Cambridge IGCSE · Chemistry 0620 · Notes

Electrochemistry

Read online at **pastopic.com/cambridge/chemistry-0620/notes/electrochemistry**

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Read first: **Ionic and metallic bonding**, **Formulae and equations**

What you need to know

By the end of this topic you should be able to:

1. **Define electrolysis**: the breaking down (decomposition) of an **ionic compound**, when **molten or in aqueous solution**, by the passage of an **electric current**.
2. **Identify the parts of an electrolytic cell**: the **anode** is the positive electrode, the **cathode** is the negative electrode, and the **electrolyte** is the molten or aqueous substance that is being electrolysed.
3. **Name the products at each electrode, and say what you would see**, when these are electrolysed with inert electrodes (platinum or carbon/graphite): molten lead(II) bromide, concentrated aqueous sodium chloride and dilute sulfuric acid.
4. **State the general rule**: metals or hydrogen form at the cathode; non-metals (other than hydrogen) form at the anode.
5. **Predict the products of electrolysing any molten binary compound** (a compound of just two elements, such as zinc chloride).
6. **State why metal objects are electroplated**: to improve their appearance and their resistance to corrosion.
7. **Describe how a metal object is electroplated.**
8. **Extended only:** describe how charge moves during electrolysis: electrons in the external circuit, electrons lost or gained at the electrodes, and ions moving in the electrolyte.
9. **Extended only:** name the products and describe what you would see when aqueous copper(II) sulfate is electrolysed with carbon/graphite electrodes, and with copper electrodes.
10. **Extended only:** predict the products at each electrode when a **halide** (chloride, bromide or iodide) is electrolysed in **dilute** or **concentrated** aqueous solution.
11. **Extended only:** write ionic half-equations for the reactions at the anode (oxidation) and at the cathode (reduction).
12. **State that a hydrogen–oxygen fuel cell** uses hydrogen and oxygen to produce electricity, and that water is the only chemical product.
13. **Extended only:** describe the advantages and disadvantages of hydrogen–oxygen fuel cells compared with gasoline (petrol) engines in vehicles.

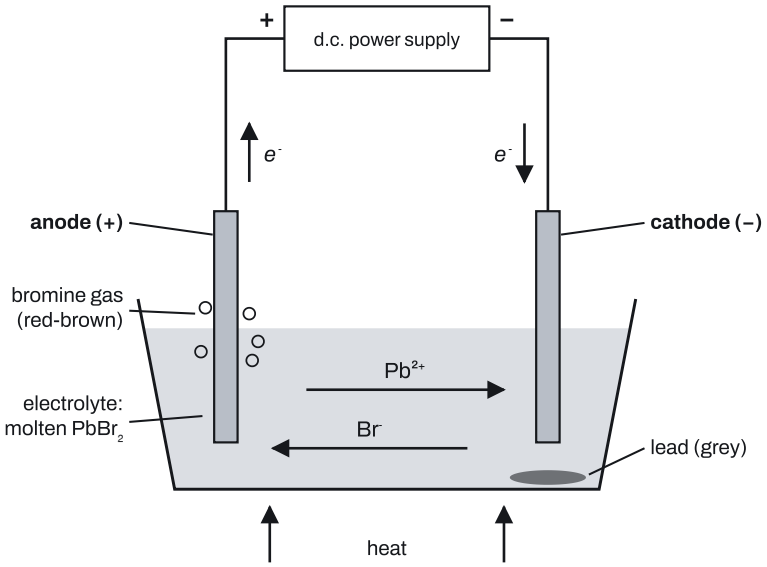
Understand it

Why electrolysis needs ions that can move

An ionic compound such as lead(II) bromide is made of positive ions (Pb^{2+}) and negative ions (Br^{-}). In the **solid**, the ions are held in fixed places in the lattice, so the solid does not conduct electricity. **Melt** it, or **dissolve** it in water, and the ions become free to move. Now the liquid conducts, and the current breaks the compound down into new substances. That is **electrolysis**, and because new substances are made it is a **chemical change**.

Metals and graphite also conduct, but they conduct with moving **electrons** and are not broken down. The liquid that conducts with moving **ions** and is broken down is the **electrolyte**.

The electrolytic cell



A cell has two **electrodes**: rods that carry the current into and out of the electrolyte.

- The **anode** is joined to the **positive (+)** terminal of the power supply.
- The **cathode** is joined to the **negative (−)** terminal.

Opposite charges attract. **Positive ions (cations) move to the cathode**; **negative ions (anions) move to the anode**. When they arrive, they change into atoms or molecules:

- at the **cathode**, positive ions **gain** electrons; a metal (or hydrogen) forms;
- at the **anode**, negative ions **lose** electrons; a non-metal forms.

Remember it as: **metals and hydrogen at the cathode, non-metals at the anode.**

Inert electrodes are made of **graphite (carbon)** or **platinum**. They conduct electricity but do not react with the electrolyte or the products, so the only changes are to the electrolyte.

How charge moves (Extended)

Extended only: the current is carried in two different ways.

- In the **wires** (the external circuit), **electrons** move. They flow from the anode, round through the power supply, to the cathode.
- In the **electrolyte**, **ions** move: cations towards the cathode, anions towards the anode. Electrons **never** travel through the electrolyte.
- At the **electrodes** the two meet: anions give electrons to the anode, those electrons go round the circuit, and the cathode gives electrons to the cations.

Losing electrons is **oxidation**; gaining electrons is **reduction**. So **oxidation always happens at the anode** and **reduction at the cathode**.

Molten binary compounds

A **binary** compound has just two elements: one metal and one non-metal. When it is molten there are only two kinds of ion, so the products are easy:

- **cathode:** the metal;
- **anode:** the non-metal, as its element (chlorine $\mathrm{Cl_2}$, bromine $\mathrm{Br_2}$, iodine $\mathrm{I_2}$, oxygen $\mathrm{O_2}$).

Molten compound	Cathode (−)	Anode (+)
lead(II) bromide, $\mathrm{PbBr_2}$	lead	bromine
zinc chloride, $\mathrm{ZnCl_2}$	zinc	chlorine
potassium iodide, KI	potassium	iodine
zinc oxide, ZnO	zinc	oxygen

For **molten lead(II) bromide** you see **red-brown gas** (bromine vapour) at the anode and a **grey/silvery metal** at the cathode. The lead forms as a liquid at this temperature and collects at the bottom of the crucible.

Aqueous solutions: the water joins in

Water contains a few hydrogen ions, $\mathrm{H^+}$, and hydroxide ions, $\mathrm{OH^-}$. So in any aqueous solution **two kinds of ion arrive at each electrode**, and only one of them is changed (discharged).

At the cathode, $\mathrm{H^+}$ competes with the metal ion:

- if the metal is **more reactive than hydrogen** (sodium, potassium, magnesium, zinc and so on), **hydrogen** forms and the metal ions stay in solution;
- if the metal is **less reactive than hydrogen** (copper, silver), the **metal** forms.

So sodium can never be made by electrolysing a sodium chloride **solution**: hydrogen forms instead.

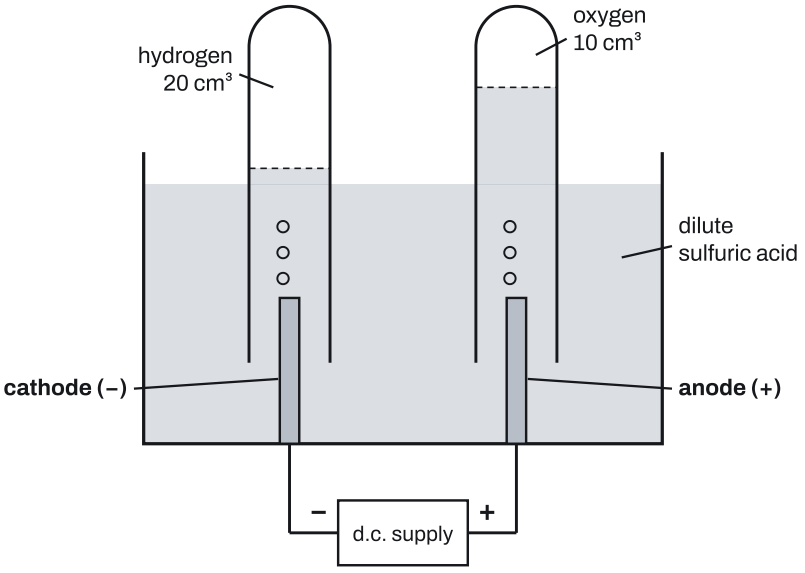
At the anode, $\mathrm{OH^-}$ competes with the negative ion:

- a **halide** (chloride, bromide or iodide) in **concentrated** solution: the **halogen** forms;
- a **halide** in **dilute** solution: **oxygen** forms;
- a **sulfate**: **oxygen** forms.

Electrolyte (inert electrodes)	Cathode (−)	Anode (+)
concentrated aqueous sodium chloride	hydrogen	chlorine
dilute sulfuric acid	hydrogen	oxygen
Extended only: dilute aqueous sodium chloride	hydrogen	oxygen
Extended only: concentrated aqueous potassium bromide	hydrogen	bromine
Extended only: concentrated aqueous copper(II) chloride	copper	chlorine
Extended only: aqueous copper(II) sulfate	copper	oxygen

Concentrated aqueous sodium chloride: bubbles of colourless gas (hydrogen) at the cathode and bubbles of **pale yellow-green** gas (chlorine) at the anode. The sodium and hydroxide ions left behind make **sodium hydroxide** solution, so the liquid near the cathode turns alkaline.

Dilute sulfuric acid: bubbles of colourless gas at **both** electrodes: hydrogen at the cathode and oxygen at the anode. The volume of hydrogen is **twice** the volume of oxygen, because two molecules of hydrogen form for every molecule of oxygen.



Aqueous copper(II) sulfate: two kinds of electrode (Extended)

Extended only: copper(II) sulfate solution is blue because of its Cu^{2+} ions.

With inert (carbon/graphite) electrodes:

- **cathode:** $\mathrm{Cu^{2+}}$ ions gain electrons and a **pink-brown** coating of copper forms, so the cathode **gets heavier**;
- **anode: bubbles** of a colourless gas, oxygen;
- **electrolyte:** the blue colour **fades** (gets paler), because $\mathrm{Cu^{2+}}$ ions are being used up.

With copper electrodes:

- **anode:** the copper anode itself loses electrons, $\mathrm{Cu \rightarrow Cu^{2+} + 2e^-}$. Copper atoms become ions and go into the solution, so the anode **gets thinner and lighter**. **No oxygen** forms.
- **cathode:** copper forms, exactly as before, so it **gets heavier**.
- **electrolyte:** for every $\mathrm{Cu^{2+}}$ ion removed at the cathode, one enters at the anode, so the concentration of $\mathrm{Cu^{2+}}$ and the blue colour **stay the same**. The mass lost by the anode equals the mass gained by the cathode.

Ionic half-equations (Extended)

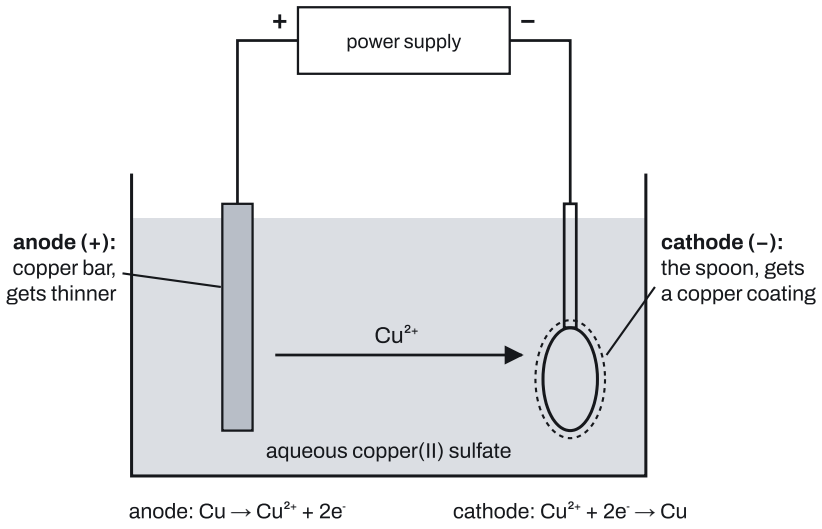
Extended only: a half-equation shows what happens to the particles at one electrode, with electrons written as $\mathrm{e^-}$. The atoms **and** the charges must balance.

At the cathode (reduction: electrons gained)	At the anode (oxidation: electrons lost)
$\mathrm{Pb^{2+} + 2e^- \rightarrow Pb}$	$\mathrm{2Br^- \rightarrow Br_2 + 2e^-}$
$\mathrm{2H^+ + 2e^- \rightarrow H_2}$	$\mathrm{2Cl^- \rightarrow Cl_2 + 2e^-}$
$\mathrm{Cu^{2+} + 2e^- \rightarrow Cu}$	$\mathrm{4OH^- \rightarrow 2H_2O + O_2 + 4e^-}$
$\mathrm{Na^+ + e^- \rightarrow Na}$ (molten only)	$\mathrm{Cu \rightarrow Cu^{2+} + 2e^-}$ (copper anode)
$\mathrm{Zn^{2+} + 2e^- \rightarrow Zn}$	$\mathrm{2O^{2-} \rightarrow O_2 + 4e^-}$ (molten oxide)

Check the charges: in $\mathrm{4OH^- \rightarrow 2H_2O + O_2 + 4e^-}$ the left side has charge $4 \times (-1) = -4$ and the right side $4 \times (-1) = -4$. The atoms balance too: 4 O and 4 H on each side.

Electroplating

Electroplating uses electrolysis to coat an object with a thin layer of another metal. It is done to **improve the appearance** of the object and to **protect it from corrosion** (for example, chromium on a steel tap).



1. The **object to be plated is the cathode** (joined to –).
2. The **anode is a piece of the plating metal** (joined to +).
3. The **electrolyte is an aqueous solution of a salt of the plating metal**: copper(II) sulfate for copper, silver nitrate for silver, nickel(II) sulfate for nickel.

The plating metal's ions are reduced on the object, and the anode dissolves to replace them. It is the same as electrolysing copper(II) sulfate with copper electrodes: the colour of the solution stays the same.

Hydrogen–oxygen fuel cells

A **fuel cell** makes electricity straight from a chemical reaction. A hydrogen–oxygen fuel cell is fed **hydrogen** (the fuel) and **oxygen** (from the air), and the only chemical product is **water**:

$$2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$$

It converts **chemical energy into electrical energy**. It is **not** electrolysis: electrolysis uses electricity to break a compound down, but a fuel cell makes electricity by joining hydrogen and oxygen. The reaction is exothermic, and it is a redox reaction: hydrogen is oxidised and oxygen is the oxidising agent.

Extended only: compared with a gasoline (petrol) engine in a car:

- **Advantages:** water is the only product, so no carbon dioxide (a greenhouse gas), carbon monoxide or oxides of nitrogen come out of the car; fuel cells turn more of the fuel's energy into useful energy (more efficient).
- **Disadvantages:** hydrogen is a gas, so it is hard to store: it needs heavy tanks at high pressure; hydrogen is flammable (explosive with air); there are few hydrogen filling stations; much hydrogen is made from fossil fuels (for example by cracking hydrocarbons), which does release carbon dioxide.

Key facts and formulas

Nothing for this topic is printed in the exam except the **Periodic Table**, which gives each element's group (and so its ion's charge). Everything else is **Learn it**.

Formula	Status
Ion charges from the group number in the Periodic Table	Given
Electrolysis = decomposition of an ionic compound, molten or in aqueous solution, by an electric current	Learn it
Anode = positive electrode; cathode = negative electrode; electrolyte = the molten or aqueous substance electrolysed	Learn it
Metals or hydrogen form at the cathode; non-metals (other than hydrogen) at the anode	Learn it
Molten binary compound: metal at the cathode, non-metal at the anode	Learn it
Inert electrodes: graphite (carbon) or platinum; they conduct and do not react	Learn it
Concentrated aqueous NaCl: hydrogen (cathode), chlorine (anode); dilute sulfuric acid: hydrogen (cathode), oxygen (anode), volumes $2:1$	Learn it
Electroplating: object = cathode, plating metal = anode, electrolyte = solution of the plating metal's salt	Learn it
Fuel cell: $2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$; water is the only product; chemical → electrical energy	Learn it
Extended only: electrons move in the external circuit (anode → cathode); ions move in the electrolyte	Learn it
Extended only: aqueous cathode: hydrogen, unless the metal is less reactive than hydrogen (copper, silver)	Learn it
Extended only: aqueous halide at the anode: concentrated → halogen; dilute → oxygen	Learn it
Extended only: $2\mathrm{H^+} + 2\mathrm{e^-} \rightarrow \mathrm{H_2}$; $\mathrm{Cu^{2+}} + 2\mathrm{e^-} \rightarrow \mathrm{Cu}$; $2\mathrm{Cl^-} \rightarrow \mathrm{Cl_2} + 2\mathrm{e^-}$	Learn it
Extended only: $4\mathrm{OH^-} \rightarrow 2\mathrm{H_2O} + \mathrm{O_2} + 4\mathrm{e^-}$; $\mathrm{Cu} \rightarrow \mathrm{Cu^{2+}} + 2\mathrm{e^-}$	Learn it
Extended only: oxidation (electrons lost) at the anode; reduction (electrons gained) at the cathode	Learn it

How to do it

In the questions we have tagged for this topic (192 questions, 2021–2025, on Papers 1–4), the types came up this often. 46 of the 192 questions mix types, so the counts add up to more than 192.

Question type	Questions
Name or choose the products at each electrode	92
Hydrogen–oxygen fuel cells	40
Write or choose an ionic half-equation	29
Define electrolysis or the electrolyte, or name the process	22
Name an inert electrode material, or say why it is suitable	22
Electroplating	21
Describe what is seen at the electrodes or in the electrolyte	20
Label the anode, cathode or electrolyte on a diagram	18
Aqueous copper(II) sulfate: copper or inert electrodes	10
Explain conduction, oxidation or reduction, or a chemical change	9
Charge transfer: electrons in the wire, ions in the electrolyte	8
Rare: pH change and litmus tests after electrolysis	3

1. Name or choose the products at each electrode (92 questions)

1. **Molten or aqueous?** Read the state carefully: "molten" and "aqueous" give different products.
2. **Molten binary compound:** the metal at the cathode (−), the non-metal element at the anode (+). Done.
3. **Aqueous solution, cathode:** hydrogen, unless the metal is copper or silver (less reactive than hydrogen), in which case the metal.
4. **Aqueous solution, anode:** a concentrated chloride, bromide or iodide gives the halogen; a dilute halide or a sulfate gives oxygen.
5. Write the **element** name: "chlorine", not "chloride"; "lithium", not "lithium ions".

For example, concentrated aqueous magnesium bromide: magnesium is more reactive than hydrogen, so **hydrogen** at the cathode; concentrated bromide, so **bromine** at the anode.

Variations you will meet:

- **Core named cases:** molten lead(II) bromide (lead, bromine); concentrated aqueous sodium chloride (hydrogen, chlorine); dilute sulfuric acid (hydrogen, oxygen).
- **Volumes of gas:** dilute sulfuric acid gives twice as much hydrogen (cathode) as oxygen (anode). If 30 cm³ of hydrogen is collected, 15 cm³ of oxygen is collected.

- **Working backwards:** "hydrogen and oxygen form, so what was the electrolyte?" Choose a dilute solution whose metal is more reactive than hydrogen (dilute sulfuric acid, dilute sodium chloride). "Hydrogen and bromine form" means a **concentrated** bromide of a reactive metal.
- **Which electrode in a diagram gives hydrogen?** Find the negative electrode dipping into an **aqueous** solution (in a molten compound there is no hydrogen at all).
- **All the products of brine:** concentrated aqueous sodium chloride gives three products: hydrogen, chlorine and sodium hydroxide (left in the solution).
- **Two electrolytes compared** (for example molten and concentrated aqueous sodium chloride): the anode gives chlorine in both, but the cathode gives sodium from the melt and hydrogen from the solution.

2. Hydrogen–oxygen fuel cells (40 questions)

Almost all are multiple choice. Check each statement against these facts:

1. **Reactants:** hydrogen (the fuel) and oxygen (from the air). Hydrogen does not come from the air.
2. **Product:** water only, so no carbon dioxide.
3. **Equation:** $2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O}$. Reject $\mathrm{H_2O_2}$, the reverse reaction, and "$2\mathrm{O}$".
4. **Energy:** chemical energy → electrical energy (the main useful output is electricity, not heat). The reaction is exothermic.
5. **It is not electrolysis**, and water is made, not broken down.
6. **Extended only:** it is redox; hydrogen is oxidised and oxygen is the oxidising agent.

Variations you will meet:

- **Extended only: one advantage and one disadvantage** compared with a petrol engine: water is the only product / no carbon dioxide; hydrogen is hard to store (high-pressure, heavy tanks) / few filling stations. Give one clear point each.
- **Where the hydrogen comes from:** electrolysis of water or acid, or cracking hydrocarbons; not from the air.

3. Write or choose an ionic half-equation (29 questions)

Extended only.

1. **Pick the ion that is discharged** at that electrode (using type 1).
2. **Write the ion on the left and the element on the right.** Gases and halogens are diatomic: $\mathrm{H_2}$, $\mathrm{Cl_2}$, $\mathrm{Br_2}$, $\mathrm{O_2}$.
3. **Balance the atoms**, then **add electrons** to balance the charge: on the **left** at the cathode (gained), on the **right** at the anode (lost).
4. **Check:** the total charge is the same on both sides.

For example, the cathode in molten aluminium oxide: $\mathrm{Al^{3+}}$ needs three electrons: $\mathrm{Al^{3+}} + 3\mathrm{e^-} \rightarrow \mathrm{Al}$.

Variations you will meet:

- **Oxygen at the anode** from a dilute or sulfate solution: $4\mathrm{OH}^- \rightarrow 2\mathrm{H_2O} + \mathrm{O_2} + 4\mathrm{e}^-$. This is the one asked most; learn it whole.
- **Multiple choice**: wrong options put the right equation at the wrong electrode, put electrons on the wrong side, write Br instead of $\mathrm{Br_2}$, or give $\mathrm{Na}^+ + \mathrm{e}^- \rightarrow \mathrm{Na}$ for a sodium chloride **solution**.
- **Copper anode:** $\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+} + 2\mathrm{e}^-$ (the anode itself is oxidised).
- **Completing a half-equation** that is partly written: count the charges to find the number of electrons.

4. Define electrolysis or the electrolyte, or name the process (22 questions)

1. **Electrolysis:** the decomposition (breakdown) of an **ionic compound**, when **molten or in aqueous solution**, by the passage of an **electric current**. Every one of the bold ideas is worth including; the definition is usually 2 marks.
2. **Electrolyte:** the molten or aqueous ionic substance that conducts and is broken down.
3. **"Name the process"** that makes a metal or a gas from a molten or dissolved compound with electricity: **electrolysis**.

In multiple choice, reject "forming ions using a current", "coating an object with metal" (that is electroplating) and anything that says covalent compounds are broken down.

5. Name an inert electrode material, or say why it is suitable (22 questions)

1. **Materials:** graphite (carbon), a non-metal; or platinum, a metal.
2. **Why suitable:** it **conducts electricity** and it is **inert** (unreactive: it does not react with the electrolyte or the products).
3. **"Inert"** means unreactive; it does not take part in the reaction.

Read the question: if platinum is already named, "another material" means graphite; if it asks for a **non-metal**, graphite; a **metal**, platinum.

6. Electroplating (21 questions)

1. **Object = cathode (−).** It is where the metal ions are reduced to metal.
2. **Plating metal = anode (+).**
3. **Electrolyte = aqueous solution containing ions of the plating metal**, for example any soluble copper salt such as copper(II) sulfate.
4. **Reasons:** better appearance, and resistance to corrosion. Not to make it stronger, softer, a better conductor or an insulator.

Variations you will meet:

- **Observations:** the object gains a coating of the plating metal's colour (pink-brown for copper), the anode gets thinner, and the colour of the electrolyte does not change.

- **Choose the right apparatus** from four diagrams: object at –, plating metal at +, and an electrolyte of the plating metal's salt (silver nitrate for silver).
- **Extended only:** half-equation at the object, for example $\mathrm{Ag^+ + e^- \rightarrow Ag}$ or $\mathrm{Ni^{2+} + 2e^- \rightarrow Ni}$.

7. Describe what is seen at the electrodes or in the electrolyte (20 questions)

An **observation** is what you would see, not the name of the product. "Hydrogen forms" is a product; "bubbles" is an observation.

Product	What you see
any gas	bubbles (effervescence) at the electrode
chlorine	bubbles of pale yellow-green gas
bromine	red-brown gas (from a melt), or an orange-brown solution (from an aqueous bromide)
iodine	brown solution, or a black solid
lead	grey or silvery metal (a liquid in the hot melt)
copper	pink-brown solid coating the cathode
hydrogen or oxygen	bubbles of colourless gas

Extended only: copper(II) sulfate with inert electrodes: the cathode gets a pink-brown coating (its mass increases), there are bubbles at the anode and the blue colour gets paler.

8. Label the anode, cathode or electrolyte on a diagram (18 questions)

1. **Find the + and – of the power supply.** In a cell symbol the **longer** line is positive.
2. **Anode** = the electrode joined to +; **cathode** = the electrode joined to –.
3. Draw the label line to the **electrode rod itself**, not to the wire or the + sign.
4. **Electrolyte:** the label line must end in the **liquid**, not on the beaker or crucible.

If asked to complete a circuit, join each electrode to a terminal with a continuous line, with no gaps.

9. Aqueous copper(II) sulfate: copper or inert electrodes (10 questions)

Extended only. Fill in this table from memory:

	Inert (carbon) electrodes	Copper electrodes
cathode	copper forms; mass increases	copper forms; mass increases
anode	bubbles of oxygen; mass unchanged	copper dissolves; mass decreases
solution	blue fades	blue stays the same

Why the anode loses mass: copper atoms lose electrons, $\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+} + 2\mathrm{e}^{-}$, and the ions go into the solution. **Why the colour stays:** each Cu^{2+} removed at the cathode is replaced by one from the anode. The same happens with copper electrodes in copper(II) chloride solution.

10. Explain conduction, oxidation or reduction, or a chemical change (9 questions)

- **Why does the molten or aqueous compound conduct?** It contains **ions that can move** (mobile ions). In the solid the ions cannot move.
- **Which substances conduct?** Metals and graphite (moving electrons); molten or dissolved ionic compounds (moving ions). A solid ionic compound does not.
- **Extended only: why is the anode reaction oxidation?** The ions **lose electrons** there. At the cathode ions **gain electrons**: reduction.
- **Physical or chemical change?** Electrolysis is a **chemical** change, because **new substances are made**.

11. Charge transfer: electrons in the wire, ions in the electrolyte (8 questions)

Extended only.

1. **External circuit (wires):** electrons, flowing from the **anode** to the **cathode** through the power supply.
2. **Electrolyte:** ions: cations to the cathode, anions to the anode.
3. **At the electrodes:** anions lose electrons at the anode; cations gain electrons at the cathode.

In a diagram question, electrons never cross the liquid; if one electrode is where oxidation happens, it is the anode, and electrons leave it along the wire.

12. Rare: pH change and litmus tests after electrolysis (3 questions)

- **Brine:** after concentrated sodium chloride is electrolysed, the solution contains sodium hydroxide, so it is **alkaline**: litmus turns blue. Damp litmus held in the chlorine at the anode is **bleached**.
- **Acid:** when an acid is electrolysed and hydrogen is given off, H^{+} ions are removed, so the solution becomes less acidic and its **pH rises**.
- One older question asked about a simple cell made of two different metals. That is not in the 2026–2028 syllabus.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

Molten calcium chloride is electrolysed using graphite electrodes.

(a) State what is meant by the term *electrolysis*. **[2]**

(b) Name the products at the anode and at the cathode. **[2]**

(c) Give **two** reasons why graphite is suitable for the electrodes. **[2]**

(d) Explain why solid calcium chloride cannot be electrolysed. **[1]**

(a) The decomposition of an ionic compound, when molten or in aqueous solution, **B1**, by the passage of an electric current. **B1**

(b) Anode (+): **chlorine**. **B1** Cathode (−): **calcium**. **B1** (A molten binary compound gives the non-metal at the anode and the metal at the cathode.)

(c) It conducts electricity **B1**; it is inert (it does not react with the electrolyte or the products). **B1**

(d) In the solid the ions are held in fixed positions and cannot move, so it does not conduct. **B1**

Example 2

This question is about electrolysis of aqueous solutions using inert electrodes.

(a) Complete the table. **[4]**

Electrolyte	Product at cathode	Product at anode
concentrated aqueous potassium bromide		
dilute aqueous potassium bromide		

(b) Write the ionic half-equation for the reaction at the cathode in both experiments. **[2]**

(c) State the colour change you would see near the anode with the concentrated solution. **[1]**

(a) Potassium is more reactive than hydrogen, so **hydrogen** forms at the cathode in both. **B1 B1** At the anode, the concentrated bromide gives **bromine B1** and the dilute bromide gives **oxygen**. **B1**

(b) $2\mathrm{H}^+ + 2\mathrm{e}^- \rightarrow \mathrm{H}_2$. **M1** for H^+ and e^- as the only things on the left, **A1** for the balanced equation (charge on each side $= 0$).

(c) The colourless solution turns orange-brown. **B1**

Example 3

Aqueous copper(II) sulfate is electrolysed in two experiments. In experiment 1 the electrodes are graphite. In experiment 2 they are copper.

(a) In experiment 1, describe what is seen at each electrode and in the solution. **[3]**

(b) Write the ionic half-equation for the formation of oxygen at the anode in experiment 1. **[3]**

(c) In experiment 2, the anode has a mass of 12.50 g at the start and 11.86 g at the end. The cathode starts at 10.00 g. Find the final mass of the cathode, and state what happens to the colour of the solution. Explain both answers. **[4]**

(a) Cathode: a pink-brown solid (copper) forms. **B1** Anode: bubbles of colourless gas. **B1** Solution: the blue colour fades. **B1**

(b) $4\mathrm{OH}^- \rightarrow 2\mathrm{H_2O} + \mathrm{O}_2 + 4\mathrm{e}^-$. **M1** for OH^- losing electrons, **M1** for only $\mathrm{H_2O}$ and O_2 as products (besides the electrons), **A1** for the fully balanced equation.

(c) The anode loses $12.50 - 11.86 = 0.64$ g of copper, which dissolves as Cu^{2+} ions: $\mathrm{Cu} \rightarrow \mathrm{Cu}^{2+} + 2\mathrm{e}^-$. **M1** The same mass of copper is deposited on the cathode, so its final mass is $10.00 + 0.64 = 10.64$ g. **A1** The colour **stays the same B1**, because every Cu^{2+} ion removed at the cathode is replaced by one from the anode, so the concentration of Cu^{2+} does not change. **B1**

Example 4

A steel key is to be electroplated with nickel.

(a) Give **two** reasons for electroplating the key. **[2]**

(b) Describe how the key is electroplated. Name the electrodes and a suitable electrolyte. **[3]**

(c) Write the ionic half-equation for the reaction at the key. **[2]**

(d) A car uses a hydrogen–oxygen fuel cell. Write the equation for the overall reaction, and give one advantage and one disadvantage of the fuel cell compared with a petrol engine. **[4]**

(a) To improve its appearance **B1** and to protect it from corrosion (rusting). **B1**

(b) The key is the cathode (joined to the negative terminal). **B1** The anode is a piece of nickel. **B1** The electrolyte is an aqueous solution of a nickel salt, such as nickel(II) sulfate. **B1** When the current flows, nickel forms on the key.

(c) $\mathrm{Ni^{2+} + 2e^- \rightarrow Ni}$. **M1** for $\mathrm{Ni^{2+}}$ gaining electrons, **A1** for the balanced equation.

(d) $\mathrm{2H_2 + O_2 \rightarrow 2H_2O}$. **M1** for the correct formulae, **A1** for the balancing. Advantage: water is the only product, so no carbon dioxide is released. **B1** Disadvantage: hydrogen is hard to store, because it needs heavy high-pressure tanks. **B1**

Common mistakes

- **Writing the ion's name instead of the element.** The anode product is "chlorine", "bromine" or "fluorine", not "chloride", "bromide" or "fluoride"; the cathode product is "lithium", not "lithium ions". Examiners mark these wrong every year.
- **Putting the right products at the wrong electrodes.** Metals and hydrogen go to the negative cathode; non-metals to the positive anode. Check which electrode is + before you write.
- **Sodium from a sodium chloride solution.** In an **aqueous** solution a reactive metal is never formed at the cathode; hydrogen is.
- **Carbon dioxide at a graphite anode.** For the cells in this topic the product at the anode is oxygen or a halogen. Graphite electrodes are inert here.
- **Labelling loosely.** A label line that ends on the wire, the + sign, or the crucible scores nothing. Point to the electrode rod, or into the liquid for the electrolyte.
- **"Cathode mass stays the same"** for copper(II) sulfate. Copper is deposited on the cathode, so its mass increases, with either kind of electrode.
- **Giving a product when an observation is asked for.** "Hydrogen is formed" is not an observation; "bubbles" is. Give colours with gases where you can: pale yellow-green chlorine, red-brown bromine.
- **An incomplete definition of electrolysis.** Include "ionic compound", "molten or aqueous" and "electric current". Many answers leave out that the compound must be ionic.
- **Half-equation slips (Extended):** Br instead of $\mathrm{Br_2}$, electrons on the wrong side, or charges that don't balance. Always add up the charge on each side.
- **Mixing up the electroplating set-up.** The object to be plated is the **cathode**, not the anode, and the electrolyte must contain the plating metal's ions.
- **Not reading "other" or "non-metal".** If platinum is named and you are asked for another inert material, the answer is graphite; "conducts electricity" is not a material.
- **Calling a fuel cell "electrolysis"**, or not remembering that its reactants are hydrogen and oxygen.

How to get the marks

- **"State" or "name":** a single word or phrase is enough, but it must be exact: the element's name, spelt correctly. Formulae are accepted if fully correct ($\mathrm{Cl_2}$, not Cl).

- **"Define":** learn the definition of electrolysis word for word in meaning: ionic compound, molten or aqueous, broken down, electric current. Each idea earns credit.
- **"Describe the observations":** say what you would see (bubbles, a colour, a coating, a colour fading, "no change"). "No change" is a real answer when nothing changes, as for the colour with copper electrodes.
- **Half-equations (Extended):** marks usually come as: the right species on the left, the right products, then fully balanced. Write the whole equation even if you are unsure of the balancing; the first marks still count.
- **"Explain":** give the reason, not just the fact. "The anode loses mass **because** copper atoms lose electrons and form Cu^{2+} ions that go into solution."
- **Advantages and disadvantages (Extended):** one clear point each, compared with petrol. "Better for the environment" is too vague; "no carbon dioxide produced" earns the mark.
- **Physical or chemical change:** the answer and the reason are one mark together: "chemical, because new substances are made".
- **Labels:** one clear label line per part, touching the right thing, with the word written at the end.

Quick check

1. Molten lithium bromide is electrolysed with platinum electrodes. Name the product at each electrode and describe what you would see at the anode.
2. Dilute sulfuric acid is electrolysed and 36 cm³ of gas is collected at the cathode. Name this gas, and name the gas at the anode and give its volume.
3. Concentrated aqueous sodium chloride is electrolysed with inert electrodes. **(Extended)** Write the half-equation at the anode and say whether it shows oxidation or reduction.
4. A silver bracelet is to be made by plating a copper bracelet with silver. Which electrode is the copper bracelet, what is the other electrode, and what is a suitable electrolyte?
5. State the only chemical product of a hydrogen–oxygen fuel cell, and the energy change that takes place.

Answers

1. Cathode: **lithium**. Anode: **bromine**, seen as a red-brown gas. (A molten binary compound: metal at the cathode, non-metal at the anode.)
2. Hydrogen, at the cathode. Oxygen forms at the anode, and its volume is half that of the hydrogen: $36 \div 2 = 18$ cm³.
3. $2\mathrm{Cl}^- \rightarrow \mathrm{Cl}_2 + 2\mathrm{e}^-$. The chloride ions lose electrons, so it is **oxidation**. (Charge: -2 on each side.)
4. The copper bracelet is the **cathode** (joined to –). The anode is a piece of **silver**. The electrolyte is aqueous **silver nitrate** (a soluble silver salt).
5. **Water**. Chemical energy is converted into electrical energy.

Past questions to try

- **0620/42/M/J/25 Q3**: the definition, then copper(II) sulfate with platinum and with copper electrodes, including the oxygen half-equation.
- **0620/43/O/N/24 Q2**: complete a table of products and observations for two aqueous electrolytes (Extended).
- **0620/32/M/J/25 Q5**: label a cell for molten zinc chloride and name its products (Core).
- **0620/41/M/J/23 Q5**: electrons and ions carrying the charge, and a fuel cell equation (Extended).