

Splitting compounds with electricity

Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Electrolysis uses direct current to split a molten or dissolved ionic compound. Positive ions move to the negative cathode and gain electrons; negative ions move to the positive anode and lose electrons. In solutions, hydrogen forms at the cathode unless the metal is less reactive, and halogens or oxygen form at the anode.

Level: Chemistry grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** GCSE C4

What is electrolysis?

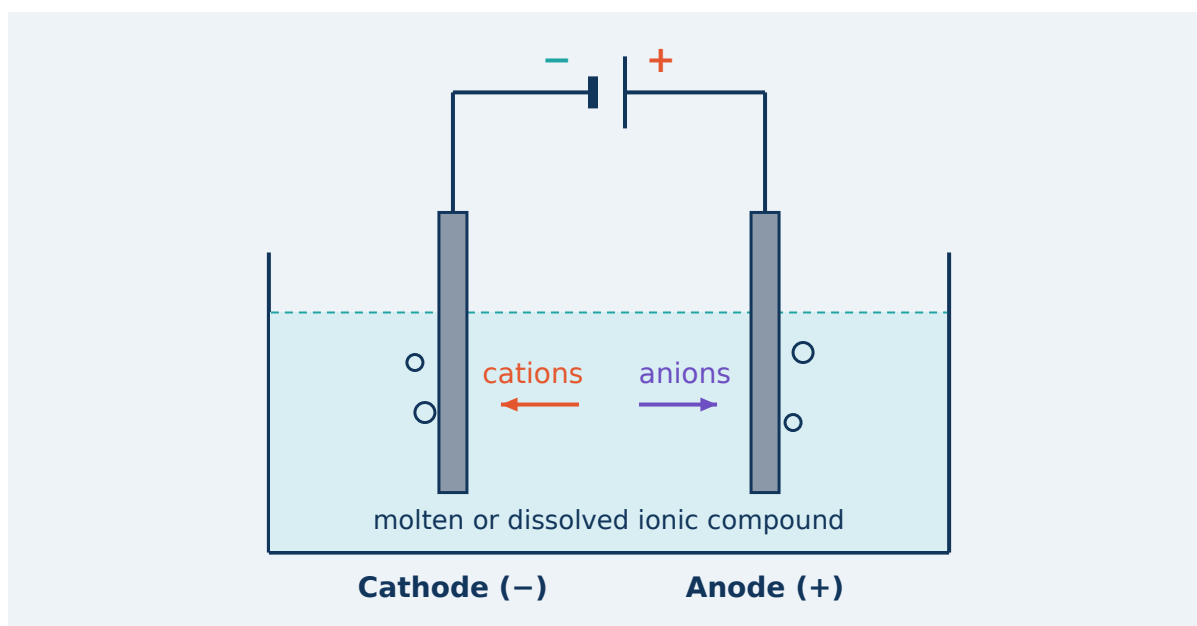
Electrolysis uses an electric current from a battery or power supply to split an ionic compound into elements. It only works when the ions are free to move, which means the compound must be **molten** or **dissolved in water**. A solid crystal holds its ions in fixed positions, so it cannot carry current.

Definition

Electrolysis is the decomposition of an ionic compound by passing direct current through it. The liquid that conducts is the **electrolyte**. The two conductors dipping into it are the **electrodes**: the **anode** is connected to the positive terminal and the **cathode** to the negative terminal.

Where do the ions go?

Opposites attract. Positive ions (cations) move to the negative cathode, where they *gain* electrons and are reduced. Negative ions (anions) move to the positive anode, where they *lose* electrons and are oxidised. Each change is written as a **half equation**.



Cations travel to the cathode and anions to the anode.

Key law

Cathode: ions gain electrons (reduction). Anode: ions lose electrons (oxidation). Half equations must balance in atoms and in charge, and the electrons gained at the cathode equal the electrons lost at the anode.

Worked example

Molten lead(II) bromide, PbBr_2 , is electrolysed with inert electrodes. Write the half equations.

Cathode: $\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}$, so molten lead forms. Anode: $2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{e}^-$, so brown bromine gas forms. Two electrons are gained and two lost, so the overall change is $\text{PbBr}_2 \rightarrow \text{Pb} + \text{Br}_2$. **Cathode: lead. Anode: bromine.**

What forms when the electrolyte is a solution?

Water adds extra ions: H^+ and OH^- . Now two cations and two anions compete, and only one of each is discharged. With inert electrodes (carbon or platinum) the rules below usually work.

Key law

Cathode: a metal forms if it is less reactive than hydrogen (copper, silver); otherwise hydrogen forms. Anode: a halogen forms if chloride, bromide or iodide ions are present; otherwise oxygen forms.

Electrolyte	Cathode product	Anode product
Molten lead(II) bromide	Lead	Bromine
Copper(II) sulfate solution	Copper	Oxygen
Concentrated sodium chloride solution	Hydrogen	Chlorine

Electrolyte	Cathode product	Anode product
Dilute sulfuric acid	Hydrogen	Oxygen

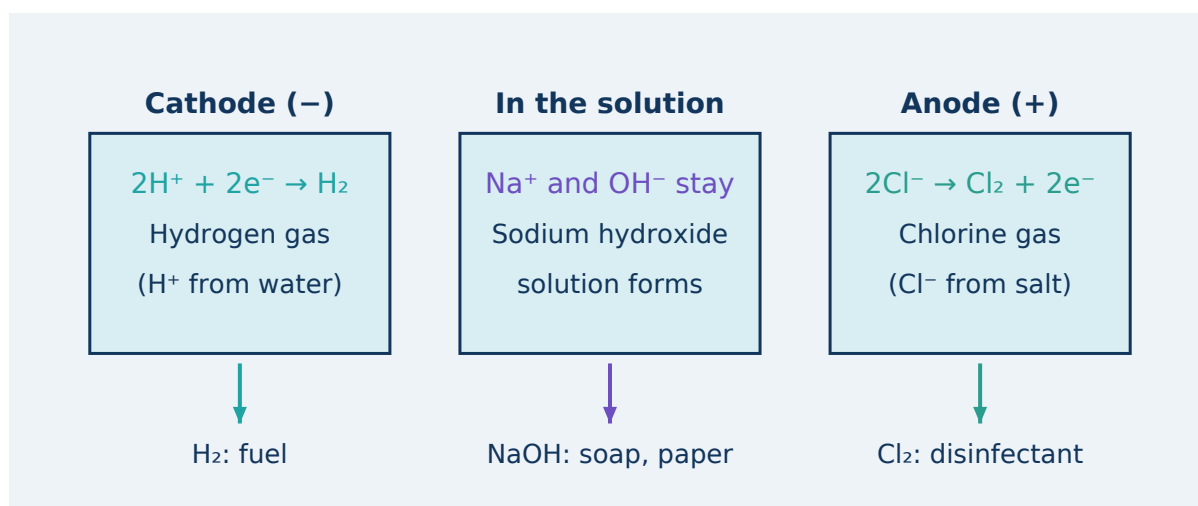
At the anode, hydroxide ions are discharged when no halide is present: $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$. At the cathode in acid, $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$.

Common mistake

Do not write that sodium metal forms when brine is electrolysed. Sodium is more reactive than hydrogen, so Na^+ stays in solution and hydrogen gas is released instead. Also remember that in electrolysis the anode is the *positive* electrode.

How is brine electrolysed in industry?

Concentrated sodium chloride solution (brine) gives three useful products at once. Chlorine disinfects water and makes plastics such as PVC. Hydrogen is used as a fuel and in making margarine. The solution left behind contains Na^+ and OH^- , which is sodium hydroxide, used in soap and paper.



Three products from one cheap solution: hydrogen, chlorine and sodium hydroxide.

Worked example

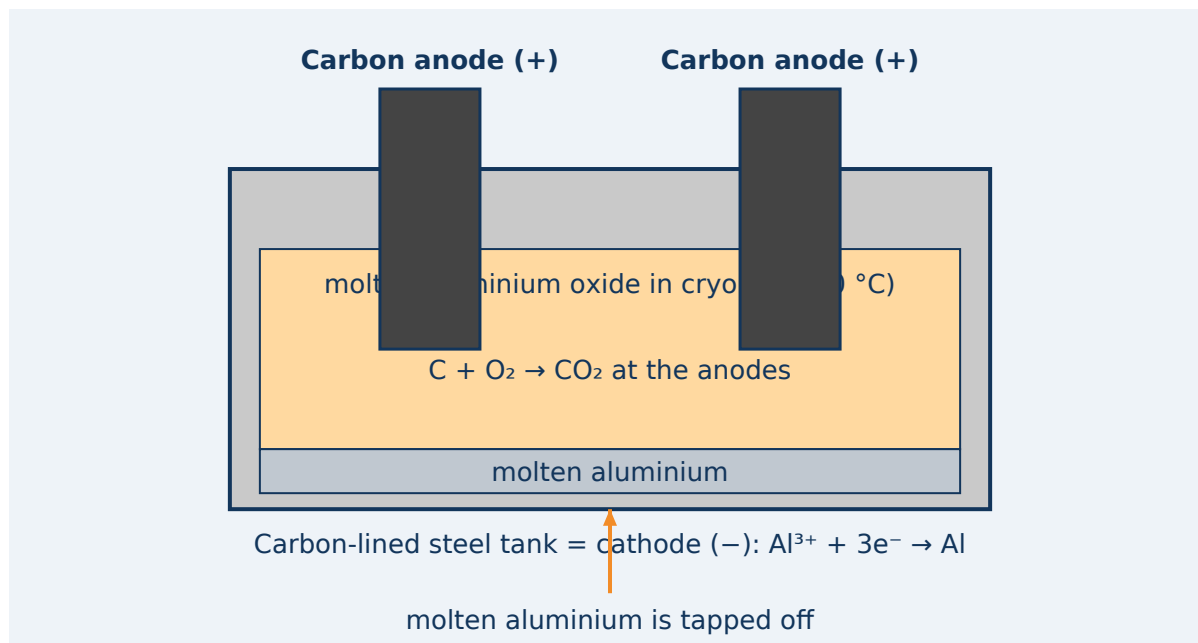
Mei electrolyses brine and collects 12 dm^3 of chlorine (1 mol of gas occupies 24 dm^3). Find the volume of hydrogen, the moles of electrons and the mass of sodium hydroxide (Ar: Na = 23, O = 16, H = 1).

$n(\text{Cl}_2) = 12 \div 24 = 0.50 \text{ mol}$. Each Cl_2 releases 2e^- , so 1.0 mol of electrons flows. Each H_2 needs 2e^- , so $n(\text{H}_2) = 0.50 \text{ mol}$, a volume of **12 dm^3** . 1.0 mol of electrons also leaves 1.0 mol of OH^- , so 1.0 mol $\text{NaOH} = \mathbf{40 \text{ g}}$.

How is aluminium extracted by electrolysis?

Aluminium oxide melts at 2072°C , far too hot to be practical. Dissolving it in molten cryolite lowers the working temperature to about 950°C and saves a great deal of energy. At the

carbon-lined steel cathode, $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$. At the carbon anodes, $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$, and the hot oxygen burns the anodes: $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$. The anodes therefore wear away and are replaced regularly.



The cell for aluminium: carbon anodes burn away and must be replaced.

Worked example

A plant makes 4 mol of aluminium. Find the electrons needed and the mass of CO_2 released if all the oxygen burns carbon (Ar: C = 12, O = 16).

4 mol Al^{3+} need $4 \times 3 = 12$ mol of electrons. Those electrons come from $6\text{O}^{2-} \rightarrow 3\text{O}_2 + 12\text{e}^-$, giving 3 mol of O_2 . Each O_2 makes one CO_2 , so $n(\text{CO}_2) = 3$ mol and $m = 3 \times 44 =$ **132 g**.

Lina's tip

Remember PANIC: Positive is Anode, Negative Is Cathode. For the changes, use OIL RIG: Oxidation Is Loss, Reduction Is Gain (of electrons).

Key points to remember

- The electrolyte must be molten or dissolved so that ions can move
- Cathode (–): reduction, gain of electrons; anode (+): oxidation, loss of electrons
- Cathode in solution: metal less reactive than hydrogen, otherwise H_2
- Anode in solution: halogen if a halide is present, otherwise O_2
- Brine gives H_2 , Cl_2 and NaOH ; aluminium oxide is electrolysed in molten cryolite

Splitting compounds with electricity: frequently asked

questions

Why does solid sodium chloride not conduct but molten sodium chloride does?

In the solid the ions are locked in a lattice and cannot move. When molten or dissolved, the ions are free to travel to the electrodes and carry the current.

Why is hydrogen made instead of sodium when brine is electrolysed?

Sodium is more reactive than hydrogen, so H^+ ions from water gain electrons more easily than Na^+ ions. Hydrogen gas bubbles off and Na^+ stays in solution.

Which electrode is positive in electrolysis?

The anode is positive because it is joined to the positive terminal of the supply. Negative ions are attracted to it and lose electrons there.

Why is cryolite added when making aluminium?

Cryolite dissolves aluminium oxide and lets the mixture melt at about $950\text{ }^{\circ}\text{C}$ instead of $2072\text{ }^{\circ}\text{C}$. This saves large amounts of energy and money.

Why do the carbon anodes in an aluminium cell need replacing?

Oxygen formed at the anodes is hot enough to react with the carbon and form carbon dioxide. The anodes slowly burn away.