Half equations at electrodes

4.4.3.5 · Chemical changes · revision notes

Higher tier only. Writing and balancing half equations for the reactions at each electrode, and explaining that reduction happens at the cathode and oxidation at the anode. These can come up in any electrolysis question, often as 'complete the half equation'.

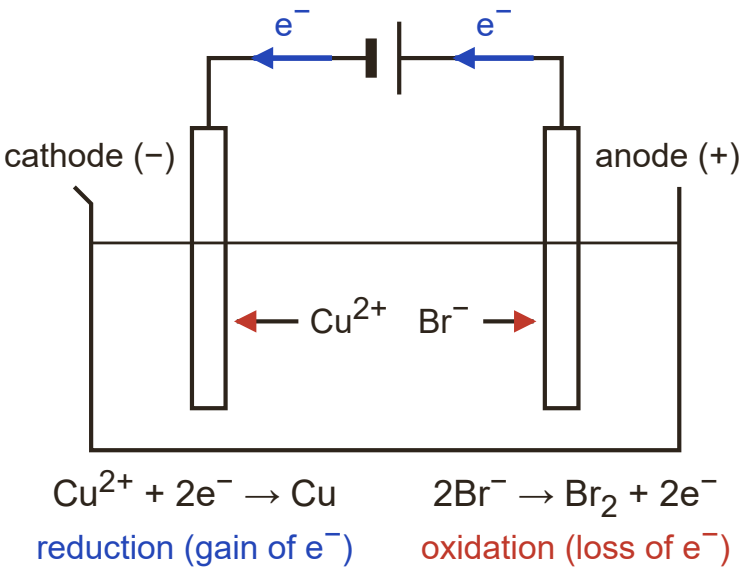
Key facts

- Cathode: reduction (gain of electrons)
- $Cu^{2+} + 2e^- \rightarrow Cu$
- $2Cl^- \rightarrow Cl_2 + 2e^-$
- $2O^{2-} \rightarrow O_2 + 4e^-$
- Anode: oxidation (loss of electrons)
- $2H^+ + 2e^- \rightarrow H_2$
- $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$
- $Al^{3+} + 3e^- \rightarrow Al$

Notes

Reduction and oxidation at the electrodes

- At the **cathode** (negative), positive ions **gain electrons**: this is **reduction**.
- At the **anode** (positive), negative ions **lose electrons**: this is **oxidation**.



Example: copper(II) bromide solution. Electrons leave at the anode and arrive at the cathode through the wires.

- OIL RIG: Oxidation Is Loss, Reduction Is Gain of electrons.

Cathode half equations

- Metal ions: $Cu^{2+} + 2e^- \rightarrow Cu$; $Na^+ + e^- \rightarrow Na$; $Al^{3+} + 3e^- \rightarrow Al$.
- Hydrogen: $2H^+ + 2e^- \rightarrow H_2$.
- The electrons are on the **left**, because they are gained.

Anode half equations

- Halide ions: $2Cl^- \rightarrow Cl_2 + 2e^-$ (the same pattern for Br^- and I^-).
- Oxide ions in a molten oxide: $2O^{2-} \rightarrow O_2 + 4e^-$.
- Hydroxide ions in an aqueous solution: $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$.
- The electrons are on the **right**, because they are lost. They can also be written as a subtraction on the left, e.g. $2Cl^- - 2e^- \rightarrow Cl_2$.

Balancing a half equation

- 1. Balance the atoms, e.g. $2Br^-$ are needed to make one Br_2.
- 2. Add electrons to whichever side makes the total charge the same on both sides.
- Example check: $4OH^-$ has a total charge of 4−, while $O_2 + 2H_2O$ has no charge, so $4e^-$ go on the right.

How to answer each type of question

Complete a half equation

1 mark each | **Grade 6**

1. Balance the atoms first.
2. Work out the total charge on each side.
3. Add the number of electrons that makes the charges equal.

Example. Complete these half equations.

(a) Ag^+ + ... → Ag

(b) $2Br^- \rightarrow Br_2$ + ...

(c) ....$OH^- \rightarrow O_2 + 2H_2O + 4e^-$

Model answer.

(a) e^- (1)

(b) $2e^-$ (1)

(c) 4 (1)

Write both half equations for an electrolysis

2 marks | Grade 7

1. Predict the product at each electrode first.
2. Cathode: positive ion + electrons → element. Anode: negative ions → element + electrons.
3. Check atoms and charges balance.

Example. Copper(II) chloride solution is electrolysed using inert electrodes.
Write half equations for the reactions at the cathode and at the anode.

Model answer.

Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$ (1)

Anode: $2Cl^- \rightarrow Cl_2 + 2e^-$ (1)

Say whether a half equation shows oxidation or reduction

2 to 3 marks | Grade 7

1. Find the electrons: on the right (lost) = oxidation; on the left (gained) = reduction.
2. Give the reason in terms of electrons.
3. Oxidation happens at the anode, reduction at the cathode.

Example. During the electrolysis of dilute sulfuric acid, this reaction happens at one electrode:
$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$
(a) Is this oxidation or reduction? Give a reason.
(b) At which electrode does it happen?

Model answer.

(a) Oxidation (1) because the hydroxide ions lose electrons (1)

(b) The anode / positive electrode (1)

Write the half equation for oxygen at the anode

2 marks | Grade 8

1. Oxygen comes from hydroxide ions in aqueous solutions.
2. Balance O atoms: $4OH^-$ make one O_2 and two H_2O.
3. Four negative charges on the left means $4e^-$ on the right.

Example. Sodium sulfate solution is electrolysed using inert electrodes.
Write a balanced half equation for the formation of oxygen at the anode.

Model answer.

Correct species: $OH^- \rightarrow O_2 + H_2O + e^-$ (1)

Balanced: $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ (1)

Don’t lose marks

- Putting electrons on the wrong side: gained electrons go on the left, lost electrons on the right.
- Writing Cl instead of Cl_2, or H instead of H_2.
- Writing e^{2-} instead of $2e^-$.
- Getting the oxygen half equation wrong: learn $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ exactly.
- Saying reduction happens at the anode.

More tips

Memory tricks

- RED CAT and AN OX: REDuction at the CAThode, OXidation at the ANode.
- The number of electrons for a metal ion equals its charge: Al^{3+} needs $3e^-$.
- Gases are diatomic (H_2, O_2, Cl_2), so start with $2H^+$ or $2Cl^-$.
- Final check: count the total charge on each side, with each electron counting as 1−.

Exam technique

- In 'complete the half equation' questions, check the charges balance before moving on.
- Both ways of writing an anode reaction are accepted: $2Cl^- \rightarrow Cl_2 + 2e^-$ or $2Cl^- - 2e^- \rightarrow Cl_2$.
- State symbols are not needed in half equations unless the question asks for them.

What each grade needs

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

Grade 5 — **State where oxidation and reduction happen**
Reduction (gain of electrons) happens at the cathode; oxidation (loss of electrons) happens at the anode.

Grade 6 — **Write cathode half equations for metal ions**
For example, $Cu^{2+} + 2e^- \rightarrow Cu$.

Grade 6 — **Write anode half equations for halide ions**
For example, $2Cl^- \rightarrow Cl_2 + 2e^-$.

Grade 7 — **Write the half equation for hydrogen**
$2H^+ + 2e^- \rightarrow H_2$.

Grade 8 — **Write the half equation for oxygen**
From hydroxide ions in solution: $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$.

Grade 8 — **Complete and balance supplied half equations**
Balance the atoms first, then add electrons so the total charge is equal on both sides.

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