

ESAT

Physics

Thermal physics

Free lesson notes

Covers

P4.1 to P4.4

Format

Lesson, worked examples, self-check

Price

Free

About this lesson

Thermal physics answers three everyday questions. What *is* temperature, and how is it different from the energy something stores? How does thermal energy get from a hot place to a cold one? And how much energy does it take to warm something up? The first two questions give us *conduction*, *convection* and *thermal radiation*. The third gives one of the most useful equations in GCSE-level physics, $E = mc\Delta T$.

This lesson builds each idea from the particle model, so that you can *explain* what happens rather than just recall it. We start with particles, temperature and internal energy. Then we take the three methods of transfer in turn (conduction, convection, radiation), and finish with specific heat capacity: where the equation comes from, how it is measured, and how to use it for kettles, mixing hot and cold water, heat losses, cooling curves and scaling arguments. Every worked example has a diagram or a number you can check, and the last section is about estimating and reasoning without a calculator.

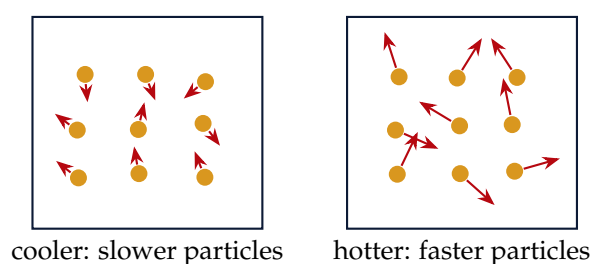
How to use it. Cover each worked example and try it before reading the solution. In the real ESAT there is no calculator, so the numbers here are chosen to be friendly: practise doing the arithmetic by hand. Finish with the self-check, then the practice set. Specification codes covered: P4.1 (conduction), P4.2 (convection), P4.3 (thermal radiation) and P4.4 (heat capacity).

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1 Particles, temperature and internal energy

Everything around you is made of tiny particles (atoms and molecules) that are never at rest. In a solid they vibrate about fixed positions; in a liquid and a gas they also move from place to place. Because they move, they have *kinetic energy*. Because they attract and repel one another, they also have *potential energy*. The total of all of these energies, for every particle in the object, is its **internal energy**.

When an object is heated its internal energy goes up, and (provided it is not melting or boiling) the particles move faster. So the *average kinetic energy* of the particles rises. That average is what a thermometer measures: **temperature is a measure of the average kinetic energy of the particles**.



Temperature and internal energy are different things. Temperature is an *average per particle*. Internal energy is a *total*, so it depends on how many particles there are as well. A bath of water and a cup of water, both at 40°C , have particles with the same average kinetic energy, but the bath contains about four hundred times as many particles, so it holds about four hundred times as much internal energy.

Which way does energy flow? Thermal energy always flows spontaneously from a region at a higher temperature to a region at a lower temperature, and it keeps flowing until the temperatures are equal (*thermal equilibrium*). This depends on the temperature difference, not on the total energy stored: a small hot cup of tea warms a large cold bath a tiny amount, even though the bath holds far more energy.

Key ideas

- **Internal energy** = total kinetic + potential energy of all the particles.

- **Temperature** = a measure of the average kinetic energy of the particles.
- Thermal energy flows from hot to cold until the temperatures are equal.
- There are three ways it travels: **conduction** (through a material, by particle vibrations and electrons), **convection** (by a moving fluid) and **radiation** (infrared waves, needing no material).

Worked example: same temperature, different energy

A bath holds 100 kg of water and a cup holds 0.25 kg of water. Both are at 40 °C. Compare their internal energies and say in which direction energy flows if the cup is poured into the bath.

The number of particles is proportional to the mass, so the bath has $100 \div 0.25 = 400$ times as many particles and about 400 times the internal energy. Since the two are at the *same* temperature, there is no net flow of energy at all: thermal equilibrium. (If the cup were hotter, energy would flow from the cup to the bath, even though the bath stores more.)

Common mistakes

- Using “heat” and “temperature” as if they were the same. Temperature is an average, energy is a total.
- Saying “cold flows in”. Thermal energy flows out of the warm object; cold is just the lack of it.
- Saying “heat rises”. It is hot *fluids* that rise (convection); energy conducts in every direction equally.

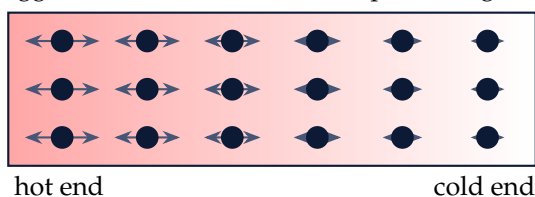
2 Conduction (P4.1)

Conduction is the transfer of thermal energy through a material (or between objects in contact) without the material itself moving. It is the main way energy travels in solids.

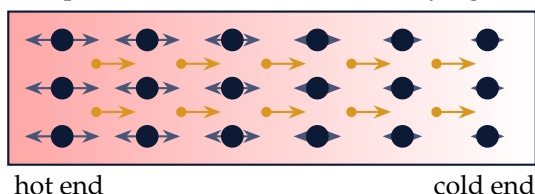
The mechanism in a non-metal. In a solid, each particle is held to its neighbours by bonds, like balls joined by springs. Heat one end and the particles there vibrate with bigger and bigger amplitude. Because they are bonded to their neighbours, they shake them too, so the neighbours vibrate more, and so on along the rod. The energy is passed from particle to particle although no particle travels along the rod.

Why metals are special. A metal has, in addition, *free electrons*: outer electrons that are not attached to any single atom and wander through the whole lattice. At the hot end these electrons gain kinetic energy and move fast. They travel quickly through the metal, colliding with atoms and other electrons and handing on energy far faster than vibrations alone can. That is why metals are by far the best thermal conductors, and (for the same reason of free electrons) also good electrical conductors.

(a) non-metal: bigger vibrations at the hot end pass along from atom to atom



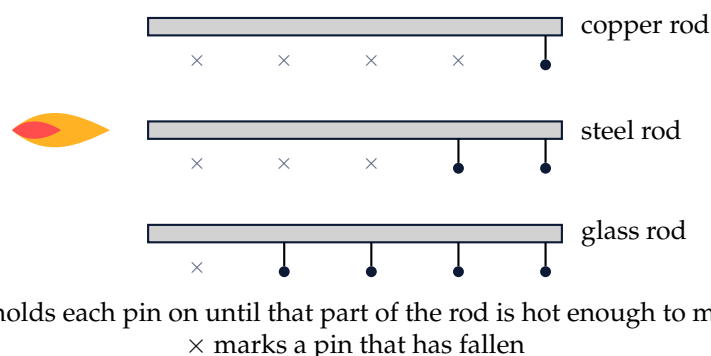
(b) metal: the same, plus free electrons (amber) carrying energy as they drift



Insulators. Wood, plastic, glass and ceramics have no free electrons, so they conduct poorly. *Gases* are even poorer conductors: the particles are far apart and collide only occasionally, so there are few chances to hand on energy. This is why *trapped air* is the basis of most insulation (wool, fibreglass, foam, double glazing). The air must be trapped in tiny pockets, because if it were free to circulate it would carry energy by convection instead.

Comparing conductors experimentally. Rods of equal size but different materials are heated at one end. Pins are stuck along each rod with wax. Wax melts when it reaches a certain temperature, so a pin falls when that part of the rod has

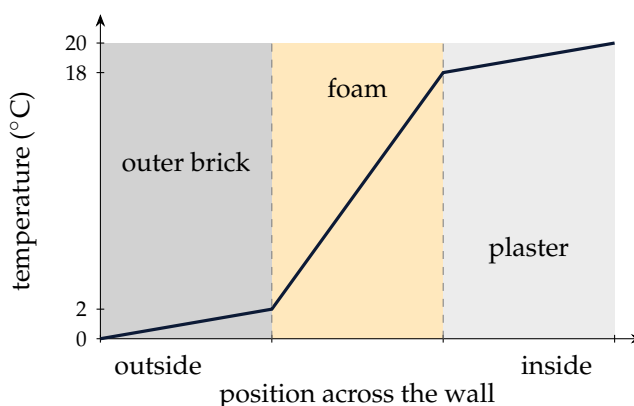
become hot. The more pins that have fallen after a given time, the further the energy has travelled, and the better the conductor.



What affects the rate of conduction? The energy transferred per second is larger for (a) a greater temperature difference between the two ends, (b) a larger cross-sectional area, (c) a shorter path (a thinner wall), and (d) a material with higher conductivity (metal rather than wood).

Why does a metal handle feel colder than a wooden one at the same temperature? Both are at room temperature, below the temperature of your skin. Your hand loses energy to both, but the metal conducts energy away from the skin much faster, so the skin cools faster, and the nerves report “cold”. The thermometer would show the same temperature for each.

Layers in series. Consider a wall made of layers, with the inside kept warm and the outside cold. Once the temperatures have settled (a *steady state*), the same amount of energy per second must cross every layer. If one layer received more than it passed on, it would be warming up, which contradicts the steady state. A good conductor passes on this energy with a small temperature difference across it; a poor conductor needs a big temperature difference to push the same energy through. So on a graph of temperature against position, the line is *shallow* across good conductors and *steep* across good insulators.



Worked example: reading a wall graph

The wall in the graph has an outer brick layer, a foam layer and a plaster layer, all the same thickness. The temperature is 0°C outside and 20°C inside. How is the 20°C difference shared between the layers, and what does that tell you about the foam?

Reading the graph: the temperature changes by 2 across the brick ($0 \rightarrow 2$), by 16 across the foam ($2 \rightarrow 18$) and by 2 across the plaster ($18 \rightarrow 20$); the total is $2 + 16 + 2 = 20^{\circ}\text{C}$. The same energy per second crosses each layer, and the foam needs $16 \div 2 = 8$ times the temperature difference to pass it on, so (for equal thickness) the foam is 8 times worse as a conductor than the brick. Most of the temperature difference is “used up” across the best insulator.

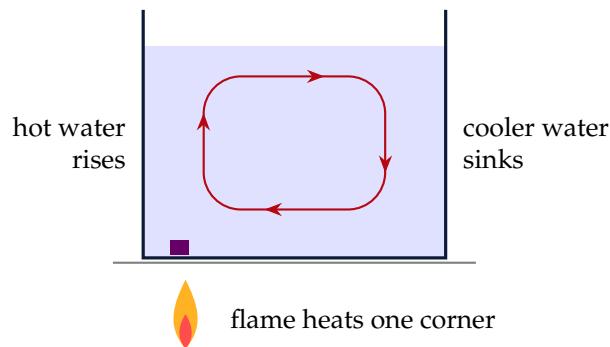
Common mistakes

- Thinking metals feel cold because they are *at a lower temperature*. They are the same temperature as the wood; they just carry energy away from your hand faster.
- Saying particles “travel along the rod” in conduction. In non-metals they only vibrate; the energy travels, the particles do not (in metals, electrons do move, but only drift).
- Forgetting that trapped air only insulates while it cannot circulate. Large air gaps allow convection.

3 Convection (P4.2)

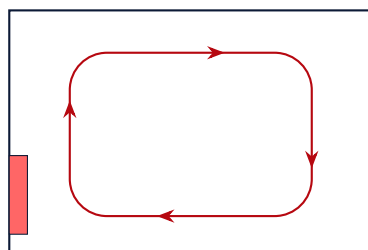
Convection is the transfer of thermal energy by the movement of a *fluid* (a liquid or a gas). The moving fluid physically carries the energy with it. Because particles in a solid cannot flow, and because a vacuum has no particles, convection cannot happen in solids or in a vacuum.

Why does hot fluid rise? Heat a fluid and its particles move faster and push further apart. The same mass of fluid now takes up a larger volume. Density is mass divided by volume (we study it properly in the Matter lesson), so the heated fluid is *less dense* than the cooler fluid around it. Cooler, denser fluid is pulled down more strongly by gravity, so it sinks and pushes the warmer, less dense fluid upwards, just as a cork rises in water. The cooler fluid that has moved in is then heated in turn, and so a continuous circulation, a **convection current**, is set up.

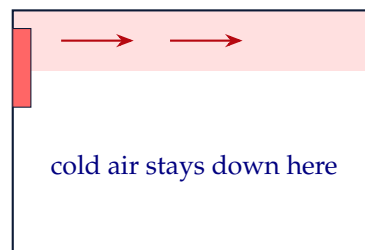


In the beaker above, a crystal of dye shows the flow: the water is heated at one corner, rises there, travels across the top, cools, sinks on the far side and returns along the bottom.

Convection in action. In a room heated by a radiator low on the wall, warm air rises, spreads across the ceiling, cools, sinks on the far side of the room and flows back towards the heater. If the heater were placed near the ceiling instead, the warm air would just stay at the top, because it is already less dense than the air below it: no circulation is started and the floor stays cold.



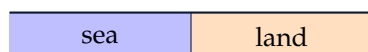
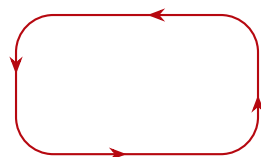
(a) heater near the floor:
warm air rises, cool air sinks,
the whole room circulates



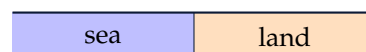
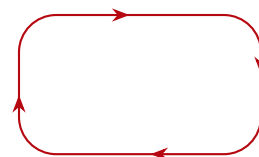
(b) heater near the ceiling:
warm air stays at the
top, the floor stays cold

This explains design choices that ESAT likes to ask about. An electric kettle's element is at the *bottom*, so the heated water rises and the whole kettle heats. A hot-water tank has its heater low and its outlet at the top. A fridge's cooling unit is at the *top* of the cabinet: the air next to it is cooled and becomes denser, so it sinks through the food compartment. And a sea breeze is a giant convection current:

day: land hotter, air
over land rises, breeze
blows from sea to land



night: land cooler, air
over sea rises, breeze
blows from land to sea



By day the land warms faster than the sea, the air over the land is heated and rises, and cooler air flows in from the sea to replace it. By night the land cools faster, and the circulation reverses.

Worked example: how much does warm air expand?

Air at 20 °C is warmed at constant pressure by 20 °C to 40 °C. Its volume increases by about 7%. By what percentage does its density fall, and does the warmed air rise or sink?

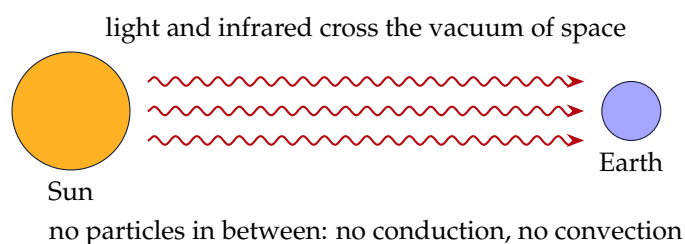
The mass of the air does not change, but its volume is 1.07 times larger, so the density is $\frac{1}{1.07} = 0.93$ of what it was, a fall of about 7%. The warmed air is less dense than the surrounding 20 °C air, so it rises.

Common mistakes

- Describing convection as “heat rises”. It is the *fluid* that rises, because it has become less dense.
- Saying convection happens in solids. Solid particles cannot flow, so only conduction acts in a solid.
- Explaining density change by saying the particles “get bigger”. The particles are the same size: they are *further apart* on average.

4 Thermal radiation (P4.3)

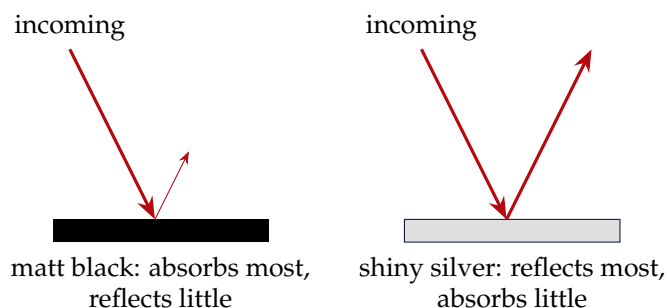
Thermal radiation is energy carried by infrared electromagnetic waves. *Every* object emits it, all the time, whatever its temperature. Unlike conduction and convection it needs *no material*: it crosses a vacuum, which is how the Sun warms the Earth.



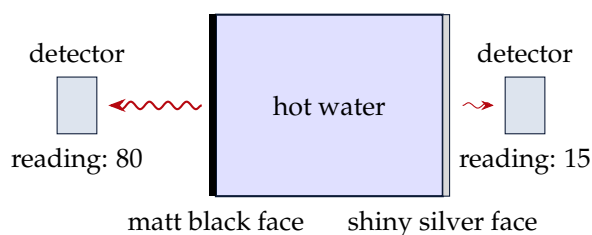
Two facts organise everything about radiation.

1. The hotter an object, the more radiation it emits. The power radiated rises very steeply with temperature, so a hot object loses energy much faster than a warm one. An object also *absorbs* radiation from its surroundings. Whether it warms or cools depends on the balance: if it absorbs more than it emits, its temperature rises; if it emits more, it falls; when they are equal the temperature stays constant.

2. The surface matters. Dark, matt surfaces are *good absorbers* and *good emitters* of infrared. Light, shiny surfaces *reflect* most of the radiation that arrives and are *poor absorbers* and *poor emitters*.



Comparing emitters: the Leslie cube. A metal cube is filled with hot water. Its four vertical faces have different finishes. An infrared detector is held at the same distance from each face, and the readings are compared. For two faces of a matt black and a shiny silver finish, the matt black face gives a much larger reading: it is the better emitter. (The comparison is fair only if the faces are at the same temperature and the detector is the same distance away each time.)



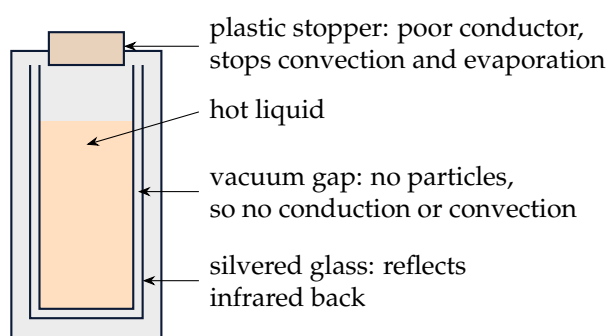
A steady temperature is a balance. When an object sits in sunshine it warms until it loses energy as fast as it gains it. The hotter it gets, the faster it loses energy (by radiation and by air currents), so there is a temperature at which loss equals gain, and there it stays.

Worked example: a steady temperature in sunlight

A metal plate absorbs 120 W of sunlight. Its total energy loss (radiation and air) is 5 W for every 1 °C it is above the surrounding air. By how much does it end up warmer than the air? It is then painted shiny silver, so that it absorbs only 40 W. What is the new steady temperature rise?

The temperature stops rising when energy loss equals energy gain: $5 \Delta T = 120$, so $\Delta T = 24$ °C above the air. After painting, $5 \Delta T = 40$, so $\Delta T = 8$ °C. The shiny plate stays much cooler, because it absorbs less.

The **vacuum flask** defeats all three methods at once.



The vacuum between the double walls stops conduction and convection (there are no particles to do either), the silvered surfaces reflect infrared radiation back, and the stopper (a poor conductor) closes the top so that convection and evaporation cannot carry energy out. A flask keeps cold drinks cold in just the same way, by keeping energy *out*.

Exam tip

When a question asks you to “explain” a design (a flask, a roof, a radiator, a fridge, an emergency blanket), go through the three mechanisms in turn: which of conduction, convection and radiation does each feature block or help?

Common mistakes

- Saying radiation “only comes from hot objects”. Everything emits infrared; it is just much weaker for cool objects.
- Thinking black objects are good absorbers but poor emitters (or the opposite). Good absorbers are *also* good emitters.
- Saying a vacuum stops radiation. Radiation travels through a vacuum; in a flask the *silvering* deals with it.

5 Specific heat capacity (P4.4)

How much energy must we supply to warm something by a given amount? Experiments (with a heater of known power and a thermometer) give three robust observations.

- **Double the mass**, with the same temperature rise: you need *twice* as much energy, because there are twice as many particles to speed up. So $E \propto m$.
- **Double the temperature rise**, with the same mass: you need *twice* the energy. So $E \propto \Delta T$.

- **Change the material:** the energy needed differs. Warming 1 kg of water by 1 °C takes about ten times as much as warming 1 kg of copper.

The first two together say $E \propto m \Delta T$, and the third says the constant of proportionality depends on the material. We call that constant the **specific heat capacity**, c :

$$E = m c \Delta T \quad \Longleftrightarrow \quad c = \frac{E}{m \Delta T}.$$

The specific heat capacity of a material is the energy needed to raise the temperature of 1 kg of it by 1 °C. Its unit is J/(kg · °C). Here E is in joules, m in kilograms and ΔT is the temperature *change*.

material	c in J/(kg · °C)
water	4200
air	1000
aluminium	900
iron / steel	450
copper	400

Water's value is unusually high. That is why it is used in central heating and car cooling systems (a lot of energy stored per kilogram), and why the sea warms and cools much more slowly than the land.

Power and time. Power is energy per second, $P = E/t$, so $E = Pt$. Combining with $E = mc\Delta T$ gives $Pt = mc\Delta T$, so the time to heat something is $t = \frac{mc\Delta T}{P}$ (all in SI units: watts, seconds, kilograms).

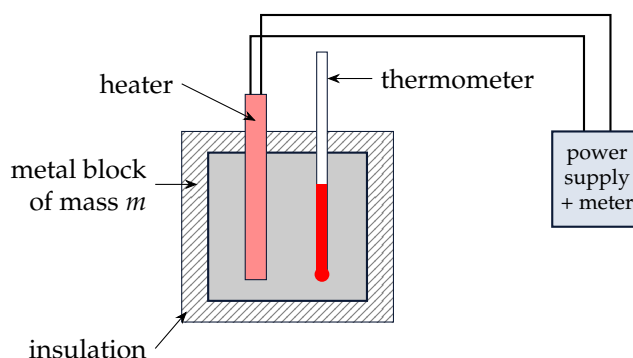
Worked example: energy to warm water

How much energy is needed to warm 0.5 kg of water from 20 °C to 40 °C?
 $\Delta T = 40 - 20 = 20$ °C. $E = mc\Delta T = 0.5 \times 4200 \times 20 = 42\,000$ J.

Worked example: how long does a kettle take?

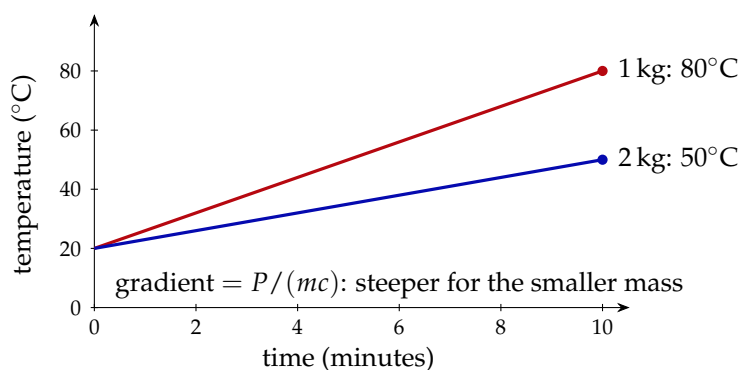
A 2.1 kW kettle contains 1.0 kg of water at 20 °C. How long does it take to reach 80 °C if no energy is lost?
 $E = mc\Delta T = 1.0 \times 4200 \times 60 = 252\,000$ J. $t = E/P = 252\,000 \div 2100 = 120$ s, i.e. two minutes.

Measuring a specific heat capacity. A metal block is lagged to reduce losses. A heater of known power P and a thermometer are placed in holes in the block (a drop of oil in each hole improves thermal contact). The block is weighed, the starting temperature is noted, the heater is switched on for a measured time t , and the final temperature is read.



Then $E = Pt$ (or VIt from a voltmeter and ammeter), and $c = \frac{E}{m\Delta T}$. Because the experiment is not perfect, some of the energy supplied warms the surroundings, so the temperature rise is *smaller* than it should be. The result for c , which divides by ΔT , is therefore *too large*. Lagging, a lid and a short experiment all reduce the error.

Reading a temperature–time graph. With a constant power and good insulation the temperature rises linearly. The gradient is the rise per second, $\frac{\Delta T}{t} = \frac{P}{mc}$. For the same heater, a block of *twice the mass* warms at *half the rate*.



Worked example: specific heat capacity from a graph

In the graph above the 1 kg sample of water is heated by a heater whose power is 420 W. Show that the graph is consistent with $c = 4200 \text{ J/(kg} \cdot ^\circ\text{C)}$ and find the temperature after 10 minutes for 2 kg.

The line for 1 kg rises from 20 to 80 in 10 minutes: gradient $60 \div 600 \text{ s} = 0.1 ^\circ\text{C/s}$. Then $\frac{P}{mc} = \frac{420}{1 \times 4200} = 0.1$, consistent. For 2 kg the gradient is halved to 0.05, giving a rise of $0.05 \times 600 = 30 ^\circ\text{C}$, so the temperature is $50 ^\circ\text{C}$.

Common mistakes

- Using the final temperature in $E = mc\Delta T$ instead of the *change* in temperature.
- Using grams: $c = 4200$ refers to kilograms. Convert 500 g to 0.5 kg first.
- Believing heat loss makes the measured c too small. Less temperature rise means a larger $E/(m\Delta T)$.
- Forgetting to convert minutes to seconds when using $E = Pt$.

6 Mixing, losses and cooling curves

Mixing hot and cold. Energy is conserved. If no energy escapes, the energy lost by the hot object equals the energy gained by the cold one, and they end at a common temperature T_f between the two starting temperatures:

$$m_1 c_1 (T_1 - T_f) = m_2 c_2 (T_f - T_2).$$

Each side is an $mc\Delta T$ for one object, with ΔT taken as a *positive* change. If the two materials are the same, c cancels. If the masses are equal and the materials are the same, the final temperature is exactly half-way between.

Worked example: mixing water

0.20 kg of water at $80 ^\circ\text{C}$ is poured into 0.30 kg of water at $20 ^\circ\text{C}$. Find the final temperature.

The c cancels. $0.20(80 - T) = 0.30(T - 20)$, so $16 - 0.2T = 0.3T - 6$, so $22 = 0.5T$ and $T = 44 ^\circ\text{C}$. (Check: it is closer to 20 than to 80 because there is more cold water. The hot water lost 0.2×36 units and the cold gained 0.3×24 : both 7.2.)

Flowing water. For a shower or a flow heater, work with rates. In one second a mass $\dot{m} = \frac{m}{t}$ of water flows through and is warmed by ΔT , so the power transferred to the water is $P = \dot{m} c \Delta T$ (with $\dot{m}$ in kg/s).

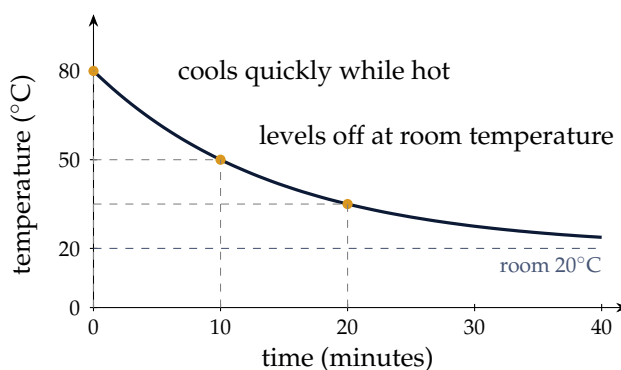
Worked example: an electric shower

An electric shower of power 8.4 kW heats a flow of 0.10 kg/s of water, and all the energy goes into the water. By how much does the temperature rise?

$P = \dot{m} c \Delta T$, so $\Delta T = \frac{8400}{0.10 \times 4200} = \frac{8400}{420} = 20 ^\circ\text{C}$. Doubling the flow rate would halve the temperature rise.

Losses and efficiency. In practice some energy is lost. If the heater is only 80% efficient, only 80% of Pt reaches the water: useful energy = $0.80 Pt$. A steady heating power can be *balanced* by losses: if a heater delivers 600 W and the container loses 100 W, only 500 W is left to warm the contents.

Cooling curves. A hot object loses energy faster than a warm one, because the rate of loss depends on how much hotter it is than its surroundings. So a graph of temperature against time falls steeply at first and then flattens, approaching room temperature but never going below it. The gradient at any point tells you the rate of cooling there.



Worked example: reading a cooling curve

The curve shows 0.50 kg of water cooling in a room at 20 °C. Find the average power lost during the first 10 minutes and during the next 10 minutes.

First 10 minutes: the temperature falls from 80 to 50, which is 30 °C. Energy lost = $0.50 \times 4200 \times 30 = 63\,000$ J in 600 s, so $P = 63\,000 \div 600 = 105$ W. Next 10 minutes: 50 → 35 is 15 °C, so the energy is half as much and $P = 52.5$ W. The loss rate halved because the temperature *above the room* halved (from 30 to about 15).

Common mistakes

- Mixing: using $T_f - T_i$ for both sides so a negative appears, or forgetting the masses are different. Write “lost = gained” with both changes positive.
- Applying $E = Pt$ with the *heater power* when the question gives the *efficiency*.
- Drawing a cooling curve that goes below room temperature, or straight down.

7 Estimation and scaling

ESAT has no calculator, so you will often be asked for “about how much” rather than an exact value, or how an answer changes when a quantity is scaled. Two tools are invaluable.

Round, then compute. A kettle holds about 1.5 kg of water, is rated about 3 kW, and is heated from 20 °C to 100 °C. Energy: $1.5 \times 4200 \times 80 \approx 5 \times 10^5$ J. Time: $5 \times 10^5 \div 3000 \approx 170$ s, close to three minutes, which matches experience. If your answer were 2 s or 2 h you would know something had gone wrong: always compare with your everyday sense.

Scaling. Suppose a solid cube of side L cools by radiation and convection from its surface. The rate at which it loses energy is proportional to its *surface area*, which is $6L^2$ (so $\propto L^2$). The energy it has to lose per degree is proportional to its *mass*, $\propto L^3$. So the rate of temperature fall is

$$\frac{\text{energy lost per second}}{mc} \propto \frac{L^2}{L^3} = \frac{1}{L}.$$

Double the side and the cube cools at *half* the rate; it has four times the area but eight times the mass. This is why small things (a baby, a mouse, a tiny coin of metal) cool faster than large ones, and why a big pan of soup stays warm for longer than a cupful.

Worked example: scaling a cube

Two copper cubes have sides 2 cm and 6 cm, with the same surface finish, and start at the same temperature in the same room. Compare their initial rates of temperature fall.

Side ratio = 3. Area ratio = $3^2 = 9$ (so the big cube loses energy 9 times faster) but mass ratio = $3^3 = 27$. The big cube has 27 times the energy to lose per degree, so its rate of temperature fall is $9 \div 27 = \frac{1}{3}$ of the small cube’s. (In general, $1/L$.)

Worked example: estimating a bath

About how much energy is needed to heat a bath of 100 kg of water by 30 °C? About how long would a 3 kW heater take?

$E = mc\Delta T = 100 \times 4200 \times 30 = 12.6 \times 10^6 \approx 1 \times 10^7$ J (about 13 megajoules). Time = $E/P = 12.6 \times 10^6 \div 3000 = 4200$ s, about 70 minutes. This is why baths are filled from a large heating system and not from a kettle.

Exam tip

When two things change at once (mass and temperature rise, or power and time), use proportionality: write $E \propto mc\Delta T$, then multiply the factors. Doubling m and tripling ΔT gives six times the energy, with no need for c at all.

8 Putting it together

A routine for any thermal question. (1) Identify the mechanism: conduction (solid, contact, metals vs insulators), convection (fluid moving because of density differences) or radiation (infrared, any surface, even a vacuum). (2) If a quantity of energy is involved, write $E = mc\Delta T$ and/or $E = Pt$, and convert to kilograms, joules, seconds. (3) If the question is about graphs, remember that the gradient of a temperature–time graph is related to power divided by mc , and that a levelling-off means loss rate has risen to equal supply. (4) If something is scaled, use proportionality. (5) Sanity-check the size of your answer.

Which mechanism? A quick map: solids and metals $\Rightarrow$ conduction; liquids and gases that are free to move $\Rightarrow$ convection; anything that crosses empty space, or works through glass or a shiny surface $\Rightarrow$ radiation; and a design that keeps something hot or cold $\Rightarrow$ usually all three, so check each in turn.

Common mistakes

- Mixing up the three mechanisms, for example calling heat from a fire on your face convection (it is mostly radiation).
- Not subtracting the starting temperature to get ΔT .
- Using the wrong sign convention when comparing graphs: a steeper line means a bigger rate of change, so a *smaller* mc for a given power.

Check yourself

Try these without looking back, then compare with the answers on the next page.

1. Explain, using particles, why a metal conducts thermal energy better than glass.
2. Why is the freezer compartment of a fridge placed at the top?
3. Two identical cans of hot water are painted, one matt black and one shiny silver. Which cools faster, and why?
4. How much energy warms 2.0 kg of water by 10°C ?
5. A 1.0 kW heater warms 0.50 kg of water by 20°C . How long does it take, with no losses?
6. 1 kg of water at 90°C is mixed with 1 kg of water at 10°C . Final temperature?
7. Why does the measured specific heat capacity in a school experiment tend to be too large?
8. A cube cools. A second cube of the same material has side three times as long. How does the rate of temperature fall compare?

Answers to the self-check

1. A metal has free electrons that move through the lattice and carry energy quickly, as well as vibrations passed between atoms. Glass has only the vibrations.
2. Air cooled by it becomes denser and sinks, setting up a convection current that cools the whole cabinet. At the bottom, the cold air would simply stay there.
3. The matt black can. It is the better emitter of infrared, so it loses energy by radiation faster.
4. $2.0 \times 4200 \times 10 = 84\,000\text{ J}$.
5. $E = 0.50 \times 4200 \times 20 = 42\,000\text{ J}$, so $t = 42000 \div 1000 = 42\text{ s}$.
6. Equal masses of the same liquid: half-way, 50°C .
7. Some of the supplied energy warms the surroundings, so the block's temperature rise is smaller than expected, and $c = E/(m\Delta T)$ comes out larger.
8. One third (area $\times 9$, mass $\times 27$).

Next step

Heurisco's *ESAT Physics: Thermal Physics Practice Set* has twenty original exam-style questions on this lesson, with diagrams and graphs, in order of difficulty, with a full worked solution and a note on the trap in each.