Three types of cells are used in the chloro-alkali industry:

- Membrane cell
- Diaphragm cell
- Mercury cell

In all these cells:

Similarities	Differences
The electrolysis of saturated $NaC\ell(aq)$ produces $NaOH(aq)$, $C\ell_2(g)$ and $H_2(g)$.	The way in which $C\ell_2(g)$ and $NaOH(aq)$ are prevented from mixing to ensure a high purity of the products.

(I) The membrane cell

An electrolytic cell is used. → A selectively permeable membrane → $C\ell_2(g)$ and $NaOH(aq)$ separated.

A selectively permeable membrane → Only allows through positive ions ($Na^+(aq)$).

Only allows through positive ions ($Na^+(aq)$). → Is also known as a cation permeable membrane.

A selectively permeable membrane ↔ Is also known as a cation permeable membrane.

During the process, a lot of electrical energy is converted to chemical energy and a number of non-spontaneous redox reactions occur.
The oxidation half-cell and the reduction half-cell are separated by the cation exchange membrane. This membrane lets only cations through. The $Na^+(aq)$ cations (from the $NaC\ell(aq)$ solution) move from the oxidation half-cell to the cathode. This prevents $OH^-(aq)$ anions from moving from the reduction half-cell to the anode, since the product would then be a mixture of $C\ell_2(g)$ and $O_2(g)$.
The anode is positive and the cathode is negative, as is the case with all electrolytic cells.
A saturated sodium chloride solution known as brine, $NaC\ell(aq)$, is pumped into the oxidation half-cell (at the anode). This is where the OH^- ions and the $C\ell^-$ ions compete to be oxidised.

The $C\ell^-$ ions are oxidised to $C\ell_2(g)$ ions.

$$2C\ell^-(aq) \rightarrow C\ell_2(g) + 2e^-$$

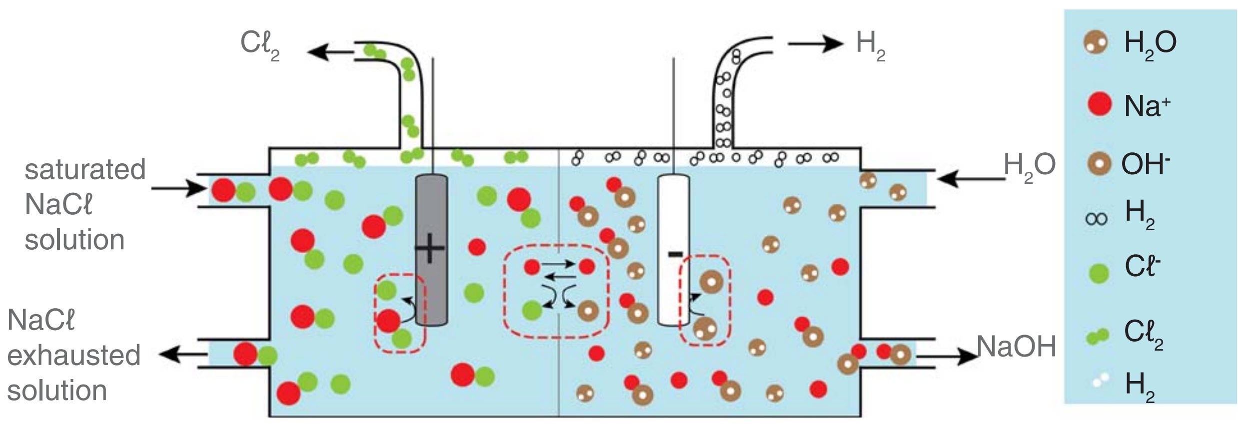
The Na^+ ions compete at the cathode and the H^+ ions compete at the cathode to be reduced.

H^+ from the H_2O is reduced to form $H_2(g)$, because H_2O is a stronger oxidising agent than Na^+ and is reduced more easily.

$$2H_2O(\ell) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

The net cell reaction is therefore:

$$2NaC\ell(aq) + 2H_2O(\ell) \rightarrow H_2(g) + C\ell_2(g) + 2NaOH(aq)$$



The Na^+ ions that move from the anode compartment through the membrane to the cathode, and the OH^- ions that cannot move through the cation exchange membrane to the anode form a sodium hydroxide solution, NaOH(aq).

The three products are therefore $C\ell_2$(g), H_2(g) and NaOH(aq).

Quick facts

- Chlorine gas is used to disinfect water, to kill bacteria, in bleaches and in the manufacturing of insecticides and herbicides, PVC, chlorine and hydrochloric acid.
- Hydrogen gas is used in the Haber process to prepare ammonia, as well as for hydrogenation of vegetable oils to manufacture margarine. It is used as fuel in rockets and in the production of hydrochloric acid, HCℓ.
- Sodium hydroxide, also known as caustic soda, is used in oven cleaners and during the manufacturing process of paper, textiles, soap, cleaning products and bleaches.

Advantages	Disadvantages
• Most environmentally friendly cell • Uses less electricity than the other two cells and is therefore cheaper. • Produces a very pure product.	There are dangers associated with the products: • $C\ell_2$(g) is toxic and shouldn't be inhaled • H_2(g) is combustible • NaOH(aq) is corrosive and should be allowed to enter the groundwater

(II) The diaphragm cell

Asbestos diaphragm separates the $C\ell_2$(g) and NaOH(aq).

Allows both cations and anions through.

Liquid level in the anode half cell is kept higher than in the cathode half cell.

Prevents OH^-(aq) from moving through the diaphragm to the anode.

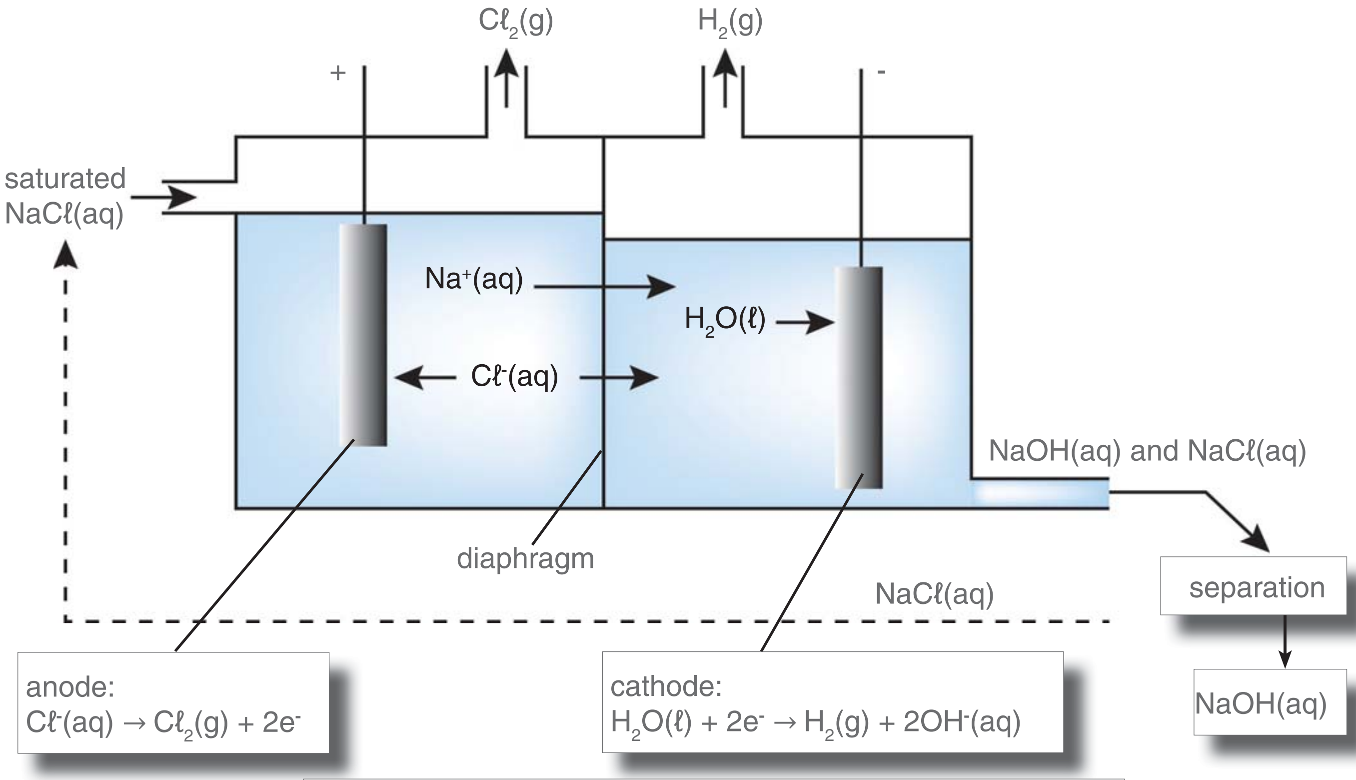
Nadeel:
Migrasie van $C\ell^-$(aq) na katodehalfsel
Gevolg:
Gevormde NaOH(aq) is met $NaC\ell$(aq) gekontamineer.

As in the membrane cell, a saturated salt solution ($NaC\ell$(aq)) is pumped into the cell at the anode.

The $C\ell^-$(aq) is oxidised to $C\ell_2$(g) which is removed at the anode.

At the cathode, H_2O(ℓ) is reduced to H_2(g) and OH^-(aq).

H_2(g) is released at the cathode and the OH^-(aq) combines with the Na^+(aq) to form NaOH(aq). Some of the $C\ell^-$(aq) that moves through the diaphragm to the cathode half cell, contaminates the NaOH(aq) as it forms $NaC\ell$(aq).



cell reaction: $2C\ell^-(aq) + 2H_2O(\ell) \rightarrow 2OH^-(aq) + C\ell_2(g) + H_2(g)$

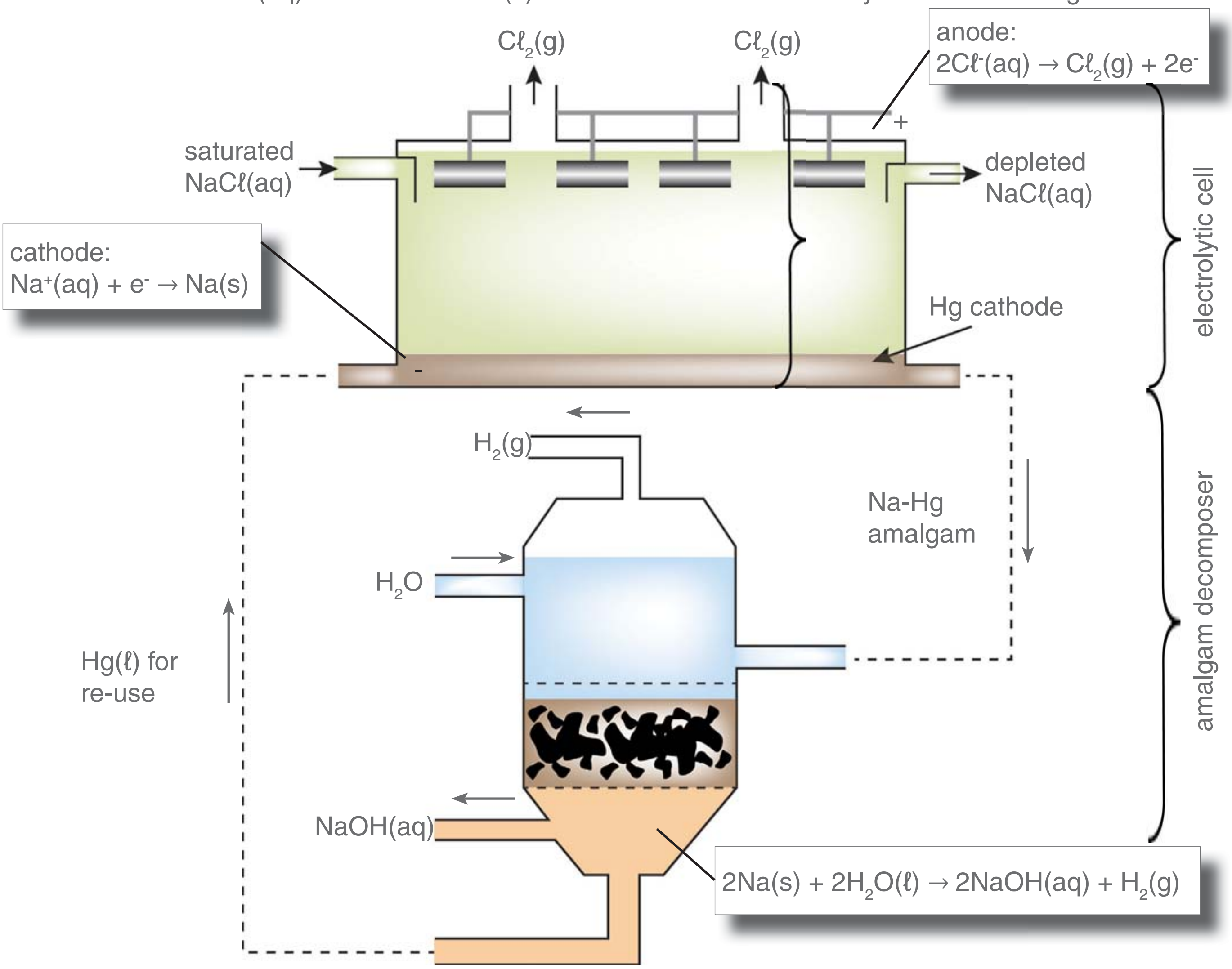
Disadvantages

- The use of asbestos in the diaphragm is a health risk for workers.
- Disposal of asbestos diaphragms (when no longer usable) into the environment, is a further health risk.
- The NaOH(aq) formed in the cell is of a lower concentration and not as pure as that obtained in the membrane cell.
- Additional energy is thus needed for the separation of the NaOH(aq) and the NaCℓ(aq).

(III) The mercury cell

The system consists of two cells:

- An electrolytic cell and an amalgam decomposer.
- In this cell the mercury cathode prevents the mixing of $C\ell_2$(g) and NaOH(aq).
- A saturated salt solution (NaCl(aq)) is pumped into the electrolytic cell. $C\ell^-$(aq) is oxidised to $C\ell_2$(g) and this is then removed at the anode.
- At the cathode Na^+(aq) is reduced to Na(s) that dissolves in the mercury to form an amalgam.



cell reaction: $2C\ell^-(aq) + 2H_2O(\ell) \rightarrow 2OH^-(aq) + C\ell_2(g) + H_2(g)$

Quick facts

Na(s) dissolves in mercury to form an amalgam.

The sodium-mercury mixture, or amalgam, moves to the amalgam decomposer.
After addition of water Na(s) reacts with $H_2O(\ell)$ to form NaOH(aq) and $H_2(g)$.

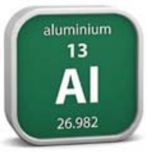
Advantages	Disadvantages
• Products obtained from this cell are very pure. • The chlorine produced can be used without further purification.	• Mercury, a heavy metal, can leak into water sources posing a huge health risk to humans and the environment. • Traces of mercury may also be present in products.

Quick facts

Mercury is a heavy metal and therefore all mercury cells are being phased out.

D Extraction of aluminium

Aluminium is obtained from the electrolytic reduction of the melted impure aluminium oxide, bauxite.



- Bauxite is imported from Australia. The plant is in Richards Bay, since it is the closest South African harbour to Australia.
- Crushed bauxite is treated with a concentrated sodium hydroxide solution to get pure alumina ($A\ell_2O_3$).
- The 'red mud' waste is pumped into red mud tailing dams and contains iron(III) oxide.
- A very strong current has to be passed through the alumina to reduce the aluminium ions, since $A\ell(s)$ is a strong reducing agent and $A\ell^{3+}(aq)$ is a weak oxidising agent. The cost involved is high.
  The process is quite uneconomical.
- Alumina's ($A\ell_2O_3$) melting point is very high (2 045°C). That is why cryolite ($Na_3A\ell F_6$) is added, which lowers the melting point so that electrolysis can occur at ±950°C.
- The overall cell equation is: $2A\ell_2O_3(\ell) \rightarrow 4A\ell(\ell) + 3O_2(g)$
- A steel tank is covered with a carbon lining and acts as the cathode.

Quick facts

Bauxite contains iron oxide, silicon dioxide and titanium dioxide.