

Cambridge OCR GCSE Chemistry A — Chemistry

Topic C1

Particles

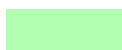
Specification J248 · Cambridge OCR

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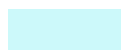
Revision notes for one topic, free to download.

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 State of matter

- solid, liquid or gas; the physical form a substance takes at a given temperature and pressure.

Define Melting point

- the temperature at which a solid becomes a liquid; the same temperature at which the liquid freezes.

Define Physical change

- a change in which no new substance is made; the particles themselves are unchanged and the change can usually be reversed.

Define Element

- a substance made of only one type of atom.

Define Atom

- the smallest particle of an element that still has the chemical properties of that element.

Define Proton

- a subatomic particle in the nucleus with relative charge +1 and relative mass 1.

Define Electron

- a subatomic particle outside the nucleus with relative charge -1 and a relative mass so small it is treated as negligible.

Define Mass number

- the total number of protons and neutrons in the nucleus of an atom.

Define Particle model

- a model that treats all matter as very large numbers of tiny particles, in constant motion, with forces of attraction between them.

Define Change of state

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

Define Boiling point

- the temperature at which a liquid becomes a gas throughout its volume, not just at the surface.

Define Chemical change

- a change in which atoms are rearranged into one or more new substances; not usually reversible by simply reversing the conditions.

Define Compound

- a substance in which atoms of two or more elements are chemically joined together.

Define Nucleus

- the tiny, dense, positively charged centre of an atom, containing the protons and neutrons and almost all of the mass.

Define Neutron

- a subatomic particle in the nucleus with relative charge 0 and relative mass 1.

Define Atomic number (proton number)

- the number of protons in the nucleus of an atom; it fixes which element the atom is.

Define Isotopes

- atoms of the same element with the same number of protons but different numbers of neutrons, and so different mass numbers.

Define Ion

- an atom, or group of atoms, that has lost or gained electrons and therefore carries an overall charge.

Define Order of magnitude

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

C1.1 The particle model

A simple particle model represents the arrangement of particles in the different states of matter and explains what is observed during changes of state. It does not explain why different materials have different properties — for that, the particles themselves and the way they are held together must be different in some way.

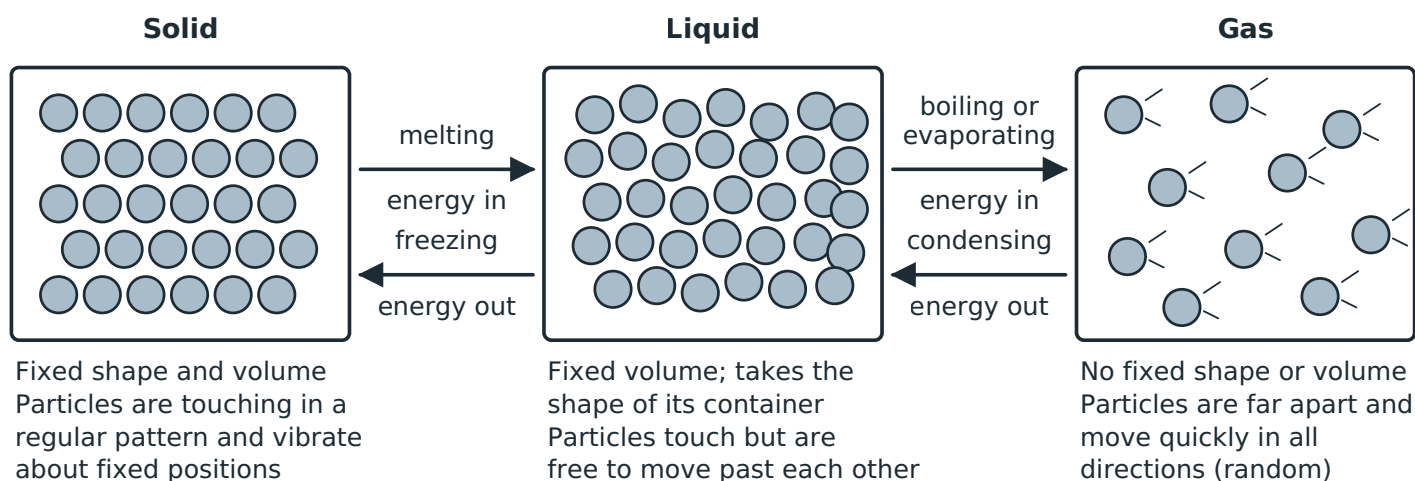
The main features of the particle model (C1.1a)

The model has four claims, and everything else follows from them.

- All matter is made of very small **particles**.
- The particles are in **constant motion**, and the hotter the substance the faster they move.
- There are **forces of attraction** between the particles.
- There is **space between the particles** — in a gas, a great deal of it.

Property	Solid	Liquid	Gas
Arrangement	Regular, closely packed pattern	Close together but irregular	Far apart and completely random
Movement	Vibrate about fixed positions	Move past one another, sliding and rolling	Move quickly in all directions, colliding
Forces of attraction	Strong	Weaker than in a solid, but still significant	Very weak or negligible
Shape and volume	Fixed shape, fixed volume	Takes the shape of the container, fixed volume	Fills the container completely
Density and compressibility	Most dense; cannot be compressed	Slightly less dense; almost incompressible	Least dense; easily compressed

The three states of matter, the changes of state between them, and the limitations of the simple particle model.



Melting and freezing happen at the melting point. Boiling and condensing happen at the boiling point. The stronger the forces between the particles, the higher the melting point and the boiling point.

HT only — Limitations of the simple particle model

In this model the particles are drawn as small solid spheres, all identical, with no forces between them. Real particles are not solid inelastic spheres, are not all the same, and forces do act between them.

ANALOGY

The particle model — the school hall. Particles in a **solid** are pupils standing in rows in assembly: each keeps a fixed place and can only fidget. In a **liquid** the same pupils mill about in a crowded corridor, still touching but able to slide past one another. In a **gas** they are scattered across a playing field, sprinting in all directions, almost never in contact. Nothing is added or removed at any stage — the same pupils, differently arranged, which is exactly why a change of state is a physical change.

WATCH OUT

Learners commonly hold, intuitively, that **matter is continuous** — that the space between gas particles is filled with something, or does not exist at all, and that **particles expand when they are heated**. The idea of genuinely empty space is uncomfortable because nothing you can see or feel supports it. Two corrections: (i) between the particles of a gas there is *nothing*, not air and not "gas"; (ii) heating makes particles **move faster and spread further apart** — an individual particle does not swell. Learners also find it hard to accept that **changes of state are reversible**, and that the substance is the same substance in each state.

Changes of state are named by the direction of travel:

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

Explaining a change of state in particle terms always follows the same route: **heating gives the particles more energy in their kinetic energy stores, so they move faster; at the melting or boiling point that energy is used to overcome the forces of attraction holding the particles together, so the temperature stays constant while the state changes**. Cooling is the reverse — particles slow, attractions pull them back together, and energy is transferred to the surroundings.

Changes of state are **reversible**: freeze the water you just melted and you have exactly the ice you started with, of exactly the same mass. The amount of substance is conserved throughout (WS1.1a).

NOTE

Maths outcome CM1.1i (M5b). You should be able to **represent three-dimensional shapes in two dimensions and vice versa** when looking at chemical structures, for example the allotropes of carbon met later in C2.3. A textbook drawing of a giant structure is a flat slice through a solid object: the particles carry on above and below the page in every direction.

Physical changes and chemical changes (C1.1b)

	Physical change	Chemical change
New substance made?	No — the same particles, rearranged	Yes — atoms are rearranged into new substances
What changes	Arrangement, spacing and energy of particles	The bonds between atoms are broken and new ones made
Reversibility	Usually easily reversed (freeze the melt)	Not usually reversed by simply reversing the conditions
Mass	Conserved	Conserved (though gas may escape and appear lost)
Typical signs	Change of state, dissolving, a mixture forming	Colour change, gas given off, a precipitate, a temperature change, light

Worked examples of the distinction:

- Ice melting, wax melting, iodine subliming, salt dissolving in water and iron filings being mixed with sulfur are **physical changes** — you could get the starting materials back.
- Magnesium burning in air, heating copper carbonate until it turns black, and iron reacting with sulfur when heated are **chemical changes** — a new substance with new properties has been made.

Dissolving is the one that catches people out: sugar dissolving in water is a **physical** change, because the sugar molecules are still sugar molecules and can be recovered by crystallisation.

HIGHER TIER**HT ONLY The limitations of the particle model (C1.1c)**

HT ONLY In the simple model, particles are drawn as **inelastic spheres — like bowling balls**. That picture is useful, but you must be able to explain what it leaves out (C1.1c):

- **HT ONLY** It does not take into account the **forces of attraction between particles**. Bowling balls do not stick to each other, so the model alone cannot explain why one substance melts at 0 °C and another at 1500 °C, or why a liquid holds together at all.
- **HT ONLY** It does not take into account the **size of the particles**. Real particles differ enormously in size, and drawing them all as identical spheres hides that.
- **HT ONLY** It does not take into account the **space between the particles**. Diagrams tend to show particles touching, which exaggerates how much of a solid or liquid is actually occupied.
- **HT ONLY** The spheres are shown as **solid and featureless**, with no internal structure — yet atoms have a nucleus and electrons, and the particles in many substances are molecules or ions rather than atoms.

Because of these omissions, the simple model **cannot explain why different materials have different properties**. That explanation needs the particles themselves, and the way they are held together, to be different — which is the whole of Topic C2.

C1.2 Atomic structure

An atom is the smallest component of an element that gives the element its properties, and those properties are explained by models of atomic structure. Current models describe atoms as made of protons, neutrons and electrons: a nucleus of protons and neutrons, surrounded by electrons. Atoms of an element have equal numbers of protons and electrons; atoms of different elements have different numbers of protons; atoms of the same element may have different numbers of neutrons.

How and why the atomic model has changed over time (C1.2a)

You should be able to describe **how** the model changed and, just as importantly, **why**: each change was forced by **new experimental evidence** that the existing model could not explain. A scientific model is accepted only while it fits the evidence.

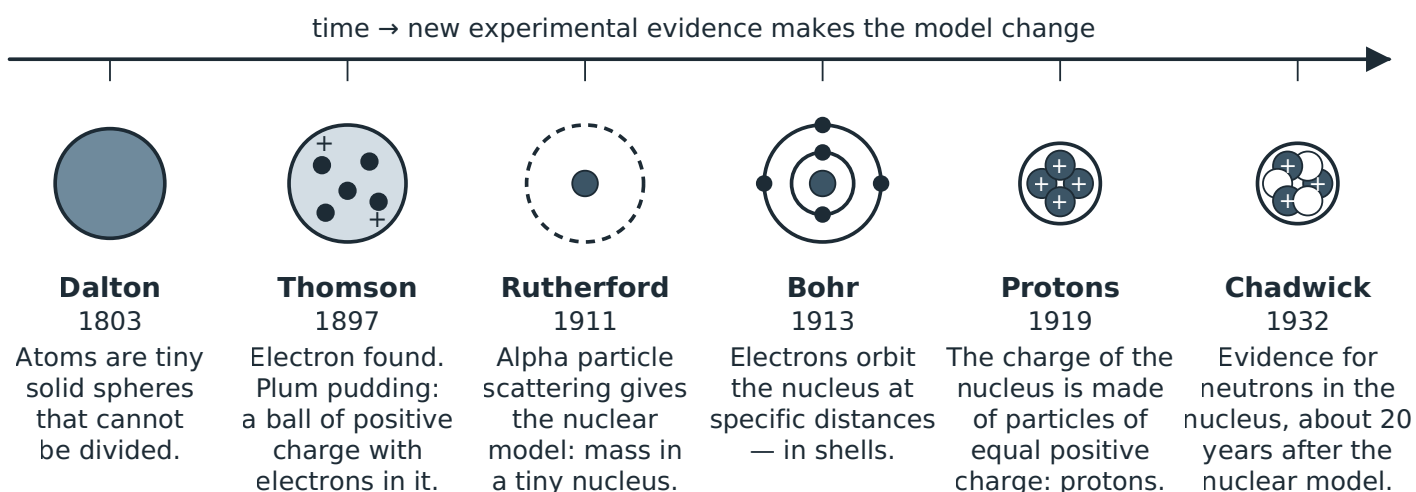
Model	Who, and when	The key idea	What forced the change
Solid sphere	Dalton , early 1800s	Atoms are tiny, indivisible spheres; each element has its own kind of atom; atoms are rearranged, not destroyed, in reactions	Discovery of a particle far lighter than any atom
Plum pudding	Thomson , 1897	The electron was discovered, so the atom must be divisible: a ball of positive charge with negative electrons embedded in it	The alpha-scattering results could not be explained
Nuclear	Geiger and Marsden's experiment, interpreted by Rutherford , 1909–1911	Almost all the mass and all the positive charge are in a tiny nucleus ; the rest of the atom is mostly empty space	Electrons orbiting anywhere should spiral in; line spectra were unexplained
Shell (energy level)	Bohr , 1913	Electrons orbit the nucleus at fixed distances in energy levels (shells) , which makes the atom stable	Later work showed the nucleus itself is made of protons and neutrons

The alpha-particle scattering experiment (Geiger and Marsden). A beam of alpha particles was fired at a very thin gold foil, and a movable detector recorded where they went.

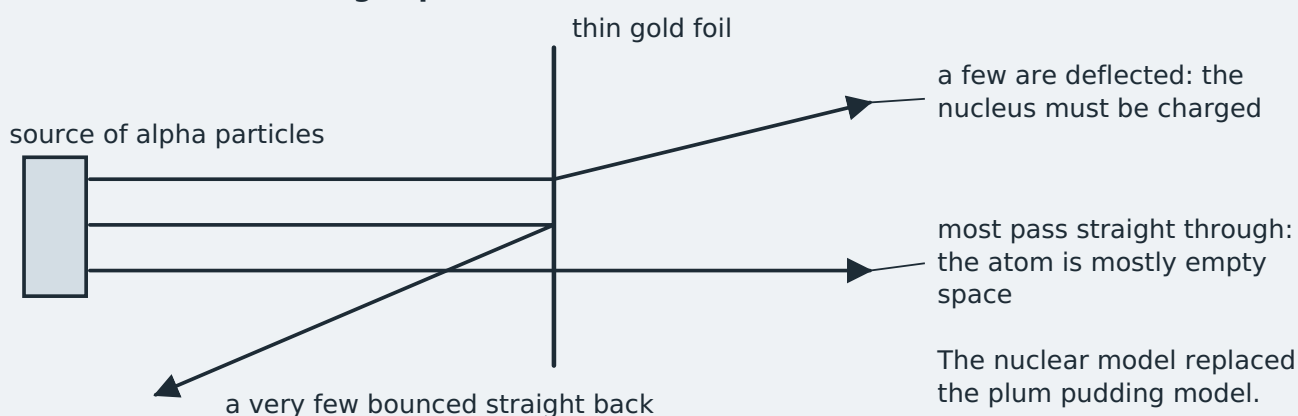
- **Most passed straight through** with no deflection → the atom is **mostly empty space**.
- **A small number were deflected** through large angles → there is a **concentrated positive charge** to repel them.
- **A very few bounced almost straight back** → that positive charge is in a **tiny, very dense** region — the nucleus.

The plum pudding model predicted that all the alpha particles would pass through with only slight deflection, because the positive charge was spread thinly. It could not survive this result, so it was replaced. The neutron was identified about twenty years later, completing the picture of the nucleus.

How the model of the atom changed as new experimental evidence appeared.



Rutherford's scattering experiment



NOTE

Why models change (WS1.1i, WS1.2b). Models are judged against evidence, not against how sensible they feel. New evidence is published, checked by other scientists (peer review) and repeated; a model that cannot explain a reliable observation is modified or abandoned. The current model may itself be refined — that is normal science, not a failure. The spec names Dalton, Thomson, Rutherford, Bohr, and Geiger and Marsden; a timeline of the atomic model is OCR's suggested activity for this outcome.

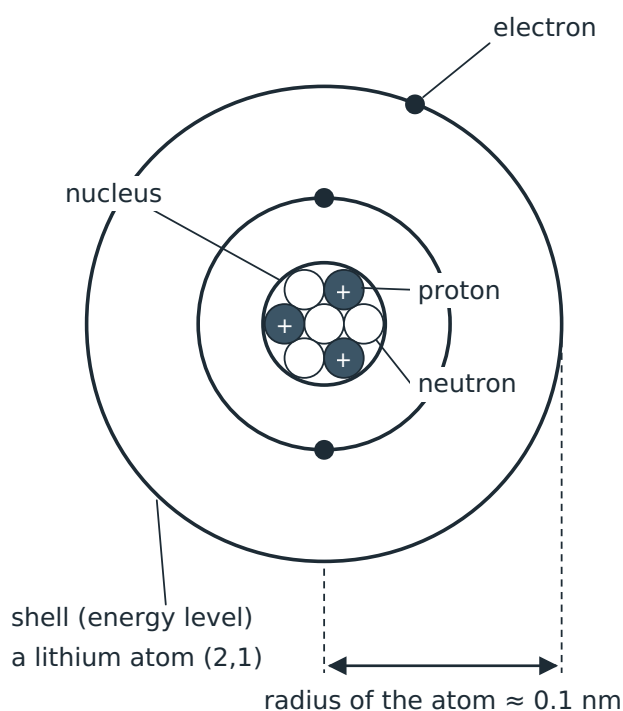
The nuclear atom (C1.2b)

You must be able to describe the atom as:

- a **positively charged nucleus** at the centre, **surrounded by negatively charged electrons**;
- with the **nuclear radius much smaller than the radius of the atom** — smaller by a factor of about ten thousand;
- with **most of the mass concentrated in the nucleus**, because protons and neutrons are nearly two thousand times heavier than electrons.

An atom is **neutral overall** because the number of protons equals the number of electrons, so the +1 and −1 charges cancel exactly.

The nuclear model of the atom, with the nucleus drawn far larger than it really is.



Particle	Relative charge	Relative mass
Proton	+1	1
Neutron	0	1
Electron	-1	very small (about 1/1800)

Size and mass of an atom

Radius of an atom ≈ 0.1 nm (1×10^{-10} m).

The radius of the nucleus is less than 1/10 000 of the radius of the atom (about 1×10^{-14} m).

Almost all of the mass of an atom is in the nucleus.

Atomic number = number of protons. Mass number = number of protons + number of neutrons. In an atom the number of electrons = the number of protons, so an atom has no overall charge.

ANALOGY

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

The size of atoms and molecules (C1.2c)

You must recall the typical size (order of magnitude) of atoms and small molecules: **typical atomic radii and bond lengths are of the order of 10^{-10} m** — that is 0.1 nm, or 1 ångström.

The subatomic particles (C1.2d)

You must recall the relative charges and approximate relative masses of the three subatomic particles.

Particle	Where it is	Relative charge	Relative mass
Proton	In the nucleus	+1	1
Neutron	In the nucleus	0	1
Electron	In shells around the nucleus	-1	very small — about 1/1836, taken as negligible

Two consequences worth stating in an exam answer:

- The **mass number** counts only protons and neutrons, because the electrons contribute almost nothing to the mass.
- Losing or gaining electrons changes the **charge** of a particle but not, for practical purposes, its **mass**.

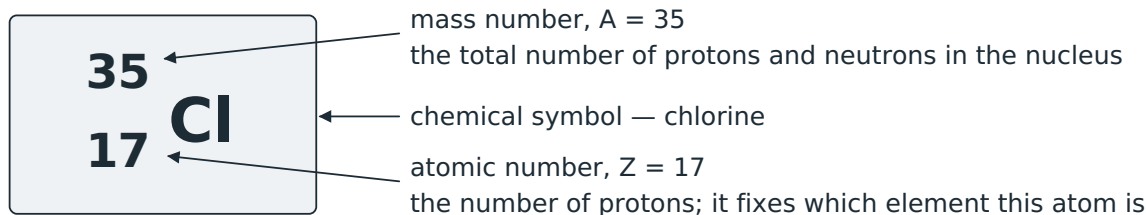
Atomic number, mass number, isotopes and ions (C1.2e)

The **standard notation** places the mass number above the atomic number, in front of the chemical symbol:

${}^{23}_{11}\text{Na}$ — mass number $A = 23$ on top, atomic number $Z = 11$ below.

Reading the standard notation, and what changes in an isotope and in an ion.

The standard notation for an atom



Isotopes — the neutrons differ

chlorine-35 — 17 protons, 18 neutrons

chlorine-37 — 17 protons, 20 neutrons

Both are neutral atoms with 17 electrons.

Same atomic number, different mass number:
the same element, a different neutron count.

Ions — only the electrons differ

aluminium atom — 13 protons, 14 neutrons,
13 electrons

aluminium ion, Al^{3+} — 10 electrons

Three electrons have been lost; the nucleus
is unchanged, so it is still aluminium.

number of neutrons = mass number – atomic number = $A - Z$

electrons in a neutral atom = Z

electrons in an ion = $Z - (\text{charge on the ion})$

WATCH OUT

Learners commonly struggle with **isotopes** because they assume a neutral atom must have **equal numbers of protons and neutrons**. It must have equal numbers of protons and *electrons* — that is what makes it neutral. Neutrons are uncharged, so the number of them is free to vary, and that is precisely what an isotope is.

A second, very common error is thinking that a **positive ion has gained protons, or a negative ion has lost protons** — that is, that the **nucleus** changes. It does not. Ions form only by the **loss or gain of electrons**; the proton number, and therefore the element, is unchanged. Na and Na^+ are both sodium.

Learners also find it hard to **distinguish the properties of atoms from those of molecules**. An oxygen atom, O , and an oxygen molecule, O_2 , are not the same thing and do not behave the same way.

NOTE

Why relative atomic masses are not whole numbers. An element's relative atomic mass is the **mean** mass of its atoms, weighted by how common each isotope is. Chlorine is a mixture of about three parts ${}^{35}\text{Cl}$ to one part ${}^{37}\text{Cl}$, which is why the Periodic Table gives 35.5 rather than a whole number — even though no single chlorine atom has a mass number of 35.5. The formal definitions of relative atomic mass, relative molecular mass and relative formula mass come in C2.1c.

NOTE

Electrons in shells — where this goes next. The Bohr model puts electrons in energy levels (shells) at fixed distances from the nucleus: the first holds up to 2 electrons, the next up to 8, and shells fill from the inside out, so sodium is 2,8,1. J248 assesses the **arrangement of electrons and its link to the Periodic Table and to chemical reactions in C2.2c and C2.2h**, not in C1.2 — but you need the idea here to make sense of Bohr's contribution to the atomic model.