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SECONDARY 4 · CHEMISTRY · ELECTROLYSIS

Electrolysis

Theory and worked examples

Recap from Sec 3: ideas this chapter uses

Electrolysis questions in Sec 4 papers mix in many Sec 3 ideas: ions, redox, the reactivity series and the tests for gases. Read this recap first. Every practice question in this chapter can be answered from these notes and this recap.

- Halogens (Group 17): Chlorine is a toxic, greenish-yellow gas; bromine is a reddish-brown liquid that gives a reddish-brown vapour and an orange solution in water; iodine gives a brown solution. A more reactive halogen displaces a less reactive one from its halide: $Cl_2(aq) + 2Br^-(aq) \rightarrow 2Cl^-(aq) + Br_2(aq)$ (colourless to orange).
- pH and Universal Indicator: Acidic (pH below 7): red, orange or yellow. Neutral (pH 7): green. Alkaline (pH above 7): blue or purple. Acids contain $H^+(aq)$ ions; alkalis contain $OH^-(aq)$ ions.
- Tests for ions (QA): Cu^{2+}: aqueous sodium hydroxide gives a light blue precipitate, insoluble in excess. Cl^-: dilute nitric acid then aqueous silver nitrate gives a white precipitate. Metal ions react with OH^- ions to form insoluble hydroxide precipitates, e.g. $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$.
- Gas volumes: Equal volumes of gases (at the same temperature and pressure) contain equal numbers of molecules: one mole of any gas occupies 24 dm^3 at r.t.p.

Sec 3 idea	What to remember
Ions	Metal atoms lose electrons to form positive ions (cations), e.g. Na^+, Mg^{2+}, Cu^{2+}, Ag^+, Pb^{2+}, Zn^{2+}. Non-metal atoms gain electrons to form negative ions (anions), e.g. Cl^-, Br^-, I^-. Some ions contain several atoms: OH^-, SO_4^{2-}, NO_3^-.
Ionic and covalent	Ionic compounds (a metal with a non-metal, e.g. NaCl, $CuSO_4$) are made of ions. Simple covalent substances (e.g. glucose, ethanol, hexane) are made of molecules and contain no ions. Metals conduct electricity because they have free (delocalised) electrons.
Redox and electrons	Oxidation is loss of electrons; reduction is gain of electrons (OIL RIG). Oxidation and reduction always happen together.
Oxidation states	An element is 0. A simple ion has the oxidation state of its charge: Cu^{2+} is +2, Cl^- is −1. An increase in oxidation state is oxidation; a decrease is reduction.
Reactivity series	Most reactive first: K, Na, Ca, Mg, Zn, Fe, Pb, (H), Cu, Ag. Hydrogen is placed between lead and copper. A more reactive metal forms positive ions more easily.
Tests for gases	Hydrogen: a lighted splint is extinguished with a 'pop'. Oxygen: relights a glowing splint. Chlorine: a greenish-yellow gas that turns damp blue litmus paper red and then bleaches it (white).

What is electrolysis?

Electrolysis is the conduction of electricity through an ionic compound (an electrolyte), when molten or dissolved in water, leading to chemical changes at the electrodes. The electrical energy breaks the compound down (decomposes it) into new substances. The current enters and leaves the electrolyte through two rods called electrodes. Inert electrodes, such as carbon (graphite) or platinum, carry the current but do not react themselves.

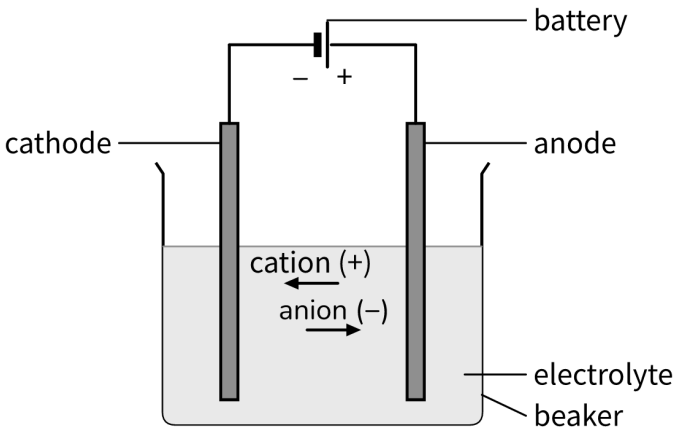
KEY IDEA

PANIC: Positive is the Anode; Negative Is the Cathode. Electrons flow in the external circuit; ions move in the electrolyte.

- Electrons flow through the external circuit (the wires): from the anode, through the battery, to the cathode.
- Ions carry the charge through the electrolyte: positive ions (cations) move to the cathode; negative ions (anions) move to the anode.
- Electrons never travel through the electrolyte.

WORDS TO KNOW

electrolyte	a molten ionic compound or an aqueous solution of ions that conducts electricity and is decomposed by it
electrode	a rod or plate that carries the current into or out of the electrolyte
anode	the positive electrode, joined to the positive terminal of the battery; oxidation happens here
cathode	the negative electrode, joined to the negative terminal of the battery; reduction happens here
inert electrode	an electrode that does not take part in the reaction, e.g. carbon (graphite) or platinum



WORKED EXAMPLE

In a cell like the one above, the electrode on the left is joined to the negative terminal of the battery. (a) Name the electrode on the left. (b) State what carries the current in the wires and in the electrolyte.

1. What is asked: a name for the electrode, then the particles that move in two different places.
2. The idea: the electrode joined to the negative terminal is the cathode. In a metal wire the current is a flow of electrons; in the electrolyte it is the movement of ions.
3. Apply it: positive ions move to the cathode and negative ions to the anode.

(a) The cathode (the negative electrode). (b) In the wires, electrons flow (from the anode to the cathode through the battery). In the electrolyte, ions carry the charge: positive ions move to the cathode and negative ions move to the anode.

TRY THIS

Why is graphite called an inert electrode?

Answer: It conducts electricity but does not react (it is not changed) during the electrolysis.

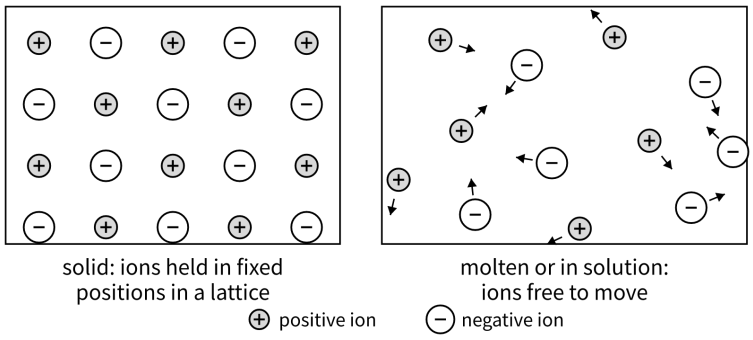
Electrolysis as evidence for ions

A solid ionic compound such as lead(II) bromide does not conduct electricity. When it is melted, or when an ionic compound is dissolved in water, it conducts and is decomposed. This shows that ionic compounds are made of charged particles (ions): in the solid the ions are held in fixed positions in a lattice and cannot move; when molten or in solution the ions are free to move and carry the charge. Covalent substances such as glucose solution or ethanol do not conduct, because they are made of molecules and have no ions.

KEY IDEA

An electrolyte conducts by moving ions and is decomposed. A metal conducts by moving electrons and is not changed.

Substance	Conducts?	Chemical change?	Why
solid sodium chloride	No	No	ions held in fixed positions in the lattice
molten sodium chloride	Yes	Yes (decomposed)	ions free to move
aqueous sodium chloride	Yes	Yes (decomposed)	ions free to move
copper wire (a metal)	Yes	No	free electrons carry the charge
ethanol, glucose solution	No	No	covalent molecules: no ions



WORKED EXAMPLE

Kavitha tested four substances with a battery, two carbon electrodes and a bulb. Solid potassium iodide: bulb off. Molten potassium iodide: bulb on, a purple vapour at one electrode. Liquid hexane: bulb off. Aqueous potassium iodide: bulb on, bubbles at one electrode and a brown colour at the other. Explain the results for solid and molten potassium iodide, and why hexane does not conduct.

1. What is asked: explain a difference between two states of the same compound, then a covalent liquid.
2. The idea: only mobile ions can carry charge through a compound.
3. Apply it: potassium iodide is ionic; hexane is a hydrocarbon, a covalent substance.

In solid potassium iodide the ions are held in fixed positions in a lattice and are not free to move, so it does not conduct. In molten potassium iodide the ions are free to move and carry the charge, so it conducts and is decomposed at the electrodes. Hexane is made of covalent molecules and has no ions (and no free electrons), so it cannot conduct.

What happens at the electrodes

When an ion reaches an electrode and gains or loses electrons, it turns into an atom or a molecule. We say the ion is discharged. At the cathode, positive ions gain electrons: this is reduction. At the anode, negative ions lose electrons: this is oxidation. The electrons released at the anode flow round the circuit and are used at the cathode, so the numbers of electrons lost and gained are always equal.

KEY IDEA

Reduction at the Cathode (both consonants); oxidation at the Anode (both vowels).

WORDS TO KNOW

discharge	an ion gains or loses electrons at an electrode and becomes a neutral atom or molecule
half-equation	an ionic equation for the change at ONE electrode, showing the electrons

CHAPTER 1

Practice Questions

Part 2: Electrolysis



In the practice questions

24 questions, 77 marks. For each multiple-choice question, write the letter of the correct option (A, B, C or D) in the brackets. Write your other answers on the lines given. The answers are on page 376.

- Section A: Multiple-Choice Questions: 15 questions, 15 marks
- Section B: Structured Questions: 7 questions, 42 marks
- Section C: Free-Response Questions: 2 questions, 20 marks

Name: _____ Class: _____ Date: _____

SECONDARY 4 · CHEMISTRY · ELECTROLYSIS

Electrolysis

INSTRUCTIONS

- 24 questions, 77 marks in total.
- Answer all questions in the spaces provided.
- For MCQs, write the letter (A, B, C or D) in the brackets.
- Write your other answers on the lines given, in full sentences.

Section A: Multiple-Choice Questions

1 Which substance is an electrolyte? ( ) [1]

(A) solid copper
(B) molten lead(II) bromide
(C) solid sodium chloride
(D) liquid ethanol

2 Why does solid potassium chloride not conduct electricity? ( ) [1]

(A) It contains no ions.
(B) Its electrons are not free to move.
(C) Its ions are held in fixed positions in a lattice.
(D) It is made of covalent molecules.

3 Which row is correct for the anode in electrolysis? ( ) [1]

	Sign of the anode	Process at the anode
A	positive	oxidation
B	positive	reduction
C	negative	oxidation
D	negative	reduction

(A) A (B) B (C) C (D) D

4 Molten potassium chloride is electrolysed using inert electrodes. Which row shows the products? ( ) [1]

	Cathode	Anode
A	hydrogen	chlorine
B	chlorine	potassium
C	potassium	oxygen
D	potassium	chlorine

Ⓐ A Ⓑ B Ⓒ C Ⓓ D

5 Which half-equation shows the reaction at the anode during the electrolysis of dilute sulfuric acid? ( ) [1]

Ⓐ $2H^+(aq) + 2e^- \rightarrow H_2(g)$

Ⓑ $4OH^-(aq) \rightarrow 2H_2O(l) + O_2(g) + 4e^-$

Ⓒ $4OH^-(aq) + 4e^- \rightarrow 2H_2O(l) + O_2(g)$

Ⓓ $SO_4^{2-}(aq) \rightarrow SO_2(g) + O_2(g) + 2e^-$

6 Which statements about an electrolytic cell are correct?

1 Electrons flow through the wires from the anode to the cathode.
2 Electrons flow through the electrolyte from the cathode to the anode.
3 Positive ions move through the electrolyte towards the cathode. ( ) [1]

Ⓐ 1 and 3 only Ⓑ 1 and 2 only Ⓒ 2 and 3 only Ⓓ 1, 2 and 3

7 Concentrated aqueous sodium chloride is electrolysed using carbon electrodes. Which ion is discharged at the anode, and why? ( ) [1]

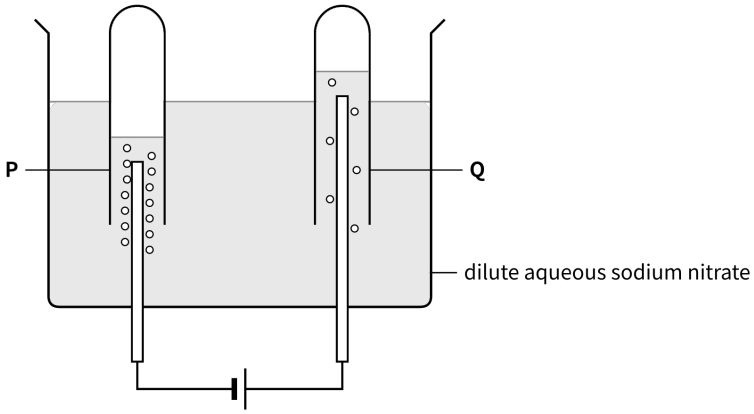
Ⓐ OH^-, because hydroxide is less reactive than chloride

Ⓑ Cl^-, because chlorine is more reactive than oxygen

Ⓒ Cl^-, because it is present at a much higher concentration than OH^-

Ⓓ OH^-, because it is present at a higher concentration than Cl^-

8 The diagram shows the electrolysis of dilute aqueous sodium nitrate. The gases are collected in tubes P and Q.
Which gases are in P and in Q? ( ) [1]



(A) P: oxygen; Q: hydrogen
(B) P: chlorine; Q: hydrogen
(C) P: hydrogen; Q: chlorine
(D) P: hydrogen; Q: oxygen

9 Aqueous copper(II) sulfate is electrolysed using inert electrodes. Which row describes the changes in the electrolyte? ( ) [1]

	Blue colour	pH of the solution
A	fades	decreases
B	fades	increases
C	stays the same	decreases
D	stays the same	increases

(A) A (B) B (C) C (D) D

10 Aqueous silver nitrate is electrolysed using platinum electrodes. What are the products at the cathode and at the anode? ( ) [1]

(A) hydrogen and oxygen
(B) silver and oxygen
(C) silver and nitrogen dioxide
(D) hydrogen and nitrogen

11 A solution contains copper(II) nitrate and magnesium nitrate. It is electrolysed using carbon electrodes. Which substance forms first at the cathode? ( ) [1]

(A) hydrogen (B) magnesium (C) nitrogen (D) copper