Electrolysis of Water

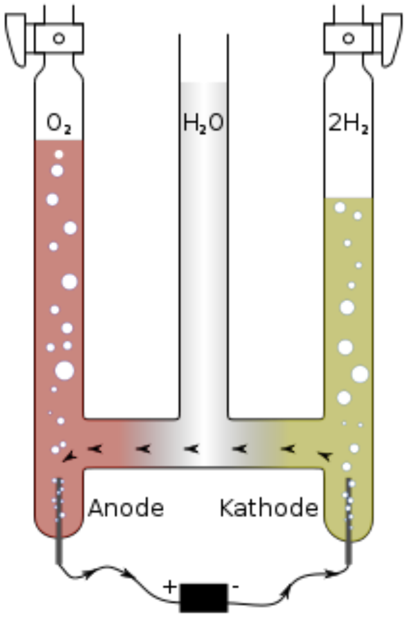
Electrolysis is the driving of a non-spontaneous chemical reaction by passing a direct electric current through an electrolyte.
In electrolysis, positive ions migrate to the cathode and negative ions to the anode. The reactions occurring depend on electron transfer at the electrodes and are therefore **redox reactions**.

At the **anode (+)** negative ions in solution may lose electrons to form neutral species. Alternatively, atoms of the anode can lose electrons and go into solution as positive ions. The process is oxidation.

At the **cathode (-)** positive ions in solution can gain electrons to form neutral species. Cathode reactions are reduction reactions.

Electrolyte: A liquid that conducts electricity as a result of the presence of positive and negative ions.
Electrode: A conductor that emits or collects electrons in a cell. Usually an inert material such as platinum.

The Electrolysis of Water



In the school laboratory hydrogen and oxygen production via electrolysis is usually performed using a **Hoffman Voltameter**. This is an expensive piece of equipment due to the intricate shaped glassware and use of platinum electrodes.
In this article we will describe the preparation of a simple electrolysis cell that can be cheaply made and used year after year in the science classroom.

Ordinary tap water can be used for the electrolysis of water. Water decomposes above 2.0 V into hydrogen and oxygen in a process known as **electrolysis**. More bubbles form on the negative (hydrogen) electrode than on the positive (oxygen) electrode.

At the **anode (+)** water decomposes to form oxygen and hydrogen ions:

$$2H_2O\ (l) \rightarrow O_2\ (g) + 4H^+\ (aq) + 4e^- \qquad E^o_{ox} = -1.23\ V$$

At the **cathode (-)** water decomposes into hydrogen and hydroxide ions:

$$2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq) \qquad E^o_{red} = -0.83\ V$$

And the **overall reaction**:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g) \qquad E^o_{cell} = -2.06\ V$$

The negative cell value (E^o_{cell}) indicates that the process will not proceed spontaneously and electrical energy has to be added.

Pure water conducts electricity very poorly so a water-soluble **electrolyte** has to be added to "close the circuit". This electrolyte dissociates into cations and anions that carry the charge through the liquid. Care must be taken not to select a salt with ions that are easier electrolyzed than water. Sodium (Na^+) is safe as cation, as well as SO_4^{2-} or CO_3^{2-} as anions. Usually sodium hydroxide, NaOH, sodium bicarbonate, $NaHCO_3$ or dilute sulphuric acid is used.

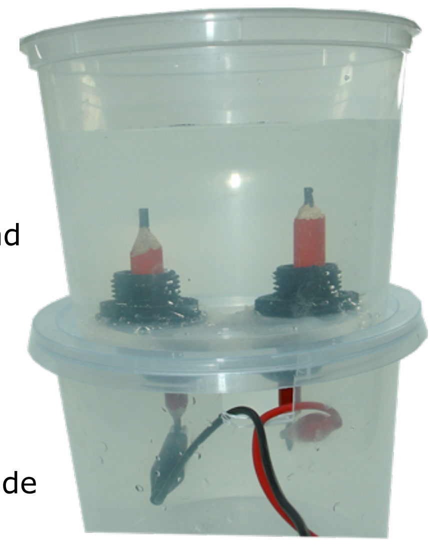
MAKING A BASIC ELECTROLYSIS CELL

Materials required

- Two plastic containers (about 500 ml volume) with lids *(Cheaply found at Variety or Dollar Stores)*
- Two round pencils or two round graphite pencils from an art shop
- Two cable glands *(A 16mm gland known as "M16 Nylon Cable Gland" from an* electrical wholesaler, works well*)*
- Two jumper leads with alligator clips
- Hand DC Generator **or** 9V battery *(Hand DC generators are sold on eBay and Variety Stores for charging mobile phones.The charger should be able to deliver at least 2.5 V)*
- Sodium hydroxide or sodium bicarbonate
- Test tubes (x2)
- Drill bit / metal rod, diameter of cable gland (16 mm)
- Scissors, knife, two test tubes for gas collection

Preparing the cell

1. Wear gloves and melt two 16 mm holes through the bottom of the plastic container using a metal rod or back of a drill bit. The two cable glands should fit through the holes.
2. Fit the gland with the rubber seal ring on the inside.
3. Clean the wood from the ends of two pencils to expose the graphite.
4. Push the pencils into the glands and tighten so the pencils sit water tight.
5. Cut a hole through the lid of the second container and cut a slit in the container to accommodate the pencils and leads →
6. Connect the alligator clips to the pencils and to the generator / battery. *(You may have to purchase a connector or prepare a connection that can connect the generator to the electrical wires).*
7. Fill the container with water to cover the electrodes and dissolve some caustic soda or sodium bicarbonate in the water.
8. Two test tubes that fit over the inner glands can be used to collect the gases.



What is happening?

Hydrogen forms at the cathode (-) and oxygen at the anode (+).

Hydrogen, is slowly emerging as the renewable energy carrier of the future.
Note that hydrogen is not seen as an energy *source* but rather as an energy *carrier*.

Here are some criteria for a future chemical fuel, and hydrogen ticks all the boxes:

- ✓ Provides a large energy storage per unit mass: H_2 combustion in air → 142 MJ/kg
- ✓ Is a fluid for ease of transportation
- ✓ Is non-toxic to plants & animals
- ✓ Provides no solid combustion residue → water vapour
- ✓ Yields non-toxic products harmless to environment → water
- ✓ Be made of common chemical elements → water
- ✓ Made from a widespread product to reduce transport → water
- ✓ Easily manufactured at a low cost
- ✓ Be used in existing power generation equipment

Most commercial hydrogen today is produced from natural gas in a process known as **steam reforming**, but the production of CO are causing problems

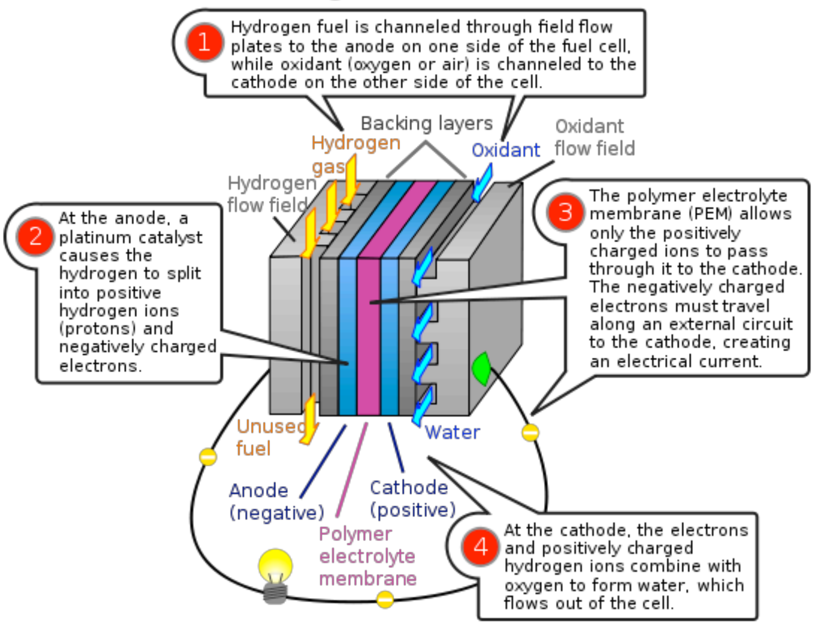
$$CH_4 + H_2O \rightarrow 3H_2 + CO$$

Hydrogen's stored energy can be released through **combustion** in a familiar exothermic reaction with the accompanying loss of heat energy

$$2H_2 + O_2 \rightarrow 2H_2O + 142 \text{ kJ/g}$$

But using hydrogen in a **fuel cell** leads to much *higher efficiencies* and the *direct production* of electrical energy (no noise, no emission).

Proton exchange membrane fuel cell



In a Proton Exchange Membrane Fuel Cell (PEM FC), the following reactions occur:

$$\text{Anode} - : \quad 2H_2 \dashrightarrow 4H^+ + 4e^-$$

$$\text{Cathode} + : \quad O_2 + 4e^- + 4H^+ \dashrightarrow 2H_2O$$

References

1. Hoffman, P; Hydrogen - The Optimum Chemical Fuel, Applied Energy, Vol 47, 1994, P 183 -199
2. Images: WikiMedia Commons