A chemical reaction may be either accompanied by the evolution or the absorption of the heat energy. This, energy is expressed in the units of **Kilo-joules per mole**, which is written as **Kj/mole** or **Kjmole^{-1}.**

Bond Energy: Whenever a chemical reaction takes place, all the old bonds of the reactants are broken and the new bonds are formed between the newly formed productants. Thus, bond energy is defined as the energy required to break all the bonds present in one mole of a substance.

Or

The energy released in the formation of all the bonds in one molecule of a substance.

For example, the bond energy of H—H bond in hydrogen gas is 435.6 Kj/mole i.e 435.6 kj of heat energy is required to break all the H — H bonds in one mole of hydrogen gas or 435.6 Kj of heat energy is released when one mole of H— H bonds are formed between the free hydrogen atoms to give rise to one mole of hydrogen gas as shown under:

$$\underset{\text{Hydrogen mol.}}{H_2\,(g)} + 435.6\text{ Kj} \longrightarrow \underset{\text{Hydrogen atoms}}{2H\,(g)}$$

OR

$$\underset{\text{Hydrogen atoms}}{H\,(g) + H\,(g)} \longrightarrow \underset{\text{Hydrogen mol.}}{H_2} + 435.6\text{ Kj}$$

Types of Chemical Reactions: On the basis of energy changes, a chemical reaction can be grouped into two main categories, as explained under:

I) Exothermic Chemical Reaction: A chemical reaction accompanied by the evolution of heat energy is called as **Exothermic Chemical Reaction.** In these chemical reactions, the heat energy evolved in the formation of new bonds is more than the energy consumed in the breaking of old bonds.

Example: 1. When carbon is burnt in presence of air, carbon dioxide is formed and 395 Kj of heat energy is evolved as shown under:

$$\underset{\text{Carbon}}{C} + \underset{\text{air}}{O_2} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} + 395\text{ Kj}$$

2. When nitrogen combines with hydrogen to form ammonia at 450^0C and 500 atm. Pressure, 93.7 Kj of heat energy is evolved as shown under:

$$\underset{\text{Nitrogen}}{N_2} + \underset{\text{hydrogen}}{3H_2} \xrightarrow[500\text{ atm}]{450^0\text{ C}} \underset{\text{Ammonia}}{2NH_3} + 93.72\text{ Kj}$$

II) Endothermic Chemical Reaction: A chemical reaction accompanied with the absorption of heat energy is called as **Endothermic Chemical Reaction.** In these reactions, the energy evolved in the formation of new bonds is less than the energy required to break all the old bonds.

Example: 1. When nitrogen combines with oxygen to form nitric acid, heat energy of 180 Kj is absorbed as shown under:

$$\underset{\text{Nitrogen}}{N_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{nitric acid}}{2NO} - 180\text{ Kj}$$

2. When carbon reacts with sulphur to produce carbon sulphide, 10 Kj of heat energy is absorbed as shown under:

$$\underset{\text{carbon}}{C} + \underset{\text{sulphur}}{2S} \longrightarrow \underset{\text{carbon disulphide}}{CS_2} - 107\text{ Kj}$$

Heat of Chemical Reaction: The heat of a chemical reaction is defined as the energy absorbed or evolved during a chemical change represented by a chemical equation. For example, when two moles of hydrogen reacts with one mole of oxygen, two moles of water are formed and 483 Kj of heat energy is evolved as shown below:

$$\underset{\text{hydrogen}}{2H_2} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{water}}{2H_2O\,(l)} + 483\text{ Kj}$$

The heat of a reaction is expressed in the units of Kilo joules which iswritten as Kj.

Types of heat of a Chemical Reaction: The heat of a chemical reaction may be of the following types:

I) HEAT OF FORMATION: When a compound is formed during a chemical change, heat energy is either evolved or absorbed and the amount of heat energy evolved or absorbed during the formation of compound is called as the **heat of formation** of that compound. It is expressed in the units of **Kilo joules/mole.** For example,

a) Heat of formation of HCL molecule: When one mole of hydrogen gas combines with one mole of chlorine gas to form two molecules of hydrochloric acid, 184.7 Kj of heat is evolved as shown under:

$$\underset{\text{Hydrogen}}{H_2} + \underset{\text{chlorine}}{Cl_2} \longrightarrow \underset{\text{Hydrochloric acid}}{2HCl} + 184.7\ Kj$$

Thus, heat of formation of HCl is ½ (184.7) = 92.35 Kj/mole.

b) Heat of formation of H_2O molecule: When one mole of hydrogen gas combines with half a mole of oxygen, one mole of water is formed and 241.5 Kj of heat energy is evolved as shown under:

$$\underset{\text{Hydrogen}}{H_2\,(g)} + \underset{\text{oxygen}}{\tfrac{1}{2}O_2\,(g)} \longrightarrow \underset{\text{Water}}{H_2O\,(l)} + 241.5\ Kj$$

Thus, heat of formation of water is 241.5 Kj/mole.

c) Heat of formation of CO_2 molecule: When one mole of carbon combines with one mole of oxygen, one mole of carbon dioxide is formed and heat energy of 395 Kj is evolved as shown as under:

$$\underset{\text{Carbon}}{C\,(s)} + \underset{\text{oxygen}}{O_2\,(g)} \longrightarrow \underset{\text{carbon dioxide}}{CO_2\,(g)} + 395\ Kj$$

Thus, heat of formation of carbon dioxide is 395 Kj/mole.

d) Heat of formation of NH_3 molecule: When one mole of nitrogen gas combines with three moles of hydrogen gas, two moles of ammonia are formed and 92 Kj of heat energy is evolved as shown under:

$$\underset{\text{Nitrogen}}{N_2\,(g)} + \underset{\text{hydrogen}}{3H_2\,(g)} \longrightarrow \underset{\text{ammonia}}{2NH_3\,(g)} + 92\ Kj$$

Thus, heat of formation of ammonia is ½ (92) = 46 Kj/mole.

e) Heat of formation of CS_2 molecule: When one mole of carbon reacts with two moles of sulphur, one mole of carbon disulphide is formed and heat energy of 107 Kj is absorbed as shown under:

$$C\,(s) + 2S\,(s) \longrightarrow CS_2\,(l) - 107\ Kj$$

Thus, heat of formation of carbon disulphide is 107 Kj/mole.

II) HEAT OF COMBUSTION: Heat of combustion of a substance is defined as the amount of heat energy evolved when one mole of a substance is completely burnt. For example,

a) Heat of combustion of carbon: When one mole of carbon is completely burnt in presence of oxygen, heat energy of 395 Kj is evolved as shown under:

$$\underset{\text{Carbon}}{C\,(s)} + \underset{\text{oxygen}}{O_2\,(g)} \longrightarrow \underset{\text{carbon dioxide}}{CO_2\,(g)} + 395\ Kj$$

Thus, heat of formation of pure carbon is 395 Kj/mole.

b) Heat of combustion of methane: When one mole of methane is completely burnt in presence of oxygen, heat energy of 890 Kj is evolved out as shown under:

$$\underset{\text{Methane}}{CH_4\,(g)} + \underset{\text{oxygen}}{O_2\,(g)} \longrightarrow \underset{\text{carbon dioxide}}{CO_2\,(g)} + \underset{\text{water}}{H_2O\,(l)} + 890\ Kj$$

Thus, heat of combustion of methane is 890 Kj/mole.

PHOTOCHEMISTRY AND PHOTOCHEMICAL REACTIONS

Those chemical reactions which take place with the absorption or evolution of light energy are referred to as **photochemical reactions** and the study of photochemical reactions is known as **photo-chemistry.** In these reactions, light energy absorbed is used in breaking bonds of the reactant molecules to initiate the reaction. For example,

i) Photo-chemical combination of H_2 and Cl_2 molecules: The combination of hydrogen and chlorine molecules is a photochemical reaction. When a mixture of hydrogen and chlorine gas is exposed to sunlight, hydrochloric acid is formed, as shown under:

$$\underset{\text{Hydrogen}}{H_2\,(g)} + \underset{\text{chlorine}}{Cl_2\,(g)} \xrightarrow{\text{Sunlight}} \underset{\text{hydrochloric acid}}{2HCl\,(g)}$$

However, the reaction is completed in three steps as described under:

Step I: In the first step, chlorine gas molecule which is photo chemically active dissociates into two chlorine atoms, as shown under:

$$\underset{\text{Chlorine molecule}}{Cl_2} \xrightarrow{\text{light}} \underset{\text{chlorine atoms}}{2Cl}$$

Step II: In the second step, the highly reactive chlorine atom combines with a hydrogen molecule to form hydrogen chloride gas and free hydrogen atom, as shown under:

$$\underset{\text{Hydrogen}}{H_2} + \underset{\text{chlorine atom}}{Cl} \longrightarrow \underset{\text{hydrogen chloride}}{HCl} + \underset{\text{free Hyd. Atom}}{H}$$

Step III: In the third step, the highly reactive free hydrogen atom reacts with another molecule of chlorine gas to form hydrogen chloride molecule and free chlorine atom, as shown under:

$$\underset{\text{Hydrogen atom}}{H} + \underset{\text{chlorine}}{Cl_2} \longrightarrow \underset{\text{hydrogen chloride}}{HCl} + \underset{\text{free chl. Atom}}{Cl}$$

In this way, two hydrogen chloride molecules are formed by the photochemical combination of hydrogen and chlorine gas molecules.

b) Photosynthesis: The process in which green plants utilize inorganic compounds like water and carbon dioxide to synthesize energy rich complex organic molecules (carbohydrates) in presence of chlorophyll with the aid of sunlight is referred to as **photosynthesis.** It is a photochemical process and can be represented as under:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \longrightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

c) Photography: It is also a photochemical reaction. The photographic film used contains a photosensitive compound *silver bromide* coated on it. When the light reflected by the object fall on it, a photochemical reaction takes place in which silver bromide dissociates into silver particles and bromine as shown below:

$$\underset{\text{Silver bromide}}{AgBr} \xrightarrow{\text{Sunlight}} \underset{\text{silver particles}}{Ag} + \underset{\text{bromine}}{Br}$$

When this exposed film is developed in a laboratory, a photographic image of the object is obtained on the film which can be transferred on to a photographic paper to get a positive image of the object.

d) Photochemical pollution: Sometimes atmospheric pollution is caused by the photochemical reaction of the various gases emitted through industrial and automobile exhaust like SO_2 and NO_2. These gases absorb sunlight and produce highly reactive free radicals which react with other molecules present in the air and form various toxic compounds as explained under:

i) Pollution due to NO_2: The photochemical interaction of NO_2 in the atmosphere produces a highly noxious compound called nitric acid. The reaction takes place in the following steps:

Step I: When nitrogen dioxide molecule absorbs sunlight, it dissociates into nitric oxide and free oxygen atom.

$$\underset{\text{Nitrogen dioxide}}{NO_2} \xrightarrow{\text{Sunlight}} \underset{\text{nitric oxide}}{NO} + \underset{\text{free oxygen atom}}{(O)}$$

Step II: The highly reactive free oxygen atom combines with another molecule of nitrogen dioxide to form free nitrate radical.

$$\underset{\text{Nitrogen dioxide}}{NO_2} + \underset{\text{free oxygen atom}}{(O)} \longrightarrow \underset{\text{nitrate radical}}{NO_3}$$

Step III: The highly reactive nitrate radical combines with another molecule of nitrogen dioxide to form nitrogen penta-oxide molecule.

$$\underset{\text{Nitrogen trioxide}}{NO_3} + \underset{\text{nitrogen dioxide}}{NO_2} \longrightarrow \underset{\text{nitrogen pent-oxide}}{N_2O_5}$$

Step IV: Nitrogen penta-oxide molecule in the above reaction combines with water present in the atmosphere to form nitric acid.

$$\underset{\text{N-penta-oxide}}{N_2O_5} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{nitric acid}}{2HNO_3}$$

The nitric acid formed in this way combines with atmospheric water and comes down on to the earth in the form of acid rain and causes pollution.

ii) Pollution due to SO_2: The photochemical reaction of sulphur dioxide in the atmosphere produces a highly toxic substance called as sulphuric acid. The overall process and its formation can be summarized as under:

Step I: Photochemical dissociation of atmospheric sulphur dioxide into sulphur monoxide and oxygen:

$$SO_2 \xrightarrow{\text{light}} SO + (O)$$

Sulphur dioxide S. monoxide oxygen

Step II: Combination of sulphur dioxide molecule and oxygen atom to form sulphur trioxide molecule.

$$SO_2 + (O) \longrightarrow SO_3$$

Sulphur dioxide oxygen sulphur trioxide

Step III: Interaction of sulphur trioxide molecule with atmospheric water to form sulphuric acid.

$$SO_3 + H_2O \longrightarrow H_2SO_4$$

Sulphur trioxide water sulphuric acid

Sulphuric acid formed in this way fall on to the earth in the form of acid rain and causes pollution.

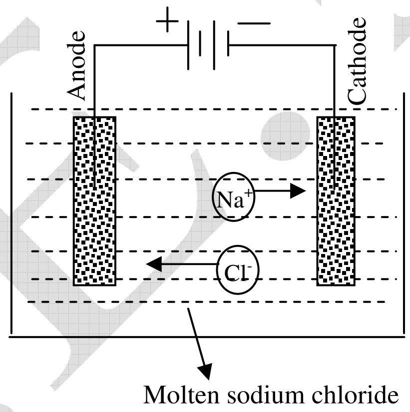
ELECTROCHEMISTRY & ELECTROCHEMICAL REACTIONS

Those chemical reactions which are brought about by the electrical energy or give rise to the production of the electrical energy are referred to as **electrochemical reactions** and the branch of chemistry which deals with the study of the electrochemical reactions is referred to as **electrochemistry**. For example,

i) Electrolysis: A substance which conducts electricity when dissolved in water (molten state) is known as **electrolyte,** and the decomposition of electrolyte by the action of electric current is referred to as **electrolysis.** For example,

Electrolysis of Molten Sodium Chloride (NaCl):

When an electric current is passed through molten sodium chloride, it dissociates into Na^+ and Cl^- ions. The Na^+ ion moves towards the cathode, where they gain electrons to rise to neutral sodium atoms. However, the Cl^- ions move towards the anode, where they loose electrons to form neutral chlorine atoms. In this way, the electrolysis of the molten sodium chloride produces metal sodium and chlorine gas. The overall reaction can be summarized as under:



$$NaCl \xrightarrow{\text{Electrolysis}} Na^+ + Cl^-$$

Molten sodium chloride sodium ion chlorine ion

Reaction at cathode: $Na^+ + e^- \longrightarrow Na$

Sodium ion electron sodium atom

Reaction at anode: $Cl^- - e^- \longrightarrow Cl$

Chlorine ion electron chlorine atom

Thus, the overall reaction can be represented as under:

$$\mathbf{Na^+ + Cl^- \longrightarrow Na + \tfrac{1}{2} Cl_2}$$

(From molten sodium chloride) metal sodium chlorine gas

ii) Electroplating: It is a process of depositing a thin layer of metal over the surface of another metal with the help of electric current mainly for its decoration or protection against rusting etc. The method is based on the following principles:

1. The metal to be electroplated is made negative electrode (cathode) by connecting it to the negative terminal of a battery.
2. The metal to be deposited is made positive electrode (anode) by connecting it to the positive terminal of the battery.
3. A water soluble salt of the metal (salt-solution) to be deposited is taken as electrolyte.

However, on passing the electric current through the solution metal from anode gets dissolved into the solution and then deposited as a thin layer on the cathode.

iii) Electro Refining: The process of purifying or refining metals such as zinc, copper, aluminum etc with the help of electric current is referred as **electro refining.** The method is based on the following principles:

a) A thick block of the impure metal to be purified is made positive electrode (anode) by connecting it to the positive terminal of a battery.
b) A thin strip of the pure metal is made negative electrode (cathode) by connecting it to the negative terminal of a battery.
c) A water-soluble salt of the metal (salt solution) to be refined or purified is taken as electrolyte. However, on passing the electric current through the solution, the impure metal from anode gets dissolved into the solution and then gets deposited on the cathode in the pure form, while the impurities settle down at the anode as anode mud.

FARADAY'S LAWS OF ELECTROLYSIS: Regarding electrolysis, Faraday enunciated two laws known as Faraday's Laws of Electrolysis. These laws are:

First Law: This law states that "The mass of a substance produced during electrolysis is directly proportional to the quantity of electrolysis passed". i.e.

One faraday of electricity produces one mole of a substance.
Two faraday of electricity produces two moles of a substance.
Three faraday of electricity produces three moles of a substance.

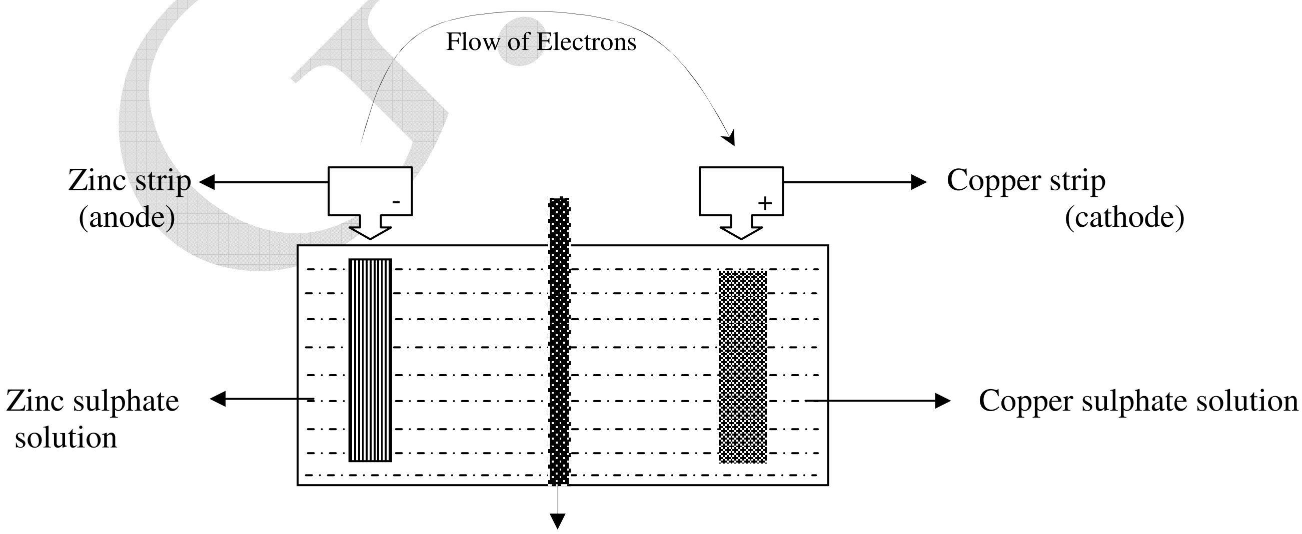
Second Law: This law states that "The number of faradays required to discharge one mole of an ion during electrolysis is equal to the number of charges on that ion". i.e.

One mole of a single charged ion will require one faraday to get discharged.
One mole of a double charged ion will require two faradays to get discharged.
One mole of a triple charged ion will require three faradays to get discharged.

ELECTRO CHEMICAL CELL: An Electro Chemical Cell is a device used to produce electric durrent from spontaneous chemical reaction i.e. to convert chemical energy into electrical energy. The first electro chemical cell was designed by *Galvani* and *A.Volta* independently at the same time in 1796, thus it is also known as a *Galvanic or Voltaic cell.*

Principle of an Electro Chemical Cell: An Electro Chemical Cell works on the principle of spontaneous oxidation-reduction reaction involving transfer of electrons from the oxidized substance to the reduced substance through a wire constituting electric current in the circuit.

Construction of an Electro Chemical Cell: A simple zinc-copper Electro Chemical Cell consists of a strip of a metal zinc dipped in a zinc sulphate solution and a strip of metal copper dipped in a copper sulphate solution. The two solutions are separated by a porous partition, which is permeable to the ions, but it prevents the two solutions from mixing into one another. The zinc strip is connected to the negative terminal of a battery so that it acts as a cathode and a copper strip is connected to the positive terminal so that it acts as an anode of the Electro Chemical Cell as shown under in the diagram.



Working of an Electro Chemical Cell: When two electrodes are connected by an external circuit (wire), an electric current starts flowing in the external circuit as described under:

i) As metal zinc is more reactive than metal copper, so zinc atoms give out electrons easily and get oxidized to zinc ions, as shown under in the reaction:

$$\underset{\text{Zinc metal}}{Zn} \xrightarrow{\text{Oxidation}} \underset{\text{zinc ion}}{Zn^{2+}} + \underset{\text{free electrons}}{2e^-}$$

These electrons get accumulated on the zinc electrode and imparts a negative charge to it, but due to the higher concentration these electrons flow through the external circuit towards the copper anode constituting electric current in the external circuit.

ii) When the electrons reach the copper anode, the positively charged copper ions from the copper sulphate solution are attracted towards the anode. The copper ions accept the free electrons flowing through the external circuit and get reduced to copper atoms as shown below:

$$\underset{\text{Copper ion}}{Cu^{2+}} + \underset{\text{free electrons}}{2e^-} \xrightarrow{\text{Reduction}} \underset{\text{copper atom}}{Cu}$$

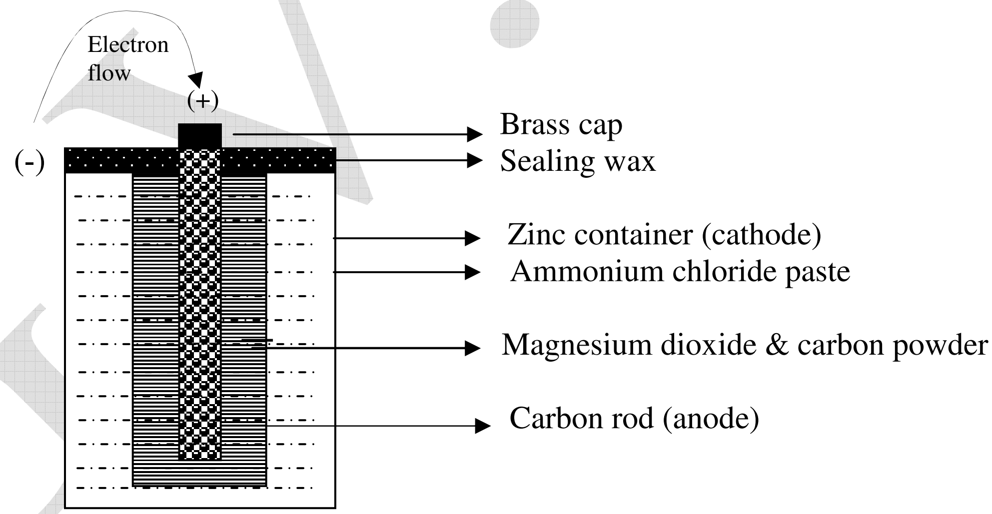
The overall reaction taking place in a zinc copper electro chemical cell can be summarized as under:

$$\underset{\text{Metal zinc}}{Zn\,(s)} + \underset{\text{copper ions}}{Cu^{2+}\,(aq.)} \longrightarrow \underset{\text{metal zinc}}{Zn^{2+}\,(aq.)} + \underset{\text{copper ions}}{Cu\,(s)}$$

A zinc-copper electrochemical cell produces a potential difference of about 1.1 volts, however, by making a combination of different metals, the production can be changed.

DRY CELL: A dry cell is a device which converts chemical energy into electric energy. The first cell of this type was designed by *Lechlanche* in 1868.

Construction of a Dry Cell: A Dry Cell consists of a carbon rod fitted in the centre of a zinc container. The carbon rod is surrounded by a mixture of manganese dioxide and powdered carbon. Rest of the empty space of the zinc container is filled with a moist paste of ammonium chloride. In this arrangement, the centrally located carbon rod acts as anode (positive electrode) and the zinc container as cathode (negative electrode), while the paste of ammonium chloride acts as the electrolyte. To facilitate momentum of the ions, a small amount of water is added to it and the top of the container is closed with the sealing wax. The carbon rod extending beyond the wax is covered with a brass cap for better contact. The container is insulated externally with a card board case or a paint.



A Dry Cell

Working of Dry Cell: The working of a Dry Cell is based on the spontaneous oxidation-reduction reaction involving transfer of electrons from the zinc container (cathode) to the magnesium dioxide through the circuit as explained under:

i) When an external circuit is provided to the cell by connecting the anode to the cathode with a conducting wire. The zinc atoms give out electrons and get oxidized to zinc ions. These electrons starts flowing through the wire towards the anode and constitute the electric current in the external circuit, as shown under:

$$\underset{\text{Zinc metal}}{Zn} \xrightarrow{\text{Oxidation}} \underset{\text{zinc ion}}{Zn^{2+}} + \underset{\text{free electrons}}{2e^-}$$

ii) When the electrons flowing through the external circuit reach the carbon anode, they reduce the manganese dioxide (manganese-IV oxide) to manganese-III oxide in presence of ammonia chloride. This

Reduction

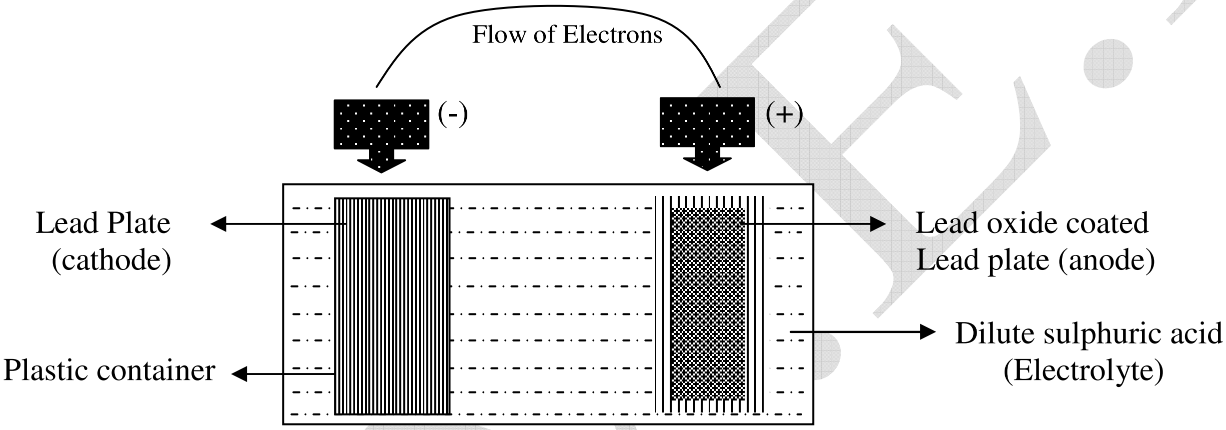
oxidation-reduction reaction continues and provide continous supply of electrons constituting the electric current in the external circuit.

$$\underset{\text{Mag. IV dioxide}}{2MnO_2} + \underset{\text{ammonium ions}}{2NH^{+4}} + 2e^- \longrightarrow \underset{\text{Mag. III oxide}}{Mn_2O_3} + \underset{\text{ammonia}}{2NH_3} + \underset{\text{water}}{H_2O}$$

In this way, the oxidation of zinc and reduction of manganese dioxide provides a continous supply of about 1.5 volts from a dry cell.

LEAD STORAGE CELL: Unlike to dry cells, which possesses a single life, there are cells which can be recharged again and again and used as a source of electric current. These are called storage cells or rechargeable cells. The most important rechargeable or storage cell is lead storage cell.

Construction of a Lead Storage Cell: A typical lead storage cell consists of two electrodes suspended in sulphuric acid kept in a plastic container. One of the two electrodes comprises of a lead plate, which acts as a cathode and the other of the lead dioxide coated on a lead plate acts as anode of the cell. The inside of the cell is filled with dilute sulphuric acid acting as electrolyte of the cell. This type of arrangement of two electrodes produces electric current of two volts only. Thus an actual lead storage cell consists of a series of plates fixed alternatively so to produce a current of about 12 volts.



Working of a Lead Storage Cell: The working of lead storage cell is based on the spontaneous oxidation-reduction which involves transfer of electrons from lead cathode to lead dioxide anode, through the external circuit as explained under:

i) When the two electrodes are connected by external circuit, the atoms of the lead cathode get oxidezed and give out electrons which flow through the circuit and constitute the electric current.

$$\underset{\substack{\text{Lead atom}\\ \text{(from cathode)}}}{Pb} + \underset{\substack{\text{Sulphate ions}\\ \text{(From anode)}}}{SO_4^{2-}} \xrightarrow{\text{Reduction}} \underset{\substack{\text{lead sulphate}\\ \text{(White ppt.)}}}{Pb\,SO_4} + \underset{\text{free electrons}}{2e^-}$$

The oxidized lead atoms or lead sulphate forms a white precipitate which sticks to the anode.

ii) When the electrons released at the cathode flow through the external circuit and reach on to the anode, they reduce lead dioxide to lead sulphate (a white ppt.) which sticks to the anode.

$$\underset{\substack{\text{Lead dioxide}\\ \text{(From anode)}}}{PbO_2} + \underbrace{4H^+ + SO_4^{2-}}_{\substack{\text{(Hydrogen and sulphate ions)}\\ \text{(From sulphuric acid)}}} + 2e^- \longrightarrow \underset{\substack{\text{lead sulphate}\\ \text{(white ppt.)}}}{PbSO_4} + 2H_2O$$

In this process or reduction, sulphuric acid is used up and water is formed due to which concentration of the sulphuric acid decreases during the discharge process and it gets diluted more. When the cell is used, both the electrodes get coated with lead sulphate ppt. and, the cell is said to be discharged as it stops giving out current. At this stage, the cell needs to be recharged, so that it is ready to be used once more.

Recharging of a Lead Storage Cell: In the discharged condition, both the electrodes of a lead storage cell consists of lead sulphate and the electrolyte is more dilute due to the addition of water to it. Thus an external source of electric current is connected to it, in the opposite direction to that of the discharging current. This electric current reversal of the oxidation-reduction reaction at the two electrodes and restores their original conditions. Infact, when the direct current is passed through the discharged battery, the lead sulphate deposited on the electrodes (cathode) is reduced back to the metallic lead.

Electric
current

$$\underset{\text{Lead sulphate}}{PbSO_4} + 2e^- \longrightarrow \underset{\text{metal lead}}{Pb} + \underset{\text{sulphate}}{SO_4^{2-}}$$

However, the lead sulphate deposited at the anode in oxidized back to lead dioxide.

$$PbSO_4 + 2H_2O \xrightarrow[\text{current}]{\text{Electric}} PbO_2 + 4H^+ + SO_4^{2-} + 2e^-$$

When whole of the lead sulphate is connected into metallic lead at cathode and lead dioxide at anode, the original charged condition of the battery is ready to produce electric current once again.

However, the overall oxidation-reduction reaction taking place in the lead storage cell during the discharging and charging phases is given as:

$$Pb + PbO_2 + 2H_2SO_4 \underset{\text{Discharging}}{\overset{\text{Charging}}{\rightleftarrows}} 2PbSO_4 + H_2O$$

CORROSION OF METALS: When a metal is exposed to air containing water vapour, its upper surface gets peeled off as a result of corrosion and the metal is gradually eaten up. This process of slow destruction of metals as a result of oxidation reaction with the air and moisture of the atmosphere is referred to as **corrosion of metals.** The corrosion of metals involves transfer of electrons from the metal to the oxygen through water, due to which the metallic surface forms a mixture of metallic oxide and metallic hydroxide leading to the corrosion of the metals as explained under:

When a metallic surface comes in contact with air and moisture, the metal (say iron) loses electrons and get oxidized to iron III ions, as shown under:

$$\underset{\text{Iron atom}}{Fe} \xrightarrow{\text{Oxidation}} \underset{\text{iron III ion}}{Fe^{3+}} + 3e^-$$

The oxygen gas takes these electrons and get reduced to oxide ion, as shown under:

$$\underset{\text{Oxygen}}{O_2} + 2e^- \xrightarrow{\text{Reduction}} \underset{\text{oxide ion}}{2O^{2-}}$$

When the iron III ion and oxide ion combine together, iron III oxide is formed, as shown under:

$$\underset{\text{iron III ion}}{2Fe^{3+}} + 3O2^- \longrightarrow \underset{\text{iron III oxide}}{Fe_2O_3}$$

However, the iron III ion also reacts with hydroxide ions of the moisture (water) of the air and forms iron III hydroxide.

$$\underset{\text{Iron III ion}}{Fe^{3+}} + \underset{\text{hydroxide ion}}{3OH^-} \longrightarrow \underset{\text{iron III hydroxide}}{Fe(OH)_3}$$

Conditions necessary for Corrosion: The corrosion of metals is an oxidation process and requires following two conditions:

1. Presence of oxygen in the air. 2. Presence of moisture or water in the air.

However, the rate of corrosion increases if two metals are in contact with each other and the air presence in the atmosphere of these metals is polluted with acidic gases like sulphur dioxide, nitrogen dioxide and carbon dioxide.

Prevention of Corrosion: The process of corrosion can be prevented by the following precautionary measures:

1. By coating the surface of a metal with a protective layer of paint, varnish or grease.
2. By coating a thick layer of corrosion resistant metals like Zinc, tin or chromium.
3. By applying a thin layer of oil over the surface of the metal.
4. By alloying the metal with other metals like chromium and nickel.

Corrosion of Iron or :**Rusting":** When a piece of iron is exposed to moist air or kept in water, it gets covered by a layer of reddish brown substance called as **rust** and the process is referred to as **rusting of iron** or simply **rusting.** Rust is formed by the action of oxygen and water on iron, and is a mixture of iron oxide (Fe_2O_3) and iron hydroxide [$Fe(OH)_3$], as shown under:

$$\underset{\text{iron}}{4Fe} + \underset{\text{oxygen}}{3O_2} + \underset{\text{water}}{3H_2O} \longrightarrow \underbrace{Fe_2O_3 + 2Fe(OH)_3}_{\text{rust}}$$

Thus, rusting of iron is an oxidation process in which metal iron is oxidized to form iron oxide and iron hydroxide when it exposed to the moist air. The rust is soft and porous. It gradually falls off from the surface of iron and then the air surface below it starts rusting due to which an object of iron loses its strength.

Prevention of Rusting: The only way to prevent rusting of iron is to keep air and water away. This can be done as follows:

1. Rusting of iron can be prevented, by covering its surface with paint, varnish, grease, enamel etc.

2. Rusting of iron can be prevented by galvanization i.e. by depositing a thin coating of metal zinc over its surface.
3. Rusting of iron can be prevented by coating its surface with corrosion resistant metals like tin, nickel, chromium and aluminum.
4. Rusting of iron can be prevented by alloying metals like chromium and nickel, so as to get stainless steel, which is highly corrosion resistant.
5. Rusting of iron can be prevented by coating its surface with iron II, III oxide or by a phosphate.

TEXTUAL QUESTIONS:

Ans 1. Here atomic no. of carbon = 12 a.m.u

So, 12 gms of carbon = 1 mole of carbon

Given that heat of combustion of carbon = 395 Kj/mole

Thus, oxidation of 12 gms of carbon gives heat energy of 395 Kj.

So, heat energy liberated by 0.1 Kj or 100 gms = $\frac{395}{12}$ x 100 Kj = 32916 Kj

Ans 2. Heat liberated by the combustion of 1 Kg of carbon = 329.16 Kj

= 329.16 x 1000 joules

= $\frac{329.16 \times 1000}{4184}$ calories

= 7874.65 calories

Now heat liberated = Q calories

Mass of water = m = 15 Kg = 15000 gms

Specific heat of water = S = 1 Cal/^{0} C

Since, Q = m x S x t

7874.65 = 15000 x 1 x t

t = 525^0C

Therefore, final temperature = 25 + 525 ^{0}C = 550^0 C

Ans 3. When metal mercury combines with oxygen, mercuric oxide is formed as shown under:

$$2Hg + O_2 \longrightarrow 2HgO + 180\ Kj\ \text{[elolved]}$$

Since, 2 moles of HgO are formed, so heat of formation of HgO = ½ (180) Kj = 90 Kj/mole. So the equation for the formation of HgO can be represented as:

$$Hg + \tfrac{1}{2}(O_2) \longrightarrow HgO + 90\ Kj$$

Ans 4. **(i)** Here atomic no. of Hg = 200

So, 1 mole of Hg = 200 gms

Molecular mass of HgO = 200 + 16 = 216

Therefore, 1 mole of HgO = 216 gms

Thus, the above equation can be shown as:

$$\underset{\text{(432 gms)}}{2HgO} + 180\ Kj \longrightarrow \underset{\text{(400 gms)}}{2Hg} + O_2$$

From the above equation, we have

To decompose 432 gms of HgO, heat required = 180 Kj

So, to decompose 54 gms of HgO, heat required = (180/432) x 54 = 22.5 Kj

(ii) Also decomposition of 432 gms of HgO gives 400 gms of Hg

So, decomposition of 54 gms of HgO gives (400/432) x 54 = 50 gms of Hg

Ans 5. **(i)** For the sugar, we have

Heat of combustion of sugar = 2825 Kj/mole

Since, molecular mass of $C_6H_{12}O_6$ = 6 x 12 + 12 x 1 + 6 x 16 = 180 gms

Therefore, mass of 1 mole of sugar = 180 gms

Thus, complete combustion of 180 gms (1mole) of sugar yields heat energy = 2825 Kj

So, complete combustion of 1 gm of sugar will produce 2825/180 = 15.7 Kj

(ii) Now, for cyclohexane, we have,

Given that heat of combustion of cyclohexane = 3950 Kj

Since, molecular mass of C_6H_{12} = 6 x 12 + 1 x 12 = 84 gms

Thus, complete combustion of 84 gms (1mole) of cyclohexane yields heat energy = 3950 Kj
So, complete combustion of 1 gm of cyclohexane will produce = 3950/84 = 47 Kj
Thus, from the above calculation, it is clear that 1 gm of cyclohexane produces more energy than 1 gm of sugar.

Ans 6. Fat would give more energy to the body, because the heat of combustion of cyclohexane related to fat is more than the heat of combustion of sugar related to fat.

Ans 7. Since, copper atom releases two electrons to form carbon ions.

$$\underset{\text{1 mole (63.5gms)}}{Cu} \longrightarrow Cu^{++} + \underset{\text{2 moles (2 Faradays)}}{2e^-}$$

Thus, 63.5 gms of carbon metal releses electricity = 2 Faradays.

So, 12.91 gms will release = $\frac{63.5 \times 12.91}{2}$ = 0.406 Faradays

Ans 8. **(i)** Since, quantity of electricity = I x t
Here, I = 16 ampere, t = 100.5 min.
Therefore, quantity of electricity passed = 16 x 100.5 x 60 sec. = 96480 = (say 96500 columbs)

(ii) The reaction of formation of metal sodium during electrolysis of sodium chloride can be given:

$$\underset{\text{1 mole}}{Na^+} + \underset{\substack{\text{1 mole} \\ \text{(1F=96500C)}}}{e^-} \longrightarrow \underset{\text{23 grams}}{Na}$$

Thus, on passing 96500 C of current, 23 grams of metal sodium will be obtained.

Ans 9. The first reaction can be written as:

$$Zn \longrightarrow Zn^{2+} + 2e^- + 0.76\ V \text{ ---------------(i)}$$

And the second reaction as,

$$Cu + 0.34\ V \longrightarrow Cu^{2+} + 2e^-$$

If we reverse this reaction, it is clear that 0.34 volts of electricity will be produced. i.e.

$$Cu^{2+} + 2e^- \longrightarrow Cu + 0.34\ V \text{ ---------------(ii)}$$

Adding equation (i) and (ii), we have,

$$Zn + Cu^{2+} + 2e^- \longrightarrow Zn^{2+} + 2e^- + 0.76\ V + 0.34\ V$$

We get,

$$Zn + Cu^{2+} \longrightarrow Zn^{2+} + Cu + 1010\ V$$

Thus, the total electricity produced will be 1.10 Volts.