

4.3 Electrolysis

Name: _____ Class: _____ Date: _____

Total: 35 marks

KEY WORDS electrolysis • cathode • anode

Objective

Predict electrolysis products and write half-equations. Original questions for spec statements 4.4.3.1–4.4.3.5.

1 Key knowledge and worked examples

Electrolyte: molten or dissolved ionic compound – **ions free to move**, so it conducts. Cations (+) → **cathode** (–); anions (–) → **anode** (+); ions are **discharged** as elements.

Molten binary compound (PbBr_2): **metal at the cathode, non-metal at the anode.**

Aluminium extraction: molten Al_2O_3 + **cryolite** – cryolite **lowers the melting point**, saving energy and cost; the **carbon anode reacts with the oxygen made** and must be replaced; electrolysis is used because aluminium is more reactive than carbon.

Aqueous solutions: at the **cathode** – **hydrogen** forms if the metal is more reactive than hydrogen, otherwise the metal; at the **anode** – **oxygen**, unless **halide ions** are present, then the halogen.

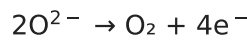
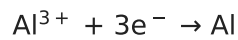
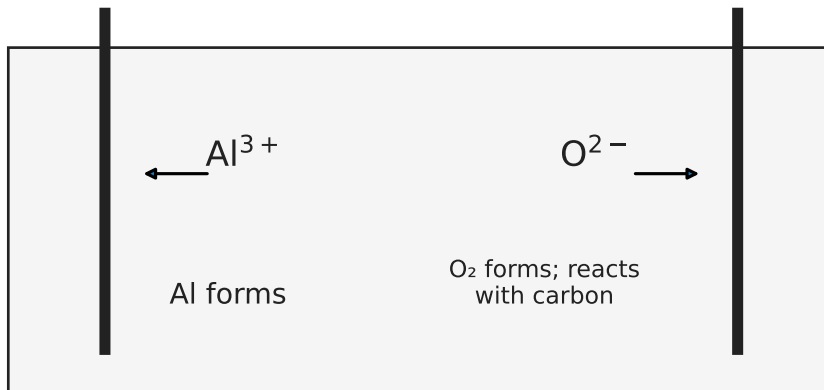
(HT) Half-equations:

- $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$; $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$; $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$
- $2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{e}^-$; $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$; $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$

Molten aluminium oxide dissolved in cryolite

- cathode

+ carbon anode



Mobile ions carry charge in the melt; electrons move through the external circuit.

Worked example (3 marks, HT). Molten aluminium oxide is electrolysed. Give both half-equations.

Cathode: $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$. Anode: $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$. Charges balance – oxidation at the anode, reduction at the cathode.

2 Practice

2.1 Why does solid sodium chloride not conduct electricity but molten sodium chloride does? [2]

2.2 Name the product at each electrode when molten lead bromide is electrolysed. [2]

2.3 What forms at the anode when concentrated sodium chloride solution is electrolysed? [1]

3 Exam-style questions

3.1 Explain why cryolite is mixed with aluminium oxide in aluminium extraction, and why the carbon anodes need regular replacement. [4]

3.2 Predict the products of electrolysis of aqueous copper sulfate using inert electrodes, explaining the electrode processes. [4]

3.3 (*HT*) Write half-equations for the electrolysis of dilute sulfuric acid at each electrode. [4]

3.4 Using inert electrodes, predict both products for (a) molten NaCl, (b) aqueous NaCl, (c) aqueous CuCl₂ and (d) aqueous Na₂SO₄ under the specified GCSE rules. Explain why the cathode product differs between (a) and (b). [6]

3.5 Develop a hypothesis for electrolysis of aqueous copper(II) sulfate with inert electrodes. Describe evidence you would seek at each electrode, the relevant gas test, two conditions to control when comparing solutions, and one precaution concerning gases. Explain why the ions and the external wire carry charge in different ways. [7]

3.6 (*HT*) Complete and balance both half-equations for molten zinc chloride. Then correct $2\text{OH}^- \rightarrow \text{O}_2 + \text{H}_2\text{O} + 2\text{e}^-$ for oxygen formation from aqueous hydroxide ions. Show how both atoms and charge check in your corrected oxygen equation. [5]

Solutions

2.1 In the solid, the ions are fixed in the lattice and cannot move; when molten the ions are free to move to the electrodes and carry charge.

2.2 Lead at the cathode; bromine at the anode.

2.3 Chlorine.

3.1 The mixture has a much lower melting point than pure aluminium oxide; so less energy is needed to keep it molten – lower heating cost. At the anode, oxygen is produced; the hot carbon anode reacts/burns with the oxygen to form carbon dioxide, so it is used up and must be replaced.

3.2 At the cathode, copper deposits – copper is less reactive than hydrogen, so Cu^{2+} is discharged in preference to H^+ : $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$. At the anode, oxygen forms from the hydroxide ions of the water – no halide present: $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$.

3.3 Cathode (negative): $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$. Anode (positive): $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$.

3.4 In cathode/anode order: (a) sodium/chlorine; (b) hydrogen/chlorine; (c) copper/chlorine; (d) hydrogen/oxygen. The molten compound contains no water. In aqueous NaCl, water provides hydrogen ions and sodium is above hydrogen, so hydrogen forms instead of sodium.

3.5 Hypothesis: copper at the cathode and oxygen at the anode. Seek a pink-brown copper deposit at the cathode and bubbles of a gas that relights a glowing splint at the anode. Control any two of electrode material, electrode spacing, voltage, concentration or test time for the stated comparison. Use small gas quantities with good ventilation/teacher supervision; never smell gases. Mobile ions carry charge through the solution; electrons carry charge through the external metal wire.

3.6 $\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn}$; $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$. Correct oxygen equation: $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$. Four oxygen and four hydrogen atoms occur on both sides. Total charge is -4 on both sides; the electrons are products in oxidation.