Cambridge IGCSE · Physics 0625 · Notes

Kinetic particle model of matter

Read online at **pastopic.com/cambridge/physics-0625/notes/kinetic-particle-model**

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Read first: **Pressure**

What you need to know

This topic explains solids, liquids and gases with one idea: everything is made of tiny particles that are always moving. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of it you should be able to:

1. **Know how solids, liquids and gases differ**: whether each has a fixed shape and a fixed volume, whether it can flow, and whether it can be squashed (compressed).
2. **Know the names of the changes of state**: melting, freezing (solidifying), boiling, evaporation and condensation. Changes straight from solid to gas or gas to solid are not needed.
3. **Describe the particles in a solid, a liquid and a gas**: how they are arranged, how far apart they are and how they move, and draw simple particle diagrams of each state.
4. **Link the motion of particles to temperature**: hotter means faster particles. There is a lowest possible temperature, **absolute zero** (-273 °C), where the particles have the least kinetic energy.
5. **Describe why a gas has a pressure**, and why that pressure changes, using the motion of its particles and their collisions with a surface.
6. **Know that the random jiggling of tiny specks** (such as smoke in air or pollen in water) is evidence for the particle model, and **explain this Brownian motion** as the result of random collisions between the specks and the particles of the gas or liquid.
7. **Describe, without numbers, what happens to the pressure of a fixed mass of gas** when its temperature changes at constant volume, and when its volume changes at constant temperature.
8. **Convert between kelvin and degrees Celsius** with $T\ (\text{in K}) = \theta\ (\text{in }^\circ\text{C}) + 273$.
9. **Extended only:** know that the forces and distances between the particles (atoms, molecules, ions and electrons), and how they move, decide the properties of solids, liquids and gases.
10. **Extended only:** explain gas pressure as the **forces** the particles exert when they collide with a surface, giving a **force per unit area**.
11. **Extended only:** know that tiny specks are pushed about by collisions with **light, fast-moving molecules**, and use the words **atoms** or **molecules** for these, keeping **particles** (or specks) for the much bigger things you see moving.
12. **Extended only:** recall and use $pV = \text{constant}$ for a fixed mass of gas at constant temperature, including its graph.

Understand it

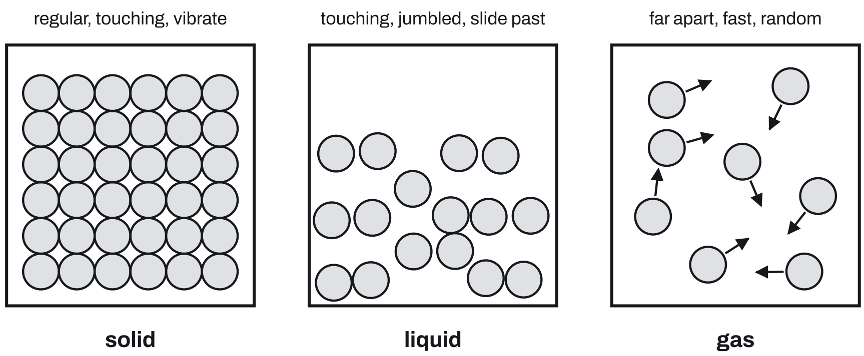
Everything is made of moving particles

Every substance is made of particles far too small to see: atoms, molecules or ions. The **kinetic particle model** says two things about them:

- they are **always moving** ("kinetic" means to do with motion), and they have energy in their kinetic store;
- there are **forces of attraction** between them, strong when the particles are close together and almost nothing when they are far apart.

Whether a substance is a solid, a liquid or a gas depends on the contest between these two: the attraction pulling the particles together and their motion shaking them apart.

Solids, liquids and gases



	Solid	Liquid	Gas
Arrangement	regular pattern (a lattice), in fixed positions	irregular (random), no fixed positions	random, spread through the whole container
Separation	very close, touching	close, mostly touching	far apart, lots of empty space
Motion	vibrate about fixed positions only	move around and slide over each other, randomly	move quickly and randomly in straight lines until they hit something
Forces between particles	strong	strong enough to keep them together	very weak (negligible)
Shape	fixed	takes the shape of the bottom of its container	fills the whole container
Volume	fixed	fixed	none of its own: fills whatever it is in
Flow	no	yes	yes

	Solid	Liquid	Gas
Compress it?	no	no (hardly at all)	yes, easily

These properties all come straight from the particles:

- **A solid keeps its shape** because strong forces hold each particle in place; it can only vibrate.
- **A liquid flows and takes the shape of its container** because the particles can move past each other, but it **keeps its volume** because they stay touching.
- **A gas can be compressed** because its particles are **far apart**: squeezing just reduces the empty space between them. In a liquid or solid the particles are **already touching**, so there is no space to squeeze out. The particles themselves never get smaller.
- **A gas fills its container** because the forces between its particles are too weak to hold them together.

When water boils, the steam takes up more than a thousand times the volume of the liquid it came from. There are the same number of particles, and each is the same size; they are just much further apart. So the same mass takes up a much bigger volume and the density falls.

Drawing particle diagrams. Draw circles of equal size. Solid: rows of touching circles in a neat grid. Liquid: circles mostly touching but jumbled, with a few small gaps, filling the bottom of the box. Gas: a few circles (the question may ask for at least 10), well spread out, none touching, randomly placed; arrows can show random directions.

Extended only. The particles here can be atoms, molecules, ions or (in metals) electrons. How strongly they attract, how far apart they are and how fast they move explains the properties in the table: strong forces and small distances make solids rigid; weaker hold and freedom to move make liquids flow; negligible forces and large distances let gases spread out and be compressed.

Changes of state

Change	Name
solid → liquid	melting
liquid → solid	freezing (solidifying)
liquid → gas, throughout the liquid, at the boiling point	boiling
liquid → gas, from the surface, below the boiling point	evaporation
gas → liquid	condensation

In each change the particles stay the same size and the same number; what changes is their arrangement, separation and motion. When ice **melts**, the particles break out of their regular pattern and start to move around each other, but stay close together. When steam **condenses**, the particles slow down and come together: afterwards they are **close together and slide over each other**, like any liquid. A puddle drying up or water disappearing from a dish is **evaporation**.

Temperature and the motion of particles

The higher the temperature, the faster the particles move, and the more kinetic energy they have on average. Heat a gas and its particles speed up; heat a solid and its particles vibrate more strongly about their positions. Cool a substance and its particles slow down.

Keep cooling, and the particles get slower and slower. There is a temperature where they have the **least possible kinetic energy**: they can't slow down any more, so nothing can be colder. This lowest possible temperature is **absolute zero**, -273 °C. (Absolute zero is about **kinetic** energy, nothing to do with gravitational potential energy or weight.)

The kelvin scale

The **kelvin** scale starts at absolute zero, so it has no negative temperatures. Its steps are the same size as Celsius degrees:

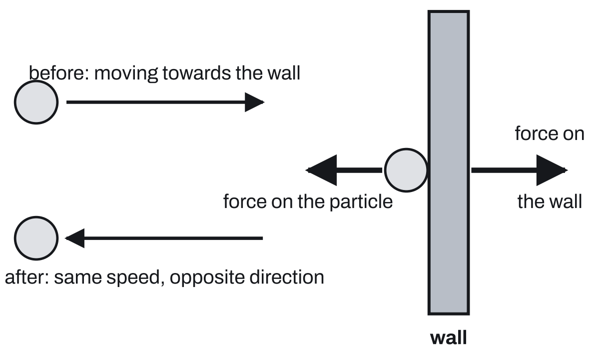
$$T\ (\text{in K}) = \theta\ (\text{in }^\circ\text{C}) + 273 \qquad \text{and} \qquad \theta\ (\text{in }^\circ\text{C}) = T\ (\text{in K}) - 273.$$

	°C	K
absolute zero	-273	0
pure ice melts	0	273
a warm room	20	293
pure water boils (standard atmospheric pressure)	100	373

Write kelvin as "K", not "°K". Because the steps are the same size, a **change** of temperature is the same number in both: a rise from 10 °C to 40 °C is a rise of 30 K. Water is liquid between 273 K and 373 K.

Why a gas has a pressure

The particles in a gas move fast in random directions. Every time one hits the wall of its container it **bounces off**, and in doing so it pushes on the wall. Each push is tiny, but there are enormous numbers of collisions every second on every part of the wall, so together they make a steady push over the whole surface. That push on each unit of area is the **pressure** of the gas. The particles also collide with each other, but those collisions are not what makes the pressure on the wall.



Extended only. When a particle bounces off the wall its velocity reverses, so its **momentum changes**. A change of momentum needs a force (force = change in momentum ÷ time), so the wall exerts a force on the particle, and the particle exerts an equal and opposite force on the wall. The total force from all the collisions, divided by the area of wall, is the pressure: $p = \frac{F}{A}$, a **force per unit area**. The particle's speed, and so its kinetic energy, is the same after bouncing as before; only its direction, and so its momentum, changes.

So the pressure of a gas goes up if the particles hit the walls **more often** (more collisions per second on each unit of area), or **harder** (they move faster, so each collision has a bigger change of momentum and a bigger force).

Changing the temperature at constant volume

Heat a gas in a **sealed rigid container** (a bottle, a can, a tyre whose volume doesn't change):

- the particles **move faster** (more kinetic energy);
- so they hit the walls **more often** and **harder** (with more force);
- so the **pressure increases**.

Cool it and everything reverses: slower particles, fewer and gentler collisions, lower pressure. The number of particles, their size, their mass and the average distance between them all stay the same, because the container's volume is fixed.

Changing the volume at constant temperature

Push a piston into a cylinder of gas **slowly** so the temperature stays the same:

- the temperature is the same, so the particles move at the **same speed**;
- but there is **less space**, so the particles are closer together and each part of the wall is hit **more often** (more collisions per second per unit area);
- so the **pressure increases**.

Pull the piston out and the pressure goes down, because the particles hit each unit of area less often. The particles don't move faster or slower, and they don't get bigger or smaller.

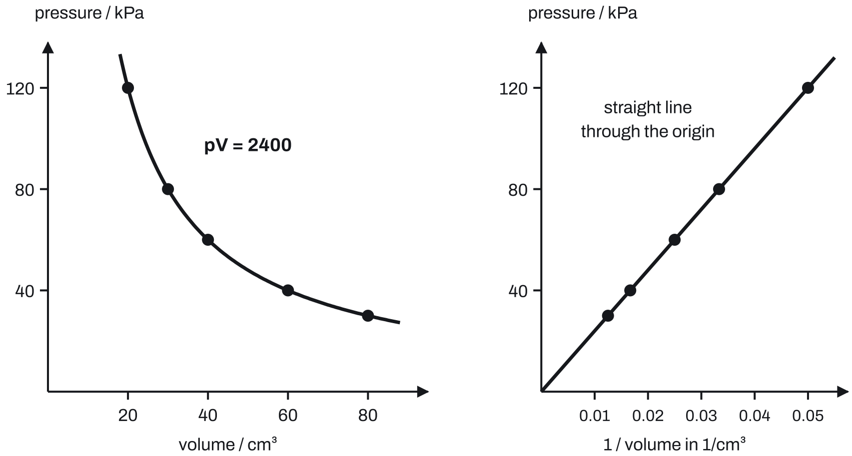
The same ideas explain everyday effects. The air in a car tyre warms up on a long journey, so its pressure rises. A bubble rising through water gets bigger, because the water pressure on it gets less. A sealed balloon held above a heater swells: the air inside gets hotter, the particles hit the rubber harder and more often, and the air expands until the pressure inside matches the pressure outside again.

pV = constant

Extended only. For a **fixed mass** of gas at **constant temperature**, halving the volume doubles the pressure, and doubling the volume halves it. Pressure is **inversely proportional** to volume:

$$pV = \text{constant} \qquad \text{so} \qquad p_1V_1 = p_2V_2.$$

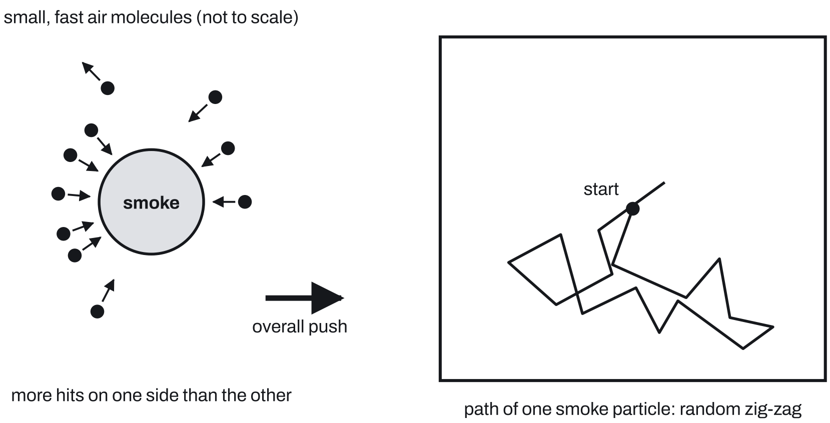
Squeeze 200 cm³ of gas at 100 kPa into 50 cm³ (a quarter of the volume) and the pressure becomes $\frac{100 \times 200}{50} = 400$ kPa (four times as much). Any units work, as long as both pressures use the same unit and both volumes use the same unit.



The graph of p against V is a **curve** that falls steeply and then levels off, getting closer to both axes but never touching them. It is not a straight line. Plot p against $\frac{1}{V}$ instead and you get a **straight line through the origin**. If a gas does not follow $pV = \text{constant}$, something else changed: the temperature went up or down, or gas leaked in or out.

Brownian motion: evidence for moving particles

Shine a bright light from the side into a small glass cell of air with a little smoke in it, and look through a microscope. The smoke particles show up as bright specks that **jiggle about in a random, zig-zag way**, never stopping. The same happens to pollen grains in water. This is **Brownian motion**.



path of one smoke particle: random zig-zag

The smoke particles are being hit, all the time, by the air molecules around them. The molecules are too small to see, and move fast in random directions. At any instant more of them happen to hit one side of a smoke particle than the other, so it gets an overall push and moves a little way. A moment later the push comes from a different direction. The path is a zig-zag of short straight lines of different lengths in random directions.

This is **evidence for the kinetic particle model**: something invisible must be hitting the specks, and it must be moving randomly and never stopping. The specks move faster if the air is warmer (because the molecules move faster) and more slowly if it is cooler.

Extended only. The molecules that do the pushing are **much lighter** than the smoke particle but move **much faster**. Many small, fast hits from uneven directions push the heavy speck about. Keep the words straight: the air or water **molecules** (or atoms) do the hitting; the smoke or pollen **particles** are what you see moving. The molecules are not heavier or bigger than the speck, and the speck doesn't move by itself, or because of convection currents or the light.

Key facts and formulas

The 0625 papers have no formula sheet, so learn every equation.

Formula	Status
$T\ (\text{in K}) = \theta\ (\text{in }^\circ\text{C}) + 273$; so $\theta = T - 273$	Learn it
Absolute zero $= 0$ K$= -273$ °C: the particles have the least kinetic energy	Learn it
Pure ice melts at 0 °C (273 K); pure water boils at 100 °C (373 K) at standard atmospheric pressure	Learn it
A temperature change of 1 °C is a change of 1 K	Learn it
Pressure $p = \dfrac{F}{A}$ (force per unit area)	Learn it
Extended only: $pV = \text{constant}$ for a fixed mass of gas at constant temperature, so $p_1V_1 = p_2V_2$	Learn it
Extended only: p against V is a curve; p against $\dfrac{1}{V}$ is a straight line through the origin	Learn it

How to do it

We have tagged 171 questions for this topic across Papers 1–4, 2021–2025; 21 are repeats on other papers, leaving 150 different questions. 25 of the 150 mix two or more types, so the counts add up to more than 150.

Question type	Questions
Gas pressure explained with particles	62
Particles in solids, liquids and gases	43
Temperature, absolute zero and the kelvin scale	30
Extended only: $pV = \text{constant}$ calculations and graphs	21
Brownian motion	18
Changes of state	7

1. Gas pressure explained with particles (62 questions)

1. **Decide what changed**: the temperature (at constant volume), the volume (at constant temperature), or the number of particles.
2. **Say what happens to the particles' speed.** Temperature up: faster. Temperature down: slower. Temperature constant: same speed.
3. **Say what happens to the collisions with the walls**: more (or less) **frequent**, and, if the speed changed, **harder** (or gentler).
4. **Conclude**: so the pressure increases (or decreases).

For example, "A sealed can of air is cooled. State and explain what happens to the pressure": the pressure decreases; the air particles move more slowly, so they hit the walls of the can less often and with less force.

Variations you will meet:

- **"Describe how the gas exerts a pressure."** The particles move fast and randomly; they collide with the walls; each collision pushes on the wall (exerts a force); pressure is the force per unit area. **Extended only:** say the particles' **momentum changes** as they bounce off, which needs a force.
- **Only the volume changes (piston or syringe).** The speed and kinetic energy stay the same. Only the frequency of collisions changes. The average distance between the particles goes down when the gas is compressed, and up when it expands. A wrong option often says the particles "travel more quickly" or "hit harder".
- **Only the temperature changes (sealed container).** Speed changes, frequency changes, force of each collision changes. The distance between particles, their number, mass and size stay the same. "The particles move further apart" is **not** correct for a rigid container.
- **Which quantity stays the same?** For a sealed bottle being cooled, the volume of the air stays the same; the pressure, the particles' energy and the force on the cap all fall.
- **More particles in the same box at the same temperature**: more collisions per second, so the pressure increases.
- **Heated gas pushing a free piston out** (constant pressure). Each collision is harder, because the particles are faster, but the gas spreads into a bigger volume, so collisions happen less often. The two effects balance and the pressure stays the same. A balloon warming up works the same way: it expands and its pressure stays constant.
- **Two changes in turn**, such as heating at constant volume, then expanding at constant temperature: take each stage separately (pressure up, then pressure down).
- **Putting samples in order of pressure**, with the same mass of gas at different volumes and temperatures: smaller volume and higher temperature both mean higher pressure.
- **A gas cylinder or tyre in the sun**, or **a balloon above a heater**: the air gets hotter, the particles speed up, so the pressure rises (or the balloon expands).
- **Removing the lid** of a warmed bottle: particles escape until the pressure inside falls back to atmospheric pressure.
- **Extended only: a molecule bouncing back at the same speed**: its kinetic energy stays the same but its momentum changes (the direction reverses).

2. Particles in solids, liquids and gases (43 questions)

1. **Describe three things** for each state: **arrangement** (regular / random), **separation** (touching / close / far apart) and **motion** (vibrate about fixed positions / move around each other / move fast and randomly).
2. Use the table in "Understand it" and match the words to the state.
3. **For a property** (compressing, flowing, shape, volume), give the particle reason.

Variations you will meet:

- **"Describe the arrangement, separation and motion"** of a solid, a liquid or a gas: one point for each. A solid: regular pattern, close together (touching), vibrate about fixed positions. A liquid: random arrangement, close together (mostly touching), move around and slide past each other. A gas: random, far apart, move quickly in random directions.
- **Draw the particles** in a box: equal circles; a gas needs at least the number asked for (often 10), well spread, none touching.
- **Which state is described?** "Move freely at high speed, far apart": a gas. "Vibrate about fixed positions, closely packed": a solid. "Move freely, speed decreasing": a gas cooling.
- **Why can a gas be compressed but a liquid can't?** The gas particles are far apart, with spaces between them; the liquid particles are already touching. The particles themselves can't be squashed, don't get more compressible, and don't attract more strongly.
- **Which properties does a liquid have?** It flows and has a fixed volume, but no fixed shape and can hardly be compressed. It does not fill the whole container: that's a gas. A sample whose shape depends on its container could be a liquid or a gas.
- **What stays the same when a liquid turns to gas?** The mass (the number of particles). Its ability to flow also stays: both liquids and gases flow. Volume, shape, compressibility and density all change.
- **Boiling water to steam**: the volume increases hugely and the density decreases, because the particles are much further apart.
- **Expansion and state**: for the same temperature rise, a gas expands the most and a solid the least, because the particles in a gas are far apart and the forces between them are weakest.
- **Forces between particles** (**Extended only** in the explanation): strong in solids, weaker hold in liquids, weak or negligible in gases.
- **A liquid in a hot container**: describe the liquid's particles. Don't say they are far apart; liquid particles are mostly touching.

3. Temperature, absolute zero and the kelvin scale (30 questions)

1. **To convert °C to K, add 273.** To convert K to °C, take away 273.
2. **For a temperature change**, the number is the same in both scales: do not add 273.
3. **For motion**, hotter means faster particles (more kinetic energy); colder means slower.

For example, 25 °C is $25 + 273 = 298$ K. Nitrogen boils at 77 K, which is $77 - 273 = -196$ °C. Mercury melts at -39 °C, which is $-39 + 273 = 234$ K.

Variations you will meet:

- **"State the lowest possible temperature"**: -273 °C, or 0 K. Its name is **absolute zero**. At absolute zero the particles have the **least kinetic energy** (they vibrate as little as possible). It is not about weight or gravitational potential energy.
- **Fixed points in both scales**: ice melts at 0 °C (273 K); water boils at 100 °C (373 K).
- **What state is water in at a temperature in kelvin?** Below 273 K: solid. From 273 K to 373 K: liquid. Above 373 K: gas.
- **The formula as a letter equation**: $T = \theta + 273$, so $\theta = T - 273$.
- **What happens to the particles** when a substance is heated or cooled: faster or slower (more or less kinetic energy). In a gas: "the particles move more quickly", not "vibrate faster". In a solid: "they vibrate more (or less)" about fixed positions; they don't move further apart much.
- **Average speed and total kinetic energy** of the particles in a sealed gas both increase when it is heated.

4. pV = constant calculations and graphs (21 questions)

Extended only.

1. **Check the conditions**: a fixed mass of gas at constant temperature.
2. **Write** $p_1V_1 = p_2V_2$ and put in the three values you know.
3. **Solve for the unknown**: $p_2 = \dfrac{p_1V_1}{V_2}$ or $V_2 = \dfrac{p_1V_1}{p_2}$.
4. **Sense check**: a smaller volume must give a larger pressure, and the other way round. Give the unit.

For example, 30 cm³ of gas at 100 kPa is squeezed at constant temperature until its volume has **decreased by** 20 cm³. The new volume is $30 - 20 = 10$ cm³, so $p_2 = \dfrac{100 \times 30}{10} = 300$ kPa. Using 20 cm³ as the new volume gives 150 kPa, which is wrong.

Variations you will meet:

- **"Decreased by" or "increased by"**: work out the new volume first. If the question asks for the **change** in pressure, subtract at the end.
- **Which is the start and which is the end?** Read carefully which volume and pressure are "before". Mixing them up gives an option that looks right.
- **Gas shared between two containers**: when a tap opens into an empty container, the final volume is the total of both. 60 cm³ at 150 kPa spreading into an empty 40 cm³ container gives $\dfrac{150 \times 60}{100} = 90$ kPa.
- **Changing the size of a box**: a cube whose sides double has $2^3 = 8$ times the volume, so the pressure is $\dfrac{1}{8}$ of the original.
- **A table of readings**: check pV for each row; the row whose product is different is the wrong one. The trend to state is "as the pressure increases, the volume decreases".
- **Filling balloons from a cylinder**: find the total volume the gas would take up at the balloons' pressure. The cylinder can't empty itself below the outside pressure, so take away the cylinder's own volume before dividing by one balloon's volume (see Example 4). If the question tells you the volume of gas released, use

that volume instead.

- **A bubble rising through water**: use the **total** pressure (atmospheric $+\ \rho g h$, from the pressure topic) at each depth. The bubble grows as it rises, because the pressure falls. From 10 m down in water, where the total pressure is $1.0 \times 10^5 + 1000 \times 9.8 \times 10 = 1.98 \times 10^5$ Pa, a 2.0 cm³ bubble grows to $\dfrac{1.98 \times 10^5 \times 2.0}{1.0 \times 10^5} = 3.96 \approx 4.0$ cm³ at the surface.
- **"Complete the equation for p_2"**: $p_2 = \dfrac{p_1 V_1}{V_2}$.
- **"State and explain how the final pressure compares if the temperature rises during compression"**: it is **greater** than $\dfrac{p_1 V_1}{V_2}$, because the faster particles also hit harder and more often.
- **Graphs.** Pick the p against V curve that falls and levels off, never touching the axes (not a straight line and not rising). If pressure is plotted against time while the volume is slowly reduced, the pressure rises. If the measured curve lies above the ideal one, the gas got hotter or more gas leaked in; below it, the gas cooled or leaked out.

5. Brownian motion (18 questions)

1. **Describe it**: the specks (smoke or pollen) move **randomly**, in a jerky zig-zag of short straight lines, all the time.
2. **Explain it**: they are hit by the air (or water) **molecules**, which are too small to see and move **fast** in **random** directions. The hits are uneven, more from one side than the other, so there is an overall force and the speck moves; the direction keeps changing.
3. **Say what it shows**: that the particles of the air or water are moving, which is evidence for the kinetic particle model.

Variations you will meet:

- **"State the name of the motion"**: Brownian motion (not diffusion or convection). If asked to **describe** it, the name alone isn't enough: say it's random.
- **Draw the path**: a series of short straight lines of different lengths in random directions, joined end to end. Not a smooth curve, a circle or a straight line.
- **Which statement is correct?** The specks are pushed by **lighter**, fast-moving molecules (**Extended only** detail), not heavier ones; not by convection currents, the light or their own atoms; and it doesn't need heating. The molecules move the speck; the speck doesn't move the molecules.
- **Where is it seen?** In liquids and gases only (the molecules must be free to move around).
- **A smoke particle hit by one fast nitrogen molecule**: the smoke particle starts to move, and the light molecule bounces back.
- **Cooler air**: the specks move more slowly, because the molecules hitting them are slower.
- **Uneven bombardment**: many molecules on different sides, not one single molecule and not another speck.

6. Changes of state (7 questions)

1. **Name the change**: melting (solid → liquid), freezing or solidification (liquid → solid), boiling or evaporation (liquid → gas), condensation (gas → liquid).
2. **Describe the particles before and after**, using arrangement, separation and motion.

Variations you will meet:

- **Steam at 100 °C turning to water at 100 °C**: condensation. The particles are then close together and slide over each other.
- **Ice melting**: the particles change from a regular arrangement to a random one, and from vibrating in place to moving around each other.
- **Water disappearing** from a dish or a floor: evaporation.
- **A heating graph** (temperature against time) for a solid heated until it is a gas: the flat parts are where the state changes (melting, then boiling); the sloping parts are single states.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) Describe the arrangement, separation and motion of the particles in a solid and in a gas. **[6]**

(b) Explain, in terms of particles, why a gas can be compressed but a liquid cannot. **[2]**

(c) State the name of the process in which (i) a solid becomes a liquid, (ii) a gas becomes a liquid. **[2]**

(a) Solid: the particles are in a regular pattern **B1**, very close together (touching) **B1**, and vibrate about fixed positions **B1**.

Gas: the particles are arranged randomly **B1**, far apart **B1**, and move quickly in random directions **B1**.

(b) In a gas the particles are far apart, with large spaces between them that can be reduced **B1**. In a liquid the particles are already touching, so there is almost no space to reduce **B1**.

(c) (i) melting **B1**; (ii) condensation **B1**.

Example 2

A tin can with a tight lid contains air at 17 °C.

(a) Calculate the temperature of the air in kelvin. **[2]**

(b) The can is put in a freezer, where the air cools to -23 °C. State the new temperature in kelvin. State and explain what happens to the pressure of the air in the can. Use your ideas about air particles. **[4]**

(c) State the lowest possible temperature in °C and give its name. **[2]**

(a) $T = \theta + 273$ **C1** $= 17 + 273 = 290$ K **A1**.

(b) $-23 + 273 = 250$ K **B1**. The pressure **decreases B1**. The air particles move more slowly (have less kinetic energy) **B1**, so they hit the walls of the can less often and with less force **B1**.

(c) -273 °C **B1**, absolute zero **B1**.

Example 3

Extended only. A syringe contains 60 cm³ of air at a pressure of 1.0×10^5 Pa. The end is sealed and the plunger is pushed in slowly until the volume is 24 cm³. The temperature does not change.

(a) Calculate the new pressure of the air. **[3]**

(b) Explain, in terms of the air molecules, why the pressure has increased. **[3]**

(c) Explain, in terms of the momentum of the molecules, how the air exerts a pressure on the plunger. **[3]**

(a) $pV = \text{constant}$ (or $p_1V_1 = p_2V_2$) **C1**.

$1.0 \times 10^5 \times 60 = p_2 \times 24$ **C1**, so $p_2 = \dfrac{6.0 \times 10^6}{24} = 2.5 \times 10^5$ Pa **A1**.

(b) The temperature is the same, so the molecules move at the same speed **B1**. They are closer together, in a smaller volume **B1**, so they hit each unit area of the walls more often (more collisions per second per unit area) **B1**.

(c) The molecules hit the plunger and bounce off, so their momentum changes **B1**. A change of momentum needs a force, so the molecules exert a force on the plunger **B1**. Pressure is this force per unit area of the plunger **B1**.

Example 4

Extended only. A cylinder of volume 0.040 m³ contains helium at a pressure of 2.5×10^6 Pa. Helium is let out into balloons until the pressure in the cylinder has fallen to atmospheric pressure, 1.0×10^5 Pa. Each balloon holds 0.012 m³ of helium at atmospheric pressure. The temperature stays constant.

(a) Calculate the volume the helium would occupy at atmospheric pressure. **[2]**

(b) Calculate the number of balloons that can be filled. **[2]**

(a) $p_1V_1 = p_2V_2$: $2.5 \times 10^6 \times 0.040 = 1.0 \times 10^5 \times V_2$ **C1**, so $V_2 = 1.0$ m³ **A1**.

(b) The cylinder stays full of helium at atmospheric pressure, so 0.040 m³ never leaves: the volume available for balloons is $1.0 - 0.040 = 0.96$ m³ **C1**. Number of balloons $= \dfrac{0.96}{0.012} = 80$ **A1**. (Forgetting the helium left in the cylinder gives $\dfrac{1.0}{0.012} = 83.3$, so 83 balloons, which is wrong.)

Common mistakes

- **Saying liquid particles are far apart.** They are close together and mostly touching; only gas particles are far apart. Examiners see this mistake every year when candidates describe a liquid.
- **Leaving out one of the three.** "Describe the arrangement, separation and motion" needs all three for each state. Giving only one point, or describing motion twice, loses marks.
- **Saying the particles themselves change.** The particles don't expand, shrink, get heavier or melt. In a change of state or when a gas is heated or compressed, only their spacing, arrangement and speed change.
- **"More collisions" on its own.** Say **more frequent** collisions (more collisions per second) with the **walls**. Collisions between particles don't cause the pressure on the wall. When the temperature rises, also say the collisions are **harder** (more force).
- **Saying the particles speed up when a gas is compressed at constant temperature.** Constant temperature means constant speed; only the frequency of collisions changes.
- **Not linking collisions to force.** "The particles collide with the walls" is not enough to explain pressure. Say each collision exerts a **force** on the wall and pressure is **force per unit area**.
- **Mixing up Brownian motion.** Calling it diffusion; thinking the water molecules are bigger or heavier than the pollen; saying pollen molecules move the water. The small, fast, invisible **molecules** hit the big, visible **particles**.
- **Absolute zero as "zero gravitational energy"** or "no weight". It is the temperature where the particles have the **least kinetic energy**.
- **Adding 273 to a temperature change.** A rise from 10 °C to 40 °C is 30 K, not 303 K.
- **Misreading pV questions.** Swapping the initial and final values, or using "decreased by 15 cm³" as if it were the new volume. Write p_1, V_1, p_2, V_2 out before substituting.
- **Vague direction words.** "The pressure changes" earns nothing: say **increases** or **decreases**.

How to get the marks

- **"State and explain"** needs the statement (pressure increases) **and** the reason (particles faster, collide more often and harder). The statement mark can't be earned from the explanation alone.

- **Particle explanations of pressure** are marked point by point, usually from: particles move fast and randomly; they collide with the walls; the collisions exert a force; pressure is force per unit area. **Extended only:** momentum changes as they bounce back. Aim for at least as many clear points as there are marks.
- **"Use your ideas about particles (or molecules)"**: the answer must mention the particles and what they do. An answer about the gas "expanding" alone gets nothing.
- **Describe particle structure** with the key words: regular / random, touching / close / far apart, vibrate / slide past each other / move quickly and randomly.
- **Drawing particles**: equal-sized circles, the right number, the right spacing (touching for solids and liquids, well apart for gases).
- **Kelvin**: write $T = \theta + 273$ first; there is often a mark for it. Give the unit K.
- **"State the value of absolute zero"**: -273 °C, with the minus sign and the unit. If the unit is asked for, "0 K" is also fine.
- **Extended only: pV calculations**: write $pV = \text{constant}$ or $p_1V_1 = p_2V_2$ (the first mark), substitute, then give the answer with a unit, to 2 or 3 significant figures.
- **Brownian motion**: "describe" wants random, zig-zag movement; "explain" wants collisions with (fast-moving, randomly moving) molecules of the liquid or gas, uneven from different sides.
- **Multiple choice**: decide first what stays constant (temperature? volume?), then what that means for the speed and the collisions. Most wrong options break one of these links.

Quick check

1. Convert -40 °C to kelvin, and 350 K to degrees Celsius.
2. Describe the separation and the motion of the particles in a liquid, and state the name of the change from gas to liquid.
3. A sealed rigid container of gas is cooled. State and explain what happens to the pressure of the gas. Use ideas about particles.
4. Pollen grains in water, seen through a microscope, move about randomly. Explain why.
5. **Extended only.** A fixed mass of gas has a volume of 500 cm³ at a pressure of 120 kPa. It expands at constant temperature to 800 cm³. Calculate the new pressure.

Answers

1. $-40 + 273 = 233$ K. $350 - 273 = 77$ °C.
2. The particles are close together (mostly touching) and move around, sliding past each other randomly. Gas to liquid is condensation.
3. The pressure decreases. The particles move more slowly, so they hit the walls less often and with less force.
4. The pollen grains are hit by water molecules, which are too small to see and move fast in random directions. At any moment more molecules hit one side of a grain than the other, so there is an overall force that pushes it, first one way and then another.
5. $p_2 = \frac{p_1 V_1}{V_2} = \frac{120 \times 500}{800} = 75$ kPa.

Past questions to try

- **0625/33/O/N/21 Q6**: drawing particles in a solid and a gas, naming changes of state, then Brownian motion (Core).
- **0625/32/M/J/24 Q5**: the particles in a metal block, cooling it, and absolute zero (Core).
- **0625/42/M/J/23 Q4**: pressure with temperature at constant volume, absolute zero, then a pV calculation (Extended).
- **0625/41/O/N/21 Q3**: pressure explained with momentum, then $pV = \text{constant}$ for a balloon sinking in a lake (Extended).