

# Aluminium Metallurgy

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## Introduction

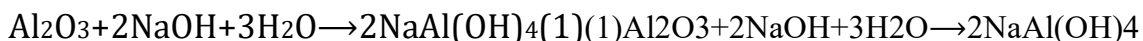
Aluminum is too high in the [electrochemical series](#) (reactivity series) to extract it from its ore using carbon reduction. The temperatures needed are too high to be economic. Instead, it is extracted by electrolysis. The ore is first converted into pure aluminum oxide by the Bayer Process, and this is then electrolyzed in solution in molten cryolite - another aluminum compound. The aluminum oxide has too high a melting point to electrolyse on its own. The usual aluminum ore is bauxite. Bauxite is essentially an impure aluminum oxide. The major impurities include iron oxides, silicon dioxide and titanium dioxide.

## The Bayer Process

### *Reaction with sodium hydroxide solution*

Crushed bauxite is treated with moderately concentrated sodium hydroxide solution. The concentration, temperature and pressure used depend on the source of the bauxite and exactly what form of aluminum oxide it contains. Temperatures are typically from 140°C to 240°C; pressures can be up to about 35 atmospheres.

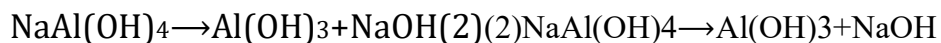
High pressures are necessary to keep the water in the sodium hydroxide solution liquid at temperatures above 100°C. The higher the temperature, the higher the pressure needed. With hot concentrated sodium hydroxide solution, aluminum oxide reacts to give a solution of sodium tetrahydroaluminate.



The impurities in the bauxite remain as solids. For example, the other metal oxides present tend not to react with the sodium hydroxide solution and so remain unchanged. Some of the silicon dioxide reacts, but goes on to form a sodium aluminosilicate which precipitates out. All of these solids are separated from the sodium tetrahydroaluminate solution by filtration. They form a "red mud" which is just stored in huge lagoons.

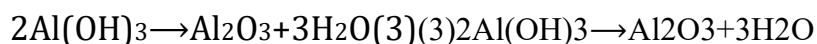
### *Precipitation of aluminum hydroxide*

The sodium tetrahydroaluminate solution is cooled, and "seeded" with some previously produced aluminum hydroxide. This provides something for the new aluminum hydroxide to precipitate around.



### **Formation of pure aluminum oxide**

Aluminum oxide (sometimes known as alumina) is made by heating the aluminum hydroxide to a temperature of about 1100 - 1200°C.

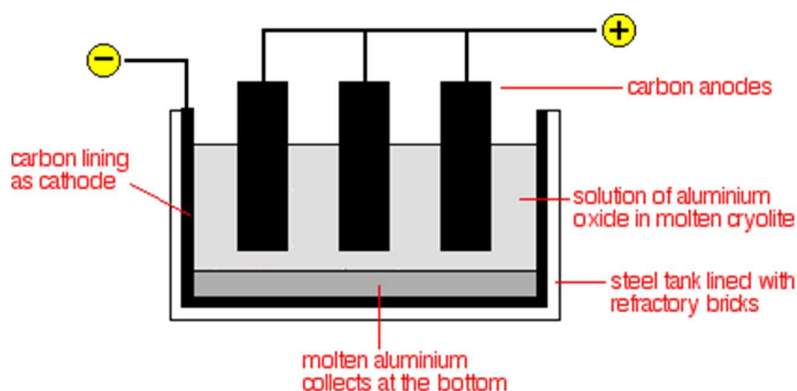


### Conversion of the aluminum oxide into aluminum by electrolysis

The aluminum oxide is electrolyzed in solution in molten cryolite,  $\text{Na}_3\text{AlF}_6$ . Cryolite is another aluminum ore, but is rare and expensive, and most is now made chemically.

## The electrolysis cell

The diagram shows a very simplified version of an electrolysis cell.



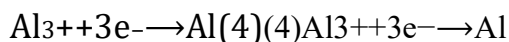
Although the carbon lining of the cell is labelled as the cathode, the effective cathode is mainly the molten aluminum that forms on the bottom of the cell. Molten aluminum is syphoned out of the cell from time to time, and new aluminum oxide added at the top. The cell operates at a low voltage of about 5 - 6 volts, but at huge currents of 100,000 amps or more. The heating effect of these large currents keeps the cell at a temperature of about 1000°C.

### The electrode reactions

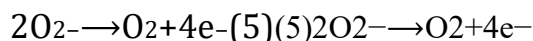
These are very complicated - in fact one source I've looked at says that they aren't fully understood. For chemistry purposes at this level, they are always simplified (to the point of being wrong! - see comment below).

This is the simplification:

Aluminum is released at the cathode. Aluminum ions are reduced by gaining 3 electrons.



Oxygen is produced initially at the anode.



However, at the temperature of the cell, the carbon anodes burn in this oxygen to give carbon dioxide and carbon monoxide. Continual replacement of the anodes is a major expense.

## **Some economic and environmental considerations**

This section is designed to give you a brief idea of the sort of economic and environmental issues involved with the extraction of aluminum. I wouldn't claim that it covers everything! Think about:

- The high cost of the process because of the huge amounts of electricity it uses. This is so high because to produce 1 mole of aluminum which only weighs 27 g you need 3 moles of electrons. You are having to add a lot of electrons (because of the high charge on the ion) to produce a small mass of aluminum (because of its low relative atomic mass).
- Energy and material costs in constantly replacing the anodes.
- Energy and material costs in producing the cryolite, some of which gets lost during the electrolysis.

## **Environmental problems in mining and transporting the bauxite**

Think about:

- Loss of landscape due to mining, processing and transporting the bauxite.
- Noise and air pollution (greenhouse effect, acid rain) involved in these operations.

## **Extracting aluminum from the bauxite**

Think about:

- Loss of landscape due to the size of the chemical plant needed, and in the production and transport of the electricity.
- Noise.
- Atmospheric pollution from the various stages of extraction. For example: carbon dioxide from the burning of the anodes (greenhouse effect); carbon monoxide (poisonous); fluorine (and fluorine compounds) lost from the cryolite during the electrolysis process (poisonous).
- Pollution caused by power generation (varying depending on how the electricity is generated.)
- Disposal of red mud into unsightly lagoons.
- Transport of the finished aluminum.

## **Recycling**

Think about:

- Saving of raw materials and particularly electrical energy by not having to extract the aluminum from the bauxite. Recycling aluminum uses only about 5% of the energy used to extract it from bauxite.
- Avoiding the environmental problems in the extraction of aluminum from the bauxite.
- Not having to find space to dump the unwanted aluminum if it wasn't recycled.

- (Offsetting these to a minor extent) Energy and pollution costs in collecting and transporting the recycled aluminum.

## Uses of aluminum

Aluminum is usually alloyed with other elements such as silicon, copper or magnesium. Pure aluminum isn't very strong, and alloying it adds to its strength. Aluminum is especially useful because it

- has a low density;
- is strong when alloyed;
- is a good conductor of electricity;
- has a good appearance;
- resists corrosion because of the strong thin layer of aluminum oxide on its surface. This layer can be strengthened further by anodizing the aluminum.

Anodizing essentially involves etching the aluminum with sodium hydroxide solution to remove the existing oxide layer, and then making the aluminum article the anode in an electrolysis of dilute sulphuric acid. The oxygen given off at the anode reacts with the aluminum surface, to build up a film of oxide up to about 0.02 mm thick. As well as increasing the corrosion resistance of the aluminum, this film is porous at this stage and will also take up dyes. (It is further treated to make it completely non-porous afterwards.) That means that you can make aluminum articles with the colour built into the surface.

Some uses include:

# Use of Aluminium

- Aluminium is used in a huge variety of products including:

- **cans**
- **foils**
- **kitchen utensils**
- **window frames**
- **aeroplane parts.**

- **Coins**
- Aluminium is a good electrical conductor and is often used in
- **electrical transmission lines.**

- Aluminium coatings have many uses, including

- **telescope mirrors**
- **decorative paper**
- **packages**
- **toys.**



## References

Jim Clark ([Chemguide.co.uk](http://Chemguide.co.uk))