

IGCSE Chemistry CIE

5. Chemical Energetics

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5.1 Exothermic & Endothermic Reactions

5.1.1 Endothermic & Exothermic Reactions

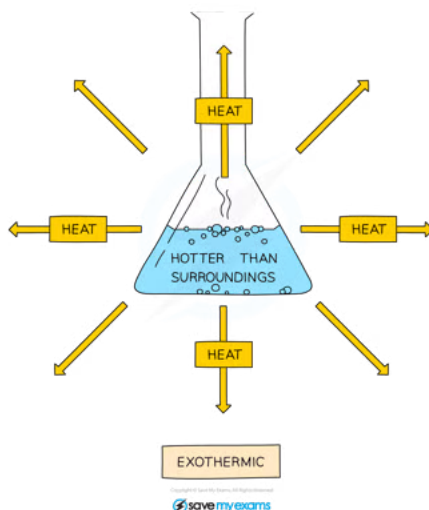
Exothermic & Endothermic Reactions

Heat Exchange in Reactions

- Chemical reactions occur so that elements can achieve a more stable energy state by gaining a full outer shell of electrons
- This is done by **chemical bonding** (we have already seen ionic and covalent bonding) where old bonds are broken, and new bonds are formed)
- This process involves the **transfer of thermal energy** into and out of reaction mixtures
- The terms used to describe this are the **system** (what happens in the chemical reaction) and the **surroundings** (anything other than the chemicals reacting)
- The energy within the system comes from the **chemical bonds** themselves which could be considered as tiny stores of chemical energy

Exothermic Reactions

- In exothermic reactions thermal energy is **transferred to** the surroundings so the temperature of the surroundings increases
- This energy is transferred from the chemical energy store of the chemical system to the surroundings and so the energy of the system falls – this means that the energy change is negative
- The overall transfer is from the system to the surroundings
- Combustion, oxidation, and neutralisation reactions are typical exothermic reactions
- Hand warmers used in the wintertime are based on the release of heat from an exothermic reaction
- Self-heating cans of food and drinks such as coffee and hot chocolate also use exothermic reactions in the bases of the containers



YOUR NOTES



Diagram showing the transfer of heat energy outwards from an exothermic reaction

YOUR NOTES



Endothermic Reactions

- In endothermic reactions thermal energy is **taken in from** the surroundings so the temperature of the surroundings decreases
- This energy is transferred **to** the chemical energy store of the chemical system and so the energy of the system increases – this means the energy change is positive
- The overall transfer is from the surroundings to the system
- These types of reactions are much less common than the exothermic reactions
- Electrolysis, thermal decomposition reactions and the first stages of photosynthesis are typical endothermic reactions
- Sports injury treatments often use cold packs based on endothermic reactions to take heat away from a recently injured area to prevent swelling

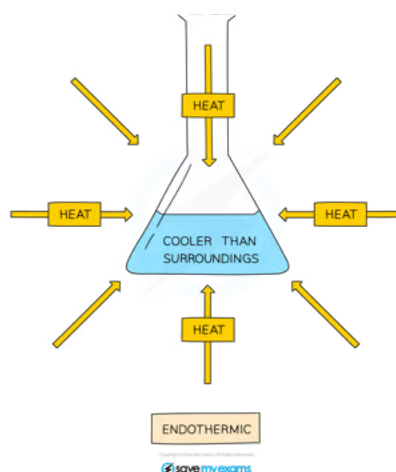
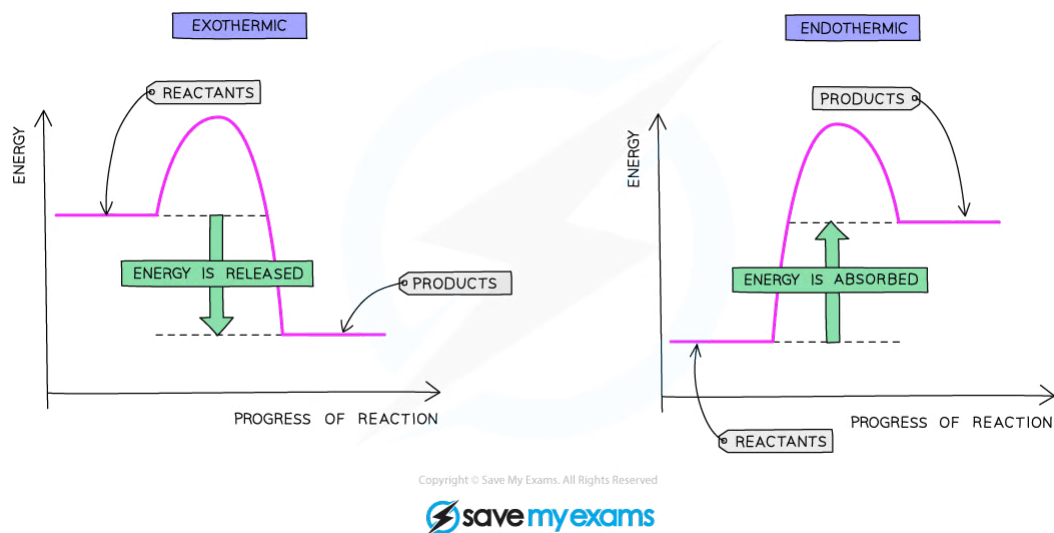


Diagram showing the transfer of heat energy from the surroundings into an endothermic reaction

Energy Level Diagrams

- **Reaction pathway diagrams** are graphical representations of the relative energies of the reactants and products in chemical reactions
- The energy of the reactants and products are displayed on the y-axis and the reaction pathway (a bit like time) is shown on the x-axis
- The difference in height between the energy of reactants and products represents the **overall energy change** of a reaction.
 - This is usually a sketch but can be drawn to scale if data is provided
- Arrows on the diagrams indicate whether the reaction is exothermic (overall reaction arrow is downwards pointing, showing that the system has lost energy) or endothermic (overall reaction arrow is upwards pointing, showing that the system has gained energy)
- The initial increase in energy represents the **activation energy (E_a)**, which is the minimum energy that colliding particles must have in order to react
- The greater the initial rise, the more energy that is required to get the reaction going e.g. more heat needed

- You can identify a reaction pathway diagram for an **exothermic reaction** as the energy of the **product** is **lower** than the reactants (as thermal energy has been transferred to the surroundings)
- You can identify a reaction pathway diagram for an **endothermic reaction** as the energy of the **product** is **higher** than the reactants (as thermal energy has been taken in from the surroundings)



Reaction profile of an exothermic reaction and an endothermic reaction



Exam Tip

To help you remember whether a chemical system is exothermic or endothermic:

- In **EX**othermic reactions heat **EX**its the system and in **EN**dothermic reactions heat **EN**ters the system.
- Exothermic reactions always give off heat and they feel hot, whereas endothermic reactions take heat in and they feel cold.

You should be able to interpret reaction pathway diagrams (you do NOT need to be able to draw them for core)

YOUR NOTES



5.1.2 Enthalpy Change & Activation Energy

YOUR NOTES

**Enthalpy Change & Activation Energy****EXTENDED**

- For atoms or particles to react with each other in a chemical system they must first of all come into contact with each other in a **collision**
- A number of factors come into play when analysing collisions such as **energy**, **orientation**, and **number of collisions per second** (the **frequency** of collisions)
- In terms of the energy of the collision, there is a **minimum amount of energy** required for the collision to be successful, that is for the particles to react together
- This minimum amount of energy is called the **activation energy (E_a)**
- Different reactions have different activation energies, depending on the chemical identities involved
- Reactions which have higher activation energies require more energy to start than those with lower activation energies
- The **transfer of thermal energy** during a reaction is called the **enthalpy change, ΔH** , of the reaction.
- ΔH is either a positive or a negative value depending on whether the reaction is exothermic or endothermic

Reaction Pathway Diagrams

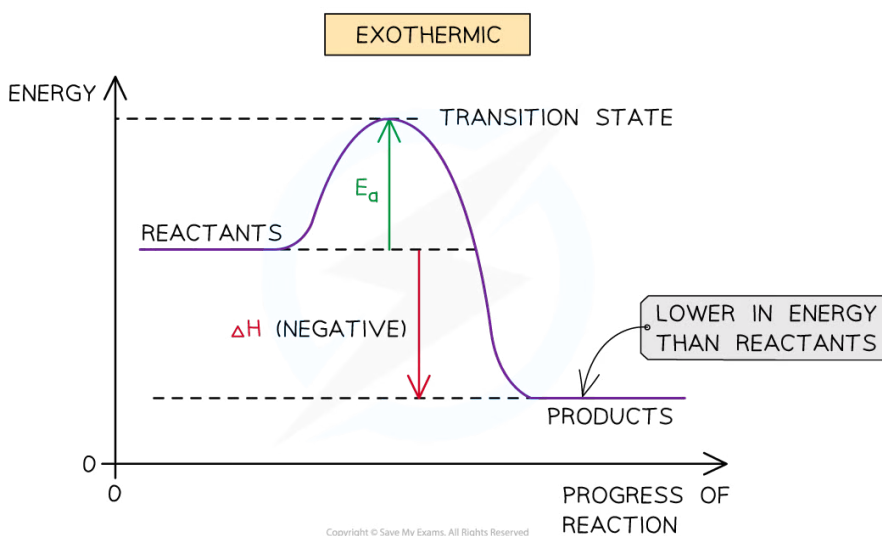
YOUR NOTES



EXTENDED

Exothermic reactions

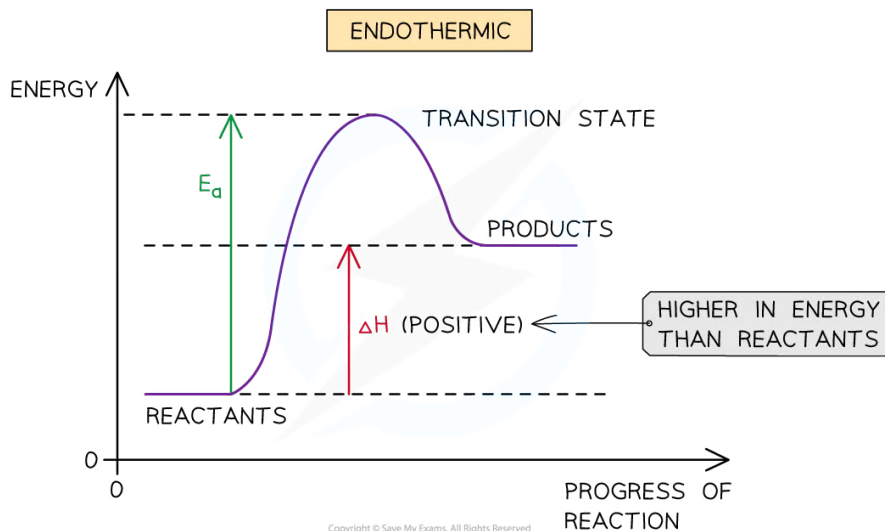
- If more energy is released than is absorbed, then the reaction is **exothermic**
- More energy is released when new bonds are formed than energy required to break the bonds in the reactants
- The change in energy is negative since the products have less energy than the reactants
- Therefore an exothermic reaction has a **negative** ΔH value
- The reaction pathway diagram for an exothermic reaction is shown below



The reaction pathway diagram for exothermic reactions

Endothermic reactions

- If more energy is absorbed to break bonds than is released to form new bonds, this reaction is **endothermic overall**
- The change in energy is positive since the products have more energy than the reactants
- Therefore an endothermic reaction has a **positive** ΔH value, which is shown on the energy level diagrams and in calculations



The reaction pathway diagram for endothermic reactions.



Exam Tip

You **must** be able to draw these pathway diagrams and label the following parts:

- Reactants
- Products
- Enthalpy change of the reaction, ΔH
- Activation energy, E_a

YOUR NOTES



5.1.3 Bond Breaking & Bond Forming

YOUR NOTES



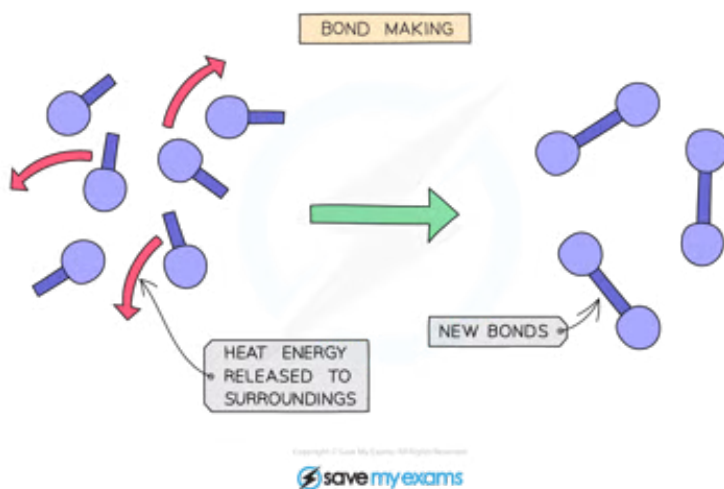
Bond Breaking & Bond Forming

EXTENDED

- Whether a reaction is endothermic or exothermic depends on the difference between the energy needed to **break** existing bonds and the energy released when the new bonds are **formed**
- **Bond breaking** is always an **endothermic** process as energy needs to be taken in from the surroundings to break the chemical bonds
- **Bond making** is always an **exothermic** process as energy is transferred to the surroundings as the new bond is formed

Exothermic reactions

- If more energy is released than is absorbed, then the reaction is **exothermic**
- More energy is released when new bonds are formed than energy required to break the bonds in the reactants
- The change in energy is negative since the products have less energy than the reactants
- Therefore an exothermic reaction has a **negative** ΔH value



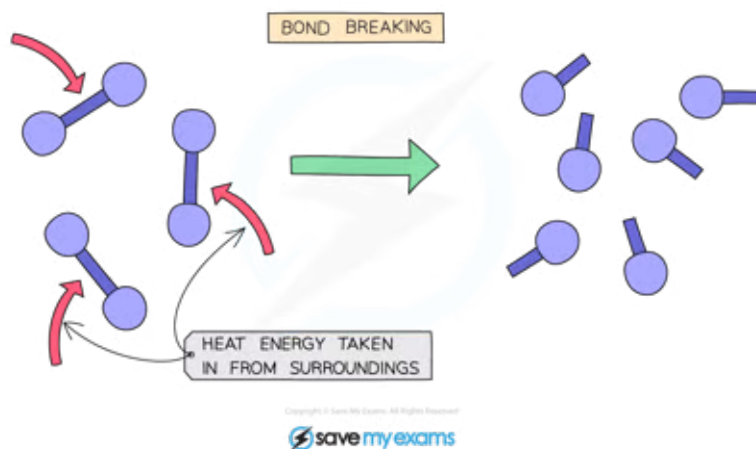
Making new chemical bonds releases energy which radiates outwards from the reaction to the surroundings in the form of heat

Endothermic reactions

- If more energy is absorbed to break bonds than is released to form new bonds, this reaction is **endothermic overall**
- The change in energy is positive since the products have more energy than the reactants
- The symbol ΔH (delta H) is used to show the change in heat energy. H is the symbol for enthalpy, which is a measure of the total **heat of reaction** of a chemical reaction

- Therefore an endothermic reaction has a **positive** ΔH value, which is shown on the energy level diagrams and in calculations

YOUR NOTES



Breaking chemical bonds requires energy which is taken in from the surroundings in the form of heat

Bond Energy Calculations

Energy of reaction calculations

- Each chemical bond has specific bond energy associated with it
- This is the amount of energy required to **break** the bond or the amount of energy given out when the bond is **formed**
- This energy can be used to calculate how much heat would be released or absorbed in a reaction
- To do this it is necessary to know the bonds present in both the reactants and products

Method

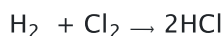
- Write a balanced equation if none is present already
- Optional – draw the displayed formula in order to identify the type and number of bonds more easily
- Add together all the bond energies for all the bonds in the reactants – this is the ‘energy in’
- Add together the bond energies for all the bonds in the products – this is the ‘energy out’
- Calculate the enthalpy change:

$$\text{Enthalpy change } (\Delta H) = \text{Energy taken in} - \text{Energy given out}$$



Worked Example

Hydrogen and chlorine react to form hydrogen chloride gas:



The table below shows the bond energies.

Bond	Bond energy (kJ/mole)
H–H	436
Cl–Cl	243
H–Cl	432

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Calculate the enthalpy change, ΔH , for the reaction and deduce whether it is exothermic or endothermic.

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Answer:



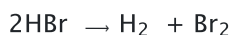
Step	Working out
1. Calculate the energy in	Energy in = $436 + 243 = 679$ kJ/Mole
2. Calculate the energy out	Energy out = $2 \times 432 = 864$ kJ/Mole
3. Calculate the enthalpy change	Enthalpy change = $679 - 864 = -185$ kJ/Mole
4. Comment on the result and deduce the nature of the reaction	Enthalpy change is a negative number hence energy has been lost to the surrounding and the reaction is exothermic

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Worked Example

Hydrogen bromide decomposes to form hydrogen and bromine:



The table below shows the bond energies.

Bond	Bond energy (kJ/mole)
H-Br	366
H-H	436
Br-Br	193

Calculate the enthalpy change, ΔH , for the reaction and deduce whether it is exothermic or endothermic.

Answer:

Step	Working out
1. Calculate the energy in	Energy in = $2 \times 366 = 732$ kJ/Mole
2. Calculate the energy out	Energy out = $436 + 193 = 629$ kJ/Mole
3. Calculate the enthalpy change	Enthalpy change = $732 - 629 = +103$ kJ/Mole
4. Comment on the result and deduce the nature of the reaction	Enthalpy change is a positive number hence energy has been absorbed from the surrounding so the reaction is endothermic

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Exam Tip

When answering questions to calculate the enthalpy change using bond energies,, it is helpful to write down a **displayed formula** equation for the reaction **before** identifying the type and number of bonds, to avoid making mistakes. The reaction thus becomes: $\text{H-H} + \text{Cl-Cl} \rightarrow \text{H-Cl} + \text{H-Cl}$

