

Elements, compounds and mixtures

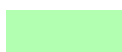
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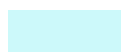
Revision notes for one topic, free to download.

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 Mixture

- two or more substances together but **not chemically joined**; each keeps its own properties.

Define Alloy

- a mixture of a metal with one or more other elements.

Define Relative molecular / formula mass (M_r)

- the sum of the A_r values of every atom in the formula.

Define Chromatography

- separating dissolved substances by how they distribute between two phases.

Define Ionic bond

- the strong electrostatic attraction between oppositely charged ions.

Define Metallic bond

- the attraction between positive metal ions and a sea of delocalised electrons.

Define Nanoparticle

- a particle roughly 1–100 nm across, holding a few hundred to a few thousand atoms.

Define Pure substance

- in chemistry, a single element or a single compound and nothing else.

Define Formulation

- a mixture made to a recipe, each component present in a measured quantity.

Define Relative atomic mass (A_r)

- the average mass of an atom of an element compared with **one twelfth of the mass of an atom of carbon-12**, allowing for the abundance of each isotope.

Define Empirical formula

- the simplest whole-number ratio of atoms of each element in a compound.

Define R_f value

- distance moved by a substance $\div$ distance moved by the solvent; between 0 and 1.

Define Covalent bond

- a shared pair of electrons, attracted to the nuclei of both atoms.

Define Polymer

- a very large molecule made by joining many monomers into a chain.

C2.1 Purity and separating mixtures

Elements and compounds are pure substances; mixtures are impure. Pure substances can be identified using melting point. Many useful materials are mixtures, and there are many ways of separating them.

Melting point as a test of purity (C2.1b)

- A **pure** substance melts **sharply at one fixed temperature** and boils at one fixed temperature.
- An **impure** one melts **over a range**, and that range is **lower** — which is why salt is spread on icy roads. Impurities **raise** boiling points and spread them over a range.
- So measure the melting point and compare it with the data-book value.

What "pure" means in chemistry (C2.1a)

- **Scientific use:** a pure substance contains **only one element or one compound**. Distilled water is pure; sea water is not.
- **Everyday use:** natural or unadulterated — "pure orange juice", "pure wool". Both are **mixtures**.
- A mixture is impure because its components are **not chemically joined** and can be separated **physically**.

WATCH OUT

Learners commonly **misuse the word pure**, confusing it with a natural substance or one that has not been tampered with. In chemistry it means one thing: **a single element or compound**. They also think that **once something dissolves the solution is pure** — a solution is a **mixture** of solute and solvent, however clear it looks.

Relative formula mass (C2.1c)

Empirical formulae (C2.1d)

Deduce the empirical formula **from the relative numbers of atoms, or from a model or diagram** — and **work back the other way**.

- The **empirical** formula is the simplest whole-number ratio; the **molecular** formula gives the real number of atoms per molecule. Ethene is C_2H_4 but **CH₂**; benzene C_6H_6 but **CH**; water is H_2O both ways.
- **Ionic compounds are always empirical formulae** — a lattice has no molecules, so NaCl means a 1 : 1 ratio of Na^+ to Cl^- .
- From a model: **count each element's atoms, then divide by the highest common factor**.

Formulations (C2.1e)

Many useful materials are **formulations** — mixtures in which every component is present in a **measured quantity**, so the product performs identically every time. **Alloys** are the spec's named example: steel (iron and carbon), brass, solder. An alloy is **harder** than the pure metal because differently sized atoms disrupt the layers, so they cannot slide. Paints, fuels, fertilisers and medicines are formulations too — each still a **mixture**, so chemically **impure**.

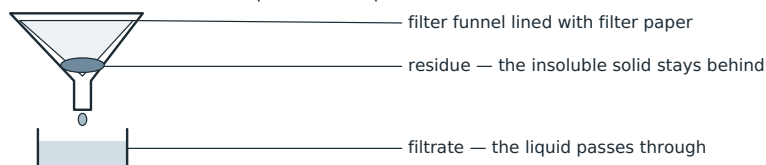
Separating mixtures (C2.1f)

Technique	What it separates	How it works
Filtration	Insoluble solid from a liquid	Liquid passes through as filtrate , solid trapped as residue
Crystallisation	A dissolved solid from its solution	Evaporate to saturation, then cool slowly so crystals grow
Simple distillation	A liquid from a solution	Boil, then condense the vapour; solids stay behind
Fractional distillation	Miscible liquids of different boiling point	A column gives a temperature gradient; lowest-boiling reaches the top first
Paper / thin layer chromatography	Dissolved solutes with different attractions to the phases	The solvent carries them at different speeds
Gas chromatography	Vaporisable components of a complex mixture	A carrier gas moves them along a column; each leaves at a different time

Filtration, crystallisation, simple distillation and fractional distillation.

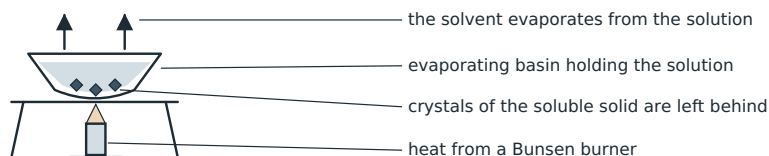
Filtration

Separates an insoluble solid from a liquid, for example sand from water.



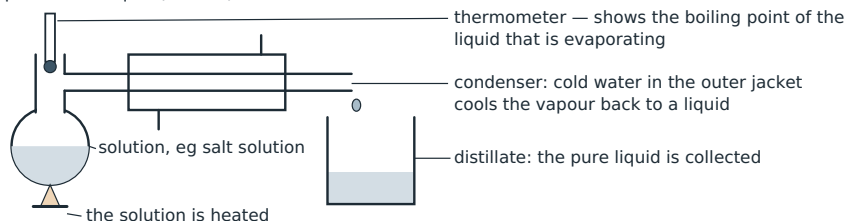
Crystallisation

Separates a soluble solid from its solution, for example salt from salt solution.



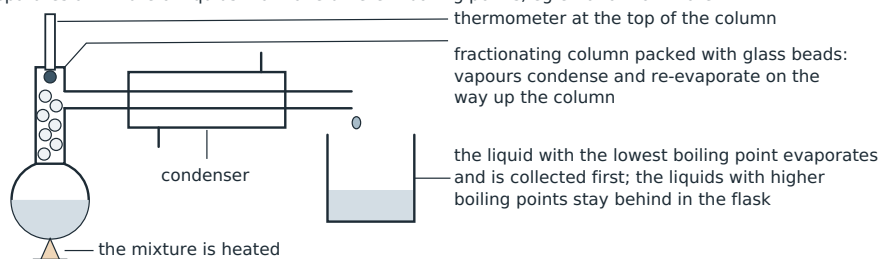
Simple distillation

Separates the liquid (solvent) from a solution — the dissolved solid is left in the flask.



Fractional distillation

Separates a mixture of liquids that have different boiling points, eg ethanol from water.



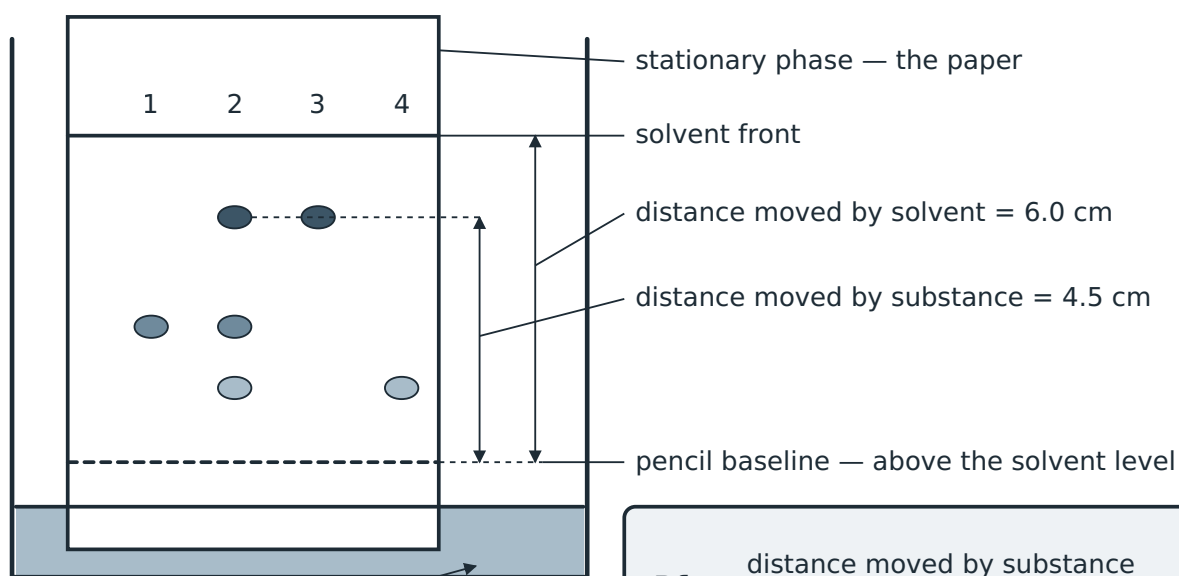
Chromatography (C2.1g–h)

The technique (C2.1g)

1. Rule the baseline in **pencil** — pencil is insoluble and will not run.
2. Spot the samples on it, keeping the spots small; dry and re-spot to concentrate them.
3. Stand the paper or TLC plate in solvent with the **solvent level below the baseline**, or the spots dissolve away; cover the tank.
4. Remove it before the solvent reaches the top and **mark the solvent front in pencil at once**.
5. Solvents may be **aqueous** or **non-aqueous** (ethanol, propanone), changing how far each substance travels. Colourless spots are revealed by a **locating agent** such as ninhydrin, or by ultraviolet light.

The two phases (C2.1h). The **stationary phase** does not move — the paper, or the silica layer on a plate; the **mobile phase** is the solvent moving through it. Separation depends on the **distribution of each substance between the phases**: the more soluble in the solvent, the **further** it travels.

Paper chromatography, and how an R_f value is measured.



mobile phase — the solvent, which moves up the paper

- 1 pure substance — one spot only
- 2 mixture — separates into three spots
- 3 reference substance A
- 4 reference substance B

$$R_f = \frac{\text{distance moved by substance}}{\text{distance moved by solvent}}$$

$$R_f = 4.5 \div 6.0 = 0.75 \text{ (no units)}$$

A pure compound gives a single spot in all solvents; a mixture separates into several spots. Separation depends on the distribution of the substances between the two phases.

ANALOGY

Chromatography — a coach party in a shopping centre. The coach is the mobile phase, the shops the stationary phase. Everyone starts together at the entrance (the baseline). Shoppers who ignore the shops stay on the coach and get a long way; those who keep stopping fall behind. Nobody turns into anybody else — they simply end up spread out along the route, which is what a chromatogram shows.

Interpreting chromatograms (C2.1i)

- **One spot** in a lane = a **pure** substance; two or more = a mixture, one spot per soluble component.
- A substance matching a reference in **both colour and R_f** , in **the same run**, is likely to be that substance.
- R_f values compare only **within one chromatogram**: they depend on solvent, phase and temperature.

Choosing a method (C2.1j–k)

Suggest a purification technique from the properties given (C2.1j): insoluble solid → **filtration**; want the dissolved solid back → **crystallisation**; want the liquid back → **simple distillation**; two miscible liquids with different boiling points → **fractional distillation**; small amounts dissolved → **chromatography**.

Suggest chromatographic methods for distinguishing pure from impure substances (C2.1k) using paper, thin layer (TLC) and gas chromatography. *TLC is faster, gives sharper spots and copes with colourless substances under UV; gas chromatography separates very complex mixtures, so it checks fuels, drugs and food additives. In every case: a pure substance gives one spot or one peak, an impure one gives more.*

C2.2 Bonding

A simple electron energy level model explains the basic chemical properties of elements. Reactions are explained by losing, gaining or sharing electrons, and an atom's ability to do so depends on its atomic structure.

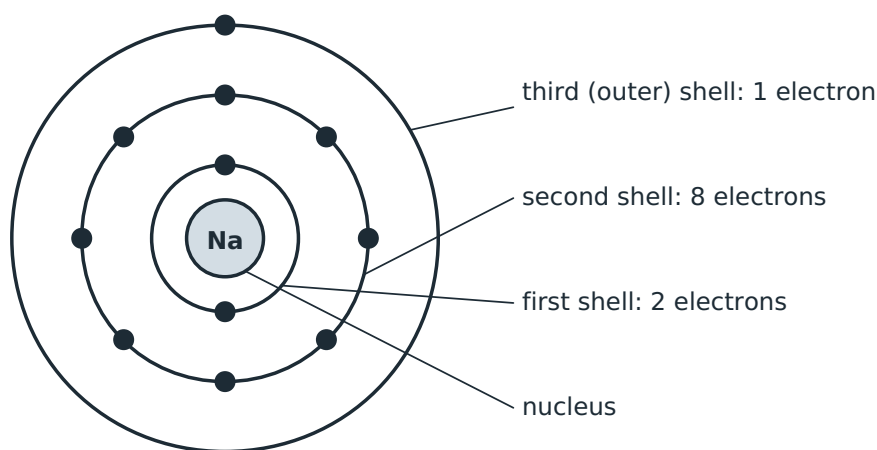
Electron arrangement and the Periodic Table (C2.2c)

- Electrons occupy **energy levels (shells)**, filling from the inside out: **2**, then **8**, then **8**.
- Write arrangements with commas: sodium (11) is **2,8,1**; chlorine (17) is **2,8,7**; argon (18) is **2,8,8**.
- **Group number = number of outer-shell electrons; period number = number of occupied shells.**
- Electrons equal protons, so position follows from the **atomic number** — how the modern table is ordered.

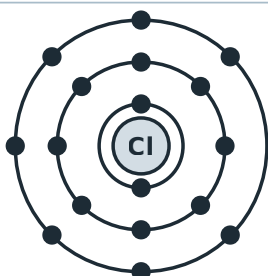
Metals and non-metals (C2.2a–b)

- **Metals** are shiny, good conductors of heat and electricity, malleable and ductile, mostly with high melting points; **non-metals** are dull, poor conductors (graphite excepted), brittle when solid, and many are gases.
- Metals **lose** electrons to form **positive ions**; non-metals **gain** or **share** electrons, forming **negative ions** with metals.
- **Metal oxides are basic**, reacting with acids to give salts, and soluble ones give alkaline solutions; **non-metal oxides are acidic**, dissolving to give acidic solutions.
- Metals sit **left and centre** of the Periodic Table, non-metals **upper right (C2.2b)**, because metals have **few outer-shell electrons**, easily lost, while non-metals have **nearly full outer shells** — the one difference behind every property above.

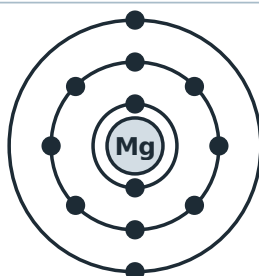
Electron arrangements, and how the outer shell fixes the group and the number of shells fixes the period.



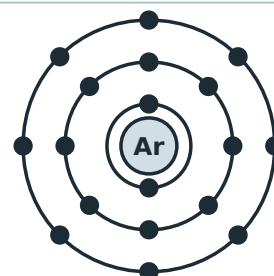
Sodium (Na), 2,8,1
11 protons, so 11 electrons



Chlorine (Cl)
2,8,7
Group 7: 7 outer electrons



Magnesium (Mg)
2,8,2
Group 2: 2 outer electrons



Argon (Ar)
2,8,8
Group 0: full outer shell

- Electrons occupy the lowest available energy levels (the innermost shells) first: 2, then 8, then 8.
- Electrons in the outer shell = the group number. Group 0 atoms have a full outer shell.

Types of bonding and structure (C2.2d–e)

	Ionic	Covalent	Metallic
Between	Metal and non-metal	Non-metal atoms	Metal atoms
Electrons	Transferred, giving + and – ions	Shared in pairs between two atoms	Delocalised across the structure
The bond is	Electrostatic attraction between oppositely charged ions, in all directions	Attraction of both nuclei to the shared pair	Attraction between positive ions and the sea of delocalised electrons
Structure	Giant ionic lattice	Simple molecules, giant covalent structures or polymers	Giant lattice of layers of ions
Example	NaCl, MgO	H ₂ O, CO ₂ ; diamond, SiO ₂ ; poly(ethene)	Cu, Fe, Mg

Simple molecules have strong covalent bonds inside them but only **weak intermolecular forces** between them; **giant covalent structures** have covalent bonds throughout the lattice and no molecules; **polymers** are very long covalent molecules, so their intermolecular forces add up (C2.2d-e).

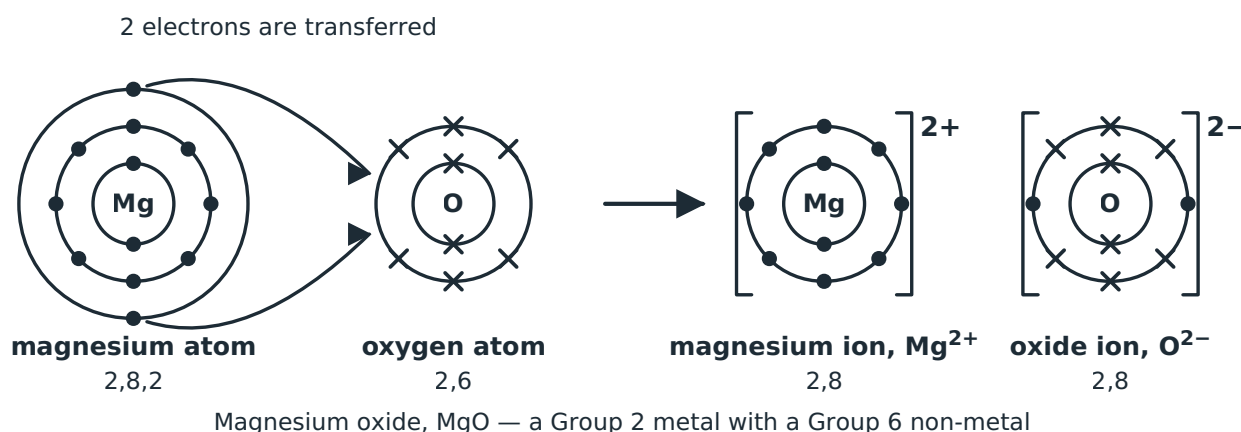
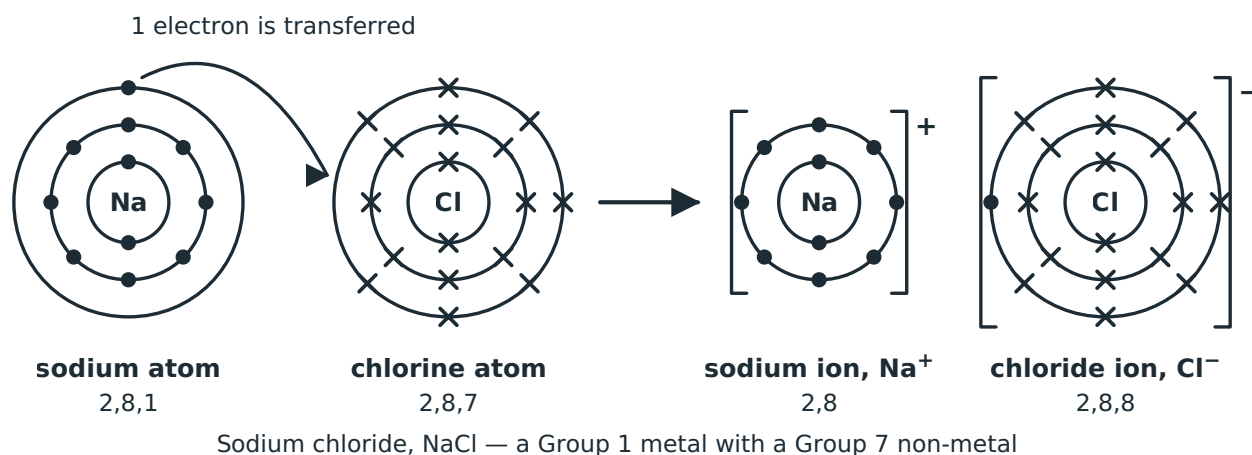
Dot and cross diagrams, and the limits of models (C2.2f-g)

Drawing them (C2.2f). Show **outer-shell electrons only**, dots for one atom and crosses for the other. **Covalent:** overlap the outer shells, shared pair in the overlap — one pair in H_2 , two in O_2 , three in N_2 . **Ionic:** draw the ions **separately, in square brackets with the charge outside** — Na^+ as 2,8, Cl^- with eight outer electrons, one of them the transferred dot.

ANALOGY

Ionic versus covalent — giving versus sharing. An ionic bond is a **transfer of ownership**: the metal hands its outer electron over for good, both particles become charged, and opposite charges attract in **every direction on every neighbour** — hence a giant lattice. A covalent bond is a **shared season ticket**: neither atom gives anything away, both nuclei are attracted to the same pair, so the bond acts only **between those two atoms** and a separate molecule results. Both attractions are electrostatic; what differs is whether the electrons are handed over or held in common.

Dot and cross diagrams for the transfer of electrons in ionic bonding.



● = an electron from the metal atom ✕ = an electron from the non-metal atom

Metal atoms lose electrons to form positively charged ions; non-metal atoms gain electrons to form negative ions. Both ions get the electronic structure of a noble gas.

Dot and cross diagrams and displayed formulae for simple molecules.

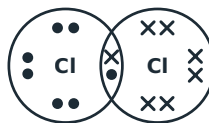
Hydrogen, H₂

displayed formula



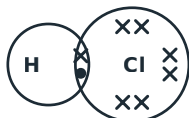
Chlorine, Cl₂

displayed formula



Hydrogen chloride, HCl

displayed formula



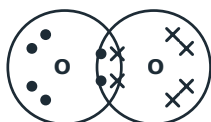
Water, H₂O

displayed formula



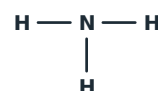
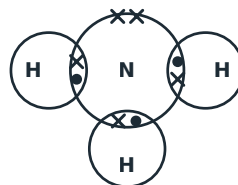
Oxygen, O₂

displayed formula



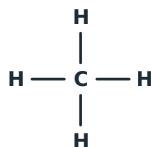
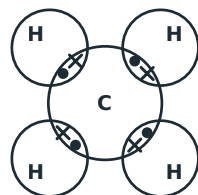
Ammonia, NH₃

displayed formula



Methane, CH₄

displayed formula



Key

• = an electron from one atom

× = an electron from the other atom

Only the outer shell electrons are shown.

Each shared pair of electrons is one covalent bond, shown as one line in the displayed formula.

Limitations (C2.2g)

- **Dot and cross diagrams** — electrons are not really labelled, they are identical; no shape, no relative size.
- **Ball and stick models** (OCR's suggested activity here) — good for shape and bond angles, but a bond is not a solid rod, atoms are not hard balls, and the spacing is exaggerated.
- **2D drawings** of giant structures show only a fragment; the lattice continues in every direction. No model does everything, so chemists pick the one showing the feature they need.

WATCH OUT

Learners commonly do not appreciate that **the nucleus does not change when an electron is lost, gained or shared** — only the electrons move. They also **find it hard to predict how many atoms must bond** to give everything a stable outer shell, which is why MgCl₂ and Na₂O cause trouble: balance the charges first, then write the formula. Two more from OCR's list: **chemical bonds are not physical things made of matter** — a bond is a force of attraction, not a stick or glue; and **a pair of ions such as Na⁺ and Cl⁻ is not a molecule** — every Na⁺ is surrounded by six Cl⁻ throughout a giant lattice, so "NaCl" is a **ratio**. Learners also lack **awareness of the 3D nature of bonding**, and so of **molecular shape**: water is bent, not straight.

Reactions, electron arrangement and Mendeleev (C2.2h–i)

Reactions and electrons (C2.2h). Elements react to reach the full outer shell of a noble gas. **Group 1** atoms have one easily lost outer electron, so they form 1+ ions; **Group 7** atoms need one more, so they form 1– ions; **Group 0** atoms already have a full shell and are unreactive — the strongest evidence for the model. Elements in a group react alike **because they have the same number of outer electrons**, which follows from the atomic number.

Mendeleev to the modern table (C2.2i). Mendeleev ordered the known elements by **relative atomic mass** but kept those with similar properties in the same group, **leaving gaps** for undiscovered elements and predicting their properties — swapping a few pairs out of mass order to make the pattern work. Once **atomic number** was known the anomaly vanished: ordering by **number of protons** places every element correctly, and the repeating pattern of outer-shell electrons explains the periodicity. The noble gases were added as Group 0.

C2.3 Properties of materials

This section explores the physical properties of elements and compounds, and how the nature of their bonding is a factor in those properties.

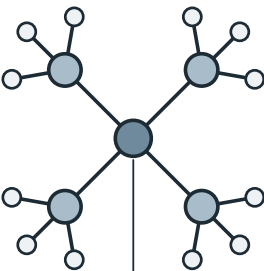
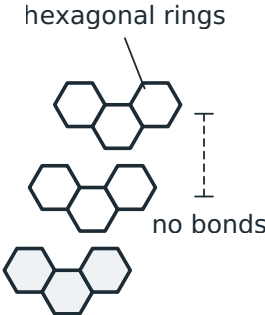
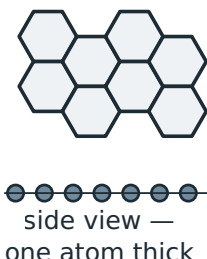
Diamond, graphite, fullerenes and graphene (C2.3c)

- **Diamond** — giant covalent, each carbon bonded to **four** others in a rigid 3D lattice: very hard, very high melting point (many strong covalent bonds), and **does not conduct**, having no free electrons.
- **Graphite** — giant covalent, each carbon bonded to **three** others in **layers of hexagons**, with weak forces between the layers and **one delocalised electron per atom**: soft and slippery as the layers slide, high melting point, and it **conducts**.
- **Graphene** — a **single layer of graphite**, one atom thick: very strong for its mass, transparent and an excellent conductor, used in electronics and composites.
- **Fullerenes** — carbon in **hollow cages, spheres or tubes** built from rings, C₆₀ being buckminsterfullerene: simple molecular, so a far **lower melting point** than diamond; cages carry other molecules, and nanotubes are strong and conduct.

Carbon and organic compounds (C2.3a–b)

- **Carbon forms four covalent bonds (C2.3a)** — it has four outer electrons and needs four more.
- Carbon atoms bond strongly **to each other** as well as to other elements, building **chains, branched chains and rings** of almost unlimited length (C2.3b).
- Hence the **vast array of natural and synthetic organic compounds**, grouped into **families of similar compounds** whose members differ by chain length, so properties follow a predictable trend.

Diamond, graphite, graphene and the fullerenes.

Diamond	Graphite	Graphene	Fullerenes
 each C: 4 bonds	 hexagonal rings no bonds	 side view — one atom thick	 C₆₀ — a hollow ball  carbon nanotube
Each carbon atom forms 4 covalent bonds — giant covalent structure Very hard, very high melting point Does not conduct electricity	Each carbon atom forms 3 covalent bonds, in layers of hexagonal rings No bonds between layers, so it is soft 1 delocalised electron per atom — conducts	A single layer of graphite — one atom thick Very strong for its low mass Conducts electricity Used in electronics and composites	Molecules of carbon with hollow shapes, based on hexagonal rings (some 5- or 7-carbon rings) C₆₀ was the first one Nanotubes: cylinders, high length:diameter

Bond strength, intermolecular forces and changes of state (C2.3d–e)

Melting and boiling points (C2.3d). Energy is needed to overcome the forces between the particles, and which forces those are sets the temperature.

- **Simple molecular substances melt and boil at low temperatures:** only the *weak intermolecular forces* are overcome — the covalent bonds inside the molecules are not broken.
- **Giant covalent and ionic structures melt at very high temperatures:** strong bonds or attractions run through the whole lattice.
- Within a family, **larger molecules have stronger intermolecular forces**, so boiling point rises down the family — the basis of fractional distillation.

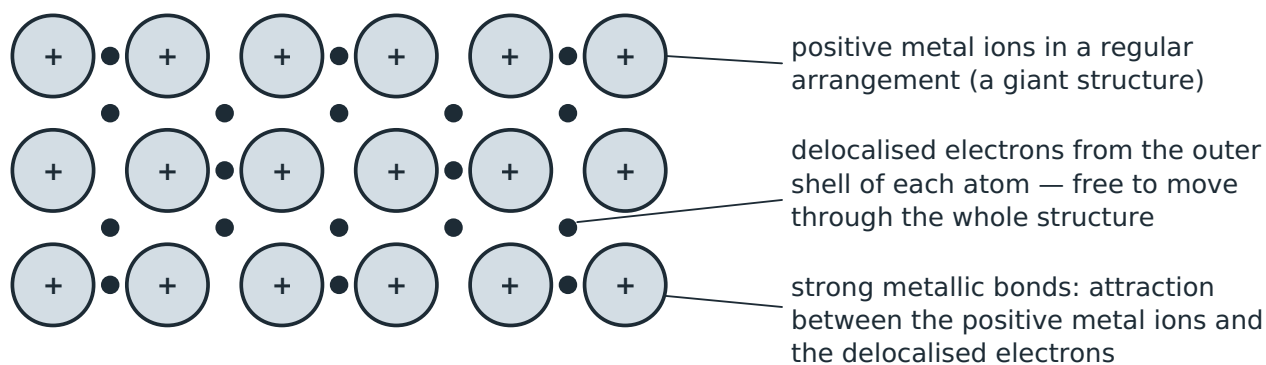
Predicting states from data (C2.3e). Below the melting point → solid; between the two values → liquid; above the boiling point → gas. So at 25 °C oxygen (bp –183 °C) is a gas, water (mp 0 °C, bp 100 °C) a liquid and sodium chloride (mp 801 °C) a solid; at 1500 °C sodium chloride (bp 1413 °C) has become a gas while silicon dioxide (mp 1610 °C) is still solid. Very high melting points signal giant structures, low ones simple molecules.

Bulk properties and bonding (C2.3f)

Bulk properties follow from **the types of bond present, their strength relative to intermolecular forces, and how the bonds are arranged.**

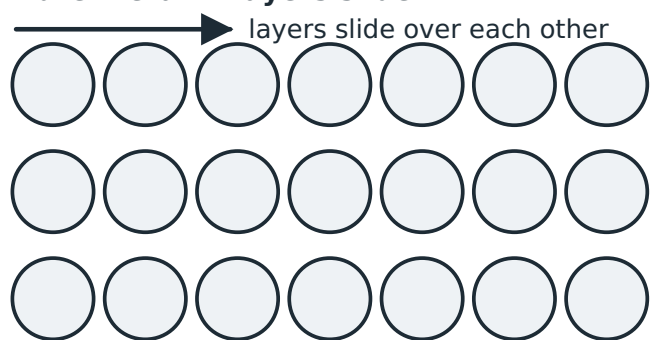
- **Ionic compounds** — high melting points; **brittle**, because displacing the layers brings like charges together and they repel; **do not conduct when solid but do when molten or dissolved**, the ions being free to move.
- **Simple molecules** — low melting and boiling points; **never conduct**, having no overall charge.
- **Giant covalent** — very high melting points, hard, insoluble, non-conducting (graphite and graphene excepted).
- **Polymers** — solid but flexible; long chains touch at many points, so intermolecular forces add up.
- **Metals** — conduct through **delocalised electrons**; malleable and ductile as **layers of ions slide**; high melting points.

Metallic bonding, and why a pure metal is malleable but an alloy is harder.



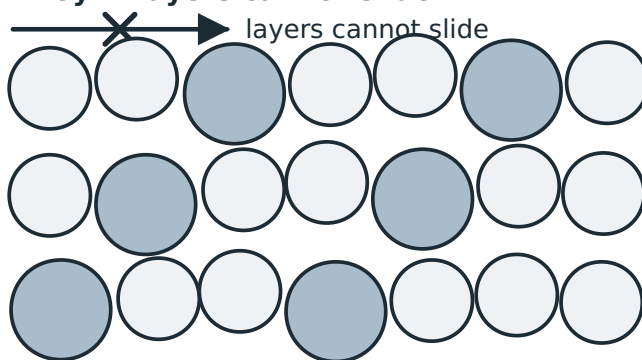
Metals conduct electricity and thermal energy because the delocalised electrons are free to move through the whole structure, carrying charge and energy.

Pure metal — layers slide



The atoms are all the same size, so the layers of atoms can slide over each other. Pure metals are soft and can be bent and shaped.

Alloy — layers cannot slide



The larger shaded atoms are atoms of a different element. They distort the layers, so the layers can no longer slide over each other — the alloy is harder.

WATCH OUT

Learners commonly have a **limited understanding of what can happen during a chemical reaction** — that substances may **explode, burn, contract, expand or change state**. A bang, a flame, a colour change, a precipitate or a temperature rise are all *observations*, and any may accompany a reaction. The matching structural error is expecting **atoms themselves to have the bulk properties of the material** (C2.3f): one copper atom is not shiny, malleable or a conductor, and one water molecule is not wet. **Bulk properties belong to the structure, not the particle.**

CHEMISTRY ONLY Nanoparticles (C2.3g–j)

CHEMISTRY ONLY Comparing "nano" dimensions with atoms and molecules (C2.3g). Nanoparticles are about **1–100 nm**, that is 1×10^{-9} to 1×10^{-7} m. An atomic radius is about 1×10^{-10} m, so a nanoparticle is **tens to a thousand times wider than an atom** and holds a few hundred to a few thousand atoms.

CHEMISTRY ONLY Surface area to volume and properties (C2.3h). As particles shrink, the proportion of atoms at the **surface** rises steeply. Chemistry happens at surfaces, so nanoparticles are **far more reactive** than the same mass of ordinary powder, and their optical, electrical and melting behaviour can differ from the bulk material.

CHEMISTRY ONLY Properties and uses (C2.3i). **Catalysts** — huge surface area per gram, so less expensive metal is needed. **Sun creams** — nanoparticulate titanium dioxide and zinc oxide block ultraviolet light yet stay **transparent**. **Silver nanoparticles** in dressings, socks and masks kill bacteria. **Deodorants, cosmetics and self-cleaning surfaces** use thin, even coatings. **Carbon nanotubes** are strong and conduct, so they appear in electronics, sensors and composites.

CHEMISTRY ONLY Possible risks (C2.3j). Explain them, do not just list them:

- They are small enough to be **breathed deep into the lungs, enter the bloodstream and cross into cells**, and may pass through skin.
- Their **very high reactivity** can produce effects the bulk material never shows, so bulk safety data cannot be assumed to apply.
- **Long-term effects on health and the environment are not yet known**, because the materials are new and studies are short.
- They are already in consumer products, so exposure runs ahead of the evidence — an argument for more testing, labelling and regulation. A good answer weighs these risks against the benefits above.