Chapter 7

ELECTROCHEMISTRY

Time Allocation

Teaching periods	= 12
Assessment period	= 3
Weightage	= 12

Major Concepts

7.1 Oxidation and Reduction

7.2 Electrochemical Cells

7.3 Corrosion and its Prevention

7.4 Alloy Formation

STUDENTS LEARNING OUT COMES (SLO'S)

Students will be able to:

- Define oxidation and reduction in terms of loss or gain of oxygen or hydrogen. .
- Explain oxidation and reduction in terms of loss or gain of electrons.
- Describe the nature of electrochemical processes.
- Sketch an electrolytic cell, label the cathode and the anode.
- Identify the direction of movement of cations and anions towards respective electrodes. .
- List the possible uses of an electrolytic cell.
- Sketch a Danniell cell, labeling the cathode, the anode, and the direction of flow of the electrons.
- Distinguish between electrolytic and Galvanic cells.
- Define corrosion.
- Describe rusting of iron as an example of corrosion.
- Summarize the methods used to prevent corrosion.
- Explain electroplating of metals on steel (using examples of zinc, Tin and chromium plating).
- Describe how a battery produces electrical energy.

INTRODUCTION:

In our daily life we use digital watches, calculators, cars and mobile phones powered by batteries or dry cells.

Extraction of metals like aluminum, copper and electro plating of metals are few applications of electrochemistry. It can be defined as the branch of chemistry which deals with electro chemical reactions, electrolyte and electrochemical cells is called electrochemistry.

"or" It deals with the conversion of electrical energy into chemical energy and chemical energy into electrical energy.

7.1 OXIDATION AND REDUCTION REACTIONS:-

The chemical reactions in which chemical energy changes into electrical energy or Vice Versa are called electrochemical reactions.

Oxidation may involve introduction of oxygen or removal of Hydrogen from a chemical substance.

Example:

$$C + O_2 \longrightarrow CO_2 \text{ (burning of coal)}$$

$$2C_8H_{18} + 25\,O_2 \longrightarrow 16\,CO_2 + 18\,H_2O \text{ (combustion of octane)}$$

$$N_2H_4 + O_2 \longrightarrow N_2 + 2H_2O \text{ (removal of Hydrogen from Hydrazine)}$$

Similarly, reduction may involve addition of Hydrogen or removal of oxygen from a chemical substance.

Example:

$$CuO + C \longrightarrow Cu + CO \quad \text{(reduction of copper oxide)}$$

$$CH_2 = CH_2 + H_2 \xrightarrow[(200^\circ C)]{Ni} CH_3 - CH_3 \quad \text{(Reduction of ethene)}$$

$$Fe_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Fe + \text{Heat} \quad \text{(Reduction of Iron oxide)}$$

Oxidation and reduction reactions are electrochemical reactions. In electrochemistry oxidation and reduction reactions involve transfer of electrons.

The electrochemical reaction in which atom molecule or ion loses electron and its oxidation number increases is called oxidation reaction.

Example: $Cu \longrightarrow Cu^{++} + 2\dot{e}$ (Oxidation)

The electrochemical reaction in which atoms, molecule or ion accepts electron and its oxidation number decreases is called reduction reaction.

Example: $S + 2\dot{e} \longrightarrow S^{2-}$ (Reduction reaction)

Oxidation and reduction reactions can be summarized as

Table 7.1

Oxidation	Reduction
Addition of Oxygen	Addition of Hydrogen
Removal of Hydrogen	Removal of Oxygen
Loss of electron by a substance	Gain of electrons by a substance
Increase in oxidation number of a substance	Decreases in oxidation number of a substance

Oxidizing and Reducing Agents:-

Oxidation occurs due to oxidizing agent and reducing agent is responsible for reduction. Oxidizing agents are substances that accept electrons. Similarly reducing agents are substances which lose electrons.

Do You Know?

Photosynthesis is an example of redox reaction.

Photosynthesis produces glucose.

$6CO_2 + 6H_2O + \text{sun light} \longrightarrow C_6H_{12}O_6 + 6O_2$

Water (H_2O) under goes oxidation by losing electrons and form hydrogen ions. Carbon dioxide (CO_2) accept electrons and hydrogen ions to form glucose ($C_6H_{12}O_6$)

Example: $Zn + Cl_2 \longrightarrow ZnCl_2$

Zinc undergoes oxidation by losing electrons and it act as reducing agent while chlorine undergoes reduction by accepting electrons and act as oxidizing agent. A table of oxidizing agents and reducing agents is given below.

Table 7.2

Oxidizing Agent	Reducing Agent
H_2SO_4, HNO_3, $KMnO_4$, $K_2Cr_2O_7$, Cl_2, Br_2, I_2 etc.	Alkali metals, Al, H_2S, Zn, NaH, KH etc.

Test Yourself

- Identify the oxidizing and reducing agents from the following.
  1. Al 2. Na 3. H_2S 4. H_2SO_4 5. $KMnO_4$ 6. Zn
- Identify the oxidizing and reducing agents for the following reaction.

$H_2 + Cl_2 \longrightarrow 2HCl$

7.2 ELECTROCHEMICAL CELLS:

The device which convert chemical energy into electrical energy or vise versa using redox reaction are called electrochemical cells.

The electrochemical reactions are carried out in electrochemical cells. It consists of two electrodes at which redox reaction occurs. The electrode at which oxidation takes place is called Anode and electrode at which reduction occurs is called Cathode. The reactions occurs at each electrode is called half cell reaction. The overall cell reaction is the combination of two half cell reactions. Each electrode is in contact with battery and electrolyte present in cell. Electrochemical cells are of two types.

(1) Electrolytic Cells **(2) Galvanic Cells or Voltaic Cells**

7.2.1 Concepts of Electrolyte:

An electrolyte consists of free moving ions and conduct electricity. Acids, bases and salts in molten or in aqueous solution form are electrolytes. Some strong and weak electrolytes are shown below in table 7.3.

Table 7.3

	Strong Electrolyte	Weak Electrolyte
Acids	HCl, HNO_3, HI, H_2SO_4	H_2S, H_2CO_3, CH_3COOH
Bases	KOH, $NaOH$, $LiOH$	NH_4OH, $Ca(OH)_2$, $Mg(OH)_2$
Salts	KI, $NaCl$, $CuSO_4$	PbI, $KHCO_3$, $AgCl$

The substances which are unable to conduct electricity in molten state or in aqueous solution form are called non electrolytes.

Example: Benzene, Glucose, Sucrose and Urea etc are non- electrolytes.

Test Yourself

- Define electrolyte?
- What are strong electrolytes?
- What are non-electrolytes?
- Identify strong and weak electrolytes from the following

  1. $HCl_{(aq)}$, 2. $KI_{(aq)}$, 3. $NaOH_{(aq)}$, 4. $H_2S_{(aq)}$, 5. $CH_3COOH_{(aq)}$, 6. $NH_4OH_{(aq)}$

7.2.2 Electrolytic cells and Electrolysis:-

The electrolysis involves redox reactions and carried out in electrolytic cell. In electrolysis current passes through an electrolyte, due to this migration of positive and negative ions towards cathode and anode takes place. As a result of redox reaction ions are discharged at their respective electrodes.

The type of cell which uses electricity for a non spontaneous reaction to occur is called electrolytic cell.

An electrolytic cell consists of electrolyte in a vessel, electrodes and a battery.

The diagram of an electrolytic cell is shown in figure 7.1.

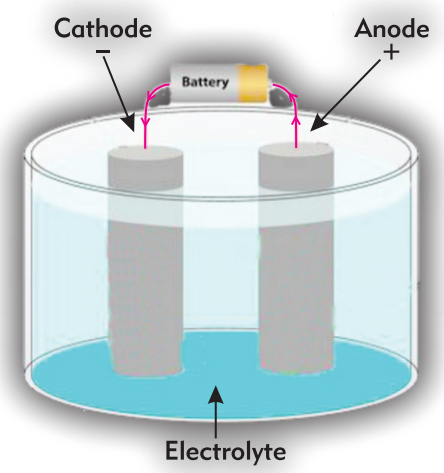


Fig 7.1 Electrolysis in electrolytic cell

The figure shows that electrons from battery enter through cathode at which positive ions are reduced by accepting electrons. At anode negative ions loses electrons and undergoes oxidation. It means at cathode reduction occurs and oxidation takes place at anode.

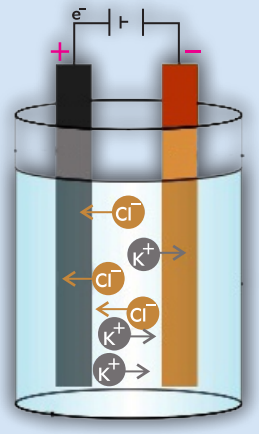
At Cathode $M^+ + e^- \longrightarrow M$ (Reduction = Gain of electron)

At Anode $X^- \longrightarrow X + e^-$ (Oxidation = loss of electron)

Test Yourself

i. Sketch electrolytic cell for electrolysis of molten potassium chloride

ii. Identify cathode and anode, oxidation, reduction reaction, movement of electron from the following sketch of electrolytic cell.



Applications of Electrolytic cells:-

Important uses of electrolytic cell are given below.

I. It is used to prepare sodium metal from molten sodium chloride using the down's cell.

ii. It is used to prepare caustic soda (NaOH) from aqueous sodium chloride solution by Nelson's cell. It is also used to obtain chlorine gas.

iii. It is used to extract aluminum metal.

iv. It is used in electro refining of copper.

v. Electrolytic cells are used for electro plating of metals.

7.2.3 Faraday's law of Electrolysis:-

Michael Faraday was a British chemist who greatly contributed in the field of electrochemistry. He observed the quantitative relationship between current and the amount of substance collected at electrodes.

He conducted several experiments regarding electrolysis and put forward two laws of electrolysis based on his observation.

Faraday's First law of Electrolysis:-

It states that amount of any substance that is deposited or liberated at an electrode during electrolysis is directly proportional to the quantity of electricity passed through the electrolyte.

$W \propto A \times t \qquad W \propto Q \qquad I = \frac{Q}{t} \qquad Q = It$

or $W = ZAt$

In this equation W = weight of the substance deposited or liberated at electrode.

A = Current in Ampere

t = Time in second

Z = Electrochemical Equivalent

Ampere (A) $\times$ time (t) = Coulomb (C)

If A = 1 Amp, t = 1 Sec then W = Z

Electrochemical equivalent is the weight of the substance collected at the electrodes when one coulomb of electric charge is passed through the electrolyte for 1 second.

Faraday's Second law of Electrolysis:-

The amount of different substances deposited or liberated due to passage of same quantity of current through different electrolytes are proportional to their chemical equivalent masses.

For an element

$$\text{Equivalent mass} = \frac{\text{Atomic weight}}{\text{valency}}$$

Example: Chemical equivalent of Al $= \frac{27}{3} = 9g$

Chemical equivalent of Ag $= \frac{108}{1} = 108$ g

Quantity of charge which deposits or liberates 1 gm equivalent weight of substance is called 1 Faraday (F).

1 F = 96500 Coulombs

Example:

Take three electrolytic solution of silver nitrate, copper sulphate and aluminum nitrate in three electrolytic cells and same quantity of current (96,500 coulombs) is passed through them. As a result 108 gm of silver, 31.75 gm of copper and 9 gm of aluminum are collected at their respective electrodes.

Batteries:-

We use lot of electrical devices having batteries as a source of electricity. A battery consists of group of galvanic cells connected in a series.

Examples of batteries include dry cell, lead storage battery, mercury battery etc.

Batteries are classified as primary (non rechargeable) and secondary (rechargeable) batteries.

Scientist are working for enhancing high energy, safety, recycle of batteries for mobile phones, transportation, computer technology etc.

Dry Cell:-

It is also known as Leclanche cell.

It is a type of primary cell which produce electricity using redox reaction between their chemical substances placed in it. It uses zinc as anode, magnese dioxide as cathode and aqueous ammonium chloride (NH_4Cl) or zinc chloride ($ZnCl_2$) as electrolyte. The cell diagram is given in Fig 7.2.

A copper cap is fixed on the top of the carbon rod for conduction of electricity.

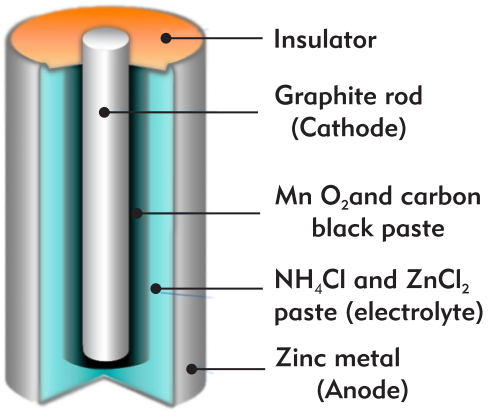


Fig 7.2 Dry cell

Zinc and graphite are then connected by a metal wire as a result following chemical reactions take place

Reaction at Anode $Zn \longrightarrow Zn^{+2} + 2\dot{e}$

Reaction at Cathode $2NH_4^+ + 2MnO_2 + 2e^- \longrightarrow Mn_2O_2 + 2NH_3 + H_2O$

It produces a potential of 1.5 volt.

Lead Storage Battery:-

A battery is a device which produces electricity through electro chemical reactions. Lead storage battery is an example of secondary cell in which chemical changes can be reversed. It has several voltaic cells connected in series .It contain lead plates which serve as anode and lead oxide (PbO_2) which acts as cathode. These electrodes are immersed in electrolytic solution of dilute sulphuric acid (H_2SO_4). Chemical changes during charging and discharging processes can be shown as

$$Pb + PbO_2 + 2H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O$$

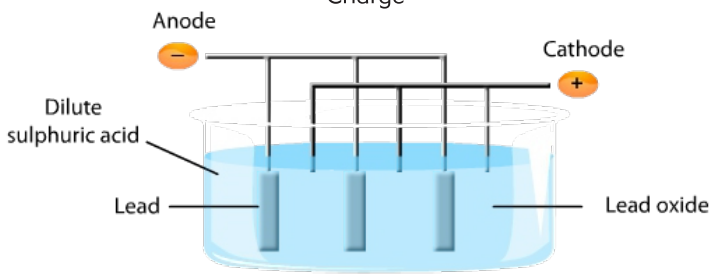


Fig: 7.3 Lead storage battery

Alloy Formation:-

Alloy is the mixture of metal with metal or metal with non metal. There are about 7000 alloys which are used for different purposes in the world.

Example: Brass is an alloy of Copper (Cu) and Zinc (Zn). Steel is a alloy of iron and carbon.

Alloy can be prepared by mixing elements in different proportions. In alloy it become difficult for layers of metal atoms to slide over each other. So alloy is harder and stronger than pure metal.

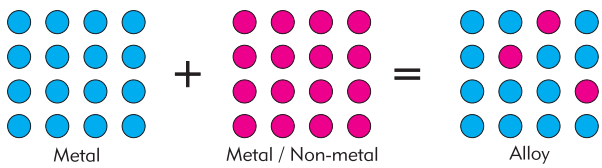


Fig 7.4 Alloy formation

Some important alloys are summarized below

Table 7.4

Name of Alloy	Components	Applications
Bell metal	Cu - Sn	Casting of bell
Brass	Cu - Zn	Door nobs and hard rails due to antibacterial nature, Hose nozzles, Stamping dies.
Bronze	Cu - Zn - Sn	Coins, medals, tools, etc.
Monel	Ni - Cu - Fe	Corrosion resistant containers
Duralumin	Al - Cu - Mg - Ni	Boat, Air craft etc
Solder	Sn - Pb - Cu - Sb	Joining electrical components into circuits.
Alnico	Fe - Al - Ni - Co	Magnets used in loud speakers
Amalgam	Hg - Ag - Cu - Zn	Dental filling
Cupronickel	Cu - Ni - Mn	Coins
Pewter	Sn - Cu - Pb - Sb - Bi	Ornaments
Sterling silver	Ag - Cu	Cutlery set, Medical tools
White gold (18 Karat)	Au - Pb - Ag - Cu	Jewelry

Do You Know?

24 karat gold is called 100% pure gold.

Addition of metals to gold form different colour.

Alloys of gold:

Yellow gold (22K) Alloy contains 91.67% gold with Ag, Cu, Zinc as other component.

Red gold (18K) contains 75% gold with Cu as other component.

White gold (18K) contains 75% gold with Cu, Ag as other component.

7.3 Corrosion and its Prevention:

Metals react with oxygen in presence of moisture and can form harmful metal oxide. These metal oxide layers are porous and expose metal for further reaction with oxygen to form harmful metal oxide. It is called Corrosion of metal.

7.3.1 Rusting of Iron

Corrosion of iron is an electro chemical process. Iron under goes redox reaction in presence of air or water to form iron (III) oxide ($Fe_2O_3 . nH_2O$) called rusting of iron. Rusted surface of iron provide no protection to underlying iron and eventually convert whole iron into reddish brown rust. Rusting occurs at different places of metal surface. A metal surface area of less moisture act as anode and oxidizes iron in this region .

$$Fe_{(s)} \longrightarrow Fe^{+2}_{(aq)} + 2\dot{e}$$

Metal surface with high moisture contents act as cathode and reduces atmospheric oxygen to OH^- ions.

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

The Fe^{+2} ions further reacts with oxygen to form rust iron (III) oxide($Fe_2O_3 . nH_2O$)

Prevention from corrosion:

All metals can be prevented from corrosion by following methods.

1- Alloying:

Formation of alloy prevents metal from corrosion by reducing its ability of oxidation.

Example: Iron (Fe) can be changed into stainless steel by mixing with chromium (Cr) and Nickle (Ni). Thus iron (Fe) is prevented from corrosion.

2- Metallic Coating (Electroplating)

All metals can be protected from corrosion by coating its surface with other metal like tin (Sn) or zinc (Zn). The coating of metal at the surface of other metal by electrolytic process is called electroplating. Metals like iron can be electroplated with chromium (Cr), Nickle (Ni) and silver (Ag).

3- Cathodic Protection:

It is applied to protect underground pipes tanks, oil rigs etc from corrosion by making these materials as cathode. The active metal like magnesium (Mg) or aluminum (Al) is used as Anode and connected with iron (Fe). These active metals itself oxidizes and prevent other metal from corrosion.

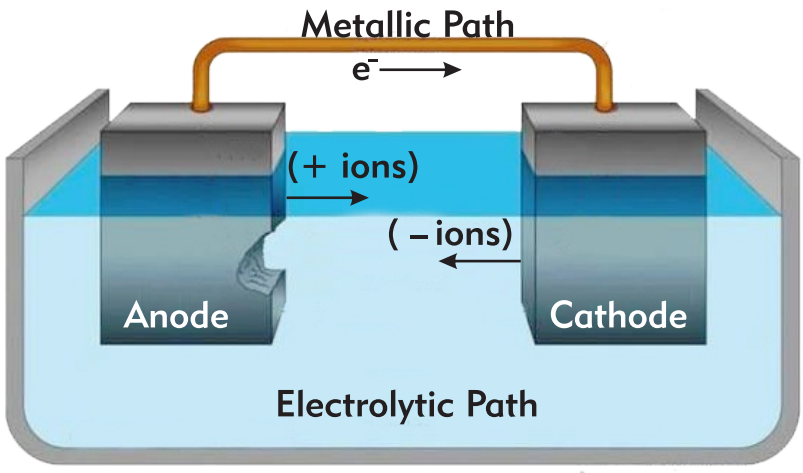


Fig: 7.5

4- Coating with paint:

A metal is commonly coated with paint to protect it from corrosion. Paint prevents the reaction of metal with oxygen moisture and other harmful chemical agents.

Test Yourself

- What is corrosion of metal?
- Name the methods which are used to protect metal from corrosion.
- How cathodic protection prevent metal from corrosion?

7.3.2 Electroplating on Steel:

The process of deposition of metal at the surface of other metal through electrolysis is called electroplating.

Tin Plating:

Steel spoon can be tin plated by using acidified tin sulphate as electrolyte. Tin (Sn) metal is used as anode and steel spoon is used as cathode. When current passes through electrolyte tin ions (Sn^{+2}) deposits at cathode as tin (Sn) metal. Tin (Sn) electrode is then changes into tin ion (Sn^{2+}).

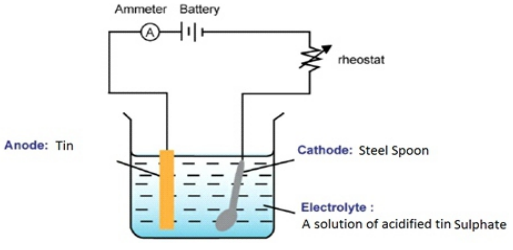


Fig 7.6 Tin plating of steel spoon

$SnSO_{4(aq)} \rightleftharpoons Sn^{++} + SO_4^{2-}$

$Sn \longrightarrow Sn^{++} + 2e^-$ (Anode reaction)

$Sn^{2+} + 2e^- \longrightarrow Sn$ (Cathode reaction)

Zinc Plating:

The process in which zinc is electrolytically coated at the surface of other base metal is called galvanizing. Potassium zinc cyanide is used as electrolyte to produce zinc ions(Zn^{+2}). Zinc (Zn) metal serves as anode and steel object is used as cathode. During electrolysis Zn^{++} deposits at cathode and Zinc (Zn) anode is then changes into zinc ion Zn^{2+}.

Following reactions occur during zinc electroplating.

$Zn \longrightarrow Zn^{2+} + 2\bar{e}$ (Reaction at anode)

$Zn^{+2} + 2e^- \longrightarrow Zn$ (Reaction at cathode)

Electroplating of Silver:

In this process silver (Ag) is coated electrolytically at the surface of steel or other metal. It is called silver plating. In this process aqueous solution of silver chloride (AgCl) is used as electrolyte to produce silver (Ag^+) ions. Silver (Ag) metal is used as anode and steel object like spoon used as cathode. Silver (Ag^+) ions are reduced at cathode by accepting electron. Silver anode loses electron and oxidized to silver (Ag^+) ion.

Following chemical changes takes place.

$$AgCl \rightleftharpoons Ag^+ + Cl^-$$

At cathode

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

At anode

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

Chromium Plating:

The process in which chromium (Cr) is coated electrolytically at the surface of other base metal is called chromium plating. Acidified chromium sulphate $Cr_2(SO_4)_3$ is taken as electrolyte. Chromium metal serves as anode and other metal object is used as cathode.

Following chemical changes take place in chromium plating.

$$Cr_2(SO_4)_{3(aq)} \rightleftharpoons 2Cr^{3+}_{(aq)} + 3SO_4^{2-}{}_{(aq)}$$

Reaction at anode:

$$Cr \rightleftharpoons Cr^{3+} + 3\bar{e}$$

Reaction at Cathode:

$$Cr^{3+} + 3\dot{e} \rightleftharpoons Cr$$

Chromium plated objects are used in Auto parts industries.

Society, Technology and Science:

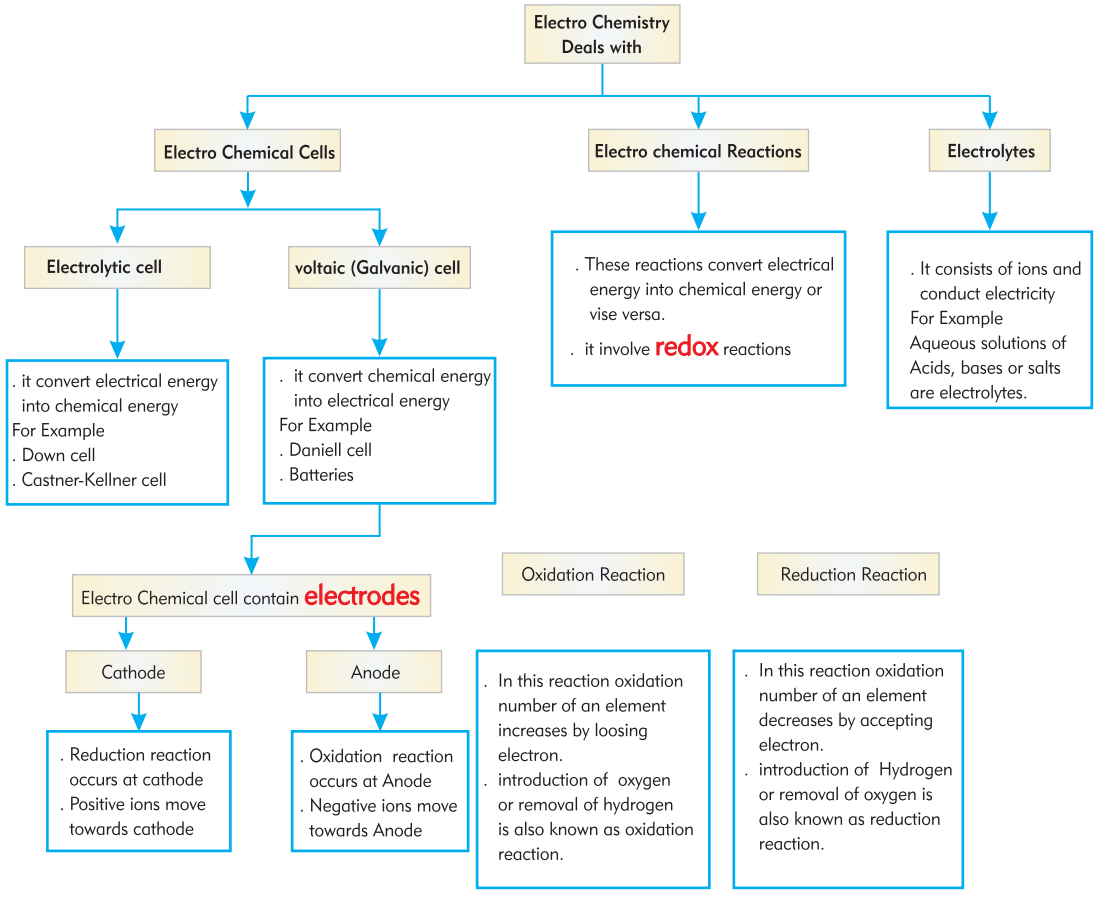
Iron is reactive metal. It can react with food items and can spoil food.

Tin is non toxic, less reactive and resistant to corrosion. Tin can not react with organic acids or salt present in food so tin plated cans are used for beverages and for storing foods.

Silver is lustrous white metal. Many metal objects are silver plated to enhance its beauty and strength against corrosion.

Thin layer of silver on metal surface form durable layers. Thick coating of silver on metal surface is soft and gradually turns black, due to formation of silver sulphide(Ag_2S).

Concept Map


Electro Chemistry Deals with
Electro Chemical Cells
Electro chemical Reactions
Electrolytes
Electrolytic cell
voltaic (Galvanic) cell
. These reactions convert electrical energy into chemical energy or vise versa.
. it involve redox reactions
. It consists of ions and conduct electricity
For Example
Aqueous solutions of Acids, bases or salts are electrolytes.
. it convert electrical energy into chemical energy
For Example
. Down cell
. Castner-Kellner cell
. it convert chemical energy into electrical energy
For Example
. Daniell cell
. Batteries
Electro Chemical cell contain electrodes
Oxidation Reaction
Reduction Reaction
Cathode
Anode
. Reduction reaction occurs at cathode
. Positive ions move towards cathode
. Oxidation reaction occurs at Anode
. Negative ions move towards Anode
. In this reaction oxidation number of an element increases by loosing electron.
. introduction of oxygen or removal of hydrogen is also known as oxidation reaction.
. In this reaction oxidation number of an element decreases by accepting electron.
. introduction of Hydrogen or removal of oxygen is also known as reduction reaction.

Summary

- Oxidation is the loss of electron by chemical substance.
- Reduction is the gain of electron by chemical substance.
- An electrolyte consists of free moving ions and conduct electricity.
- An electrode is an electrical conductor.
- The electrode at which oxidation occurs is called anode.
- The electrode at which reduction occurs is called cathode.
- Electrolysis is a process of migration of ions towards cathode and anode when current passes through en electrolyte.
- Oxidizing agent helps in oxidation by accepting electrons.
- Reducing agent helps in reduction by losing electrons.
- A galvanic cell converts chemical energy into electrical energy.
- An electrolytic cell uses electrical energy to drive a non spontaneous reaction.
- Corrosion of iron is called rusting.
- Corrosion of metal can be prevented by alloying, paint or electroplating metal by zinc, tin, silver, chromium etc.
- An alloy is a mixture of metal with metal or metal with non metal.

Exercise

SECTION- A: MULTIPLE CHOICE QUESTIONS

Tick Mark (✓) the correct answer

1. Alloy of Cu - Sn is called _____
   (a) Brass (b) Bronze
   (c) Monel (d) Bell metal
2. Which one is Alloy.
   (a) Graphite (b) Mercury
   (c) Steel (d) Water
3. Value of 1 Farady is equal to _____.
   (a) 9.65 C (b) 9650 C
   (c) 96500 C (d) 965 C
4. Which one is non electrolyte.
   (a) Aqueous HCl (b) Aqueous NaCl
   (c) Molten KCl (d) Urea
5. Which one is oxidizing agent.
   (a) Al (b) H_2S
   (c) Cl_2 (d) NaH
6. Which one is reducing agent.
   (a) H_2SO_4 (b) HNO_3
   (c) Al (d) I_2
7. Which one forms weak electrolyte solution with water
   (a) HCl (b) KOH
   (c) NaCl (d) CH_3COOH
8. In dry cell _____ is used as cathode.
   (a) Zn (b) Cu
   (c) Sn (d) graphite
9. 1g equivalent weight of Al is equal to _____.
   (a) 9 g (b) 27g
   (c) 54 g (d) 1 g

10. Which one is correct statement.
    (a) Oxidation occurs at cathode.
    (b) Reduction occurs at anode
    (c) Reduction occurs at cathode
    (d) Ions lose electrons at cathode.

SECTION- B: SHORT QUESTIONS:

1. Define oxidation, reduction reactions with examples.
2. Why ionic compounds conduct electricity in molten or in aqueous solutions only?
3. What is electrolytic cell? Explain with diagram.
4. Define oxidizing and reducing agent with examples.
5. Examine the following chemical equations and identify.
   (i) Oxidizing agent (ii) Reducing agent
   (iii) Substance undergoes oxidation
   (iv) Substance undergoes reduction

   1. $Zn + Cl_2 \longrightarrow ZnCl_2$
   2. $Br_2 + H_2S \longrightarrow 2HBr + S$
   3. $2Ca + O_2 \longrightarrow 2CaO$
   4. $2Li + S \longrightarrow Li_2S$

   Identify the Alloy.

Components	Alloy
Cu – Zn	
Cu – Al – Mg – Ni	
Cu – Zn – Sn	

SECTION- C: DETAILED QUESTIONS:

1. Describe the dry cell with diagram.
2. What is battery? How lead storage battery works?
3. Explain process of electrolysis in electrolytic cell.
4. What is Alloy? Explain its classification with examples.
5. What is rusting? How it can be prevented.
6. What is electroplating? How steel object can be electroplated with Tin, Zinc and Silver?
7. State and explain Faraday first and second law of electrolysis.