IGCSE CHEMISTRY 0620 · CHAPTER 5 NOTES · ~9 MIN READ

Chemical energetics

Why reactions get hot or cold, how to read an energy-profile diagram, and how to calculate the energy change of a reaction from bond energies.

Exothermic & endothermic | Energy profiles | ΔH | Activation energy | Bond energies

RS by Riyaz Sir
mentorriyaz.in

No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- **Exothermic** reactions give energy **out** to the surroundings — the temperature **rises**. **Endothermic** reactions take energy **in** — the temperature **falls**.
- An **energy profile** shows the energy of reactants and products. The gap between them is **ΔH**. EXT
- **Activation energy (Ea)** is the energy hill reactants must climb before reacting. EXT
- EXT **ΔH = energy to break bonds − energy released making bonds.** Breaking takes in energy. Making releases it.

BY THE END YOU CAN

- Define exothermic and endothermic reactions and give examples.
- Read an energy-profile diagram and say whether a reaction is exothermic or endothermic.
- Label activation energy and ΔH on a profile and give the sign of ΔH. EXT
- Calculate ΔH from bond energies. EXT

1 Exothermic and endothermic reactions

Heat out or heat in

Exothermic reaction — a reaction that transfers thermal energy **to the surroundings**. The temperature of the surroundings **rises**.

Endothermic reaction — a reaction that takes in thermal energy **from the surroundings**. The temperature of the surroundings **falls**.

	Exothermic	Endothermic
energy	given out	taken in
temperature of surroundings	goes up	goes down
products compared with reactants	lower in energy	higher in energy
ΔH EXT	negative (−)	positive (+)
examples	burning fuels, neutralisation, respiration, rusting, adding water to quicklime	thermal decomposition ($CaCO_3$ → CaO + CO_2), photosynthesis, dissolving ammonium nitrate in water, citric acid + sodium hydrogencarbonate

MEMORY TRICK

EXO = **EXIT** — energy exits the reaction. **ENDO** = energy goes **IN**.

PICTURE IT

A campfire is exothermic: you feel heat leaving it. A cold pack is endothermic: it pulls heat out of your skin, so it feels cold.

How to measure it

- Put the reactants in a **polystyrene cup** (an insulator, so little heat is lost) with a lid, stir, and use a **thermometer** to measure the temperature at the start and the highest (or lowest) temperature.
- **Rise** in temperature → exothermic. **Fall** in temperature → endothermic.

EXAM TIP

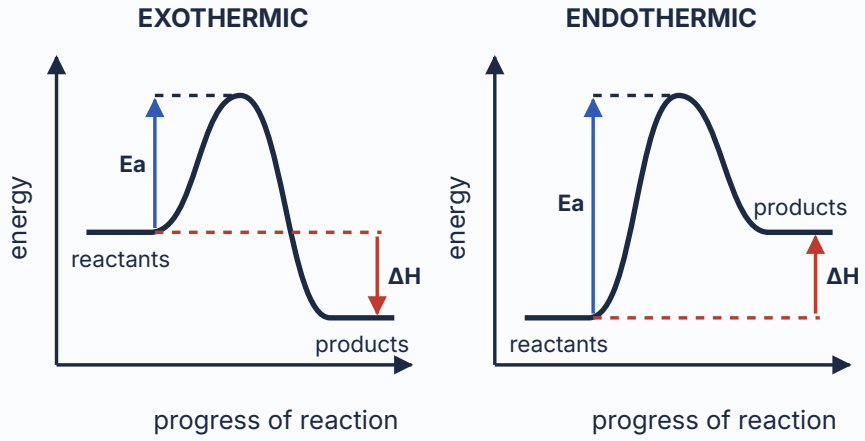
Always describe the change in the **temperature of the surroundings** (or the mixture), not "the reaction gets hot". Give numbers if you are asked to describe results: "temperature rose from 21 °C to 27 °C".

COMMON MISTAKE

"Endothermic reactions get hot because they need heating." They need heat **from the surroundings**, so the temperature of the surroundings **falls**.

2 Energy profile diagrams

Reading a reaction pathway



products have less energy
energy released to the surroundings
ΔH is negative (−)

products have more energy
energy taken in from the surroundings
ΔH is positive (+)

Energy profiles. Left: exothermic — products are lower than reactants. Right: endothermic — products are higher.

- The **vertical axis** is energy. The **horizontal axis** is progress of reaction (from reactants to products).
- **Exothermic:** the products are **lower** than the reactants. The difference is energy **released** to the surroundings.
- **Endothermic:** the products are **higher** than the reactants. The difference is energy **taken in** from the surroundings.
- EXT **ΔH** is drawn as a vertical arrow between the reactants level and the products level.
- EXT **Activation energy (Ea)** is the vertical arrow from the reactants up to the top of the hump.

Activation energy (Ea) EXT — the minimum energy that colliding particles need in order to react.

EXT ΔH = energy of products − energy of reactants

negative for exothermic, positive for endothermic

- EXT **Both** exothermic and endothermic reactions have an activation energy. The hump is the energy needed to start breaking bonds.

PICTURE IT

A boulder in a dip on a hillside: you must push it **up** over the hump (Ea) before it can roll down to the valley (an exothermic reaction). Even when the valley is much lower, the push is still needed — a match is needed to light a candle.

- EXT A **catalyst** lowers the hump (it gives an alternative route with lower Ea), but ΔH stays the same. See the rates chapter.

WORKED EXAMPLE

EXT **A reaction has reactants at 200 kJ, a peak at 350 kJ and products at 120 kJ. Find Ea and ΔH, and say whether it is exothermic.**

1. Ea = peak − reactants = 350 − 200 = **150 kJ**
2. ΔH = products − reactants = 120 − 200 = **−80 kJ**
3. **ΔH is negative and the products are lower, so it is exothermic**

EXAM TIP

In a "draw a profile" question: (1) label the axes "energy" and "progress of reaction"; (2) draw reactants and products at the right relative levels; (3) draw the **hump**; (4) show **Ea** from the reactants and **ΔH** between the levels, each with an arrow.

COMMON MISTAKE

Drawing Ea from the **products** or measuring it down to zero. Ea starts at the **reactants** level.

COMMON MISTAKE

Writing a positive ΔH for an exothermic reaction. Exothermic = **negative** ΔH.

3 Bond energies EXT

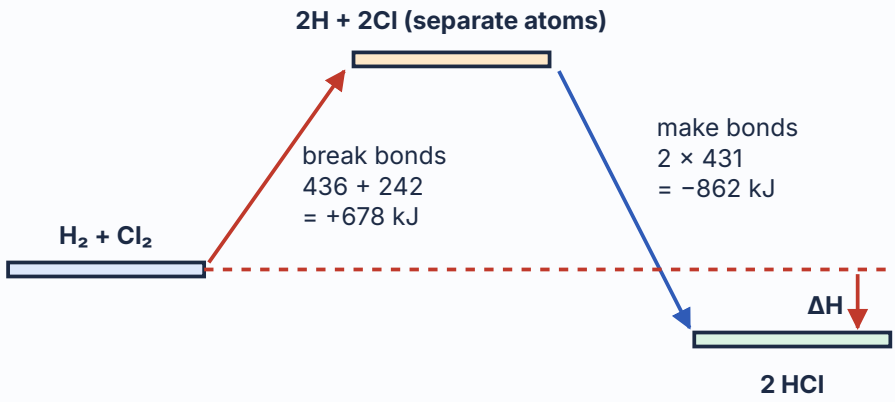
Breaking takes energy, making releases it

Bond energy — the energy needed to break one mole of a particular covalent bond, in kJ/mol.

- **Breaking bonds is endothermic** — energy must be put in to pull atoms apart.
- **Making bonds is exothermic** — energy is released when atoms join.
- The overall energy change depends on which is bigger:
- more energy released making new bonds than taken in breaking old ones → **exothermic**
- more energy taken in breaking bonds than released making new ones → **endothermic**

$$\Delta H = \Sigma \text{(energy of bonds broken)} - \Sigma \text{(energy of bonds made)}$$

in kJ/mol



ΔH = energy to break bonds − energy released making bonds
= 678 − 862 = −184 kJ/mol → exothermic
bond energies: H–H 436 · Cl–Cl 242 · H–Cl 431 kJ/mol

Hydrogen + chlorine → hydrogen chloride. Breaking the bonds costs 678 kJ. Making new bonds gives back 862 kJ, so the reaction is exothermic.

WORKED EXAMPLE

EXT **Calculate ΔH for $H_2 + Cl_2 \rightarrow 2HCl$. Bond energies: H–H = 436, Cl–Cl = 242, H–Cl = 431 kJ/mol.**

1. Bonds broken: 1 × H–H + 1 × Cl–Cl = 436 + 242 = 678 kJ
2. Bonds made: 2 × H–Cl = 2 × 431 = 862 kJ
3. ΔH = 678 − 862 = **−184 kJ/mol**
4. **Negative, so it is exothermic**

WORKED EXAMPLE

EXT **Calculate ΔH for $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. Bond energies: C–H = 413, O=O = 498, C=O = 805, O–H = 464 kJ/mol.**

1. Bonds broken: 4 × C–H = 4 × 413 = 1652; 2 × O=O = 2 × 498 = 996
2. Total broken = 1652 + 996 = 2648 kJ
3. Bonds made: 2 × C=O = 2 × 805 = 1610; 4 × O–H = 4 × 464 = 1856
4. Total made = 1610 + 1856 = 3466 kJ
5. **ΔH = 2648 − 3466 = −818 kJ/mol (exothermic)**

WORKED EXAMPLE

EXT **Calculate ΔH for $N_2 + O_2 \rightarrow 2NO$. Bond energies: N≡N = 945, O=O = 498, N=O (in NO) = 631 kJ/mol.**

1. Bonds broken: 945 + 498 = 1443 kJ
2. Bonds made: 2 × 631 = 1262 kJ
3. ΔH = 1443 − 1262 = **+181 kJ/mol**
4. **Positive, so it is endothermic — this is why nitrogen and oxygen only react at the very high temperatures inside a car engine**

EXAM TIP

Count the bonds for **every** molecule: draw the displayed formula. In CH_4 there are 4 C–H bonds; in H_2O there are 2 O–H bonds; in CO_2 there are 2 C=O bonds. Then do **broken − made**.

COMMON MISTAKE

Subtracting the wrong way round. If your answer for a burning fuel is **positive**, check again — fuels release energy, so ΔH should be **negative**.

COMMON MISTAKE

Saying that breaking bonds **releases** energy. It does not — breaking always takes energy **in**.

4 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Give two examples of exothermic reactions.
2. What happens to the temperature of the surroundings in an endothermic reaction?
3. Name one endothermic process.
4. Are the products higher or lower in energy than the reactants in an exothermic reaction?
5. EXT What is the sign of ΔH for an endothermic reaction?
6. EXT Define activation energy.
7. EXT Is breaking a bond exothermic or endothermic?

EXAM-STYLE

8. EXT Draw and label an energy profile for an exothermic reaction. [4]
9. EXT Calculate ΔH for $2H_2 + O_2 \rightarrow 2H_2O$. Bond energies: H–H 436, O=O 498, O–H 464 kJ/mol. [3]
10. EXT A student says "Exothermic reactions do not need any energy to start". Explain why this is wrong. [2]
11. Describe an experiment to show that a reaction is exothermic. [3]

Show answers

1. any two from: burning, neutralisation, respiration, rusting
2. it falls
3. thermal decomposition of calcium carbonate / photosynthesis / dissolving ammonium nitrate
4. lower
5. positive (+)
6. the minimum energy colliding particles must have in order to react
7. endothermic
8. axes: energy (vertical) and progress of reaction (horizontal)
   reactants level higher than products level
   hump between them
   Ea arrow from reactants to the top of the hump, and ΔH arrow (downwards) from reactants to products
9. broken: 2 × 436 + 498 = 872 + 498 = 1370 kJ
   made: 4 × 464 = 1856 kJ
   ΔH = 1370 − 1856 = −486 kJ/mol
10. bonds in the reactants must be broken first, which takes energy
    this is the activation energy, e.g. a match is needed to light a fuel
11. mix the reactants in a polystyrene (insulated) cup
    measure the temperature with a thermometer before and after, stirring
    the temperature goes up

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