Edexcel GCSE Chemistry

Your notes

Electrolytic Processes

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Electrolysis

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Electrolysis

- When an electric current is passed through a **molten or aqueous ionic compound** the compound **decomposes** or breaks down
- Liquids and solutions that are able to conduct electricity are called **electrolytes**
- Covalent compounds **cannot conduct electricity** hence they do not undergo electrolysis
- An electrolytic cell is the name given to the set-up used in electrolysis and which consists of the following:
  - **Electrode:** a rod of metal or graphite through which an electric current flows into or out of an electrolyte
  - **Electrolyte:** ionic compound in molten or dissolved solution that conducts the electricity
  - **Anode:** the positive electrode of an electrolysis cell
  - **Anion:** negatively charged ion which is attracted to the anode
  - **Cathode:** the negative electrode of an electrolysis cell
  - **Cation:** positively charged ion which is attracted to the cathode

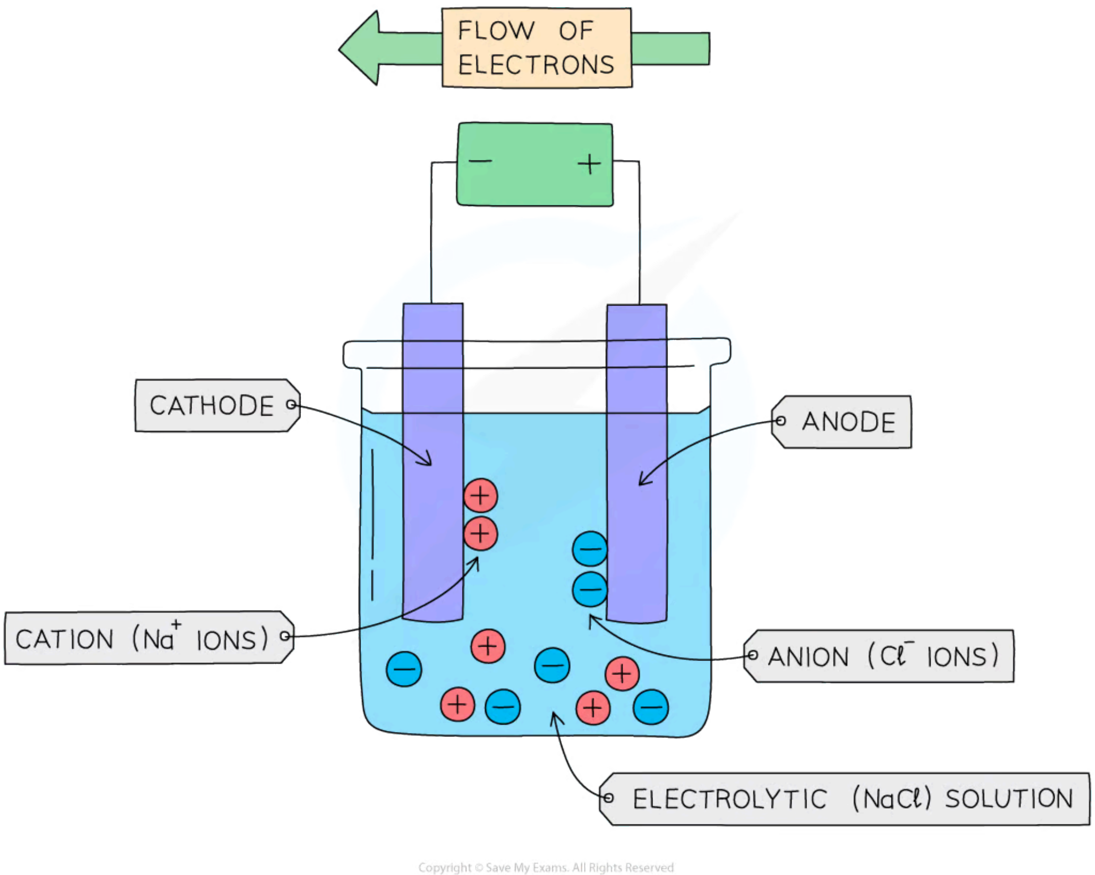

Diagram showing the direction of movement of electrons and ions in the electrolysis of NaCl

- During electrolysis the electrons move from the power supply towards the **cathode**
- Electron flow in electrochemistry thus occurs in **alphabetical** order as electrons flow from the **anode** to the **cathode**
- Positive ions within the electrolyte migrate towards the **negatively** charged electrode which is the **cathode**
- Negative ions within the electrolyte migrate towards the **positively** charged electrode which is the **anode**

Examiner Tips and Tricks

Your notes

When a metal conducts it is the **electrons** that are moving through the metal. When a salt solution conducts it is the **ions** in the solution that move towards the electrodes while carrying the electrons.

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Electrolysis of Aqueous Solutions

Rules:

- Aqueous solutions will always have water present
- Some water molecules split up into hydrogen and hydroxide ions, H^+ and OH^-, which participate in the electrolysis reactions

Positive Electrode

- Negatively charged OH^- ions and non-metal ions are attracted to the positive electrode
- If halide ions (Cl^-, Br^-, I^-) and OH^- are present then the halide ion is discharged at the anode, loses electrons and forms a halogen (chlorine, bromine or iodine)
- If no halide ions are present, then OH^- is discharged at the anode, loses electrons and forms oxygen gas
- In both cases, the other negative ion remains in solution

Negative Electrode

- H^+ ions and metal ions are attracted to the negative electrode but only one will gain electrons
- Either hydrogen or a metal will be produced
- If the metal is above hydrogen in reactivity series, hydrogen will be produced – bubbling will be seen at the cathode

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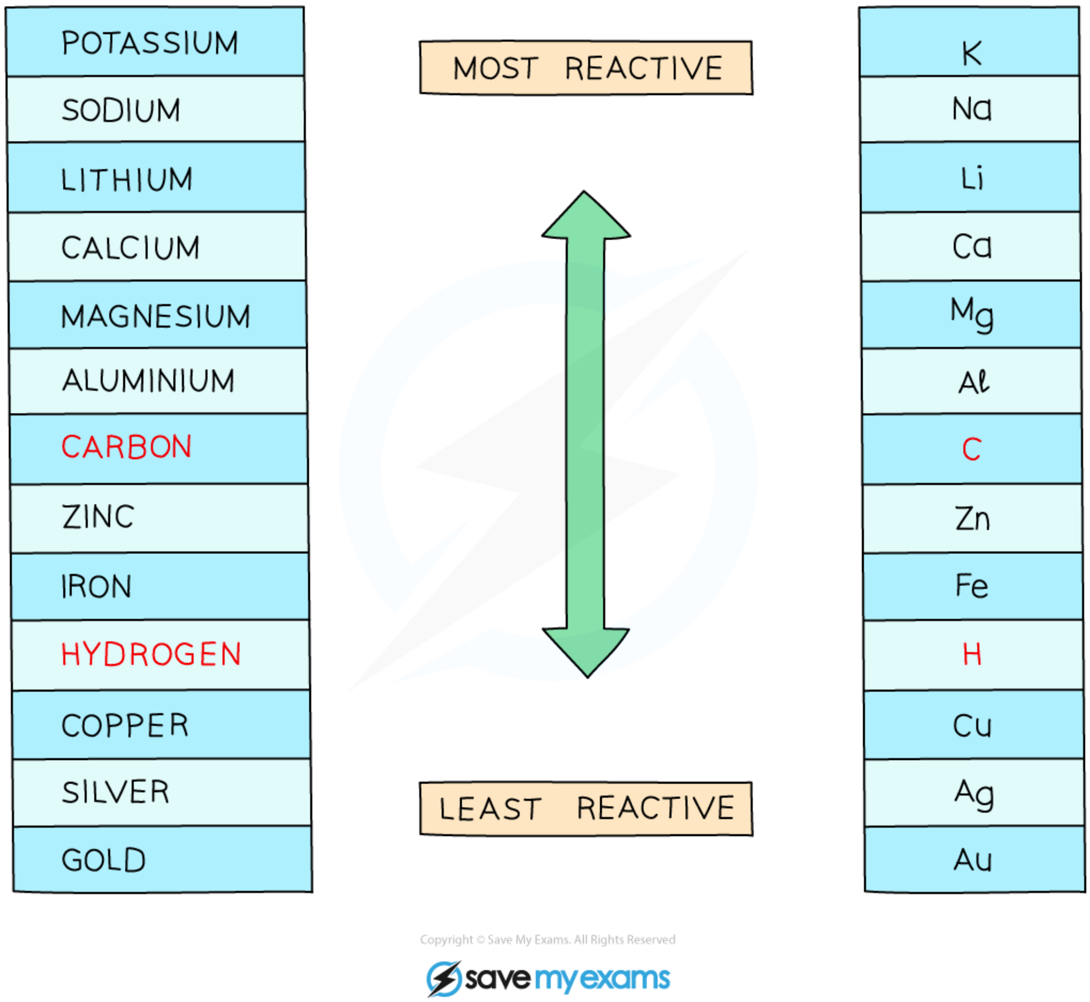

The reactivity series of metals enables chemists to predict the products at the cathode in the electrolysis of aqueous solutions

Electrolysing aqueous solution where there are gaseous products

- The apparatus can be modified for the collection of gases by using inverted test tubes over the electrodes
- The electrodes are made from graphite which is inert and does not interfere with the electrolysis reactions

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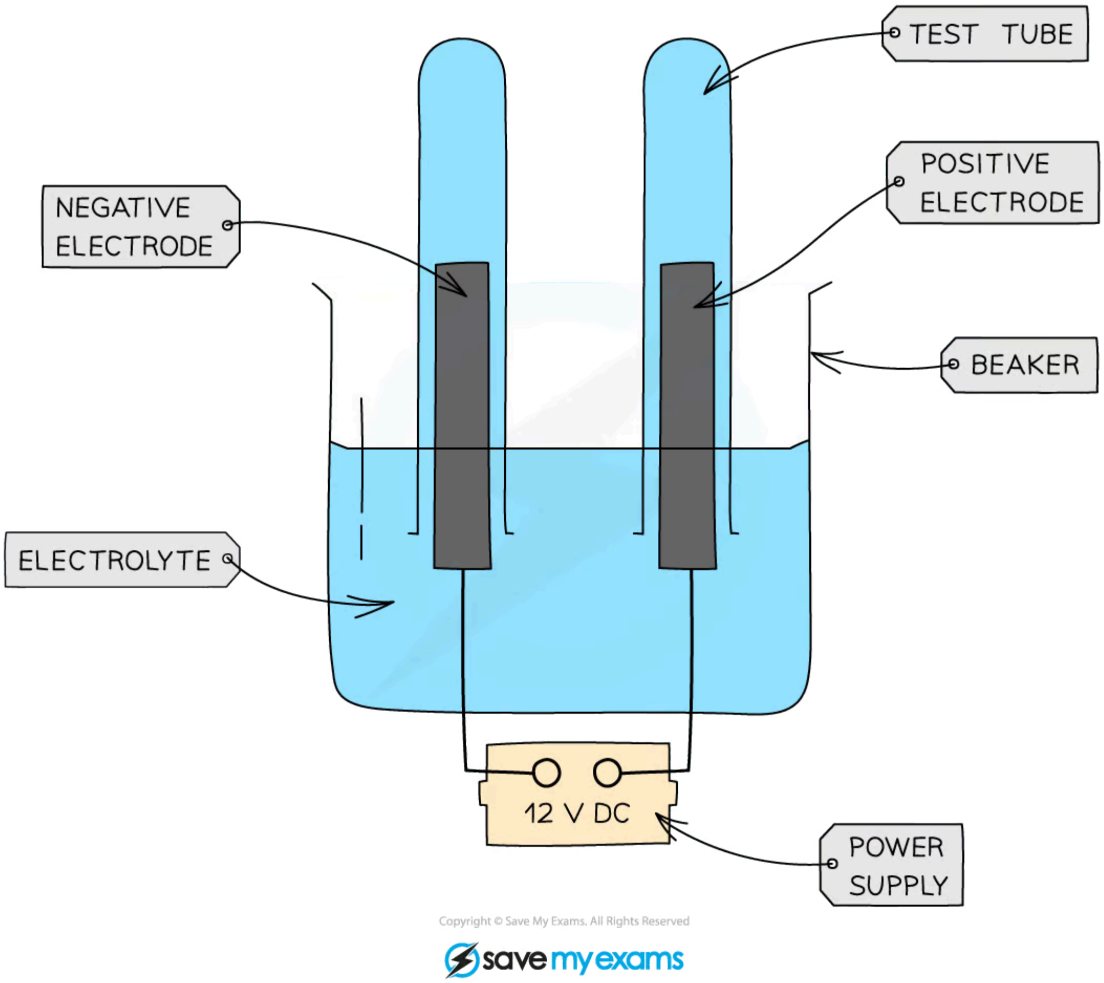

The electrolysis of aqueous solutions using inverted test tubes to collect gases at the electrodes

Using Named Electrolytes

- The products at the electrodes from solutions of copper chloride, sodium chloride, sodium sulfate and water acidified with sulfuric acid are as follows:

The Products of Electrolysing Aqueous Solutions

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Aqueous Solution	Product at Anode	Product at Cathode
Sodium Chloride ($NaCl$)	Chlorine gas released	Hydrogen gas released
Copper(II) Chloride ($CuCl_2$)	Chlorine gas released	Copper is lower than hydrogen in the reactivity series so copper is preferentially discharged as a metal
Sodium Sulfate (Na_2SO_4)	Oxygen gas released	Hydrogen gas released
Dilute Sulfuric Acid (H_2SO_4)	Oxygen gas released. H_2O more readily gives up electrons than SO_4^{2-}	Hydrogen gas released

Explaining the products

- **copper chloride:**
  - copper is below hydrogen so **copper(II) ions** are preferentially discharged at the cathode; **chlorine** is a halogen, so is preferentially discharged at the anode
- **sodium chloride:**
  - sodium is above hydrogen so **hydrogen ions** are preferentially discharged at the cathode; **chlorine** is a halogen, so is preferentially discharged at the anode
- **sodium sulfate:**
  - sodium is above hydrogen so **hydrogen ions** are preferentially discharged at the cathode; **hydroxide ions** are preferentially discharged over sulfate ions, so oxygen is produced at the anode
- **acidified water:**
  - **hydrogen ions** are discharged at the cathode; **oxygen** from water molecules is preferentially discharged at the anode

Examiner Tips and Tricks

Once you have identified the ions, the next step is to decide towards which electrode will they be drawn and identify the product formed. It helps if you recall the reactivity series.

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Electrolysis of Molten Compounds

Electrolysis of Molten Compounds

- Binary ionic compounds consists of just two elements joined together by ionic bonding
- When these compounds are heated beyond their melting point, they become molten and can conduct electricity as their ions can move freely and carry the charge
- These compounds undergo electrolysis and decompose into their constituent elements
- Lead(II) bromide is an ionic solid with a relatively low melting point and can be used to illustrate the electrolysis of a molten compound

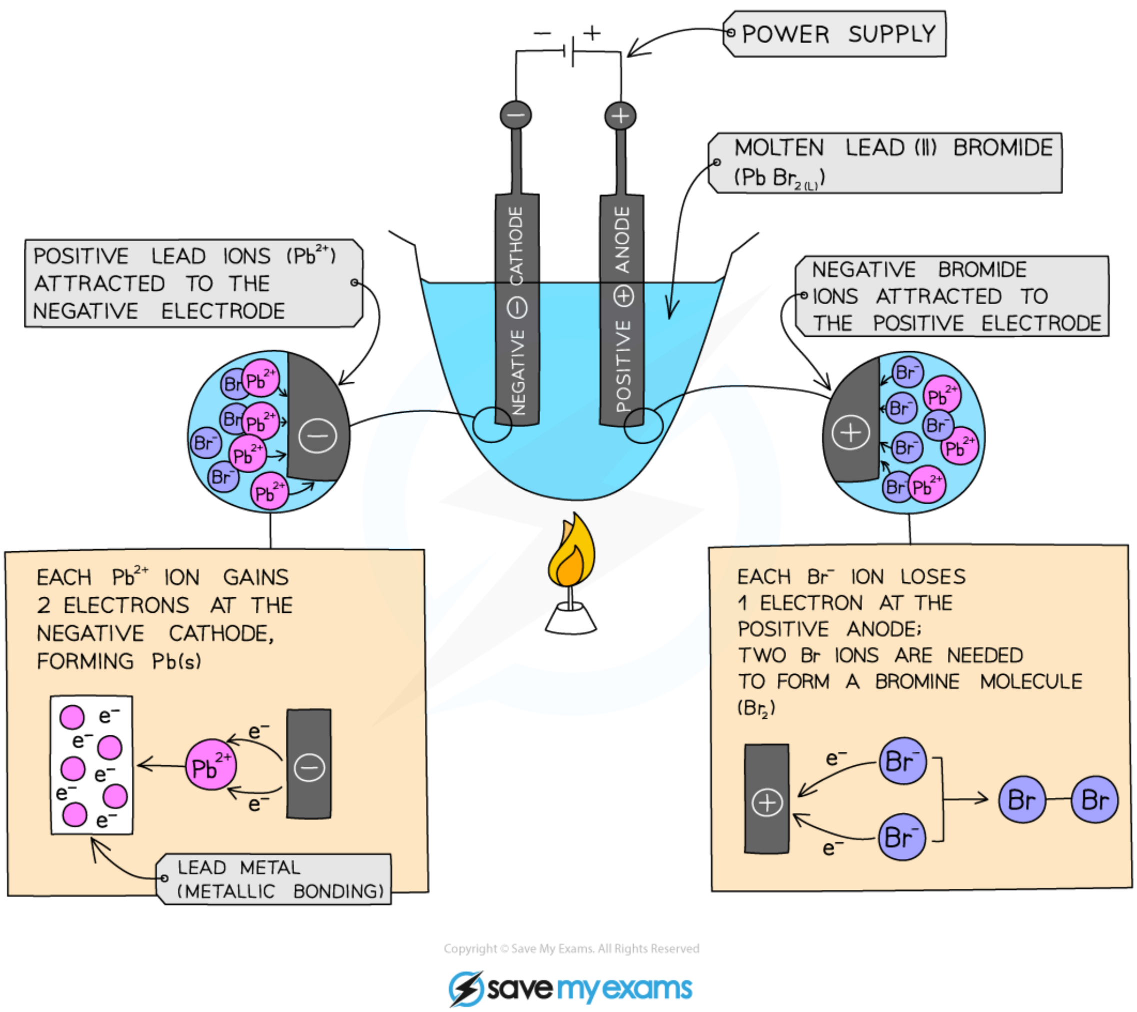

Diagram showing the electrolysis of lead(II) bromide

Method:

- Add lead(II) bromide into a crucible and heat so it will turn molten, allowing ions to be free to move and conduct an electric charge
- Add two graphite rods as the electrodes and connect this to a power pack or battery
- Turn on the power pack or battery and allow electrolysis to take place
- Negative bromide ions move to the positive electrode (anode) and lose two electrons to form bromine molecules. There is bubbling at the anode as brown bromine gas is given off
- Positive lead ions move to the negative electrode (cathode) and gain electrons to form grey lead metal which deposits on the bottom of the electrode

Electrode Products:

Anode: Brown fumes of bromine gas

Cathode: A grey bead of molten lead is formed

Predicting the Products

- To predict the products of any binary molten compound first identify the ions present
- The **positive** ion will migrate towards the **cathode** and the **negative** ion will migrate towards the **anode**
- Therefore the **cathode** product will always be the metal and the product formed at the **anode** will always be the **non-metal**
- For example,
  - **Zinc chloride** will produce **zinc** at the **cathode** and **chlorine** at the **anode**

Examiner Tips and Tricks

Remember electrodes need to be inert such as graphite or platinum so that they don't participate in a side reaction with the electrolyte.

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Electrolysis & Redox

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Electrolysis & Redox

- In electrochemistry we are mostly concerned with the **transfer of electrons**, hence the definitions of oxidation and reduction are applied in terms of **electron loss** or **gain** rather than the addition or removal of oxygen
- Oxidation is when a substance **loses electrons** and reduction is when a substance **gains electrons**
- As the ions come into contact with the electrode, electrons are either lost or gained and they form **neutral** substances
- These are then **discharged** as products at the electrodes
- At the anode, negatively charged ions lose electrons and are thus **oxidised**
- At the cathode, the positively charged ions gain electrons and are thus **reduced**
- This can be illustrated using half equations which describe the movement of electrons at each electrode

Electrolysis of molten lead(II) bromide

- In the electrolysis of molten lead(II) bromide the half equation at the negative electrode (cathode) is:

$$Pb^{2+} + 2e^- \rightarrow Pb \qquad \textbf{Reduction}$$

- At the positive electrode (anode) bromine gas is produced by the discharge of bromide ions:

$$2Br^- - 2e^- \rightarrow Br_2 \qquad \textbf{Oxidation}$$

or

$$2Br^- \rightarrow Br_2 + 2e^-$$

Examiner Tips and Tricks

At the anode, it doesn't matter whether you subtract the electrons on the left or add them on the right. Most chemists prefer to add them on the right, because chemical equations, by convention, generally involve the addition of materials rather than the subtraction.

Electrolysis of aqueous sodium chloride

- In the electrolysis of aqueous sodium chloride the half equation at the negative electrode (cathode) is:

$$2H^+ + 2e^- \longrightarrow H_2 \quad \textbf{Reduction}$$

- At the positive electrode (anode) chlorine gas is produced by the discharge of chloride ions:

$$2Cl^- - 2e^- \longrightarrow Cl_2 \quad \textbf{Oxidation}$$

or

$$2Cl^- \longrightarrow Cl_2 + 2e^-$$

Electrolysis of dilute sulfuric acid

- In the electrolysis of dilute sulfuric acid the half equation at the negative electrode (cathode) is:

$$2H^+ + 2e^- \longrightarrow H_2 \quad \textbf{Reduction}$$

- At the positive electrode (anode) oxygen gas is produced by the discharge of water molecules:

$$2H_2O - 2e^- \longrightarrow O_2 + 2H^+ \quad \textbf{Oxidation}$$

or

$$2H_2O \longrightarrow O_2 + 2H^+ + 2e^-$$

Electrolysis of aqueous copper(II) chloride

- In the electrolysis of aqueous copper(II) sulfate the half equation at the negative electrode (cathode) is:

$$Cu^{2+} + 2e^- \longrightarrow Cu \quad \textbf{Reduction}$$

- At the positive electrode (anode) chlorine gas is produced by the discharge of chloride ions:

$$2Cl^- - 2e^- \longrightarrow Cl_2 \quad \textbf{Oxidation}$$

or

$$2Cl^- \longrightarrow Cl_2 + 2e^-$$

Examiner Tips and Tricks

In electrode half equations the charges on each side of the equation should always balance . It may seem odd that water molecules are discharged and not hydroxide ions, but remember that acidic solutions will not contain any hydroxide ions.

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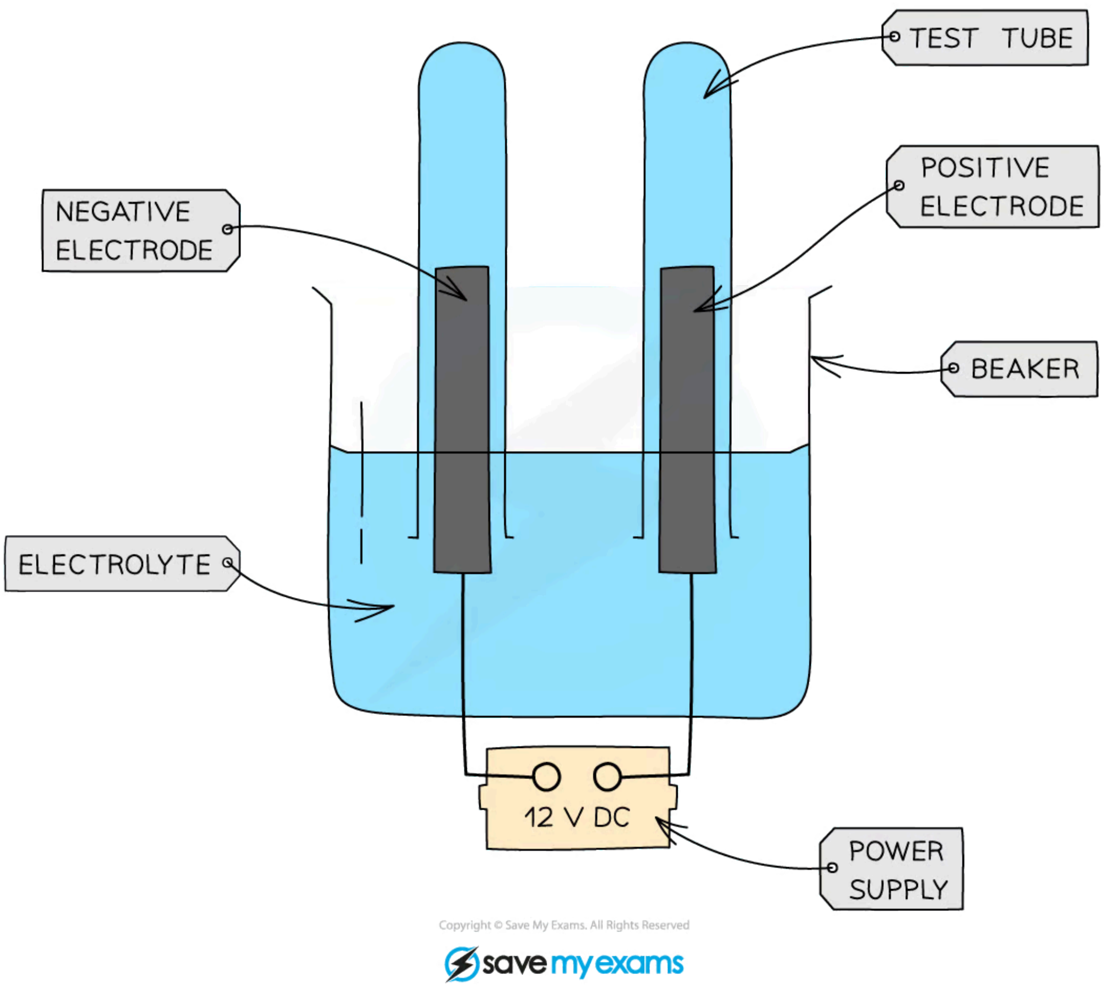
Core Practical: Electrolysis of Copper(II)Sulfate

Part 1 – Electrolysis with Passive Electrodes

Aim:

To electrolyse copper(II) sulfate solution using inert(graphite) electrodes

Diagram:



Apparatus for the electrolysis of copper(II)sulfate using passive(inert) electrodes

Your notes

Method: (Graphite electrodes)

- Pour copper sulfate solution into a beaker
- Place two **graphite** rods into the copper sulfate solution. Attach one electrode to the **negative** terminal of a DC supply, and the other electrode to the **positive** terminal
- Completely fill two small test tubes with copper sulfate solution and position a test tube over each electrode as shown in the diagram
- Turn on the power supply and observe what happens at each electrode
- Test any gas produced with a glowing splint and a burning splint
- Record your observations and the results of your tests

Analysis of results:

- Record observations of what happens at each electrode, including the results of the gas tests

Conclusion:

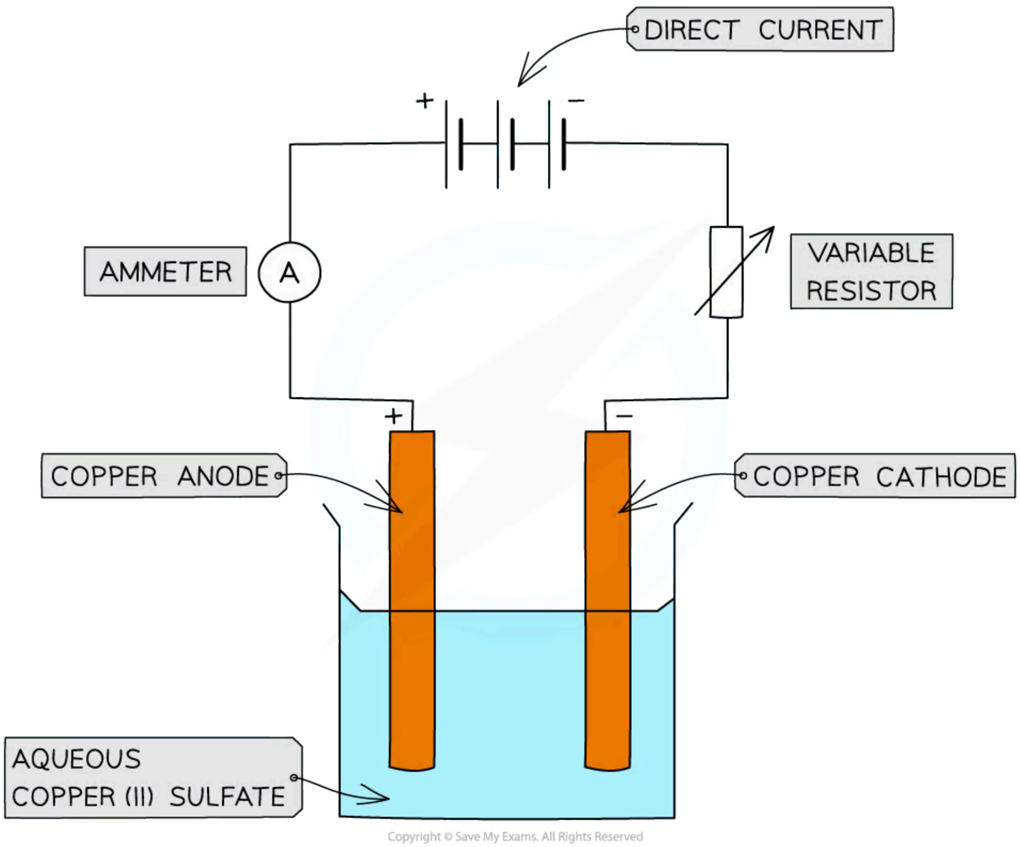
- **Copper** metal is formed at the negative electrode and **oxygen** gas is formed at the positive electrode

Part 2: Electrolysis with Active Electrodes

Aim:

To electrolyse copper(II) sulfate solution using active(copper) electrodes**Diagram:**

Your notes



Apparatus for the electrolysis of copper(II)sulfate using active electrodes

Method: (copper electrodes)

- Pour copper sulfate solution into a beaker
- Measure and record the mass of a piece of copper foil. Attach it to the **negative** terminal of a DC supply, and dip the copper foil into the copper sulfate solution
- Repeat with another piece of copper foil, but this time attach it to the **positive** terminal
- Make sure the electrodes do **not touch each other**, then turn on the power supply
- Adjust the power supply to achieve a constant current and leave for 20 minutes
- Remove one of the electrodes and wash it with distilled water, then dip it into propanone
- Lift the electrode out and allow all the liquid to evaporate. **Do not wipe** the electrodes clean. Measure and record the mass of the electrode
- Repeat with the other electrode making sure you can identify which electrode is which

Your notes

- Repeat the experiment with fresh electrodes and different currents.

Analysis of results:

- Record the currents used and the masses of each electrode in suitable table format
- Calculate the change in mass of each electrode

Conclusion:

- The **cathode increases** in mass while the **anode** decreases
- This occurs as copper atoms are **oxidised** at the anode and form ions while copper ions are **reduced** at the cathode, forming copper atoms
- The gain in mass by the negative electrode is the **same** as the loss in mass by the positive electrode
- Therefore the copper deposited on the negative electrode must be the **same** copper ions that are lost from the positive electrode
- That implies that the concentration of the Cu^{2+} ions in the solution remains **constant**

Hazards, risks and precautions

Hazard symbols to show substances that are corrosive, harmful to health and flammable

- Copper(II) sulfate solution is corrosive and harmful to health as it is a skin irritant and can cause serious eye damage
- Propanone, which is often used to clean the electrodes, is flammable
- Avoid contact with the skin and use safety goggles when handling copper(II) sulfate solution
- Propanone should be kept away from naked flames, e.g. a Bunsen burner

Explaining the Electrolysis of Copper(II)Sulfate

Your notes

Copper refining

- The electrolysis of $CuSO_4$ using graphite rods produces oxygen and copper
- By changing the electrodes from graphite to pure and impure copper, the products can be changed at each electrode
- Electrolysis can be used to purify metals by separating them from their impurities
- In the set-up, the **impure** metal is always the **anode**, in this case the impure copper
- The cathode is a thin sheet of **pure** copper
- The electrolyte used is an aqueous solution of a **soluble salt** of the pure metal at the anode, e.g. $CuSO_4$
- Copper atoms at the anode lose electrons, go into solution as ions:

$$\mathbf{Cu \rightarrow Cu^{2+} + 2e}$$

- The anode thus becomes **thinner** due to loss of atoms and the impurities fall to the bottom of the cell as sludge
- The copper(II) ions are attracted to the cathode where they gain electrons and form now purified copper atoms
- The cathode gradually becomes **thicker**

$$\mathbf{Cu^{2+} + 2e^- \rightarrow Cu}$$

- The anode sludge is a highly valuable material and is further refined as it often contains small quantities of precious metals like silver which are found as impurities in the unrefined copper