

Metals: Extraction, Alloys, and Applications

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Metals: Extraction, Alloys, and Applications

How a metal is extracted from its ore, what alloys it forms, and whether it is essential or toxic to living things all follow from its chemistry. The reactivity series determines the extraction method; the structure of an alloy determines its improved properties; and the chemistry of heavy metals explains their toxicity.

Extraction of Metals

The method of extraction depends on position in the reactivity series. Reactive metals hold their electrons weakly but lose them easily to form stable compounds — this means a lot of energy is required to reverse this and reclaim the metal.

| Position | Extraction method | Examples |
|------------------------------------|--|-------------------|
| Above carbon (very reactive) | Electrolysis of molten compound | K, Na, Ca, Mg, Al |
| Below carbon (moderately reactive) | Reduction by carbon or CO in a blast furnace | Zn, Fe, Pb |
| Below hydrogen (unreactive) | Found native; heated or chemically reduced | Cu, Ag, Au |

Extraction of Iron (Blast Furnace)

Two extraction processes come up repeatedly on the syllabus: iron, which sits below carbon and can be reduced by carbon monoxide, and aluminium, which sits above carbon and must be extracted by electrolysis.

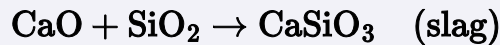
Iron is extracted from iron ore (haematite, Fe_2O_3) by reduction with carbon monoxide in a blast furnace. Coke (carbon), iron ore, and limestone are fed in at the top; hot air is blasted in at the bottom.

<BlastFurnace />

Key reactions:

- 1. Carbon burns to form CO ; $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$

- 2. CO reacts with more coke to form CO: $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$
- 3. CO reduces iron oxide: $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$
- 4. Limestone removes silica impurities as slag:



Molten iron sinks to the bottom and is tapped off. The product is **pig iron**, which is brittle due to its high carbon content (~4%). It is converted to steel by controlled oxidation to reduce carbon content to 0.1–1.5%.

Extraction of Aluminium

Aluminium is above carbon in the reactivity series, so carbon cannot reduce it. It is extracted by electrolysis of molten aluminium oxide. Key points:

- Ore is **bauxite** (Al₂O₃ aluminium oxide)
- Bauxite is dissolved in molten **cryolite** to lower the melting point from ~2000 °C to ~950 °C
- The molten mixture is electrolysed: Al³⁺ is reduced at the cathode, O²⁻ is oxidised at the carbon anodes
- Carbon anodes burn away as they react with the oxygen produced: $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$

The high energy cost of electrolysis makes aluminium more expensive to produce than iron despite aluminium being more abundant in the Earth's crust.

Corrosion of Metals

Corrosion is the gradual destruction of a metal due to reactions with its environment.

Rusting of Iron

The corrosion of iron is specifically called **rusting**. For rusting to occur, **both oxygen (from air) and water** must be present.

- Rust is hydrated iron(III) oxide: $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$
- Rust is flaky and easily falls off, exposing fresh iron to further corrosion.

Corrosion of Aluminium

Aluminium is higher in the reactivity series than iron, yet it resists corrosion beautifully. When freshly cut aluminium is exposed to air, it rapidly reacts with oxygen to form a thin, transparent, and strongly adhering layer of

aluminium oxide (Al_2O_3)

). This unreactive oxide layer coats the metal and physically prevents oxygen and water from reaching the metal underneath, stopping further corrosion.

Alloys

Pure metals are rarely used as extracted. Most applications need something stronger, harder, or more corrosion-resistant than any single pure metal provides, which is why alloys exist.

Pure metals are often too soft or too brittle for practical uses. Mixing metals (or adding non-metals) produces **alloys** with improved properties.

| Alloy | Composition | Properties | Uses |
|------------------|--------------------------|---|--|
| Steel | Iron + carbon (0.1–1.5%) | Stronger and harder than pure iron | Construction, tools, vehicles |
| Stainless steel | Iron + chromium + nickel | Corrosion resistant | Cutlery, kitchen equipment, surgical instruments |
| Aluminium alloys | Al + Cu, Mg, or Mn | Light but much stronger than pure Al | Aircraft, bicycles, packaging |
| Solder | Lead + tin | Low melting point | Joining electronic components |
| Brass | Copper + zinc | Harder than Cu, good corrosion resistance | Pipes, musical instruments |

Alloys have different properties from their component metals because the different-sized atoms disrupt the regular lattice arrangement, preventing layers from sliding over each other. This is why alloys are stronger and harder than pure metals.

Metals in Living Systems

Not all of this is industrial. Several metals are biologically essential, filling roles in living organisms that no other element can take over.

Metals play essential biological roles:

| Metal | Role |
|-------------------------------|---|
| Iron (Fe) | Central atom in haemoglobin — carries oxygen in red blood cells |
| Magnesium (Mg) | Central atom in chlorophyll — essential for photosynthesis |
| Calcium (Ca) | Bone and teeth structure; muscle contraction; nerve signalling |
| Zinc (Zn) | Trace element; cofactor for many enzymes |
| Sodium (Na) and Potassium (K) | Nerve impulse transmission; fluid balance |

Harmful Effects of Toxic Metals

Some metals are toxic rather than essential. What makes heavy metals resistant and durable also means they accumulate in living tissue rather than breaking down.

| Metal | Source of exposure | Effects |
|--------------|---|--|
| Lead (Pb) | Old paint, car exhaust (from leaded petrol), old plumbing | Neurotoxin; damages brain development in children; causes learning difficulties |
| Mercury (Hg) | Broken thermometers, coal combustion, fish | Affects nervous system; methylmercury accumulates in fish and through the food chain |
| Cadmium (Cd) | Battery disposal, cigarette smoke, contaminated soils | Kidney damage; causes itai-itai disease (bone softening) |
| Arsenic (As) | Mining waste, contaminated groundwater | Carcinogenic; causes skin lesions and organ damage |

Heavy metals are particularly dangerous because they are not biodegradable — they accumulate in organisms (bioaccumulation) and become more concentrated at higher trophic levels in a food chain (biomagnification).