Cambridge IGCSE · Physics 0625 · Notes

Thermal properties and temperature

Read online at **pastopic.com/cambridge/physics-0625/notes/thermal-properties-and-temperature**

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Read first: **Kinetic particle model of matter**, **Energy, work and power**

What you need to know

This topic is about what heating does to a substance: it gets bigger, it gets hotter, and at the right temperature it changes state. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

1. **Describe thermal expansion**: solids, liquids and gases all get bigger when heated (at constant pressure) and smaller when cooled. For the same temperature rise a gas expands most and a solid least.
2. **Describe everyday uses and problems of thermal expansion**, such as the gaps in railway tracks and bridges, sagging power cables, liquid-in-glass thermometers and bimetallic strips.
3. **Extended only:** explain, using how the particles are arranged and how they move, **why** gases expand more than liquids, and liquids more than solids.
4. **Know that heating an object so its temperature rises increases its internal energy.**
5. **Extended only:** describe a rise in temperature as a rise in the **average kinetic energy** of all the particles in the object.
6. **Extended only:** define **specific heat capacity** as the energy needed per unit mass per unit rise in temperature, and recall and use $c = \dfrac{\Delta E}{m\,\Delta\theta}$.
7. **Extended only:** describe experiments to measure the specific heat capacity of a solid and of a liquid.
8. **Describe melting and boiling**: energy goes in, but the temperature does not change while the state changes.
9. **Know that pure water melts at 0 °C and boils at 100 °C** at standard atmospheric pressure.
10. **Describe condensation and solidification (freezing)** in terms of what the particles do.
11. **Describe evaporation** as the more-energetic particles escaping from the **surface** of a liquid, and **know that evaporation cools the liquid** that is left.
12. **Extended only:** describe the differences between **boiling and evaporation**.
13. **Extended only:** describe how **temperature, surface area and air movement** over the surface change the rate of evaporation.
14. **Extended only:** explain why an object **touching an evaporating liquid** cools down.

Understand it

Thermal expansion

Heat a substance and its particles move faster: in a solid they vibrate more strongly, in a liquid or gas they move about more quickly. Faster-moving particles push each other further apart, so the **average distance between the particles increases** and the substance takes up more space. That is **thermal expansion**. Cool it and the particles slow down and move closer together: it **contracts**.

Three things never change when something expands:

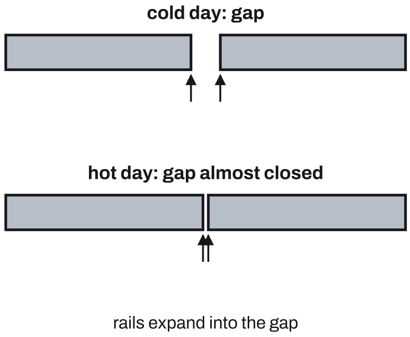
- **the mass**: no particles are added or lost;
- **the size of each particle**: the particles do not expand, they move further apart;
- **the number of particles**.

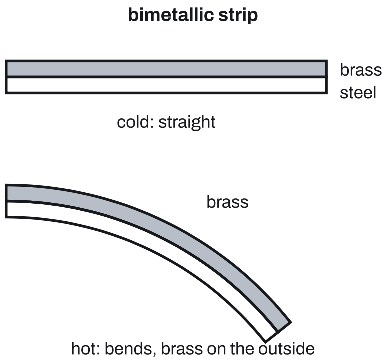
Because the mass stays the same but the volume goes up, **the density goes down** when a substance is heated. A solid expands in **every direction**: its length, width and height all grow, and a hole in a metal plate gets bigger too, just as if the hole were made of metal.

How much does each state expand? For the same temperature rise, at constant pressure:

$$\text{gas (most)} \;>\; \text{liquid} \;>\; \text{solid (least)}$$

Extended only. The difference comes from the forces between the particles. In a **solid** the particles are held in fixed positions by strong forces, so extra vibration only pushes them apart a tiny amount. In a **liquid** the particles are still close, but the forces hold them less tightly, so they move apart more. In a **gas** the forces between the particles are very weak (almost none) and the particles are already far apart, so faster particles spread out much more freely. It is **not** that gas particles themselves expand more.





Uses and problems of thermal expansion

Expansion is small, but the forces are huge, so engineers must allow for it.

Problems that must be allowed for:

- **Railway tracks and bridges** have **gaps** (expansion joints) between sections. On a hot day the metal expands into the gap. With no gap, the rails would push on each other and **buckle**. One end of a bridge often rests on **rollers** so it can move as it expands.
- **Overhead power cables** are hung **slack** (sagging) when they are put up. On a cold day they contract and get shorter; if they were tight they could snap or pull the pylons over.
- **Glass** can crack if one part is heated much faster than another, because the hot part expands and the cold part doesn't.

Useful applications:

- **Liquid-in-glass thermometers**: the liquid (alcohol or mercury) expands up a narrow tube as it gets hotter, and contracts when it cools.
- **Bimetallic strips**: two metals that expand by different amounts are joined. When heated, the strip bends, with the metal that expands **more** on the **outside** of the curve. The bending can open or close a switch, so a bimetallic strip is used in **thermostats** and fire alarms.
- **Fitting tight parts together**: heat a metal ring (or tyre, or collar) so it expands, slip it over the wheel or shaft, and let it cool: it contracts and grips tightly. To fit a shaft **into** a hole, cool the shaft (it shrinks) and heat the part with the hole (the hole grows).
- **Loosening a tight metal lid or nut**: heat it and it expands away from what it is stuck to.

Liquids expand too: a flask of liquid with a narrow tube in the stopper works like a thermometer; the level rises when the flask is warmed and falls when it is cooled. A liquid that expands more per degree rises more when warmed **and** falls more when cooled. Gases expand most of all: warm a flask of air sealed by a small drop of liquid in a tube and the drop is pushed up the tube, mainly by the **air** expanding.

Temperature and internal energy

Every object has **internal energy**: the total energy of all its particles, mostly the kinetic energy of their motion plus the energy stored in the forces between them.

- **When the temperature of an object rises, its internal energy increases.** When it cools, its internal energy decreases.
- **Extended only:** temperature is linked to the **average kinetic energy** of the particles. A rise in temperature means the particles are moving faster on average, so their average kinetic energy is greater.

You don't have to heat something to raise its internal energy: doing work on it does too. Stirring water hard in an insulated tub makes it warmer, because the work done by stirring increases the water's internal energy.

Internal energy depends on the **amount** of material as well as its temperature. A cup of very hot coffee has a higher temperature than a swimming pool, but the pool has far more internal energy, because it has vastly more particles.

Specific heat capacity

Extended only. Some materials warm up quickly, others slowly. It takes 4200 J to warm 1 kg of water by 1 °C, but only about 900 J to warm 1 kg of aluminium by 1 °C. This property is the **specific heat capacity**, c:

The specific heat capacity of a substance is the energy needed to raise the temperature of **unit mass** (1 kg) of it by **1 °C**.

$$c = \frac{\Delta E}{m\,\Delta\theta} \qquad \text{so} \qquad \Delta E = m\,c\,\Delta\theta$$

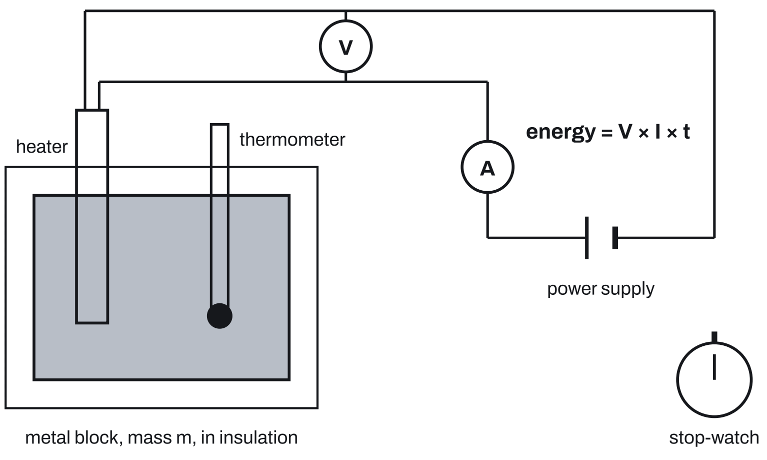
where ΔE is the energy transferred (J), m the mass (kg), and $\Delta\theta$ the **change** in temperature (°C). The unit of c is J/(kg °C). "Specific" means "per kilogram".

For example, warming 2.0 kg of water by 5 °C takes $2.0 \times 4200 \times 5 = 42\,000$ J. The same formula works backwards: when an object **cools**, $mc\Delta\theta$ is the energy it **gives out**.

A **higher** specific heat capacity means **more** energy is needed for the same mass and the same temperature rise, so with the same heater it takes longer to warm up (and it gives out more energy as it cools). A material with a **low** specific heat capacity heats up and cools down quickly.

Measuring specific heat capacity

Extended only. The idea is to put a known amount of energy into a known mass and measure the temperature rise.



For a solid (for example an aluminium block with two holes):

1. Measure the **mass** m of the block on a **balance**.
2. Put an electric **heater** in one hole and a **thermometer** in the other (a drop of oil or water in the hole helps the thermometer touch the block). Wrap the block in **insulation**.
3. Record the **starting temperature** θ_1.

4. Switch on the heater and start a **stop-watch**. Record the **voltmeter** reading V and the **ammeter** reading I (or use a joulemeter, which reads the energy directly).
5. After a set time t, switch off, and record the **highest** temperature θ_2 that the thermometer reaches.
6. Energy supplied $\Delta E = VIt$ (or Pt for a heater of power P); temperature rise $\Delta\theta = \theta_2 - \theta_1$; then $c = \dfrac{\Delta E}{m\,\Delta\theta}$.

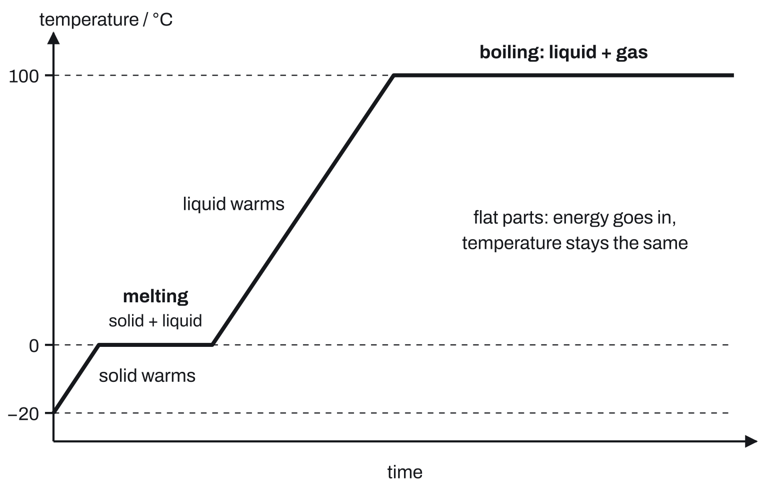
For a liquid (for example water): measure the mass of an empty beaker, then with the liquid in it, to get the mass of liquid. Put an immersion heater and a thermometer in the liquid, insulate the beaker (and give it a lid), and **stir** so the whole liquid is at the same temperature. The measurements and the calculation are the same.

Why is the measured value usually too big? Some of the energy from the heater warms the **surroundings**, the container or the heater itself, not the block. The temperature rise is smaller than it would be, so $\dfrac{\Delta E}{m\,\Delta\theta}$ comes out too high. For the same reason, the **real time** needed to heat something is always **longer** than the time you calculate. Insulation reduces this.

Changes of state

Change	Name	Energy
solid → liquid	melting	taken in
liquid → gas	boiling or evaporation	taken in
gas → liquid	condensation	given out
liquid → solid	solidification (freezing)	given out

Melting and boiling happen at a fixed temperature. Heat a pure solid at a steady rate and plot its temperature against time: you get a **heating curve**.



- **Sloping parts**: the substance is in one state, and the energy put in raises its temperature (and internal energy).

- **Flat parts**: the state is changing. **Energy is still going in, but the temperature stays the same** until the whole substance has changed state. The energy is used to pull the particles apart against the forces between them, not to make them move faster. The lower flat part is the **melting point**; the upper one is the **boiling point**.
- The boiling part is usually **longer** than the melting part, because pulling liquid particles completely apart into a gas needs more energy than loosening a solid into a liquid.

For pure **water** at standard atmospheric pressure: it **melts at 0 °C** and **boils at 100 °C**. A mixture of ice and water stays at 0 °C until all the ice has melted, however much energy goes in.

A **cooling curve** is the heating curve backwards: the temperature falls, stays **flat at the freezing point** while the liquid solidifies (energy is given out, so the temperature doesn't drop), then falls again. The freezing point of a pure substance is the same temperature as its melting point.

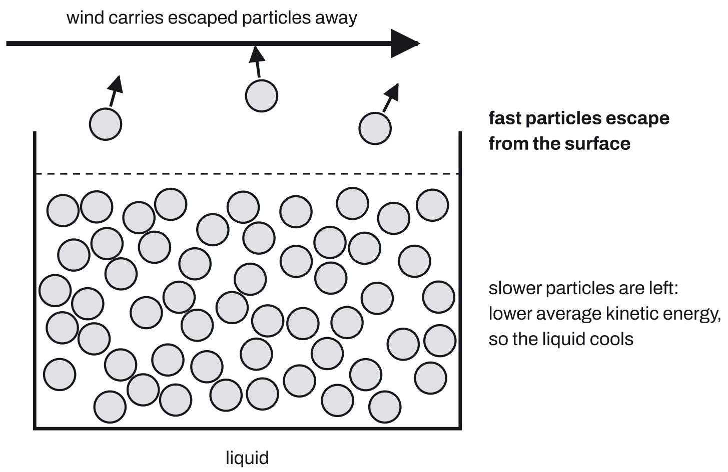
Condensation (gas to liquid): the gas particles lose energy and slow down; when they come close together the attractive forces hold them, so they form a liquid in which the particles are close together but still slide past each other. Energy is **given out** to the surroundings. Water forming on a cold window or on the outside of a glass of iced drink is water vapour from the air condensing on the cold surface.

Solidification (liquid to solid): the particles lose energy and slow down until the forces lock them into **fixed positions** in a regular pattern, where they can only vibrate. Energy is **given out**, so the temperature stays constant while it happens.

When water boils into steam at 100 °C, the **mass** of steam is the same as the mass of water lost, but the **volume** is much greater, because the particles are much further apart.

Evaporation

A puddle dries up even though it never gets to 100 °C. The particles in a liquid move at many different speeds. Now and then a particle near the **surface** is moving fast enough, in the right direction, to break away from the others and **escape into the air**. That is **evaporation**: the **more-energetic particles escape from the surface** of the liquid.



Evaporation cools the liquid. The fastest particles leave, so the particles left behind have a **lower average kinetic energy**, and a lower average kinetic energy means a **lower temperature**.

Extended only: cooling things that touch the liquid. When the liquid cools below the temperature of whatever it is touching (your skin, a bottle, a thermometer bulb), energy flows from that object into the liquid. That energy lets more particles escape, and the object loses thermal energy, so **it cools down too**. This is why sweating cools you, why a wet cloth wrapped round a bottle keeps it cool, and why a thermometer with a wet bulb reads lower than a dry one when air blows over them.

Extended only: what makes evaporation faster?

Change	Why it speeds up evaporation
Higher temperature of the liquid	more particles have enough energy to escape
Larger surface area (a wide, shallow dish)	more particles are at the surface, where they can escape
Air moving over the surface (wind, a fan)	escaped particles are blown away, so fewer fall back into the liquid

Dry, warm, windy weather dries washing fastest. Humid, still, cold weather dries it slowest.

Extended only: boiling and evaporation compared.

Boiling	Evaporation
happens only **at the boiling point**	happens at **any temperature** (below the boiling point)
happens **throughout** the liquid: **bubbles** of vapour form inside it	happens **only at the surface**; no bubbles
needs a **continuous supply of energy** (a heater)	can happen with no heater: energy comes from the liquid and its surroundings
temperature of the liquid **stays constant**	the liquid **cools**
fast	slow

Key facts and formulas

The 0625 papers have no formula sheet, so learn every equation.

Formula	Status
Extended only: $c = \dfrac{\Delta E}{m\,\Delta\theta}$, so $\Delta E = mc\,\Delta\theta$ (c in J/(kg °C))	Learn it
Energy from a heater: $\Delta E = Pt$, and $P = VI$, so $\Delta E = VIt$	Learn it
Extended only: in mixing, energy lost by the hot object $=$ energy gained by the cold one (no losses)	Learn it

Formula	Status
Density $\rho = \frac{m}{V}$, so $m = \rho V$ (for water, 1 cm³ has a mass of 1 g)	Learn it
Pure water melts at 0 °C and boils at 100 °C at standard atmospheric pressure	Learn it
Expansion: gas $>$ liquid $>$ solid; mass constant, density decreases	Learn it

Write θ (or T) for temperature and t for time, and E for energy, not Q (which is charge). Examiners ignore the wrong symbols.

How to do it

We have tagged 192 questions for this topic across Papers 1–4, 2021–2025; 26 are repeats on other papers, leaving 166 different questions. 13 of the 166 mix two or more types, so the counts add up to more than 166.

Question type	Questions
Evaporation, and boiling compared with it	49
Changes of state and heating or cooling curves	46
Thermal expansion: effects, uses and explanations	35
Extended only: specific heat capacity calculations	32
Internal energy and temperature	14
Extended only: measuring specific heat capacity	6

Some older questions (2021–2022) also ask about **specific latent heat**, **thermal capacity** and how thermometers are designed (sensitivity, range, fixed points). These were removed from the syllabus from 2023, so skip those parts, for example part (b) of **0625/43/O/N/22 Q5** and part (a)(i) of **0625/43/M/J/21 Q4**.

1. Evaporation, and boiling compared with it (49 questions)

1. **Name it**: liquid disappearing below its boiling point (a puddle drying, washing drying, a pond's level falling) is **evaporation**.
2. **Describe it with particles**: the **more-energetic** (faster) particles escape from the **surface** of the liquid into the air.
3. **Say what happens to the liquid left**: its particles have a lower average kinetic energy, so **it cools**.

Variations you will meet:

- **Multiple choice on what escapes**: individual **molecules** (not ions, not electrons, not tiny drops), the **most** energetic ones, from the **surface** only. Only particles with enough energy can escape.
- **Does the remaining liquid get hotter or cooler?** Cooler. So an option saying the temperature increases is wrong.

- **Extended only: which weather dries things fastest?** Hot and windy. Give **one** change if asked for one, and link it to the rate: "a higher air temperature, so more particles have enough energy to escape, so the puddle evaporates faster".
- **Extended only: which container evaporates fastest?** The one with the **largest surface area** of liquid. Adding more water to a narrowing container can **reduce** the surface area and so slow evaporation.
- **Extended only: bubbling air through a liquid** speeds up evaporation because it increases the surface area and carries escaped particles away (not because it cools the liquid).
- **Extended only: cooling by evaporation**: sweat, a wet cloth round a milk carton or can, water splashed on a face, a wet thermometer bulb. Say: the liquid takes **energy from the object** (skin, milk, bulb) to evaporate; the more-energetic particles escape, so the liquid is left cooler; energy flows from the object to the liquid, so the **object cools**.
- **Extended only: differences between boiling and evaporation**: pick from the table in "Understand it". Be specific: "boiling happens throughout the liquid; evaporation only at the surface", not "boiling is faster".
- **Extended only: a wet windscreen or clothes dryer**: the heater gives the water particles more energy; more of them escape from the surface; the moist air is carried away.

2. Changes of state and heating or cooling curves (46 questions)

1. **Name the change** from the two states: melting, boiling (or evaporation), condensation, solidification (freezing).
2. **Energy**: melting and boiling take energy in; condensation and solidification give energy out.
3. **Temperature**: while a pure substance changes state, its temperature **stays constant**.

Reading a heating (or cooling) curve:

1. **Flat parts** are changes of state. The **lower** flat part is the **melting point**, the **higher** one the **boiling point**. Read their temperatures off the axis.
2. **Sloping parts** are one state warming (or cooling): below the melting point it is solid, between the flat parts liquid, above the boiling point gas.
3. On a flat part there are **two states together** (solid and liquid while melting; liquid and gas while boiling).
4. On a sloping part the energy **raises the temperature** (and the internal energy); on a flat part it **changes the state** at constant temperature.

Variations you will meet:

- **Sketch a cooling curve** from given data (for example "cools from 50 °C to its melting point of 20 °C in 30 minutes, then takes 30 minutes to freeze, then cools to 5 °C"): a curve falling to the melting point, a **horizontal** line at the melting point for the freezing time, then falling again. The falling parts curve, getting less steep as the temperature nears room temperature.
- **Draw the curve for a more powerful heater**: the same melting and boiling temperatures, but every section happens **sooner** (steeper slopes, shorter flat parts).
- **Which substance has the lower melting or boiling point?** Compare the heights of the flat parts on the two curves.

- **At what temperature, which state?** A substance that melts at -78 °C and boils at 23 °C is a **liquid** at 0 °C and a **gas** at 100 °C.
- **Water's numbers**: melts at 0 °C, boils at 100 °C (at standard atmospheric pressure). The difference between these two fixed points is 100 °C. Of four liquids with different boiling points, water is the one at 100 °C.
- **Melting ice and boiling water side by side**: both stay at constant temperature (0 °C and 100 °C) while they change state.
- **Condensation and solidification with particles**: particles lose energy and slow down, and come closer together (condensation), or settle into fixed positions and only vibrate (solidification).
- **Where does water on a cold glass come from?** Water vapour in the air condenses on the cold surface.
- **Mass and volume across a change of state**: mass stays the same; steam has a much greater volume than the water it came from. A solid melting in a closed container keeps its volume roughly the same but takes the shape of the container.
- **A density–time graph**: density falls sharply as a solid melts, or rises sharply as a gas condenses.
- **Which terms mean the same change?** Boiling and evaporation name the same change of state (liquid → gas), even though they happen in different ways. Freezing and solidification are the same change too.

3. Thermal expansion: effects, uses and explanations (35 questions)

1. **Decide whether the question wants expansion (heating) or contraction (cooling).**
2. **Say what changes**: volume (length, width and height; holes get bigger too) and density go up or down; the **mass does not change**.
3. **For a problem**, say what would happen with no allowance (the rails **buckle**, the cable **snaps**) and how it is solved (a **gap**, **slack** cables, **rollers**).
4. **For an application**, name it and say how expansion makes it work.

Variations you will meet:

- **Gaps in railway tracks or bridges**: to allow for **expansion on hot days**. **Slack cables**: to allow for **contraction on cold days**. Read the question: the cables are hung slack **because** they would get shorter in the cold.
- **Useful or unwanted?** Thermometers, bimetallic strips (thermostats) and loosening a tight nut by heating are **useful**. Bridges, railway lines, cables are problems to allow for.
- **Not caused by expansion**: melting, a metal surface warming in sunlight, ice forming on a pond.
- **Fitting parts**: heat the outer part (the ring or the part with the hole), cool the inner part.
- **Bimetallic strip**: the metal on the **outside** of the curve expands more on heating.
- **Liquids in flasks and thermometers**: the level rises because the **liquid expands** (more than the glass). With air in the flask and a small drop of liquid in the tube, it is the **air** that expands.
- **Mass and density on heating**: mass stays the same; density decreases.
- **Order of expansion**: gas most, solid least. **Extended only:** explain it with the forces and spacing: particles in a solid are held strongly in fixed positions; the forces between gas particles are very weak, so they move apart easily. **Do not** say the particles themselves expand.

- **Extended only: why a solid (or liquid) expands with particles**: the particles vibrate (or move) more, so the average distance between them increases.

4. Specific heat capacity calculations (32 questions)

Extended only.

1. **Write the equation**: $c = \dfrac{\Delta E}{m\,\Delta\theta}$ (or $\Delta E = mc\,\Delta\theta$).
2. **Get the units right**: mass in **kg** when c is in J/(kg °C) (200 g $= 0.20$ kg). If c is given in J/(g °C), keep the mass in grams.
3. **Find the temperature change** $\Delta\theta = \theta_{\text{final}} - \theta_{\text{start}}$ (a positive number for heating or cooling). Don't use the final temperature on its own.
4. **Substitute and solve**, and give the unit.

For example, heating 200 g of aluminium ($c = 900$ J/(kg °C)) from 20 °C to 70 °C takes $0.20 \times 900 \times 50 = 9000$ J.

Variations you will meet:

- **Energy given out on cooling**: the same equation. 0.30 kg of water cooling from 80 °C to 30 °C gives out $0.30 \times 4200 \times 50 = 63\,000$ J.
- **Find the final temperature**: $\Delta\theta = \dfrac{\Delta E}{mc}$, then **add** it to the starting temperature. $27\,000$ J into 2.0 kg of aluminium at 20 °C: $\Delta\theta = \dfrac{27\,000}{2.0 \times 900} = 15$ °C, so it reaches 35 °C.
- **With a heater**: energy $= Pt$ (or VIt), so the minimum time is $t = \dfrac{mc\,\Delta\theta}{P}$. Warming 0.60 kg of water by 30 °C with a 1500 W heater needs $0.60 \times 4200 \times 30 = 75\,600$ J, which takes at least $\dfrac{75\,600}{1500} = 50.4$ s. The real time is longer, because some energy heats the container and surroundings. The power needed for a given time is $P = \dfrac{\Delta E}{t}$.
- **Mass from a volume**: $m = \rho V$. 250 cm³ of water has a mass of 250 g $= 0.25$ kg. Convert the volume to m³ if the density is in kg/m³.
- **Mixing a hot object into cold water**: energy lost by the hot object $=$ energy gained by the water. Each side has its own mass, specific heat capacity and temperature change; both end at the same final temperature (see Example 3).
- **Which material?** "More energy is needed to raise the temperature of 1 kg by 1 °C" means a **higher** specific heat capacity. For blocks of the same material, energy per kilogram (for the same temperature change) is the same: blocks of 100 g and 200 g made of the same metal transfer energy in the ratio $1 : 2$.
- **Comparing heating times** for two liquids on the same hotplate: time is proportional to mc. Oil with half the specific heat capacity of water and 0.90 times its density, same volume, same temperature rise: $0.90 \times 0.5 = 0.45$ of the time.
- **Choosing the expression**: $c = \dfrac{\Delta E}{m\,\Delta T}$, and with a heater $c = \dfrac{Pt}{m\,\Delta\theta}$.

- **Internal energy from a graph**: read the energy for 1 kg over the temperature change, then scale it by the mass.

5. Internal energy and temperature (14 questions)

1. **Temperature up ⇒ internal energy up**; temperature down ⇒ internal energy down.
2. **Extended only:** say **why** with particles: a higher temperature means a higher **average kinetic energy** of the particles (they move or vibrate faster).

Variations you will meet:

- **A hot gas cools**: its internal energy decreases because the **average kinetic energy** of its particles decreases (not their potential energy due to gravity, and not their spacing).
- **Which change increases the internal energy of water?** Heating it (from 25 °C to 40 °C). Freezing, condensing onto a window and evaporating in a breeze all take energy **out** of the water.
- **Heating an object**: its volume **and** its internal energy increase; the number of atoms and the melting point stay the same.
- **Doing work**: stirring water raises its temperature, because the work done increases its internal energy.
- **Hot coffee and a swimming pool**: the coffee's temperature is higher, but the pool has much more internal energy; when the coffee cools its internal energy decreases.
- **Extended only: water cooled by ice**: the water particles lose kinetic energy (move more slowly), so the internal energy of the water decreases.
- **Kelvin and absolute zero** sometimes appear here; they are covered in the kinetic particle model note: add 273 to a Celsius temperature to get kelvin.

6. Measuring specific heat capacity (6 questions)

Extended only.

1. **Apparatus**: balance (mass), thermometer (temperature), heater with a **voltmeter and ammeter** (or a joulemeter), a **stop-watch** (time), insulation.
2. **Readings**: mass; temperature **at the start and at the end**; voltage and current (or power); heating time.
3. **Calculation**: $\Delta E = VIt$; $c = \dfrac{\Delta E}{m\,\Delta\theta}$.
4. **Error**: energy is lost to the surroundings, so the measured energy is greater than the energy the block really gained, and c comes out **too big**; the real time is longer than calculated.

Variations you will meet:

- **"Which extra apparatus is needed?"** A stop-watch, a voltmeter and a balance (the thermometer is already there).
- **"Describe an experiment"**: list the measurements, the equations and one improvement (insulation, stirring a liquid, waiting for the highest temperature).

- **"Why is the measured energy greater than calculated?"** Some energy is transferred to the surroundings.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

A student heats some solid wax in a tube at a steady rate. The temperature of the wax rises from 20 °C to 55 °C in the first 3 minutes. It then stays at 55 °C until 9 minutes, and after that rises again.

(a) State the melting point of the wax. **[1]**

(b) Describe what is happening to the wax between 3 and 9 minutes, and explain why its temperature does not change although the heater is still on. **[2]**

(c) Later, the liquid wax is left to cool to room temperature. Describe the shape of its cooling curve. **[2]**

(d) A few drops of ethanol are spilled on the bench and some of it evaporates. Describe evaporation in terms of particles, and state its effect on the ethanol that is left. **[3]**

(a) 55 °C **B1** (the flat part of the graph).

(b) The wax is melting (changing from solid to liquid) **B1**. The energy supplied is used to change the state, not to raise the temperature **B1**.

(c) The temperature falls, then stays constant at 55 °C while the wax solidifies **B1**, then falls again, levelling off at room temperature **B1**.

(d) The more-energetic particles **B1** escape from the surface of the liquid **B1**. The ethanol that is left cools down **B1**.

Example 2

Extended only. A kettle contains 0.50 kg of water at 20 °C. The specific heat capacity of water is 4200 J/(kg °C).

(a) Calculate the energy needed to heat the water to its boiling point. **[3]**

(b) The power of the kettle is 2.0 kW. Calculate the shortest time the kettle can take to do this. **[2]**

(c) The kettle actually takes 95 s. Suggest why, and calculate the efficiency of the kettle. **[3]**

(a) $\Delta\theta = 100 - 20 = 80$ °C **C1**. $\Delta E = mc\,\Delta\theta$ **C1** $= 0.50 \times 4200 \times 80 = 168\,000$ J (1.7×10^5 J) **A1**.

(b) $t = \dfrac{\Delta E}{P}$ **C1** $= \dfrac{168\,000}{2000} = 84$ s **A1**.

(c) Some energy heats the kettle itself and the surroundings, not the water **B1**. Energy supplied $= 2000 \times 95 = 190\,000$ J **C1**, so efficiency $= \dfrac{168\,000}{190\,000} = 0.88$, or 88% **A1**.

Example 3

Extended only. A metal block of mass 0.080 kg is heated to 95 °C and then put into 0.20 kg of water at 20 °C in an insulated cup. The final temperature of the water and the block is 25 °C. The specific heat capacity of water is 4200 J/(kg °C). Calculate the specific heat capacity of the metal. Assume no energy is transferred to the cup or the surroundings. **[4]**

Energy gained by the water $= 0.20 \times 4200 \times (25 - 20) = 4200$ J **C1**.

Energy lost by the block $=$ energy gained by the water **C1**, and the block's temperature falls by $95 - 25 = 70$ °C, so

$$0.080 \times c \times 70 = 4200 \quad \textbf{C1}$$
$$c = \frac{4200}{0.080 \times 70} = 750\ \mathrm{J/(kg\ ^\circ C)} \quad \textbf{A1}$$

Example 4

Extended only. A student measures the specific heat capacity of an aluminium block of mass 1.0 kg, using the apparatus in the fourth diagram.

(a) State the readings the student must take. **[3]**

(b) The heater runs at 12 V and 4.0 A for 500 s. The temperature of the block rises from 18.0 °C to 42.0 °C. Calculate the specific heat capacity of aluminium. **[3]**

(c) The accepted value is 900 J/(kg °C). Explain why the student's value is higher, and suggest one improvement. **[2]**

(a) Mass of the block (balance) **B1**; temperature at the start and the highest temperature at the end **B1**; voltage, current and heating time **B1**.

(b) $\Delta E = VIt = 12 \times 4.0 \times 500 = 24\,000$ J **C1**. $\Delta\theta = 42.0 - 18.0 = 24.0$ °C **C1**.

$$c = \frac{\Delta E}{m\,\Delta\theta} = \frac{24\,000}{1.0 \times 24.0} = 1000\ \mathrm{J/(kg\ ^\circ C)} \quad \textbf{A1}$$

(c) Some of the energy from the heater is transferred to the surroundings, so the temperature rise is smaller than it should be and c comes out too high **B1**. Wrap the block in more insulation **B1**.

Common mistakes

- **Saying the particles expand.** When a substance is heated, the particles move faster and **further apart**; the particles themselves stay the same size. Examiners see "the molecules expand" every year.
- **Stating a problem without the consequence.** "Railway tracks expand" is not a problem on its own; say the rails would **buckle** (and the gaps prevent it). Many candidates leave applications of expansion blank: learn two uses and two problems.
- **Getting the order of expansion wrong.** Gas most, solid least, for the same temperature rise.
- **Mass changing on heating.** Mass never changes when something expands; its density decreases.
- **Mixing up boiling and evaporation.** Vague answers such as "boiling is faster" or "boiling makes bubbles" miss the point: say boiling happens **throughout** the liquid at **one temperature**, evaporation only at the **surface** at **any temperature**.
- **Explaining evaporation with "bonds breaking".** Say the **more-energetic** (faster) particles **escape from the surface**. For cooling, say the particles left behind have a **lower average kinetic energy**.
- **Linking the weather to evaporation without saying why.** "It's windy" needs "so escaped particles are blown away and can't return". Give only one change when one is asked for; "colder and windier" contradicts itself.
- **Thinking the temperature rises while ice melts.** During melting or boiling the temperature stays constant even though energy goes in.
- **Mixing up melting and boiling points on a graph**: the lower flat part is melting, the higher one boiling.
- **Specific heat capacity definitions missing a part.** It is energy per **unit mass** per **unit rise in temperature** (per kg per °C). Leaving out either "per" loses marks, and it is not the energy to change the state.
- **Grams in a kg formula.** 150 g is 0.15 kg when c is in J/(kg °C).
- **Using the final temperature instead of the change.** $\Delta\theta$ is the **difference**: from 20 °C to 58 °C is 38 °C.
- **Muddled symbols**: t for temperature, or Q for energy. When time and temperature both appear, putting the time into $\Delta\theta$ gives nonsense.
- **Forgetting the unit**, or writing J or J/kg instead of J/(kg °C).

How to get the marks

- **Calculations**: write the equation ($\Delta E = mc\,\Delta\theta$) first, then the substitution with the temperature **change**, then the answer with its unit. The equation and the substitution each earn a mark even if the arithmetic slips.
- **"Show that"**: give every step and one more significant figure than the value printed.
- **Mixing questions**: write "energy lost by the metal $=$ energy gained by the water" as a line of working; there is a mark for it.
- **"Define specific heat capacity"**: energy **needed (or transferred)** per **unit mass** per **unit temperature rise** (or: to raise the temperature of 1 kg by 1 °C). An equation in words with every symbol defined also earns the marks.

- **"Use your ideas about particles (or molecules)"**: the answer must mention particles and what they do (more-energetic particles escape; particles move further apart; particles slow down and come closer).
- **"State and explain"**: the statement (for example "evaporation is slower") **and** the reason, linked with "so" or "because".
- **"Describe an experiment"**: name the apparatus, the readings (start **and** end temperatures), the equations, and one precaution.
- **"State two differences"**: each point must compare both processes, for example "boiling occurs throughout the liquid, evaporation only at the surface".
- **Graphs**: "sketch" means the right shape with the key values marked (the flat part at the right temperature and for the right time); keep flat parts horizontal.
- **Multiple choice**: check two things in every row: the direction (increase or decrease) and the reason. Most wrong options have one of the two backwards.

Quick check

1. Name the change of state from gas to liquid, and from liquid to solid. What happens to the temperature of a pure substance while it is melting?
2. Explain why overhead cables are hung slack between pylons. **Extended only:** explain why a gas expands much more than a solid for the same rise in temperature.
3. **Extended only.** Calculate the energy needed to heat 250 g of cooking oil from 20 °C to 60 °C. The specific heat capacity of the oil is 2000 J/(kg °C).
4. **Extended only.** A 2.0 kg metal block absorbs $36\ 000$ J and its temperature rises from 15 °C to 35 °C. Calculate the specific heat capacity of the metal.
5. **Extended only.** State two differences between boiling and evaporation, and three ways of making a puddle evaporate faster.

Answers

1. Condensation; solidification (freezing). The temperature stays constant while it melts, even though energy is being supplied.
2. On cold days the cables contract (get shorter); if they were tight they could snap or pull on the pylons. **Extended:** the forces between gas particles are very weak and the particles are far apart, so when they move faster they spread out easily; the particles in a solid are held in fixed positions by strong forces, so they only move slightly further apart.
3. $\Delta E = mc\,\Delta\theta = 0.25 \times 2000 \times 40 = 20\,000$ J.
4. $c = \dfrac{\Delta E}{m\,\Delta\theta} = \dfrac{36\,000}{2.0 \times 20} = 900$ J/(kg °C).
5. Boiling happens throughout the liquid (with bubbles), evaporation only at the surface; boiling happens only at the boiling point, evaporation at any temperature (also: boiling needs a continuous energy supply; evaporation cools the liquid). Faster evaporation: a higher temperature, a larger surface area (spread it out), and air moving over it (wind or a fan).

Past questions to try

- **0625/31/O/N/21 Q4**: sketching a cooling curve with freezing at the melting point (Core).
- **0625/42/M/J/24 Q4**: two differences between evaporation and boiling (Extended).
- **0625/42/F/M/24 Q4**: defining specific heat capacity, then mass, energy and power for heating oil (Extended).
- **0625/41/O/N/24 Q4**: the experiment to measure specific heat capacity, expansion and evaporation explained with particles (Extended).