

Thermal Physics

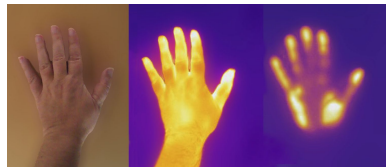
IGCSE Physics ■ Topic 2

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





States of matter

solid

regular; vibrate
about fixed positions

liquid

close; can slide – take
the container's shape

gas

far apart, fast;
fill the container

Temperature and the particle model

All matter is moving **particles** .

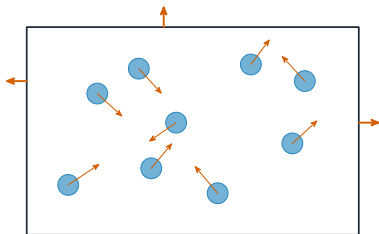
Temperature measures the **average kinetic energy** of the particles.

Lowest possible: **absolute zero** , -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:

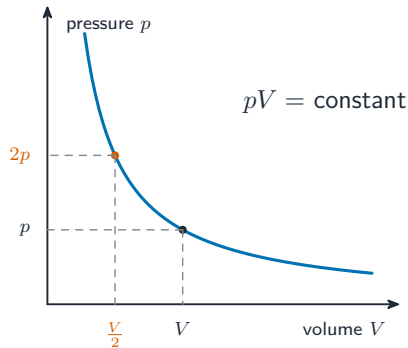
$$pV = \text{constant.}$$

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

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

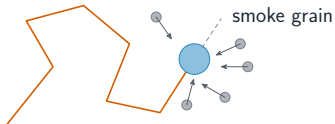
The gas pressure is the total force of countless particle hits on each unit area of the wall

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 is strong evidence for the particle model.



Thermal expansion and heat capacity



cool: a gap is left for expansion



hot: the rails expand and the gap closes

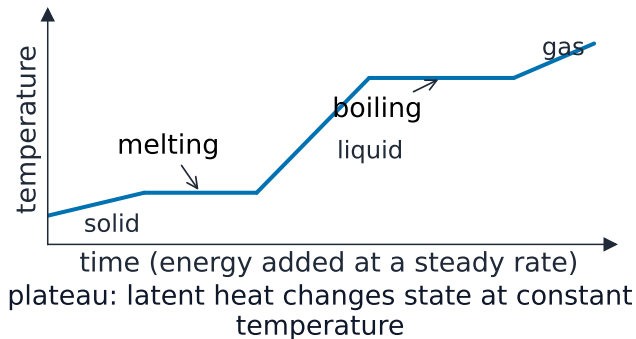
Heated matter expands (gases most). **Specific heat capacity** :

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

2.0 kg **water**, $20 \rightarrow 70^\circ\text{C}$, $c = 4200$

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

Changes of state



- **melting /boiling** – temperature **stays flat** while the state changes
- **evaporation** – 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 : gas $\rightarrow$ liquid, as particles slow enough for the attractions to hold them.

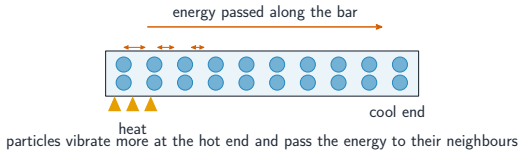
Solidification

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

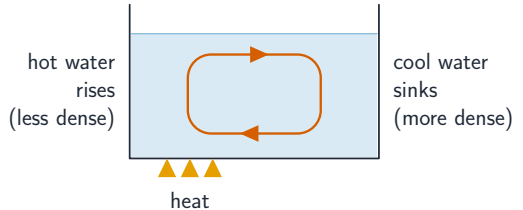
During any change of state the temperature does not move: the energy goes into breaking or making bonds, not into speeding the particles up.



Conduction and convection



***conduction** : particles pass energy*



***convection** : hot fluid rises*

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

Why metals conduct, and water does not

In a metal

Free (delocalised) **electrons** carry energy quickly through the whole solid, so metals are good **thermal conductors** .

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** 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.

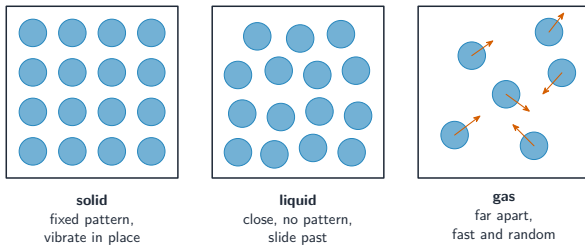
Radiation



Thermal radiation is **infrared** – it needs **no material** and crosses space.

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

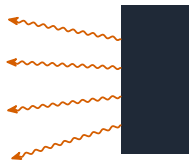
The kinetic particle model



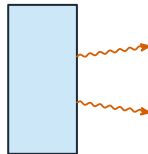
The same particles in three states: fixed and ordered in a solid, close but disordered in a liquid, far apart and fast in a gas

Radiation, continued

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

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

gaps between railway lines, bridges on rollers, and a tight metal lid loosened under hot water

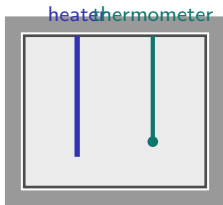
Only radiation crosses a vacuum, which is why a vacuum flask defeats the other two and then silvers its walls to defeat the third.

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** and a **thermometer**
- 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** 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**) carry the energy. Gases and most liquids conduct badly: particles far apart, no **lattice**, no free electrons.

Seeing convection

- drop a crystal of **potassium permanganate** 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

hot water, same start temperature



dull black
cools faster

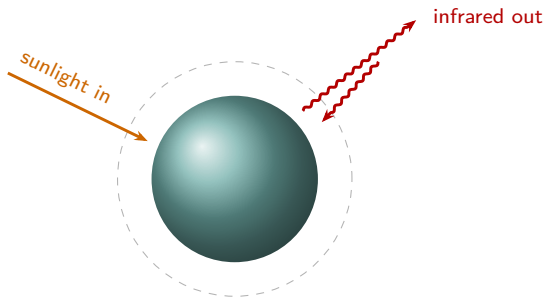


shiny silver
cools slower

- **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** 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** (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** 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** 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.



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

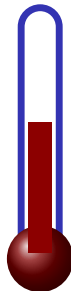
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Transfer

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