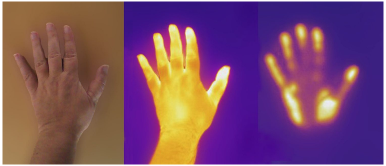
Thermal Physics

IGCSE Physics ▪ Topic 2

IGCSE Physics

What we will cover



1 States and the particle model

States of matter

solid 固体	liquid 液体	gas 气体
regular; vibrate about fixed positions	close; can slide – take the container's shape	far apart, fast; fill the container

Temperature and the particle model

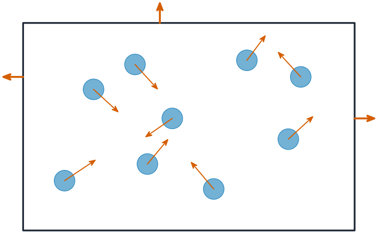
All matter is moving **particles** 粒子.

> **Temperature** 温度 measures the average kinetic energy of the particles.

Lowest possible: **absolute zero** 绝对零度, $-273°\mathrm{C}$.

$$T\,(\mathrm{K}) = \theta\,(°\mathrm{C}) + 273.$$

Gas pressure and Boyle's law



gas particles hit the walls — each hit is a tiny force.
Pressure = force per unit area

particle hits make the pressure

Fixed mass, constant temperature:

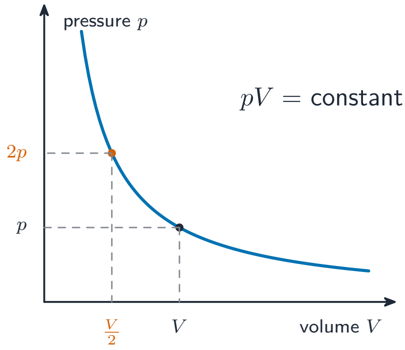
$$pV = \text{constant.}$$

$200\,\mathrm{cm}^3$ at $100\,\mathrm{kPa} \to 50\,\mathrm{cm}^3$

$$p_2 = \frac{100 \times 200}{50} = 400\,\mathrm{kPa}$$

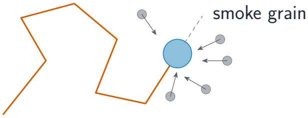
> The gas pressure is the total force of countless particle hits on each unit area of the wall

Gas pressure



At constant temperature the pressure–volume graph is a curve: halve the volume and the pressure doubles, so pV stays constant

Brownian motion



fast, invisible air particles hit the smoke grain from random directions, so it moves in a jerky, random path

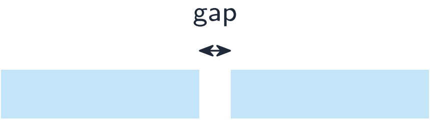
Smoke specks move in a jerky, random path – pushed by fast, invisible air particles.

> **Brownian motion** 布朗运动 is strong evidence for the particle model.

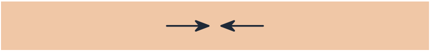
2

Heating

Thermal expansion and heat capacity



cool: a gap is left for expansion



hot: the rails expand and the gap closes

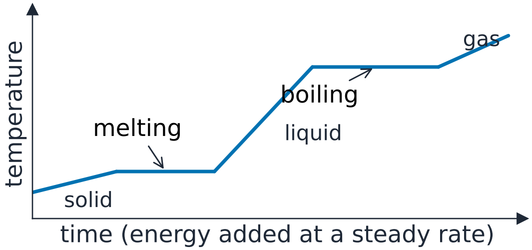
Heated matter expands (gases most).
Specific heat capacity 比热容:

$$c = \frac{\Delta E}{m\,\Delta\theta}.$$

$2.0\,\mathrm{kg}$ **water,** $20 \to 70°\mathrm{C}$**,** $c = 4200$

$\Delta E = mc\,\Delta\theta = 420\,\mathrm{kJ}$

Changes of state



plateau: latent heat changes state at constant temperature

- **melting** 熔化/**boiling** 沸腾 – temperature stays flat while the state changes
- **evaporation** 蒸发 – fastest particles leave the surface, so the liquid cools

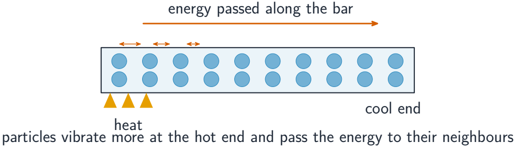
The four changes of state

Melting	Solid $\rightarrow$ liquid, at the melting point. The particles gain enough energy to break out of the lattice.
Boiling and evaporating	Liquid $\rightarrow$ gas. Boiling happens throughout the liquid at a fixed temperature; evaporation happens at the surface, at any temperature.
Condensation	**Condensation** 凝结: gas $\rightarrow$ liquid, as particles slow enough for the attractions to hold them.
Solidification	**Solidification** 凝固: liquid $\rightarrow$ solid – the reverse of melting, at the same temperature.

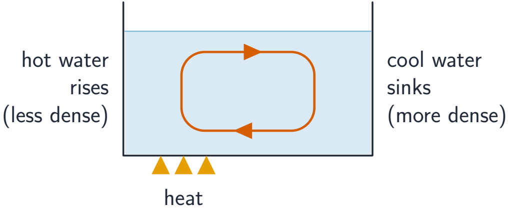
> During any change of state the temperature does not move: the energy goes into breaking or making bonds, not into speeding the particles up.

3 Thermal transfer

Conduction and convection



conduction *热传导: particles pass energy*



convection *对流: hot fluid rises*

Metals conduct well (free **electrons** 自由电子); convection needs a moving fluid, so not in solids.

Why metals conduct, and water does not

In a metal	Free (delocalised) **electrons** 电子 carry energy quickly through the whole solid, so metals are good **thermal conductors** 导热体.
In a non-metal	Only vibrations pass energy from particle to particle – much slower, so wood, plastic and air are insulators.
Specific heat capacity	Water needs a lot of energy to warm up and **cools down** 冷却 slowly, which is why it is used in heating systems and why the sea moderates a coastal climate.

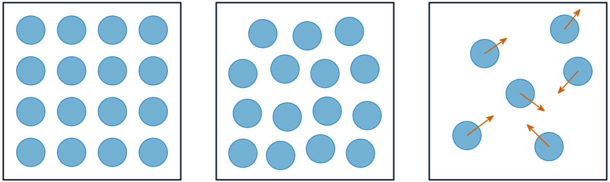
> Conduction needs particles in contact; convection needs a fluid that can move; radiation needs nothing at all.

Radiation

Thermal radiation 热辐射 is **infrared** 红外线 – it needs no material and crosses space.

> Dull black surfaces are good emitters and absorbers; shiny white ones reflect.

The kinetic particle model 分子动理论



solid
fixed pattern,
vibrate in place

liquid
close, no pattern,
slide past

gas
far apart,
fast and random

> The same particles in three states: fixed and ordered in a solid, close but disordered in a liquid, far apart and fast in a gas

Radiation, continued

dull, black surface
good emitter

shiny, white surface
poor emitter

> A dull black surface emits (and absorbs) infrared much better than a shiny, white one

The three ways thermal energy moves, and expansion

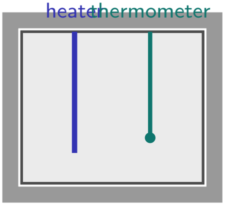
the direction	thermal energy always moves from hotter places to colder ones
conduction	through a solid, by vibrating particles and free electrons – metals are best
thermal insulators 热绝缘体	materials that conduct badly – air, wood and plastic
convection	in a fluid: warmed fluid expands, becomes less dense, and rises
radiation	infrared, needing no medium – emitted best by dull black surfaces, reflected by shiny white ones
thermal expansion 热膨胀	gaps between railway lines, bridges on rollers, and a tight metal lid loosened under hot water

Only radiation crosses a vacuum, which is why a vacuum flask defeats the other two and then silvers its walls to defeat the third.

Internal energy and specific heat capacity

Boiling water: internal energy rises with temperature; specific heat capacity is energy per kg per °C

Measuring specific heat capacity



metal block, mass m, wrapped in insulation

1. a metal block with two holes: an electric **heater** 加热器 and a **thermometer** 温度计
2. measure the mass m; note the starting temperature
3. heat for a time t, recording I and V: energy $E = IVt$ (or read a joulemeter)
4. record the rise $\Delta\theta$, then $c = \dfrac{E}{m\,\Delta\theta}$

For a liquid, heat a known mass in a container and stir it. Wrap block or container in **insulating material** 隔热材料 so less energy escapes.

Experiments: conductors and convection

Which solids conduct best?

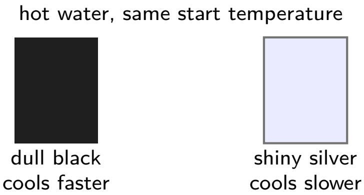
- rods of copper, iron, glass and wood, a drawing pin waxed to one end of each
- heat the other ends equally
- the pin drops first from copper, then iron, last (or never) from glass and wood

Metals win because free electrons (**delocalised electrons** 自由电子) carry the energy. Gases and most liquids conduct badly: particles far apart, no **lattice** 晶格, no free electrons.

Seeing convection

- drop a crystal of **potassium permanganate** 高锰酸钾 into water and heat gently below it
- a coloured stream rises above the heat, spreads across the top and sinks at the sides
- in air: a candle under one chimney of a smoke box pulls smoke down the other chimney and up over the flame

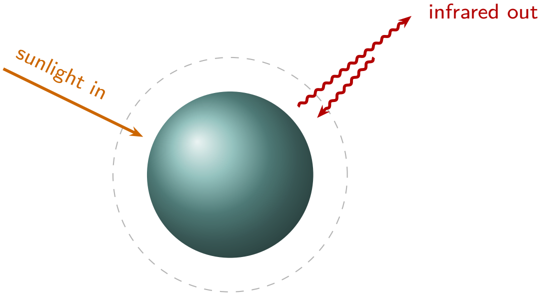
Experiments: emitters and absorbers



- **emitters**: two cans of hot water, one dull black and one shiny; the black can cools faster
- **absorbers**: the same cans, cold, at equal distances from a heater; the black can warms faster
- a **Leslie cube** 莱斯利立方体 has one finish on each face and shows the same thing

> Absorbs faster than it emits: warms. Emits faster: cools. Equal rates: steady.

The Earth's temperature



atmosphere sends part of the infrared back

- the Earth absorbs radiation from the Sun and emits infrared into space
- average temperature stays constant only while the two rates are equal
- gases in the **atmosphere** 大气 (carbon dioxide) absorb some emitted infrared and send part back down: more of them, warmer Earth
- clouds and ice reflect sunlight: less ice, more absorbed, warmer still

Everyday examples of the three transfers

Kitchen pan	metal base conducts energy fast into the food; a plastic or wooden handle is an insulator, so you can hold it
Radiator	a **radiator** 散热器 warms a room by convection: warm air rises, cooler air flows in to replace it
Fire	you feel a fire's radiation on your face at once; the air between is a poor conductor
Vacuum flask	a **vacuum flask** 保温瓶 stops all three: the vacuum stops conduction and convection, shiny surfaces stop radiation

Exam tips

- In the **kinetic particle model**, heating a gas makes its particles move faster and hit the walls harder and more often, so the pressure rises. The particles themselves do not get bigger.
- **Evaporation** happens only at the surface and at any temperature; **boiling** happens throughout the liquid at one fixed temperature. Evaporation cools the liquid left behind, because the fastest particles escape.
- During **melting** and **boiling** the temperature stays constant even though energy is still being supplied – that energy breaks the forces between particles.
- For **specific heat capacity** use $\Delta E = mc\Delta\theta$, where $\Delta\theta$ is the *change* in temperature, not the final temperature.
- Dull black surfaces are the best **emitters and absorbers** of infrared; shiny, light surfaces are the best reflectors. **Convection** needs a fluid to flow, so it cannot happen in a solid.

4 Recap

Topic 2 – key takeaways

1 Particles

temperature = average kinetic energy

2 Gas law

pV = constant at constant temperature

3 Heating

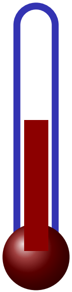
$\Delta E = mc\Delta\theta$; state changes stay flat

4 Transfer

conduction, convection, radiation

Check yourself

1. Convert $25°\mathrm{C}$ to kelvin.
2. Halve a gas's volume – what happens to its pressure?
3. Why does evaporation cool a liquid?
4. Which surface is the best emitter of infrared?



Answers **1.** $298\,\mathrm{K}$ **2.** it doubles **3.** the fastest particles leave **4.** dull black