Energy transfer in exothermic and endothermic reactions

4.5.1.1 · Energy changes · revision notes

Every chemical reaction transfers energy, either to the surroundings (exothermic) or from the surroundings (endothermic). You need to classify reactions from temperature changes, give examples and uses of each type, and describe the required practical on temperature changes in reacting solutions. Expect data questions, short recall questions and 4 to 6 mark method questions.

Key facts

- Exothermic: energy transferred **to** the surroundings, so their temperature rises
- Energy is conserved: the total energy is the same before and after a reaction
- Endothermic examples: thermal decomposition, citric acid + sodium hydrogencarbonate
- Endothermic use: sports injury cold packs
- Practical: polystyrene cup and lid reduce energy transfer with the surroundings
- Endothermic: energy taken in **from** the surroundings, so their temperature falls
- Exothermic examples: combustion, many oxidation reactions, neutralisation
- Exothermic uses: self-heating cans, hand warmers
- Temperature change = highest (or lowest) temperature − starting temperature

Notes

Energy is conserved

- Energy is never created or destroyed in a chemical reaction. There is the same amount of energy in the universe after a reaction as before it.
- If a reaction transfers energy to the surroundings, the products must have **less** energy than the reactants, by exactly the amount transferred.
- If a reaction takes in energy from the surroundings, the products have **more** energy than the reactants.
- The surroundings are everything around the reacting particles: the water the chemicals are dissolved in, the container, the thermometer and the air.

Exothermic reactions

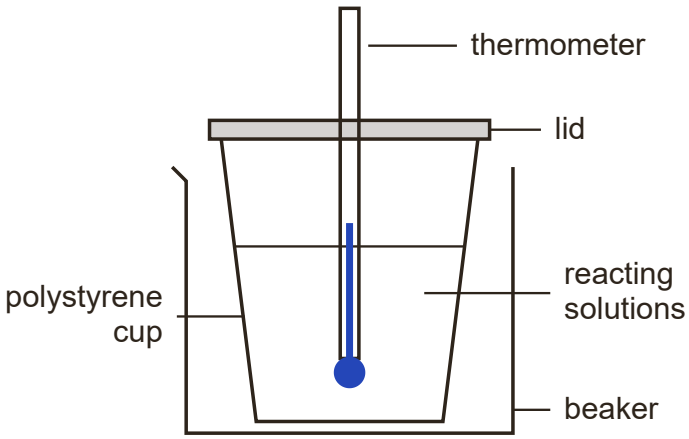
- An **exothermic** reaction transfers energy **to** the surroundings, so the temperature of the surroundings **increases**.
- Examples: combustion (burning fuels), many oxidation reactions, neutralisation (acid + alkali), metals reacting with acids, and displacement reactions.
- Everyday uses: self-heating cans of food or drink, and hand warmers.

Endothermic reactions

- An **endothermic** reaction takes in energy **from** the surroundings, so the temperature of the surroundings **decreases**.
- Examples: thermal decomposition (e.g. calcium carbonate → calcium oxide + carbon dioxide) and the reaction of citric acid with sodium hydrogencarbonate.
- Dissolving some salts, e.g. ammonium nitrate, in water also takes in energy, so the water cools.
- Everyday use: some instant cold packs for sports injuries.

Required practical: temperature changes

- You investigate a variable that affects the temperature change of reacting solutions, e.g. acid + metal, acid + carbonate, neutralisation or metal displacement.
- Use a measuring cylinder to put a set volume (e.g. 25 cm^3) of one solution into a polystyrene cup standing in a beaker.
- Record the starting temperature. Add a measured amount of the other reactant (weigh a solid on a balance), fit the lid, stir, and record the highest (or lowest) temperature.



The cup insulates, the lid cuts energy transfer to the air and the beaker stops the cup falling over.

- Temperature change = highest (or lowest) temperature − starting temperature.
- The independent variable could be the type or mass of metal, or the volume or concentration of a solution. Keep everything else the same.
- Use fresh solution for each value. Repeat each value and calculate a mean temperature change.
- Polystyrene is a good thermal insulator and a lid reduces energy transfer to (or from) the air, so the measured temperature change is closer to the true value.
- If you add an alkali to an acid in small portions, the temperature is highest when the acid has just been neutralised. After that no more energy is released, and the extra solution added cools the mixture.
  Grade 7+ only
- After the reaction ends, the mixture returns towards room temperature as energy transfers to (or from) the surroundings.

How to answer each type of question

Identify exothermic or endothermic from data

1 to 2 marks | Grade 4

1. Work out the temperature change for each reaction (final − starting temperature).
2. A rise in temperature means exothermic; a fall means endothermic.
3. Back up your choice with the data, e.g. 'the temperature fell by 4.5 °C'.

Example. A student carried out three reactions in polystyrene cups and recorded the temperatures.

Reaction	Reactants	Starting temperature in °C	Final temperature in °C
P	iron filings + copper sulfate solution	19.0	27.5
Q	citric acid + sodium hydrogencarbonate solution	20.5	16.0
R	nitric acid + potassium hydroxide solution	19.5	31.0

(a) Which reaction is endothermic? Give a reason for your answer. (2)
(b) Calculate the temperature change in reaction R. (1)

Model answer.

(a) Q (1) because the temperature decreased / fell by 4.5 °C (1)
(b) 31.0 − 19.5 = 11.5 °C (1)

Explain how the energy of the products compares with the reactants

2 marks | Grade 5

1. Say whether energy is transferred to or from the surroundings.
2. Compare the energy of the products with the energy of the reactants, using 'more' or 'less'.
3. Link to conservation of energy: the difference is the energy transferred.

Example. When methane burns, the temperature of the surroundings increases.
Explain how the energy of the products compares with the energy of the reactants. (2)

Model answer. Energy is transferred to the surroundings, so the reaction is exothermic (1). The products have less energy than the reactants, by the amount of energy transferred to the surroundings (1).

Describe a method (required practical) 4 to 6 marks **Grade 5**

1. Name the apparatus: measuring cylinder, polystyrene cup in a beaker, lid, thermometer, balance.
2. Give the steps in order with amounts: measure, record the starting temperature, add, stir, record the highest (or lowest) temperature.
3. Say how you change the independent variable and what you keep the same.
4. Finish with repeats and how you use the results (temperature change, mean).

Example. A student wants to find out how the temperature change depends on the metal used when magnesium, zinc and iron powders react with dilute hydrochloric acid.
Describe a method the student could use. (6)

Model answer.

Measure 25 cm^3 of dilute hydrochloric acid with a measuring cylinder and pour it into a polystyrene cup standing in a beaker (1). Measure and record the starting temperature of the acid with a thermometer (1). Weigh 0.5 g of magnesium powder on a balance, add it to the acid, put on a lid and stir (1). Record the highest temperature reached and work out the temperature change (1). Repeat with 0.5 g of zinc powder and then 0.5 g of iron powder, using fresh acid of the same volume and concentration each time (1). Repeat each experiment and calculate a mean temperature change for each metal (1).

This type of question is marked in levels: a complete, logically ordered method like this is Level 3 (5 to 6 marks).

Evaluate the use of a reaction in a product 3 to 4 marks **Grade 6**

1. Decide whether the product needs an exothermic reaction (to heat) or an endothermic reaction (to cool).
2. Use the data: temperature reached, cost, safety, and whether it can be reused.
3. Give points for and against, each linked to the data.
4. End with a conclusion that says which is best and why.

Example. A company is designing a self-heating can of soup. The reaction must heat the soup from 20 °C to at least 60 °C. The company tests three reactions.

Reaction	Highest temperature in °C	Cost per can	Products
X	75	12p	a harmless solid
Y	52	4p	a harmless solid
Z	90	8p	gives off a toxic gas

Evaluate which reaction the company should use. (4)

Model answer. Y is the cheapest, but it only reaches 52 °C, so it would not heat the soup to 60 °C (1). Z reaches the highest temperature and is cheaper than X, but it gives off a toxic gas, so it is not safe to use with food (1). X reaches 75 °C, which is above 60 °C, and its product is harmless (1). The company should use X, even though it costs the most, because it is the only reaction that is both hot enough and safe (1).

Don’t lose marks

- Saying an endothermic reaction 'gives out cold'. It takes in energy from the surroundings, which makes them colder.
- Saying energy is 'made', 'used up' or 'destroyed'. Energy is transferred, never created or destroyed.
- Mixing up the direction: in an endothermic reaction the thermometer reading falls, because energy is taken in from the solution around the reacting particles.
- Giving a classification with no reason. When the question says 'give a reason', 'exothermic' alone scores only 1 of the 2 marks; add 'because the temperature increased'.
- Leaving out control variables in a method: the volume and concentration of the solution, the mass of solid and the type of cup should all stay the same.

More tips

Memory tricks

- EXothermic: energy EXits to the surroundings. ENdothermic: energy ENters from the surroundings.
- Thermometer rule: reading goes up, exothermic; reading goes down, endothermic.
- Burning, neutralising and oxidising are exothermic. Splitting a compound up by heating it (thermal decomposition) is endothermic.
- Products that warm you (hand warmers, self-heating cans) use exothermic reactions; products that cool you (sports injury packs) use endothermic reactions.

Exam technique

- When you classify a reaction, always quote the data, e.g. 'exothermic, because the temperature increased by 8.5 °C'.
- In method questions, give amounts and equipment (e.g. '25 cm³ of acid measured with a measuring cylinder') and keep the steps in a logical order.
- Give temperature changes to the same precision as the data, with the unit °C, e.g. 27.5 − 19.0 = 8.5 °C.
- In 'evaluate' questions, use numbers from the data for both sides and always finish with a justified conclusion.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Define exothermic and endothermic reactions**
Exothermic reactions transfer energy to the surroundings so their temperature rises; endothermic reactions take in energy so their temperature falls.

Grade 3 — **Give examples of exothermic reactions**
Combustion, many oxidation reactions and neutralisation are all exothermic.

Grade 4 — **Give examples of endothermic reactions**
Thermal decomposition and the reaction of citric acid with sodium hydrogencarbonate are endothermic.

Grade 4 — **Classify a reaction from temperature data**
A rise in temperature means the reaction is exothermic; a fall means it is endothermic.

Grade 5 — **Explain energy conservation in a reaction**
Energy is not created or destroyed, so in an exothermic reaction the products have less energy than the reactants by the amount transferred.

Grade 5 — **Describe the temperature change required practical**
Mix measured amounts in a polystyrene cup, stir, and record the starting and the highest (or lowest) temperature.

Grade 5 — **Suggest improvements to the temperature-change practical**
For example, a lid and extra insulation reduce energy transfer to the surroundings, and repeats let you calculate a mean.

Grade 6 — **Evaluate uses of exothermic and endothermic reactions**
Judge hand warmers, self-heating cans and cold packs using given data on temperature change, cost, safety and reuse.

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