Electricity and Chemistry

Conductors and Insulators

Conductors

- Conductors are substances which have a low resistance to the passage of electricity. In other words they allow electricity to flow through them easily.
- Metals and graphite conduct electricity because they have mobile valence electrons in their structures
- Copper is used in electrical wiring because it is a good conductor of electricity, it is ductile and easily purified by electrolysis
- Thick wires carry a larger electric current than thin wires ∴ we use very thick wires in high voltage power lines to reduce friction, and reduce the amount of heat energy produced.
- Steel-cored aluminium cables are used in high voltage power lines because aluminium is a good conductor and steel strengthens the cable
- Aluminium has a low density and is resistant to corrosion.

Insulators

- An insulator is substance that resists the flow of an electric current, it does not conduct electricity
- Insulators do not conduct electricity as they do not have mobile electrons
- Examples include; plastics, glass, and ceramic materials
- PVC plastics are useful insulators- they are flexible and non-biodegradable
- Used for covering electrical wires or as short circuits in electrical equipment
- Less useful when high current is used-heat easily melts plastic
- Glass and ceramics are useful insulators-have high melting and boiling points
- Used in high voltage electricity towers to keep wires from touching metal pylons or each other
- Ceramics are not affected by water or air and can be moulded into complex shapes

Electrolysis

- Electrolysis is the breaking down of a compound using an electric current. It is the chemical reaction which takes place when an electric current is passed through an electrolyte.
- An electrolyte is a substance, which when molten or when dissolved in water can conduct electricity accompanied by a chemical reaction
- The electric current causes a chemical reaction that breaks down the ionic compound, i.e. it decomposes
- An electrode is a metal rod or carbon (graphite) rod which allows electrons to enter or leave the electrolyte (i.e. it carries electric current to and from the electrolyte)
- They are usually made from inert conductors, usually graphite or platinum
- This is so that the electrodes do not react with the electrolyte or product of electrolysis

- A cathode (-) is the metal rod connected to the negative terminal of the battery. It allows electrons to enter the electrolyte. A cathode is negatively charged
- An anode (+) is the electrode which is connected to the positive terminal of the batter, it allows electrons to leave the electrolyte. An anode is positively charged.
- At the cathode (-) the positive ion s accept electrons and become atoms. This is reduction
- At the anode (+) the negative ions give up electrons to become atoms. This is oxidation
- Oxidation takes place at the anode, and reduction at the cathode

<u>The Products of Electrolysis</u>

Electrolysis always gives a metal or hydrogen at the cathode (-) and a non-metal other than hydrogen at the anode (+)

<u>Molten compounds</u>

The electrolysis of molten ionic compounds always give a metal at the cathode (-), and a non-metal at the anode (+)

<u>Electrolysis of molten sodium chloride</u>

Using carbon/graphite electrodes

Electrolyte: molten sodium chloride

Ions present: Na^{+} and Cl^{-}

<u>Reaction at the cathode (-)</u>

Na^{+} Ions migrate to the cathode (-) where they are discharged. Each Na^{+} ion gains one electron to form a sodium atom. Molten Na metal will be seen around the cathode (-)

$$Na^{+} + e^{-} \rightarrow Na$$

<u>Reaction at the anode (+)</u>

Cl^{-} Ions migrate to the anode where they are discharged. Each Cl^{-} ion loses one electron to form a chlorine atom. Bubbles of greenish-yellow chlorine gas is formed at the anode (+)

$$2Cl^{-} - 2e^{-} \rightarrow Cl_2$$

<u>Electrolysis of molten lead (ii) bromide</u>

Using carbon/graphite electrodes

Electrolyte: molten lead (ii) bromide

Ions present: Pb^{2+} and Br^{-}

<u>Reaction at the cathode (-)</u>

The Pb^{2+} ions migrate to the cathode, where they are discharged. Each Pb^{2+} ion gains two electrons to form a lead atom. A greyish substance is seen around the cathode.

$$Pb^{2+} + 2e^- \rightarrow Pb$$

Reaction at the anode (+)

The Br^- ions migrate to the anode where they are discharged. Each Br^- ion loses one electron to form a bromine atom. A reddish-brown gas is seen around the anode (+).

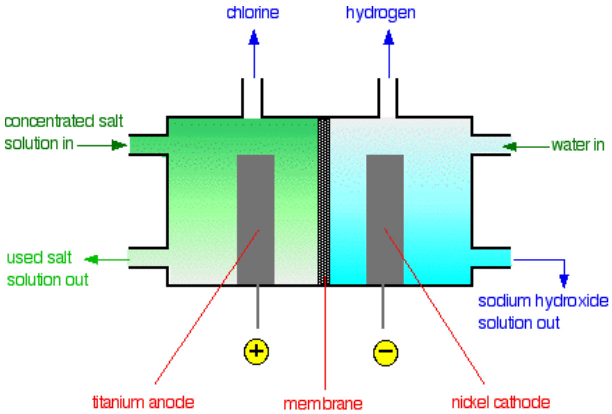
$$2Br^- - 2e^- \rightarrow Br_2$$

Selective discharge

When two different ions go to an electrode, one of them will be discharged in preference to the other. This is called selective discharge. The ion which is discharged depends on the following:

i. Its position in the reactivity series
ii. The concentration of the ion
iii. The nature of the electrode

Electrolysis of Solutions



Electrolysis of concentrated aqueous sodium chloride (brine)

Using carbon/graphite electrodes

Brine is obtained from seawater and from seams of rock salt underground. The electrolysis of brine is used to produce chlorine, hydrogen and sodium hydroxide on a large scale

Chlorine is used to make solvents, for treating drinking water and for making bleaches. Hydrogen is used for making ammonia, and for making margarine as a fuel. Sodium hydroxide is used for making soap and in the extraction of aluminium.

Brine is electrolysed ion a diaphragm cell.

Electrolyte: aqueous sodium chloride

Ions present: $NaCl \rightarrow Na^+ + Cl^-$

$H_2O \rightleftharpoons H^+ + OH^-$

Reaction at the cathode (-)

Na^+ and H^+ ions are attracted to the cathode (-). H^+ions will be discharged, each H^+ ion will gain one electron to form a hydrogen atom. Bubbles of hydrogen gas will be released at the cathode (-).

$$2H^+ + 2e^- \rightarrow H_2$$

Reaction at the anode (+)

Cl^- and OH^- ions are attracted to the anode (+). Cl^-ions will be discharged, each Cl^- ion will lose one electron to form a chlorine atom. Bubbles of greenish-yellow chlorine gas formed at the anode (+).

$$2Cl^- - 2e^- \rightarrow Cl_2$$

Electrolysis of dilute sodium chloride solution

Using carbon/graphite electrodes

Electrolyte: dilute sodium chloride

Ions present: $NaCl \rightarrow Na^+ + Cl^-$

$H_2O \rightleftharpoons H^+ + OH^-$

Reaction at the cathode (-)

Na^+ and H^+ ions are attracted to the cathode (-). H^+ions will be discharged, each H^+ ion will gain one electron to form a hydrogen atom. Bubbles of hydrogen gas will be released at the cathode (-).

$$2H^+ + 2e^- \rightarrow H_2$$

Reaction at the anode (+)

Cl^- and OH^- ions are attracted to the anode (+). The solution is dilute, the concentration of Cl^- ions is low $\therefore$ OH^- ions are discharged in preference to the Cl^- ions. Bubbles of oxygen gas will be released around the anode (+).

$$4OH^- - 4e^- \longrightarrow 2H_2O + O_2$$

Electrolysis of dilute sulphuric acid (acidified water)

Using platinum electrodes

Electrolyte; dilute sulphuric acid

Ions present: $HCl \longrightarrow H^+ + Cl^-$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Reaction at the cathode (-)

H^+ ions are attracted to the cathode (-).H^+ ions are discharged, each H^+ ion gains one electron to form a hydrogen atom. Bubbles of hydrogen are seen at the cathode (-).

$$2H^+ + 2e^- \rightarrow H_2$$

Reaction at the anode (+)

Cl^- and OH^- ions are attracted to the anode (+). The solution is dilute, the concentration of Cl^- ions is low $\therefore$ OH^- ions are discharged in preference to the Cl^- ions. Bubbles of oxygen gas will be released around the anode (+).

$$4OH^- - 4e^- \longrightarrow 2H_2O + O_2$$

Electrolysis of concentrated hydrochloric acid

Using platinum electrodes

Electrolyte; dilute sulphuric acid

Ions present: $HCl \longrightarrow H^+ + Cl^-$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Reaction at the cathode (-)

H^+ ions are attracted to the cathode (-).H^+ ions are discharged, each H^+ ion gains one electron to form a hydrogen atom. Bubbles of hydrogen are seen at the cathode (-).

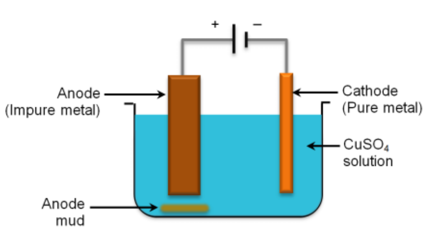
$$2H^+ + 2e^- \rightarrow H_2$$

Reaction at the anode (+)

Cl^- and OH^- ions are attracted to the anode (+). Cl^-ions will be discharged, each Cl^- ion will lose one electron to form a chlorine atom. Bubbles of greenish-yellow chlorine gas formed at the anode (+).

$$2Cl^- - 2e^- \rightarrow Cl_2$$

Refining copper



- The cathode becomes thicker as it gains more and more copper.
- After a time the cathode of pure copper is removed and replaced by a new one
- The anode loses ,ass and the impurities fall to the bottom of the electrolysis cell as anode slime

- Other valuable metals can be extracted from the anode sludge
- The overall result of this electrolysis is that pure copper is transferred from the anode to the cathode

Electrolysis of aqueous copper (ii) sulphate

Using carbon electrodes

Electrolyte: aqueous copper (ii) sulphate

Ions present: $CuSO_4 \rightarrow Cu^{2+} + SO_4{}^{2-}$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Reaction at the cathode (-)

Cu^{2+} and H^+ ions are attracted to the cathode (-). Cu^{2+} is lower than H^+ on the discharge series, so Cu^{2+} will be discharged. Each Cu^{2+} ion will gain to electrons to form a copper atom. You will observe a reddish brown solid forming around the cathode (-). The cathode increases in size/mass.

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

Reaction at the anode (+)

$SO_4{}^{2-}$ and OH^- are attracted to the anode (+). Each OH^- ion will lose one electron to form water and oxygen gas. Bubbles of oxygen will be released at the anode (+).

$$4OH^- - 4e^- \longrightarrow 2H_2O + O_2$$

NOTE: As the number of Cu^{2+} ions decreases during this electrolysis, the intensity of the blue colour will decreases (the blue colour will fade).

Electrolysis of aqueous copper (ii) sulphate

Using copper

Electrolyte: aqueous copper (ii) sulphate

Ions present: $CuSO_4 \rightarrow Cu^{2+} + SO_4{}^{2-}$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Reaction at the cathode (-)

Cu^{2+} and H^+ ions are attracted to the cathode (-). Cu^{2+} is lower than H^+ on the discharge series, so Cu^{2+} will be discharged. Each Cu^{2+} ion will gain to electrons to form a copper atom. You will observe a reddish brown solid forming around the cathode (-). The cathode increases in size/mass.

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

Reaction at the anode (+)

$SO_4{}^{2-}$ and OH^- are attracted to the anode (+). None will be discharged, instead copper atoms will lose two electrons each to form copper (ii) ions which go into the solution. The anode decreases in size/mass.

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

NOTE: The intensity of the blue colour of the solution remains the same, as when one copper ion is discharged at the cathode, another copper ion is formed at the electrode.

Electroplating

- Electroplating is used to put a thin layer of one metal on top of another metal, this is achieved by electrolysis
- The object that is being electroplated, is connected to the negative pole i.e. it becomes the cathode (-). The object can be any metal and must be extremely clean
- The plating metal is connected to the positive pole, i.e. it becomes the anode. Some typical metals used for plating are silver, gold, tin and chromium
- The electrolyte being used is a solution of the ionic compound of the plating metal
- Electroplating is used for protection of metals from corrosion and improving the appearances of metals

Example: electroplating with silver

Electrodes: cathode – (nickel spoon), anode + (silver)

Ions present: Ag^+

$$AgNO_3 \rightarrow Ag^+ + NO_3{}^-$$

Reaction at the cathode (-)

Ag^+ ions are attracted to the cathode, each Ag^+ ion gains one electron to form a silver atom, which forms a thin layer of the object being plated.

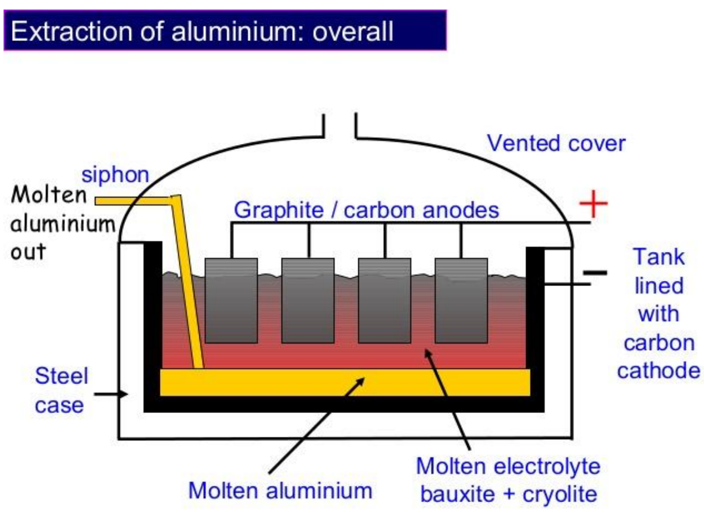
$$Ag^+ + e^- \rightarrow Ag$$

Reaction at the anode (+)

At the anode (+), each silver atom loses one electron to form a silver ion. The silver ions go into the solution.

$$Ag - e^- \longrightarrow Ag^+$$

Extracting aluminium from its ore



- The more reactive the metal, the harder it is to break down its compounds
- Electrolysis is a powerful way to break down compounds
- Aluminium is extracted by the electrolysis of aluminium oxide (alumina) dissolved in molten cryolite.
- The electrolyte cell consists of a steel tank with graphite lining on the inside and acts as the cathode (-)
- The anode (+) is a series of suspended graphite rods in the centre of the tanks

- The overall equation of the electrolysis is:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Reaction at the cathode (-)

Al^{3+} ions go to the graphite cathode (-) where they are discharged. Each Al^{3+} ion gains 3 electrons to form an aluminium atom. Molten aluminium collects at the bottom

$$Al^{3+} + 3e^{-} \rightarrow Al$$

Reaction at the anode (+)

O^{2-} ions are attracted to the carbon anode where they are discharged. Each oxide ions loses 2 electrons to form an oxygen atom.

$$2O^{2-} - 4e^{-} \rightarrow O_2$$

NOTE:

- Aluminium oxide has a high melting point, and is not a good conductor of electricity, so it is dissolved in molten cryolite to lower the temperature, and increase electrical conductivity saving energy and costs
- The oxygen gas produced at the anode reacts with carbon to form carbon dioxide gas. The carbon anodes get eaten away during this reaction and $\therefore$ have to be replaced at regular intervals
- Though aluminium is one of the most abundant materials on the earth's crust, it is rather expensive to extract because:
    i. A large amount of energy is required for electrolysis
    ii. The carbon anodes need to be replaced regularly
    iii. It produces no bi-products