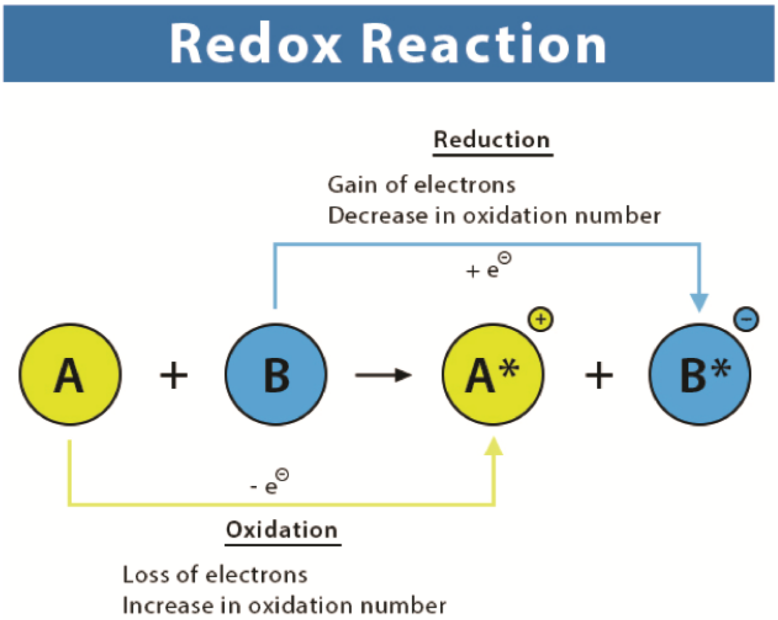
S4 New Curriculum chemistry

Theme: REDOX Reactions

Chapter 1 – Oxidation and Reduction Reactions



Oxidation

Oxidation can be defined as as

- Gaining of oxygen, for example, reaction of magnesium with oxygen

  $Mg (s) + O_2(g) \longrightarrow 2MgO(s)$

  When magnesium is burnt in oxygen there is increase in weight because oxygen reacts with oxygen to form heavier magnesium oxide

- Loss of hydrogen for example sulphur is oxidised when hydrogen sulphide reactswith chlorine

H_2S (g) + Cl_2 (g) ⟶ S (s) + 2HCl (g)

In this case hydrogen atoms are removed from sulphur to chlorine

- Loss of electrons or increase in oxidation state for example, during the reaction potassium iodide with chlorine gas to form iodine and potassium chloride

$2I^-$ (aq) + Cl_2 (g) ⟶ I_2 (aq) + $2Cl^-$ (aq)

In this reaction,the oxidation state of iodine increases from -1 to 0; hence iodide ions are oxidised.

Reduction

Reduction can be defined as

(i) Loss of oxygen for exampe when copper oxide is reacted with magnesium, copper is reduced becaused magnesium removes oxygen from copper oxide

CuO (s) + Mg (s) ⟶ Cu(s) + MgO (s)

The color of copper oxide changes from black to brown copper crystals

(ii) Addition of of hydrogen, for example, chlorine is reduced when it reacts with hydrogen to form hydrogen chloride

H_2 (g) + Cl_2 (g) ⟶ 2HCl (g)

(iii) Addition of electron, and oxidation state decrase, for example whensoulpur dioxide turns brown solution of iron (III) to a green solution of iron II

Fe^{3+} (aq) + e ⟶ Fe^{2+} (aq)

Redox reaction

In a reaction both oxidation and reduction ocurr concurrently with one reactant oxidised while another is reduced, thus redox reaction.For example, when copper is added to solution of silver nitrate solution, a green solutionof copper nitrate is formed with black ppt of silver because copper is oxidised to copper II ions while silver ions are reduced to black silver particles

$2Ag^+$ (aq) + Cu (s) ⟶ 2Ag (s) + Cu^{2+}(aq)

Oxidation state

Oxidation state refers to the charge an atom would have if electrons were completely transferred in a bond, rather than shared.

	Rule	Example	Oxidation state
1.	Oxidation state of free element or atoms is zero	Cu, S, Fe, Na, K	0
2	Oxidation state of a simple ion is equal the charge on the ion	Na^+ Cl^- Cu^{2+} Al^{3+}	+1 -1 +2 +3
3	In compound metal atoms have positive oxidation states while nonmetals have negative oxidation states but the compound has zero oxidation state for example MgO	Mg^{2+} O^{2-}	+2 -2

Trial 1

(a) Determine the oxidation states of the elements in the following compounds

(i) CaO
(ii) HCl
(iii) NaI

(b) Determine the oxidation state of copper in the following oxides

(i) CuO
(ii) Cu_2O

Oxidizing agent

An oxidizing agent **is a substance that** gains electrons **and** causes another substance to lose electrons **in a redox reaction. It is** reduced **in the process while the other substance is** oxidized**.**

Common oxidizing agents include:

- **Oxygen (O_2)** – Used in combustion and respiration.
- **Chlorine (Cl_2)**
- **Potassium dichromate –** is an oxidizing agent in the laboratory analytical methods.
- **Hydrogen peroxide (**H_2O_2**)** – A powerful oxidizer used in bleaching and disinfecting.
- **Potassium permanganate (**$KMnO_4$**)** – Common in redox titrations and water purification.
- **Chlorine (**Cl_2**)** – Used for disinfecting and in chemical synthesis.
- **Nitric acid (**HNO_3**)** – Acts as an oxidizing agent in reactions involving metals.
- **Iron(III) (**Fe^{3+}**)**

Reducing agents

A **reducing agent** is a substance that **loses electrons** and **causes another substance to gain electrons** in a redox reaction. It is **oxidized** in the process while the other substance is **reduced**.

Common reducing agents include:

- **Hydrogen (**H_2**)** – Used in many industrial reduction processes.
- **Carbon (C)** – Found in coke and charcoal, used in metal extraction.
- **Sulfur dioxide (**SO_2**)** – Acts as a reducing agent in various chemical reactions.
- **Iodide ions (**I^-**)** – Can reduce iron(III) (Fe^{3+}) to iron(II) (Fe^{2+}).
- **Tin (II) chloride (**$SnCl_2$**)** – Often used in analytical chemistry.
- **Ascorbic acid (Vitamin C)** – A mild reducing agent in biological and chemical processes.

Electrolysis

This is the decomposition of an ionic compound in molten or solution form into its constituent elements by electricity.

Note that

1. An electrolyte is an ionic substance that conducts electricity in solid of molten form.
2. Solid electrolyte do not conduct electricity because the ions cannot move because they are held together by strong ionic bonds.

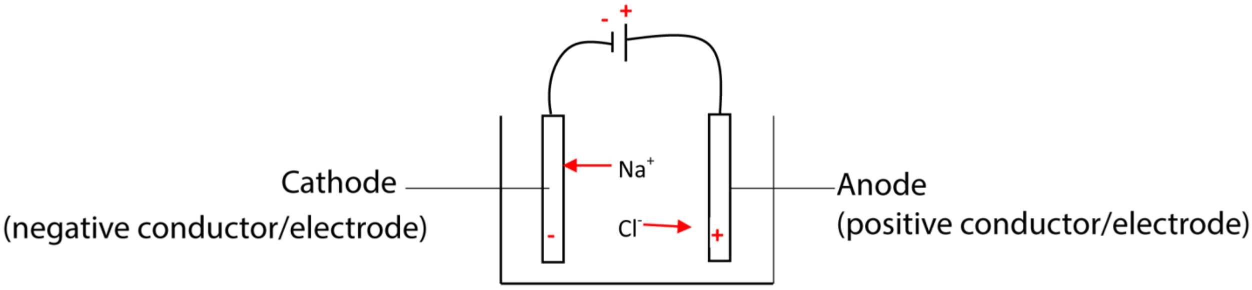
Mechanism of electrolysis

Consider electrolysis of molten sodium

In molten form sodium chloride ionizes as follows

$NaCl \rightarrow Na^+ + Cl^-$

In an electrolytic cell, unlike charges attract; Na^+ migrate to the cathode while Cl^- migrate to the anode.



At the cathode, Na^+ ion acquires an electron to become sodium atom.

$Na^+ + e \rightarrow Na$

At the anode the Cl^- loses and electron to form a Cl atom

$Cl- - e \rightarrow Cl$

The chlorine atoms combine to form chlorine a gas.

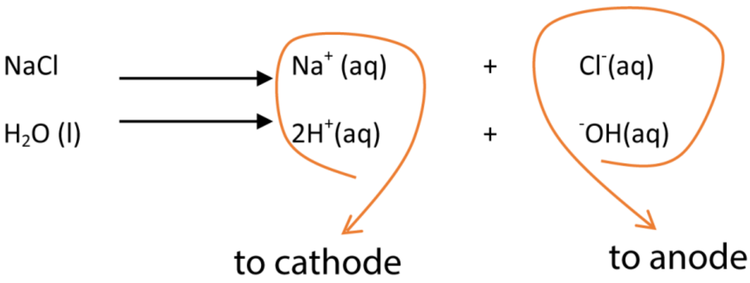
$Cl + Cl \rightarrow Cl_2$ (g)

Ultimately, sodium chloride in molten for is decomposed by electrolysis to sodium metaland chlorine gas.

Selective discharge

Consider electrolysis of sodium chloride solution

Both sodium chloride and water ionize to form ions



The positively charged ion migrate to the cathode while negatively charged ions migrate to the anode.

Factors that decide the ion to be eliminated or discharged first.

(i) Position in electro-chemical series:
Series for cations (high to low) K^+, Ca^{2+}, Na^+, Mg^{2+}, Al^{3+}, [C], Zn^{2+}, Fe^{2+}, Pb^{2+}, Cu^{2+}, Ag^+
Series for anions (high to low) SO_4^{2-}, NO_3^-, Cl^-, Br^-, I^-, -OH

The ion lower in electro-chemical series is discharged first. Consequently, during electrolysis of dilute sodium chloride, H^+ which is low in the reactivity series than Na^+ is discharged at the cathode whereas, ^-OH ions are discharged at the anode.

At the cathode

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

At the anode

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

(ii) Concentration:

When Cl^-, Br^- or I^- are concentrated, then they will be discharged with respect to ^-OH.

In this case electrolysis of concentrated sodium chloride solution liberates chlorine at the anode and hydrogen gas at the cathode (concentration does not affect Na^+)

At the cathode

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

At the anode

$2Cl^-\ (aq) - 2e \rightarrow Cl_2(g)$

(iii) Nature of electrode

(a) When mercury cathode is used Na^+ is discharged with preference to H^+. Therefore, electrolysis concentrated sodium chloride using mercury cathode liberate Na at the cathode and chlorine gas at the anode (due to high concentration of Cl^-).

At the cathode

$Na^+(aq) + e \rightarrow Na$

At the anode

$2Cl^-\ (aq) - 2e \rightarrow Cl_2(g)$

Application of electrolysis

1. Industrial preparation of gases; Cl_2, H_2 and O_2.
2. Extraction of metal: metals above carbon in the reactivity series are almost all extracted by electrolysis.

Example Extraction of sodium.

Ore: molten NaCl

Anode: iron cylinder is cheap and has a melting point above the melting point of NaCl.

Cathode: carbon because it does not react with chloride.

Calcium chloride added to the mixture to

- lower the melting point of sodium chloride from 800^0Cto 600^0C,
- reduce solubility of sodium in molten sodium chloride,
- Lower the corrosive vapor of sodium chloride.

Sodium is collected in dry nitrogen to protecting it from reacting with air.

At the cathode

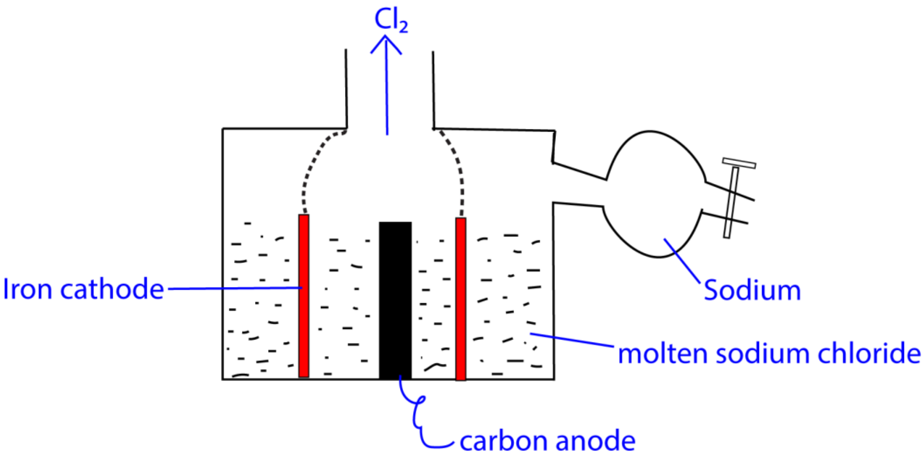
$Na^+ + e \rightarrow Na$

At the anode

$2Cl^- - 2e \rightarrow Cl_2(g)$

Setup

The setup is such chlorine produced in a different compartment not react with sodium



When sodium amalgam is dropped in water, sodium reacts to form sodium hydroxide and hydrogen gas.

$2Na + 2H_2O\ (l) \rightarrow 2NaOH\ (aq) + H_2(g)$

Sodium hydroxide is concentrated to form pellets.

Preparation of sodium hydroxide

By electrolysis of concentrated solution of sodium chloride using carbon anode and mercury cathode. At the anode chlorine is liberated and at mercury cathode Na^+ instead of H^+ is discharged and dissolved in mercury to form mercury amalgam.

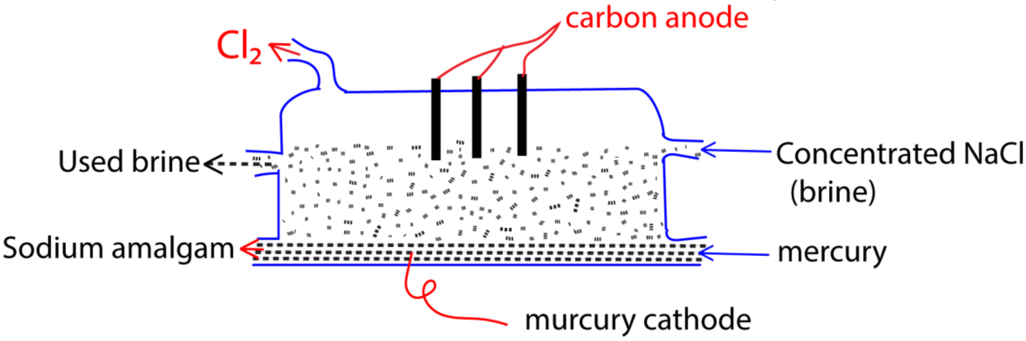
At the cathode

$Na^+ + e \rightarrow Na$

At the anode

$2Cl^- - 2e \rightarrow Cl_2(g)$

Set up for industrial preparation of sodium hydroxide



This process is disadvantageous because it releases poisonous mercury into the environment

Purification of copper

Anode: impure copper (dissolves)

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

Cathode (copper is deposited)

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

Electrolyte: copper sulphate solution

Copper migrated from the anode to the cathode.

Faraday's Laws of electrolysis

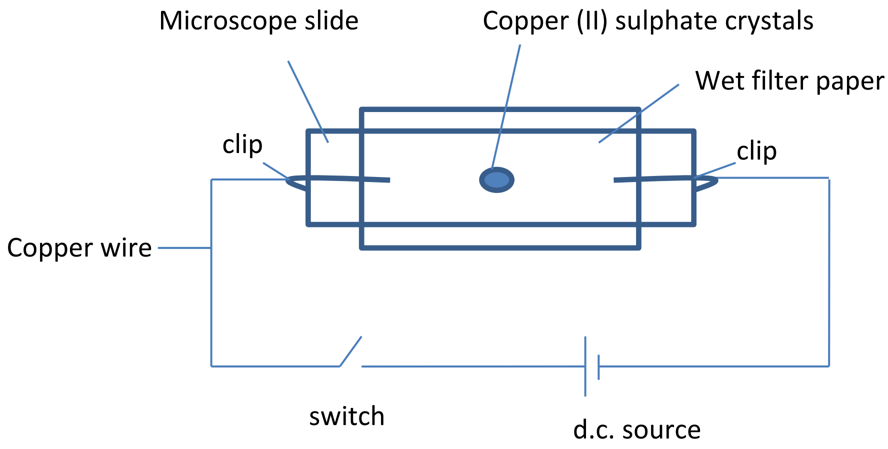
1. The mass of a substance liberated at an electrode is proportional to the quantity of electricity used.
   The quantity of electricity Q in coulombs = It
   (I = current of electricity in amperes, t = time in second)
2. The moles of electricity required to liberate one mole of an element is proportion to the charge on its ions. (1mol of electricity = 1Faraday = 1F = 96500 C)
   Example
   Calculate the mass of copper liberated by a current of 1A for 1hour. (Cu = 63.5)

   Quantity of electricity Q= It = 1 x (1 x 60 x 60) = 3600C
   $Cu\ (s) - 2e \rightarrow Cu^{2+}\ (aq)$

   It implies that (96500 x2) C is required to liberate 63.5 g of copper
   Therefore, 3600C will liberate $\frac{63.5\ x\ 3600}{2\ x\ 96500}$ = 1.18g

Revision questions

1. Dilute sulphuric acid was electrolyzed using carbon electrodes.
   (a) State was observed at the
      (i) Anode (1mrk)
      (ii) Cathode (1mark)
   (b) Write an equation for the reaction at the anode (2marks)
   (c) Dilute copper (II) was electrolyzed using copper electrodes. State what was observed at the anode (1mark)
2. (a) Both copper wire and copper (II) sulphate conduct electric current.
   Name the particles which conduct electricity current in
   (i) Copper wire
   (ii) Aqueous copper (II) ions
   (b) The set up apparatus in the diagram below was used to find out what happens when an electrolyte is connected to a source of electric current.



   State what was observed
   (i) When the switch was closed
   (ii) If copper sulphate crystal was replaced with potassium manganite (VII) crystal and the switch closed once again.
   (c) (i) Give a reason for the observation you have made in (b)(i) and (ii)
   (ii) State any general conclusion that can be drawn following the reason you have given in (c)(i).

3. An aqueous solution of potassium iodide was electrolyzed between carbon electrode
   (a) State what was observed at the anode
   (b) (i) Name the product formed at the anode
   (ii) Describe the test that can be carried out to identify the product at the cathode
   (c) Litmus paper was dropped into the solution around the cathode at the end of the experiment.
      (i) State what was observed
      (ii) Give a reason for your answer in (c)(i).
   (d) Draw a labelled diagram of a setup of an apparatus that can be used to prepare oxygen by electrolysis of water.

4. (a) State two factors that can determine the product formed at an electrode during electrolysis
   (b) Explain why aqueous solution of copper (II) chloride conducts electric current whereas solid copper (II) chloride does not.
   (c) a dilute solution of copper (II) chloride was electrolyzed using graphite electrodes
      (i) state what was observed at the cathode and write equation for the reaction that took place.
      (ii) Name the substance that was produced at the anode.
      (iii) Explain how the product you have named in (c)(ii) above is formed at the anode and write equation to illustrate your answer.
   (d)The electrolysis of copper (II) chloride was repeated using copper electrodes. State what was observed at the anode and briefly explain your answer.

5. (a) An aqueous solution of copper (II) sulphate was electrolyzed between graphite electrode.

   (i) state what was observed at the cathode

   (ii) write equation for the reaction that took place at the anode.

   (b) The solution that remained after electrolysis in (a) was tested with litmus solution

   (i) state what was observed

   (ii) Give a reason for your answer in (b)(i)

   (c) The electrolysis in (a) was repeated using copper electrode that had been weighed before the experiment. State the change in mass of the electrode that took place after electrolysis.

6. Acidified water was electrolyzed using platinum electrode

   (a) Write an equation for the reaction that took place at then

   (i) anode (1½ marks)

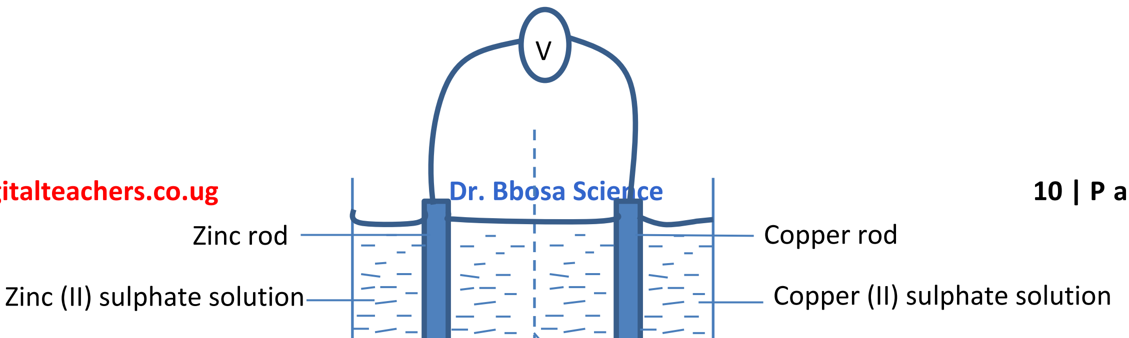
   (ii) cathode (1½ marks)

   (b) Name one other substance that can be used as electrode in the electrolysis of acidified water. (1marks)

7. (a) (i) using an example state the difference between an electrolyte and an electrode.(04marks)

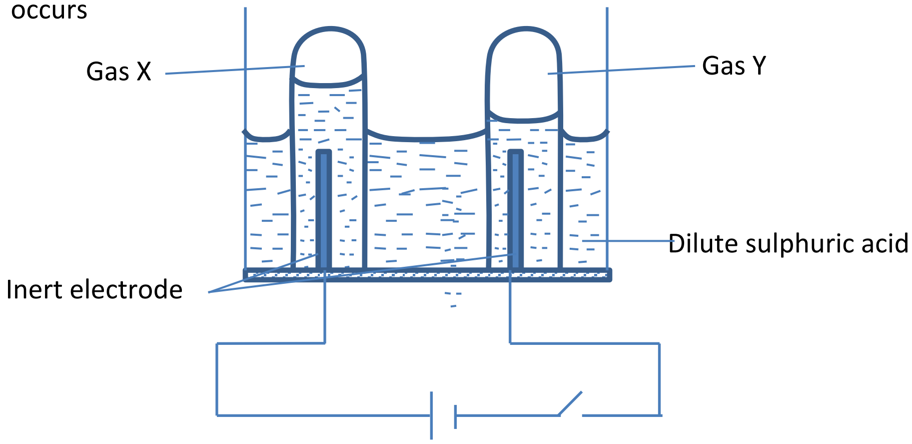
   (ii) Explain why aqueous solution of sodium chloride conducts electricity whereas solid sodium chloride does not. (02mark)

   (b) The diagram below shows a set-up of an electrochemical cell which can be used to compare the reactivity of zinc and copper.



(i) Identify the rod that is positively charged (01)
(ii) Identify R and state it purpose (1 ½ mark)
(iii) Write equation for the reaction taking place at the copper and zinc rods (03 marks)
(iv) Write equation for the overall reaction in the cell. (1 ½ marks)
(v) State what would happen if zinc metal is dropped in a solution containing copper (II) ions (02)

8. The diagram below shows an electrolytic cell in which electrolysis of dilute sulphuric acid occurs



(i) Name the gases X and Y that are evolved during electrolysis (02marks)
(ii) Give equation for the reaction occurring at the anode. (02marks)
(iii) Indicate the direction of electrons in the circuit. (01mark)
(iv) Calculate the volume of gas X produced when the current of one ampere flows for 10 minutes through the electrolyte. [1 faraday = 9.6×10^4 coulombs, I mole of a gas occupies 2.4×10^4 cm^3 at room temperature and pressure]
(v) State two industrial application of electrolysis other than manufacture of sodium hydroxide

(b) sodium hydroxide can be manufactured using a mercury cell. How would the manufacturing process affect the environment? (3 ½ marks)

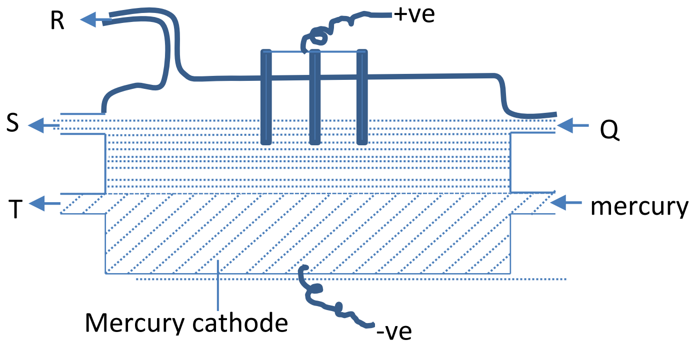
9. A notation for electromotive cell is given below

$Zn (s)/Zn^{2+}(aq)//Pb^{2+}(aq) /Pb(s)$

(a) Name two substance that can be used as electrolytes (2marks)
(b) State which of the electrode is the anode
(c) Write equation for the reaction at
   (i) The anode
   (ii) The cathode

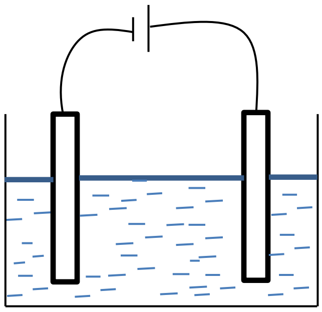
(d) Write the overall equation for the cell reaction

10. During the manufacture of sodium hydroxide, concentrated sodium chloride solution (brine)is electrolyzed using a mercury cathode as shown in the diagram below



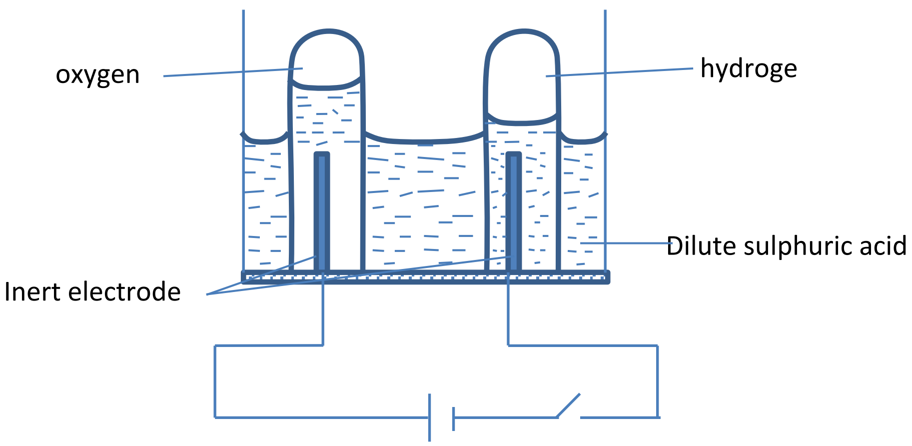
(a) Name the substance used as the anode
(b) Name the substance
    (i) Taken in at Q
    (ii) Taken out through R, S, T.
(c) Name one other substance formed during the manufacture of sodium hydroxide
(d) Describe briefly how solid sodium hydroxide can be obtained from the products of electrolysis.

11. The diagram below shows an arrangement of apparatus used for purification of copper



(a) Name the substance used as
    (i) Anode
    (ii) Cathode
    (iii) Electrolyte
(b) Write equation for the reaction that took place at
    (i) Anode
    (ii) cathode

Suggested answers

1.0	(a)	(i)	Colorless gas
		(ii)	colorless gas
	(b)		$4OH^-(aq)$ -4e ⟶ $2H_2O(l) + O_2(g)$
	(c)		Anode decrease in size
2	(a)	(i)	Electrons
		(ii)	Ions
	(b)	(i)	Blue color moves towards the cathode
		(ii)	Purple color moves towards the anode
	(c)	(i)	Blue Cu^{2+} migrate to the cathode
	(d)		During electrolysis cations migrate to the cathode whereas anions migrate to the anode
3.	(a)		Brown color
	(b)	(i)	Iodine
		(ii)	A blue color forms when a drop of iodine solution is added
	(c)	(i)	Color of litmus turns blue
		(ii)	Removal of hydrogen ion and iodide ion leaves an alkaline solution of KOH
	(d)		
4	(a)		- Position in the reactivity series - Concentration - Nature of electrode
	(b)		In aqueous solution copper (II) chloride ions are free to move whereas in in solid state ions do not move
	(c)	(i)	Brown coat formed on graphite

			Cu^{2+}(aq) + 2e $\longrightarrow$ Cu(s) (copper ions are lower than hydrogen ions in reactivity series)
		(ii)	oxygen
		(iii)	OH^- ions are lower than Cl^- in the reactivity series and is preferentially discharged $4OH^-$ (aq) -4e $\longrightarrow$ $2H_2O$ (l) + O_2(g)
	(d)		The anode decrease in size due to oxidation Cu(s) – 2e $\longrightarrow$ Cu^{2+}(aq)
5	(a)	(i)	Brown coat formed on graphite Cu^{2+}(aq) + 2e $\longrightarrow$ Cu(s) (copper ions are lower than hydrogen ions in reactivity series)
	(b)	(i)	Turned litmus solution red
		(ii)	Removal of copper ions from solution leaves acid H^+
	(c)		The anode decrease in size due to oxidation Cu(s) – 2e $\longrightarrow$ Cu^{2+}(aq) The cathode increase in size due to deposition Cu^{2+}(aq) +2e $\longrightarrow$ Cu(s)
6	(a)	(i)	Anode : $4OH^-$ (aq) -4e $\longrightarrow$ $2H_2O$ (l) + O_2(g)
		(ii)	Cathode: $2H^+$(aq) + 2e $\longrightarrow$ H_2(g)
	(b)		Graphite
7	(a)	(i)	An electrolyte is an ionic compoudnthat conducts electricity in solution of molten form while electrodes are conductors dissolved in electrolytic solution
		(ii)	Aqueous sodium chloride conducts electricity be cause it has free moving ions whereas solid sodium chloride has ion that do not move.
	(b)	(i)	Copper rod
		(ii)	R is porous partition that allow exchange of charges without mixing the solutions or completes the circuit
		(iii)	At zinc rod Zn – 2e $\longrightarrow$ Zn^{2+}(aq) Copper rod Cu^{2+}(aq) + 2e $\longrightarrow$ Cu(s)

		(iV)	Zn (s) + Cu^{2+}(aq) ⟶ Zn^{2+}(aq) + Cu(s)
8.	(a)	(i)	X= oxygen and Y = hydrogen
		(ii)	$4OH^-$ (aq) -4e ⟶ $2H_2O$ (l) + O_2(g)
		(iii)	From anode to cathode
		(iV)	Q = it = (1 x 10 x 60) = 600C (96000 x 4) produce 24000cm^3 of oxygen 600C produce $\frac{24000 \; x \; 600}{96000 \; x \; 4}$ = 37.5 cm^3
		(v)	Electoplating Extraction of metals Purification of copper
	(b)		Mercury when released in the environment is very poisonous, it accumulate through food chains
9	(a)		Zinc sulphate and copper sulphate
	(b)		The anod e is zinc
	(c)	(i)	Zn (s) – 2e ⟶ Zn^{2+}(aq)
		(ii)	Cu^{2+}(aq) + 2e ⟶ Cu(s)
		(iv)	Zn (s) + Cu^{2+}(aq) ⟶ Zn^{2+}(aq) + Cu(s)
10.	(a)		Carbon
	(b)	(i)	Brine/concentrated sodium chloride solution
		(ii)	R – chloride S- used brine T- sodium amalgam
	(c)		hydrogen
	(d)		Sodium amalgam is dissolve in water. Sodiun reacts with water to for sodium hydroxide and hydrogen 2Na (s) + $2H_2O$(l) ⟶ 2NaOH(aq) + H_2(g) Sodium hydroxide solution is concentrated by evaporation to formpellets.

11	(a)	(i)	Anode isImpure copper sulphate
		(ii)	Cathode is pure copper sulphate
	(b)	(i)	Cu (s) – 2e $\longrightarrow$ Cu^{2+}(aq)
		(ii)	Cu^{2+}(aq) + 2e $\longrightarrow$ Cu(s)

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Dr. Bbosa Science