IGCSE PHYSICS 0625 · CHAPTER 6 NOTES · ~13 MIN READ

Thermal physics

Particles explain everything here: states of matter, gas pressure, expansion, melting and boiling, and the three ways heat travels.

Particle model | Changes of state | Brownian motion | Absolute zero | Gas pressure & pV = constant | Thermal expansion | Specific heat capacity | Evaporation

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- Solids vibrate in place, liquids slide past each other, gases fly about freely.
- **Higher temperature = faster particles.** Absolute zero (−273 °C = 0 K) is where they have the least energy. **T = θ + 273**.
- Gas pressure is caused by particles **colliding with the walls**. EXT For a fixed mass of gas at constant temperature, **pV = constant**.
- Heat travels by **conduction** (solids), **convection** (fluids) and **radiation** (no particles needed).
- Melting and boiling take in energy **without changing the temperature**. EXT **ΔE = mcΔθ**.

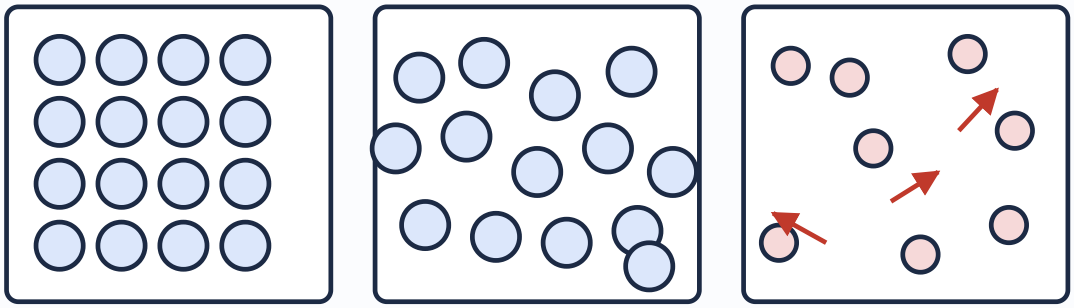
BY THE END YOU CAN

- Draw particle diagrams and explain the properties of solids, liquids and gases.
- Explain the flat parts of a heating curve and Brownian motion.
- Explain gas pressure and use T = θ + 273 (and pV = constant EXT).
- Explain thermal expansion, evaporation, and compare evaporation with boiling. EXT
- Use ΔE = mcΔθ and describe how to measure c. EXT
- Describe and explain conduction, convection and radiation, and how a vacuum flask works.

Riyaz Sir

1 The particle model

Solids, liquids and gases



SOLID
fixed pattern,
vibrate on the spot

LIQUID
close but random,
slide past each other

GAS
far apart, fast,
random directions

The same particles in three states. Add energy and the particles move faster and further apart.

	Solid	Liquid	Gas
shape	fixed	takes the shape of the container	fills the container
volume	fixed	fixed	fills the container
spacing	touching, regular pattern	touching, random	far apart
movement	vibrate on the spot	slide past each other	fast, random, in all directions
forces between particles	strong	weaker	almost none
compressed?	no	hardly	easily

- EXT A solid keeps its shape because strong forces hold the particles in fixed positions. A gas is easy to squash because its particles are far apart, with empty space between them.

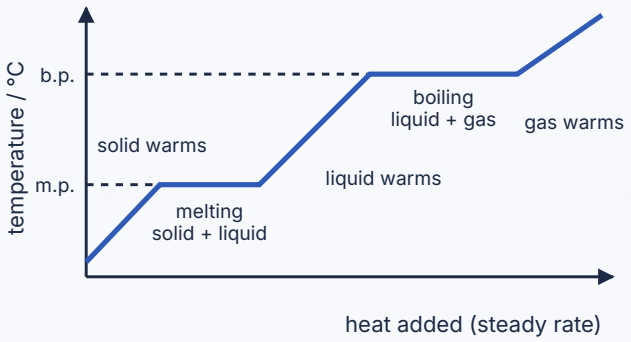
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Changes of state

- **Melting** (solid → liquid), **freezing** (liquid → solid), **boiling** and **evaporation** (liquid → gas), **condensation** (gas → liquid).
- Water melts and freezes at **0 °C** and boils at **100 °C** at standard pressure.
- These are physical changes: the same particles are still there, only their arrangement and motion change.
- **Condensation:** the gas particles lose energy and slow down, and the attractions pull them together. **Solidification:** the particles lose energy and settle into fixed positions.

COMMON MISTAKE

"The temperature rises during melting." It stays constant until all the solid has melted.



flat parts: energy changes the state, not the temperature

Heating a solid at a steady rate. The graph goes flat while the state changes: the energy is separating the particles, not speeding them up.

Evidence for particles: Brownian motion

- Look at smoke in air, or pollen grains in water, under a microscope: the visible specks jiggle randomly.
- The tiny fast-moving **molecules** of the air or water hit the speck unevenly from different sides, pushing it about at random.
- This is evidence that molecules exist, are in constant motion, and that the motion is random.
- EXT Atoms and molecules are invisible. The speck you see is a much bigger particle made of a huge number of atoms.

2 Temperature and gases

Temperature and absolute zero

- A higher temperature means the particles have more kinetic energy and move faster, on average.
- **Absolute zero is −273 °C (0 K)**, the lowest temperature possible, where particles have the least kinetic energy.

$$T = \theta + 273$$

T in kelvin (K), θ in degrees Celsius (°C). A change of 1 K equals a change of 1 °C

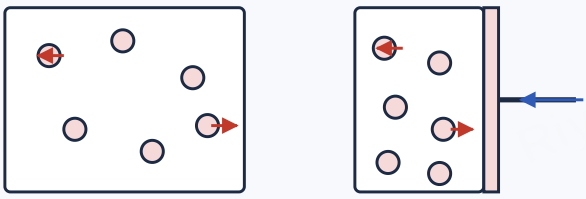
WORKED EXAMPLE

Convert 27 °C to kelvin and 350 K to °C.

1. $T = \theta + 273 = 27 + 273 =$ **300 K**
2. **$\theta = T - 273 = 350 - 273 = 77$ °C**

Gas pressure

gas pressure = particles hitting the walls



big volume: few collisions
→ **low pressure**

small volume: more collisions
→ **high pressure**

at constant temperature p × V = constant

Squeeze the gas into a smaller space and the particles hit the walls more often, so the pressure goes up.

- Each particle hits a wall and bounces back, giving a tiny force. Billions of hits a second add up to a steady **pressure** (force on each unit of area).
- **Heat a gas in a sealed, rigid container:** the particles move faster, so they hit the walls **harder and more often**, and the pressure rises.
- **Squash a gas into a smaller volume (same temperature):** the same particles hit the walls **more often**, so the pressure rises.

EXT $p V = \text{constant}$

for a fixed mass of gas at constant temperature, $p_1V_1 = p_2V_2$

WORKED EXAMPLE

EXT **A gas at 100 kPa has a volume of 6.0 litres. It is squeezed to 2.0 litres at constant temperature. Find the new pressure.**

1. $p_1V_1 = p_2V_2$
2. $100 \times 6.0 = p_2 \times 2.0$
3. **$p_2 = 600 \div 2.0 = 300$ kPa**

- EXT A graph of p against V is a curve that falls as V rises; a graph of p against 1 ÷ V is a straight line through the origin.

COMMON MISTAKE

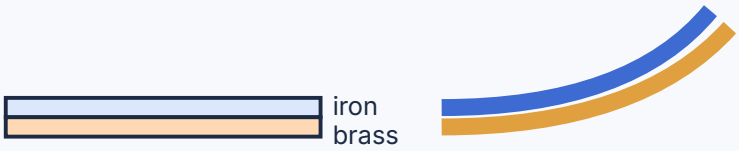
"The pressure rises because the particles expand or get hotter." Say that they hit the walls harder and more often.

3 Expansion and specific heat capacity

Thermal expansion

- Solids, liquids and gases **expand** when heated. Gases expand most and solids least.
- The particles do not get bigger — they move further apart.
- EXT Gas particles are far apart and free to move, so they spread a lot. In solids, strong forces hold the particles together, so the expansion is small.

cold: straight **heated: bends**



brass expands MORE than iron, so the strip curves with the brass on the outside of the bend

used in thermostats: it bends away and breaks the circuit when it gets too hot

A bimetallic strip. The two metals expand by different amounts, so the strip bends. This is used in thermostats and fire alarms.

- Consequences: gaps are left in bridges and railway lines; overhead cables sag in hot weather; the liquid in a thermometer expands up the tube.

Specific heat capacity

EXTENDED

Specific heat capacity (c) — the energy needed to raise the temperature of 1 kg of a substance by 1 °C.

EXT $\Delta E = m\,c\,\Delta\theta$

$c = \frac{\Delta E}{m\,\Delta\theta}$ in J/(kg °C). Water: about 4200 J/(kg °C)

WORKED EXAMPLE

EXT **How much energy is needed to heat 2.0 kg of water from 20 °C to 80 °C? (c = 4200 J/(kg °C))**

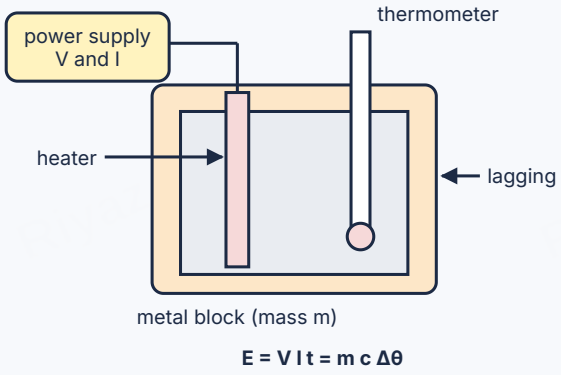
1. $\Delta\theta = 80 - 20 = 60$ °C
2. $\Delta E = mc\Delta\theta = 2.0 \times 4200 \times 60$
3. **= 504 000 J (504 kJ)**

- **Method:** measure the mass m, record the start temperature, switch on the heater for a time t while noting V and I, then record the highest temperature.
- Energy supplied $\Delta E = V\,I\,t$, so **$c = VIt \div (m\Delta\theta)$**.
- Heat loss means $\Delta\theta$ is smaller than it should be, so the value of c comes out **too big**. Wrapping the block in lagging reduces this.

WORKED EXAMPLE

EXT **A 1.0 kg aluminium block is heated by a 50 W heater for 3.0 minutes. Its temperature rises by 10 °C. Find c.**

1. Energy = Pt = 50 × 180 = 9000 J
2. $c = \Delta E \div (m\Delta\theta) = 9000 \div (1.0 \times 10)$
3. **= 900 J/(kg °C)**



Measuring c. The heater supplies $\Delta E = V\,I\,t$, and the thermometer shows the temperature rise. Lagging reduces heat loss.

4 Evaporation and boiling

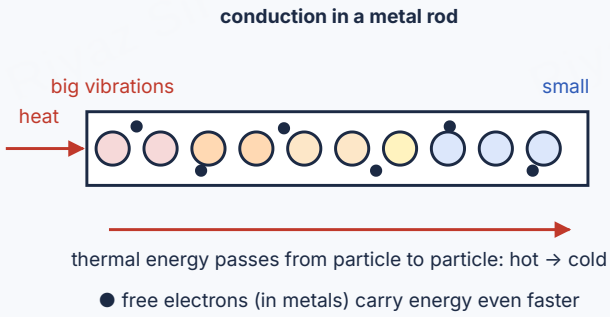
Evaporation and boiling

	Evaporation	Boiling
where	at the surface only	throughout the liquid (bubbles)
temperature	any temperature below the boiling point	only at the boiling point
speed	slow	fast

- **Evaporation** is the escape of the most energetic particles from the surface of a liquid.
- The particles left behind have a lower average kinetic energy, so the liquid **cools**. That is why sweating cools you.
- EXT Evaporation is faster with a **higher temperature**, a **larger surface area** and **moving air** (it carries the escaped particles away).
- EXT A drop of alcohol on your skin evaporates and takes energy from the skin, so the skin feels cold.

5 Transfer of thermal energy

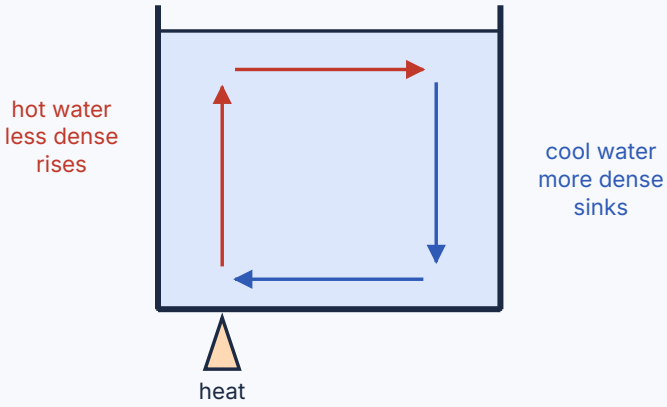
Conduction



Heat one end of a rod. Particles at the hot end vibrate more and pass energy on to their neighbours. In metals, free electrons carry energy even faster.

- Conduction is the main method in **solids**. Metals are good conductors. Plastic, wood, glass, liquids and gases are poor conductors (insulators).
- EXT In non-metals the energy passes from one vibrating particle to the next. In metals **free electrons** also carry energy through the metal, which is why metals are the best conductors.
- EXT Liquids and gases are poor conductors because their particles are further apart, so collisions are less frequent.
- **Experiment:** fix drawing pins with wax along rods of different metals and heat one end. The pin on the best conductor drops first.

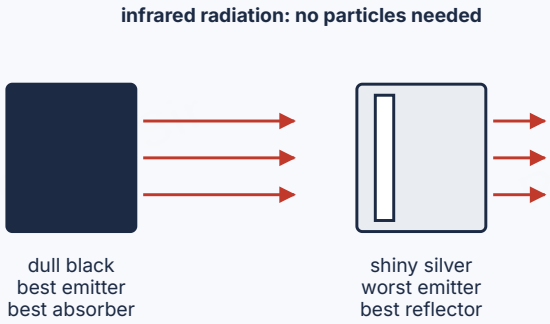
Convection



Hot fluid expands and becomes less dense, so it rises. Cool fluid is more dense and sinks. This sets up a convection current.

- Convection happens only in **fluids** (liquids and gases) because the particles must be free to move.
- Examples: a heater warming a room; why the heating element is at the bottom of a kettle; why a freezer compartment is at the top of a fridge.

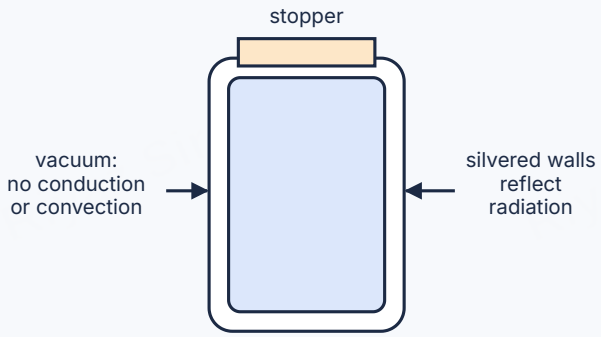
Radiation



Infrared radiation needs no particles. Dull black surfaces are the best emitters and best absorbers. Shiny silver surfaces are the worst emitters and the best reflectors.

- All objects emit infrared radiation, and the hotter the object, the more it emits. Radiation can cross a vacuum — this is how the Sun's heat reaches Earth.
- EXT The emission rate also depends on the **surface area**.
- EXT **Experiment:** fill two identical cans, one dull black and one shiny, with hot water. The black can cools faster, so it is the better emitter. To test absorbers, put black and shiny plates the same distance from a heater and see which warms first.
- EXT For a steady temperature, energy in = energy out. If energy in is bigger than energy out, the temperature rises. Earth's temperature depends on this balance between the radiation it absorbs and the radiation it emits (see chemistry of the environment).

Putting it together



a vacuum flask stops all three ways of losing heat

A vacuum flask stops all three: the vacuum blocks conduction and convection, and the silvered walls reflect radiation.

- Everyday uses: pans have metal bases (conduction) and plastic handles (insulators); a radiator warms a whole room by convection currents; cavity-wall insulation traps air in small pockets where it cannot circulate.
- EXT A coal fire warms you by **radiation** (you feel it directly), and warms the room by **convection** (hot air rises) and some conduction. In a car radiator, hot coolant passes through thin metal fins that conduct and radiate heat, and moving air takes it away by convection.

6 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Which state has particles vibrating in fixed positions?
2. Convert 300 K to °C.
3. Why does the temperature stay constant while ice melts?
4. Why does a gas in a sealed container have a higher pressure when heated?
5. Which method of heat transfer works through a vacuum?
6. Why is the heating element in a kettle near the bottom?

EXAM-STYLE

7. EXT 0.40 kg of water cools from 90 °C to 40 °C. How much energy does it release? (c = 4200 J/(kg °C))
8. EXT A gas has a pressure of 2.0×10^5 Pa and volume 0.30 m³. It is compressed to 0.12 m³ at constant temperature. Find the new pressure.
9. Explain why sweating cools the body. [3]
10. EXT Explain why metals are better conductors of heat than plastics. [2]
11. Describe how a vacuum flask keeps a hot drink hot. [3]

Show answers

1. solid
2. 300 − 273 = 27 °C
3. The energy goes into overcoming the forces between the particles, not into raising their kinetic energy.
4. The particles move faster, so they hit the walls harder and more often.
5. radiation
6. Hot water rises and cold water sinks, so convection currents heat all the water.
7. $\Delta\theta = 50$ °C
   $\Delta E = 0.40 \times 4200 \times 50 = 84\,000$ J
8. $p_1V_1 = p_2V_2$
   $2.0 \times 10^5 \times 0.30 = p_2 \times 0.12$
   $p_2 = 5.0 \times 10^5$ Pa
9. The most energetic particles escape from the surface of the sweat
   so the average kinetic energy of the particles left behind falls
   energy is taken from the skin, so it cools
10. In metals free electrons carry energy through the material
    as well as the vibrations passing from particle to particle
11. The vacuum between the walls stops conduction and convection
    the silvered surfaces reflect radiation back
    the stopper is an insulator

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