Chem Factsheet

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# The Extraction of Aluminium

**To succeed in this topic you need to:**
- **Understand and learn the relevant equations;**
- **Understand the principles in electrolysis;**
- **Be able to write balanced half equations.**

**After working through this Factsheet you will:**
- **Know the physical and chemical processes involved in extracting aluminium;**
- **Recognise that these processes occur on an industrial scale;**
- **Have experience in using this knowledge in exam style questions.**

Aluminium is the most abundant metal in the Earth's crust, and is of tremendous importance. The properties of the metal make it very useful.

Some important properties of aluminium:
- Shiny surface when polished
- Low density metal
- Malleable
- Good electrical conductor
- Good thermal conductor, with ability to act as thermal insulator also, as polished surface reflects infra-red radiation
- Resistant to corrosion due to formation of self protecting formation of oxide layer on surface

New uses for aluminium are being discovered all the time, here are just a few.

| Use of aluminium | Reasons for use |
|---|---|
| Overhead power cables | Good electrical conductor, low density |
| Food and drinks packaging | Resistant to corrosion, affordable |
| Transport manufacture | Low density, resistant to corrosion |
| Saucepans and cooking foil | Good thermal conductor, resistant to corrosion, low density |
| Blankets for athletes and premature babies | Shiny surface reflects radiated heat so acts as insulator |
| Reflective coating on glass in cameras and car headlights | Shiny surface, resistant to corrosion, malleable |

As aluminium is such a useful and abundant metal, millions of tonnes are produced annually. Because of the importance of the extraction of aluminium, it is frequently examined in AS and A2 papers.

**The Extraction of Aluminium**

**Raw materials**

The aluminium ore mined for the production of aluminium is called **bauxite**. Bauxite rock contains the following compounds:

| Chemical name | Formula | Description |
|---|---|---|
| Hydrated aluminium oxide | $Al_2O_3.2H_2O$ | Source of aluminium |
| Silicon (IV) oxide | $SiO_2$ | Acidic impurity |
| Iron (III) oxide | $Fe_2O_3$ | Basic impurity |

The first stage in the extraction of aluminium is to mine the bauxite, and then to produce pure aluminium oxide.

Candidates require an understanding of these purification processes; exam question often focus on how the amphoteric nature of aluminium oxide is utilised (see Factsheet 19).

The ground bauxite is crushed and heated under pressure a concentrated solution of sodium hydroxide.

**Learn these equations!**

The amphoteric aluminium oxide reacts and dissolves in the alkali:

$Al_2O_3(s) + 2NaOH(aq) \rightarrow 2NaAlO_2(aq) + H_2O(l)$

The acidic silicon (IV) oxide reacts and dissolves in the alkali:

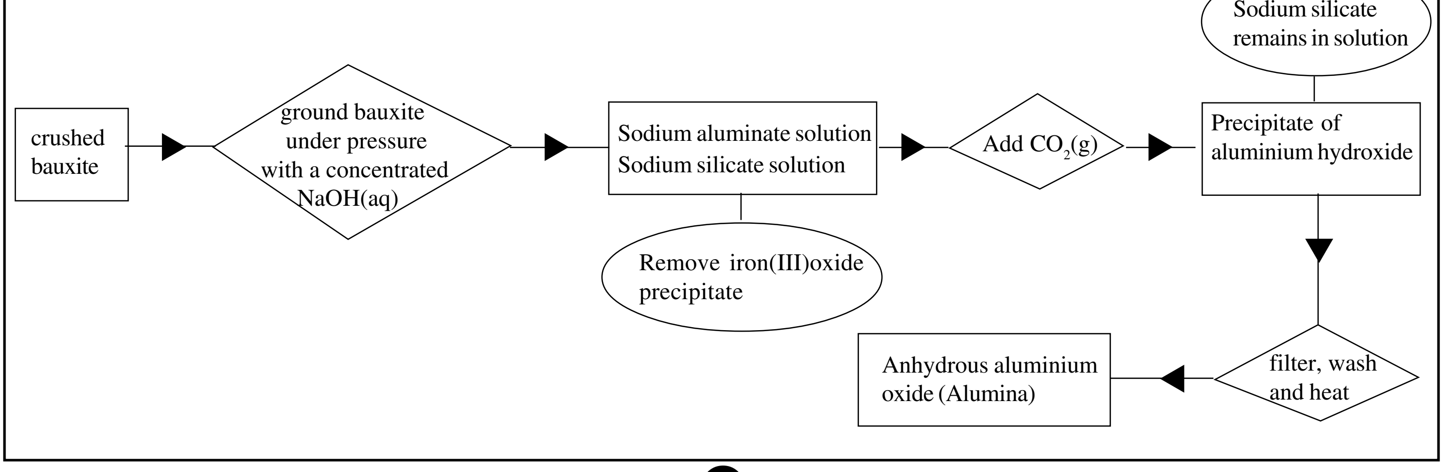
$SiO_2(s) + 2NaOH(aq) \rightarrow Na_2SiO_3(aq) + H_2O(l)$

The basic iron (III) oxide does not react with the alkali, so is precipitated and can be filtered out.

Carbon dioxide gas, which is acidic, is then blown through the remaining solution. The sodium aluminate reacts and a precipitate of aluminium hydroxide is formed, whilst the sodium silicate remains in solution.

The aluminium hydroxide precipitate is filtered off, washed and heated, forming the desired product, purified anhydrous aluminium oxide, sometimes known as alumina (Fig 1).

**Fig 1. Extraction of aluminium**



## Extraction using Electrolysis

Before 1886 aluminium was extracted from its compounds by displacement, and since aluminium is itself quite a reactive metal, a very reactive metal such as sodium had to be used. This made the extraction of aluminium, and hence the cost of the metal, very expensive.

The Hall-Heroult process of extraction, which involves electrolysis, lowered the costs and has allowed aluminium to be manufactured on an industrial scale.

The industrial plants themselves tend to be located at the coast, so the purified aluminium oxide can be shipped in, and near to an adequate supply of affordable electricity.

### The Electrolyte

Pure aluminium oxide has a melting point of 2040°C, making it unsuitable as an electrolyte. Not only would this temperature be very expensive to maintain, but also the handling of a liquid at this temperature would be difficult.

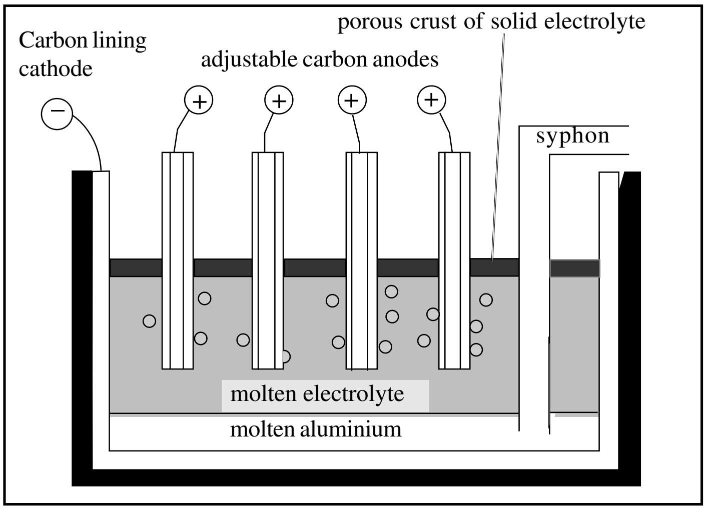
Consequently a **solvent** must be used. The solvent is molten **cryolite**, sodium hexafluoroaluminate, $Na_3AlF_6$, which dissolves the aluminium oxide whilst having a much lower melting point.

The electrolyte contains:

| Name | Formula | Quantity | Purpose |
|---|---|---|---|
| Aluminium oxide | $Al_2O_3$ | 10% | Source of aluminium |
| Cryolite | $Na_3AlF_6$ | 80% | Solvent |
| Calcium fluoride | $CaF_2$ | 10% | Lower melting temperature of mixture |

The electrolyte mixture is melted and maintained above its melting point at around 900°C by a current of 100 000 amps.

**Fig 2. Electrolytic cell for aluminium extraction**




At the cathode, aluminium ions are reduced: $Al^{3+} + 3e^- \rightarrow Al(l)$

The aluminium (mp 660°C) is a liquid at the working temperature, so can be siphoned off and cast into blocks for sale and use.

At the anode, oxygen ions are oxidised: $2O^{2-} \rightarrow O_2(g) + 4e^-$

The carbon graphite anodes must be replaced every month as at the high temperatures in the cell they react with the oxygen gas formed, producing carbon dioxide gas, hence the anodes themselves are gradually burning away.

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

This is why the carbon anodes are 'adjustable'.
Any remaining carbon is recycled as new anodes are produced.

**Exam Hint:** *Several questions on past exam papers have concerned the anodes in this process. Be very clear in your explanation and use the equations where appropriate.*

## Cost

The extraction of aluminium is an expensive process due to the high temperatures and electrical energy required, so the recycling of aluminium makes economic sense. The low melting point of aluminium (660°C) makes it easy to separate from other metals, and relatively cheap to melt down and re-use.

## Practice Questions

1. Name the rock which is mined as aluminium ore.
2. Explain why aluminium and alloys of aluminium are used in the manufacture of aircraft.
3. Explain why pure aluminium oxide is not used as the electrolyte in the extraction of aluminium.
4. Write balanced half equations to show the reactions which occur at the electrodes in the extraction of aluminium.
5. State the biggest cost to the manufacturer in the production of aluminium.
6. What are the anode and cathode made from in the electrolytic cell used in the manufacture of aluminium?
7. Give reasons why aluminium is recycled.
8. Why must the anodes be periodically replaced during the electrolysis?
9. What would happen if the power supply to the electrolytic cell were to be stopped for more than a couple of hours?

**Answers**

1. Bauxite
2. Aluminium has a low density and is resistant to corrosion. NB Alloys of aluminium tend to be used for the structure of aircraft as pure aluminium is not strong enough.
3. Melting point of aluminium oxide is too high to produce molten electrolyte (expensive to maintain high temps and difficult to handle). Instead the aluminium oxide is dissolved in molten cryolite which allows electrolysis to occur at a lower temperature, around 900°C.
4. $Al^{3+} + 3e^- \rightarrow Al(l)$ cathode
   $2O^{2-} \rightarrow O_2(g) + 4e^-$ anode
5. Electricity.
6. Carbon graphite.
7. From:
   - Cheaper to recycle than to manufacture
   - Less waste in environment
   - Preserve reserves of aluminium ore
   - Less pollutants and greenhouse gases produced during recycling processes compared to manufacture, especially if fossil fuel used to produce electricity required.
8. The carbon anode burns in the oxygen produced at the anode producing carbon dioxide gas.
9. The contents of the cell would solidify.

***Acknowledgements:*** *This Factsheet was researched and written by Kieron Heath.* ***Curriculum Press, Bank House, 105 King Street, Wellington, Shropshire, TF1 1NU. ChemistryFactsheets*** *may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. No part of these Factsheets may be reproduced, stored in a retrieval system, or transmitted, in any other form or by any other means, without the prior permission of the publisher.* ***ISSN 1351-5136***