

3 · Particle model of matter

AQA · GCSE · Physics

The particle model: matter from the inside

Why does a metal spoon sink while a huge ship floats? Why does sweat cool you down? Both answers live in the particle model. This reference covers **AQA GCSE Physics 8463, topic 4.3 Particle model of matter**.

How the exam treats this topic:

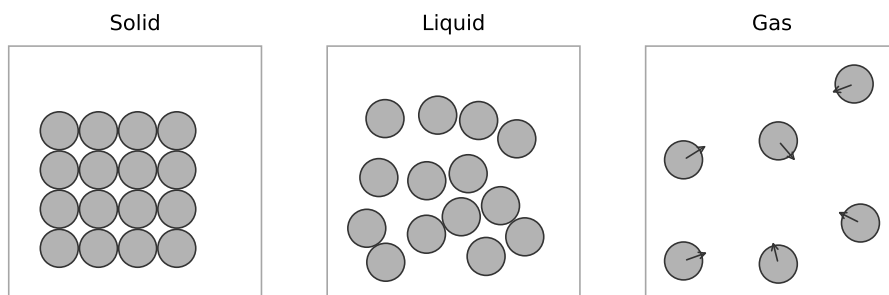
- Paper 1 (4.1–4.4) carries this topic. Practise choosing and rearranging $\rho = m/V$, $\Delta E = mc\Delta\theta$, $E = mL$ and $pV = \text{constant}$. Use the Physics Equations Sheet supplied for your examination series when one is provided.
- Pressure in gases and doing work on a gas are **physics only** (work on a gas also Higher Tier).
- You must **interpret heating and cooling graphs** that include changes of state.
- You must distinguish **specific heat capacity** from **specific latent heat** in words and in calculations.

Density of materials

$$\rho = \frac{m}{V}$$

- ρ **density** in kg/m^3 ; m mass in kg; V volume in m^3 .
- Use consistent units. To express a result in kg/m^3 , convert g/cm^3 . $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$ (multiply by 1000: a cm^3 is a millionth of a m^3 and a gram is a thousandth of a kg).

The particle model explains the states of matter:



Same-sized schematic particles; equal viewing volumes

Pattern, contact, spacing.

State	Arrangement	Motion
solid	close, regular	vibrate about fixed positions
liquid	close, irregular	move past each other
gas	far apart	random; straight paths between collisions

- Solids and liquids have similar densities because their particles are similarly packed; a gas is mostly empty space.
- Ice is unusual: water **expands** on freezing, so ice is slightly *less* dense than water.

Worked example. A ring has mass 9.46 g and volume 0.44 cm³. Find its density in kg/m³.

- Convert both first: $m = 9.46 \text{ g} = 9.46 \times 10^{-3} \text{ kg}$; $V = 0.44 \text{ cm}^3 = 4.4 \times 10^{-7} \text{ m}^3$.

$$\rho = \frac{m}{V} = \frac{9.46 \times 10^{-3} \text{ kg}}{4.4 \times 10^{-7} \text{ m}^3} = 21\,500 \text{ kg/m}^3$$

■ Actual exam demands: density

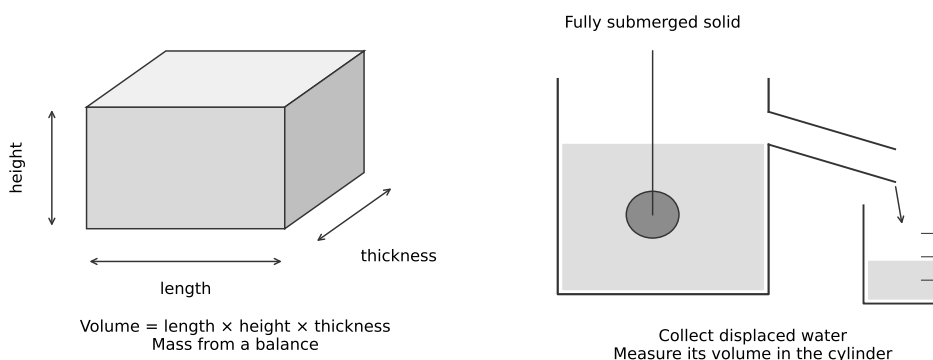
AQA June 2025 8463/1H Q01.3: 824000 kg of seawater passes a turbine each second; density is 1030 kg/m³. Choose $\rho = m/V$, then rearrange:

$$V = m/\rho = 824000 \text{ kg}/(1030 \text{ kg/m}^3) = 800 \text{ m}^3$$

This is the volume passing in each second. **AQA June 2024 Q07.5** reverses the ring example: given density 21500 kg/m³ and volume 0.44 cm³, calculate mass. Convert the volume, then use $m = \rho V = 21500 \text{ kg/m}^3 \times 4.4 \times 10^{-7} \text{ m}^3 = 0.00946 \text{ kg}$.

Teacher-written liquid example. The empty cylinder is 42 g; cylinder plus 60 cm³ of liquid is 90 g. Subtract $m = 90 \text{ g} - 42 \text{ g} = 48 \text{ g}$, then $\rho = m/V = 48 \text{ g}/60 \text{ cm}^3 = 0.80 \text{ g/cm}^3$.

■ Required practical 5: density



Regular shapes from dimensions; irregular shapes by displacement.

- **Regular solid:** measure length, width and thickness with a ruler (or micrometer/Vernier callipers), multiply for V ; find m on a balance; $\rho = m/V$.
- **Irregular solid:** fill a displacement (eureka) can to the spout, wait for dripping to stop, lower the object in on thin string; the volume of water collected in a measuring cylinder equals the object's volume.
- **Liquid:** find the mass of an empty measuring cylinder, then the mass with a known volume inside; subtract for m .
- Accuracy points: read the measuring cylinder at eye level on a flat surface (avoid parallax); use thin string so it displaces almost no water; repeat and average.

AQA June 2022 8463/1H Q02.1–02.4: describe a complete rock-density method, then interpret $2.55 \pm 0.10 \text{ g/cm}^3$ as the interval 2.45–2.65 g/cm³. Repeated readings allow a mean and reduce random-error effects; they do not remove a systematic calibration error. In a cylinder-displacement method, subtract initial volume from final volume, fully submerge the rock and avoid trapped bubbles.

Changes of state and internal energy

When a substance **melts, freezes, boils, evaporates, condenses or sublimates** :

- **Mass is conserved** in a closed system: the number of particles does not change. If vapour leaves an open container, the remaining material loses mass, but the total including the escaped vapour is conserved.
- Changes of state are **physical changes** : reverse the change and the material recovers its original properties. (A chemical change makes new substances; melting does not.)

Internal energy is the **total kinetic and potential energy of all the particles** that make up a system. Heating a system increases the particles' energy, and that energy goes one of two ways:

1. it **raises the temperature** – the particles' kinetic energy grows;
2. it **produces melting or boiling** – the particles' potential energy increases as their arrangement changes. For a pure substance changing state at constant pressure, temperature stays constant. During freezing or condensation, energy is released and potential energy decreases.

Specific heat capacity and temperature changes

While the temperature changes, the energy needed follows (also met in topic 1):

$$\Delta E = m c \Delta \theta$$

Specific heat capacity c (J/kg °C) is the energy needed to raise the temperature of **one kilogram** by **one degree Celsius**.

Worked example. 0.030 kg of olive oil ($c = 1800 \text{ J/kg } ^\circ\text{C}$) warms from $21 ^\circ\text{C}$ to $96 ^\circ\text{C}$.

- Temperature change first: $\Delta\theta = 96 - 21 = 75 ^\circ\text{C}$.

$$\Delta E = mc\Delta\theta = 0.030 \times 1800 \times 75 = 4050 \text{ J}$$

Teacher-written heating-pad example. A 0.20 kg pad with $c = 900 \text{ J/(kg } ^\circ\text{C)}$ warms from $22 ^\circ\text{C}$ to $46 ^\circ\text{C}$. First find $\Delta\theta = 46 - 22 = 24 ^\circ\text{C}$, then:

$$\Delta E = mc\Delta\theta = 0.20 \text{ kg} \times 900 \text{ J/(kg } ^\circ\text{C)} \times 24 ^\circ\text{C} = 4320 \text{ J}$$

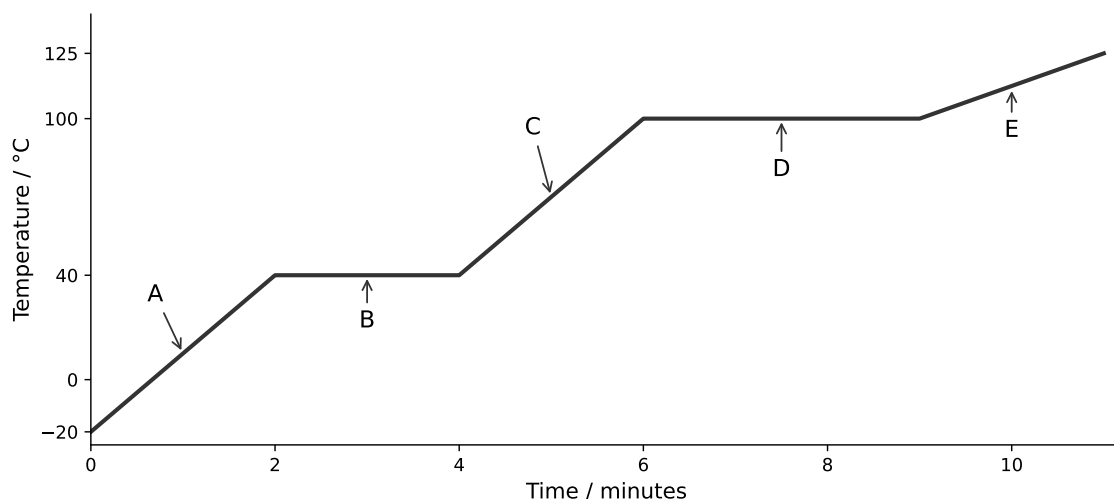
The RP1 method, error analysis and percentage-difference work are covered on sheet 1.3 – the same equation, the same practical.

Specific latent heat and heating graphs

For a pure substance **melting or boiling at constant pressure**, temperature remains constant while energy enters. Freezing and condensation release energy at constant temperature under the same conditions. The energy needed is called **latent heat** :

$$E = mL$$

- E energy for the change of state in J; m mass that changes state in kg; L **specific latent heat** in J/kg.
- **Specific latent heat** is the energy needed to change the state of **one kilogram** of a substance with **no change of temperature**.
- **Fusion** : solid to liquid. **Vaporisation** : liquid to vapour. These are different changes, with different values of L . For water, the specific latent heat of vaporisation is much greater than that of fusion; use the value for the stated material and change.



A and C warm single phases; B is melting; D is boiling; E warms the gas. The temperatures are for this generic substance, not water.

Reading the graph:

- Rising sections: energy goes into kinetic energy – the temperature climbs ($\Delta E = mc\Delta\theta$).
- Flat sections: energy goes into potential energy – the state is changing ($E = mL$). For the same material, change of state and constant net heating power, a longer plateau means more mass changed state. If L or heating power differs, time alone does not identify the mass.
- Cooling has the reverse sequence of state changes: flat while a pure substance freezes or condenses at constant pressure, releasing latent heat. Rates and durations need not mirror the heating graph.

Distinguishing the two: specific heat capacity involves a **temperature change**; specific latent heat involves a **change of state at constant temperature**.

Teacher-written worked example. A 30 W heater runs for 11 minutes and boils off 6.6×10^{-3} kg of water already at its boiling point. Estimate L assuming all heater energy reaches the boiling water, then explain the effect of heat loss.

- Convert: $E = Pt = 30 \text{ W} \times 660 \text{ s} = 19800 \text{ J}$.

$$L = \frac{E}{m} = \frac{19800 \text{ J}}{6.6 \times 10^{-3} \text{ kg}} = 3.0 \times 10^6 \text{ J/kg}$$

■ Actual exam demands: boiling and energy accounting

AQA June 2025 8463/1H Q08.1–08.2: 9950 J boils 50 g of nitrogen at its boiling point. Convert $m = 0.050$ kg, choose $E = mL$ and rearrange:

$$L = E/m = 9950 \text{ J}/0.050 \text{ kg} = 199000 \text{ J/kg}$$

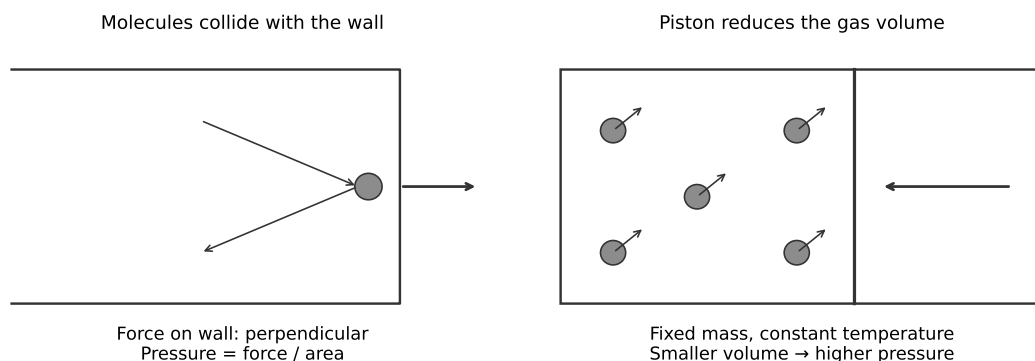
During boiling, potential energy increases while average kinetic energy and temperature remain constant; internal energy increases.

AQA June 2022 Q08.3–08.5: beaker-and-water mass falls from 0.080 kg to 0.071 kg while the heater transfers 25200 J. The evaporated mass is 0.009 kg, so $L = E/m = 25200 \text{ J}/0.009 \text{ kg} = 2.8 \times 10^6 \text{ J/kg}$. Heat transferred to the surroundings makes the heater-energy estimate of L too high. Conversely, including water lost before boiling overstates the mass associated with the measured boiling energy and makes the estimate too low. Identify which measured quantity is biased before predicting the result.

Particle motion in gases

The molecules of a gas are in **constant random motion**. Its temperature is related to the **average kinetic energy** of the molecules: hotter gas, faster particles.

Explain gas pressure using the particle model:



The force on the wall is perpendicular to it; molecules can approach obliquely.

1. the moving molecules **collide with the container walls**;
2. each collision exerts a **force at right angles** to the wall;
3. pressure is force per unit area – the total of many tiny collisions spread over the wall.

Temperature up (constant volume) → pressure up: the molecules move faster on average, so they hit the walls **more often** and **harder** (larger force each impact), so the force per unit area rises.

Actual explanation – AQA June 2025 8463/1H Q08.3: after the nitrogen has boiled, its gas temperature rises in the sealed fixed-volume container. Mean kinetic energy and mean speed increase; collisions exert greater force and occur more frequently, so pressure increases. State the fixed-volume condition.

Pressure in gases (physics only)

A gas can be compressed or expanded by pressure changes. For a **fixed mass of gas at constant temperature**:

$$pV = \text{constant}$$

- p pressure in pascals, Pa; V volume in m^3 .
- Before/after form: $p_1V_1 = p_2V_2$.

The particle explanation of each direction:

- **Volume up $\rightarrow$ pressure down** (constant temperature): at the same average speed, molecules collide with each unit area of wall less frequently, so force per unit area falls.
- **Volume down $\rightarrow$ pressure up**: at the same average speed, molecules collide with each unit area of wall more frequently, so force per unit area rises.

Worked example. A syringe holds 50 cm^3 of air at 100 kPa. It is compressed to 20 cm^3 at constant temperature.

- Convert or keep consistent: volumes in cm^3 cancel; pressures must be consistent.

$$p_1V_1 = p_2V_2 \quad \Rightarrow \quad p_2 = \frac{p_1V_1}{V_2}$$
$$p_2 = \frac{p_1V_1}{V_2} = \frac{100 \text{ kPa} \times 50 \text{ cm}^3}{20 \text{ cm}^3} = 250 \text{ kPa}$$

Doing work on a gas (physics only, Higher Tier)

Work is the transfer of energy by a force. In a rapid compression with little heat transfer to the surroundings, work done on the gas **increases its internal energy** and can raise its temperature.

The credited chain (bicycle pump): pushing the pump's handle does work on the trapped gas $\rightarrow$ energy is transferred to the gas's particles $\rightarrow$ their average kinetic energy rises $\rightarrow$ the temperature of the gas increases (the pump feels warm).

A gas doing work on its surroundings can cool if energy is not replaced by heating. Compression or expansion does not always change temperature: sufficiently slow changes with heat exchange can be approximately isothermal. Do not apply $pV = \text{constant}$ to a rapid compression that heats the gas unless constant temperature is stated or justified.

Checklist before you call this topic done

- Convert g/cm^3 to kg/m^3 , and cm^3 to m^3 , before using $\rho = m/V$.
- Describe RP5 for regular solids, displacement and liquids, with accuracy points.
- State that mass is conserved in changes of state and that they are physical changes.
- Define internal energy as total kinetic plus potential energy of the particles.
- Choose between $\Delta E = mc\Delta\theta$ (temperature changes) and $E = mL$ (state changes).
- Read heating graphs: rising = kinetic energy, plateau = latent heat.
- Explain gas pressure from wall collisions; use $pV = \text{constant}$ with consistent units.
- (physics only, HT) Explain why doing work on a gas raises its temperature.