

Thermal Physics

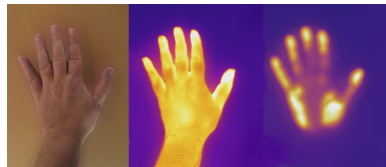
IGCSE Physics ■ Topic 2

IGCSE Physics



What we will cover

- 1 States of matter
- 2 The kinetic particle model
- 3 Specific heat capacity
- 4 Changes of state
- 5 Conduction convection radiation
- 6 Recap



1

States and the particle model

States of matter

solid 固体

regular; vibrate
about fixed positions

liquid 液体

close; can slide – take
the container's shape

gas 气体

far apart, fast;
fill the container

Temperature and the particle model

All matter is moving **particles** 粒子.

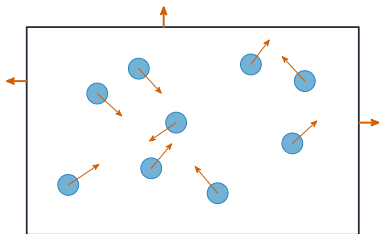
Temperature 温度 measures the **average kinetic energy** of the particles.

Lowest possible: **absolute zero** 绝对零度,
 -273°C .

$$T(\text{K}) = \theta(^{\circ}\text{C}) + 273.$$



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:

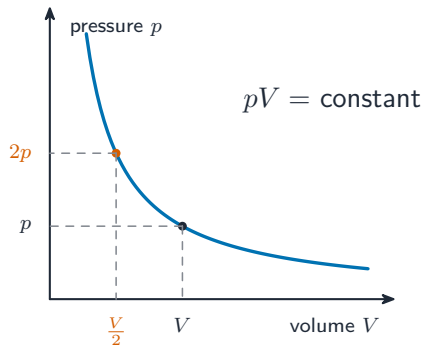
$$pV = \text{constant.}$$

$$200 \text{ cm}^3 \text{ at } 100 \text{ kPa} \rightarrow 50 \text{ cm}^3$$

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

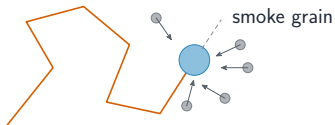
The gas pressure is the total force of countless particle hits on each unit area of the wall

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

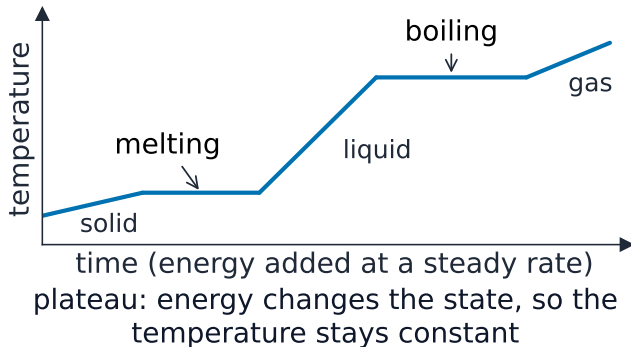
Heated matter expands (gases most). **Specific heat capacity** 比热容:

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

2.0 kg **water**, 20 → 70°C,
 $c = 4200$

$$\Delta E = mc\Delta\theta = 420 \text{ kJ}$$

Changes of state



- **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

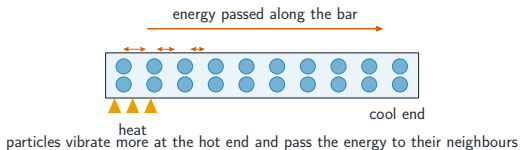
Solidification 凝固: liquid $\rightarrow$ solid – the reverse of melting, at the same temperature.

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

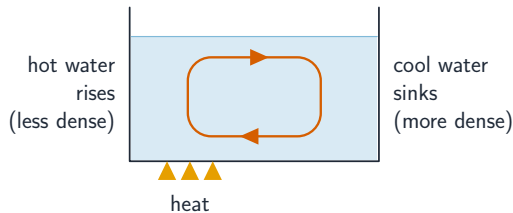
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Thermal transfer

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.

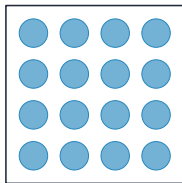
Radiation



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

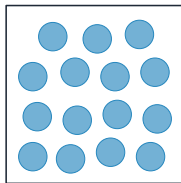
Dull black surfaces are good **emitters and absorbers**; shiny white ones reflect.

The kinetic particle model 分子动理论



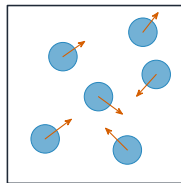
solid

fixed pattern,
vibrate in place



liquid

close, no pattern,
slide past



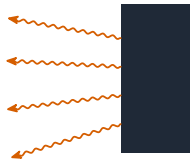
gas

far apart,
fast and random

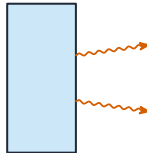
The same particles in three states: fixed and ordered in a solid, close but disordered in a liquid, far apart and fast in a gas

Dull black and shiny white surfaces

infrared



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

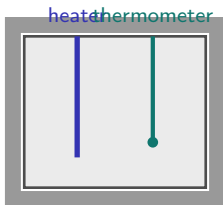
Only radiation crosses a vacuum, which is why a vacuum flask defeats the other two and then silvers its walls to defeat the third.

Internal energy and specific heat capacity



Boiling water: internal energy rises with temperature; specific heat capacity is energy per kg per $^{\circ}\text{C}$

Measuring specific heat capacity



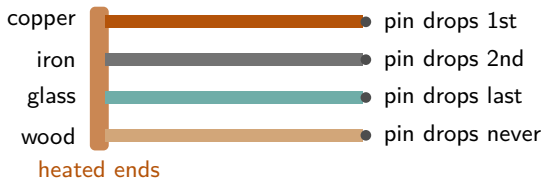
metal block, mass m , wrapped in insulation

- 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 $c = \frac{E}{m\Delta\theta}$

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?

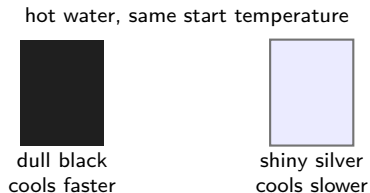


Waxed drawing pin on each rod; ends heated equally. Metals win: **delocalised electrons** 自由电子 (free electrons) carry the energy. Gases and most liquids conduct badly: particles far apart, no **lattice** 晶格.

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

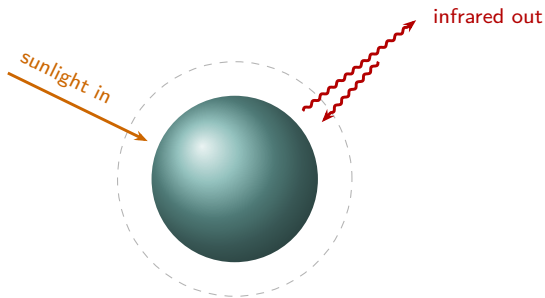
Experiments: emitters and absorbers



- **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.

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Recap

Topic 2 – key takeaways

1

Particles

temperature = average kinetic energy

2

Gas law

$pV = \text{constant}$ at constant temperature

3

Heating

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

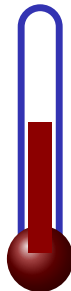
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Transfer

conduction, convection, radiation

Check yourself

- 1 Convert 25°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 K 2. it doubles 3. the fastest particles leave 4. dull black