

Metallic Bonding and Types of Solids

Why do metals conduct, why is diamond hard, and why does salt melt at 801 °C?

●○○ Beginner

Bonding & Molecular Structure

Last reviewed 5 October 2026

Before you start: it helps to understand [Ionic and Covalent Bonds](#).

What is it?

Three kinds of strong bond hold matter together: **ionic** (between ions), **covalent** (shared pairs of electrons) and **metallic**.

Metallic bonding is the attraction between **positive metal ions** arranged in a regular lattice and a “sea” of **delocalized electrons** that are free to move through the whole structure. Each metal atom gives its outer electrons to the sea; the electrons are shared by all the ions at once, rather than belonging to one bond.

The type of bonding, and the way the particles are arranged, decide the kind of **solid** a substance forms:

Type of solid	Particles	Held by	Examples
Ionic	Positive and negative ions	Ionic bonds throughout a lattice	NaCl, MgO, CaCO ₃
Molecular	Small molecules	Weak intermolecular forces between molecules (strong covalent bonds inside them)	Ice, iodine, sugar, CO ₂ (dry ice)
Covalent network	Atoms	Covalent bonds throughout a giant structure	Diamond, graphite, silicon dioxide (quartz)
Metallic	Metal ions in a sea of electrons	Metallic bonding	Copper, iron, aluminium, alloys

KEY IDEA

To predict properties, ask **what has to be overcome** to melt the solid. Molecular solids only need weak forces **between** molecules to be overcome, so they melt at low temperatures. Ionic, network and metallic solids need **strong bonds** to be broken or loosened, so they melt at high temperatures.

Why does it matter?

- **Choosing materials.** Wires are copper (conducts), drill tips are diamond (hard), cookware is metal (conducts heat) and insulators are often ionic or network ceramics.
- **Explaining everyday observations.** Why salt dissolves but sand does not, why a metal spoon bends but a crystal of salt shatters, why pencils write.
- **Alloys.** Steel, brass and bronze are designed by changing the metallic lattice.

How does it work?

1. Properties of metals from the electron sea

- **Electrical conductivity:** the delocalized electrons move when a voltage is applied, in the solid and the liquid.
- **Thermal conductivity:** mobile electrons carry energy quickly through the metal.
- **Malleable and ductile:** layers of ions can slide over each other without breaking the bonding, because the electron sea moves with them. (In an ionic crystal, sliding brings like charges together, and the crystal shatters.)
- **Shiny:** the free electrons absorb and re-emit light.
- **High melting points** (mostly): the attraction between ions and electrons is strong. More delocalized electrons per atom and smaller ions give stronger bonding (sodium melts at 98 °C, but iron at 1538 °C).

2. Alloys

An **alloy** is a mixture of a metal with other elements. Atoms of a different size disrupt the regular layers, so they slide less easily: alloys are usually **harder and stronger** than the pure metal. Examples: steel (iron with a little carbon), brass (copper and zinc), bronze (copper and tin).

3. Comparing the four types of solid

Property	Ionic	Molecular	Covalent network	Metallic
Melting point	High (NaCl 801 °C)	Low (I ₂ 114 °C)	Very high (SiO ₂ about 1700 °C; diamond above 3500 °C)	Low to very high (Na 98 °C, W 3422 °C)
Conducts as solid?	No	No	No (except graphite)	Yes
Conducts when molten or dissolved?	Yes: ions are free to move	No	No	Yes (molten)
Hardness	Hard but brittle	Soft	Very hard (diamond)	Malleable
Soluble in water?	Often	Polar ones may be	No	No

4. Diamond and graphite

Both are pure carbon, but the atoms are bonded differently:

- **Diamond:** each carbon is bonded to **four** others in a rigid 3D network. Extremely hard; does not conduct.
- **Graphite:** each carbon is bonded to **three** others in flat **layers** of hexagons. The fourth electron of each atom is delocalized along the layer, so graphite **conducts electricity**. The layers are held together only weakly, so they slide: graphite is soft and slippery, which is why it works in pencils and as a lubricant.

∞ THINK OF IT LIKE THIS

A metal is like a crowd of people (the ions) standing in rows in a pool of water (the electrons). Push the crowd and the rows slide along, still surrounded by water: the metal bends instead of breaking. Push an ionic crystal and positive meets positive: it splits apart.

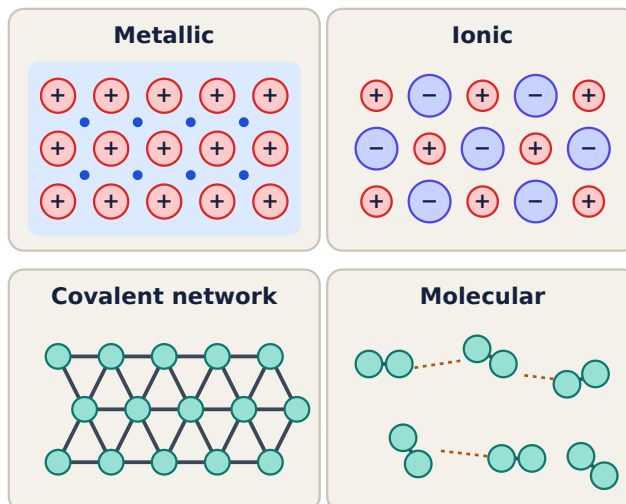
🔍 MORE PRECISELY

The “electron sea” is a simple picture of what band theory describes more exactly: in a metal, atomic orbitals merge into **bands** of closely spaced energy levels, and a partly filled band lets electrons move freely. In insulators the filled and empty bands are separated by a large gap; in **semiconductors** such as silicon the gap is small, so a few electrons can cross it, and more do as the temperature rises. Graphene, a single layer of graphite, is one of the strongest and most conductive materials known.

Visualise it

Four types of solid

What holds the particles together?



Dots: free electrons · dashes: weak forces between molecules

The four types of solid, by what holds the particles together.

Worked example

WORKED EXAMPLE: Classifying solids from their properties

Question: Classify each solid. A: melts at 1085 °C, conducts as a solid. B: melts at 801 °C, conducts only when molten. C: melts at 114 °C, does not conduct. D: melts at about 1700 °C, does not conduct even when molten.

- Step 1** A conducts as a solid: **metallic** (it is copper).
- Step 2** B conducts only when molten, high melting point: **ionic** (sodium chloride).
- Step 3** C low melting point, non-conductor: **molecular** (iodine).
- Step 4** D very high melting point, never conducts: **covalent network** (silicon dioxide).

WORKED EXAMPLE: Explaining a property

Question: Explain why solid sodium chloride does not conduct electricity, but molten sodium chloride does.

In the solid, the ions are held in fixed positions in the lattice and cannot move. When the solid melts (or dissolves), the ions become **free to move** and carry charge. Ionic compounds have no delocalized electrons, so the moving charges are the ions themselves.

 WORKED EXAMPLE: Composition of an alloy

Question: A brass key has a mass of 25.0 g and is 70.0 % copper by mass. What masses of copper and zinc does it contain?

Step 1 Copper:

$$\begin{aligned}m_{\text{Cu}} &= \frac{70.0}{100} \times 25.0 \text{ g} \\ &= 17.5 \text{ g}\end{aligned}$$

Step 2 Zinc (the rest):

$$\begin{aligned}m_{\text{Zn}} &= 25.0 \text{ g} - 17.5 \text{ g} \\ &= 7.5 \text{ g}\end{aligned}$$

Common mistake

 **COMMON MISTAKE:** Thinking melting a molecular solid breaks covalent bonds

When ice melts, the **O–H bonds inside** the water molecules stay intact. Only the weak forces **between** molecules are overcome. That's why molecular solids melt at low temperatures.

 **COMMON MISTAKE:** Saying ionic solids conduct because of electrons

Ionic compounds conduct (when molten or dissolved) because **ions** move, not electrons. Metals and graphite conduct because **electrons** move.

 **COMMON MISTAKE:** Expecting all network solids to be insulators

Graphite is a network solid that **conducts**, because each carbon has one delocalized electron. Diamond does not, because all four outer electrons are used in bonds.

 NOTATION NOTE

- “Giant structure”, “giant covalent” and “macromolecular” are other names for covalent network solids.
- The formula of a network or ionic solid (SiO_2 , NaCl) gives the **ratio** of atoms or ions, not a molecule.

Remember this

REMEMBER THIS

- **Metallic bonding:** positive ions attracted to a sea of delocalized electrons.
- Metals conduct (mobile electrons), are malleable (layers slide) and shiny.
- Alloys are harder than pure metals because different-sized atoms stop the layers sliding.
- **Four solids:** ionic (ions), molecular (molecules, weak forces), covalent network (atoms, giant structure), metallic.
- Molecular solids melt low; ionic, network and most metallic solids melt high.
- Graphite conducts (delocalized electrons in layers); diamond does not.

References

1. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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