Cambridge IGCSE · Physics 0625 · Notes

Transfer of thermal energy

Read online at **pastopic.com/cambridge/physics-0625/notes/transfer-of-thermal-energy**

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Read first: **Kinetic particle model of matter**, **Thermal properties and temperature**

What you need to know

Thermal energy always moves from hotter places to colder ones. It does so in three ways: **conduction**, **convection** and **radiation**. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of this topic you should be able to:

1. **Describe experiments that show which materials are good thermal conductors** and which are bad ones (thermal **insulators**).
2. **Extended only:** describe how conduction happens in **all solids** through **lattice vibrations**, and in **metals** also through the movement of **free (delocalised) electrons**.
3. **Extended only:** explain, using particles, why **gases and most liquids are bad conductors**.
4. **Extended only:** know that many solids conduct better than insulators but worse than good conductors (conduction is a scale, not two groups).
5. **Know that convection is an important way thermal energy moves in liquids and gases.**
6. **Explain convection using density changes**, and describe experiments that show convection.
7. **Know that thermal radiation is infrared radiation** and that **every object emits it**.
8. **Know that thermal radiation needs no medium**: it can cross a vacuum.
9. **Describe how surface colour (black or white) and texture (dull or shiny)** affect how well a surface **emits, absorbs and reflects** infrared radiation.
10. **Extended only:** know that an object stays at a **constant temperature** only when it loses energy at the **same rate** as it receives energy.
11. **Extended only:** know what happens when an object receives energy **faster** or **slower** than it loses it.
12. **Extended only:** know how the **Earth's temperature** depends on the balance between incoming radiation and radiation emitted from the Earth's surface.
13. **Extended only:** describe experiments that tell **good and bad emitters** of infrared radiation apart.
14. **Extended only:** describe experiments that tell **good and bad absorbers** of infrared radiation apart.
15. **Extended only:** describe how the **rate of emission** of radiation depends on the object's **surface temperature** and **surface area**.
16. **Explain everyday uses and effects** of conduction, convection and radiation, such as heating a **kitchen pan** and heating a **room by convection**.

17. **Extended only:** explain harder cases where **more than one** method matters, such as a **fire** burning wood or coal and a **car radiator**.

Understand it

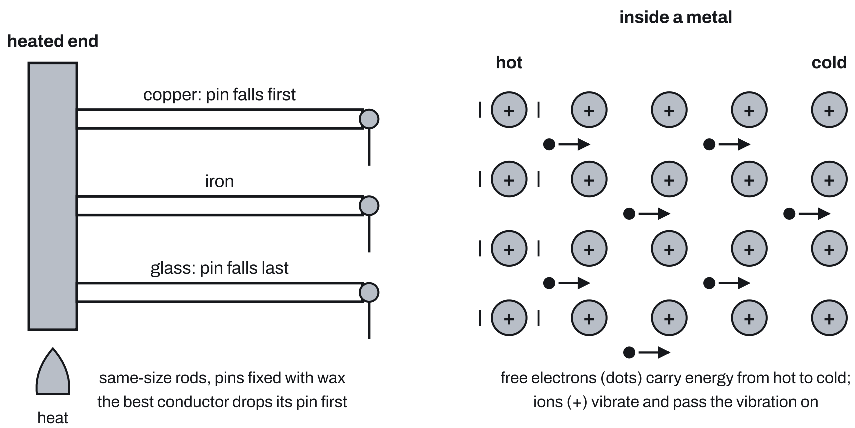
Conduction

Conduction is thermal energy passing through a material **without the material itself moving**. It is the main way energy travels through **solids**.

Some materials let energy through quickly: **good thermal conductors**, such as copper, aluminium, silver and other **metals**. Others let it through slowly: **bad conductors** or **thermal insulators**, such as wood, plastic, rubber, glass, cloth, polystyrene and, above all, **air**.

Experiment: comparing conductors. Take rods of different materials, all the **same size and shape**. Stick a pin (or a small ball) to the far end of each rod with wax, or coat each rod with wax. Heat the other ends **equally** (from one flame, or all dipped in the same hot water) and start a stop-watch.

- The wax melts first, and the pin drops first, on the **best conductor**.
- With a coating of wax, a **longer length** of wax melts on a better conductor in the same time.
- To make it a fair test: rods of the same length and thickness, the same amount of wax, the same size of pin, and the same heat source at the same temperature.



Simple demonstrations point the same way. A metal spoon in hot tea soon feels hot at the handle; a wooden spoon doesn't. If you hold one end of a copper rod and one end of a wooden rod and put the other ends in ice, the copper feels **colder**, because it conducts energy **out of your hand** faster. Water is a bad conductor too: boil the water at the **top** of a test-tube and the water at the bottom stays cold (convection can't help, because warm water stays at the top).

Extended only: how conduction works.

- **Lattice vibrations (all solids).** The particles (atoms, molecules or ions) of a solid sit in fixed positions and vibrate. At the hot end they vibrate harder. They knock into their neighbours and make **them** vibrate harder, and so on along the material. The particles don't travel along the rod; only the vibration does. This is slow.

- **Free electrons (metals only).** A metal also contains **free (delocalised) electrons** that can move anywhere in it. At the hot end they gain kinetic energy, travel **quickly** through the metal, and pass their energy on when they **collide with ions** further away. The ions stay where they are and only vibrate. This extra path is why **metals are much better conductors** than non-metals, which can only use lattice vibrations.
- **Gases and most liquids are bad conductors.** Their particles are **much further apart** than in a solid (a gas especially), so they collide with each other far less often and pass energy on slowly. This is why trapped air is such a good insulator: in wool, fur, foam, double glazing and the air gaps in a paper cup holder.
- **Conduction is a scale.** Between the best conductors (copper, silver) and the best insulators (air, foam) there are many solids that conduct moderately, such as glass, stone and brick.

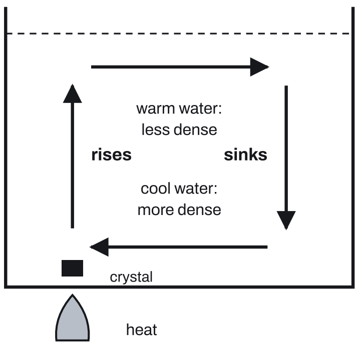
Convection

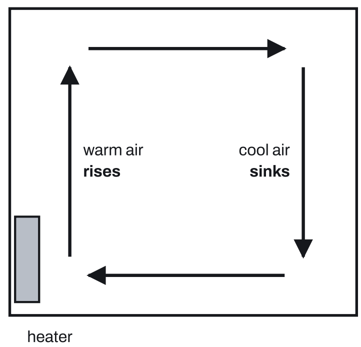
Convection is the transfer of thermal energy by the **movement of the warmer liquid or gas itself**. It happens only in **liquids and gases** (fluids), never in solids, because the particles of a solid can't flow.

Here is how a **convection current** forms, in terms of **density**:

1. The fluid near the heater is warmed. Its particles move faster and further apart, so it **expands**.
2. The same mass now takes up more volume, so its **density decreases**.
3. The warm, **less dense** fluid **rises**.
4. Cooler, **denser** fluid **sinks** to take its place, and is warmed in its turn.
5. The rising fluid cools, becomes denser and sinks again, so the fluid goes round in a loop.

Note that the **particles** don't get less dense or bigger: the **fluid** becomes less dense because its particles spread out.





a heater near the floor sets up a convection current

Experiments showing convection.

- **In water**: drop a small coloured crystal (such as potassium manganate(VII)) carefully to the bottom of a beaker of cold water, close to one side. Heat the beaker gently **just under the crystal** (a small flame or candle on a tripod). The coloured water rises from above the flame, spreads across the top, sinks on the far side and comes back along the bottom. The same works in a square loop of glass tube heated at one lower corner.

- **In air**: hold a light paper or thin-metal spiral (or a small fan) above a candle or lamp. The rising warm air makes it turn. Smoke from a smouldering paper held near a fire or chimney also shows where the air is moving.

Everyday convection.

- A **room heater** is put **low down**, so warm air rises from it and the whole room is warmed by the current it sets up. An **air conditioner** or the cooling unit in a fridge is put **high up**, so the cold, dense air sinks.
- A **hot-water tank** is heated low down; hot water rises and is taken from the **top**. Water **below** a heater stays cold, because warm water doesn't sink.
- **Hot-air balloons**, rising smoke, flames, and gliders using rising **thermal currents** are all convection.
- **Sea breezes**: on a sunny day the land warms faster than the sea. Air above the land warms, becomes less dense and rises; cooler, denser air from above the sea flows in to replace it, so the breeze blows **from the sea to the land**.

Radiation

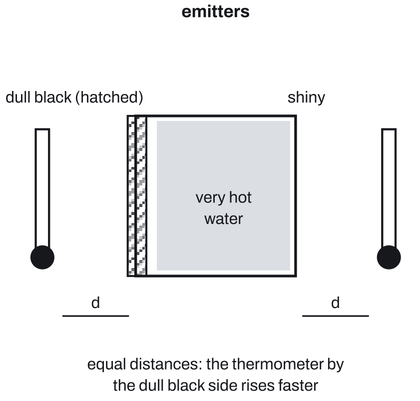
Thermal radiation is **infrared radiation**, part of the electromagnetic spectrum. **Every object emits it**, and the hotter an object is, the more it emits. Because it is an electromagnetic wave it needs **no medium**: it travels through a **vacuum**, so it is how energy reaches the **Earth from the Sun** across space. It also passes through air, and through some glass and water.

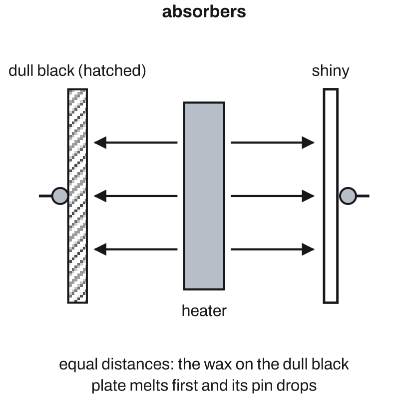
Colour and texture. When infrared radiation meets a surface, some is **absorbed** (warming the surface), and the rest is **reflected**.

Surface	Absorbing	Emitting	Reflecting
dull black	best absorber	best emitter	worst reflector
shiny white (or silver)	worst absorber	worst emitter	best reflector

Remember the rule: **a good absorber is also a good emitter**. Black beats white, and dull beats shiny, for both absorbing and emitting. So:

- solar panels and solar water pipes are **dull black**, to absorb as much as possible;
- houses in hot countries are painted **white**, to reflect sunlight;
- a black car warms up faster in the sun **and** cools down faster at night than an identical white car;
- the fins on the back of a fridge are **black** so they emit well; a heater's reflector and the foil behind a radiator are **shiny**, so they reflect infrared back into the room.





Extended only: experiment to compare emitters. Use a metal cube (a Leslie cube) with sides of different finishes, or two identical cans, one painted dull black and one shiny. Fill with **very hot water** (the same mass at the same starting temperature in each can). Place thermometers (or infrared detectors) at the **same distance** from each surface and read them after the same time. The reading is higher by the **dull black** surface: it is the better emitter. Alternatively record how fast the water in each can **cools**: the dull black can cools faster. Keep everything else the same: size of the cans, mass and starting temperature of the water, distance, and whether lids are on.

Extended only: experiment to compare absorbers. Put two identical metal plates at **equal distances** on either side of a radiant heater, one dull black and one shiny, with a pin stuck on the back of each with wax. Switch on and time how long each pin takes to drop: the pin on the **dull black** plate drops first, so it is the better absorber. Or put thermometers with blackened and shiny bulbs, or identical cans of cold water painted differently, the same distance from a lamp or heater, and see which warms fastest.

Extended only: what sets the rate of emission. An object emits infrared faster when its **surface temperature is higher** and when its **surface area is larger**. Colour and texture matter too (dull black emits most). So:

- a large sheet emits more than a small one at the same temperature;
- the same mass of metal cools faster when spread into a shape with a bigger surface area;
- two stars giving out the **same power**: the **bigger** one must have the **lower** surface temperature, since its larger area would otherwise make it emit more.

Extended only: balance of energy. An object is receiving and losing energy at the same time.

- It stays at a **constant temperature** only when it transfers energy away **at the same rate** as it receives it. "No energy transfer" is wrong: both flows are still happening.
- If it receives energy **faster** than it loses it, its temperature **rises**. As it gets hotter it emits faster, until the two rates are equal again and the temperature settles.
- If it loses energy **faster** than it receives it, its temperature **falls**.

A can of hot water in a room cools until it reaches a steady temperature, then stays there: from then on it gains and loses energy at equal rates.

Extended only: the Earth's temperature. The Earth absorbs radiation from the Sun and emits infrared radiation from its surface into space. Its average temperature stays roughly constant when these rates balance. Anything that changes the balance changes the temperature:

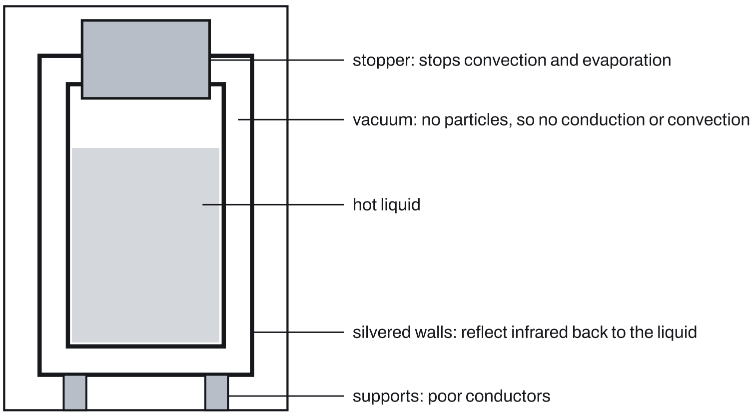
- **more greenhouse gases** (carbon dioxide, methane, water vapour) absorb more of the infrared emitted by the surface and send some back down, so less escapes to space and the Earth **warms**;
- **less ice and snow** (which are white and reflect sunlight) means the surface absorbs more radiation and warms;
- **more cloud** reflects more incoming sunlight during the day (cooling), but traps outgoing infrared at night (warming).

Uses and consequences

Heating food in a pan (Core). The hotplate heats the pan's base by **conduction** (there is no air gap). The metal base, often **copper** or **aluminium**, is a **good conductor**, so energy passes quickly through it to the food or water. The water in the pan is heated through by **convection**. The **handle** is wood or plastic, a **bad conductor**, so it stays cool enough to hold. **Shiny** sides are poor emitters, so less energy is lost by radiation. A **lid** stops warm air and steam carrying energy away by convection and evaporation.

Heating a room by convection (Core). A heater warms the air next to it by **conduction**. That air expands, becomes **less dense** and **rises**; cooler, denser air moves down and across to the heater to replace it. The loop carries warm air round the whole room. A heater also radiates infrared, and **shiny foil** on the wall behind it reflects infrared back into the room instead of letting the wall absorb it.

Keeping things hot or cold: the vacuum flask.



- The **vacuum** contains **no particles**, so energy **cannot** cross it by **conduction or convection** (both need particles). Radiation **can** cross it.
- The **silvered** walls reduce **radiation**: the inner surface is a poor emitter, and the silvering **reflects** infrared back towards the liquid.
- The **stopper** (plastic or cork, a bad conductor) stops convection currents and evaporation out of the top.
- The glass and the plastic **supports** are bad conductors.

It works both ways: the same flask keeps a cold drink cold.

Extended only: a fire burning wood or coal.

- **Radiation**: the glowing fire emits infrared in all directions, straight to people in front of it. This is the main way you feel a fire's warmth.
- **Convection**: hot gases above the fire are less dense and rise up the chimney, drawing fresh air (with oxygen) in at the bottom, which keeps the fire burning. Much of the energy is carried away up the chimney this way. The warmed air in the room also circulates by convection.
- **Conduction**: through the metal grate and the fireplace or stove walls. A metal stove then heats the room by radiation (a **dull black** stove or chimney pipe emits well) and by convection of air past its hot surfaces.

Extended only: a car radiator. The engine gets very hot. A liquid coolant is pumped through channels in the engine, where it is heated by **conduction** from the hot metal, and then carries the energy away as it flows (a pumped, "forced" convection). It flows to the **radiator** at the front of the car, which is made of thin metal tubes joined to many thin metal **fins**:

- energy passes through the thin metal walls and fins by **conduction** (metals are good conductors);
- the fins give a **large surface area**, so energy passes quickly to the air flowing past; the moving air carries the energy away by **convection** (helped by a fan and by the car's motion);
- the radiator is often painted **dull black**, so it also loses energy by **radiation**.

The same design, **metal fins** painted **black**, is used on the cooling pipes at the back of a fridge.

Key facts and formulas

The 0625 papers have no formula sheet, and this topic has no calculation formula of its own. Learn these facts.

Formula	Status
Conduction: solids (best in metals); convection: liquids and gases only; radiation: needs no medium, crosses a vacuum	Learn it
Density $\rho = \frac{m}{V}$: heating a fluid increases V at constant m, so ρ decreases and the warm fluid rises	Learn it
Dull black: best absorber and best emitter, worst reflector; shiny white or silver: worst absorber and emitter, best reflector	Learn it
Extended only: rate of emission increases with surface temperature and with surface area	Learn it
Extended only: constant temperature $\iff$ rate of energy received $=$ rate of energy transferred away	Learn it
Extended only: rate received $>$ rate lost $\Rightarrow$ temperature rises; rate received $<$ rate lost $\Rightarrow$ temperature falls	Learn it

Formula	Status
Area of one face of a square sheet $= s^2$; surface area of a cube $= 6s^2$	Learn it

How to do it

We have tagged 143 questions for this topic across Papers 1–4, 2021–2025; 16 are repeats on other papers, leaving 127 different questions. 22 of the 127 mix two or more types, so the counts add up to more than 127.

Question type	Questions
Radiation: infrared, colour and texture, emitters and absorbers	40
Naming the method, and everyday uses (pans, flasks, heaters, the Sun)	33
Convection and density	31
Good and bad conductors, and conduction experiments	19
Extended only: how conduction works (lattice, free electrons, gases)	18
Extended only: rate of emission and energy balance	13

1. Radiation: infrared, colour and texture, emitters and absorbers (40 questions)

1. **Decide what the surface is doing**: is it **absorbing** (warming up in sunlight or near a heater), **emitting** (a hot object cooling, or warming the things around it), or **reflecting**?
2. **Apply the rule**: dull black absorbs and emits best; shiny white or silver absorbs and emits worst and reflects best. Dull beats shiny; black beats white.
3. **Link it to the result**: better emitter ⇒ cools faster (or warms nearby things more); better absorber ⇒ warms faster; better reflector ⇒ warms slower.

Variations you will meet:

- **Which surface is best (or worst) at…?** Four options of dull/shiny black/white. Best absorber or emitter: **dull black**. Worst absorber, worst emitter, best reflector: **shiny white**.
- **Two containers of hot water, one dull black and one shiny white**: the black one **cools faster** (larger temperature drop), because black is the better **emitter**. Don't say "better absorber" when the object is losing energy: examiners see this often.
- **Hands or thermometers near two sides of a hot cube or plate**: the one by the **dull black** side gets warmer, because that side **emits** more. (The sides are at the same temperature.)
- **Suggest a reading** for the thermometer by the shiny side: **above room temperature** but **below** the reading by the black side.
- **Solar panels, a shower bag, a road, tarmac**: black, so it is a good **absorber** of infrared from the Sun, so it gets hotter. Tarmac gets hotter than the air above it because it absorbs infrared well, while air absorbs little.

- **White houses, white pipes, shiny foil**: white and shiny surfaces **reflect** infrared. Foil behind a heater reflects it **back into the room**.
- **Black car and white car**: the black one warms faster in sunlight **and** cools faster at night.
- **Improve a solar heater**: paint the pipe dull black (better absorber); use a metal pipe (better conductor); make it longer or flatter (more area in the sunlight); slow the water flow; cover it with glass or insulate the back.
- **What is thermal radiation? Infrared**, an electromagnetic wave. It travels through a vacuum, air, glass and water. It is not "heat waves" or microwaves.
- **Extended only: describe an experiment** to compare emitters or absorbers: see "Understand it". Say what you **keep the same** (distance, size, mass and starting temperature of the water) and what you **measure** (temperature after a set time, or time for the pin to drop).

2. Naming the method, and everyday uses (33 questions)

1. **Where is the energy going?** Through a solid ⇒ **conduction**. Through a liquid or gas that is **moving** ⇒ **convection**. Through empty space or across a gap from a hot glowing object ⇒ **radiation**.
2. **In an everyday device**, name **each** method it reduces or uses, and say how.

Variations you will meet:

- **Sun to Earth**: **radiation** (only radiation crosses the vacuum of space). A hot can in outer space cools by **conduction** through the metal, then **radiation** from its surface.
- **Through the walls of a pan, a can, a pipe or a glass beaker**: **conduction**. **Within the water** in them: **convection**.
- **Pans**: base a **good** conductor, handle a **poor** conductor (wood or plastic). A wooden spoon is used because wood is a good **insulator**.
- **A grill** cooks food below it by **radiation**, not convection: hot air rises away from food below it.
- **Hotplates**: a metal hotplate touching the pan heats it by **conduction**; a glowing heater under glass also radiates.
- **Vacuum flask**: the vacuum stops **conduction and convection** (no particles); silvered walls reduce **radiation**; the stopper stops convection and evaporation.
- **Keeping a drink hot**: a **lid** (stops convection and evaporation) makes more difference than a holder. A cup holder with **air gaps** works because air is a poor conductor. A **polystyrene** cup: the plastic and the trapped air are poor conductors, and air trapped in tiny bubbles can't move, so there is no convection.
- **A hot-water tank**: water above the heater is heated by **convection**, water below it only by **conduction** (slowly).
- **Keeping water in a tank hot**: insulate it (lagging, foam), or put a lid on.

3. Convection and density (31 questions)

1. **Heated fluid expands**, so its **density decreases**.
2. The warm, **less dense** fluid **rises**.

3. **Cooler, denser** fluid **sinks** to replace it.
4. This sets up a **convection current** that carries energy through the whole fluid.

Variations you will meet:

- **Which states? Liquids and gases only** (air and water, never wood or any solid).
- **The false statement**: "cooler liquid rises above warmer liquid" or "hot liquid is denser than cold liquid" are wrong.
- **Direction on a diagram**: warm fluid goes **up** above the heater, cool fluid comes **down** on the far side. In a gap at floor level near a heater, the air is **cool** and moving **towards** the heater.
- **Compare two points in a current**: the rising part is **warmer and less dense**; the sinking part is **cooler and denser**. Near a lump of ice floating in water, the water **sinks** below the ice because it is cooled and becomes denser.
- **Explain how a heater warms a whole room** (a favourite 3–4 mark question): air near the heater is heated; it expands and becomes less dense; it rises; cooler, denser air sinks and moves in to replace it; this sets up a convection current round the room.
- **Hot water at the top of a tank**: hot water is less dense, so it rises to the top, where it is drawn off.
- **A fan or spiral turning above a candle**: air heated by the candle is less dense, rises, and pushes the blades as it flows past.
- **Describe an experiment**: crystal at the bottom of a beaker of water, heat gently beneath it, the colour shows the water rising above the flame and sinking elsewhere.
- **Sea breeze, gliders, hot-air balloons**: all warm air rising because it is less dense.
- **Not convection**: a spoon handle getting hot in a drink (conduction).

4. Good and bad conductors, and conduction experiments (19 questions)

1. **Metals are good conductors; non-metals (wood, plastic, glass, rubber) and fluids are poor conductors.**
2. **In a rod experiment**, the wax on the **best** conductor melts **first** (its pin drops first, and in a set time a **longer** strip of wax melts).

Variations you will meet:

- **Which rod drops its pin first?** The best conductor (copper or silver before aluminium, before brass, before iron or steel; glass last).
- **Read a bar chart of times**: the **shorter** the time for the pin to fall, the **better** the conductor.
- **Fair test**: same length and thickness of rod, same amount of wax and size of pin, same heat source kept at the **same temperature**.
- **Describe the experiment** (Paper 3): rods of the same size, pins fixed with wax on the ends, heated equally at the other end; time how long each pin takes to fall; shortest time = best conductor.
- **Copper and wood in ice**: the copper feels **colder**, because copper conducts energy out of your hand faster.

- **Glass beaker of hot water**: your hand takes a few seconds to feel hot because **glass is a poor conductor**.
- **Metal and plastic rods (or spoons) in hot water, or with ice on the end**: the metal end warms faster, and ice on the metal spoon melts first.
- **Water boiling at the top of a test-tube while the bottom stays cold**: water (and glass) are **poor conductors**.
- **Two blocks in contact**: energy flows from hot to cold until they are at the same temperature, so the internal energy of the hot block **decreases** and that of the cold block **increases**.

5. How conduction works: lattice and free electrons (18 questions)

Extended only.

1. **All solids**: particles at the hot end **vibrate** more; they make neighbouring particles vibrate more; energy passes along through **lattice vibrations**.
2. **Metals also**: **free (delocalised) electrons** gain energy at the hot end, **move** quickly through the metal, and **collide with ions** further away, passing on energy.
3. **Compare**: metals conduct much better because they have free electrons; non-metals (wood, plastic) have only lattice vibrations.

Variations you will meet:

- **"Explain how thermal energy is conducted through the copper"** (3 marks): free or delocalised electrons in the metal; they carry energy through the metal from hot to cold; they collide with distant ions; and ions vibrate and pass vibrations to neighbouring ions. Give **both** mechanisms when the question says "two ways" or mentions both the lattice and the electrons.
- **Multiple choice on who moves**: **electrons move through** the metal; **ions vibrate** about fixed positions and do **not** travel or leave the surface.
- **Why metal is better than wood**: metal has free electrons; wood doesn't, so wood conducts only by lattice vibrations and is an insulator.
- **Why gases are poor conductors compared with solids**: gas particles are **far apart**, so they collide less often and pass on energy slowly.
- **Which material conducts best from a table?** A **solid with free electrons** (a metal). Gases conduct worst.
- **Direction**: free electrons carry energy from the **hotter** end to the **cooler** end.

6. Rate of emission and energy balance (13 questions)

Extended only.

1. **Rate of emission** goes **up** with a **higher surface temperature**, a **larger surface area**, and a darker, duller surface.
2. **Constant temperature** means energy is received and lost **at the same rate**.

3. Receiving faster than losing ⇒ temperature **rises**; losing faster than receiving ⇒ temperature **falls**.

Variations you will meet:

- **Which change reduces the rate of emission?** Reducing the surface area **and** reducing the temperature; changing dull to shiny, or black to white.
- **Which container radiates at the lowest rate?** The **smallest**, **coolest** one (for the same colour). Compare areas with $6s^2$ for a cube: doubling the side makes the area 4 times as big.
- **Which surface emits most slowly?** Shiny white **and** small area.
- **Rank spheres or sheets at the same temperature**: compare one factor at a time. Of two objects the same colour, the bigger one emits faster; of two the same size, the black one emits faster. So big and black is first, small and white is last.
- **Stars**: same power from a bigger star ⇒ **lower** surface temperature.
- **Same mass, same material, different shapes**: the one with the larger surface area **cools faster** but, cooling to the same final temperature, both lose the **same** amount of internal energy.
- **"Why does the temperature stay constant?"**: the rate of energy transfer **from** the object equals the rate **to** it. Not "it stops losing energy".
- **An object moved into warm surroundings**: it now gains energy faster than it loses it, so its internal energy and temperature rise.
- **The Earth's temperature**: explained by the balance of absorbed sunlight and emitted infrared (see "Understand it").

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 metal saucepan of water stands on an electric hotplate. The base of the pan is copper, its handle is plastic, and the outside of the pan is polished and shiny.

(a) Name the method by which thermal energy passes through the copper base, and the main method by which the whole of the water is heated. **[2]**

(b) Explain why the base is copper and the handle is plastic. **[2]**

(c) Explain one advantage of keeping the outside of the pan shiny. **[2]**

(a) Conduction **B1**; convection **B1**.

(b) Copper is a good thermal conductor, so energy passes quickly to the water **B1**. Plastic is a poor conductor (an insulator), so the handle stays cool enough to hold **B1**.

(c) A shiny surface is a poor emitter of infrared radiation **B1**, so less energy is lost from the pan and the water heats faster **B1**.

Example 2

A cooling unit is fixed high up on the wall of a room.

(a) Explain, using ideas about density, how the unit cools the whole room. **[4]**

(b) Suggest why the unit would work badly if it were fixed near the floor. **[1]**

(a) Air next to the unit is cooled and contracts **B1**, so its density increases **B1**. The cool, denser air sinks **B1**, and warmer, less dense air rises to take its place and is cooled in turn, setting up a convection current round the room **B1**.

(b) The cold, dense air would stay near the floor and not circulate, so the upper part of the room stays warm **B1**.

Example 3

Extended only. An aluminium pan and a clay pot of the same size and thickness are filled with boiling water.

(a) Explain, in terms of particles, how thermal energy passes through the wall of the aluminium pan. **[3]**

(b) Explain why the outside of the clay pot stays much cooler than the outside of the aluminium pan. **[2]**

(c) A layer of still air between two walls is often used as insulation. Explain, in terms of particles, why air is a poor conductor. **[1]**

(a) Aluminium contains free (delocalised) electrons **B1**, which gain energy at the hot inner surface and move quickly through the metal, colliding with ions further on **B1**. Also the ions at the hot side vibrate more and pass their vibrations on to neighbouring ions **B1**.

(b) Clay has no free electrons **B1**, so it conducts only by lattice vibrations, which transfer energy much more slowly **B1**.

(c) The air particles are far apart, so they collide less often and pass energy on slowly **B1**.

Example 4

Extended only. Two hollow metal cubes are painted dull black. Cube P has sides of 0.20 m and cube Q has sides of 0.40 m. Both are filled with water at 70 °C.

(a) Calculate the surface area of each cube and state which cube emits radiation at the greater rate. **[3]**

(b) A metal plate in sunlight is at a steady temperature. State what this tells you about the energy transfers. **[1]**

(c) A cloud moves away and the plate now receives energy at 120 W while it is transferring energy away at 90 W. Describe what happens to the temperature of the plate, calculate the energy the plate gains in the first 10 minutes if these rates stayed the same, and explain why the temperature eventually stops rising. **[4]**

(a) Area of P $= 6 \times 0.20^2 = 0.24$ m² **C1**; area of Q $= 6 \times 0.40^2 = 0.96$ m² **C1**. Q emits at the greater rate, because it has the larger surface area at the same temperature and colour **A1**.

(b) It is receiving energy at the same rate as it transfers energy away **B1**.

(c) It receives energy faster than it loses it, so its temperature rises **B1**. Net rate $= 120 - 90 = 30$ W **C1**, so in $10 \times 60 = 600$ s it gains $30 \times 600 = 18\,000$ J **A1**. As it gets hotter it emits faster, until it transfers energy away at 120 W; then the rates are equal and its temperature stays constant **B1**.

Common mistakes

- **Saying "black is a good absorber" when the object is cooling.** A hot container cooling down is **emitting**; say the dull black surface is the better **emitter**. Read whether energy is going in or out.
- **Thinking shiny white is a good emitter** because it "gives off" light. Shiny and white surfaces are **poor** emitters and **poor** absorbers; they are good **reflectors**.
- **Using "good absorber and emitter" without choosing.** When a question is about emission, write about emission.
- **Explaining convection without density.** "Heat rises" or "hot particles rise" earns nothing. Say the fluid **expands**, becomes **less dense** and **rises**; cooler, **denser** fluid sinks.
- **Saying the particles become less dense or expand.** It is the **fluid** whose density falls, because its particles move further apart.
- **Saying convection happens in solids**, or giving convection for energy passing through a metal wall. Through a solid it is **conduction**.
- **Giving convection for a grill.** Hot air rises away from food below a grill; it is heated by **radiation**.
- **Describing conduction with only electrons, or only the lattice**, when asked for both. And saying **ions move** along the metal: they only **vibrate**; it is the free electrons that travel.
- **Answering "why is conduction worse in a gas" with "gas particles move faster".** The point is that the particles are **far apart**, so collisions are less frequent.
- **Saying a vacuum stops radiation.** The vacuum stops conduction and convection; the **silvered** surfaces reduce radiation.
- **Saying "no energy transfer" for an object at constant temperature.** Energy is still received and lost, at **equal rates**.
- **Mixing up the region**: thermal radiation is **infrared**, not microwaves or ultraviolet.

How to get the marks

- **"State the method"**: one word, **conduction**, **convection** or **radiation**. Adding a second, wrong method contradicts your answer and loses the mark.
- **"Use your ideas about density"**: the marks are for the chain: heated ⇒ expands ⇒ **less dense** ⇒ **rises**; cooler ⇒ **denser** ⇒ **sinks**; a **current** forms. Write each link.
- **"Explain in terms of particles (or electrons)"**: name the particles and what they do: **free/delocalised electrons move** and **collide with ions**; **ions vibrate** and pass vibrations to **neighbouring** ions. Each idea is usually a separate mark ("any three from").
- **"State and explain which container…"**: name the container **and** give the reason with the right word (**emitter**, **absorber** or **reflector**).
- **"Suggest a value"**: a sensible number that fits the physics, for example between room temperature and the other reading.
- **"Describe an experiment"**: say what is set up (same size, same distance, same starting temperature), what is **measured** (temperature after a fixed time, or time for the pin to fall) and **how you decide** (the higher reading, or the shorter time, shows the better emitter or conductor). A labelled diagram helps.
- **"Explain why the temperature stays constant"**: "the rate of energy transfer **to** it equals the rate **from** it". Both halves are needed.
- **Everyday devices**: for each feature, give the method it affects **and** whether it reduces or increases it (for example "silvered walls reflect infrared, reducing radiation").
- **Multiple choice**: many options pair a right fact with a wrong reason. Check both columns of every row.

Quick check

1. Name the main method of thermal energy transfer in each case: (a) through the metal wall of a kettle; (b) through the water in the kettle; (c) from a glowing heater to your face across a room.
2. Two identical cans hold hot water at the same temperature; one is dull black, the other shiny white. State which cools faster, and why.
3. Explain, using density, why the hot water in a tank is taken out at the top.
4. **Extended only.** A square sheet of metal 10 cm by 10 cm and a rectangular sheet 20 cm by 30 cm are painted the same and heated to the same temperature. Calculate how many times faster the larger sheet emits radiation from one face. Then name two changes that would **reduce** the rate of emission from the large sheet.
5. **Extended only.** A dark roof receives energy from the Sun at 500 W and is transferring energy away at 350 W. State and explain what happens to its temperature, and state the rate at which it must transfer energy away for its temperature to become constant.

Answers

1. (a) Conduction. (b) Convection. (c) Radiation (infrared).
2. The dull black can cools faster, because dull black is a better **emitter** of infrared radiation than shiny white.
3. The water near the heater expands and becomes less dense, so it rises to the top; cooler, denser water sinks to the bottom. The hottest water is therefore at the top.
4. Area $20 \times 30 = 600$ cm² against $10 \times 10 = 100$ cm², so the larger sheet emits $\frac{600}{100} = 6$ times as fast. Reduce the rate by lowering its temperature, by making its surface shiny (or white), or by reducing its surface area.
5. It receives energy faster than it loses it (a net gain of $500 - 350 = 150$ W), so its temperature rises. As it gets hotter it emits faster; its temperature becomes constant when it transfers energy away at 500 W.

Past questions to try

- **0625/42/O/N/24 Q5**: a tarmac road in sunshine, from absorption to convection in the air (Extended).
- **0625/33/O/N/23 Q4**: a pan's handle, sides and base, and heating a room by convection (Core).
- **0625/43/M/J/24 Q5**: electrons in metals, non-metals, and why gases conduct badly (Extended).
- **0625/32/O/N/23 Q6**: what a vacuum stops, and convection in a heated glass tube (Core).