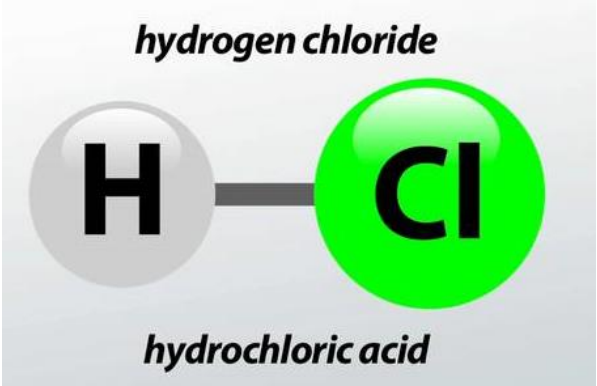
AS / A LEVEL CHEMISTRY

Introduction to enthalpy

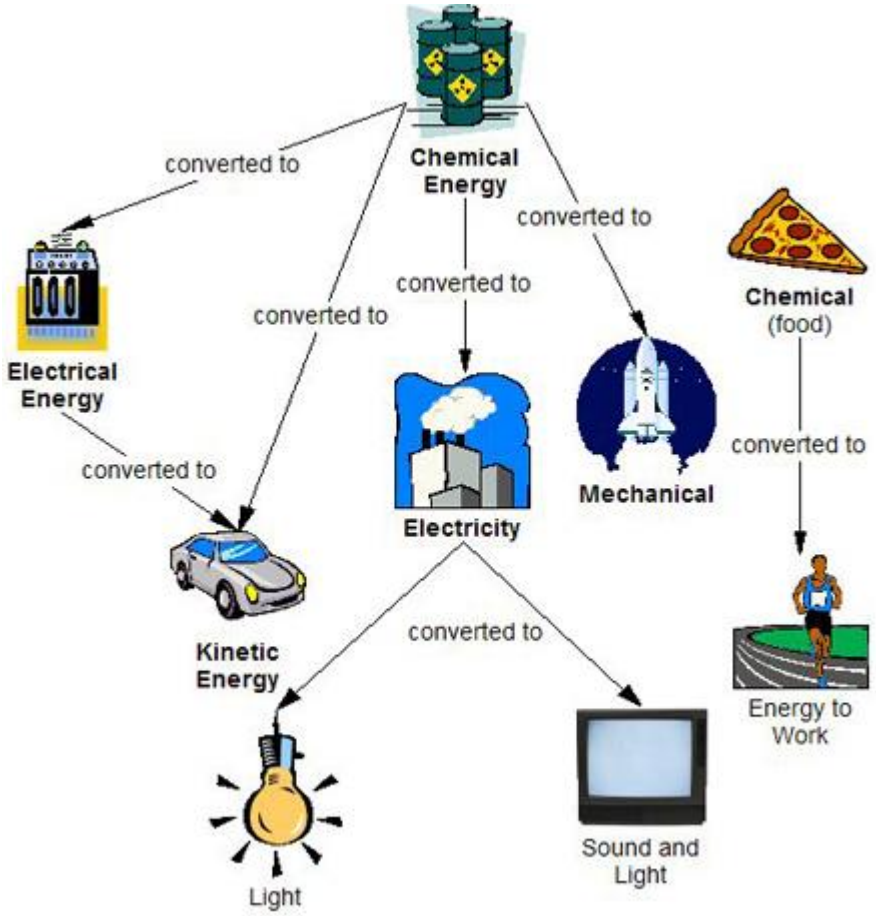
1. Conservation energy
2. System and surroundings
3. What is enthalpy
4. Standard conditions
5. Standard enthalpy change
6. Enthalpy profile diagrams
7. Activation energy
8. A variety of enthalpy changes:
    - Reaction
    - Formation
    - Combustion
    - Neutralisation
    - Solution
    - Atomisation
    - Hydration
9. Exam style questions
10. Summary

CONSERVATION OF ENERGY

- Chemical bonds are the forces of attraction that bind atoms together
  - Chemical energy lies within these chemical bonds

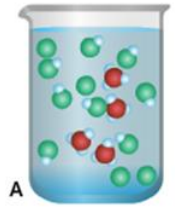


  - It is form potential energy
- In chemical reactions, energy is changed from one form to another
  - E.g. chemical energy may change to thermal energy
- No energy is lost
  - It is converted from one form to another



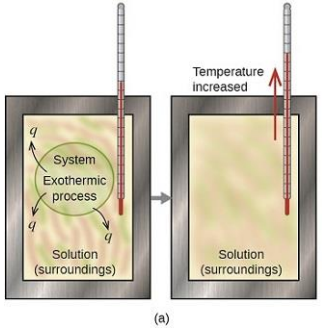
WHAT IS ENTHALPY

- Enthalpy, H, is the thermal energy that is stored in a system.
  - We can't measure the direct enthalpy of products and reactants

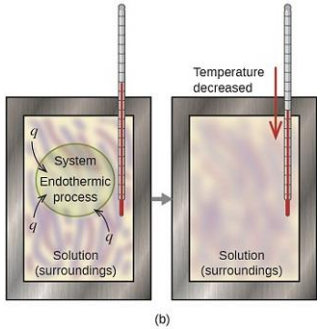


  - Instead, we can measure the amount of energy that is absorbed or released to the surroundings.
    - The method in which this is done can vary
      - You can measure the change in energy by looking at the change in thermal energy

- **Temperature increase**
  - Heat gain to surroundings
  - Heat loss in a chemical system

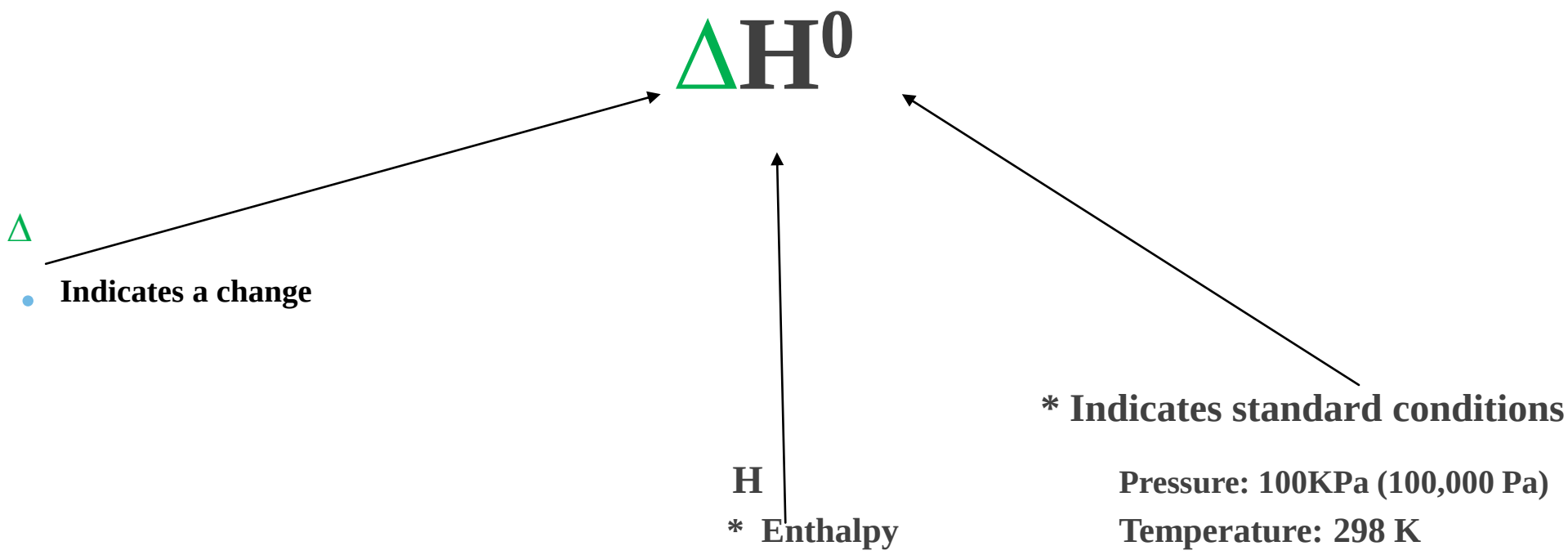


- **Temperature decrease**
  - Heat loss to surroundings
  - Heat gain in a chemical system



Enthalpy change, ΔH, is the heat energy change at a constant pressure

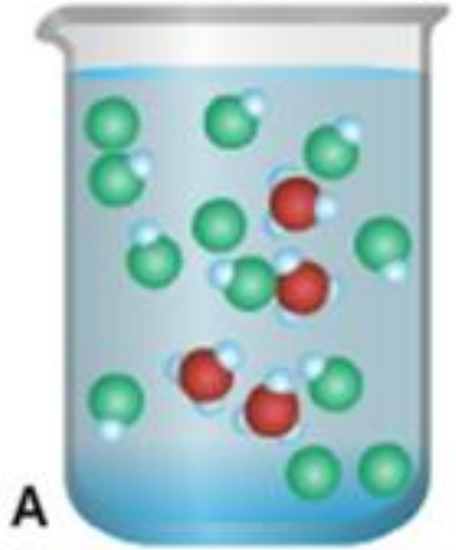
STANDARD CONDITIONS



- **Standard states** are the states which substances are under **standard conditions.**
- **For example, the standard state** of water is **liquid** and the **standard state** of magnesium is **solid.**

SYSTEM AND SURROUNDINGS

- These are part of the terminology used to discuss components of chemical reactions
- System
  - The chemical reaction
    - Atoms
    - Bonds
- Surroundings
  - Everything else



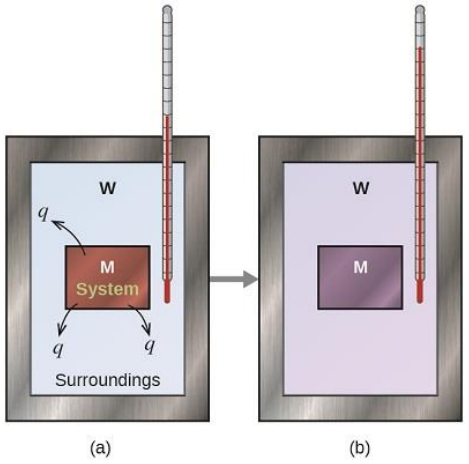
e.g. $HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$

ENTHALPY CHANGES

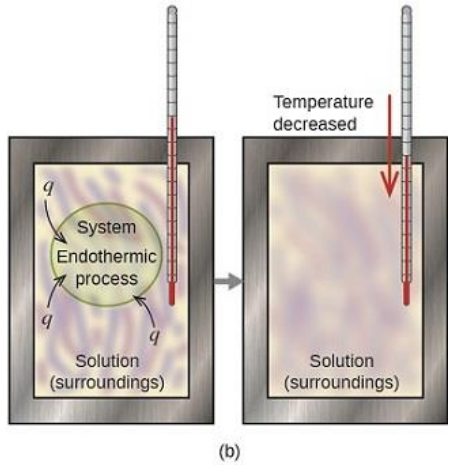
- In general, the enthalpy change is the difference between the enthalpy of the products and the reactants.

$$\Delta H = H(products) - H(reactants)$$

- From the overall enthalpy change, we can classify reactions as either:
  - Exothermic
    - Release heat



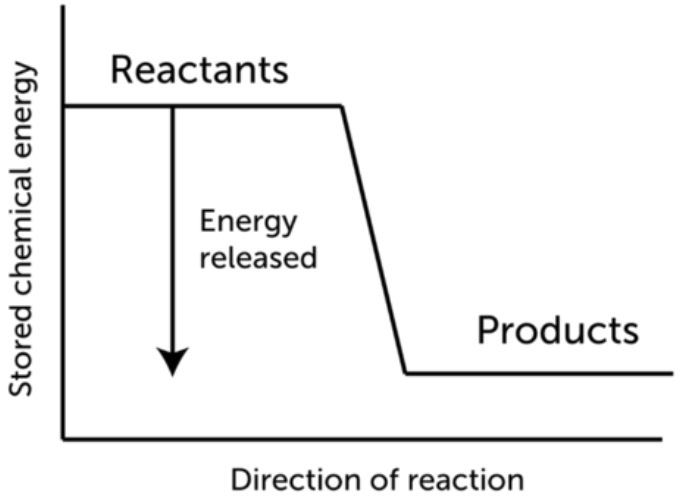
  - Endothermic
    - Absorb heat



ENTHALPY PROFILE DIAGRAMS

Exothermic Reactions

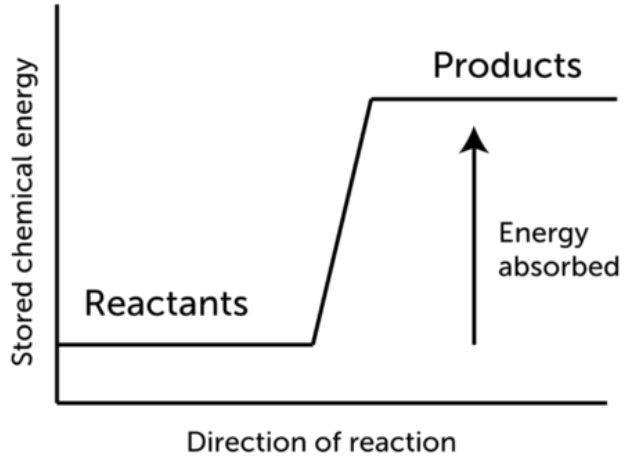
- The enthalpy of the products is smaller than the enthalpy of the reactants
- The chemical reaction release heat
- There is a heat loss from the system to the surroundings



- ΔH is **negative**

Endothermic Reactions

- The enthalpy of the products is greater than the enthalpy of the reactants
- The chemical reaction absorb heat
- There is a heat gain from the surroundings



- ΔH is **positive**

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$$
$$\Delta H = -890.3\,kJ\,mol^{-1}$$

The negative sign shows that the reaction is exothermic.

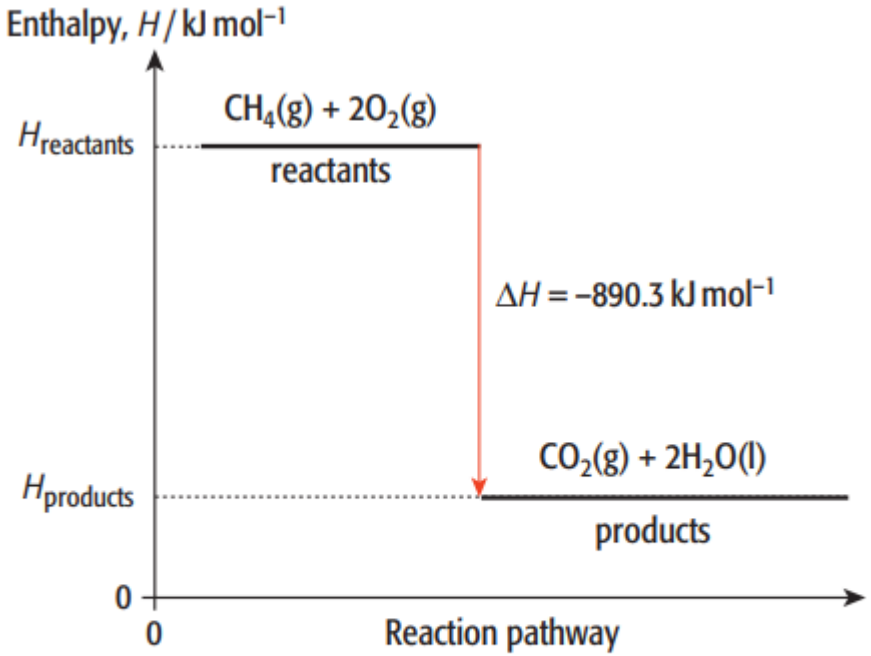


Figure 6.3 Enthalpy profile diagram for the combustion of methane.

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g) \qquad \Delta H = +572\,kJ\,mol^{-1}$$

The positive sign shows that the reaction is endothermic.

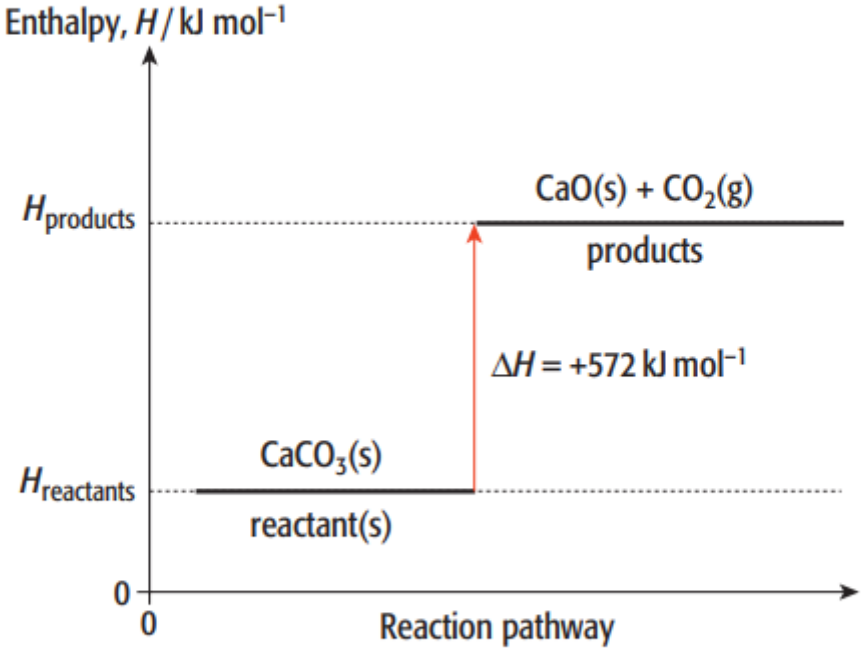
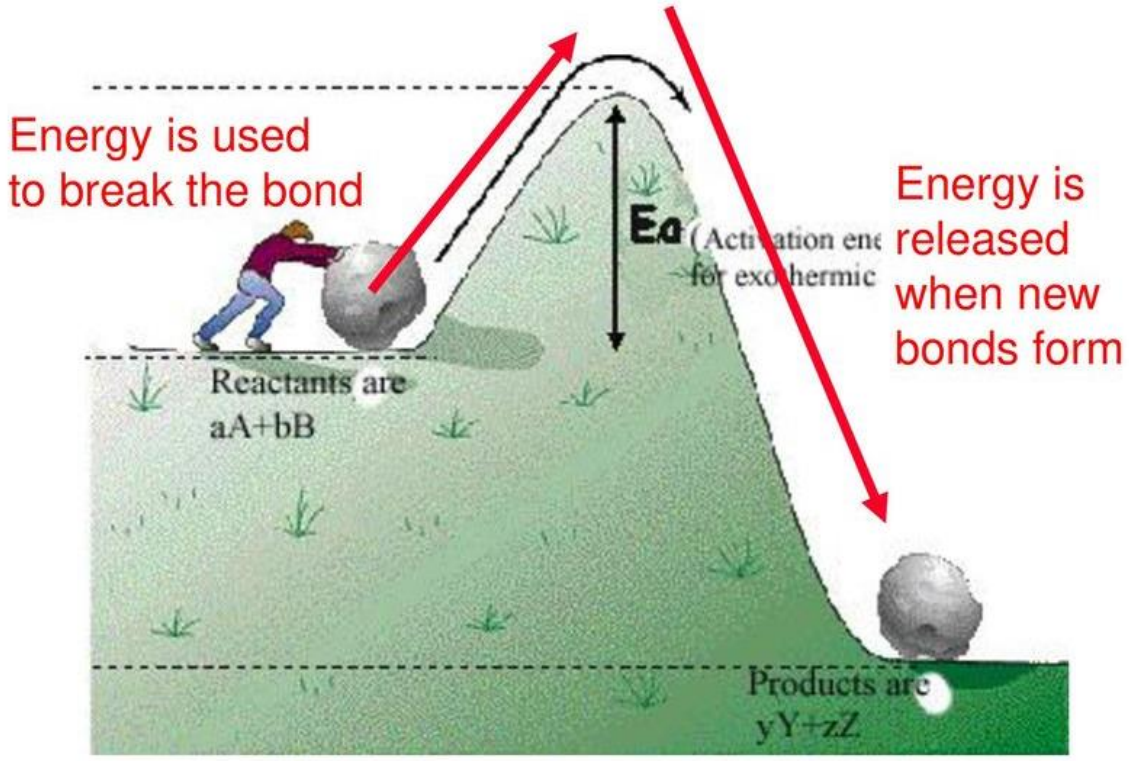


Figure 6.4 Enthalpy profile diagram for the decomposition of calcium carbonate.

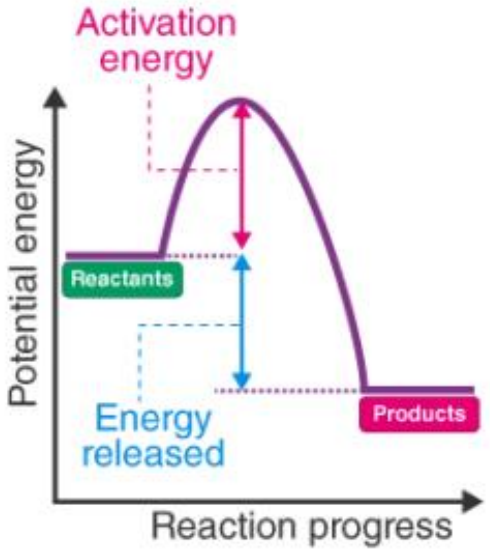
ACTIVATION ENERGY -E_A

- The activation energy is the minimum energy required to start a reaction
  - It is like rolling a ball to the top of the hill
  - In order to allow the ball to roll down the other side



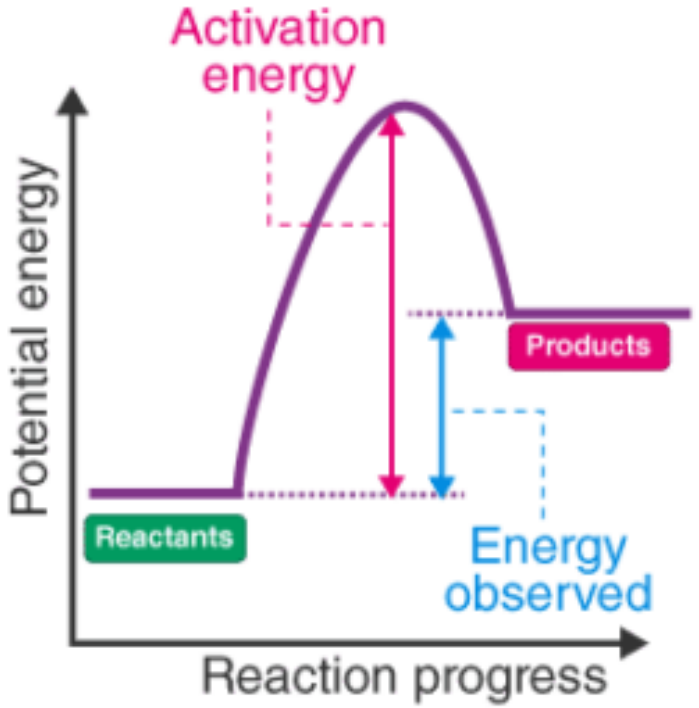
Exothermic reaction

- The products have a lower energy than the reactants
- Nevertheless, an input of energy is required to break the initial bonds and start the reaction
- Once the activation energy has been overcome, the energy output of the reaction provides enough energy to sustain the reaction
  - The reaction becomes self sustaining



Endothermic reaction

- The products have a higher energy than the reactants



ENTHALPY CHANGE OF REACTION

$\Delta_r H^0$

The energy change is associated with a given reaction

It is the enthalpy change in a chemical reaction when reactants and products are in their standard states and their molar quantities are same as shown by balanced chemical equation.

$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}$ $\quad \Delta H_r{}^o = -571.6$ KJ

$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(l)}$ $\quad \Delta H_r{}^o = -890.0$ KJ

ENTHALPY CHANGE OF FORMATION

$\Delta_f H^0$

The energy change that takes place when 1 mole of a compound is formed from its constituent elements in their standard state under standard conditions.

e.g. $Na_{(s)} + \frac{1}{2} F_{2(g)} \longrightarrow NaF_{(s)}$

Standard Enthalpies of Formation

Standard enthalpies of formation, ΔH_f°, are measured under standard conditions (25 °C and 1.00 atm pressure).

TABLE 5.3 ■ Standard Enthalpies of Formation, ΔH_f°, at 298 K

Substance	Formula	ΔH_f° (kJ/mol)	Substance	Formula	ΔH_f° (kJ/mol)
Acetylene	$C_2H_2(g)$	226.7	Hydrogen chloride	$HCl(g)$	−92.30
Ammonia	$NH_3(g)$	−46.19	Hydrogen fluoride	$HF(g)$	−268.60
Benzene	$C_6H_6(l)$	49.0	Hydrogen iodide	$HI(g)$	25.9
Calcium carbonate	$CaCO_3(s)$	−1207.1	Methane	$CH_4(g)$	−74.80
Calcium oxide	$CaO(s)$	−635.5	Methanol	$CH_3OH(l)$	−238.6
Carbon dioxide	$CO_2(g)$	−393.5	Propane	$C_3H_8(g)$	−103.85
Carbon monoxide	$CO(g)$	−110.5	Silver chloride	$AgCl(s)$	−127.0
Diamond	$C(s)$	1.88	Sodium bicarbonate	$NaHCO_3(s)$	−947.7
Ethane	$C_2H_6(g)$	−84.68	Sodium carbonate	$Na_2CO_3(s)$	−1130.9
Ethanol	$C_2H_5OH(l)$	−277.7	Sodium chloride	$NaCl(s)$	−410.9
Ethylene	$C_2H_4(g)$	52.30	Sucrose	$C_{12}H_{22}O_{11}(s)$	−2221
Glucose	$C_6H_{12}O_6(s)$	−1273	Water	$H_2O(l)$	−285.8
Hydrogen bromide	$HBr(g)$	−36.23	Water vapor	$H_2O(g)$	−241.8

ENTHALPY CHANGE OF COMBUSTION

$\Delta_C H^0$

The energy change that takes place when 1 mole of a substance is completely combusted.

e.g. $H_{2(g)} + ½\ O_{2(g)} \longrightarrow H_2O_{(l)}$

Standard Molar Enthalpies of Combustion

Substance	Combustion Reaction	Enthalpy of Combustion, ΔH_c° $(\frac{kJ}{mol}$ at 25 °C)
carbon	$C(s) + O_2(g) \longrightarrow CO_2(g)$	−393.5
hydrogen	$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(l)$	−285.8
magnesium	$Mg(s) + \frac{1}{2}O_2(g) \longrightarrow MgO(s)$	−601.6
sulfur	$S(s) + O_2(g) \longrightarrow SO_2(g)$	−296.8
carbon monoxide	$CO(g) + \frac{1}{2}O_2(g) \longrightarrow CO_2(g)$	−283.0
methane	$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$	−890.8
acetylene	$C_2H_2(g) + \frac{5}{2}O_2(g) \longrightarrow 2CO_2(g) + H_2O(l)$	−1301.1
ethanol	$C_2H_5OH(l) + 3O_2(g) \longrightarrow 2CO_2(g) + 3H_2O(l)$	−1366.8
methanol	$CH_3OH(l) + \frac{3}{2}O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$	−726.1
isooctane	$C_8H_{18}(l) + \frac{25}{2}O_2(g) \longrightarrow 8CO_2(g) + 9H_2O(l)$	−5461

ENTHALPY CHANGE OF NEUTRALISATION

$\Delta_n H^0$

The energy change associated with the formation of 1 mole of water from a neutralization reaction under standard conditions.

e.g. $HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$

Table *Heats of neutralisation between strong acids and strong alkalis*

Chemical equation	Ionic equation	ΔH (kJ mol^{-1})
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	–57.3
$HCl(aq) + KOH(aq) \rightarrow KCl(aq) + H_2O(l)$	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	–57.3
$HNO_3(aq) + NaOH(aq) \rightarrow NaNO_3(aq) + H_2O(l)$	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	–57.3
$HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l)$	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	–57.3

ENTHALPY CHANGE OF SOLUTION

The standard enthalpy change of solution (ΔH^{O}_{sol}) is the enthalpy change when one mole of solute is dissolved in a solvent to form an infinitely dilute solution under standard conditions.

$$NaOH(s) + aq \longrightarrow NaOH(aq)$$

ENTHALPY CHANGE OF ATOMISATION

- The standard enthalpy change of atomisation, ΔH^{O}_{at}, is the enthalpy change when one mole of gaseous atoms is formed from its element under standard conditions.

The standard enthalpy change of atomisation of hydrogen relates to the equation:

$$\tfrac{1}{2}\, H_{2(g)} \longrightarrow H_{(g)}\ \Delta H^{O}_{at}\ [\tfrac{1}{2}\, H_{2(g)}] = +218\ kJ{*}mol^{-1}$$

ENTHALPY CHANGE OF HYDRATION

- The standard enthalpy change of hydration of an anhydrous salt is the enthalpy change when one mole of a hydrated salt is formed from one mole of the anhydrous salt under standard conditions.

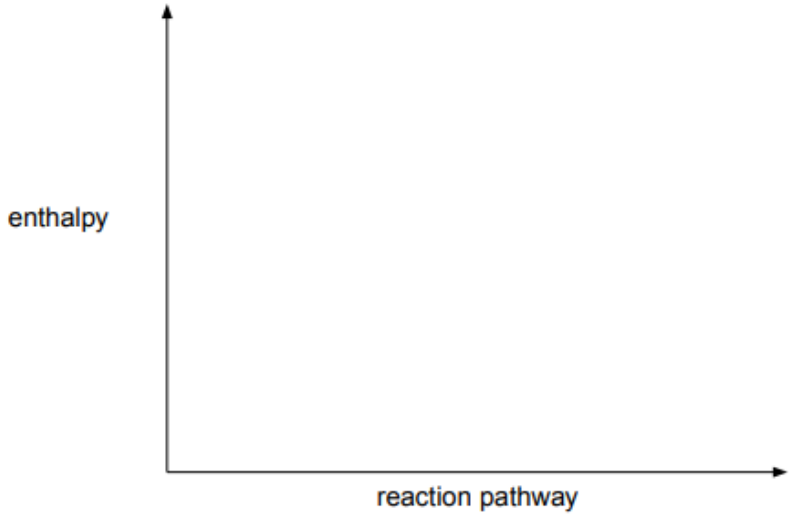
For example: $Na_2S_2O_{3(s)} + 5H_2O_{(l)} \longrightarrow Na_2S_2O_3{*}5H_2O_{(s)}$ $\Delta H^{O} = -55.0\ kJ{*}mol^{-1}$

EXAM STYLE QUESTION

1. The standard enthalpy change of formation of hexane is –199 kJ mol^{-1}.

Using the axes below, show the enthalpy profile diagram for the formation of hexane.

On your diagram label the enthalpy change of reaction, ΔH, and the activation energy, E_a.



[Total 3 marks]

2. Alkanes are important hydrocarbons since they are used as fuels in homes and in industry. It is important that the enthalpy changes involved in alkane reactions are known.

(i) Define the term *enthalpy change of formation of a compound*.

.....

.....

.....

[2]

(ii) Write the equation, including state symbols, that accompanies the enthalpy change of formation of hexane, $C_6H_{14}(l)$.

[2]

(iii) What conditions of temperature and pressure are used when measuring the **standard** enthalpy change of formation?

temperature .....

pressure .....

[1]

EXAM STYLE QUESTION

3. The combustion of butane is shown in the equation below.

$$C_4H_{10}(g) + 6\,\frac{1}{2}\,O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

(i) The standard enthalpy change of combustion of butane is –2877 kJ mol^{-1}. What does *standard* mean in this context?

.....

.....

[1]

(ii) Define the term *enthalpy change of combustion*.

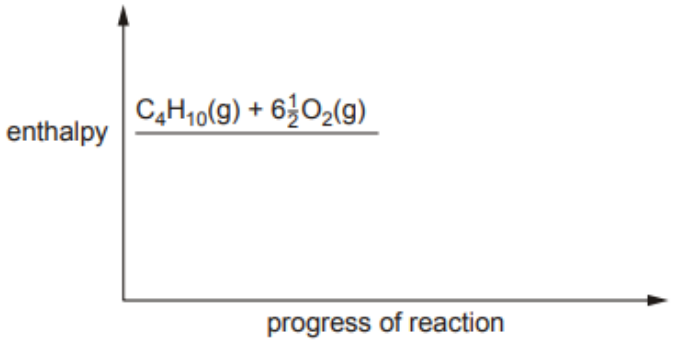
.....

.....

.....

[2]

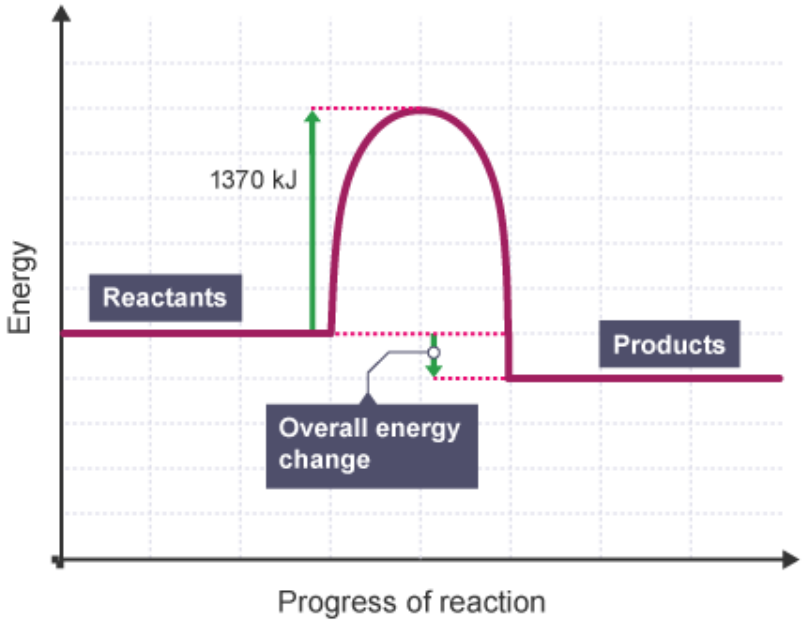
(iii) Complete the enthalpy profile diagram for the combustion of butane. Label the activation energy, E_a, and the enthalpy change, ΔH.



[3]

The diagram shows the reaction profile of an exothermic reaction.

What does the energy value of 1370 kJ represent?



[1 mark]

A	Activation energy	
B	Products energy	
C	Reactants energy	
D	Released energy	