

2 · Bonding, structure and the properties of matter

AQA · GCSE · Chemistry

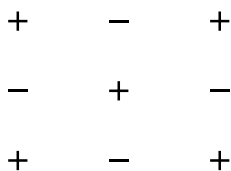
Bonding, structure and the properties of matter

- Three types of strong chemical bond hold atoms or ions together: ionic (attraction between oppositely charged ions), covalent (shared electron pairs) and metallic (delocalised electrons).
- Structure follows bonding: giant **ionic lattices** , small molecules, polymers, giant covalent structure networks and metal lattices – each predicts melting point and conductivity.
- Carbon shows every trick: **diamond** , **graphite** , **graphene** , fullerenes; nanoparticles (chemistry only) turn **surface area** into properties.

Ionic, covalent and metallic bonding (4.2.1)

Three strong chemical bonds, all explained by **electrostatic forces** :

Ionic lattice fragment



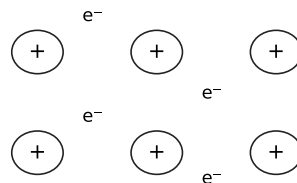
Opposite ions attract in all directions.

Small covalent molecule



Shared pair attracted to both nuclei.

Metallic structure fragment



Mobile electrons; positive ions fixed.

- **Ionic** – the bond is electrostatic attraction between oppositely charged ions. During formation, a metal atom **transfers** outer electrons to a non-metal: metal atoms lose electrons to become **positive ions**; non-metal atoms gain them to become **negative ions**; Groups 1/2 metals and 6/7 non-metals form ions with **noble-gas electronic structures**. Draw the electron transfer with **dot and cross diagrams**; deduce ion charges from group number (Group 1 → +1, Group 2 → +2, Group 6 → -2, Group 7 → -1).
- **Covalent** – non-metal atoms **share pairs of electrons**. Know dot-and-cross diagrams for **H₂, Cl₂, O₂, N₂, HCl, H₂O, NH₃, CH₄**, and line representations for small molecules, polymer repeating units and giant covalent structures.

- **Metallic** – a giant regular structure of positive metal ions with **delocalised outer electrons** free to move through the whole structure; the sharing of these electrons gives strong metallic bonding.

Know the **limitations of models**: dot-and-cross, ball-and-stick, 2D and 3D diagrams all simplify – forces are not drawn, sticks suggest gaps between touching particles, a flat drawing does not fully show 3D arrangement, and a giant structure is represented by only a fragment. Deduce empirical formulae from lattice models; molecular formulae from molecule diagrams.

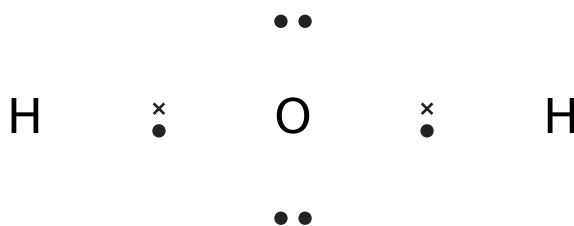
■ Build an electron diagram, then check it

For a small molecule, add the outer electrons from every atom. Choose shared pairs so hydrogen has two electrons around it and the other named atoms have eight. Add the remaining electrons as **lone pairs**. Dots and crosses record where electrons came from; the electrons themselves are identical. A single bond shares two electrons, a double bond four, a triple bond six.

Molecule	Total outer electrons	Shared pairs	Lone pairs remaining
H ₂	2	1	0
Cl ₂	14	1	3 on each Cl
O ₂	12	2	2 on each O
N ₂	10	3	1 on each N
HCl	8	1	3 on Cl
H ₂ O	8	2	2 on O
NH ₃	8	3	1 on N
CH ₄	8	4	0

Worked method: water. Oxygen supplies six outer electrons and two hydrogen atoms supply one each: total eight. Two shared O–H pairs use four electrons. The other four form two lone pairs on oxygen. Every hydrogen has two electrons around it; oxygen has eight. The flat electron drawing does not establish the molecule's 3D shape.

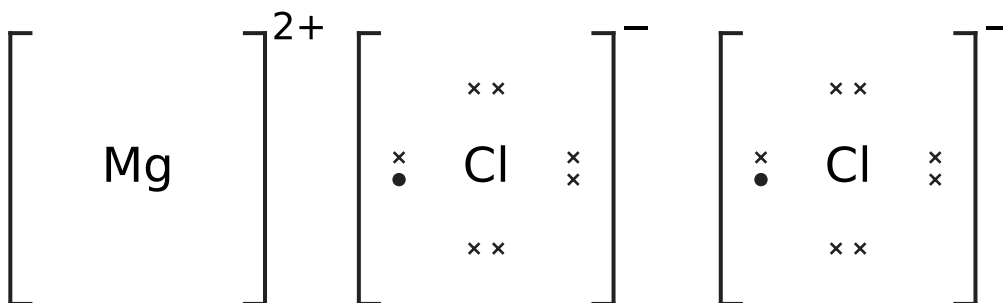
water: dots from O; crosses from H



Flat electron model: positions do not establish the 3D shape.

Worked method: magnesium chloride. Mg starts 2,8,2 and loses two electrons, becoming Mg^{2+} with configuration 2,8. Two chlorine atoms each start 2,8,7 and gain one electron, becoming two Cl^- ions with configuration 2,8,8. Draw brackets and charges around every ion. Each chloride has seven original electrons and one gained electron. An outer-electron diagram may leave Mg's former third shell empty; this does not mean the ion contains no electrons.

MgCl_2 : one Mg^{2+} and two Cl^- ions



Each chloride: seven crosses + one magnesium dot.
 Mg^{2+} has configuration 2,8; its old third shell is empty.

The formula follows charge balance: one Mg^{2+} needs two Cl^- ions, so MgCl_2 . A lattice fragment with 6 positive ions for every 12 negative ions has simplest ratio 1:2. Do not read $\text{Mg}_6\text{Cl}_{12}$ as the formula of an individual molecule: the ionic structure is giant. A finite edge of a drawing can also distort apparent counts; use the repeating pattern and charges.

A **line representation** replaces each shared pair with one line. Water is $\text{H}-\text{O}-\text{H}$, oxygen is $\text{O}=\text{O}$ and nitrogen $\text{N}\equiv\text{N}$. Lone pairs are omitted in these line formulae. In a polymer, a bracketed repeat unit represents a small section of a very long covalently bonded chain; continuation bonds cross the brackets. In a giant covalent diagram, bonds continue beyond the fragment in a network, rather than stopping at an individual molecule.

Bonding, structure and properties (4.2.2)

States of matter: solid, liquid, gas; melting/freezing at the **melting point**, boiling/condensing at the **boiling point**. Particle theory (small solid spheres) explains the changes; the stronger the forces between particles, the higher the melting/boiling points. (HT) The simple model's limits: no forces shown, all spheres, solid particles. **State symbols:** (s), (l), (g), (aq).

Structure	Bonding/forces	Melting point	Conducts electricity?
ionic lattice	strong electrostatic forces in all directions	high	only when molten or dissolved – ions free to move
small molecules	strong covalent bonds inside , weak intermolecular forces between	low – only weak intermolecular forces are overcome	no – neutral molecules have no mobile ions or delocalised electrons
polymers	strong covalent chains, stronger intermolecular forces	solid at room temperature	no
giant covalent	every atom covalently bonded	very high	generally no; graphite and graphene have mobile delocalised electrons
metals	metallic bonding – delocalised electrons	mostly high	yes – delocalised electrons carry charge (and heat)

Larger molecules → stronger intermolecular forces → higher melting/boiling points. Alloys are harder than pure metals because different-sized atoms **distort the layers**, stopping them sliding.

■ Predict a state and explain a change

At the stated pressure, a pure substance is solid below its melting point, liquid between melting and boiling points, and gas above its boiling point. At a transition temperature, two states can coexist. **Worked example:** X melts at $-15\text{ }^{\circ}\text{C}$ and boils at $65\text{ }^{\circ}\text{C}$. It is solid at $-30\text{ }^{\circ}\text{C}$, liquid at $20\text{ }^{\circ}\text{C}$ and gas at $90\text{ }^{\circ}\text{C}$. A temperature number alone is not enough without the material's transition data.

In a solid, particles vibrate around fixed positions. During melting they gain enough energy to move past one another but remain close together. During boiling, particles separate much further as attractions are overcome. Cooling reverses these changes and transfers energy to the surroundings. The particles do not swell into larger atoms on heating. An individual atom does not have the melting point, hardness or conductivity of a bulk sample: those properties depend on a collection of particles and their structure.

Use a causal explanation: **structure** $\rightarrow$ **force or charge carrier** $\rightarrow$ **property**. For solid NaCl, oppositely charged ions attract strongly in all directions, so melting needs much energy. Its ions are fixed, so it does not conduct. Molten NaCl retains charged ions, but they move and carry charge. For a metal, mobile delocalised electrons carry charge in the solid; for a small molecular liquid, moving neutral molecules alone do not carry an electrical current.

Worked comparison: a polymer chain has strong covalent bonds along it. Relatively strong intermolecular attractions between the large chains make common polymers solid at room temperature. Softening the polymer does not require breaking every covalent bond along every chain. In a giant covalent network such as silica, strong covalent bonds extend throughout the structure, so many bonds must be overcome to melt it. These are different structures even though both contain covalent bonds.

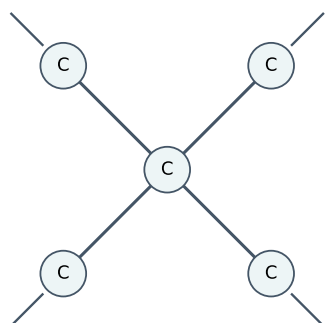
Pure metal layers can slide as the metallic attraction remains. Different-sized atoms in an alloy distort the regular layers, making sliding harder. This explains increased hardness; it does not mean that all pure metals are easily scratched or that an alloy has no movable electrons.

Structure and bonding of carbon (4.2.3)

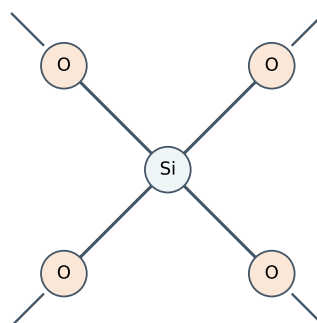
- **Diamond** – a giant covalent structure in which each carbon forms **four** covalent bonds: **very hard, very high melting point, does not conduct**.
- **Graphite** – each carbon forms **three** bonds, layers of hexagonal rings with **no covalent bonds between layers** (soft, slippery – lubricant); **one delocalised electron per atom** $\rightarrow$ conducts electricity like a metal.
- **Graphene** – a **single layer of graphite**: one atom thick, strong, conducts – electronics and composites.

- **Fullerenes** – hollow molecules of carbon hexagons (plus 5- or 7-membered rings); **Buckminsterfullerene C₆₀** is spherical. **Carbon nanotubes** – cylindrical fullerenes with huge length-to-diameter ratios: nanotechnology, electronics, materials.

Local coordination projections; bonds continue into giant 3D structures



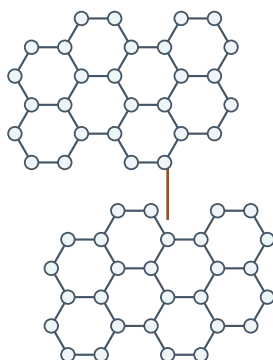
Diamond: four C neighbours



Silica: four O neighbours;
each O bridges to another Si

2D projection does not show actual bond angles. Silica oxygens are shared: SiO₂ overall.

Graphite: hexagonal covalent layers, with weaker attraction between layers



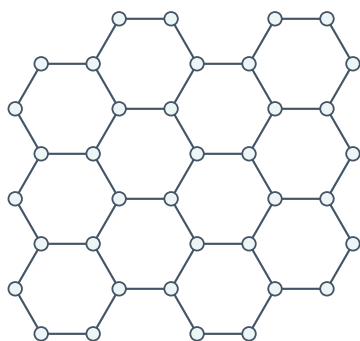
Strong covalent
bonds within layers

One delocalised
electron per carbon

No covalent bonds
between layers

Each interior carbon has three neighbours. Cut edges omit further bonds.

Graphene: one hexagonal carbon layer

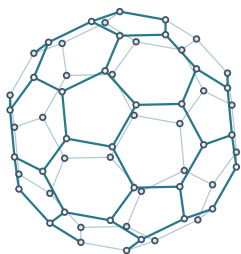


Strong covalent
connections

Delocalised
electrons

Carbon atoms shown at vertices; cut edges continue. Single-layer schematic.

C₆₀ carbon-bond projection and schematic nanotube shape



C₆₀: spherical cage
60 carbon atoms

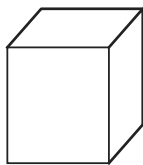


Nanotube: long hollow cylinder
large length/diameter ratio

C₆₀: 60 vertices, 90 bonds; rear edges pale. Nanotube outline omits its carbon-ring bonds.

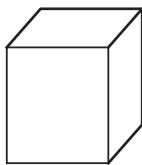
Bulk and surface properties incl. nanoparticles – chemistry only (4.2.4)

Nanoscience = structures **1–100 nm**; the smallest are of the order of a few hundred atoms. Particle size and atom count are different quantities. Nanoparticles are smaller than **fine particles** (PM_{2.5}, 100–2500 nm), which are smaller than **coarse particles/dust** (PM₁₀ in this specification, 2.5×10^{-6} – 1×10^{-5} m).



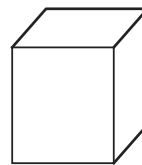
side = 100 nm
 $A/V = 0.06 \text{ nm}^{-1}$

Schematic cube; not drawn to scale.



side = 10 nm
 $A/V = 0.6 \text{ nm}^{-1}$

Schematic cube; not drawn to scale.



side = 1 nm
 $A/V = 6 \text{ nm}^{-1}$

Schematic cube; not drawn to scale.

Surface area : volume: as a cube's side **decreases 10×**, SA:V **increases 10×**. Nanoparticles may have different properties from the bulk material because of this high ratio – catalysts (smaller quantities work), medicine delivery, cosmetics, electronics. Concerns: effects inside the body and in the environment are not fully known.

■ Compare equal amounts, not just one particle

For a model cube of side l , surface area $A = 6l^2$ and **volume** $V = l^3$, so $A/V = 6/l$. The quotient has an inverse-length unit. **Worked example:** a 100 nm cube has $A = 60\,000 \text{ nm}^2$, $V = 1\,000\,000 \text{ nm}^3$ and $A/V = 0.06 \text{ nm}^{-1}$. A 10 nm cube has $A = 600 \text{ nm}^2$, $V = 1000 \text{ nm}^3$ and $A/V = 0.6 \text{ nm}^{-1}$: ten times larger. The smaller individual cube has less area, but the same total volume divided into smaller cubes has more total exposed area.

One nanometre is 10^{-9} m . A 20 nm particle is $2.0 \times 10^{-8} \text{ m}$ across, about 200 times a typical 0.1 nm atom diameter. It is not one large atom. A 0.2 nm cube would lie below the specified nanoparticle range, so it is not a suitable nanoparticle example.

Evaluate given information. Suppose equal masses of a material remove the same pollutant in 12 minutes as nanoparticles and 40 minutes in bulk form. The tested nano form acts faster; greater exposed area per mass is a plausible explanation. This result alone does not prove that a skin product is safe, cheap or environmentally harmless. Weigh the stated benefit against exposure, possible health/environmental effects and the limits of the evidence. Ask what further measurements would resolve the particular uncertainty. Do not claim that all nanoparticles enter the skin or that all are harmful.

Checklist before you call this topic done

- The three bonds in terms of electrons and electrostatic forces; ion charges from group numbers.
- Dot-and-cross for the eight named molecules; model limitations named.
- The properties table above rebuilt from memory – which forces are overcome on melting.

- Diamond vs graphite vs graphene vs fullerenes, bonding to property; apply this reasoning to an unfamiliar use.
- (Chem) SA:V factor-of-10 rule; the three particle-size bands and nanoparticle uses and concerns.