Metals: Extraction, Alloys, and Applications

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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 top; hot air is blasted in at the bottom.

<BlastFurnace />

Key reactions:

- 1. Carbon burns to form CO; $C + O2 \rightarrow CO2$

- 2. CO,reacts with more coke to form CO: $\mathrm{CO_2 + C \rightarrow 2CO}$
- 3. CO reduces iron oxide: $\mathrm{Fe2O3 + 3CO \rightarrow 2Fe + 3CO_2}$
- 4. Limestone removes silica impurities as slag:

$$\mathrm{CaCO_3 \rightarrow CaO + CO_2}$$

$$\mathrm{CaO + SiO_2 \rightarrow CaSiO_3 \quad (slag)}$$

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** (Al,Oƒ aluminium oxide)
- Bauxite is dissolved in molten **cryolite** to lower the melting point from ~2000 °C to ~950 °C
- The molten mixture is electrolysed: Al^{3}ż is reduced at the cathode, O^{2}{ is oxidised at the carbon anodes
- Carbon anodes burn away as they react with the oxygen produced: $\mathrm{C + O2 \rightarrow CO2}$

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: $Fe2O3 \cdot xH_2O$.
- 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($Al2O3$

). 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).