

Particle model of matter

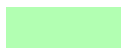
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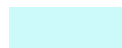
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Density

- the mass per unit volume of a material.

Define Change of state

- a physical change between solid, liquid and gas (melting, freezing, boiling, evaporating, condensing, subliming).

Define Internal energy

- the total kinetic energy and potential energy of all the particles (atoms and molecules) that make up a system.

Define Latent heat

- the energy needed for a substance to change state.

Define Specific latent heat of fusion

- specific latent heat for the change of state from solid to liquid.

Define Pressure

- the force acting normal (at right angles) to a surface, per unit area of that surface.

Define Particle model

- a model in which matter is made of small particles whose arrangement and motion explain the properties of solids, liquids and gases.

Define Physical change

- a change in which no new substance is made, so the material recovers its original properties if the change is reversed.

Define Specific heat capacity

- the amount of energy required to raise the temperature of one kilogram of a substance by one degree Celsius.

Define Specific latent heat

- the amount of energy required to change the state of one kilogram of a substance with no change in temperature.

Define Specific latent heat of vaporisation

- specific latent heat for the change of state from liquid to vapour.

Define Work

- the transfer of energy by a force.

3.1 Changes of state and the particle model**3.1.1 Density of materials**

State	Arrangement	Movement	Density	Shape / volume
Solid	Regular, touching, tightly packed	Vibrate about fixed positions	Highest	Fixed shape and volume
Liquid	Close together and touching, but random	Move around each other	Slightly below the solid	Takes container's shape, fixed volume
Gas	Far apart, random, mostly empty space	Constant random motion, fast, all directions	Very much lower	Fills its container

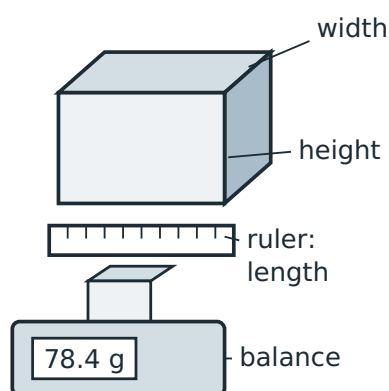
- You should be able to **draw or recognise simple diagrams** of these three arrangements.
- **Explaining the density difference:** in a solid or liquid the particles are touching, so a given volume holds a very large number of particles — high density. In a gas they are far apart, so the same volume holds far fewer — much lower density. A solid is usually slightly denser than its liquid because its particles are packed in a regular, more efficient pattern.

Measuring the density of a regular solid, an irregular solid and a liquid

Required practical 5 — density = mass ÷ volume, $\rho = m / V$

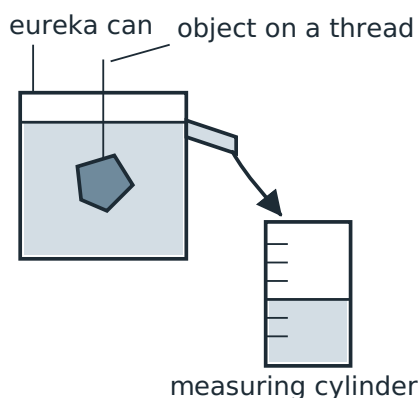
ρ in kg/m^3 (or g/cm^3) · m in kg (or g) · V in m^3 (or cm^3) · $1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$

A Regular solid



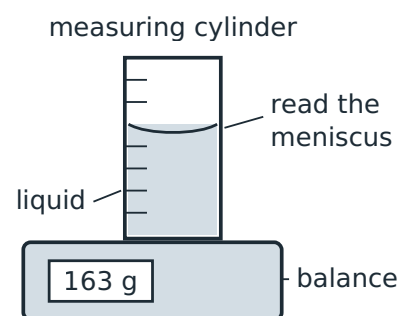
- find the mass on a balance
- measure the length, width and height with a ruler or callipers
- volume = $l \times w \times h$
- density = mass ÷ volume

B Irregular solid



- find the mass on a balance
- fill the can up to the spout, then lower the object in gently
- the water pushed out is collected in a measuring cylinder: it equals the volume of the object

C Liquid



- find the mass of the empty measuring cylinder
- pour in the liquid, find the new mass
- mass of liquid = new mass – empty mass
- read the volume in cm^3 at the bottom of the meniscus, at eye level

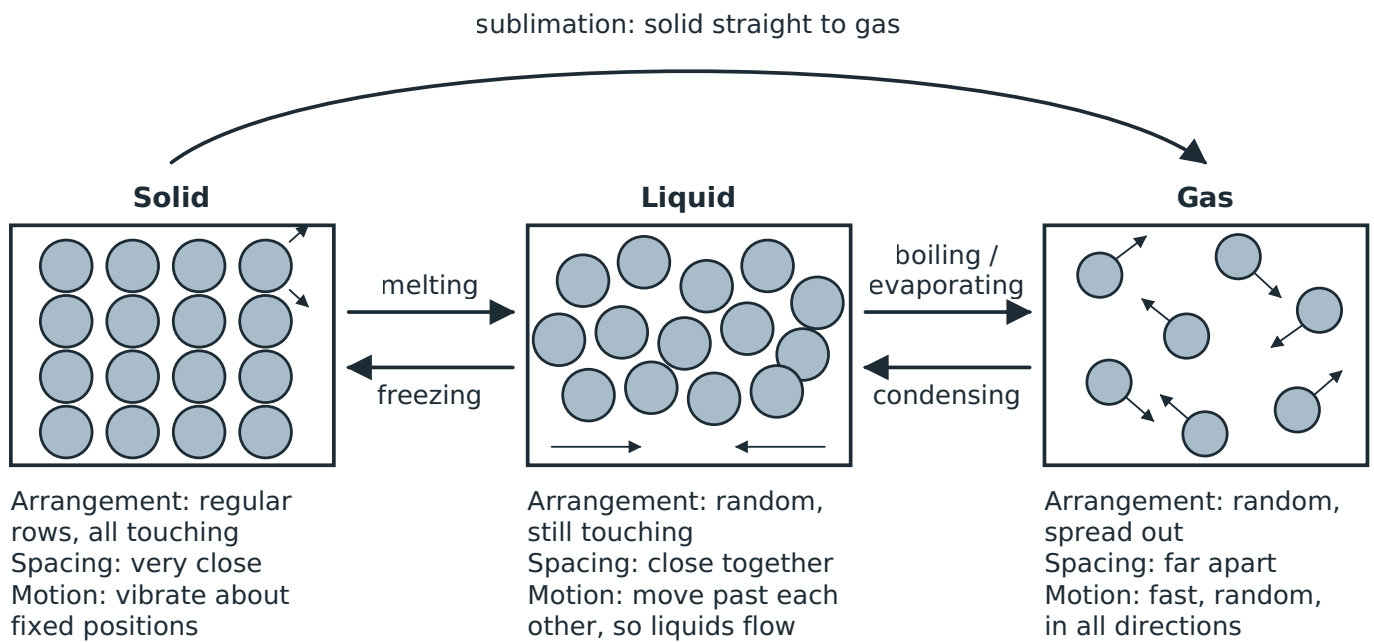
WATCH OUT

Particles do **not** get bigger, smaller or heavier when a substance is heated or changes state. Only their **spacing, arrangement and speed** change. Density changes because the **volume** changes, not the mass.

3.1.2 Changes of state

- When substances melt, freeze, boil, evaporate, condense or sublime, the number of particles does not change, so **mass is conserved**.
- Changes of state are **physical changes**, which differ from **chemical changes** because the material recovers its original properties if the change is reversed. No new substance is made.

The particle model of solids, liquids and gases, and the changes of state



A change of state is a physical change, not a chemical change — no new substance is made.
Mass is conserved: they are the same particles, just arranged and spaced differently.
Reverse the change and the material recovers its original properties.
The spacing changes, so the states have very different densities — a gas is least dense.

3.2 Internal energy and energy transfers

3.2.1 Internal energy

- Energy is stored inside a system by the **particles (atoms and molecules)** that make it up: this is **internal energy**.
- **Internal energy** is the total kinetic energy and potential energy of all the particles in the system. The kinetic part depends on how fast particles move or vibrate; the potential part depends on their separation.
- Heating changes the energy stored within the system by increasing the energy of the particles. This either **raises the temperature** (kinetic energy rises) or **produces a change of state** (potential energy rises, temperature constant).

3.2.3 Changes of state and specific latent heat

- The energy needed for a substance to change state is **latent heat**. During a change of state the energy supplied changes the internal energy but not the temperature.
- **Specific latent heat of fusion** — solid to liquid. **Specific latent heat of vaporisation** — liquid to vapour.

ANALOGY

Internal energy is the total money held by a crowd. Kinetic energy is the cash in their pockets; potential energy is money tied up in savings. Temperature only reports the *average cash per pocket* — so you can pour energy into melting ice, filling up the "savings", while the temperature reading does not move.

3.2.2 Temperature changes in a system and specific heat capacity

- The temperature rise depends on the **mass** heated, the **type of material** and the **energy input**.
- **Specific heat capacity** = the energy required to raise the temperature of **one kilogram** of a substance by **one degree Celsius**. A high value (water, 4200 J/kg °C) means a lot of energy for a small temperature rise, and slow cooling.

ANALOGY

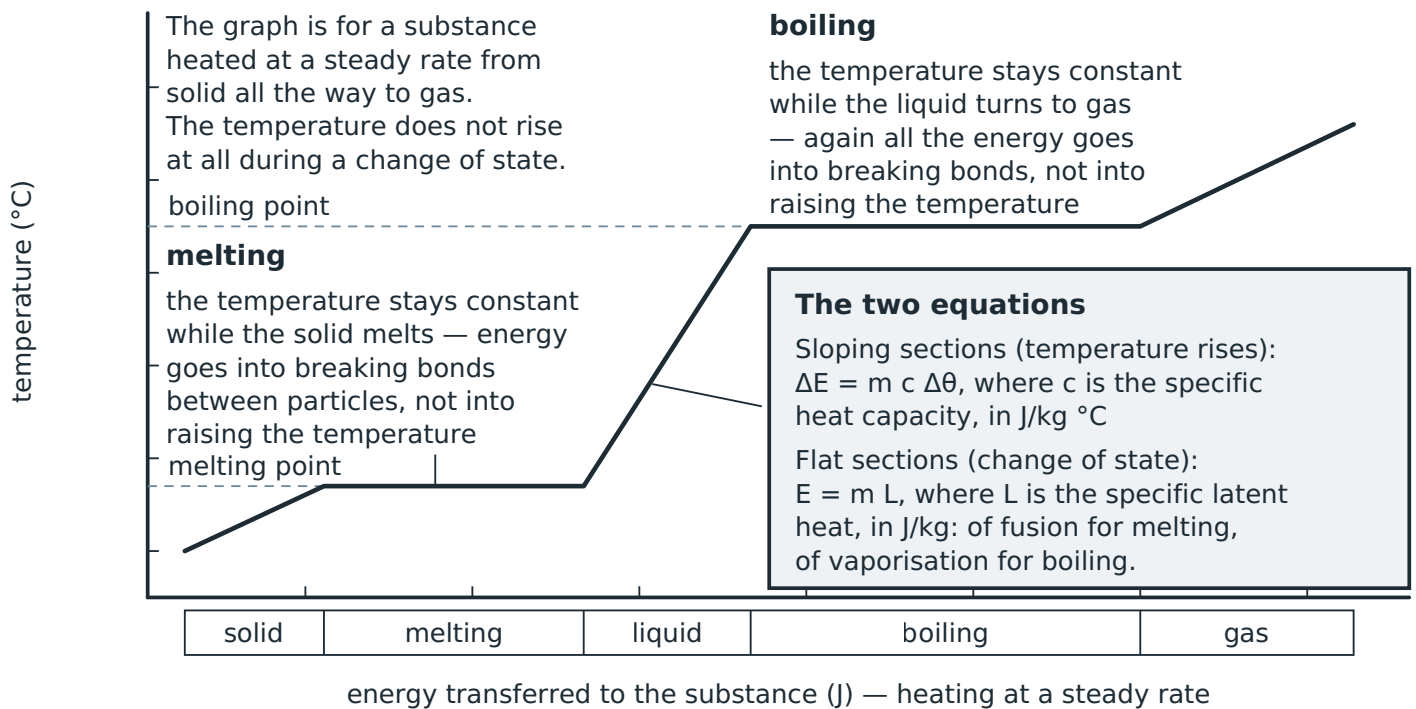
Latent heat is the queue at the door of a concert. While people are queuing, energy is being spent but nobody moves further inside — the "temperature" reading is flat. Only once everyone is through does the crowd move on again. The energy is not lost; it is stored as potential energy in pulling particles apart.

	Specific heat capacity, c	Specific latent heat, L
What changes	The temperature	The state
Energy per kg to...	raise the temperature by 1°C	change the state completely
Temperature during it	Rises or falls	Stays constant
Energy store	Kinetic energy of particles	Potential energy of particles
Equation / unit	$\Delta E = m c \Delta\theta$ / J/kg $^{\circ}\text{C}$	$E = m L$ / J/kg

Reading a heating or cooling graph (temperature against time or energy):

- **Sloping sections** — one state, **temperature changing**; use $\Delta E = m c \Delta\theta$. A steeper slope means a smaller specific heat capacity for the same heating power.
- **Flat sections** — a **change of state**. Energy is still supplied but is **breaking the forces between particles**, so the temperature does not change; use $E = m L$.
- The **first flat** is at the **melting point**, the **second** at the **boiling point**. The second is **longer** because separating particles completely needs far more energy.
- On a **cooling** graph the flat sections are freezing and condensing, with energy given out.

A heating curve: sloping sections and flat changes of state



WATCH OUT

Boiling water does not get hotter the longer you boil it. Once at 100°C all further energy goes into latent heat of vaporisation, so the temperature stays at 100°C until all the water has turned to steam.

3.3 Particle model and pressure

3.3.1 Particle motion in gases

- The molecules of a gas are in **constant random motion**, in all directions and at a range of speeds.
- **The temperature of the gas is related to the average kinetic energy of the molecules** — hotter means faster on average.
- Molecules **collide with the walls** of the container; each collision exerts a tiny force, and the total effect of billions per second is the **pressure**.
- Changing the temperature of a gas held at constant volume changes the pressure: hotter $\rightarrow$ faster molecules $\rightarrow$ collisions are **harder and more frequent** $\rightarrow$ **higher pressure**. Cooler $\rightarrow$ **lower pressure**.

ANALOGY

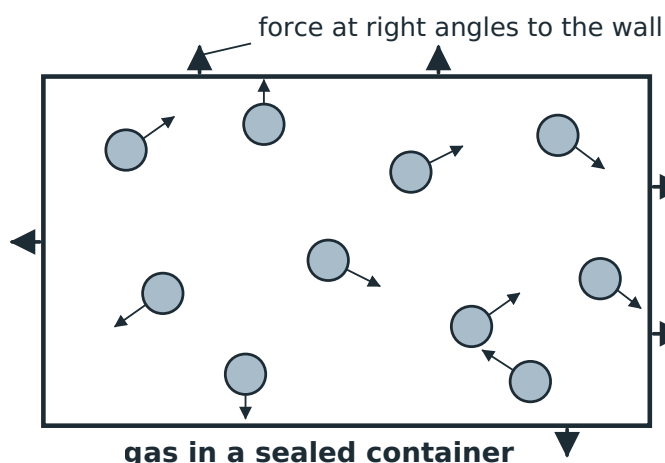
Gas pressure is hail on an umbrella. Each hailstone gives a tiny push; what you feel is the average of thousands of impacts. Heat the gas and the hailstones travel faster and arrive more often, so the push is bigger.

3.3.2 Pressure in gases **PHYSICS ONLY**

- **PHYSICS ONLY** A gas can be **compressed or expanded by pressure changes**. The pressure produces a net force at right angles to the wall of the container, or to any surface.
- **PHYSICS ONLY** Increasing the volume of a gas at constant temperature decreases its pressure: the molecules keep the **same average speed**, but have further to travel between collisions with the walls, so there are fewer collisions per second on each unit area and the pressure falls. Compressing it does the reverse.

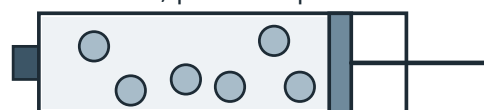
How molecular collisions produce gas pressure, and the effect of halving the volume

physics only



The molecules are in constant random motion. Each collision with a wall exerts a small force; together these forces give the pressure, which acts at right angles to the wall.

volume V , pressure p

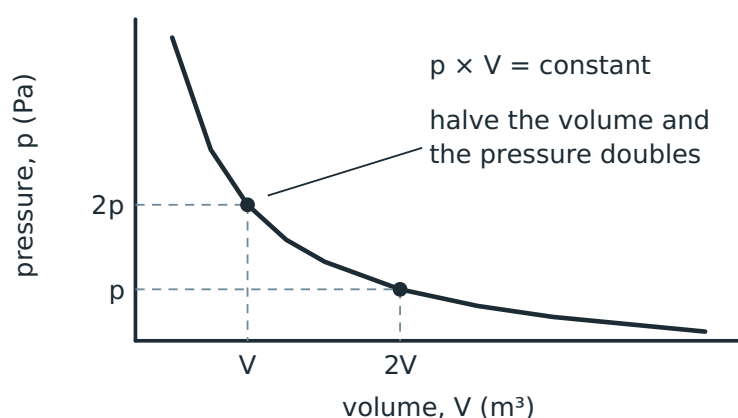


push the plunger in at constant temperature:



volume $V/2$, pressure $2p$

The same molecules hit the walls twice as often, so the pressure doubles. Temperature is unchanged, so the molecules are no faster.



Using $pV = \text{constant}$

For a fixed mass of gas held at a constant temperature: $p_1V_1 = p_2V_2$

Bigger volume $\rightarrow$ fewer collisions each second $\rightarrow$ lower pressure.

Heating a gas at constant volume makes the molecules faster, so the pressure goes up.

Higher tier: doing work on a gas (eg a bicycle pump) warms it up.

HIGHER TIER

3.3.3 Increasing the pressure of a gas **PHYSICS ONLY**

HT ONLY

- **PHYSICS ONLY HT ONLY** Work is the transfer of energy by a force.
- **PHYSICS ONLY HT ONLY** Doing work on a gas increases the internal energy of the gas and can cause an increase in its temperature.
- **PHYSICS ONLY HT ONLY** Example — a **bicycle pump**: pushing the handle applies a force that moves the piston, so work is done on the enclosed gas. Energy is transferred to the kinetic energy store of the molecules, so the average kinetic energy, and therefore the temperature, rises and the barrel feels warm.

NOTE

Where is fluid pressure? Pressure in liquids and gases ($p = F \div A$, $p = h\rho g$, atmospheric pressure, upthrust and floating) is **physics only** and the specification places it at 4.5.5, inside **Topic 5 Forces** — so it is assessed on **Paper 2**, not Paper 1. It is covered there, in section 5.5.