Electrolysis of aqueous solutions

4.4.3.4 · Chemical changes · revision notes

Predicting the products when a solution of an ionic compound in water is electrolysed with inert electrodes. Water provides H^+ and OH^- ions, so hydrogen or oxygen can form instead of the metal or non-metal. Required practical 3 is based on this.

Key facts

- Water provides H^+ and OH^- ions
- Anode: halide ions present → halogen; no halide ions → oxygen
- Copper(II) sulfate solution → copper (cathode) + oxygen (anode)
- Oxygen: relights a glowing splint
- Cathode: metal more reactive than hydrogen → hydrogen; less reactive → the metal
- Sodium chloride solution → hydrogen (cathode) + chlorine (anode), sodium hydroxide left
- Hydrogen: squeaky pop with a lit splint
- Chlorine: bleaches damp litmus paper

Notes

Ions in an aqueous solution

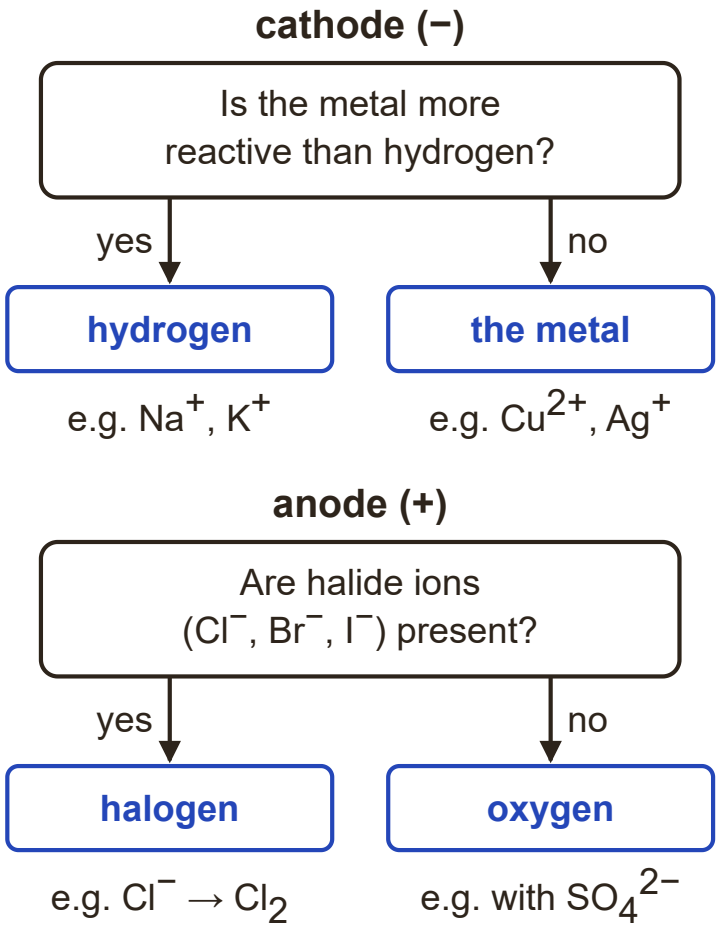
- A solution contains the ions of the compound **and** hydrogen ions (H^+) and hydroxide ions (OH^-), because a small number of water molecules break down into these ions.
- At each electrode only one product forms. Which one depends on the relative reactivity of the elements involved.

At the cathode (negative)

- **Hydrogen** is produced if the metal is **more reactive than hydrogen**, e.g. with solutions of potassium, sodium, calcium or magnesium compounds.
- The **metal** is produced if it is **less reactive than hydrogen**, e.g. copper or silver. A coating of the metal forms on the cathode.

At the anode (positive)

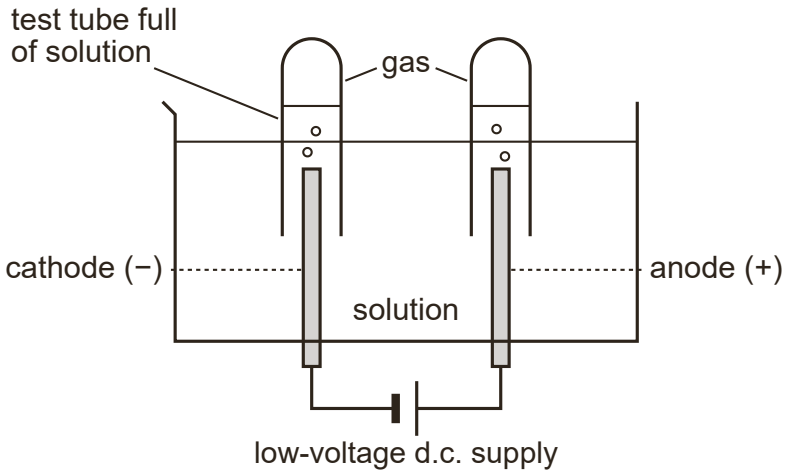
- If the solution contains **halide ions** (Cl^-, Br^- or I^-), the **halogen** is produced: chlorine, bromine or iodine.
- Otherwise, e.g. with sulfate or nitrate ions, **oxygen** is produced from the hydroxide ions.
- Examples: copper(II) chloride → copper + chlorine; copper(II) sulfate → copper + oxygen; sodium chloride → hydrogen + chlorine; sodium sulfate → hydrogen + oxygen.
- Ions that are not discharged stay in the solution: electrolysis of sodium chloride solution leaves sodium hydroxide solution, so the pH rises.



Two questions decide the products of electrolysing a solution with inert electrodes.

Required practical 3

- Put two inert electrodes (graphite rods) into the solution and connect them to a low-voltage d.c. supply.
- Collect any gas in small test tubes filled with the solution and placed over each electrode, then test it: hydrogen burns with a squeaky pop; oxygen relights a glowing splint; chlorine bleaches damp litmus paper.



Graphite electrodes, each under a test tube of the solution: any gas collects at the top of the tube, ready to test.

- Look for a metal coating on the cathode (copper is pink-brown) and colours near the anode (bromine is orange, iodine is brown).
- To measure how much forms: weigh the dried cathode before and after (metal), or collect the gas in a measuring cylinder and record its volume at set times.
- Start with a hypothesis, e.g. about how the reactivity of the metal affects the cathode product, and test several solutions under the same conditions.
- Chlorine is toxic: work in a well-ventilated room and run the electrolysis only for a short time.

How to answer each type of question

Predict the products of electrolysing a solution 2 to 4 marks **Grade 5**

1. Cathode: is the metal more reactive than hydrogen? Yes → hydrogen. No → the metal.
2. Anode: are halide ions present? Yes → the halogen. No → oxygen.
3. Name elements, e.g. chlorine, not chloride.

Example. Predict the product at each electrode when these solutions are electrolysed using inert electrodes.
(a) potassium bromide solution
(b) silver nitrate solution

Model answer.

(a) Cathode: hydrogen (1); anode: bromine (1)
(b) Cathode: silver (1); anode: oxygen (1)

Explain the products using reactivity

3 to 4 marks | **Grade 5**

1. List all the ions present, including H^+ and OH^- from water.
2. Cathode: compare the metal's reactivity with hydrogen.
3. Anode: say whether halide ions are present.

Example. Sodium chloride solution is electrolysed using inert electrodes.
Explain why hydrogen, not sodium, is produced at the cathode and why chlorine, not oxygen, is produced at the anode.

Model answer.

The solution contains hydrogen ions (from water) as well as sodium ions	(1)
Sodium is more reactive than hydrogen, so hydrogen is produced	(1)
The solution contains chloride ions, which are halide ions	(1)
so chlorine is produced instead of oxygen	(1)

6-mark: plan an investigation into electrolysing solutions

4 to 6 marks | **Grade 7**

1. Describe the apparatus: beaker of solution, two inert (graphite) electrodes, d.c. supply, test tubes over the electrodes.
2. Say what you keep the same: voltage, concentration, volume, time.
3. Say how you identify each product: gas tests, metal coating, colour changes.
4. Repeat with different solutions and say what result would support the hypothesis.

Example. A student's hypothesis is: 'When a solution of a metal chloride is electrolysed, the metal is produced at the cathode only if the metal is less reactive than hydrogen.'
Plan an investigation to test this hypothesis. [6 marks]

Model answer.

Marked in levels. A top-level answer is a clear, workable plan, such as:

Put copper(II) chloride solution in a beaker with two graphite (inert) electrodes connected to a low-voltage d.c. supply	(1)
Place a small test tube filled with the solution over each electrode to collect any gas	(1)
Switch on for a few minutes. A pink-brown coating on the cathode shows copper; a gas that burns with a squeaky pop shows hydrogen	(1)
Test the gas from the anode with damp litmus paper: it is bleached if chlorine is present	(1)
Repeat with chlorides of metals more reactive than hydrogen, e.g. sodium chloride and potassium chloride, using the same concentration, voltage and time	(1)
The hypothesis is supported if only the metal less reactive than hydrogen (copper) forms at the cathode	(1)

Don’t lose marks

- Saying sodium forms when sodium chloride solution is electrolysed: it is hydrogen.
- Forgetting that sulfate and nitrate ions are not discharged: oxygen forms instead.
- Testing chlorine with a splint: use damp litmus paper, which is bleached.
- Writing 'chloride gas' instead of chlorine.
- Forgetting the H^+ and OH^- ions from water when listing the ions present.

More tips

Memory tricks

- Cathode rule: metal below hydrogen → metal; metal above hydrogen → hydrogen.
- Anode rule: halide → halogen; no halide → oxygen.
- In GCSE questions the metals that coat the cathode are usually copper and silver.

Exam technique

- List the ions present first, including H^+ and OH^- from water, then apply the two rules.
- In explanations, compare reactivity directly: 'sodium is more reactive than hydrogen'.
- In practical questions, give the observation or test for every product.

What each grade needs

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

Grade 4 — **State the products from sodium chloride solution**
Hydrogen forms at the cathode and chlorine at the anode, leaving sodium hydroxide solution.

Grade 4 — **Explain where hydrogen and hydroxide ions come from**
A small number of water molecules break down into hydrogen ions and hydroxide ions.

Grade 5 — **Predict the product at the cathode**
Hydrogen forms if the metal is more reactive than hydrogen; otherwise the metal forms.

Grade 5 — **Predict the product at the anode**
The halogen forms if halide ions are present; otherwise oxygen forms.

Grade 6 — **Describe tests for the gases produced**
Hydrogen gives a squeaky pop, oxygen relights a glowing splint and chlorine bleaches damp litmus paper.

Grade 7 — **Plan the required practical investigation**
Use inert electrodes and a d.c. supply, identify each product, and compare solutions to test a hypothesis.

Grade 8 — **Explain which ions remain in solution**
Ions that are not discharged stay behind, e.g. Na^+ and OH^- ions form sodium hydroxide solution.

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