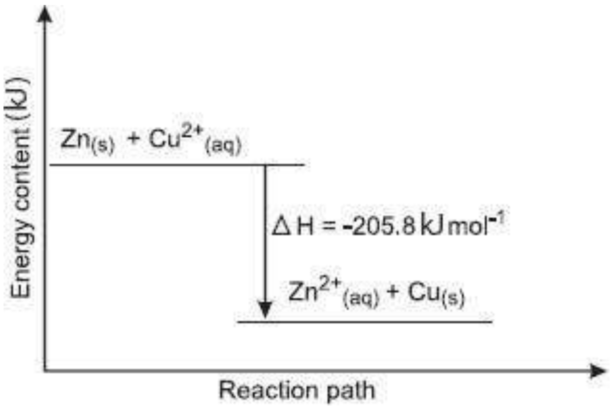
9. **Comment on your results given that the molar heat of displacement of copper (II) ions and zinc is 216 kJ mol^{-1}**

The experimental value obtained in this experiment is low because the heat lost to the surrounding and that absorbed by the apparatus is not accounted for in the calculation.

10. **Write the thermochemical equation for the reaction and represent the information in an energy level diagram.**

Thermochemical equation for the reaction is:

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+} + Cu(s)\ \Delta H = -205.8\ \text{kJ mol}^{-1}$$



Energy level diagram for displacement of copper(II) ions from solution

The value obtained when magnesium is used is higher than that of zinc and iron, while that of zinc is higher than that of iron. **The further apart the two metals are in the reactivity series, the higher the molar heat of displacement.**

4.Enthalpy of neutralisation

The enthalpy of neutralization is the enthalpy change that occurs when an acid and a base react to form water and a salt.

The molar heat of neutralisation is *the enthalpy change that occurs when an acid and a base react to produce one mole of water.*

Strong acids and strong alkalis dissociate completely in water into their ions. During neutralisation, hydrogen ions react with hydroxide ions to form water molecules. Heat energy is liberated in the process.

To determine the enthalpy of neutralization of sodium hydroxide with hydrochloric acid,

Wrap a clean 250 ml plastic beaker with tissue paper. Secure the tissue paper with a rubber band. Transfer exactly 50 cm^3 of 2 M hydrochloric acid solution into the beaker. Note the steady temperature T_1 of the hydrochloric acid solution. Using a clean dry measuring cylinder, measure exactly 50 cm^3 of 2 M sodium hydroxide solution and note its steady temperature T_2. Add the 50 cm^3 of 2 M hydrochloric acid. Carefully, stir the contents of the beaker with the thermometer while adding the sodium hydroxide solution. Note the highest temperature T_4 attained by the resulting solution. Record the results.

A sample calculation on enthalpy is shown below.

Temperature of hydrochloric acid, t_1 = 22.5°C

Temperature of sodium hydroxide solution t_2 = 22.5°C

Average temperature of the acid and alkali,

$$t_3 = \frac{t_1 + t_2}{2} = \frac{22.5 + 22.5}{2} = 22.5\ °C$$

The highest temperature of the mixture t_4

= 35.5 °C

Temperature change $\Delta T = t_4 - t_3$

= 35.5 – 22.5

= 13.0 °C

The specific heat capacity of the solution is 4.2 kJ Kg^{-1} K^{-1}. If in the experiment, 50 cm^3 of 2 M hydrochloric acid are neutralised by 50 cm^3 of 2 M sodium hydroxide, then the final volume of the resulting solution

$= 50 + 50 = 100\ cm^3$

If the density of the resulting solution is taken to be 1 g/cm^3 then:

The mass of the solution = 100 × 1 = 100 g

Heat evolved = MC ΔT

$$= \frac{100 \times 4200\ J \times 13.0}{1000}$$

= 5460 J = 5.46 kJ

Mol of hydrochloric acid used = $\frac{2 \times 50}{1000}$ = 0.1 mol. Therefore,

mol of H^+ ions = 0.1 mol since one mole of HCl produces one mole of H^+ ions.

Mol of sodium hydroxide used = $\frac{2 \times 50}{1000}$ = 0.1mol

Mol of OH^- ions = 0.1 mol.

The equation of the reaction is

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$$

Thus 1 mol of H^+ reacts with 1 mol of OH^- to form 1 mol of water.

In the reaction between the acid and the base, 0.1 mol of water are formed.

When 0.1 mol of water are formed 5.46 kJ of heat energy is evolved. Therefore, when 1.0 mol of water is formed

$$= \frac{5.46 \times 1}{0.1}$$

= 54.6 kJ of heat energy is evolved.

This is the molar heat of neutralisation of hydrochloric acid by sodium hydroxide.

The enthalpy change can be incorporated in the neutralisation equation as follows:

$$\mathbf{H^+(aq) + OH^-(aq) \longrightarrow H_2O\ (l)\ \Delta H_{neut} = -\ 54.6\ kJ\ mol^{-1}}$$

Strong acids and strong bases react to liberate about 57.2 kJ when they form one mol of water during neutralisation.

When **one of the reactants or both are weak,** the enthalpy of neutralisation is **less than in** the case when **strong acids are used with strong bases,** for example, when one **mole of hydrochloric acid (strong acid) is neutralised by one mole of ammonium hydroxide (weak base), about 51.4 kJ of heat is evolved for every one mole of water formed.**

$$\mathbf{HCl(aq) + NH_4OH(aq) \longrightarrow NH_4Cl(aq) + H_2O(l)\ \Delta H = -\ 51.4\ kJ\ mol^{-1}}$$

Similarly if **ethanoic acid (weak acid)** is neutralised by **sodium hydroxide (strong base)** only **55.2 kJ** of heat is produced for every mole of water formed.

$$\mathbf{C_2H_4CO_2(aq) + NaOH(aq) \longrightarrow C_2H_3COONa(aq) + H_2O(l)\ \Delta H = -\ 55.2\ kJ\ mol^{-1}}$$

Weak acids such as ethanoic acid or weak bases such as ammonia solution, are **only partially ionised in solution**. Therefore, **some energy is used up to ionise them** before the neutralisation takes place.

The enthalpy change obtained when a **weak acid reacts with a weak base is even lower**. For example, when ethanoic acid reacts with ammonia solution, only 50.4 kJ of heat is evolved.

$$\mathbf{CH_3COOH(aq) + NH_4OH(aq) \longrightarrow CH_3COONH_4(aq) + H_2O(l)\Delta H = -\ 50.4\ kJ\ mol^{-1}}$$

Standard Conditions For Measuring Enthalpy Changes

The standard conditions of temperature and pressure adopted are 25°C (298 K) and one atmosphere pressure (101.325 kPa) respectively. Values of enthalpy changes that are measured at these conditions are called **standard enthalpy changes**.

Standard enthalpy changes are given a special symbol; **ΔH^θ**. The symbol **'θ'** denotes '**standard'** and it implies a pressure of 101.325 kPa (i.e. one atmospheric pressure) and a temperature of 298 K (i.e., 25°C). A **subscript** is also added to the symbol to indicate the **type of enthalpy change involved.** Thus:

- **ΔH^θ_c** refers to the standard **molar enthalpy change of combustion,** e.g.,

  $$CH_4(g) + 2O_2\ O \longrightarrow CO_2(g) + 2H_2(l)\ \Delta H^\theta C_{(CH4)} = -890\ kJ\ mol^{-1}$$

- **ΔH^θ_{neut}** Refers to the standard **molar enthalpy change of neutralisaiton** e.g.

  $$HCl(aq) + NaOH(aq) \longrightarrow NaCl(aq) + H_2O(l)\ \Delta H^\theta_{neut} = -58\ kJ\ mol^{-1}$$

- **ΔH^θ_{soln}** refers to the standard **molar enthalpy change of dissolution (solution)**

  e.g., $NaNO_3\ (s) + aq \longrightarrow NaNO_3\ (aq)\ \Delta H^\theta_{Soln(NaNO3)} = +21\ kJ\ mol^{-1}$

The value of **ΔH** in a thermochemical equation refers to **molar quantities** shown in the equation. For example, the following equations show the standard molar enthalpy change of formation of water.

$$HCl\ (aq) + NaOH\ (aq) \longrightarrow NaCl\ (aq) + H_2O\ (l)$$

$$H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)\ \Delta H = -57.2\ kJ\ mol^{-1}$$

Note that **only one mole of H_2O** is shown in the above equation.

$$H_2SO_4(aq) + NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

The equation for the formation of two moles of would be:

$$2H^+(aq) + 2OH^-(aq) \longrightarrow 2H_2O(l)\ \Delta H = -114.4\ kJ^{-1}$$

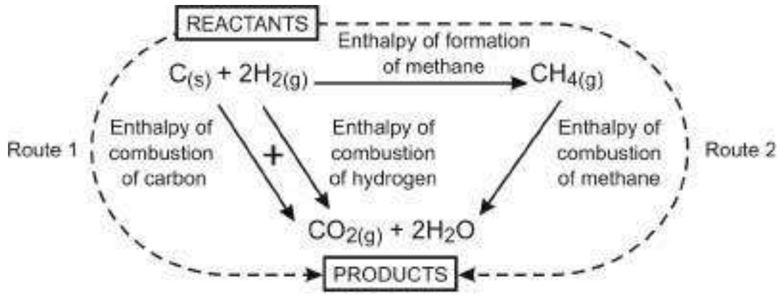
The **amount of heat evolved when two moles are formed is therefore twice what is evolved when one mole is formed.** Note that the units for **ΔH^θ is the kilo joule per mole (kJ mol^{-1}).**

Hess's Law

Hess's Law of constant heat summation states that *The energy changes in converting reactants to products is the same regardless of the route by which the chemical change occurs.*

This law is applied in determining theoretically the enthalpy change for some reactions that cannot be determined experimentally because the reactions cannot take place under normal conditions.

An **energy cycle diagram** that links the reactants and products is used. This provides various routes for which a reaction can occur and can be used to determine various enthalpies, for example the enthalpy of formation of methane.



Energy cycle diagram incorporating enthalpy of formation of methane

In the energy cycle above, there is **more than one way** of converting carbon and hydrogen into carbon(IV) oxide and water respectively. Carbon and hydrogen can either be **burned directly (route 1)** or they can **first be combined to form methane which can then be burned (route 2).**

Whether **route 1** or **route 2** is followed, the **end product is the same**. This means that the **energy changes for route 1 are equal to the energy changes for route 2.** This must be so because of the **law of conservation of energy**. The enthalpy of formation of methane can then be calculated from the expression:

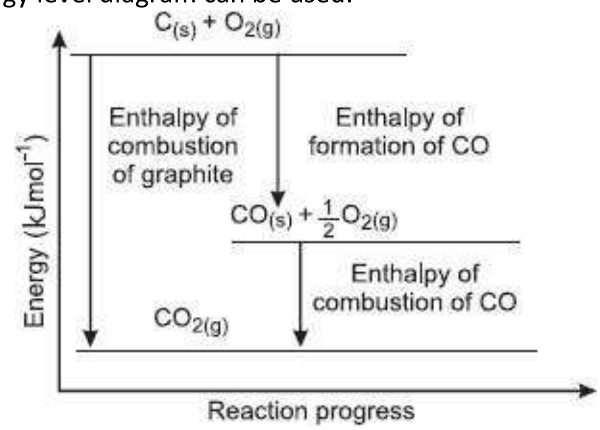
$$\boxed{\text{Enthalpy of formation of methane}} = \boxed{\text{Enthalpy of combustion of carbon}} + \boxed{\text{Enthalpy of combustion of hydrogen} \times 2} - \boxed{\text{Enthalpy of combustion of methane}}$$

$= -393 + (-286 \times 2) - (-890)$

$= -965 + 890$

$= -75 \text{ kJ mol}^{-1}$

An **energy level diagram** can also be used. For example, to determine the enthalpy of formation of **carbon (II) oxide**, the following energy level diagram can be used.



Energy level diagram for formation of carbon(II) oxide

From the energy level diagram, the enthalpy of formation of carbon(II) oxide would be given by:

Enthalpy = Enthalpy of combustion of C(s) – Enthalpy of combustion of CO(g)

ΔHθf CO(g) = ΔHθC C(s) - ΔHθC CO(g)

= –393 – –283

= – 170 kJ mol-1

Application of Hess's law relies on the **information provided by thermochemical equations for the reaction in question.**

Information provided by the thermochemical equations can be used to **draw energy cycle and energy level diagrams** linking the **equations** for a reaction as well as determine the **enthalpy change** for the **reaction**.

Worked Examples

1. The thermochemical equation for the combustion of carbon (graphite) and carbon(II) oxide are as follows:

$C(s) + O_2(g) \longrightarrow CO_2(g)$ ΔH= –393 kJ mol^{-1}

$CO(g) + \frac{1}{2} O_2(g) \longrightarrow CO(g)$ ΔH= – 283 kJ mol^{-1}

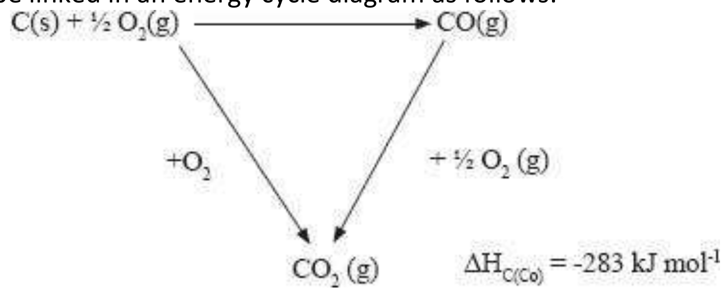
(a) Use the information provided to draw:

(i) An energy cycle diagram.

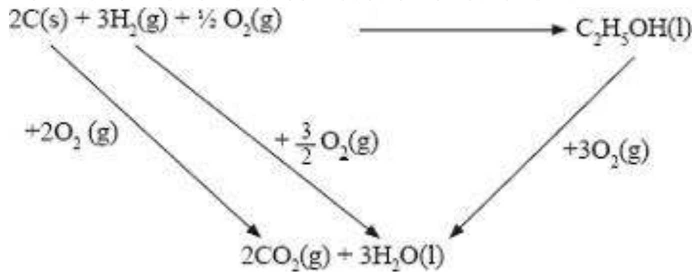
(ii) An energy level diagram for the reaction.

(b) Use the energy cycle and energy level diagrams drawn in (a) to determine the enthalpy of formation of carbon(II) oxide.

These equations can be linked in an energy cycle diagram as follows:



The energy cycle diagram for the formation and combustion of ethanol is :



From the energy level diagram:

$$\begin{matrix}\text{Enthalpy of formation} \\ \text{of ethanol}\end{matrix} = 2\times \begin{matrix}\text{Enthalpy of combustion} \\ \text{of carbon}\end{matrix} + 3\times \begin{matrix}\text{Enthalpy of combustion} \\ \text{of hydrogen}\end{matrix} - \begin{matrix}\text{Enthalpy of combustion} \\ \text{of ethanol}\end{matrix}$$

$\Delta H^{\theta}_f(C_2H_5OH(l)) = 2\Delta H^{\theta}_c\ (C(s) + 3\Delta H^{\theta}_c\ (H_2(s) - \Delta H_c(C_2H_5OH(l)$

= 2 × (–393) + 3 × (–286)–(–1368)

= –786 + (–858) – (–1368)

= –1644 + 1368

= – 276 kJ mol^{-1}

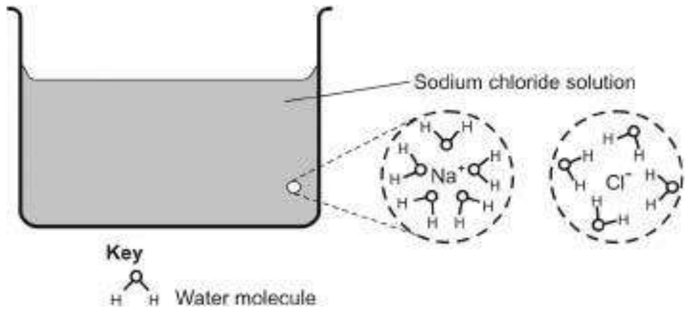
Relationship Between Heat of Solution, Hydration and Lattice Energy

Lattice energy is *the energy change when one mole of an ionic compound is formed from its constituent ions in the gaseous state.*

When an ionic substance dissolves, energy equivalent to the lattice energy is absorbed. For example, when sodium chloride is dissolved in water, the ionic bonds are first broken to release the gaseous ions.

$$NaCl(s) \xrightarrow{water} Na^{+}(g) + Cl^{-}(g) \qquad \Delta H^{\circ} = +776\ kJ\ mol^{-1}$$

The sodium and chloride, ions get surrounded by several water molecules. The water molecules surrounding the sodium ions arrange themselves in such a way that the partially negative oxygen is attracted to the positive sodium ion and the partially positive hydrogen is attracted to the negative chloride ions and the ions thus become hydrated.



The hydration process involves the formation of new bonds between the polar water molecules and the ions. The process is always exothermic. The energy given out is known as **hydration energy**.

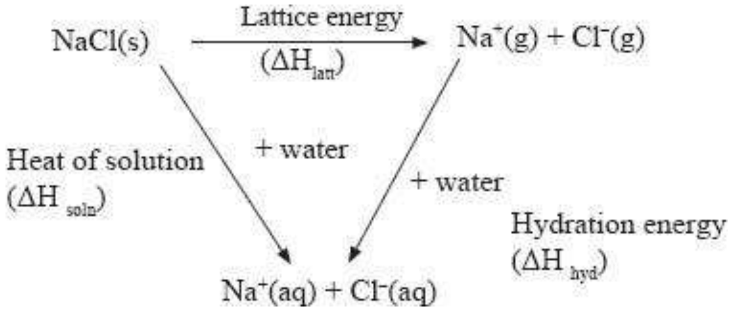
$$Na^{+}(g) \xrightarrow{H_2O} N^{+}(aq) \qquad \Delta H^{\theta} = -390\ kJ\ mol^{-1}$$

$$Cl^{-}(g) \xrightarrow{H_2O} Cl(aq) \qquad \Delta H^{\theta} = -384\ kJ\ mol^{-1}$$

Hydration *energy is defined as the energy change that occurs when one mole of gaseous ions become hydrated.*

The overall enthalpy change of solution depends on whether the endothermic or the exothermic process is larger.

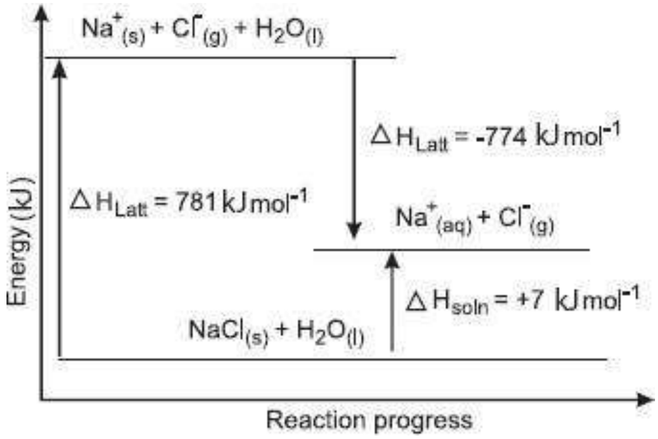
For sodium chloride, the endothermic process is greater than the exothermic process. Therefore, the enthalpy of solution of sodium chloride has a positive value. The following energy cycle diagram can be used to calculate the heat of solution of sodium chloride.



From the energy cycle diagram,

Heat of solution = Lattice energy + hydration energy

$\Delta H_{sol} = \Delta H = \Delta H_{hyd}$
$= 781 + (-774)$
$= +7\ kJ\ mol^{-1}$



Energy level diagram for dissolving sodium chloride

The lattice energy is given positive values in the calculations above because bond breaking is an endothermic process.

The hydration energy for sodium chloride is the sum of the separate hydration energies of sodium ions and chloride ions, i.e.,

$$\Delta H_{hyd}\ NaCl = \Delta H_{hyd}\ (Na^+) + \Delta H_{hyd}\ (Cl^-)$$
$$= -390 + (-384)$$
$$= -774\ kJ$$

When ions are hydrated, the amount of energy released depends on the size of the ions and the charge on the ions. .

Enthalpies of hydration of some common ions

Ion	ΔH_{hyd} (kJ mol^{-1})	Ion	ΔH_{hyd} (kJ mol^{-1})
H^+	–1075	F^-	–457
Li^+	–449	Cl^-	–384
Na^+	–390	Br^-	–351
K^+	–305	I^-	–307
NH^{+4}	–281	OH^-	–460
Mg^{2+}	–1891		
Ca^{2+}	–1562		
Al^{3+}	–4613		

Lattice energies of some ionic common compounds

Compound	ΔH kJ mol^{-1}
NaF	–915
NaCl	–781
Na Br	–743

NaI	–699
MgCl2	–2489
MgO	–3933
AgCl	–890

Fuels

A fuel *is a substance that produces useful energy when it undergoes a chemical or nuclear reaction.*

Fuels can be **solids** such as **nuclear fuel, coke, coal, charcoals and wood.**

Other fuels are **liquids** such as **petrol, kerosene and diesel oil,** or **gases** like **natural gas, biogas, water gas and petroleum gas.**

Heating Values of Fuels

The **heating value of a fuel** is ***the amount of heat energy given out when a unit mass, or a unit volume of a fuel is completely burned in oxygen.***

The heating value of a fuel is obtained by **dividing the molar enthalpy of combustion by the formula mass of the fuel.**

Heating value has the units kJ g^{-1} (kilojoules per gram).

For example, **ethanol** has an enthalpy of combustion of **-1360 kJ/mol.** On dividing this by the formula mass of ethanol, **46**, we get the heating value of ethanol as **30 kJ g^{-1}.**

Heating values of various fuels

Fuels	**Heating value in J/g**
Solid Fuels	
Charcoal	33
Coal	29
Wood	17
Liquid fuels	
Ethanol	30
Fuel oil	45
Paraffin	48
Gaseous Fuels	
Methane (natural gas)	55
Propane	50
Butane	48

How to choose a fuel

The choice of a fuel depends on the purpose it is to be used for. The following points have to be considered in each case:

- Heating value.

- Ease and rate of combustion.
- Availability.
- Ease of transportation.
- Ease of storage.
- Environmental effects.
- Cost.

For example, wood and charcoal are chosen for domestic heating because:

- They are cheap.
- The are readily available.
- They can be easily transported.
- When they burn they do not produce poisonous products.
- They burn slowly.

Methylhydrazine (CH_3NHNH_3) is used for rocket propulsion because:

- It burns very rapidly producing large amounts of gases which in turn create a huge thrust as they escape.
- It has a very high heat of combustion (4740 kJ mol^{-1}).
- It ignites easily.

Precautions Necessary When Using Fuels

Improper handling of fuels can result it death and destruction of property. Each type of fuel should be handled with the necessary care and precautions:

- Charcoal stoves should be operated in well ventilated rooms to avoid poisoning by carbon(II) oxide.
- Vehicle engines should not be left running in closed garages to avoid poisoning by carbon(II) oxide.
- Gas cylinders should be stored in well ventilated rooms far from heat sources. Only certified cylinders should be used for gas transportation.
- Fuel storage facilities should be located far away from populated areas.
- People should keep off from fuel spilled from tankers.

Environmental Effects of Fuels

Fossil fuels such as coal and petroleum contain carbon, nitrogen and sulphur compounds which on burning produce poisonous gases such as sulphur(IV) oxide, sulphur(VI) oxide, carbon(II) oxide and nitrogen(IV) oxide.

The sulphur and nitrogen oxides dissolve in rain-water to produce acid rain. Acid rain:

- Wears limestone buildings and statues.
- Corrodes iron sheets, iron gates and other metallic structures.
- Acidifies lakes leading to death of plants and animals in the lakes.
- Leaches nutrients from plant leaves leading to their death.
- Leaches minerals from the soil leading to poor soil for agricultural activities.

Carbon(IV) oxide and unburned hydrocarbons from fuels contribute to global warming. Global warming causes polar ice to melt causing inundation of low lying coastal lands. Other effects of global warming include unpredictable weather patterns and climatic changes.

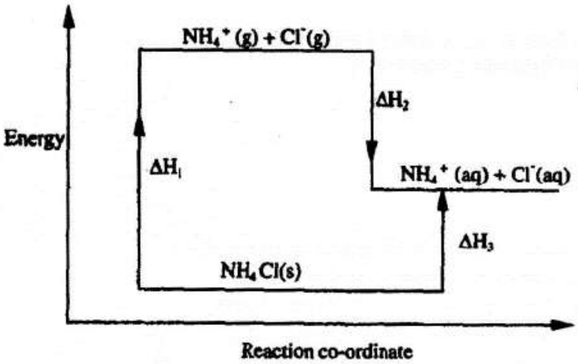
Measures that are being taken to reduce pollution:

- Designing zero emission vehicles which use solar energy or electrical energy.

- Fitting catalytic converters to vehicle exhaust systems. These catalytic converters convert nitrogen oxides to harmless nitrogen, carbon(II) oxide to carbon(IV) oxides, unburned hydrocarbons to water and carbon(IV) oxide.
- Designing engines which uses unleaded petrol.
- Electronically controlling the quantity of air mixed with fuel to ensure more complete combustion.
- Adding fuels which contain oxygen in their molecules to petrol. For example, methanol and ethanol may be added to petrol. These fuels reduce the quantities of carbon(II) oxide and unburned hydrocarbons emitted.
- Encourage other means of transport such as the use of bicycle and electric trains.

1. 2006 Q 28 P1

Study the diagram below and answer the questions that follow.



(a) What do ΔH_1 and ΔH_2 represent? (2 marks)

(b) Write an expression to show the relationship between ΔH_1, ΔH_2 and ΔH_3. (1 mark)

2. 2006 Q 2a P2

In an experiment to determine the molar heat of reaction when magnesium displaces copper, 0.15g of magnesium powder were added to 25.0cm^3 of 2.0M copper (II) chloride solution. The temperature of copper (II) chloride solution was 25 °C, while that of the mixture was 43 °C.

(i) Other than increase in temperature, state and explain the observations which were made during the reaction. (3 marks)

(ii) Calculate the heat change during the reaction (specific heat capacity of the solution= 4.2jg^{-1}K^{-1} and the density of the solution = 1g/cm^3)

(2 marks)

(iii) Determine the molar heat of displacement of copper by magnesium. (Mg=24.0). Write the ionic equation for the reaction.
(1 mark)

(iv) Sketch an energy level diagram for the reaction. (2 marks)

3. 2007 Q 10 P1

The thermo chemical equations for the formation of hydrogen peroxide under standard conditions are:

$H_2(g) + O_2(g) \longrightarrow H_2O_2(g)$; $\Delta H^\theta_f = -133kJmol^{-1}$

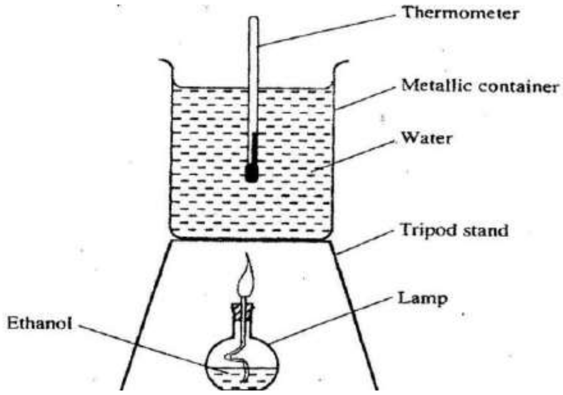
$H_2(g) + O_2(g) \longrightarrow H_2O(l)$; $\Delta H^\theta_f = -188\ kJmol^{-1}$

Write the thermo chemical equation for the molar heat of vaporization of hydrogen peroxide.
(2marks)

4. 2007 Q 1 P2

(a) State two factors that should be considered when choosing fuel for cooking. (2 marks)

(b) The diagram below represents a set–up that was used to determine the molar heat of combustion of ethanol.



During the experiment, the data given below was recorded:

Volume of water	***450 cm^3***
Initial temperature of water	***25.0 °C***
Final temperature of water	***46.5 °C***
Mass of ethanol + Lamp before burning	***125.5 g***
Mass of ethanol + lamp after burning	***124.0 g***

Calculate the:

(i) Heat evolved during the experiment. (density of water = 1g/cm^3, specific heat capacity of water = 4.2 $Jg^{-1}K^{-1}$)
(3 marks)

(ii) Molar heat of combustion of ethanol. (C = 12.0, O = 16.0, H=1.0) (2 marks)

(c) Write the equation for the complete combustion of ethanol. (1 mark)

(d) The value of the molar heat of combustion of ethanol obtained in (b) (ii) above is lower than the theoretical value. State two sources of error in the experiment.
(2 marks)

5. 2008 Q 7 P2

(a) Define the standard enthalpy of formation of a substance (1 mark)

(b) Use the thermo chemical equations below to answer the questions that follow.

1. $C_2H_6(g) + {}^7/_2O_2(g) \longrightarrow 2CO_2(g) + 3H_2O\ (L)$; ΔH_1 - 1560kjmol^{-1}

2. $C_{(graphite)} + O_2\ (g) \longrightarrow CO_2(g)$; $\Delta H_2 = -394kJmol^{-1}$

3. $H_2(g) + {}^1/_2O_2\ (g) \longrightarrow H_2O(g)$ $\Delta H_3 = -286kJmol^{-1}$

(i) Name two types of heat changes represented by ΔH_3 (2 marks)

(ii) Draw an energy level diagram for the reaction represented by equation 1. (2 marks)

(iii) Calculate the standard enthalpy of formation of ethane (2 marks)

(iv) When a sample of ethane was burnt, the heat produced raised the temperature of 500g of water by 21.5 K, (specific heat capacity of water = 4.2Jg^{-1}K$^{-)}$.
Calculate the:

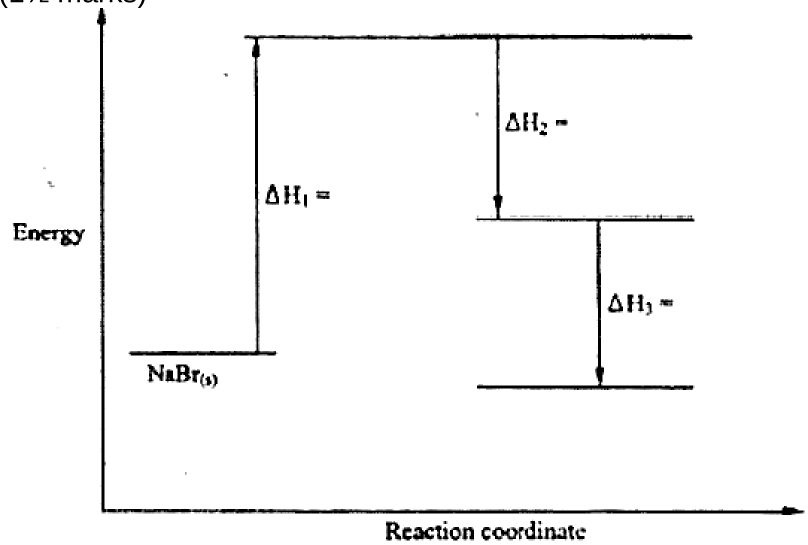
I. Heat change for the reaction (2 marks)
II. Mass of ethane was burnt. (R.F.M of ethane= 30) (2 marks)

6. 2009 Q 9 P1

(a) What is meant by molar heat of solution? (1 mark)

(b) The lattice energy of sodium bromide and hydration energies of sodium and bromide ions are: 733, 406 and 335 kJmol^{-1} respectively

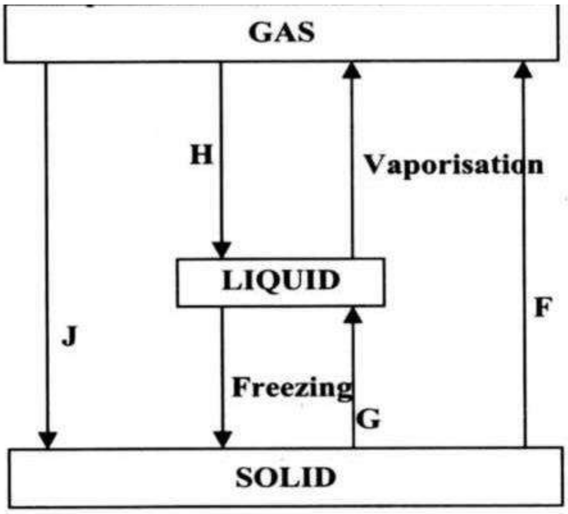
(i) Complete the energy cycle diagram above by inserting the values of ΔH_1, ΔH_2 and ΔH_3.
(1½ marks)



(ii) Determine the molar heat of solution of solid sodium bromide. (½ mark)

7. 2009 Q 5 P2

(a) **Figure 3** shows the changes that take place between state of matter. Some of them Have been identified and others labelled.



(i) Give the names of the process:

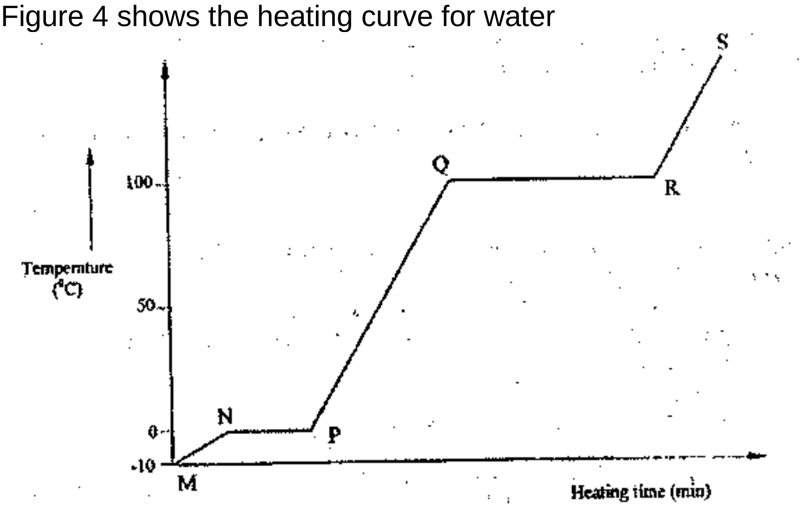
I. H (1 mark)

II. G (1 mark)

(ii) Name one substance that can undergo process **F** When left in an open container in the laboratory. (1 mark)

(iii) The process J is called deposition. Using water is an example; write an equation that represents the process of deposition. (1 mark)

(b) Figure 4 shows the heating curve for water



(i) Give the names of the intermolecular forces of attraction in the segments.

I. **MN** (1 mark)

II. **RS** (1 mark)

(ii) The heat of fusion and evaporation of water are 334.4 Jg- and 1159.4 Jg- respectively.

I. Explain why there is a big difference between the two. (2 marks)

II. How is the difference reflected in the curve? (1 mark)

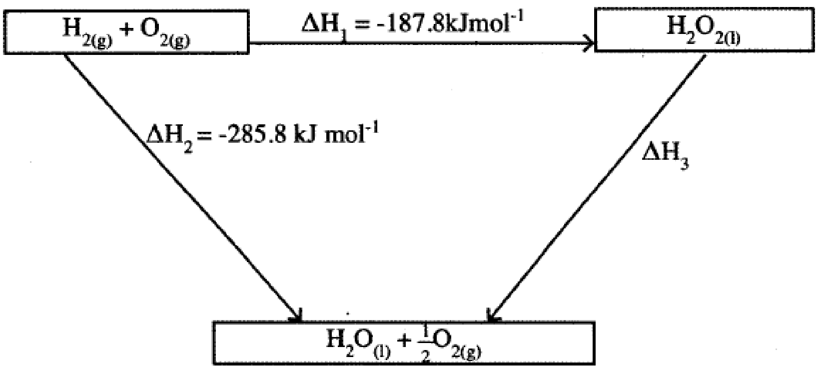
(b) Coal, oil and natural gas are major sources of energy. They are known as fossil Hydrogen is also a source of energy.

(i) State and explain two reasons why hydrogen is a very attractive fuel compared to fossil fuels (3 marks)

(ii) State one disadvantage of using hydrogen fuel instead of fossil fuel. (1mark)

8. 2010 Q 10 P1

The figure below shows an energy cycle.



(a) Give the name of the enthalpy change ΔH_1. (1 mark)

(b) Determine the value of ΔH_3. (2 marks)

9. 2010 Q 12 P1

A beaker contained 75.0cm^3 of aqueous copper (II) sulphate at 23.7 °C when scrap iron metal was added to the solution, the temperature rose to 29.3 °C.

(a) Write an ionic equation for the reaction that took place. (1 mark)

(b) Given that the mass of copper deposited was 5.83g, calculate the molar enthalpy change in kJmol-1. (Specific heat capacity of solution = 4.2Jg^{-1} K^{-1}, density of solution 1.0gcm^{-3}, Cu = 63.5) (2 marks)

10. 2010 Q 4 P2

(a) 50cm^3 of 1M copper (II)sulphate solution was placed in a 100cm^3 plastic beaker. The temperature of the solution was measured. Excess metal A powder was added to the solution, the mixture stirred and the maximum temperature was repeated using powder of metals B and C. The results obtained are given in the table below:

	A	**B**	**C**
Maximum temperature (°C)	26.3	31.7	22.0
Initial temperature (°C)	22.0	22.0	22.0

(i) Arrange the metal **A**, **B**, **C** and copper in order of reactivity starting with the least reactive. Give reasons for the order. (2 marks)

(ii) Other than temperature change, state one other observation that was made when the most reactive metal was added to the copper (II) sulphate solution. (1 mark)

(b) The standard enthalpy change of formation of methanol is -239 $kJmol^{-1}$.

(i) Write the thermal chemical equation for the standard enthalpy change of formation of methanol. (1 mark)

(ii) Methanol is manufactured by reacting carbon (II)oxide with hydrogen at 300 °C and a pressure of 250 atmospheres.
The equation for the reaction is:

$$CO_{(g)} + 2H_{2(g)} \rightleftharpoons CH_3OH_{(g)}$$

(I) How would the yield of methanol be affected if the manufacturing process above is carried out at 300 °C and a pressure of 400 atmosphere? Explain (2 marks)

(II) Use the following data to calculate the enthalpy change for the manufacture of methanol from carbon(II)oxide and hydrogen. (3 marks)

$$CO(g) + \tfrac{1}{2}O_2(g) \longrightarrow CO_2(g);\ \Delta H^{\theta} = -283kJmol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow H_2O(i);\ \Delta H^{\theta} = -286kJmol^{-1}$$

$$CH_2OH(l) + \tfrac{3}{2}O_2(g) \longrightarrow CO_2(g) + 2H_2O(l);\ \Delta H^{\theta} = -715kJmol^{-1}$$

(iii) The calculated enthalpy change in part b(ii) (II) above differ from the standard enthalpy change of formation of methanol. Give a reason. (1 mark)

11. 2011 Q 23 P1
The thermal chemical reaction between carbon and sulphur is as shown by the equation below

$$C(s) + 2S(s) \longrightarrow CS_2(l) \qquad \Delta H = +117.0\ kJmol^{-1}$$

On the grid below, sketch and label the energy diagram for the reaction. (2 marks)

12. 2011 Q 7 P2

(a) What is meant by molar heat of combustion? (1 mark)

(b) State the Hess's Law. (1 mark)

(c) Use the following standard enthalpies of combustion of graphite, hydrogen and enthalpy of formation of propane.

ΔH^{θ}_c (Graphite) = -393 $kJmol^{-1}$
ΔH^{θ}_c ($H_2(g)$) = -286 $kJmol^{-1}$
ΔH^{θ}_f (C_3H_8 (g)) = -104 $kJmol^{-1}$

(i) Write the equation for the formation of propane. (1 mark)

(ii) Draw an energy cycle diagram that links the heat of formation of propane with its heat of combustion of graphite and hydrogen. (3 marks)

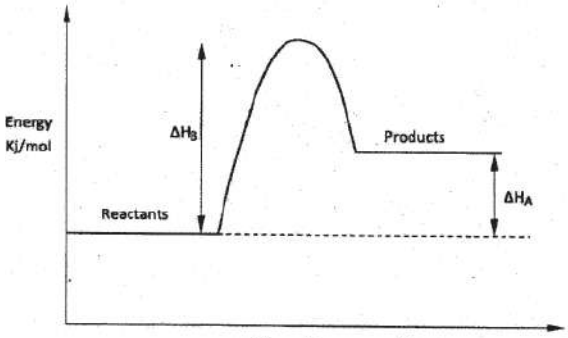
(iii) Calculate the standard heat of combustion of propane. (2 marks)

(d) Other than the enthalpy of combustion, state one factor which should be considered when choosing a fuel. (1 mark)

(e) The molar enthalpies of neutralization for dilute hydrochloric acid and dilute nitric (V) acid are -57.22 kJmol- while that of ethanoic acid is -55.2 kJmol-. Explain this observation. (2 marks)

13. 2012 Q17 P1

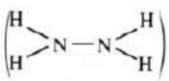
Study the energy level diagram below and answer the questions that follow.



(a) Give the name of ΔH_a (2 marks)

(b) How can ΔH_b be reduced? Give a reason (2 marks)

14. 2013 Q11 P1

Hydrazine gas,  burns in oxygen to form nitrogen gas and steam.

(a) Write an equation for the reaction (1 mark)

(b) Using the bond energies given below, calculate the enthalpy change for the reaction in (a) above.
(2 marks)

Bond	**Bond energy (kJ per mole)**
N ≡ M	944
N - N	163
N - H	388
O = O	496
H - O	463

15. 2013 Q27 P1

A student investigated a property of acids M and N by reacting equal volumes of acid M and N of the same concentration with equal volumes of 2M potassium hydroxide. The results were recorded in the table below.

Acid	Rise in temperature(Δ)K
M	4
N	2

(a) Which of the acids is likely to be a weak acid? Explain. (2 marks)
(b) Write the equation for the reaction between ethanoic acid and potassium hydroxide.

(1 mark)

16. 2013 Q2 P2

(a) (i) what is meant by the term Enthalpy of formation? (1 mark)

(ii) The enthalpies of combustion of carbon, methane and hydrogen are indicated below:

$C(s) + O_2(g) \longrightarrow CO_2(g)$; $\Delta H = -393$ kJ mol^{-1}

$H_2(g) + O_2(g) \longrightarrow H_2O$ (l); $\Delta H = -286$ kJ mol^{-1}

Enthalpy of combustion of $CH_4 = -890$ kJ mol^{-1}

I. Draw an energy cycle diagram that links the enthalpy of formation of methane to enthalpies of combustion of carbon, hydrogen and methane (2 marks)

II. Determine the enthalpy of formation of methane (2 marks)

(b) An experiment was carried out where different volumes of dilute hydrochloric acid and aqueous sodium hydroxide both at 250c were mixed and stirred with a thermometer. The highest temperature reached by each mixture was recorded in the table below

Volume of hydrochloric acid (cm^3)	5	10	15	20	25	30	35	40	45
Volume of sodium hydroxide (cm^3)	45	40	35	30	25	20	15	10	5
Highest temperature of mixture(°C)	27.2	29.4	31.6	33.8	33.6	31.8	30.0	28.4	26.6

(i) On the grid provided. plot a graph of highest temperature (vertical axis) against volume of hydrochloric acid (horizontal axis) (3 marks)

(ii) Using your graph, determine the

I. Highest temperature reached; (½ mark)

II. Volume of acid and base reacting when highest temperature is reached. (½ mark)

(iii) Calculate the amount of heat liberated during the neutralization process. (specify heat capacity is 4.2 $Jg^{-1}K^{-1}$ and the density of solution is 1.0 gcm^{-3}) (2 marks)

(c) The molar enthalpy of neutralization between hydrochloric acid and ammonia solution was found to be -52.2 kJmol^{-1}, while that of hydrochloric acid and sodium hydroxide was - 57.1 kJmol^{-1}. Explain the difference in these values. (2 marks)

17. 2014 Q14 P1

When 20cm^3 of 1 M sodium hydroxide was mixed with 20cm^3 of 1 M hydrochloric acid, the temperature rose by 6.7 °C. Assuming the density of the solution is 1 g/cm^3 and the specific heat capacity of the solution is 4.2Jg^{-1}K^{-1};

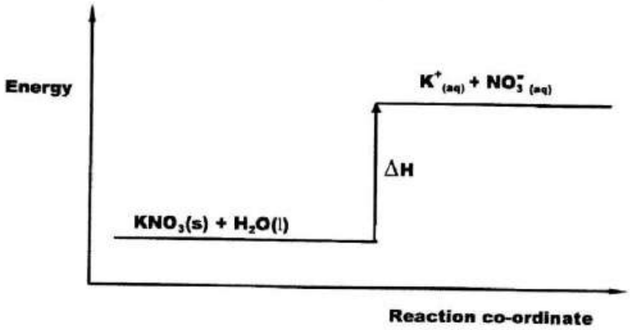
(a) Calculate the molar heat of neutralization; (2 marks)

(b) When the experiment was repeated with 1 M ethanoic acid, the temperature changes was found to be lower than that with 1 M hydrochloric acid. Explain. (1 mark)

18. 2015 Q3 P1

(a) What is meant by lattice energy? (1 mark)

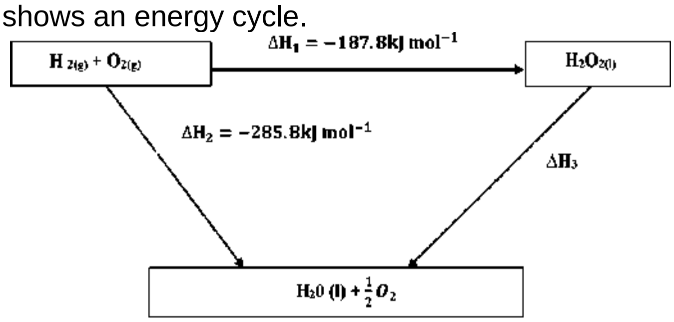
(b) Study the energy level diagram below and answer the question that follows



What type of reaction is represented by the diagram? (1 mark)

19. 2016 Q3 P1

The figure below shows an energy cycle.



(a)Give the name of the enthalpy change ΔH_1. (1 mark)

(b) Determine the value of ΔH_3. (2 Marks)

20. 2017 P1 Q19.

The following procedure was used to investigate the temperature changes that occur when sodium hydroxide solution is added to dilute hydrochloric acid.

(i) Place the acid in a glass beaker and record its temperature.
(ii) Add a known volume of sodium hydroxide solution.
(iii) Stir the mixture and record the highest temperature reached.
(iv) Repeat steps (ii) and (iii) with different volumes of sodium hydroxide solution.

(a) State two factors that must be kept constant in this experiment. (1 mark)

(b) Explain how the use of a polystyrene cup will affect the results. (1 mark)

21. 2018 P1 Q 18.

(a) Define molar heat of displacement. (1 mark)

(b) The following ionic equation represents the reaction between metal Y and an aqueous solution of Z^{2+}.

Z^{2+} (aq) + Y(s) Z(s) + Y2 (aq); ΔH = -ve

Draw an energy level diagram to represent the reaction. (2 marks)

22. 2019 P1 Q17.

The heat of solution and hydration energy of potassium chloride is -17.2 kJ and -689 kJ respectively.

Calculate the lattice energy of potassium chloride. (2 marks)

23. 2019 P1 Q 18.

Use the information in **Table 2** to answer the questions that follow.

Bond	Bond energy (KJ mol-)
C-H	412
Cl-Cl	242
C-Cl	338
H-Cl	431

(a) State what is meant by heat of reaction. (1 mark)

(b) Calculate the heat change when one mole of methane reacts completely with excess chlorine in the presence of UV light. (2 marks)

24. 2019 P2 Q5.

(a) What is meant by a molar heat of neutralisation? (1 mark)

(b) In an experiment to determine the molar heat of neutralisation, 50 cm^3 of 1 M hydrochloric acid was neutralised by adding 10 cm^3 Onions Of dilute sodium hydroxide.
During the experiment, the data in **Table 1** was obtained.

Table 1

Volume of sodium hydroxide (cm^3)	0	10	20	30	40	50	60
Temperature of mixture (°)	25.0	27.0	29.0	31.0	31.0	30.0	29.0

(i) Write the equation for the reaction in this experiment. (1 mark)

(ii) On the grid provided, plot a graph of temperature (Y-axis) against volume of sodium hydroxide (X-axis) added. (3 marks)

(iii) Determine from the graph the:

I. volume of sodium hydroxide which completely neutralises 50 cm^3 of 1M hydrochloric acid. (1 mark)

II. change in temperature, ΔT, when complete neutralisation occurred. (1 mark)

(iv) Calculate:

I. The heat change, ΔH, when complete neutralisation occurred. (Specific heat capacity = 4.2 Jg^{-1} K^{-1} density of solution 1.0 gcm^{-3}) (2 marks)

II. Molar heat of neutralisation of hydrochloric acid with sodium hydroxide. (1 mark)

(v) How would the value of molar heat differ if 50 cm^3 of 1M ethanoic acid was used instead of 1M hydrochloric acid? Give a reason. (2 marks)