Electrochemistry extras for Matric – Chlor-alkali process

(This worksheet is taken from pg 195-198 of printed notes.)

The Chlor-alkali process uses an electrolytic cell (electrical / chemical energy being converted to electrical / chemical energy) to produce **chlorine gas** (CHLOR) and **sodium hydroxide** (ALKALI) from sodium chloride, NaCl.

A saturated aqueous solution of sodium chloride (also called BRINE) is treated with a direct current to form chlorine gas, hydrogen gas and sodium hydroxide. This is a non-spontaneous redox reaction.

At the **anode**, chloride ions are oxidised to chlorine gas:

Oxi: $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$

At the **cathode**, water is reduced to form hydrogen gas and hydroxide ions:

Red: $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

Overall (net) reaction:

$2NaCl(aq) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g) + Cl_2(g)$

(**Note**: The Na^+ ions are ions. They do not change in oxidation state so are neither oxidised nor reduced in the reaction.)

Types of cells used in Chlor-alkali:

There are THREE types of cells that can be used for this process:

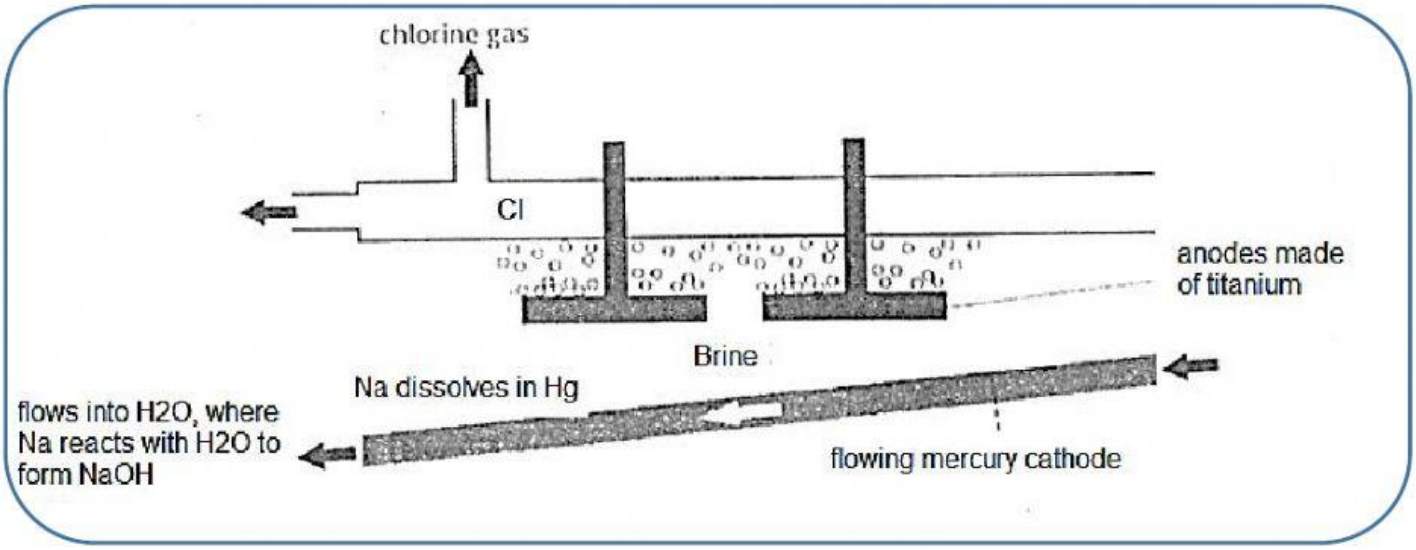
- Mercury cell
- Diaphragm cell
- Membrane cell

1. Mercury Cell

Cathode: liquid mercury (Hg)

Anode: graphite or titanium

Brine is continuously passed through the cell.



Dangers of Mercury:

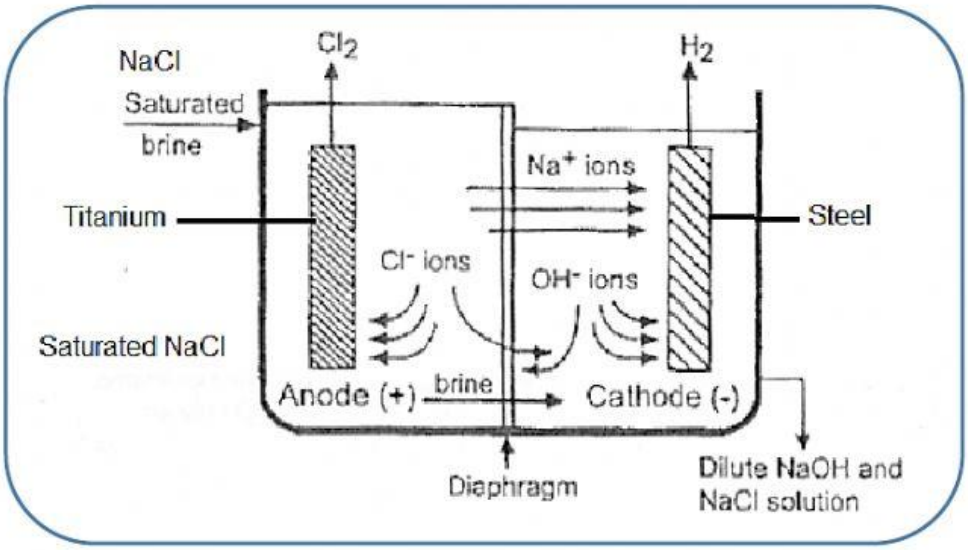
- highly volatile (easily evaporates)
- poisonous to humans (affects nervous system, reproduction, can cause cancer)

2. Diaphragm Cell

Cathode: steel

Anode: titanium

The cathode is separated from the anode by a **porous asbestos diaphragm** which allows ions to move from one compartment to the other but prevents the mixing of the gases produced at the electrodes.



Disadvantages of diaphragm cell:

- Because of the health concerns associated with asbestos, the asbestos diaphragms are being replaced with polymeric fibre diaphragms.
- Chloride ions can permeate through the diaphragm and contaminate the NaOH product with NaCl
- Diaphragms need replacing regularly

NB:
You need to know this cell in detail. For the other 2 cells, just learn the basic differences from the membrane cell

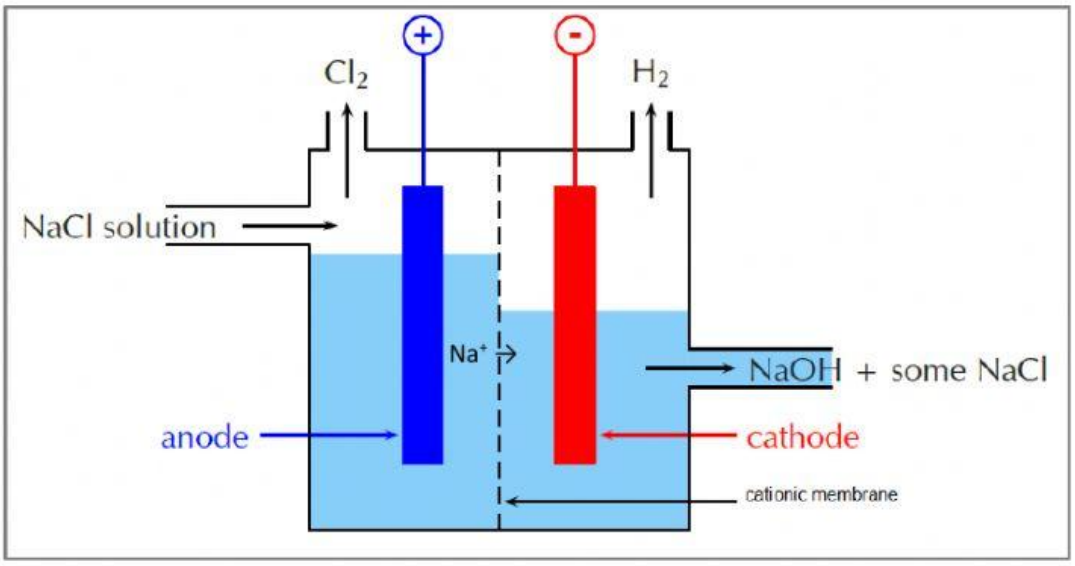
3. Membrane Cell

Cathode: steel or nickel

Anode: titanium

This is the most modern system of electrolysis.

Uses a selective **ion-exchange membrane** which is permeable to cations (Na^+) and a small amount of water, but not to anions. Chloride ions (Cl^-) are thus unable to cross the membrane and contaminate the NaOH product.



Source: Siyavula Everything Science 2016 gr 12 pg 490

https://www.youtube.com/watch?v=CDifZFFRqFg&list=PLajvcXS0n9MVUDxi1GqFoT-nuK6korYoe&index=11&t=0s

Watch this very helpful YouTube clip which demonstrates the Chlor-Alkali process with a live simulation.

To access the above simulation yourself, click on this link.

https://vula.uct.ac.za/access/content/group/9eafe770-4c41-4742-a414-0df36366abe6/Chem%20Ind%20Resource%20Pack/html/animations/Chloralkali.swf

Past Paper Question:

The chlor-alkali industry is the second largest consumer of electricity among electrolytic industries. It makes use of brine as electrolyte to produce chlorine gas, hydrogen gas and sodium hydroxide. The overall reaction can be represented by the following equation:

$$2NaCl\,(aq) + 2H_2O\,(l) \rightarrow 2NaOH\,(aq) + H_2\,(g) + Cl_2\,(g)$$

1. Brine conducts electricity because it contains _____ in solution which are free to move.

2. Write down the NAME of the reducing agent in the above reaction.

3. Write down a half-reaction to explain how the hydroxide ions are formed during this reaction (INCLUDE phase symbols)

_____ + _____ → _____ + _____

4. At which electrode is chlorine gas formed? ANODE / CATHODE

Questions to complete from Chemistry notes:

Pg 295 - Q10

Pg 296 - Q10

Pg 297 - Q11

Pg 298-299 - Q13 & Q12

Table of Comparison of Chlor-Alkali cells showing advantages and disadvantages of each method:

	Mercury cell	Diaphragm cell	Membrane cell
Construction costs	High	Low	Medium
Maintenance	Toxic mercury must be removed	Frequent replacement of diaphragms	Low maintenance
Cell voltage (V)	3,9 to 4,2	2,9 to 3,5	3,0 to 3,6
NaOH strength (wt%)	50	12	33
Steam consumption (kWh/Mt Cl_2) for concentration to 50% NaOH	0	610	180
Energy consumption (kWh/Mt Cl_2)	3360 (at 10 kA m^{-2})	2720 (at 1,7 kA m^{-2})	2650 (at 5 kA m

Table of Properties and Uses for Chlorine, Sodium Hydroxide and Hydrogen:

	Chlorine	Sodium hydroxide`	Hydrogen
Properties	Poisonous yellow-green gas with pungent odour	White crystalline solid that is alkaline and corrosive	Colourless flammable gas
Uses	• Water purification because it kills bacteria • Makes PVC • Bleaching paper and cloth • Making solvents • Making hydrochloric acid • Making paints and dyestuffs • Making disinfectants, weed killers and insecticides	• Making soaps and detergents • Making paper • Making textiles • Purification of bauxite	• Making nylon • Hardening vegetable oils for margarine • Making hydrogen peroxide • Making ammonia