Topic C1.2: Rocks and metals

Summary

Metals are found in the earth's crust in the form of ores. An **ore** is a naturally occurring material which is concentrated enough to make it economic to extract the metal. The form in which an ore exists and the method by which the metal may be extracted depend on the reactivity of the metal.

Very unreactive metals (e.g. platinum, gold) often exist in the native form (pure metal) and can be extracted from the ore by physical means. For example, small nuggets of gold are found embedded in other rocks and the gold can be separated by crushing the rock and washing away the less dense material with water.

More reactive metals (e.g. copper, iron, zinc, titanium) are generally found in compound form (e.g. carbonates, sulphides, oxides, silicates) in the ore. The ore is first concentrated by removing as many impurities as possible. It may be further processed before the metal is extracted using a competition reaction in which a more reactive element (carbon, where appropriate, because it is cheap) is heated with the concentrated ore to **displace** the metal from its compound. The ore is **reduced** to the metal.

e.g. metal oxide + carbon ⟶ metal + carbon dioxide

Very reactive metals are generally found as oxides (e.g. aluminium) or are present as ions in sea water or crystals formed by the evaporation of sea water (e.g. sodium, potassium). It would be very expensive to displace such metals using a more reactive metal so they are usually extracted by **electrolysis** of very concentrated solutions or molten salts. The mobile positive metal ions move towards the negative electrode (cathode) and gain electrons there (**reduction**) to form neutral atoms.

e.g. $Al^{3+} + 3e^{-} \longrightarrow Al$

The methods used for extraction of metals covered in this course are summarised in the table below:

Metal	Common ores	Present as…	% of earth's crust	Extraction	Purification	Cost ($/tonne)
Iron, Fe	magnetite haematite	Fe_2O_3	5.6	Displacement with carbon in Blast Furnace	Conversion to steel in Basic Oxygen Furnace	400
Copper, Cu	chalcopyrite malachite	$CuFeS_2$ $CuCO_3$	0.005	a) Conversion to the oxide followed by reduction (smelting), or b) Leaching with H_2SO_4 followed by electrolysis	Electrolytic transfer from impure Cu anode to pure Cu cathode	7 000
Aluminium, Al	bauxite	Al_2O_3	8.2	Electrolysis of solution of purified bauxite (alumina) in molten cryolite	Not necessary	3 000
Titanium, Ti	rutile ilmenite	TiO_2 $FeTiO_3$	0.6	Conversion to $TiCl_4$ followed by reduction with sodium or magnesium in an inert atmosphere (e.g. argon)	Treatment with H_2O/HCl to remove excess $Mg/MgCl_2$	15 000

The cost of a metal depends on the cost of the ore as well as the cost of extraction.

- The cost of the ore depends on its abundance and quality.
- The cost of extraction depends on the quality of the ore and the amount of energy and other raw materials required.

Alloys

Most pure metals are surprisingly soft and malleable. This is because layers of identical atoms can easily slide over one another when pressure is applied. Adding a small quantity of another metal (with atoms of a different size) hinders this process and makes the metal much harder. This is known as alloying. Alloying also changes other properties such as melting point and resistance to corrosion and by a careful selection of added elements, alloys with properties appropriate to a wide variety of applications may be created. Smart alloys (shape memory alloys) can be bent into a new shape but revert to their original shape when heated.

Iron from the Blast Furnace contains about 4% carbon and is hard but brittle. Burning off the carbon in the Basic Oxygen Furnace produces pure iron which is soft and corrodes easily (rusting). Adding other elements to pure iron forms steel. 18/8 stainless steel used in cutlery has 18% Cr / 8% Ni. Tungsten steel (used in drill bits) is very hard and heat resistant and contains 1-18% tungsten.

Properties and uses of metals and their alloys

All metals are good conductors of heat and electricity and are malleable (can be bent into shape) and ductile (can be drawn into wires). Transition metals (from the central section of the Periodic Table) tend to be strong and have high densities and melting points. **Uses** of metals are directly related to their **properties**.

Iron is cheap and strong but prone to corrosion (rusting) in the presence of water and oxygen. It is used for construction (bridges, ships, reinforced concrete, etc.) and in many consumer goods (cars, fridges, "tin" cans, etc.). In most applications, iron has to be protected from rusting. This may be achieved by coating it in a protective layer (e.g. oil, paint, plastic, chromium plating, where appropriate) or alloying with other metals to make stainless steel. High carbon steel is strong but brittle. Low carbon steel is soft and easily shaped.

Copper is a good conductor and fairly resistant to corrosion but slowly forms a green coating under normal atmospheric conditions. It is used in electrical cables, water pipes and coinage. Alloying copper with tin (to form bronze) or zinc (to make brass) modifies its properties, tailoring it for other applications.

Aluminium has a low density but is rather soft and not particularly strong. It is a good conductor of heat and electricity and is resistant to corrosion due to a thin layer of protective aluminium oxide on the surface. It can be made stronger and harder by alloying with small quantities of other metals. The addition of 4% copper with smaller amounts of magnesium and manganese gives Duralumin which is extensively used in the aerospace industry, drinks cans and elsewhere.

Titanium is a reactive metal but extremely resistant to corrosion due to a thin surface layer of titanium oxide (like aluminium). It is strong (particularly at high temperatures) and has a lower density than most transition metals. The metal and its alloys are used in aeroplanes (engines and airframes), nuclear reactors and artificial hips.

The future

The production of metal from ores is becoming more expensive due to increasing energy costs and the depletion of quality ores. New techniques for extracting metals from their ores by low energy processes are being developed. Bacteria and plants have been used to concentrate copper from low-grade ores.

Recycling of metals consumes less energy than extraction from ores. The need to recycle will become more critical as energy costs increase, ores are depleted and regulations regarding the environmental effects of mining and disposal of waste are tightened.

When comparing one process with another, always consider the **Social**, **Economic** and **Environmental** issues. Avoid vague comments such as *"…bad for the environment"*, instead using more specific comments such as *"…destroys wildlife habitats"* or *"…contributes to the greenhouse effect and consequent global warming"*.