

Thermal physics

IGCSE Physics 0625 · Unit 2 revision notes

The particle model of matter, gases, expansion, specific heat capacity, changes of state and the three ways thermal energy moves from hot to cold.

22 definitions to learn word for word, 6 equations in their own column, 19 diagrams and graphs. Read it, cover it, test yourself.

1. 2.1a States of matter and changes of state
2. 2.1b The particle model and Brownian motion
3. 2.1c Gases: pressure, temperature and volume
4. 2.2a Thermal expansion
5. 2.2b Specific heat capacity
6. 2.2c Melting, boiling and evaporation
7. 2.3a Conduction
8. 2.3b Convection
9. 2.3c Radiation
10. 2.3d Consequences of thermal energy transfer

 Definitions (mark-scheme wording)  Equations  Exam traps **Extended** = Extended tier only

2.1a States of matter and changes of state

Definitions

Melting: the change from solid to liquid at the melting point, at constant temperature.

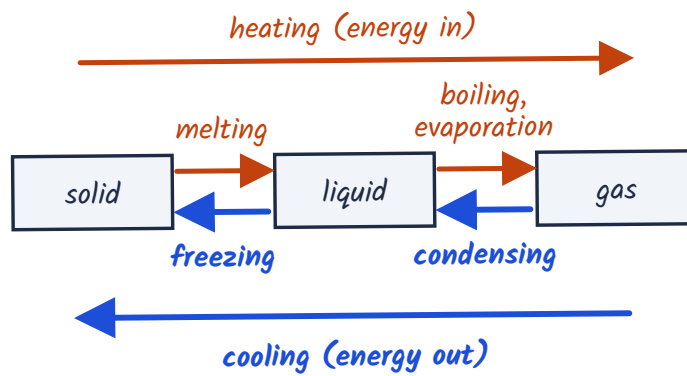
Freezing (solidification): the change from liquid to solid at the melting point, at constant temperature.

Boiling: the change from liquid to gas at the boiling point, throughout the liquid, at constant temperature.

Condensation: the change from gas (vapour) to liquid.

Key points

- ✓ **Solid:** fixed shape and fixed volume; cannot be compressed.
- ✓ **Liquid:** fixed volume but takes the shape of its container; almost incompressible; can flow.
- ✓ **Gas:** no fixed shape or volume; fills its container; **easily compressed**.
- ✓ Melting, boiling and evaporation need **energy in**; freezing and condensing give **energy out**.
- ✓ A pure substance melts and boils at **fixed temperatures**.



Changes of state: heating moves to the right, cooling moves back to the left.

Watch out!

! Freezing and melting happen at the **same** temperature ($0\text{ }^{\circ}\text{C}$ for water); they are not different points.

2.1b The particle model and Brownian motion

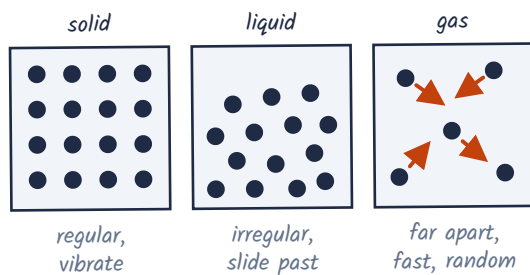
Definitions

Brownian motion: the random, zigzag movement of small particles (e.g. smoke or pollen) suspended in a fluid.

Absolute zero: the lowest possible temperature, $-273\text{ }^{\circ}\text{C}$ (0 K), at which particles have the least kinetic energy.

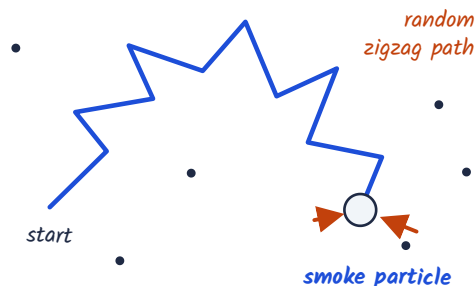
Key points

- ✓ **Solid:** particles close together in a **regular** pattern, vibrating about fixed positions.
- ✓ **Liquid:** particles close together but **irregular**; they move around and slide past each other.
- ✓ **Gas:** particles **far apart**, moving quickly and randomly in all directions.
- ✓ Higher temperature = higher **average kinetic energy** of the particles.
- ✓ Brownian motion is evidence that fluids are made of tiny **moving particles**.
- ✓ Brownian motion is caused by **random collisions** between the microscopic particles and the particles of the gas or liquid.
- ✓ **Extended** the visible particles are hit unevenly by many **light, fast-moving** (invisible) molecules; call these **atoms or molecules**, not "microscopic particles".
- ✓ **Extended** the **forces and distances** between particles (atoms, molecules, ions, electrons) and their **motion** decide the properties of solids, liquids and gases.



Particle arrangements: spacing and freedom of movement increase from solid to gas; the particles do not change size.

dots: air molecules (not visible)



Brownian motion: a smoke particle, seen through a microscope, jiggles along a random path as air molecules hit it unevenly.

Watch out!

- ! You see the **smoke particles** move, not the air molecules; the molecules are far too small to see.
- ! Particles do not expand or melt; only their **spacing and motion** change.

2.1c Gases: pressure, temperature and volume

Definitions

Kelvin (absolute) scale: a temperature scale starting at absolute zero; a change of 1 K equals a change of 1 °C.

Boyle's law: *Extended* for a fixed mass of gas at constant temperature, pressure is inversely proportional to volume.

Key points

- ✓ Gas pressure is caused by particles **colliding with the container walls**.
- ✓ Heat a gas at **constant volume**: particles move faster, hit the walls harder and more often, so **pressure rises**.
- ✓ Compress a gas at **constant temperature**: collisions with each unit area are more frequent, so **pressure rises**.
- ✓ *Extended* a particle bouncing off a wall changes momentum, so the wall exerts a force on it and it exerts an equal force on the wall.
- ✓ *Extended* pressure = total force of collisions / area of wall.
- ✓ *Extended* at constant temperature, **halving the volume doubles the pressure**.

Equations

$$T = \theta + 273$$

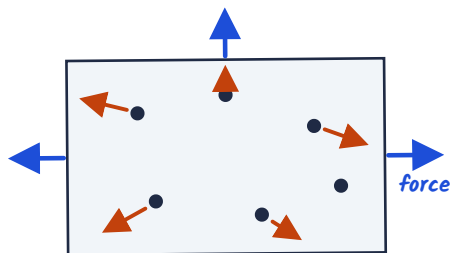
temperature in kelvin from temperature in °C
K

$$pV = \text{constant}$$

Extended fixed mass of gas at constant temperature
 $\text{Pa} \times \text{m}^3$

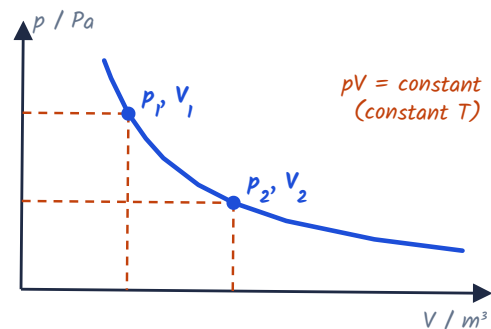
$$p_1V_1 = p_2V_2$$

Extended before and after a change at constant temperature
any matching units

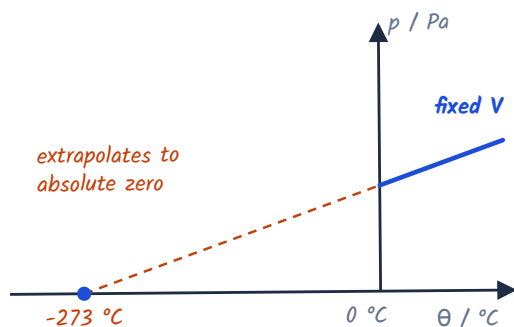


collisions with the walls exert a force

Gas pressure: every collision with a wall pushes outwards; faster or more frequent collisions mean a higher pressure.



Extended: Boyle's law. $p \times V$ is the same at every point on the curve: double the volume and the pressure halves.



Pressure of a gas at constant volume rises steadily with temperature; extrapolating to zero pressure gives absolute zero, $-273\text{ }^{\circ}\text{C}$.

Watch out!

- ! Gas calculations with temperature need **kelvin**: $20\text{ }^{\circ}\text{C}$ to $40\text{ }^{\circ}\text{C}$ is 293 K to 313 K , not "doubling the temperature".
- ! Extended: Boyle's law only works for a **fixed mass** of gas at **constant temperature**.

2.2a Thermal expansion

Definitions

Thermal expansion: the increase in length or volume of a substance when its temperature rises.

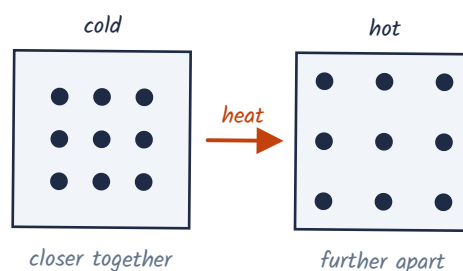
Bimetallic strip: two different metals bonded together that bend when heated because they expand by different amounts.

Key points

- ✓ Solids, liquids and gases all **expand when heated** (at constant pressure) and contract when cooled.
- ✓ **Extended** heating gives particles more kinetic energy, so they move further apart: the **average separation increases**.
- ✓ **Extended** for the same temperature rise, **gases expand most, then liquids, then solids** least.
- ✓ **Extended** this order follows the particles: **strong forces** hold solid particles close in fixed positions; gas particles are far apart with almost no forces between them.
- ✓ Consequences: **gaps** in railway tracks and bridges; power cables sag in summer; thick glass can crack if heated suddenly.
- ✓ Applications: **liquid-in-glass thermometers**, bimetallic strips in **thermostats** and fire alarms.
- ✓ A bimetallic strip bends with the metal that expands more on the **outside** of the curve.



Bimetallic strip: brass expands more than iron, so when heated the strip curls with the brass on the outside.



Extended: heating does not make particles bigger; it makes them move more, so their average separation grows.

Watch out!

! Never say the particles **get bigger** or expand; only the spaces between them increase.

2.2b Specific heat capacity

Definitions

Internal energy: the total kinetic and potential energy of all the particles in an object.

Specific heat capacity (c): Extended the energy required per unit mass per unit temperature increase.

Key points

- ✓ A rise in temperature **increases the internal energy** of an object.
- ✓ Extended a temperature rise means an increase in the **average kinetic energy of all the particles** in the object.
- ✓ Extended the same energy gives different substances different temperature rises: a **low c** heats up quickly.
- ✓ Extended water has a **high c** (about 4200 J/(kg °C)): it warms and cools slowly, useful in radiators and cooling systems.
- ✓ Extended measure c by heating a block of known mass with an electric heater; record energy (joulemeter) and temperature rise.
- ✓ Extended insulate the block and put a drop of oil in the thermometer hole for good thermal contact.
- ✓ Extended energy lost to the surroundings makes the measured c **too large**.

Equations

$$c = \Delta E / (m\Delta\theta)$$

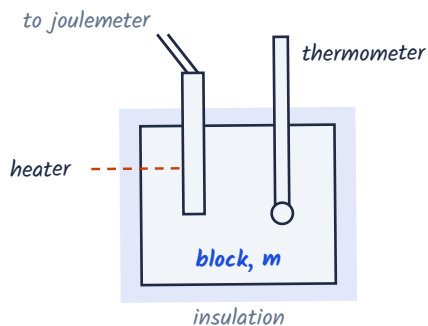
Extended specific heat capacity = energy / (mass × temperature rise)
J/(kg °C)

$$\Delta E = mc\Delta\theta$$

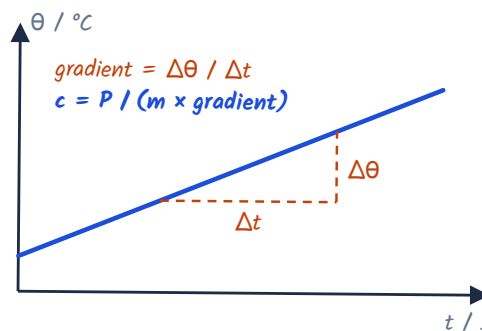
Extended energy needed to change the temperature
J

$$E = Pt$$

energy supplied by a heater of power P in time t
J



Extended: measuring c . The joulemeter gives ΔE ; the thermometer gives $\Delta \theta$; the block is weighed for m .



Extended: temperature rises steadily while the heater is on;
 $c = P / (m \times \text{gradient})$.

Watch out!

- ! Extended: $\Delta \theta$ is the temperature **change**, not the final temperature: 20 °C to 70 °C means $\Delta \theta = 50$ °C.
- ! Extended: mass must be in **kg** when c is in J/(kg °C).

2.2c Melting, boiling and evaporation

Definitions

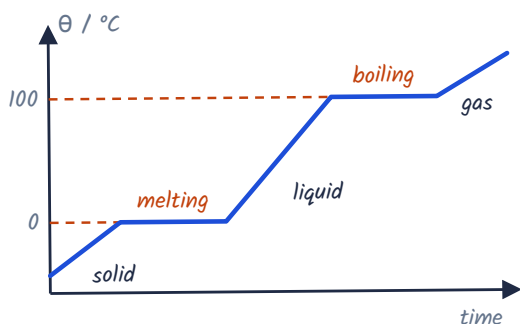
Melting point: the fixed temperature at which a pure solid turns into a liquid.

Boiling point: the fixed temperature at which a pure liquid turns into a gas throughout the liquid.

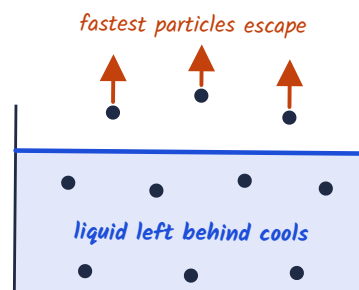
Evaporation: the escape of the more energetic particles from the surface of a liquid.

Key points

- ✓ During a change of state the **temperature stays constant**: the energy changes the particle arrangement, not their kinetic energy.
- ✓ Pure water **melts at 0 °C** and **boils at 100 °C** at standard atmospheric pressure.
- ✓ Condensation and solidification: particles **lose energy**, slow down and are pulled closer together by attractive forces (into a liquid, then a fixed solid pattern).
- ✓ Evaporation **cools** the liquid left behind: the particles that remain have a lower average kinetic energy.
- ✓ **Extended** boiling happens at **one temperature, throughout** the liquid (bubbles); evaporation happens at **any temperature**, only at the surface.
- ✓ **Extended** evaporation is faster with a **higher temperature**, a **larger surface area** and **air moving** over the surface.
- ✓ **Extended** an object in contact with an evaporating liquid is **cooled** (sweat on skin, alcohol on a thermometer bulb).



Heating curve for water: the flat sections are melting at 0 °C and boiling at 100 °C, where energy changes the state, not the temperature.



Evaporation: only the most energetic surface particles escape, so the average energy of those left falls and the liquid cools.

Watch out!

- ! Evaporation and boiling are **not** the same: evaporation needs no fixed temperature and happens only at the surface.
- ! On a heating curve the flat part is **not** "no energy going in"; energy is still supplied, it changes the state.

2.3a Conduction

Definitions

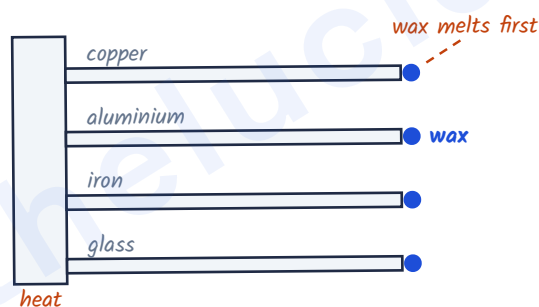
Thermal conduction: the transfer of thermal energy through a material without the material itself moving.

Thermal conductor: a material that transfers thermal energy well (e.g. metals).

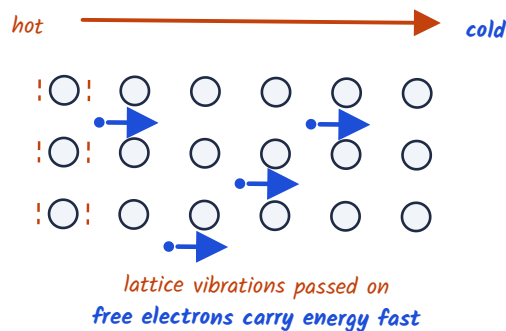
Thermal insulator: a material that transfers thermal energy poorly (e.g. plastic, wood, air).

Key points

- ✓ Test conductors: heat rods of different materials equally at one end; wax at the far end melts first on the **best conductor**.
- ✓ **Metals** are good conductors; non-metals such as glass, wood and plastic are poor.
- ✓ **Extended** in all solids, **lattice vibrations** pass energy from particle to neighbouring particle.
- ✓ **Extended** in metals, **free electrons** also move through the lattice and carry energy quickly.
- ✓ **Extended** gases and most liquids conduct badly: the particles are **far apart** and rarely pass energy on.
- ✓ **Extended** many solids (e.g. glass, concrete) conduct **better than insulators** but **less well than good conductors** such as metals.
- ✓ Trapped air (wool, foam, fur, double glazing) makes a good **insulator**.



Comparing conductors: all rods are heated equally; the wax on the copper rod melts first.



Extended: in a metal, vibrating ions pass energy along the lattice, and free electrons carry it much faster.

Watch out!

- ! Conduction does not move the material; only **energy** passes through it.
- ! Extended: explain metals with **free electrons**; lattice vibrations alone do not explain why metals are best.

2.3b Convection

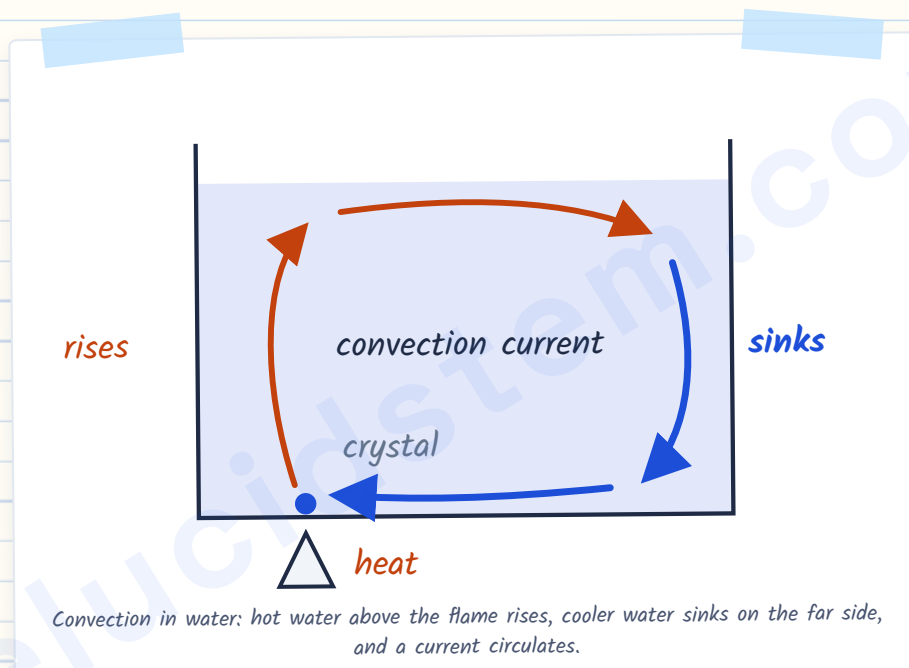
Definitions

Convection: the transfer of thermal energy by the movement of a fluid (liquid or gas) caused by differences in density.

Convection current: the circulation of a fluid in which heated, less dense fluid rises and cooler, denser fluid sinks.

Key points

- ✓ Convection happens only in **liquids and gases**, never in solids.
- ✓ Heated fluid **expands**, so its **density decreases** and it rises; cooler, denser fluid sinks to take its place.
- ✓ Convection is an important way thermal energy moves through fluids.
- ✓ Demonstration: a purple crystal (potassium manganate(VII)) at the bottom of a beaker heated at one side; the colour traces the current.
- ✓ Smoke above a candle, or a paper spiral turning above a heater, shows convection in air.



Watch out!

- ! Say "hot fluid is **less dense**, so it rises". "Heat rises" scores nothing.
- ! Convection cannot happen in a solid: the particles cannot flow.

2.3c Radiation

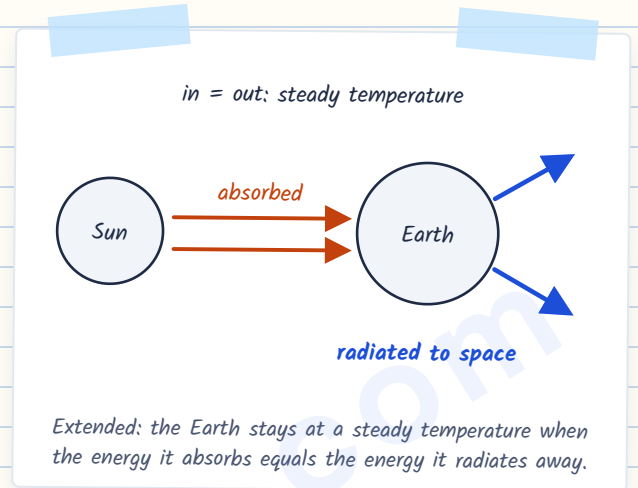
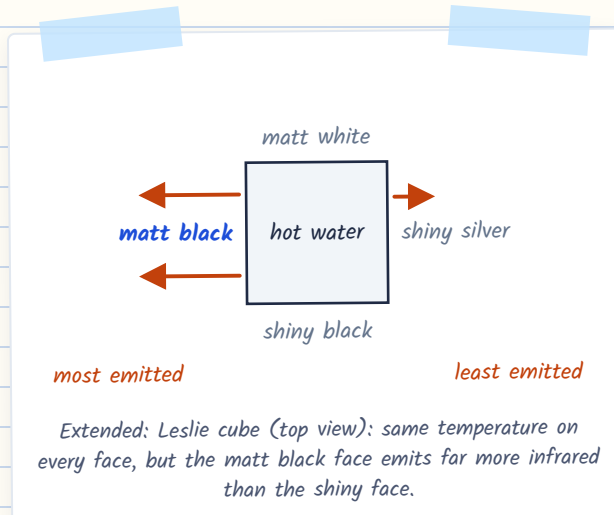
Definitions

Thermal radiation: infrared electromagnetic radiation emitted by all objects; it needs no medium.

Key points

- ✓ **All objects** emit infrared radiation.
- ✓ Radiation is the only transfer that works through a **vacuum**: this is how energy reaches us from the Sun.
- ✓ **Dull (matt) black** surfaces are the best absorbers and emitters; **shiny white or silver** surfaces are the worst, and the best reflectors.

- ✓ **Extended** emitters (Leslie cube): fill with hot water, place an infrared detector the same distance from each face; matt black reads highest.
- ✓ **Extended** absorbers: matt black and shiny plates the same distance from a heater, wax on the back of each; the wax on the **matt black** plate melts first.
- ✓ **Extended** rate of emission increases with **higher surface temperature** and **larger surface area**.
- ✓ **Extended** an object stays at **constant temperature** when it transfers energy away at the same rate as it receives it.
- ✓ **Extended** if it receives energy **faster** than it transfers it away, its temperature **rises**; if slower, its temperature **falls**.
- ✓ **Extended** the Earth's temperature depends on the balance between radiation absorbed from the Sun and radiation emitted to space.



Watch out!

- ! A good absorber is also a good **emitter**; dull black is best at both, shiny silver poorest at both.
- ! Radiation does not need particles; do not say it "travels through the air particles".

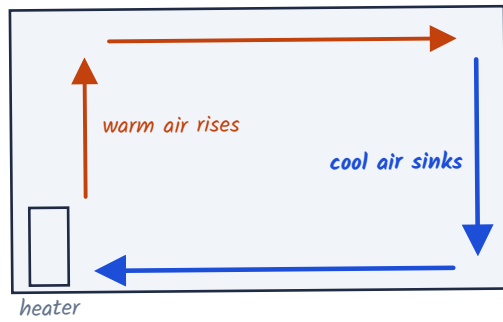
2.3d Consequences of thermal energy transfer

Definitions

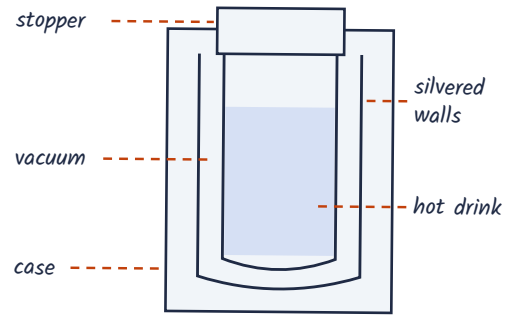
Insulation: a material or layer, often containing trapped air, that reduces the rate of thermal energy transfer.

Key points

- ✓ Cooking pan: **metal base** conducts energy to the food; **plastic or wooden handle** insulates.
- ✓ A room heater works by **convection**: warm air rises from it and cool air sinks on the far side.
- ✓ A refrigerator's cooling unit is at the **top**: cold, dense air sinks and cools the whole space.
- ✓ Homes: loft insulation, cavity wall foam and double glazing trap air or use a gap to **reduce conduction and convection**.
- ✓ Shiny foil behind radiators and on emergency blankets **reflects** infrared.
- ✓ **Extended** vacuum flask: the **vacuum** stops conduction and convection; **silvered walls** reduce radiation; the stopper cuts convection and evaporation.
- ✓ **Extended** a coal or wood fire: **radiation** warms the room in front; **convection** carries hot gases up the chimney and draws in fresh air; the grate and walls heat by conduction.
- ✓ **Extended** car radiator: coolant takes energy from the engine by **conduction and convection**; thin metal fins conduct it out and air flowing past carries it away by **convection** (some is radiated).



Heating a room by convection: warm air rises from the heater, spreads across the ceiling, cools and sinks.



Extended: vacuum flask. The vacuum blocks conduction and convection; silvered surfaces reflect infrared back.

Watch out!

- ! The vacuum stops conduction and convection only; **radiation** still crosses it, which is why the walls are silvered.
- ! Air is a poor conductor only when it is **trapped**; moving air carries energy by convection.