This page looks at the various factors which influence the choice of method for extracting metals from their ores, including reduction by carbon, reduction by a reactive metal (like sodium or magnesium), and by electrolysis. Details for the extraction of aluminum, copper, iron and titanium are given in separate pages in this section.

What are "ores"?

An ore is any naturally-occurring source of a metal that you can economically extract the metal from. Aluminum, for example, is the most common metal in the Earth's crust, occurring in all sorts of minerals. However, it isn't economically worthwhile to extract it from most of these minerals. Instead, the usual ore of aluminum is bauxite - which contains from 50 - 70% of aluminum oxide.

Copper is much rarer, but fortunately can be found in high-grade ores (ones containing a high percentage of copper) in particular places. Because copper is a valuable metal, it is also worth extracting it from low-grade ores as well. Ores are commonly oxides, for example:

- bauxite (Al₂O₃)
- haematite (Fe₂O₃)
- rutile (TiO₂)

... or sulfides, for example:

- pyrite (FeS₂)
- chalcopyrite (CuFeS₂)

Concentrating the ore

This simply means getting rid of as much of the unwanted rocky material as possible before the ore is converted into the metal. In some cases this is done chemically. For example, pure aluminum oxide is obtained from bauxite by a process involving a reaction with sodium hydroxide solution. This is described in detail on the aluminum page in this section.

Some copper ores can be converted into copper(II) sulfate solution by leaving the crushed ore in contact with dilute sulphuric acid for a long time. Copper can then be extracted from the copper(II) sulfate solution. But, in many cases, it is possible to separate the metal compound from unwanted rocky material by physical means. A common example of this involves froth flotation.

Froth flotation

The ore is first crushed and then treated with something which will bind to the particles of the metal compound that you want and make those particles hydrophobic. "Hydrophobic" literally means "water fearing". In concentrating copper ores, for example, pine oil is often used. The pine oil binds to the copper compounds, but not to the unwanted rocky material.

The treated ore is then put in a large bath of water containing a foaming agent (a soap or detergent of some kind), and
air is blown through the mixture to make a lot of bubbles. Because they are water-repellent, the coated particles of the metal compound tend to be picked up by the air bubbles, float to the top of the bath, and are allowed to flow out over the sides. The rest of the rocky material stays in the bath.

Reducing the metal compound to the metal

Why is this reduction?

At its simplest, where you are starting from metal oxides, the ore is being reduced because oxygen is being removed.

\[
\text{Fe}_2\text{O}_3 \xrightarrow{\text{removal of oxygen = reduction}} \text{Fe}
\]

\[
\text{Al}_2\text{O}_3 \xrightarrow{\text{removal of oxygen = reduction}} \text{Al}
\]

However, if you are starting with a sulfide ore, for example, that's not a lot of help! It is much more helpful to use the definition of reduction in terms of addition of electrons. To a reasonable approximation, you can think of these ores as containing positive metal ions. To convert them to the metal, you need to add electrons - reduction.

\[
\text{Fe}^{3+} + 3\text{e}^- \xrightarrow{\text{addition of electrons = recuction}} \text{Fe}
\]

\[
\text{Al}^{3+} + 3\text{e}^- \xrightarrow{\text{addition of electrons = recuction}} \text{Al}
\]

\[
\text{Cu}^{2+} + 2\text{e}^- \xrightarrow{\text{addition of electrons = recuction}} \text{Cu}
\]

Choosing a method of reduction

There are various economic factors you need to think about in choosing a method of reduction for a particular ore. These are all covered in detail on other pages in this section under the extractions of particular metals. What follows is a quick summary.

You need to consider:

- the cost of the reducing agent;
- energy costs;
- the desired purity of the metal.

There may be various environmental considerations as well - some of which will have economic costs.
Chemical Reduction

Carbon (as coke or charcoal) is cheap. It not only acts as a reducing agent, but it also acts as the fuel to provide heat for the process. However, in some cases (for example with aluminum) the temperature needed for carbon reduction is too high to be economic - so a different method has to be used. Carbon may also be left in the metal as an impurity. Sometimes this can be removed afterwards (for example, in the extraction of iron); sometimes it can't (for example in producing titanium), and a different method would have to be used in cases like this.

Other more reactive metals can be used to reduce the ore. Titanium is produced by reducing titanium(IV) chloride using a more reactive metal such as sodium or magnesium. As you will see if you read the page about titanium extraction, this is the only way of producing high purity metal.

\[
\text{TiCl}_4 + 4\text{Na} \rightarrow \text{Ti} + 4\text{NaCl}
\]

The more reactive metal sodium releases electrons easily as it forms its ions:

\[
4\text{Na} \rightarrow 4\text{Na}^+ + 4\text{e}^-
\]

These electrons are used to reduce the titanium(IV) chloride:

\[
\text{TiCl}_4 + 4\text{e}^- \rightarrow \text{Ti} + 4\text{Cl}^-
\]

The downside of this is expense. You have first to extract (or to buy) the sodium or magnesium. The more reactive the metal is, the more difficult and expensive the extraction becomes. That means that you are having to use a very expensive reducing agent to extract the titanium. As you will see if you read the page about titanium extraction, there are other problems in its extraction which also add to the cost.

Reduction by electrolysis

This is a common extraction process for the more reactive metals - for example, for aluminum and metals above it in the electrochemical series. You may also come across it in other cases such as one method of extracting copper and in the purification of copper. During electrolysis, electrons are being added directly to the metal ions at the cathode (the negative electrode). The downside (particularly in the aluminum case) is the cost of the electricity. An advantage is that it can produce very pure metals.

Contributors and Attributions

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