Extracting and using metals

Only the most unreactive metals such as gold and platinum are found as native metals.

All the other metals we use are extracted from their ores by chemical processes.
Definition: An **ore** is a rock containing enough of a metal compound for it to be worth extracting the metal from the rock.

The metal compounds in rocks are often metal oxides, sometimes metal sulphides or carbonates.

**Bauxite** contains aluminium oxide, from which we extract aluminium.

**Galena** is lead sulphide from which we obtain lead.

**Iron pyrites** (Fools Gold) is actually iron sulphide, and contains no gold. We normally obtain iron from an ore called **haematite** which contains iron oxide.
Methods for turning the metal compounds in ores into metals depend on how reactive the metal is.

Two methods commonly used are:

1) REDUCTION WITH CARBON
   Used for oxides of metals less reactive than carbon – the carbon displaces the metal, stealing the oxygen to form carbon dioxide and leaving the metal. Carbon is used because it is cheap and plentiful.

2) ELECTROLYSIS
   Can be used for any ore, but uses huge amounts of energy, so an expensive process. Therefore usually only used for metals more reactive than carbon.
Extraction and uses of Iron

Reduction is used to extract iron from its ore (haematite) which is mainly iron(III) oxide.

The iron ions are reduced to iron atoms, using carbon. This is oxidised to form carbon dioxide.

\[
\text{iron(III) oxide + carbon} \rightarrow \text{iron + carbon dioxide} \\
2 \text{Fe}_2\text{O}_3(s) + 3\text{C}(s) \rightarrow 4 \text{Fe}(l) + 3 \text{CO}_2(g)
\]
The process happens in a **blast furnace**.

**Raw materials:**

**Iron ore** – contains the iron to be extracted

**Coke** – contains the carbon to reduce the iron ore

**Air** – provides oxygen to burn the carbon, which also heats the blast furnace

**Limestone** – is mainly calcium carbonate, which removes the impurities (sand) in the iron ore by reacting to form slag, which floats on the molten iron
The chemistry:

Firstly the carbon in the coke is *oxidised* by the oxygen in the air to form carbon dioxide. This *exothermic* reaction heats the blast furnace:

\[
C(s) + O_2(g) \rightarrow CO_2(g)
\]

The carbon dioxide reacts with more oxygen to form the *reducing agent*, carbon monoxide:

\[
C(s) + CO_2(g) \rightarrow 2CO(g)
\]

The carbon monoxide then *reduces* the iron oxide in the iron ore to iron:

\[
Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)
\]

Meanwhile the calcium carbonate is *thermally decomposed* to calcium oxide. This is a base which *neutralises* the sandy impurities (silicon dioxide, an acidic non-metal oxide) to make calcium silicate:

\[
CaCO_3(s) \rightarrow CaO(s) + CO_2(g)
\]

\[
CaO(s) + SiO_2(s) \rightarrow CaSiO_3(l)
\]

calcium oxide sand slag
What comes out:

**Molten iron** – this is cast iron and contains carbon impurities. It is brittle and not yet very useful.

**Slag** – calcium silicate is a waste product, but can be used for road surfacing.

**Carbon dioxide** – produced in several of the reactions in the blast furnace.

**Nitrogen** – left over from the air going into the blast furnace, after the oxygen has been used in reactions.
The uses of iron arise from its properties. Cast iron can be alloyed to make its properties more suitable for specific purposes.

Different types of steels are alloys of iron, each with different properties. **Stainless steel** has added chromium atoms and resists corrosion, remaining shiny.

**Mild steel** is iron with up to 0.3% carbon. It is hard and strong, but not brittle, so it can be shaped e.g. for car body panels, ship building etc.

**High-carbon steels** have up to 2% carbon. They are very hard – useful for knife blades, but are brittle so cannot be bent to shape.
Extraction of lead from its ore

This is done in two stages. Firstly the lead ore (which is mainly lead sulphide) is heated in air to \textit{oxidise} it. The products are lead oxide and sulphur dioxide:

\[ 2\text{PbS}_{(s)} + 3\text{O}_2(g) \rightarrow 2\text{PbO}_{(s)} + 2\text{SO}_2(g) \]
The lead oxide is then heated with coke (carbon) in a blast furnace to cause a displacement reaction which produces lead and carbon dioxide. This works because carbon is more reactive than lead, so carbon can reduce the lead oxide to lead.

\[
2 \text{PbO}_\text{(s)} + \text{C}_\text{(s)} \rightarrow 2 \text{Pb}_\text{(l)} + \text{CO}_2\text{(g)}
\]
Extraction and Uses of Aluminium

Electrolysis is used to extract aluminium from aluminium oxide; this is obtained by purifying its ore (bauxite).

The ionic aluminium oxide is split into its elements, aluminium (a metal) and oxygen (a gas).

$$2 \text{Al}_2\text{O}_3(\text{l}) \rightarrow 4 \text{Al}(\text{l}) + 3 \text{O}_2(\text{g})$$
The aluminium oxide is mixed with cryolite, which acts as a solvent to dissolve the aluminium oxide, and allows the mixture to melt at a lower temperature (about 950°C rather than nearly 2000°C).

This saves some energy costs – although the current required is very high, so the cost of electricity is a major factor.

At the cathode, molten aluminium is collected:

\[ \text{Al}^{3+} + 3e^- \rightarrow \text{Al} \]

At the anode, oxygen is formed:

\[ 2\text{O}^2- - 4e^- \rightarrow 2\text{O}_2 \]

The anodes are made of graphite (carbon) and react with the oxygen, releasing carbon dioxide. This means they get eaten away, and have to be replaced sometimes.
The uses of aluminium arise from its properties. Pure aluminium is too soft to be much use. It can be alloyed to make their properties more suitable for specific purposes.

**Alloy**

**Pure Metal**

Harder: layers disrupted, can’t slide over each other

Soft: layers can slide over each other
Aluminium resists corrosion because it forms a thin but tough layer of aluminium oxide over the surface of the metal. This prevents the metal underneath from reacting further with oxygen or moisture from the air.

Titanium also forms a protective layer like this, so it too resists corrosion – it is also less reactive than aluminium.
By growing the oxide layer on the surface of titanium to different thicknesses, it can be made to reflect different colours of light.
Extracting titanium from rutile

Carbon can’t be used to extract titanium from its ore because the titanium reacts further with carbon, so a more reactive metal, e.g. sodium or magnesium, is used to reduce the titanium ore instead.

For both titanium and aluminium:
Extraction of these metals from their ores is expensive.

- because there are many stages in the processes
- large amounts of energy are needed
Overhead power lines are made from aluminium

- low density
- excellent conductor
- corrosion resistance
Aluminium alloys are used for commercial aircraft

- light weight (low density)
- good strength
- corrosion resistance
Titanium is used in bodies of high-performance aircraft and in some jet engine parts

- light weight (low density)
- corrosion resistant
- Keeps strength at high temperature
Titanium is used in hip-replacements.

- strength
- resistance to corrosion