Cambridge (CIE) IGCSE Chemistry

Your notes

Exothermic & Endothermic Reactions

Contents

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**
- This process involves the **transfer of thermal energy** into and out of reaction mixtures
- The terms used to describe this are:
  - **System:** the reacting chemicals
  - **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** from the system to the surroundings
  - The energy of the system decreases, which means that the energy change is **negative**
  - The temperature of the surroundings increases because thermal energy is **given out / released**
- The overall transfer is from the system to the surroundings

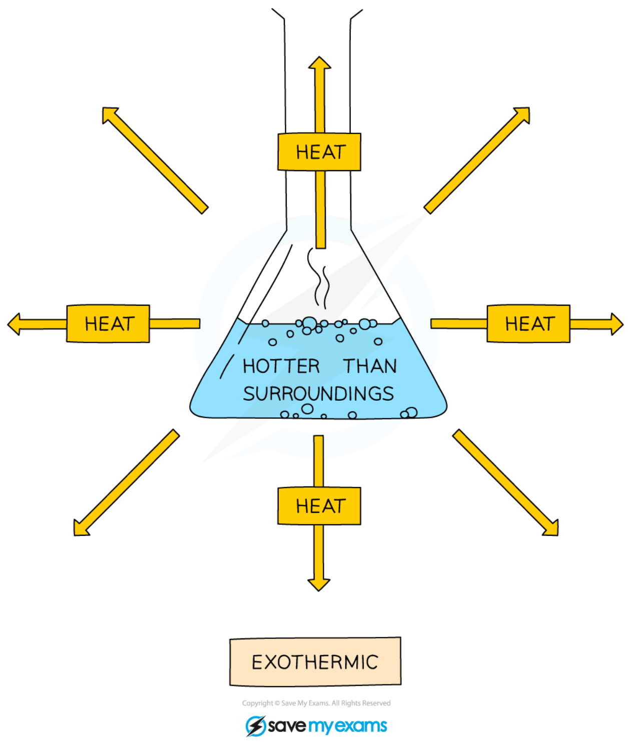


Diagram showing the transfer of heat energy outwards from an exothermic reaction

- Typical examples of exothermic reactions include:
  - **Combustion**
  - **Oxidation**
  - **Neutralisation**
- **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

Endothermic reactions

- In endothermic reactions, thermal energy is **transferred** from the surroundings to the system
  - The energy of the system increases, which means that the energy change is **positive**
  - The temperature of the surroundings decreases because thermal energy is **taken in / absorbed**
- The overall transfer is from the surroundings to the system

Your notes

Your notes

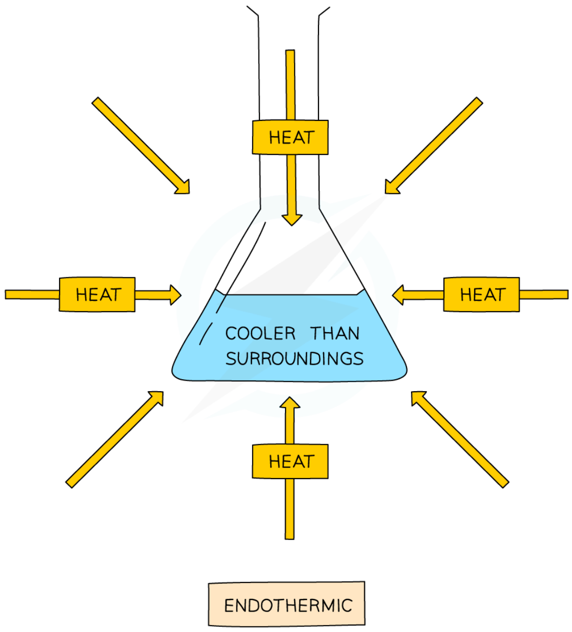


Diagram showing the transfer of heat energy from the surroundings into an endothermic reaction

- Endothermic reactions are less common than exothermic reactions
- Typical examples of endothermic reactions include:
  - Electrolysis
  - Thermal decomposition
  - The first stages of photosynthesis
- **Cold packs** for sports injuries are based on endothermic reactions, designed to take heat away from a recently injured area to prevent swelling

Worked Example

A student was investigating the temperature change for four different chemical reactions. The table shows the chemicals that the student combined for each reaction along with the initial and final temperatures of the reaction.

Experiment	Chemicals		Initial temperature (°C)	Final temperature (°C)
1	10 cm^3 NaOH	10 cm^3 HCl	19	21

2	10 cm^3 $NaHCO_3$	2 g citric acid	20	16
3	10 cm^3 $CuSO_4$	0.5 g Mg powder	20	26
4	10 cm^3 H_2SO_4	3 cm Mg ribbon	19	31

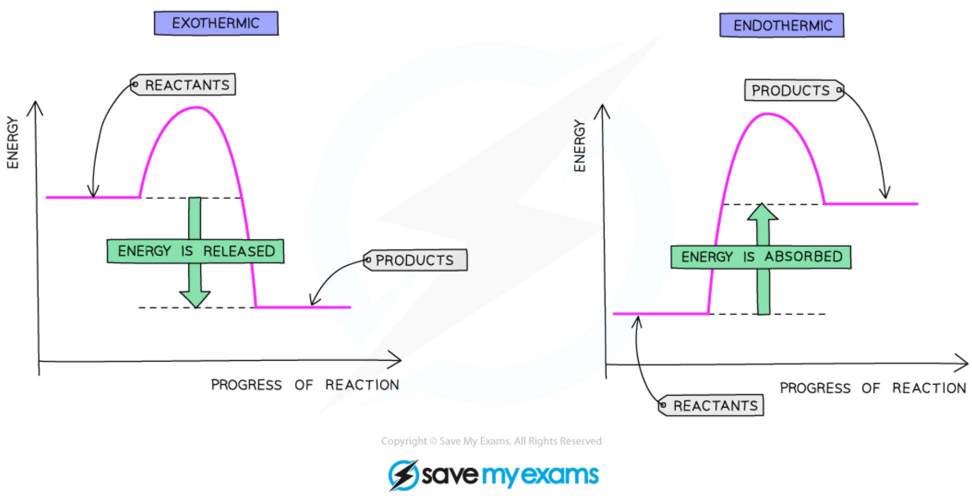
Explain whether each reaction is endothermic or exothermic.

Answers:

- Reactions 1, 3 and 4 are exothermic reactions because they show a temperature increase
- Reaction 2 is an endothermic reaction because it shows a temperature decrease

Reaction pathway diagrams

- **Reaction pathway diagrams** are graphical representations of the relative energies of the reactants and products in chemical reactions
- On a reaction pathway diagram:
  - Progress of the reaction is shown on the x-axis
  - Energy is shown on the y-axis
  - The difference in height between the energy of reactants and products is the **overall energy change** of a reaction



Reaction pathway diagram of an exothermic reaction and an endothermic reaction

- In exothermic reactions:
  - Energy is given out to the surroundings
  - The energy of the products will therefore be **lower** than the energy of the reactants

- The overall energy change is **negative**
- This is represented on the reaction profile with a downwards-arrow as the energy of the products is lower than the reactants
- In endothermic reactions:
    - Energy is taken in from the surroundings
    - The energy of the products will be **higher** than the energy of the reactants
    - The overall energy change is **positive**
    - This is represented on the reaction profile with an upwards-arrow as the energy of the products is higher than the reactants

Examiner Tips and Tricks

- 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
    - Endothermic reactions always take heat in and they feel cold.
- Core candidates will be expected to interpret reaction pathway diagrams
- Extended candidates will be expected to draw and interpret reaction pathway diagrams

Your notes

Enthalpy change & activation energy

Extended tier only

- For atoms or particles to react with each other in a chemical system they must **collide** together
- A number of factors affect the success of a collision:
  - **Energy**
  - **Orientation**
  - **Number of collisions per second** - the **frequency** of collisions

What is activation energy?

- In terms of the energy of collisions, there is a **minimum amount of energy** required for a successful collision
  - A successful collision is where the particles in the reactant(s) are rearranged to form the products
- 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 with higher activation energies require more energy to start than those with lower activation energies

What is enthalpy change?

- The **transfer of thermal energy** during a reaction is called the **enthalpy change, ΔH**, of the reaction.
- ΔH is:
  - Positive for an endothermic reaction
  - Negative for an exothermic reaction

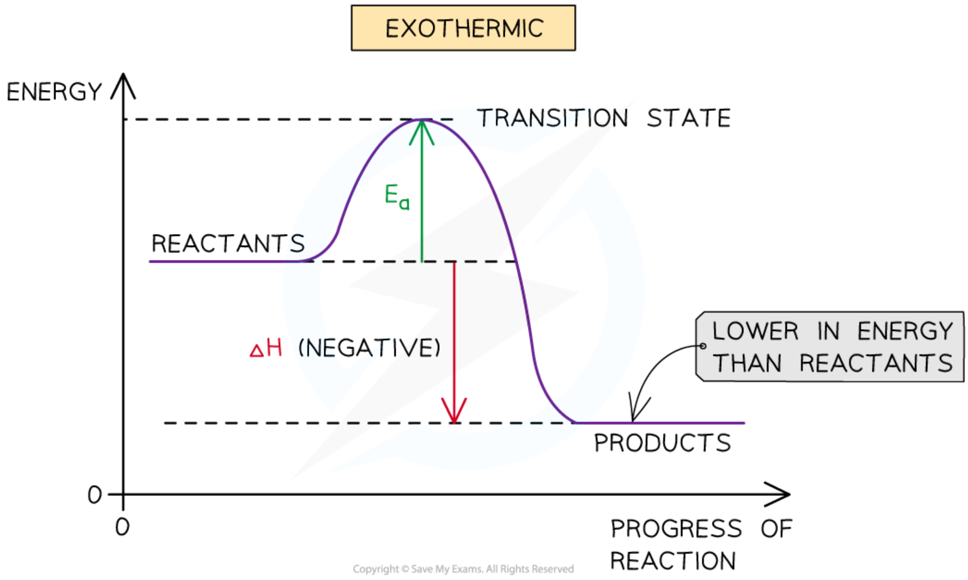
Reaction pathway diagrams

Extended tier only

Exothermic reactions

- A reaction is **exothermic** when more energy is released forming new bonds for the products than absorbed breaking the bonds in the reactants
- So, the products have less energy than the reactants

- This means that the change in energy is negative
- Therefore, an exothermic reaction has a **negative** value for enthalpy, ΔH
- The reaction pathway diagram for an exothermic reaction is:

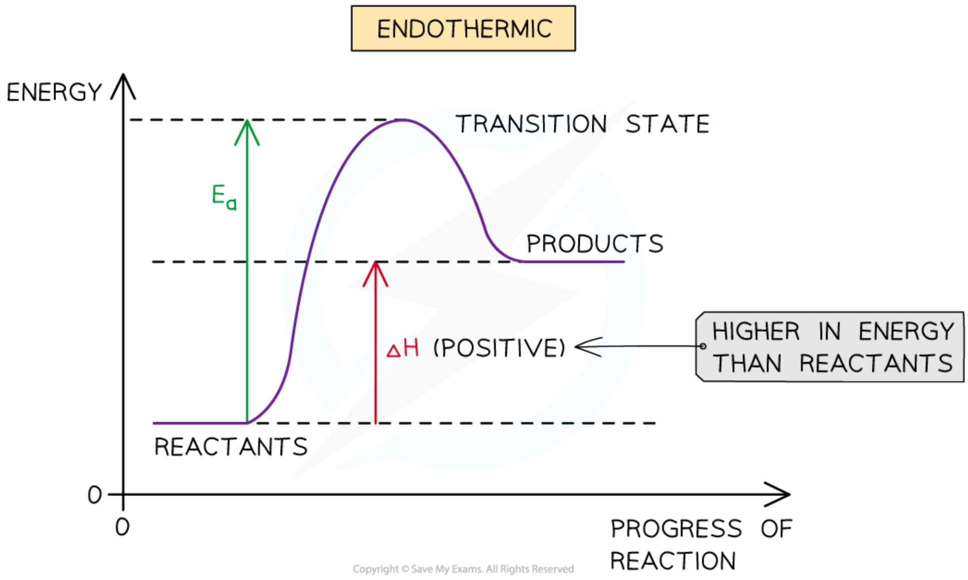


The reaction pathway diagram for exothermic reactions

Endothermic reactions

- A reaction is **endothermic** when more energy is absorbed breaking the bonds in the reactants than released forming new bonds for the products
- So, the products have more energy than the reactants
  - This means that the change in energy is positive
- Therefore, an endothermic reaction has a **positive** value for enthalpy, ΔH
- The reaction pathway diagram for an endothermic reaction is:

Your notes



The reaction pathway diagram for endothermic reactions.

Examiner Tips and Tricks

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

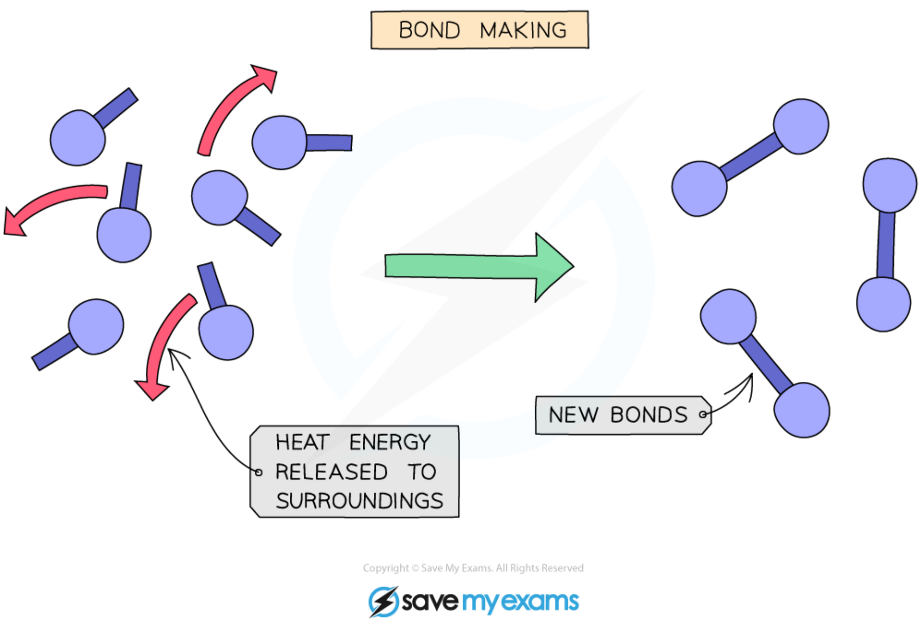
Bond breaking & bond forming

Extended tier only

- 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

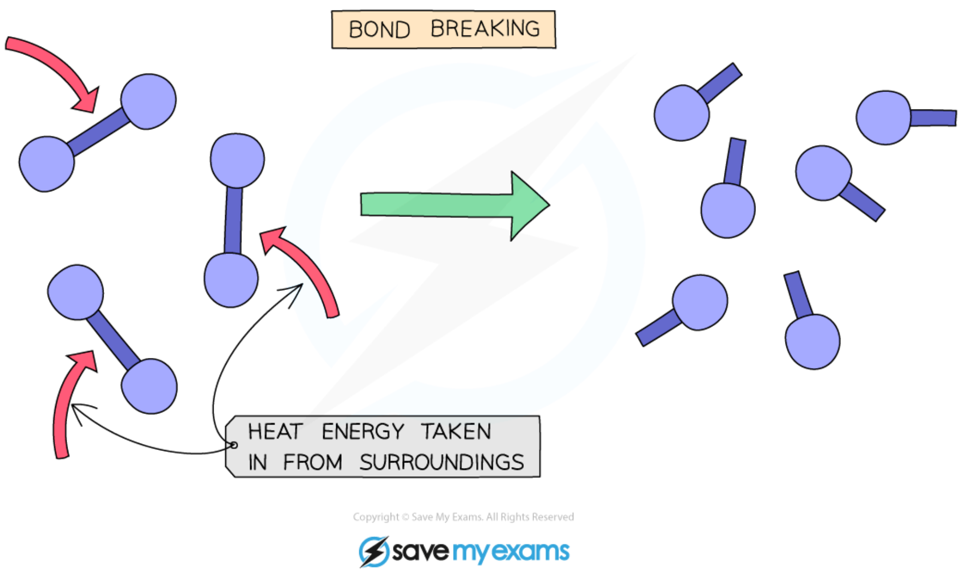
- If more energy is released than is absorbed, then the reaction is **exothermic**
- More energy is released when new bonds are formed than energy required to break the bonds in the reactants
- The change in energy is negative since the products have less energy than the reactants
- Therefore, an exothermic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



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 is used to show the change in heat energy
  - H is the symbol for enthaply, which is a measure of the total **heat of reaction** of a chemical reaction
- Therefore, an endothermic reaction has a **positive** ΔH value
  - This can be shown in reaction pathway diagrams and calculations



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

Bond energy calculations

Extended tier only

- 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

How to complete bond energy calculations

Your notes

- 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:

Enthalpy change (ΔH) = Energy taken in – Energy given out

Your notes

Worked Example

Hydrogen and chlorine react to form hydrogen chloride gas:

$$H_2 + Cl_2 \longrightarrow 2HCl$$

The bond energies are given in the table below.

Bond	Energy (kJ)
H–H	436
Cl–Cl	242
H–Cl	431

Calculate the overall energy change for this reaction and use this value to explain whether the reaction is exothermic or endothermic.

Answer:

- Calculate the energy in
  - 436 + 242 = 678 (kJ)
- Calculate the energy out
  - 2 x 431 = 862 (kJ)
- Calculate the energy change
  - 678 - 862 = **–184** (kJ)
- Since the energy change is a negative number, energy is being released (to the surroundings)
  - Therefore, the reaction is **exothermic**

Examiner Tips and Tricks

When calculating 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.

So, the reaction for the above worked example is:

$$\text{H–H} + \text{Cl–Cl} \rightarrow \text{H–Cl} + \text{H–Cl}$$

Your notes

Worked Example

Hydrogen reacts with iodine to form hydrogen iodide.

$$H_2 + I_2 \longrightarrow 2HI$$

The relevant bond energies are shown in the table below.

Bond	Energy (kJ)
H–I	295
H–H	436
I–I	151

Calculate the overall energy change for this reaction and use this value to explain why the reaction is exothermic.

Answer:

- Calculate the energy in
  - 436 + 151 = 587 (kJ)
- Calculate the energy out
  - 2 x 295 = 590 (kJ)
- Calculate the energy change
  - 587 - 590 = **-3** (kJ)
- The reaction is exothermic because:
  - **More energy is released than taken in**

Worked Example

Hydrogen bromide decomposes to form hydrogen and bromine:

$$2HBr \longrightarrow H_2 + Br_2$$

The overall energy change for this reaction is +103 kJ.

The relevant bond energies are shown in the table below.

Bond	Energy (kJ)
H–Br	366
Br–Br	
H–H	436

Calculate the bond energy of the Br–Br bond.

Answer:

- Calculate the energy in
  - 2 x 366 = 732 (kJ)
- State the energy out
  - 436 + Br–Br
- Overall energy change = energy in - energy out
  - +103 = 732 - (436 + Br–Br)
  - +103 = 732 - 436 - Br–Br
- Calculate the bond energy of the Br–Br bond
  - Br–Br = 732 - 436 - 103
  - Br–Br = +**193 (kJ)**

Your notes