CAIE IGCSE Chemistry

4.1 Electrolysis

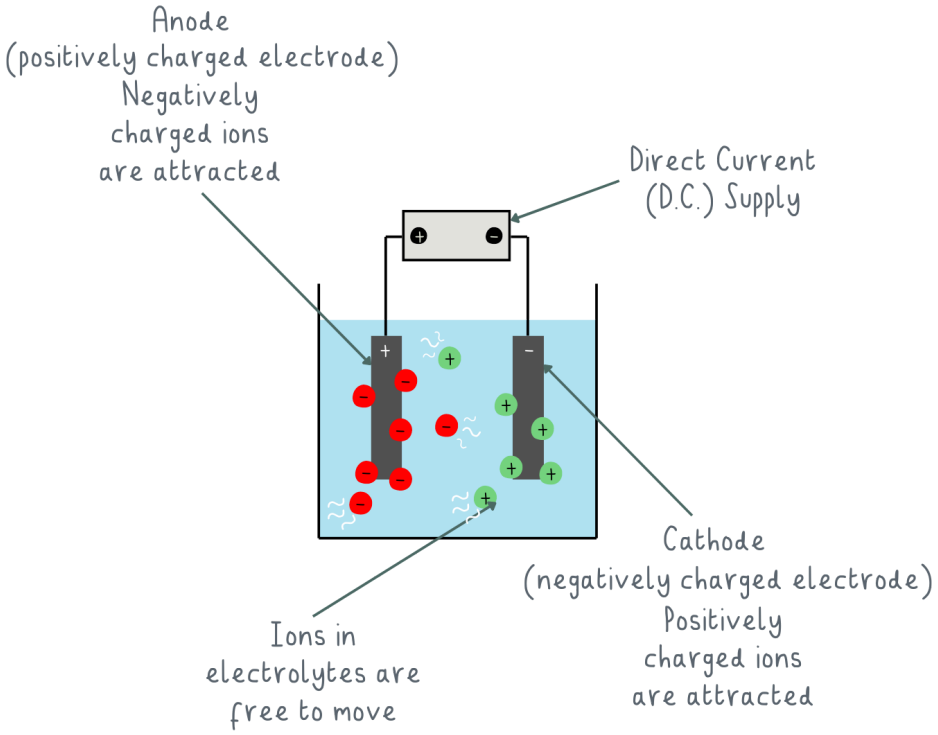
Notes

Define electrolysis

Electrolysis is the decomposition of an ionic compound, when molten or in aqueous solution, by an electric current being passed through.

Identify in simple electrolytic cells:

- The anode is the positively charged electrode- attracting negatively charged ions towards it
- The cathode is the negatively charged electrode- attracting positively charged ions towards it
- The electrolyte is an ionic compound in the molten or aqueous state that undergoes electrolysis- Ions in the electrolyte are able to move freely and are attracted towards the electrode with an opposite charge
- The electrodes are connected to a direct current (D.C) supply



Identify the products formed at the electrodes and describe the observations made during the electrolysis of:

(a) Molten lead(II) bromide

- During electrolysis of molten salts, a metal will form at the cathode and a non-metal forms at the anode
- Molten lead (II) bromide : $PbBr_2$ (l) is an electrolyte from a molten salt
- During electrolysis:
  - Pb^{2+} ions will be attracted to the cathode where they gain electrons and become Pb atoms, forming lead

- Br^- ions will be attracted to the anode where they lose electrons and become Br atoms, that then pair up to become Br_2 molecules (since bromine is diatomic), forming bromine

(b) Concentrated aqueous sodium chloride

- For electrolysis of aqueous solutions, more ions will be released in the electrolyte, since it is dissolved in water:
  - H^+ from the water and the positive ions from the ionic compound will be attracted to the cathode
  - OH^- from the water and the negative ions from the ionic compound will be attracted to the anode
  - These ions will compete at their electrodes to gain/lose electrons
  - At the cathode: (according to the the reactivity series)
    - If the metal is more reactive than hydrogen, hydrogen will be produced.
    - If the metal is less reactive than hydrogen, the metal is produced
  - At the anode:
    - Oxygen and water is produced (from the OH^- ions) unless halide ions are present
    - If halide ions are present, they lose electrons and form their halogens
- Concentrated aqueous sodium chloride: NaCl (aq) can also be referred to as 'brine'
- Concentrated aqueous sodium chloride: NaCl (aq) is an electrolyte of an aqueous solution:
  - At the cathode:
    - Na^+ ions and H^+ ions are attracted
    - Na is more reactive than hydrogen, so hydrogen ions gains electrons and produces hydrogen $H_2(g)$
  - At the anode:
    - Cl^- and OH^- ions are attracted
    - Cl^- is a halide so will lose electrons and form chlorine gas $Cl_2(g)$
  - The Na^+ and OH^- ions left behind will form NaOH (aq)

(c) Dilute sulfuric acid using inert electrodes made of platinum or carbon/ graphite

- Dilute sulfuric acid H_2SO_4 (aq) can also be referred to as 'acidified water'
- This electrolysis requires inert (will not react) electrodes made from platinum or graphite
- Dilute sulfuric acid H_2SO_4 (aq) is an electrolyte of an aqueous solution:
  - At the cathode:
    - H^+ ions (from the water and H_2SO_4) are attracted
    - H^+ ions gains electrons and becomes hydrogen gas H_2
  - At the anode:
    - OH^- and SO_4^{2-} ions are attracted
    - Since there are no halide ions, OH^- ions will lose electrons and form oxygen gas and water

State that metals or hydrogen are formed at the cathode and that non-metals (other than hydrogen) are formed at the anode

- At the cathode: (according to the the reactivity series)
  - If the metal is more reactive than hydrogen, hydrogen will be produced.
  - If the metal is less reactive than hydrogen, the metal is produced
- At the anode:
  - Oxygen and water is produced (from the OH^- ions) unless halide ions are present
  - If halide ions are present, they lose electrons and form their halogens

Predict the identity of the products at each electrode for the electrolysis of a binary compound in the molten state

- During electrolysis of molten salts, a metal will form at the cathode and a non-metal forms at the anode
- To predict the identity of the products at each electrode for the electrolysis of a binary compound in the molten state:

  E.g Predict the products at each electrode of molten aluminium oxide (Al_2O_3)

- Identify the ions that will be released from the compound:
  - The positive ion is Al^{3+} and the negative ion is O^{2-}
- State which electrode each ion will be attracted to:
  - The Al^{3+} ions will be attracted to the cathode
  - The O^{2-} ions will be attracted to the anode
- State whether each ion will lose/gain electrons and the product:
  - At the cathode, the Al^{3+} ions will gain electrons and form aluminium
  - At the anode, the O^{2-} ions will lose electrons and form oxygen gas

State that metal objects are electroplated to improve their appearance and resistance to corrosion

- Electroplating uses electrolysis to coat a thin layer of a metal (e.g. silver) onto the surface of another metal (e.g. steel)
- The purpose of electroplating is:
  1. Improving their appearance
  2. Improving their resistance to corrosion

Describe how metals are electroplated

- For electroplating to occur:
  - The cathode is the object that needs electroplating
  - The anode is the plating metal
  - The electrolyte consists ions of the plating metal
- The electrodes are involved in the electrolysis reactions
  E.g. Electroplating steel with silver
  - The cathode is made of the steel that will be electroplated
  - The anode is made of silver
  - The electrolyte is silver nitrate solution which contains silver ions

When the direct current supply is turned on:

- At the cathode: silver ions (from the electrolyte) are attracted gain electrons and become silver atoms, forming silver on the surface of the steel cathode (electroplating)
- At the anode: silver atoms lose electrons and become silver ions in the electrolyte

(Extended only) Describe the transfer of charge during electrolysis to include:

- For electrolysis to occur, charge needs to be transferred around the apparatus through charge carriers:
  - In the external circuit, the charge carriers are the electrons
  - In the electrolyte, the charge carriers are the ions

(a) The movement of electrons in the external circuit

- In the external circuit, the direct current power supply is connected to the cathode, providing electrons, causing it to become negatively charged

(b) the loss or gain of electrons at the electrodes

- At the cathode (negatively charged electrode), cations (positively charged ions) from the electrolyte are attracted and gain electrons
- At the anode (positively charged electrode), anions (negatively charged ions) from the electrolyte are attracted and lose electrons
- These electrons released at the anode transfer from the anode back to the direct current power supply

(c) the movement of ions in the electrolyte

- In the electrolyte, there are positive and negative ions, known as cations and anions, able to move freely and towards any attraction
- The cations (e.g. Na^+ ions) will move towards the cathode (since it has a negative charge)
- The anions (e.g. Cl^- ions) will move towards the anode (since it has a positive charge)

(Extended only) Identify the products formed at the electrodes and describe the observations made during the electrolysis of aqueous copper(II) sulfate using inert carbon/ graphite electrodes and when using copper electrodes

The electrolyte: Aqueous copper (II) sulfate: $CuSO_4$ (aq) contains Cu^{2+} ions, SO_4^{2-} ions and H^+ and OH^- ions from the water

Using inert carbon/graphite electrodes

- At the cathode:
  - H^+ ions and Cu^{2+} ions are attracted
  - Copper is less reactive than hydrogen (according to the reactivity series) so copper will be reduced
  - Cu^{2+} ions gain electrons and become copper atoms
  - A brown copper deposit will be visible on the surface of the electrode
  - The blue colour of the $CuSO_4$ electrolyte will fade as more copper metal is formed and the concentration of Cu^{2+} ions decreases
- At the anode:
  - OH^- and SO_4^{2-} ions are attracted
  - Since there are no halide ions, OH^- ions will lose electrons and form oxygen gas and water
  - Oxygen gas is visibly observed as there will be small bubbles formed on the surface of the electrode

Using copper electrodes

- Electrodes made of copper are not inert, so will react within the electrolysis process
- This method, using copper electrodes, is useful for purifying copper and electroplating
- At the cathode:
  - H^+ ions and Cu^{2+} ions are attracted
  - Copper is less reactive than hydrogen (according to the reactivity series) so copper will be reduced
  - Cu^{2+} ions gain electrons and become copper atoms
  - A brown copper plating will form on the surface of the electrode
- At the anode:
  - OH^- and SO_4^{2-} ions are attracted
  - But both ions are too stable and will not change
  - Hence, the copper within the anode (the anode is made of copper), will oxidise and release Cu^{2+} ions into the electrolyte
- The copper anode dissolves as it is oxidised whereas the copper cathode builds a layer of copper plating on its surface
- The blue colour of the $CuSO_4$ electrolyte stays constant since the concentration of Cu^{2+} ions in it will stay constant (as the Cu^{2+} ions being released from the anode balances the Cu^{2+} ions being reduced at the cathode).

(Extended only) Predict the identity of the products at each electrode for the electrolysis of a halide compound in dilute or concentrated aqueous solution

- In aqueous solutions, H^+ and OH^- ions are released into the electrolyte in addition to the compounds cations and anions
- At the anode:
  - OH^- ions and the halide ions are attracted
  - Because halide ions are present, they lose electrons and form their halogens:
    - Chloride Cl^- ions form chlorine Cl_2
    - Bromine Br^- ions form bromine Br_2
    - Iodide I^- ions form iodine I_2
- At the cathode: (according to the the reactivity series)
  - H^+ ions and the metal ions are attracted
  - If the metal is more reactive than hydrogen, hydrogen will be produced.
  - If the metal is less reactive than hydrogen, the metal is produced

E.g. Predict the products that will be formed at each electrode from aqueous copper chloride:

- At the anode:
  - OH^- and Cl^- ions will be attracted but since there are halide ions
  - Chloride Cl^- ions lose electrons and forms chlorine Cl_2
- At the cathode:
  - H^+ and Cu^{2+} ions will be attracted
  - Copper is less reactive than hydrogen so the Cu^{2+} ions will gain electrons and form copper atoms

(Extended only) Construct ionic half-equations for reactions at the anode (to show oxidation) and at the cathode (to show reduction)

- Half equations show what happens when ions gain or lose electrons:
  - Electrons are written as $\mathbf{e^-}$
  - The overall charge on both sides of the equation must be equal
  - The number of atoms are the same on both sides
- Oxidation is the loss of electrons, occurring at the anode
  - Negative ions (anions) will lose electrons at the anode.
  - E.g. Write a half equation to show the oxidation of chloride ions at the anode:
    1. Chloride ions Cl^- form chlorine Cl_2
       $Cl^- \rightarrow Cl_2$
    2. But there are two atoms of chlorine on the right side and only 1 on the left side so:
       $2Cl^- \rightarrow Cl_2$
    3. Add in the electrons that are lost to form chlorine and so the charges are equal on both sides
       $2Cl^- \rightarrow Cl_2 + 2e^-$

Can also be written as: $2Cl^- - 2e^- \rightarrow Cl_2$

- Reduction is the gain of electrons, occurring at the cathode
  - Positive ions (cations) will gain electrons at the cathode.
  - E.g. Write a half equation to show the reduction of aluminium ions at the cathode:
    1. Aluminium ions Al^{3+} form aluminium atoms Al
       $Al^{3+} \rightarrow Al$
    2. Add in the electrons that need to be gained to form aluminium atoms and so the charges are equal on both sides
       $Al^{3+} + 3e^- \rightarrow Al$
- Mnemonic to help remember the terms : **OILRIG**
  - **O**xidation
  - **I**s
  - **L**oss of electrons
  - **R**eduction
  - **I**s
  - **G**ain of electrons