

Cambridge OCR GCSE Combined Science A — Physics

Topic P1

Matter

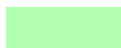
Specification J250 · Cambridge OCR

Free edition

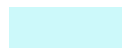
Revision notes for one topic, free to download.

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 Atom

- a positively charged nucleus surrounded by negatively charged electrons.

Define Order of magnitude

- the size of a quantity to the nearest power of ten, e.g. 10^{-10} m.

Define Change of state

- a physical change from one state to another: melting, freezing, evaporating, condensing or sublimating.

Define Chemical change

- a change making new substances, which reversing the conditions does not undo.

Define Temperature

- a measure of the average kinetic energy of the particles; *not* the same as the energy stored.

Define Specific latent heat

- the energy needed to change the state of 1 kg of a substance, with no change of temperature.

Define Specific latent heat of vaporisation

- the value for boiling, evaporating or condensing.

Define Closed system

- one from which no matter can escape, so its mass is fixed.

Define Particle model

- all matter treated as very large numbers of tiny particles in constant motion, with forces of attraction between them and space in between.

Define Nucleus

- the tiny, dense, positively charged centre of an atom, holding almost all its mass.

Define Density

- the mass per unit volume of a substance.

Define Physical change

- a change in which the material recovers its original properties if the change is reversed.

Define Internal energy

- the total energy stored by the particles of a system in their kinetic and potential energy stores.

Define Specific heat capacity

- the energy needed to raise the temperature of 1 kg of a substance by 1°C , with no change of state.

Define Specific latent heat of fusion

- the value for melting or freezing.

Define Gas pressure

- the effect of gas particles colliding with, and pushing on, the walls of their container.

P1.1 The particle model

Knowledge and understanding of the particle nature of matter is fundamental to physics. Learners need an appreciation of matter in its different forms, and must be aware of subatomic particles, their relative charges, masses and positions inside the atom. Much of this content overlaps with GCSE (9–1) Chemistry A.

How and why the atomic model has changed over time (P1.1a)

Describe both **how** the model changed and **why**: every change was forced by **new experimental evidence** the existing model could not explain. J250 names the **Thomson, Rutherford** (alongside **Geiger and Marsden**) and **Bohr** models.

Model	Who and when	The key idea	What forced the change
Plum pudding	Thomson , 1897	The electron had been discovered, so the atom is divisible: a ball of positive charge with electrons embedded in it	It predicted alpha particles would pass through foil with only slight deflection — they did not
Nuclear	Geiger and Marsden , interpreted by Rutherford , 1909–1911	Almost all the mass and all the positive charge sit in a tiny nucleus ; the rest is mostly empty space	Orbiting electrons should spiral inwards; line spectra were unexplained
Shell (energy level)	Bohr , 1913	Electrons orbit at fixed distances in energy levels (shells) , making the atom stable	Later work showed the nucleus contains protons, and twenty years on, neutrons

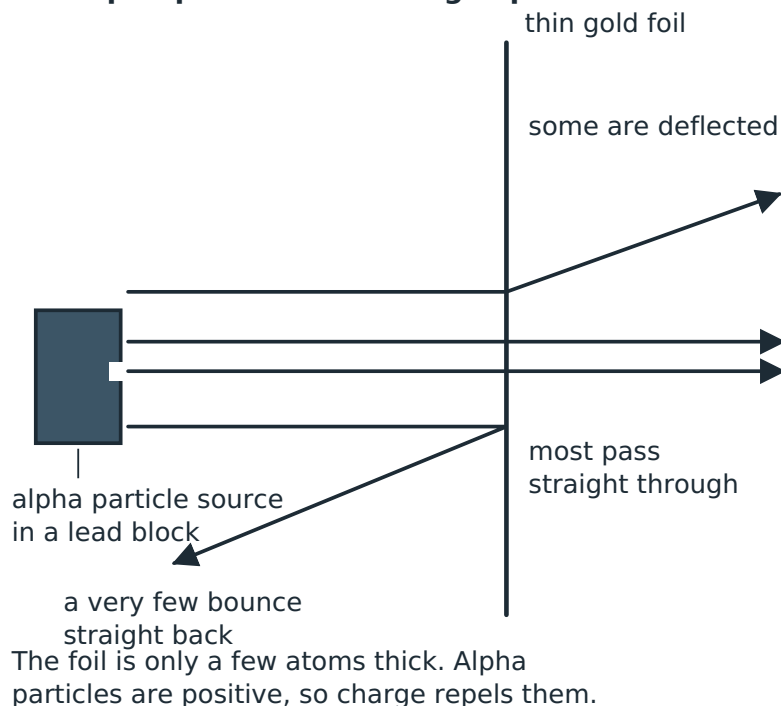
The alpha-particle scattering experiment. Alpha particles were fired at very thin gold foil and a movable detector recorded where they went.

- **Most passed straight through** undeflected → the atom is **mostly empty space**.
- **A small number were deflected** through large angles → there is a **concentrated positive charge** repelling them.
- **A very few bounced almost straight back** → that charge sits in a **tiny, very dense** region — the nucleus.

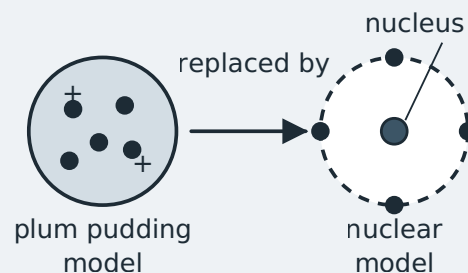
The exam point is the pattern of reasoning, and that these scientists **worked together**: a model survives only while it fits the evidence, and one reliable observation it cannot explain forces it to be modified or replaced.

The alpha particle scattering experiment and the nuclear model it produced.

The alpha particle scattering experiment



The conclusion



Most passed straight through, so the atom is mostly empty space.

A few were deflected, so there is a concentrated positive charge.

A very few bounced back, so that charge and nearly all the mass sit in a tiny, dense nucleus.

So the plum pudding model (a ball of positive charge with electrons stuck in it) was replaced by the nuclear model.

The nuclear atom (P1.1b)

Describe the atom as a **positively charged nucleus surrounded by negatively charged electrons**, with the **nuclear radius much smaller than that of the atom** (by a factor of roughly 10 000) and **almost all of the mass in the nucleus**. It is neutral overall because the nuclear positive charge is balanced exactly by the electrons.

ANALOGY

The nucleus in the atom — a pea in a stadium. Scale an atom up to a large sports stadium and the nucleus is a pea on the centre spot, the electrons specks of dust in the stands. Almost all the mass is in the pea, and almost all the atom is empty space — which is exactly why most alpha particles sailed straight through the gold foil.

Density (P1.1d, P1.1e, P1.1f)

Density is the mass per unit volume of a substance. That is the definition to write down — not "how heavy something is".

The three states differ in density because they differ in how closely the particles are packed (P1.1e).

The size of atoms and small molecules (P1.1c)

You should **recall the typical size (order of magnitude) of atoms and small molecules**: J250's figure is $1 \times 10^{-10} \text{ m}$, that is 0.1 nm.

Property	Solid	Liquid	Gas
Arrangement	Regular, closely packed pattern	Close together but irregular	Far apart, completely random
Movement	Vibrate about fixed positions	Slide past one another	Move quickly in all directions, colliding
Forces of attraction	Strong	Weaker, still significant	Very weak or negligible
Spacing	Touching	Touching	About ten times further apart in each direction
Density	Highest	Slightly lower than the solid	Far lower — often about a thousandth
Shape and volume	Fixed shape, fixed volume	Takes the container's shape, fixed volume	Fills the container completely

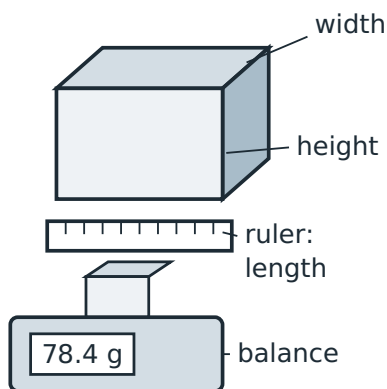
Because the same particles are simply spread further apart, a **gas has a much lower density than the liquid or solid of the same substance**. Ice is the well-known oddity: it is *less* dense than liquid water, which is why it floats.

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

PAG P1 (Materials) — density = mass ÷ volume, $\rho = m / V$

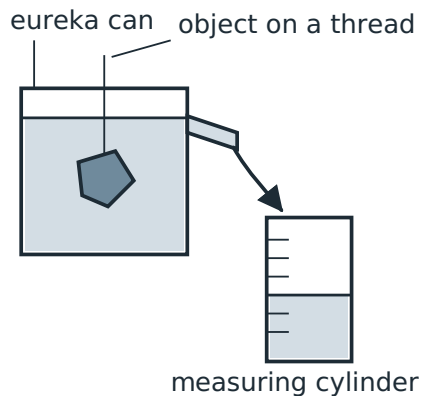
ρ in kg/m³ (or g/cm³) · m in kg (or g) · V in m³ (or cm³) · 1 g/cm³ = 1000 kg/m³

A Regular solid



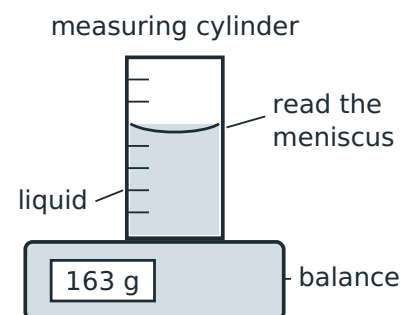
- find the mass on a balance
- measure the length, width and height with a ruler or callipers
- volume = $l \times w \times h$
- density = mass ÷ volume

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 cm³ at the bottom of the meniscus, at eye level

When a substance changes state, **mass is conserved** but the **volume changes**, so the **density changes** (P1.1f) — hold the mass fixed, change the volume, recalculate.

ANALOGY

Density — the suitcase test. Two suitcases of the same size, one packed with feathers and one with books, take up identical space but have very different masses: the books are more dense. Density is what you feel when you lift two objects of the *same size*; it is a property of the material, not of how big the lump is. A tonne of steel and a steel paperclip have the same density, 7800 kg/m³.

WATCH OUT

Learners commonly **confuse the different types of particle** — subatomic particles, atoms and molecules — and use the word "particle" for all three without noticing. Keep the language exact: a *subatomic particle* is a proton, neutron or electron; an *atom* is the smallest particle of an element; a *molecule* is two or more atoms chemically joined. An oxygen atom, O, and an oxygen molecule, O₂, are not the same thing.

Learners also commonly **misunderstand the conversions between the different units used in the measurement of volume**. Write them out every time rather than guessing: 1 cm³ = 1 × 10⁻⁶ m³ (because you cube the factor of 100), 1 m³ = 1 000 000 cm³, 1 litre = 1000 cm³, and 1 g/cm³ = 1000 kg/m³.

P1.2 Changes of state

A clear understanding of the foundations of the physical world forms a solid basis for further study of physics. Understanding the relationship between the states of matter helps to explain the everyday physical changes we see around us.

Physical changes and chemical changes (P1.2b)

A change of state is a **physical** change, and the spec gives you the test to quote: **the material recovers its original properties if the change is reversed**. Freeze the water you just melted and you have the same ice, of the same mass and melting point. In a chemical change new substances are made and reversing the conditions does not bring the original back — cooling the black solid made by heating green copper carbonate does not turn it green again.

Conservation of mass in a change of state (P1.2a)

When a substance melts, freezes, evaporates, condenses or sublimates, its mass is conserved. No particles are created or destroyed — they are only rearranged and re-spaced, so 1 kg of ice makes exactly 1 kg of water and exactly 1 kg of steam.

Students go wrong with **open systems**: a beaker on a windowsill loses mass because the vapour drifts away, not because mass has been destroyed. Seal the system — as in a distillation, where the condensed liquid is collected — and the total mass is unchanged.

- **Melting** solid → liquid, at the melting point; **freezing** is the reverse, at the same temperature.
- **Boiling** liquid → gas throughout the liquid, at the boiling point; **evaporating** is the same change at the surface only, at any temperature below the boiling point.
- **Condensing** gas → liquid; **sublimating** solid → gas directly, as solid carbon dioxide does.

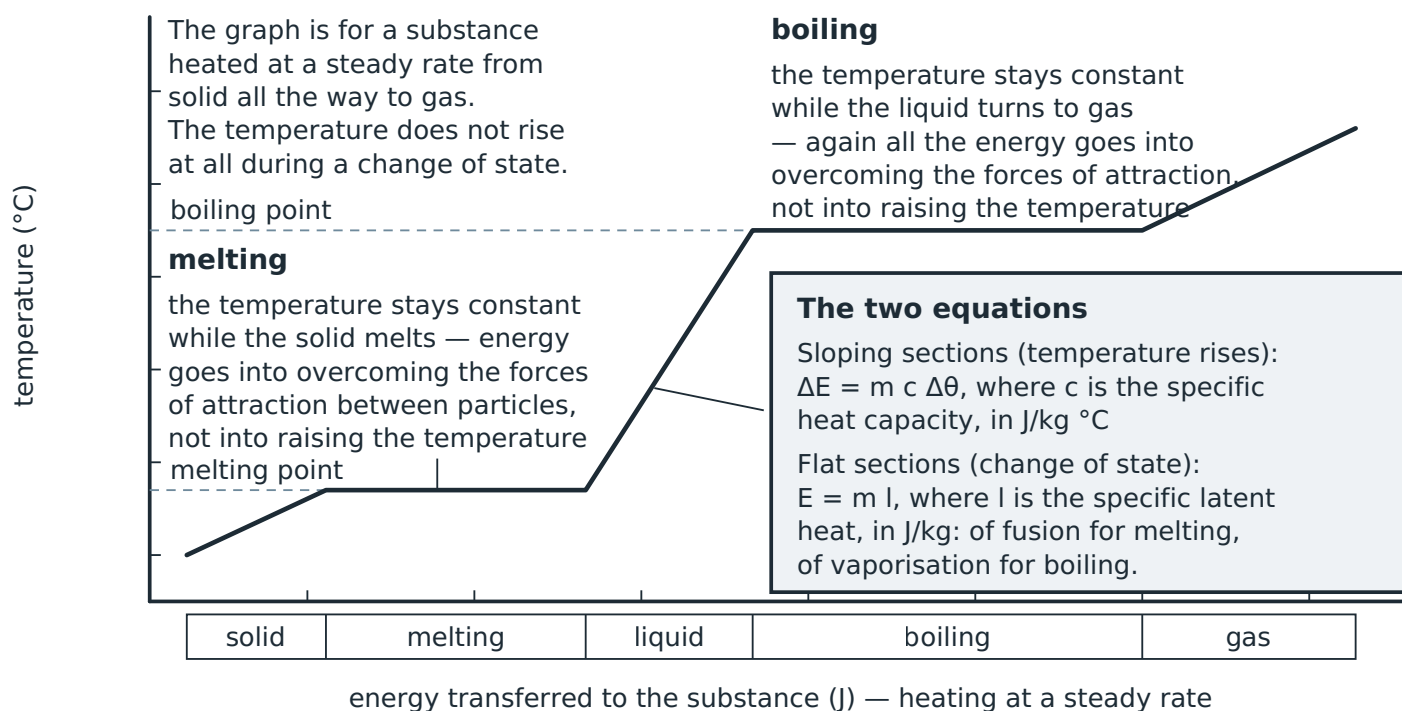
Heating a system, internal energy and temperature (P1.2c)

Heating a system transfers energy to the particles and **changes the energy stored within the system**. That extra energy does one of two things — never both at once:

1. It **raises the temperature**, because the particles move faster and their **average kinetic energy increases**; or
2. It **produces a change of state**, because the energy is used to **overcome the forces of attraction** between particles, pulling them further apart. The energy goes into the particles' **potential** energy store and the **temperature stays constant**.

This is why a heating curve for a pure substance has **flat sections (plateaux)** at the melting and boiling points: energy is still supplied at the same rate, but it is all spent separating particles rather than speeding them up. Cooling is the reverse — attractions re-form, energy is released to the surroundings, and the temperature holds steady while the substance freezes or condenses.

A heating curve, showing where specific heat capacity applies and where specific latent heat does.



WATCH OUT

Learners assume **atoms are always synonymous with particles**, and struggle to explain **what is between the particles**, instinctively "filling" the gaps with **air** or **vapour**. Between the particles of a gas there is *nothing* — not air, not gas. If it were air, the air would itself be made of particles with gaps between them, and you would never finish.

Learners also **struggle to visualise the 3D arrangement of particles** in all three states. A textbook diagram is a flat slice: the particles carry on above and below the page in every direction.

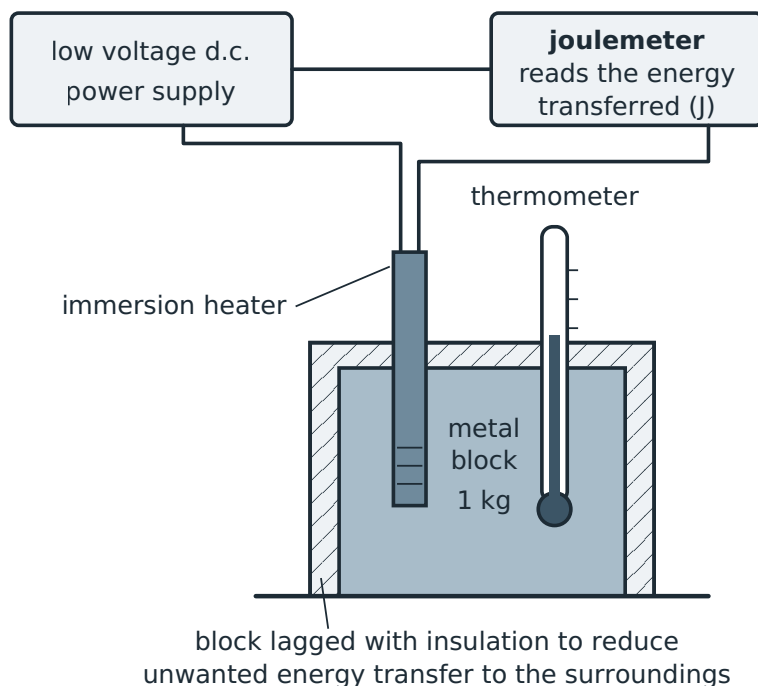
Finally, learners find it challenging to understand **how kinetic theory applies to heating materials**, and regularly **confuse the terms temperature and heat**. Keep the two apart: *temperature* is a measure of the **average kinetic energy** of the particles and is measured in °C; *heating* is a **process** that transfers **energy** (in joules) from a hotter place to a cooler one. A bath at 40 °C stores far more energy than a cup of tea at 80 °C — lower temperature, more energy, because there is far more mass.

Specific heat capacity and specific latent heat (P1.2d, P1.2e, P1.2f)

You must be able to **define specific heat capacity and distinguish between it and the term specific latent heat**. Learn the pair together, because most marks are lost by picking the wrong one.

	Specific heat capacity, c	Specific latent heat, L
Definition	The energy needed to raise the temperature of 1 kg of a substance by 1 °C	The energy needed to change the state of 1 kg of a substance
Temperature during the change	Rises	Constant
State during the change	Unchanged	Changes
Unit	J/kg °C	J/kg
Where it applies on a heating curve	The sloping sections	The flat sections

Apparatus for measuring the specific heat capacity of a metal block.



No joulemeter? Put an ammeter in series and a voltmeter across the heater, then $E = V \times I \times t$

Variables

Independent variable

the energy transferred to the block, read from the joulemeter (J)

Dependent variable

the temperature of the block ($^{\circ}\text{C}$), read from the thermometer

Control variables

the mass and material of the block, the power of the heater, the insulation, the starting temperature and the room temperature

Equation used

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

ΔE = change in thermal energy, J

m = mass, kg

c = specific heat capacity, $\text{J/kg } ^{\circ}\text{C}$

$\Delta \theta$ = temperature change, $^{\circ}\text{C}$

Rearranged: $c = \Delta E \div (m \times \Delta \theta)$

Specific latent heat of fusion is the value for melting and freezing; **specific latent heat of vaporisation** is the value for boiling, evaporating and condensing — J250 names both. For water they are about $3.34 \times 10^5 \text{ J/kg}$ and $2.26 \times 10^6 \text{ J/kg}$; vaporisation is far larger, because the particles must be separated completely rather than merely loosened. "Specific" in both terms simply means **per kilogram**.

ANALOGY

Latent heat — paying the deposit. Treat heating as paying money into an account whose balance is the temperature. On the sloping parts of the heating curve every joule raises the balance; at the melting point the account freezes until you have paid a large fixed **deposit** — the latent heat — to break the particles free of one another. "Latent" means *hidden*: the energy is genuinely supplied, it just does not show on the thermometer. It is also why steam at 100°C scalds far worse than water at 100°C : condensing on skin, it hands back the whole latent heat of vaporisation too.

Gas pressure, particle motion and temperature (P1.2g, P1.2h)

Explain how the motion of the molecules in a gas is related both to its temperature and its pressure (P1.2g) — J250 restricts this to **closed systems only**.

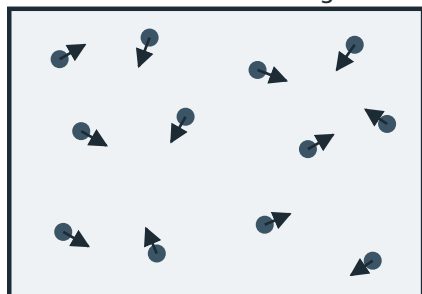
- Gas particles move **quickly, randomly and in all directions**, colliding with one another and with the container walls.
- **Gas pressure** is produced by those **collisions with the walls**. Each particle that hits a wall and rebounds exerts a tiny force on it; averaged over the huge number of collisions every second, that is a steady push over the whole wall area.
- **Temperature** is a measure of the **average kinetic energy** of the molecules. Raise the temperature and they move **faster**.
- Two things therefore fix the pressure: **how often** particles hit the walls, and **how hard** each collision is.

Explain the relationship between the temperature of a gas and its pressure at constant volume (P1.2h) — **qualitative only**. Heating a fixed mass of gas in a sealed container of fixed volume:

1. increases the average kinetic energy of the molecules, so they **move faster**;
2. so they **hit the walls more often**, and
3. each collision is **harder**, transferring more momentum;
4. the total force on the walls rises, and with the wall area unchanged the **pressure increases**.

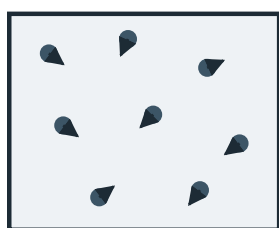
Gas pressure and the particle model

sealed container of gas



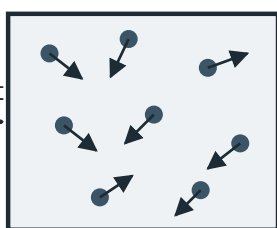
The particles of a gas move quickly, in all directions. They collide with the walls of the container, and each collision exerts a small force on the wall. Gas pressure is the total force per unit area of wall.

Heating a gas at constant volume



cool gas

heat



hot gas

Heating makes the particles move faster. They hit the walls harder and more often. The volume is fixed, so the pressure of a fixed mass of gas increases (P1.2h).

Cooling reverses this exactly — which is why a balloon put in a freezer shrinks and a warmed one swells, and why a sealed can heated over a flame can burst. No calculation is required: J250 has **no** $pV = \text{constant}$ equation and **no** $p = F \div A$ equation, so questions are worded explanations.

ANALOGY

Gas pressure — hail on a tin roof. Pressure on a container wall is like hail drumming on a tin roof: no single stone matters, but thousands a second give a steady push. Heat the gas and the hail falls both **faster** and **more often** — a harder drumming, so higher pressure. Cool it and the drumming softens.

NOTE

Not required by J250. Combined Science has **no** pressure calculations, no $pV = \text{constant}$, no pressure in liquids, upthrust, floating and sinking, and no work done on a gas — those belong to the separate physics course. The nuclear atom returns in **P4**, and internal energy in **P5**, on Paper 6 / Paper 12.