Using electrolysis to extract metals

4.4.3.3 · Chemical changes · revision notes

Why some metals are extracted by electrolysis rather than reduction with carbon, and how aluminium is extracted from a molten mixture of aluminium oxide and cryolite. Common questions ask why cryolite is used, why the anodes must be replaced and why the process is expensive.

Key facts

- More reactive than carbon (or reacts with carbon) → extracted by electrolysis of a molten compound
- Cryolite lowers the melting point → less energy needed
- Carbon anodes react with oxygen: $C + O_2 \rightarrow CO_2$, so they are replaced
- Grade 8+ only Cathode (−): $Al^{3+} + 3e^- \rightarrow Al$
- Aluminium: electrolysis of molten aluminium oxide mixed with cryolite
- Energy is needed to melt the electrolyte and to produce the current
- $2Al_2O_3 \rightarrow 4Al + 3O_2$
- Grade 8+ only Anode (+): $2O^{2-} \rightarrow O_2 + 4e^-$

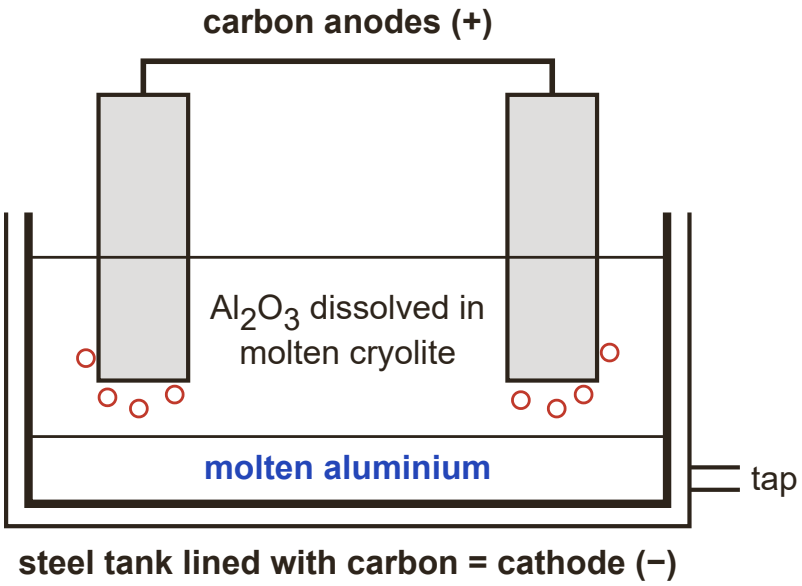
Notes

When electrolysis is used

- A metal is extracted by electrolysis if it is **too reactive** to be extracted by reduction with carbon, or if the metal **reacts with carbon**.
- The metal compound must be **molten** so that its ions can move.
- Electrolysis is **expensive**: large amounts of energy are used to melt the compound and to produce the electric current.

Extracting aluminium

- The electrolyte is a molten mixture of **aluminium oxide**, Al_2O_3, and **cryolite**.
- Aluminium oxide on its own melts at over 2000 °C. The mixture with cryolite melts at a much lower temperature (about 950 °C), so **less energy is needed**, which saves money.
- Aluminium ions (Al^{3+}) move to the **cathode** (negative), gain electrons and form molten aluminium, which collects at the bottom of the cell.
- Oxide ions (O^{2-}) move to the **anode** (positive), lose electrons and form oxygen.
- The positive electrodes (anodes) are made of **carbon**.



Oxygen forms at the carbon anodes (red bubbles) and reacts with them to make carbon dioxide, so they burn away.

Why the anodes are replaced

- At the high temperature, the oxygen produced reacts with the carbon anodes to form **carbon dioxide**: $C + O_2 \rightarrow CO_2$.
- The anodes gradually burn away, so they must be **replaced regularly**, which adds to the cost.
- Half equations: cathode $Al^{3+} + 3e^- \rightarrow Al$; anode $2O^{2-} \rightarrow O_2 + 4e^-$. Grade 8+ only
- Overall: $2Al_2O_3 \rightarrow 4Al + 3O_2$

How to answer each type of question

Explain why a metal is extracted by electrolysis, and why it is expensive

3 to 4 marks | **Grade 5**

1. Compare the metal's reactivity with carbon.
2. Say that carbon cannot remove the oxygen from (reduce) the oxide.
3. For cost, mention energy to melt the electrolyte and energy for the current (and anode replacement).

Example. Iron is extracted by heating iron oxide with carbon. Aluminium is extracted by electrolysis.
(a) Explain why aluminium cannot be extracted by heating aluminium oxide with carbon.
(b) Give two reasons why extracting aluminium by electrolysis is expensive.

Model answer.

(a) Aluminium is more reactive than carbon (1)
so carbon cannot remove oxygen from / reduce aluminium oxide (1)
(b) Any two from: a lot of energy is needed to melt the electrolyte (1); a lot of electrical energy is needed to produce the current (1); the carbon anodes have to be replaced (1)

Explain why a mixture with cryolite is used

2 marks | **Grade 5**

1. Say what the mixture does: it has a lower melting point than aluminium oxide alone.
2. Link to less energy needed, so lower costs.

Example. In the extraction of aluminium, aluminium oxide is mixed with cryolite.
Explain why.

Model answer.

The mixture has a lower melting point than aluminium oxide on its own (1)
so less energy is needed to melt it / energy costs are lower (1)

Explain why the positive electrodes must be replaced

3 marks | **Grade 5**

1. Oxygen is produced at the positive electrode.
2. The electrode is made of carbon, which reacts with the oxygen at the high temperature.
3. Carbon dioxide forms, so the electrode wears away.

Example. Explain why the positive electrodes need to be replaced regularly during the extraction of aluminium.

Model answer.

Oxygen is produced at the positive electrode (1)
The electrode is made of carbon, which reacts with the oxygen (1)
to form carbon dioxide, so the electrode burns away / gets smaller (1)

Complete the half equations

2 marks | Grade 8

1. Balance the atoms first (two oxide ions make one O_2 molecule).
2. Add electrons so the total charge is the same on both sides.

Example. Complete the half equations for the electrolysis of aluminium oxide.

$Al^{3+} + ...e^- \rightarrow Al$

$....O^{2-} \rightarrow O_2 + ...e^-$

Model answer.

$Al^{3+} + 3e^- \rightarrow Al$ (1)

$2O^{2-} \rightarrow O_2 + 4e^-$ (1)

Don’t lose marks

- Saying cryolite lowers the boiling point, or that it is a catalyst.
- Saying the anodes are replaced because they melt or dissolve: they react with oxygen to form carbon dioxide.
- Saying aluminium forms at the anode.
- Explaining the cost as 'it uses electricity' without saying large amounts of energy are needed to melt the compound too.

More tips

Memory tricks

- Cryolite cuts the melting point, so it cuts the energy bill.
- Oxygen + carbon anode → carbon dioxide: the anode 'burns away'.
- Electron check: Al^{3+} needs $3e^-$; two O^{2-} ions give up $4e^-$.

Exam technique

- Use the word 'energy' in cost answers: melting the electrolyte and producing the current both need large amounts of energy.
- The anode question has three linked points: oxygen forms, it reacts with the carbon, carbon dioxide forms so the anode wears away.
- Call the positive electrode the anode and say it is made of carbon.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 4

State when electrolysis is used for extraction

When the metal is too reactive to be extracted by carbon, or when it reacts with carbon.

Grade 5

Name the products from aluminium oxide

Aluminium forms at the cathode and oxygen forms at the anode.

Explain why electrolysis is expensive

Grade 5 Large amounts of energy are needed to melt the compound and to produce the electric current.

Grade 5 **Explain why cryolite is used**

Mixing aluminium oxide with cryolite lowers the melting point, so less energy is needed.

Grade 5 **Explain why the anodes must be replaced**

Oxygen formed at the carbon anodes reacts with them to form carbon dioxide, so they wear away.

Grade 8 **Write half equations for aluminium extraction**

$Al^{3+} + 3e^- \rightarrow Al$ at the cathode and $2O^{2-} \rightarrow O_2 + 4e^-$ at the anode.

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