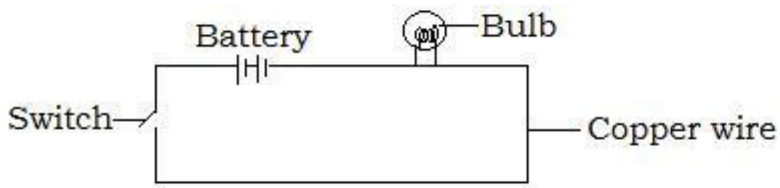
EFFECTS OF ELECTRICITY ON SUBSTANCES

Electricity is a form of energy produced as a result of flow of electrons through materials.

Investigation of electrical conductivity through solid materials
Examples of such materials include: copper wire, zinc wire, plastic, graphite, rubber.

Procedure
Connect the copper wire to the batteries through the bulb and the switch as shown below.



Results
The bulb produced light on complete connection with copper and zinc.
Conclusion
Copper and zinc wires conduct electricity and they are called **conductors**.

A conductor is a substance in solid form which can conduct electricity. Examples include; all metals and graphite (the only non metal that can conduct electricity.

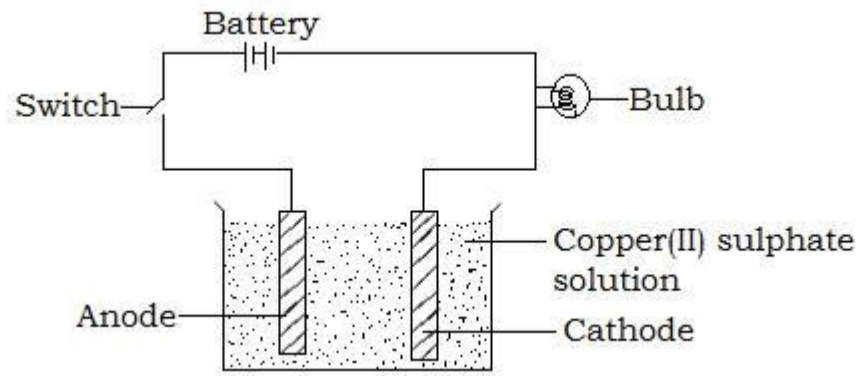
When the above experiment was repeated using rubber and plastics, the bulb did not light indicating that they do not conduct electricity and are referred to as **insulators** or **non conductors**.

A non conductor is a substance in solid form that does not conduct electricity. Examples are all non metal except graphite.

Metals conduct electricity because they have delocalized, free or mobile electrons but non metals do not have these delocalized electrons as they are all locked up in bond formation

Investigation of electrical conductivity through liquid substances in solution
Examples: ethanol, urea, hydrochloric acid, copper (II) sulphate, ethanoic acid, water, ammonium hydroxide.

Procedure
- Put the liquid under investigation in an electrolytic cell.
- Dip two rods in the liquid which can either be a metal or carbon(graphite) called electrodes
- Connect the electrodes using a conductor to a bulb via a switch to the source of power (the batteries) as shown below.



Close the switch.
Repeat the experiment with hydrochloric acid, ethanol, ethanoic acid, water, urea, ammonium, ammonium hydroxide.

Results
When ethanol and urea were used there was no light produced indicating that they do not conduct electricity, they are there fore called **non electrolytes**.
When ammonium hydroxide and ethanoic acid were used, the bulb produced a dim light indicating that they weakly conduct and are there fore **weak electrolytes**.

When copper sulphate solution and hydrochloric acid were used, the bulb produced bright light indicating that they strongly conduct electricity and are **strong electrolytes**.

ELECTROLYSIS
This is the decomposition of a substance in solution form or molten form (electrolyte) as a result of passage of electric current. The decomposition of the electrolyte takes place at the electrodes.

Definitions of common terms used in electrolysis
1. Electrolytes
This is a substance in solution form or molten state that can conduct electricity.
.

Electrolytes can be categorized as strong, weak or non electrolytes.

a) Strong electrolyte
This is a substance in solution form or molten state that ionizes completely and can easily conduct electricity. The electrolyte decomposes fully during electrolysis.
Examples include, all mineral acids, alkalis, ionic compounds.
Sodium chloride; e.g $NaCl(aq) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$,

$HCl(aq) \longrightarrow H^{+}(aq) + Cl^{-}(aq)$

b) Weak electrolytes
This is a substance in solution form which is only slightly ionized (partially ionized). The electrolyte is only partially decomposed by the electric current. Most of the ions of the electrolyte remain as un ionized ions or molecules.
Examples include:
All weak alkalis like ammonium hydroxide; $NH_4OH(aq) \rightleftharpoons NH_4^{+}(aq) + OH^{-}(aq)$

All solutions of weak acids like ethanoic acid; $CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-(aq) + H^+(aq)$
Impure water.

c) Non electrolyte

Is a substance in solution form or aqueous state that doesn't conduct electricity. This substance is not decomposed at the electrodes. Example include: all covalent compounds, like pure water, benzene, methyl benzene, petrol and diesel.

2. Electrodes

These are rods or plates or poles of conductors at which electrons enter and leave the electrolyte. The electrodes are either cathodes or anodes.

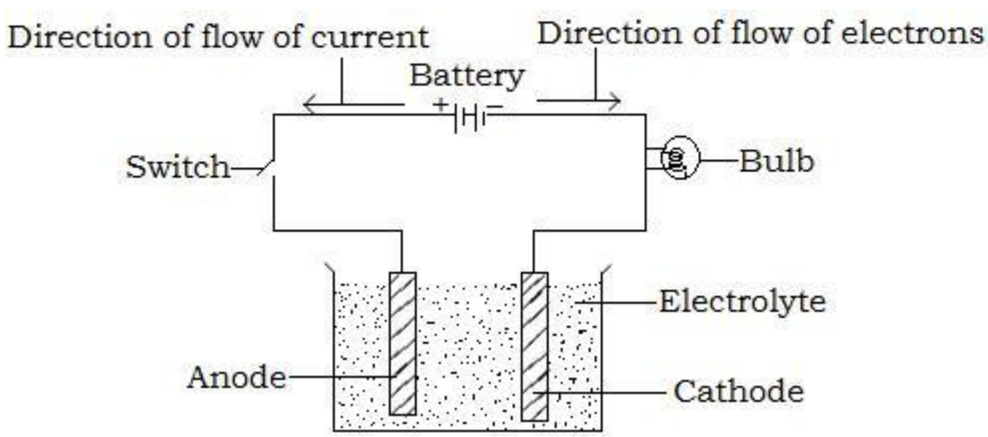
a) Anode

This is the positive electrode at which the electrons leave the electrolyte. Or is the positive electrode at which electrons enter the external circuit. It is normally connected to the positive terminal of the battery.

b) Cathode

This is the negative electrode at which the electrons enter the electrolyte or is the negative electrode at which the electrons leave the external circuit. It is connected to the negative end of the battery.

Simple electrolytic cell



In an electrolytic cell the electrolyte has to be in solution form or molten state as the ions have to be free to move so as to conduct electricity. Salts such as sodium chloride, and lead (II) bromide do not conduct electricity in solid state because the ions are held together by strong electrostatic forces of attraction and are not free and mobile. However, when the salts are melted or dissolved in water, the electrostatic forces are broken down and the ions become free and mobile and so conduct electricity.

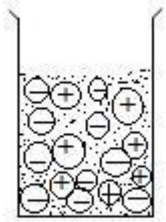
IONIC THEORY

Ionic theory was put forward to explain the phenomenon of electrolysis. According to ionic theory, electrolytes are believed to contain electrically charged particles called **ions.** The ions can be positively charged (cations) and are obtained from metals, hydrogen and ammonium or negatively charged (anions) and are obtained from non-metals e.g. , , , .
During electrolysis, the cations are attracted to the negative electrode (cathode) and the anions are attracted to the positive electrode (anode)
Examples of electrolytes and the ion produced.

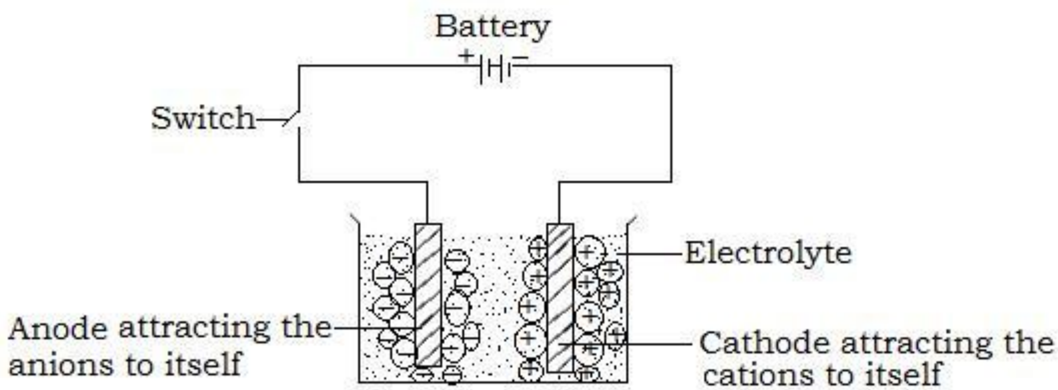
Compound	**Formula**	**Ions produced**
Sulphuric acid	H_2SO_4	H^+ and SO_4^{2-}
Sodium chloride	NaCl	Na^+ and Cl^-
Sodium hydroxide	NaOH	Na^+ and OH^-
Copper (II)sulphate	$CuSO_4$	Cu^{2+} and SO_4^{2-}

Lead(II) bromide	$PbBr_2$	Pb^{2+} and 2 Br^-
Copper (II) chloride	$CuCl_2$	Cu^{2+} and 2 Cl^-

Explanation of electrolysis by ionic theory
When current is not passed through an electrolyte, the ions are wandering randomly in solution.



When current is passed through the solution, the cathode attracts the to itself and the anode attracts to it self the anions.



When the cations reach the cathode (negative electrode), they stick to it, gain electrons and become ordinary atoms. *e.g* $H^+(aq) + e^- \longrightarrow H(g)$ .... (1)
$H^+(aq) + e^- \longrightarrow H(g)$ .... (2)
Atoms add up to give hydrogen gas as shown below
$H(g) + H(g) \longrightarrow H_2(g)$

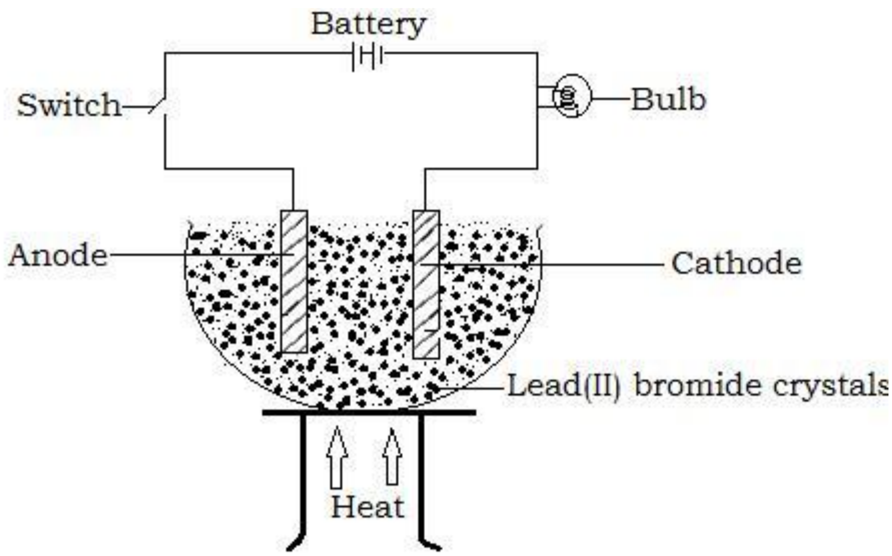
When the anions reach the anode (positive electrode), they give away the electrons and become ordinary atoms.e.g. $Cl^-(aq) \longrightarrow Cl(g) + e^-$ and $Cl^-(aq) \longrightarrow Cl(g) + e^-$
Atoms add up to give chlorine gas as shown

$Cl(g) + Cl(g) \longrightarrow Cl_2(g) + 2e-$

Experiment to show that Lead (II) bromide only conducts electricity in molten form

Electrolysis of leads (II) bromide

The electrolysis is done using carbon electrodes (graphite) as shown below.



When carbon electrodes are dipped into **solid Lead (II) bromide crystals** and the circuit completed, the **bulb did not light** indicating that there was no conduction because the ions responsible for conduction were locked up in the solid crystal by strong electrostatic forces of attraction. When heated and molten liquid formed, the forces are broken such that the ions were free and mobile. Hence there was conduction an so the bulb lit since the mobile ions produced electricity.

Lead(II)bromide ionizes according to the equation

$PbBr_2(l) \longrightarrow Pb^{2+}(l) + 2Br^-(l)$

At the cathode:

Lead(II) ions, migrate to the cathode where they gains electrons coming from the anode and they are discharged to a **silvery grey solid** of lead. Thus equation at the cathode is

$Pb^{2+}(l) + 2e- \longrightarrow Pb(s)$

Bromine ions migrate towards the anode and are discharged by losing electrons to form **red/brown vapor or liquid.** Thus, equation at the anode is

$2Br^- (l) - 2e \longrightarrow Br_2(g)or\ (l)$

Or:

$2Br^- (l) \longrightarrow Br_2(g)or\ (l) + 2e-$

Preferential or selective discharge of ions

When two or more ions of similar charges reach the electrode, one is preferentially selected for discharge and the selection depends on the following factors.

- The position of the ion in the electrochemical series
- The concentration of the electrolyte
- The nature of electrodes

1. The position of metal or radical in the reactivity series

The ion that is lower in the electrochemical series is selected for discharge in preference to one above it.

Cations (migrate to cathode)		Anions (migrate to anode)	
K^+		SO_4^{2-}	
Ca^{2+}		NO_3^-	
Na^+	Increasing ease of	Cl^-	Increasing ease of
Mg^{2+}	discharge	Br^-	discharge
Al^{3+}		I^-	
Zn^{2+}		OH^-	
Fe^{2+}			
Pb^{2+}			
H^+			
Cu^{2+}			
Ag^+			

Example: Consider the decomposition of copper(II)sulphate solution
In aqueous solution both copper(II) sulphate and water ionize as follows

$CuSO_4(aq) \longrightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$

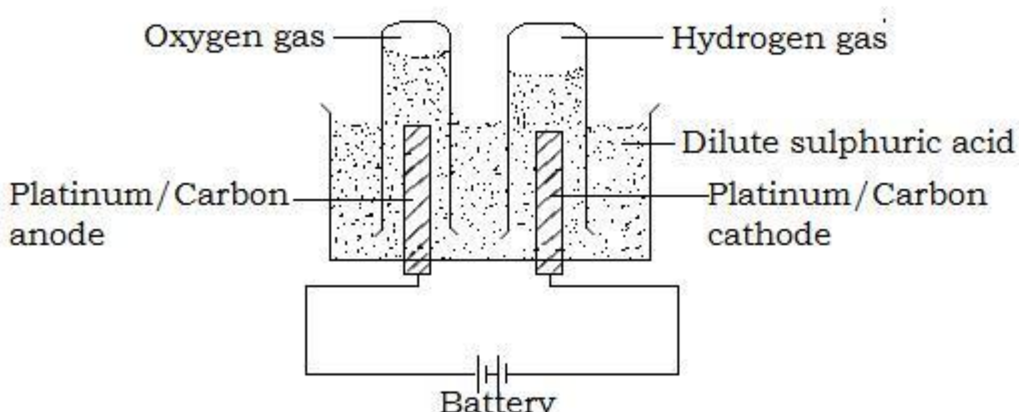
$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$

Electrolysis of some electrolytes

1. Electrolysis of dilute sulphuric acid (electrolysis of water)

The electrolysis is done by use of platinum or carbon rods for both electrodes. During the electrolysis, 2 volumes of hydrogen is produced at the cathode and one volume of oxygen is formed at the anode. Total acidity of the products remains the same as the products formed are elements of water.

Drawing of apparatus



Ions present in dilute sulphuric acid include (H^+, OH^- , SO_4^{2-}) , this is from the complete ionization of sulphuric acid and partial ionization of water.

$H_2SO_4(aq) \longrightarrow 2H^+(aq) + SO_4^{2-}(aq)$

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$

At the cathode

Hydrogen ions migrate to the cathode where they are discharged by receiving electrons from the cathode and form atoms. The hydrogen atoms pair up to form hydrogen gas (bubbles of a colorless gas that burns with a pop sound).

Equation at the cathode

$4H^+(aq) + 4e \longrightarrow 2H_2(g)$

At the anode

Both the sulphate ions and hydroxyl ions migrate to the anode. The hydroxyl ions are discharged in preference to the sulphate ions as it is below the sulphate ions in the electrochemical series.

Equation at the anode

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

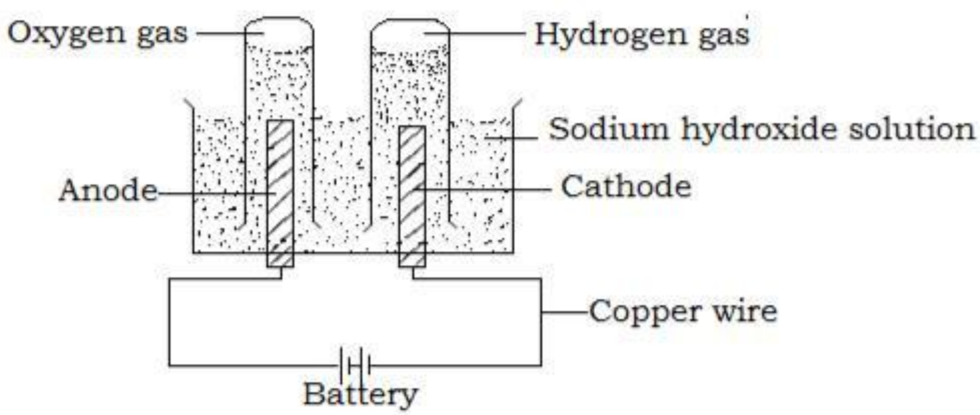
Overall equation

$4OH^-(aq) + 4H^+(aq) \longrightarrow 2H_2(g) + 2H_2O(l) + O_2(g)$

NOTE:

It should be observed be observed that the volume of hydrogen gas produced at the cathode is always twice the volume of oxygen gas produced at the anode

Electrolysis of dilute sodium hydroxide solution using carbon electrodes Setup of the apparatus



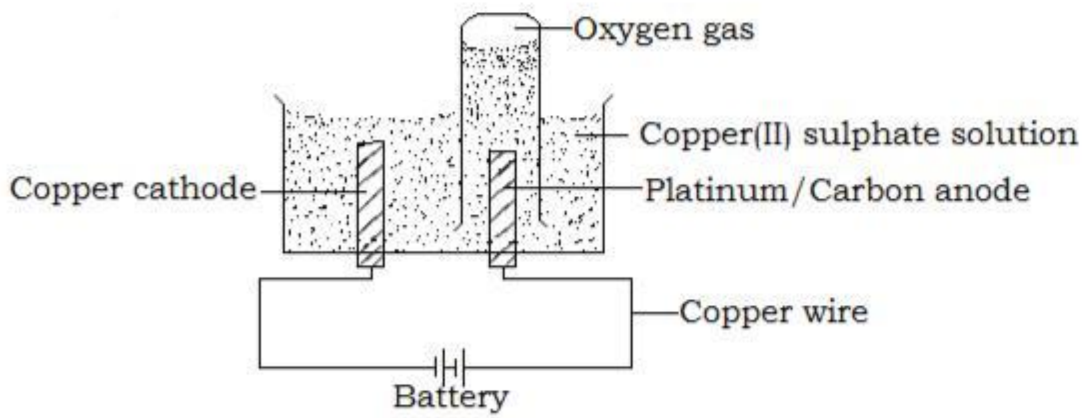
Ions present include Na^+, H^+, OH^- produced by complete ionization of sodium hydroxide and partial ionization of water .

$NaOH(aq) \longrightarrow Na^+(aq) + OH^-(aq)$

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq$

At the cathode
Both hydrogen ions and sodium ions migrate towards the cathode.
But hydrogen ions are discharged in preference to sodium ions because they are below sodium ions in the electrochemical series. Therefore, at the cathode, bubbles of a colorless gas that burns with a pop sound is produced.
Equation
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$
At the anode
At the anode, the hydroxyl ions are discharged giving off bubbles of a colorless gas that relights a glowing splint.
Equation
$4OH^-(aq) \longrightarrow 2H_2O(l) + O_2(g) + 4e^-$

Electrolysis of copper (II) Sulphate solution using copper cathode and platinum or graphite anode
Set up of apparatus



Ions present are Cu^{2+}, SO_4^{2-}, H^+ and OH^-

At the cathode
Both copper(II)ions and hydrogen ions migrate to the cathode but the copper(II) ions being lower than hydrogen in the electrochemical series, it's discharged in preference to hydrogen ions. There fore at the cathode, the copper ions gain electrons and are deposited as brown solids of copper.
Equation:
$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

At the anode
Both sulphate ions and hydroxide ions migrate to the anode, but hydroxide ions being lower than the sulphate ions in the electrochemical series are discharged forming water and oxygen gas as final products.
Equation
$4OH^-(aq) \longrightarrow 2H_2O(l) + O_2(g) + 4e^-$

Note

The blue colour of the copper (II) Sulphate fades away with time as the copper(II) ions which are responsible for the blue colour are being discharged and deposited at the cathode as a brown solid of copper metal.
The discharge of the hydroxyl ions at the anode disturbs the ionic equilibrium of water; therefore more water ionizes to restore this equilibrium.

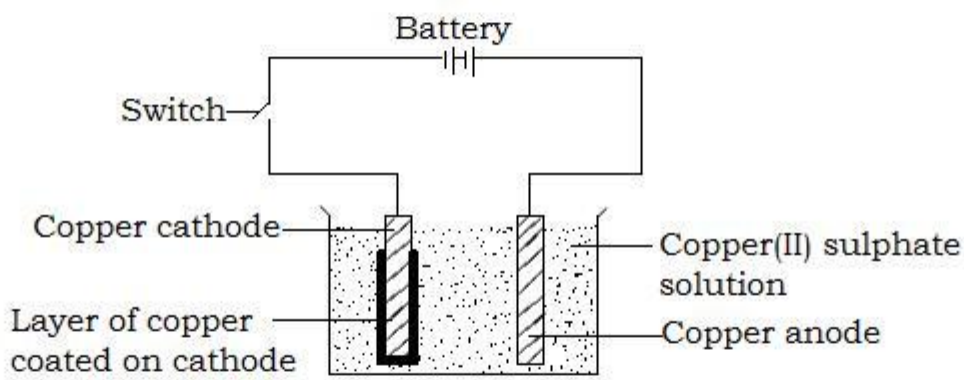
The excess hydrogen ions produced combines with the undischarged sulphate ions forming sulphuric acid which makes the solution around the anode acidic. Thus the solution around the anode turns blue litmus paper to red.

2. The nature of electrode

Different electrodes for a given electrolyte may cause different products to be formed at the electrodes.

Electrolysis of Copper(II) sulphate solution using copper

electrodes Set up of the apparatus



Ions present in solution include Cu^{2+} , SO_4^{2-}, H^+ and OH^-

At the cathode

Both copper(II) ions and hydrogen ions migrate to the cathode but copper ions are discharged in preference to hydrogen ions since it‘s below it in the electrochemical series. Since the electrodes are considered to be active.

Equation

$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$

At the anode

Both sulphate and hydroxide ions migrate to the anode but non is discharged. Instead, the copper anode goes into solution i.e. it dissolves to form copper ions. This process is called **electrode ionization**. Such a process in favored in this case as it requires less energy than the discharge of ions.

Equation

$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$

Overall equation

$Cu(s) + Cu^{2+}(aq) \longrightarrow Cu(s) + Cu^{2+}(aq)$

Note

During the experiment, the anode loses mass and the cathode gains mass. The loss in mass at the anode equals the gain in mass at the cathode. The change in mass at either electrode is proportional to the quantity of electricity passed through the electrolyte.

The intensity of the blue color of copper (II) sulphate remains constant as the process is a mere transfer of the copper ions from anode to cathode. i.e. the copper from the anode goes into solution as ions to replace the lost copper ions at the cathode.

Overall concentration of the electrolyte remains constant.

Electrolysis of dilute sodium chloride using a mercury cathode and graphite/platinum anode

Ions present; Na^+, Cl^-, H^+ and OH^-

$NaCl(aq) \longrightarrow Na^+(aq) + Cl^-(aq)$

$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq$

At the anode

Both the chloride and hydroxyl ions migrated to the anode but the hydroxyl ions being lower than the chloride ions in the reactivity series, the hydroxyl ions are discharged by losing electrons in preference to chloride ions. Therefore bubbles of colorless gas that relights a glowing splint is observed at the anode.

Equation

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

At the cathode

Both sodium and hydrogen ions move to the cathode. In this case, sodium ions are discharged despite the fact that hydrogen ions are lower than it in the electrochemical series. This is because the process requires less energy and the sodium atoms produced form an amalgam with mercury.

Equation at cathode

$Na^+(aq) + e^- \longrightarrow Na(s)$

Then

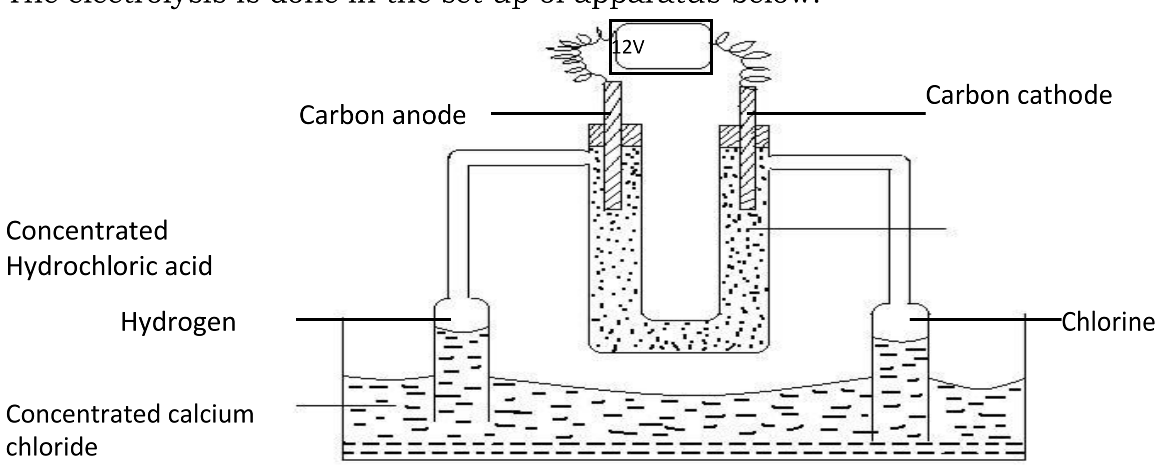
$Na(s) + Hg(l) \longrightarrow Na/Hg(l)$

3) Concentration

Increase in concentration of ions tends to promote its chance of being discharged. E.g. if concentrated Hydrochloric acid is used.

Electrolysis of concentrated hydrochloric acid using graphite electrodes

The electrolysis is done in the set up of apparatus below.



Ions present

$HCl_{(aq)} \longrightarrow H^{+}_{(aq)} + Cl^{-}_{(aq)}$

$H_2O(aq) \rightleftharpoons H^{+}(aq) + OH^{-}(aq)$

At the cathode

Hydrogen ions migrate to the cathode where they are discharged forming bubbles of a colorless gas that burns with a pop sound (hydrogen gas).

Equation

$2H^{+}(aq) + 2e^{-} \longrightarrow H_2(g)$

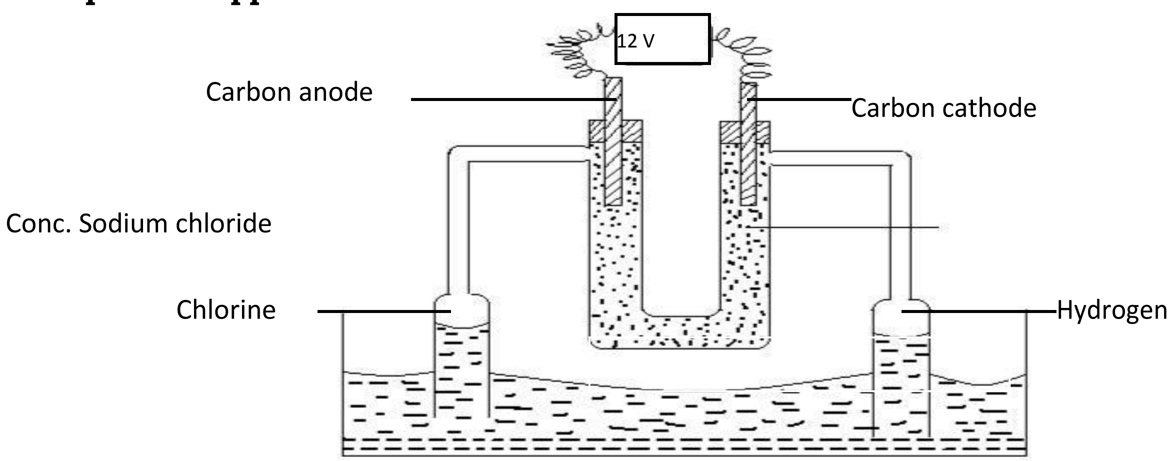
At the anode

Both the chloride and the hydroxyl ions migrate to the anode but the hydroxyl ions despite them being lower than chloride ions in the electrochemical series are not discharged. Instead the chloride ions are discharged since they are present in a much higher concentration. Therefore, a green-yellow gas that bleaches damp litmus paper is observed indicating that the gas is chlorine gas. Equation

$2Cl^{-}(aq) - 2e^{-} \longrightarrow Cl_2(g)$

Electrolysis of concentrated sodium chloride solution using graphite electrodes

Set up of the apparatus



Ions present : Na^{+}, Cl^{-}, H^{+}, OH^{-}

At the anode

Both the chloride and hydroxyl ions migrate to the anode but chloride ions being present in a much higher concentration are discharged in preference to the hydroxyl ions. There fore, bubble of a green yellow gas that bleaches damp litmus paper (chlorine) is observed.

Equation

$2Cl^{-}(aq) - 2e^{-} \longrightarrow Cl_2(g)$

At the cathode

Both sodium and hydrogen ions migrate to the cathode. Hydrogen being lower in the electrochemical series are discharged in preference to sodium ions. Therefore,

bubbles of a colorless gas that burns with a pop sound is produced at the cathode.
Equation

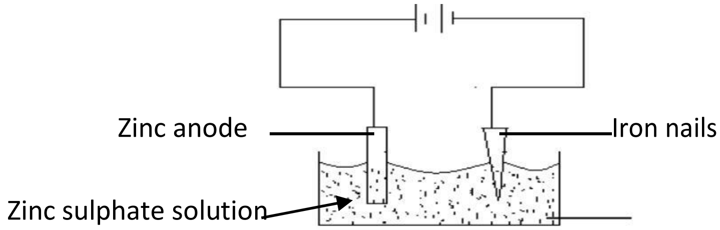
$2H^+(aq) + 2e- \longrightarrow H_2(g)$

Application of electrolysis

a) Electroplating

This is the coating of one metal by metal using electricity. In electroplating, the metal to be coated is made the cathode and the plating metal is made the anode. The electrolyte must contain ions of the metal used for coating e.g. solution of a salt of the metal used as a coating on the object. Electroplating prevents rusting and improves on the appearance of metals. For an effective electroplating; a clean cathode must be used; a steady current must flow; a steady temperature must be maintained and the concentration of the electrolytes must also be steady.

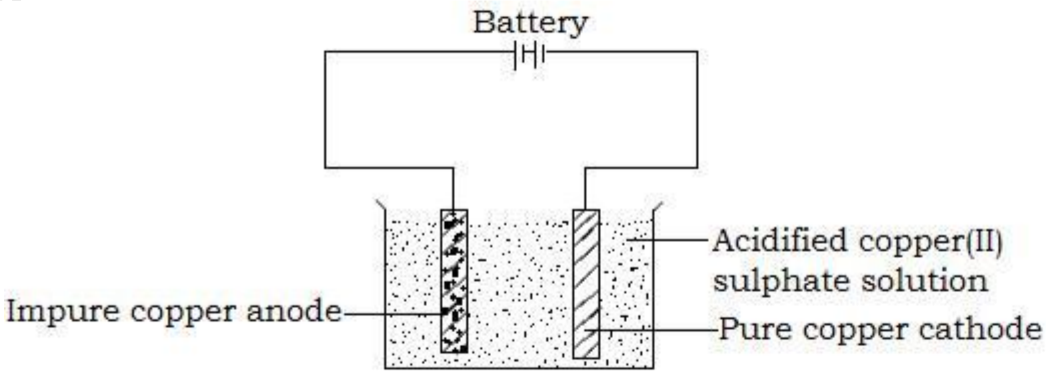
Setup used to electroplate iron nail with zinc.



b) Purification of metals.

Metals such as copper and zinc may be purified by electrolysis.
Example: purification of copper

Set up of apparatus



In this case, the impure metal is made the anode and the pure metal the cathode. The electrolyte is usually an acidified solution of a salt containing the metal to be purified. In this case acidified copper (II) sulphate solution is used. During electrolysis, the impure copper anode dissolves and their fore losses mass as copper (II) ions ( )are formed.

$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e-$

The copper (II) ions move to the pure copper cathodes where they are deposited as a brown layer of pure copper.

$Cu^{2+}(aq) + 2e- \longrightarrow Cu(s)$

The impurities (anode sludge) fall to the bottom of the cell.

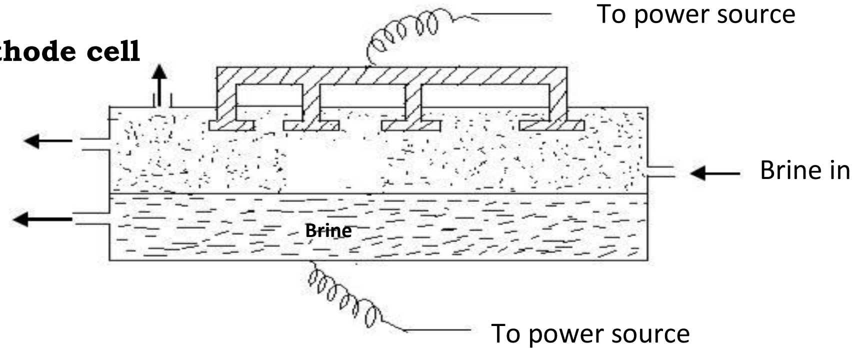
Extraction of reactive metals like sodium, and aluminium.

Manufacture of chemicals such as sodium hydroxide and chlorine

Manufacture of sodium hydroxide by electrolysis

Sodium hydroxide is manufactured industrially by the electrolysis of concentrated sodium chloride (Brine) using carbon anode and a layer of mercury as the cathode. The cell is called a **mercury cathode cell**.

The mercury cathode cell



When current is passed through the electrolyte, decomposition takes place as follows.

$$NaCl(aq) \longrightarrow Na^{+}(aq) + Cl^{-}(aq)$$

$$H_2O(aq) \rightleftharpoons H^{+}(aq) + OH^{-}(aq)$$

At the cathode

Both sodium and hydrogen ions move towards the cathode. Because of the nature of the mercury electrode, it will influence the discharge of sodium ion in preference to hydrogen ions ( ).

$$Na^{+}(aq) + e \longrightarrow Na(s)$$

The sodium formed combines with the mercury to form sodium amalgam. The sodium amalgam is dropped in water to form sodium hydroxide, hydrogen gas and mercury.

Equation

$$Na/Hg(l) + H_2O(l) \longrightarrow NaOH(aq) + H_2(l) + Hg(l)$$

The mercury is recycled back, and sodium hydroxide evaporated to dryness and used for various purposes such as manufacture of soap, paper and rayon.

At the anode

Both chloride and hydroxyl ions move to the anode. Due to the high concentration of the chloride ions, it is discharged in preference to hydroxyl ions, therefore forming chlorine gas at the anode.

$$2Cl^{-}(aq) - 2e^{-} \longrightarrow Cl_2(g)$$

e) Anodization and dyeing of aluminium

Aluminium objects may be coated with a thin layer of aluminium oxide using electricity, a process known as anodization. During the process, the aluminium object is made the anode and the electrolyte is dilute suphuric acid. The aluminium oxide coating is important in preventing corrosion.