Module -1

ATOMIC STRUCTURE-II & CHEMICAL BONDING

Bohr Model of Atoms – The main postulates of Bohr model are

1. Atom consists of a small positively charged central nucleus and electrons move around the nucleus
2. The circular path of electrons are called orbits. These orbits are designated as K, L, M, N etc with energies E_1, E_2, E_3, E_4 etc
3. As long as the electron remains in a particular shell it neither absorbs nor emit energy.
4. The frequency of radiation absorbed or emitted when the electrons shift from one orbital to another is given by $\nu = \frac{\Delta E}{h}$
5. Angular momentum of electron, $mvr = \frac{nh}{2\pi}$, Where **n** is a whole number

Advantages of Bohr's model

1. Bohr model could explain the stability of atom
2. Bohr model could explain the line spectrum of hydrogen atom

Limitation of Bohr's model

1. Bohr's model failed to explain the spectra of multi electron atom
2. It failed to explain the fine structure of line spectrum of hydrogen atom
3. It could not explain the Zeeman effect (Zeeman effect is the splitting of spectral lines in a magnetic field)
4. It could not explain the Stark effect (Stark effect is the splitting of spectral lines in an electric field)
5. It could not explain the three dimensional model of atom. Bohr proposed a flat model of atom
6. It could not explain the chemical bond formation and shape of molecules.
7. Bohr theory is against Heisenberg's uncertainty principle.

Matter wave – The wave associated with a particle is called matter wave or de Broglie wave. The wavelength λ of matter wave is given by $\lambda = \frac{h}{mv}$

Heisenberg's Uncertainty Principle – It is impossible to measure simultaneously the position and momentum of a small particle with absolute accuracy. Mathematically it can be written as $\Delta x \times \Delta p \geq \frac{h}{4\pi}$, ($The\ uncertainty\ in\ momentum, \Delta p = m\Delta v$)

Difference between Orbit and Orbital

Orbit	Orbital
Orbit is a well defined circular path around the nucleus	Orbital is the three dimensional space around the nucleus
It represents planar motion of electron	Orbital represents three dimensional motion
All orbits are circular shape	Different orbitals have different shape
Orbits do not have directional characteristics	Orbitals have directional characteristics
It is against Heisenberg's uncertainty principle.	It obeys Heisenberg's uncertainty principle.

Quantum Numbers – Quantum numbers are a set of four numbers with the help of which we can get information about an electron in an atom. The four quantum numbers are,

1. Principal quantum number (n)
2. Azimuthal quantum number(l) or angular momentum quantum number
3. Magnetic quantum number (m)
4. Spin quantum number (s)

1. Principal Quantum Number(n) – It represents the main energy level. It tells about the size of the orbital, energy of the orbital, and the maximum number of electrons present in the shell ($2n^2$). The possible values of n are 1,2,3,etc.

2. Azimuthal Quantum Number(l)– It indicates the sub shell. It tells about the shape of the orbital, relative energy, and the angular momentum of electrons. The possible values are 0 to n-1.

3. Magnetic Quantum Number(*m*) –It tells about the orientation of each of the sub shell, and the number of orbitals present in a sub shell. The possible values are **-*l*** to **+*l*** including zero (total of $2l+1$ values are possible).

4. Spin Quantum Number(*s*) – It tells about the spin of the electron. The possible values are ***+ 1/2 and - 1/2*** which represents clockwise and anticlockwise spinning of electron.

Aufbau Principle – In the ground state orbitals are filled with electrons in the increasing order of their energies. The order of increasing energy of orbitals is 1s < 2s < 2p < 3s < 3P < 4s < 3d < 4p < 5s < 4d < 5p < 6s < 4f < 5d < 6p < 7s

Pauli's exclusion Principle – No two electron in an atom can have the same value for all the four quantum numbers.

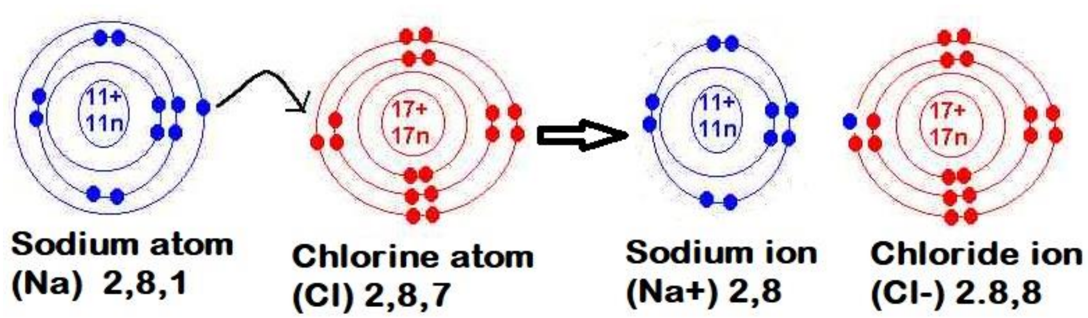
Hunds Rule of maximum multiplicity – Pairing of electrons in the orbitals of same sub shell does not take place until each orbital of the same sub shell are singly occupied with parallel spin.
Electronic configuration of ,
Nitrogen (N - 7) – $1s^2\ 2s^2\ 2p^3$
Magnesium (Mg - 12) – $1s^2\ 2s^2\ 2p^6\ 3s^2$
Potassium (K - 19) – $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^1$
Argon (Ar - 18) – $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

Chemical Bonding

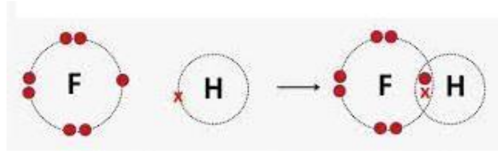
The attractive force that holds the component atoms or ions together in a molecule is called **chemical bond**.

Octet Rule - Atoms of different element combine with each other to attain eight electronic configuration (Octet) in their outermost shell.

Ionic Bond – It is the bond formed by transfer of one or more valence electrons from one atom to another. Eg. Formation of Sodium Chloride



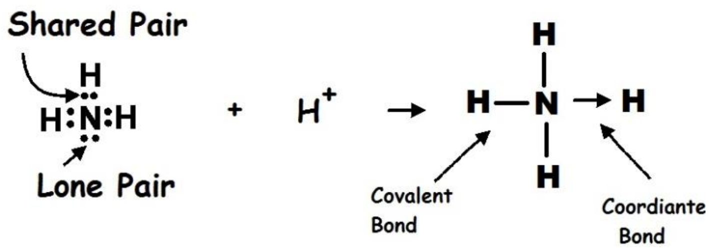
Covalent Bond – chemical bond formed by the sharing of one or more pairs of valence electrons between two atoms is called covalent bond. Eg. Hydrogen fluoride molecule



Hydrogen Fluoride

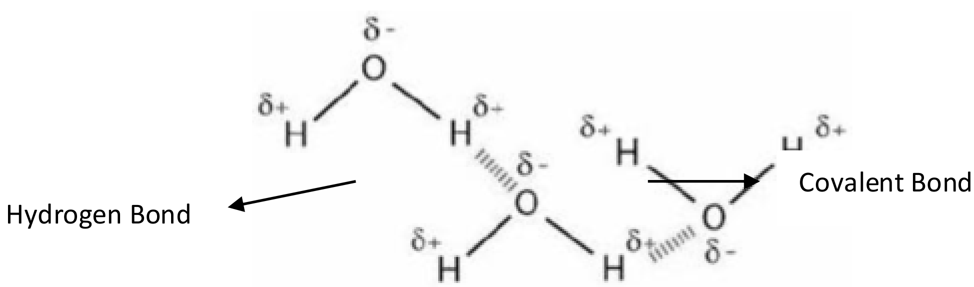
Bond Pair and Lone Pair of electrons – A shared pair of electron between two atoms in a bond is called bond pair. A pair of valence electron not involved in bonding is called Lone pair of electron.

Coordinate Bond or Dative Bond – chemical bond formed by the sharing of a pair of electrons contributed by one of the atom alone is called Coordinate Bond. The atom which donates the shared pair of electron is called donor and the atom that accepts electrons for sharing is called acceptor. Eg. Formation of Ammonium ion (NH_4^+),



Or,	**NH_3**	**+**	**H^+**	**→**	**NH_4^+**

Hydrogen Bond – The attractive force between hydrogen of one molecule with electronegative element of another molecule is called hydrogen bond. Eg. Hydrogen bonding in H_2O and HF



Hydrogen bonding in Water (H_2O)

Anomalous behaviour of water – Water is a liquid at room temperature due to strong intermolecular hydrogen bonding. When water is heated from 0°C to 4°C its volume decreases and hence density increases. After 4°C volume increases and density is decreased. This means **water has a maximum density at 4°C**. When water is heated from 0°C more and more hydrogen bond break and the water molecules come closer and hence the volume decreased.

Module 2 - SOLUTION, VOLUMETRIC ANALYSIS & WATER

Solution is a homogeneous mixture of two or more than two non-reacting components. Solute is the component that dissolves in the solvent in a solution. Solvent is the medium in which the solute dissolves.

a) **Molarity (M)** – Molarity is the number of moles of solute dissolved in one litre of solution.

$$Molarity\ \ M = \frac{w \times 1000}{m \times V}$$

Where w is the weight of solute in gram, m is molecular mass of solute and V is volume of solution in ml

b) **Normality (N)** - Normality is the number of gram equivalents of solute dissolved in one litre of solution.

$$Normality\ \ N = \frac{w \times 1000}{E \times V}$$

Where w is the weight of solute in gram, E is the equivalent mass of solute and V is volume of solution in ml

c) Parts per million (ppm) – It is the number of parts by mass of solute per million parts by mass of solution.

$$ppm = \frac{Mass\ of\ solute}{Mass\ of\ solution} \times 10^6$$

Ionic product of water, K_w,, is defined as the product of the concentrations of H^+ ions and OH^- ions in water

Mathematically, $K_w = [H^+] \times [OH^-]$, (where K_w is called ionic product of water, $[H^+]$ and $[OH^-]$ are the molar concentrations of H^+ ions and OH^- ions respectively)

In pure water $[H^+] = [OH^-] = 10^{-7}$ moles per litre at 25 °c

Therefore $K_w = [H^+] \times [OH^-] = 10^{-7} \times 10^{-7} = 10^{-14}$ moles² / Litre² at 25° C

In neutral solution $[H^+] = [OH^-] = 10^{-7}$, In acidic solution $[H^+] > [OH^-]$ and In basic solution $[H^+] < [OH^-]$

pH of a solution of a solution is defined as negative logarithm of hydrogen ion concentration in moles per litre. It is a method of expressing hydrogen ion concentration of a solution.

$pH = -\log_{10}[H^+]$

$[H^+]$ in pure water is 10^{-7} moles per litre at 25⁰C

Therefore PH of water at 25⁰C $= -\log_{10}[H^+] = -\log_{10}10^{-7} = (-7) -\log_{10}10 =$ **7**

For acidic solution pH is less than 7, and for basic solution pH is greater than 7

Applications/ importance of pH value –

1. To find acidic, basic or neutral nature of a solution.
2. Selection of pH can reduce the rate of corrosion. Eg. In boilers
3. pH of human blood is 7.36 to 7.42
4. Calculation of hydrogen ion concentration.
5. In agriculture
6. In digestive system.
7. In textile industry and sugar industry
8. I electroplating.

pOH of Scale – pOH of a solution is defined as the negative logarithm to base 10 of hydroxyl ion concentration in moles per litre.

$pOH = -\log_{10}[OH^-]$

$[OH^-]$ in pure water is 10^{-7} moles per litre at 25^0C

Therefore pOH of water at 25^0C = $-\log_{10}[OH^-]$ = $-\log_{10}10^{-7}$ = $(-7) -\log_{10}10$ = **7**

For a solution at 25^0C, $pH + pOH = 14$, and therefore

$pH = 14 - pOH$, and $pOH = 14 - pH$

Buffer solution – Solutions which can resists the change in pH when small amount of acid or base is added in to it is called buffer solution. There are two types of buffer solutions, acidic buffer and basic buffer.

Acidic buffer – It is obtained by mixing a weak acid and its salt with a strong base. Eg. (1) Acetic acid and sodium acetate.

Basic buffer – It is obtained by mixing a weak base and its salt with a strong acid. Eg. Ammonium hydroxide and ammonium chloride.

Volumetric analysis – It is a quantitative analysis involving measurement of volume of liquids.

According to the law of chemical equivalents, substances react in the ratio of their equivalent weights.

Mathematically it can be expressed as , **$N_1V_1 = N_2V_2$**

Where N_1 and N_2 are the normalities and V_1 and V_2 are the volumes of solutions of substances 1 and 2 which react completely.

(for acid base reaction substance 1 is acid and substance 2 is base or vice versa)

Standard solution – A solution of known concentration is called standard solution

Titration – It is the process of adding slowly a solution from a burette to a known volume of another solution until the reaction just completed.

End point - the point at which the indicator shows colour change during a titration is called end point.

Indicator	**pH range**	**Colour**	
		Acid Medium	**Basic Medium**
Phenolphthalein	8.3 - 10	Colourless	Pink
Methyl Orange	3.1 – 4.5	Orange red	Yellow
Litmus	4.5 – 8.3	Red	Blue

Choice of indicators in acid – base titrations -

Titration of strong acid against strong base – Eg. HCl vs NaOH, The pH change towards the end point of this type of titration is roughly from 10 to 3.5 , Hence both phenolphthalein and methyl orange can be used as indicators.

Titration of strong acid against weak base – Eg. HCl vs Na_2CO_3, The pH change towards the end point of this type of titration is roughly from 7.5 to 3.5 , Hence suitable indicator for this titration is methyl orange.

Titration of weak acid against strong base – Eg. CH_3COOH vs NaOH, The pH change towards the end point of this type of titration is roughly from 10 to 6.5 , Hence suitable indicator for this titration is phenolphthalein.

Titration of weak acid against weak base – Eg. CH_3COOH vs Na_2CO_3, There is no sharp pH change towards the end point of this type of titration. Hence none of the indicator can give correct result and such titrations are not done using acid – base indicators.

Soft Water – Water which produces lather readily with soap solution is called soft water

Hard water - Water which does not produces lather readily with soap solution is called hard water

Hardness of water is due to the dissolved impurities such as bicarbonates (HCO_3^-), chlorides (Cl^-) and sulphates ($SO4^{2-}$) of calcium and magnesium.

Why hard water do not form lather with soap – Ordinary soaps are sodium salts of fatty acids (RCOONa). When treated with hard water, soap reacts with dissolved ions (Ca and Mg) to form the insoluble salts (scum) of calcium and magnesium **{** $(RCOO)_2Ca$ and $(RCOO)_2Mg$ **}.** Therefore hard water do not form lather with soap.

Distinction between Soft water and Hard water

	Soft water	Hard water
1	Gives lather with soap readily	Does not give lather with soap readily
2	Does not form insoluble scum with soap	Form insoluble scum with soap
3	Does not contain calcium and magnesium salts	Contain calcium and magnesium salts

Hardness can be removed by

i) **Soda lime Process** – In this process required amount of slaked lime, and Soda are added to hard water to convert the soluble Calcium and Magnesium ions to insoluble carbonate (CO_3^{2-}).

$$Ca(HCO_3)_2 + Ca(OH)_2 \longrightarrow 2\,CaCO_3 + 2H_2O$$

$$CaCl_2 + Na_2CO_3 \longrightarrow CaCO_3 + 2NaCl$$

ii) Ion exchange method - in this method hard water is first passed through a tank with a bed of cation exchanger (**E-H**) where all positive ions are exchanged with H^+ ions.

$$2\,E\text{-}H + Ca^{2+} \rightarrow E_2Ca + 2H^+ \;, \quad \& \quad 2\,E\text{-}H + Mg^{2+} \rightarrow E_2Mg + 2H^+$$

The water coming out of cation exchanger is then passed through a second tank containing anion exchanger (**E-OH**) where all the anions are exchanged with OH^- ions.

$$E\text{-}OH + Cl^- \rightarrow E\text{-}Cl + OH^- \quad \& \quad 2E\text{-}OH + SO_4^{2-} \rightarrow E_2SO_4 + 2OH^-$$

The cation exchange resin is regenerated by using acid and anion exchange resin is regenerated by using alkali.

Disadvantages of Hard water

a) Formation of boiler scale - **Hard water on boiling deposits a hard scale(crust) on the inner walls of the boiler and steam pipes. This deposit is called boiler scale**. The boiler scale formed is insulating and leads to wastage of fuel.
b) **Boiler explosion** – sometimes the boiler scale cracks and the water suddenly comes in contact with the overheated iron plates of the boiler. As a result, large volume of steam is formed suddenly and a high pressure is developed inside the boiler. This may lead to the boiler explosion.
c) Corrosion - The chlorides present in hard water gets hydrolysed producing free hydrochloric acid. This acid corrode the metal with which the boiler is made

$$MgCl_2 + H_2O \longrightarrow Mg(OH)Cl + HCl$$

<u>Potable water</u> -Water which is safe to drink is called potable water.

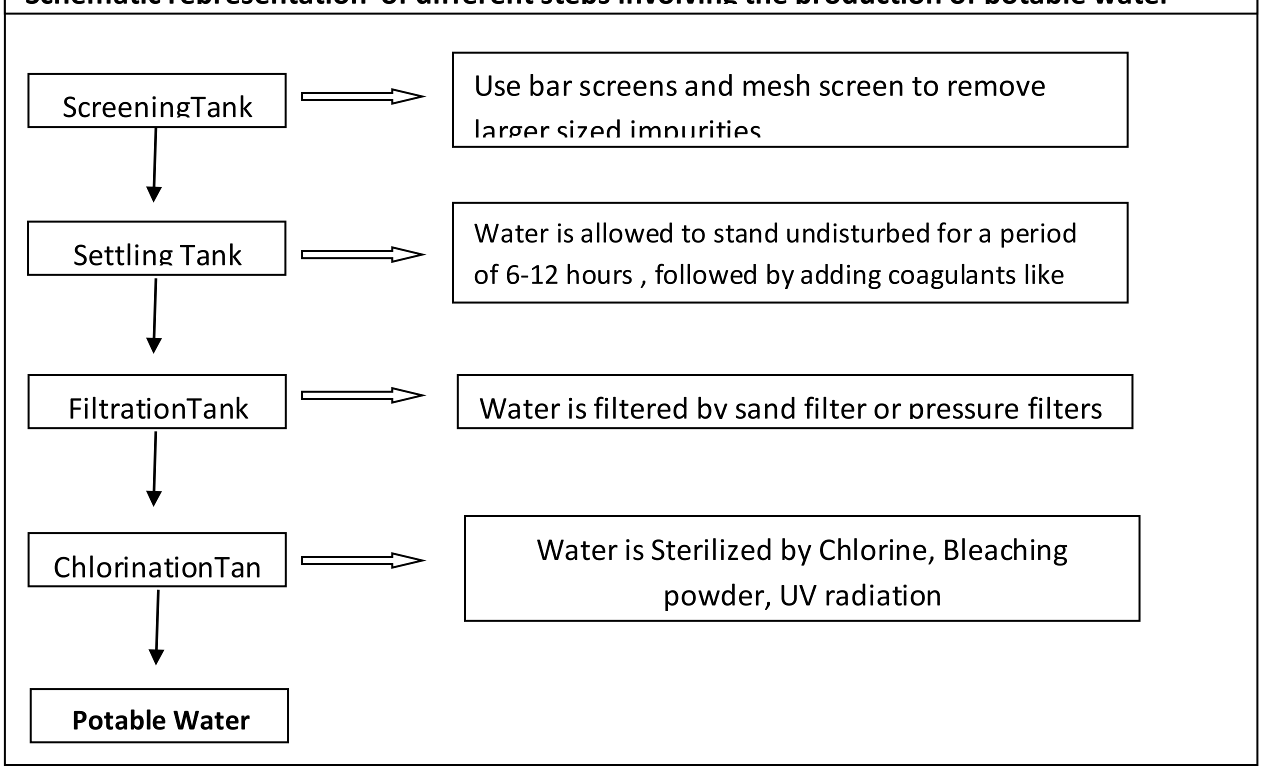
Characteristics of potable water are,

1. It should be clear and odourless
2. It should be free from disease producing micro organisms
3. It should be free from disagreeable gases like H_2S, NH_3 and minerals like nitrites.
4. It should be free from suspended impurities
5. Total dissolved solids should be less than 500ppm.
6. It should be reasonably soft.

Treatment process to make potable water- Screening, Sedimentation, Coagulation, Filtration, and sterilization

1. **Screening** - The raw water is passed through bar screens or mesh screens to remove the larger sized impurities
2. **Sedimentation** - In this process water is allowed to stand undisturbed to settle down the suspended impurities.
3. **Coagulation -** Finely divided suspended particles are made to settle down by adding certain chemicals (coagulants) like alum, ferric chloride, sodium aluminate etc.
4. **Filtration** - In this process the insoluble colloidal and bacterial impurities are removed by means of filters. The filtering medium consisting of fine sand, coarse sand, and graded gravel.
5. **Sterilization (disinfection)** - The process of destroying the disease producing bacteria and micro organisms is called Sterilization or disinfection. It can be done by following methods.
   - **(a) Sterilization by chlorine** - In this method chlorine water or chlorine gas is passed through a tank containing water.
   - **(b) Sterilization by bleaching powder** -- Bleaching powder is calcium oxy chloride ($CaOCl_2$) which when reacts with water release nascent oxygen. Nascent oxygen is a powerful germicide.
   - **(c) Sterilization by UV rays** — Ultraviolet rays can kill all the pathogenic bacteria present in water.

Schematic representation of different steps involving the production of potable water



Module 3 - Engineering materials & Nanochemistry

Alloys- An alloy is a homogeneous mixture of two or more than two metals.

Purpose of making alloy –

1. To increase the resistance to corrosion
2. To increase the hardness of metal
3. To lower the melting point of metal
4. To modify the chemical activity of metal
5. To modify colour
6. To provide better castability

Some common alloys and their uses

	Name of alloy	Composition	Uses
1.	**Brass**	Cu – 60 -90% Zn – 40 -10%	Used for making utensils, parts of machinery, wires etc
2.	**Bronze**	Cu – 80 -95% Tin (Sn) – 20 -5%	Used for making statues, coins, cooking utensils etc
3.	**Solder**	Pb - 50% Sn – 50%	Used for soldering

Glass - Glass is an amorphous, brittle, transparent solid composed of a mixture of different silicates.

General Properties of Glass

1. Glass is amorphous
2. It can be moulded into any shape
3. It is brittle
4. It has no definite melting point
5. It is good electrical insulator
6. It can absorb, reflect or transmit light
7. It can be softened on heating

Types of Glass

1. **Soda Glass (Ordinary Glass)** – It is a mixture of sodium silicate and calcium silicate. The raw materials used are sand, lime stone ($CaCO_3$) and sodium carbonate. They are cheap and softens at a lower temperature. Soda glass is used in making window glass, bottles, bulbs, jars etc.
2. **Borosilicate glass (Pyrex glass)** – This type of glass contain mixture of silicates of sodium, aluminium and boron. It can withstand high temperature and has low coefficient of expansion. It is resistant to chemicals and is used to make laboratory glass wares and kitchen wares.
3. **Safety Glass** – It is used in making wind screens of automobiles and aeroplanes. It is prepared by placing a layer of transparent plastic between two layers of glass by means of suitable adhesive.
4. **Insulating Glass** – It is prepared by two or more plates of glass separated by 6 to 13mm gap filled with dehydrated air and sealing around the edges. This air gap provides high insulation against heat.

REFRACTORIES

Refractories are material which can withstand high temperature without softening, melting or deformation. Eg. Alumina, Silica, Magnesia bricks etc.

General Properties of Refractories

1. It should be infusible
2. They must be chemically inert
3. It should have low porosity
4. It should have low thermal expansion
5. It should have high strength
6. It should have low electrical conductivity

Examples - Silica, Alumina, Magnesite, Graphite

Refractory materials are used in furnaces, kilns, incinerators, and reactors. Refractories are also used to make crucibles and moulds for casting glass and metals.

Polymers – Polymers are high molecular mass compound(Macromolecules) which are formed by joining very large number of one or more type of simple molecules.

Classification of Polymers- Based on nature of monomers

Homopolymers -Polymers consisting of single type of monomer molecules are known as homopolymers. It can be represented as –A-A-A-A-A-A-A- Eg. Polythene (monomer – ethylene), PVC (monomer – vinyl chloride) etc

Copolymer- Polymers consisting of more than one type of monomers are called copolymers. Copolymer can be represented as -A-B-A-B-A-B-A-B- Eg. Nylon-6,6 , Dacron

Classification of Polymers- Based on Mode Polymerisation

Addition polymers - The polymers formed by the repeated addition of monomer units are called addition polymers. Eg. polythene, PVC , Teflon etc.

Condensation polymers – The polymers formed by repeated condensation reaction between the monomer units are called condensation polymers. Eg. Bakelite, Polyester, Nylon66, Terylene etc.

Difference between addition polymerisation and condensation polymerisation

Addition polymerisation	**Condensation polymerisation**
1. It is due to the repeated addition of monomer units. 2. Monomers usually contain one or more double bonds 3. The monomer and polymer have same empirical formula 4. Polymerisation is due to chain growth Eg. Formation of polythene PVC, teflon	1. It is due to the series of condensation reaction between the monomer units. 2. Monomers usually contain two functional groups 3. The monomer and the polymer have different empirical formulae. 4. Polymerisation is due to step growth Eg. Formation of Nylon 6,6, bakalite, dacron

Classification of Polymers- Based on Molecular forces

Elastomers – Polymer chains are held together by weak intermolecular forces. Eg. Rubber, Buna-S, Buna-N etc.

Fibres – Polymer chains are held together by strong intermolecular forces are called fibres. Eg. Nylon 66, Terylene

Plastic – Plastic may be defined as organic material of high molecular mass which can be moulded into any desired shape by subjecting to suitable heat and pressure conditions.

Plastics are of two types-

1. Thermoplastics – Plastics which can be softened on heating and hardened on cooling are called thermoplastics. Eg. PVC, polythene, Cellulose acetate etc.

2. Thermosetting plastics – These are plastic polymers which become infusible and hard on heating. They cannot be remelted and remoulded. Eg. Bakelite, polyesters, silicones etc.

Differences between thermoplastics and thermosetting plastics

Thermoplastics	**Thermosetting plastics**
It can be remoulded and reshaped many times It becomes soft on heating and hard on cooling. These are linear polymers They are formed by addition polymerisation They are soft, weak and less brittle	It cannot be remoulded and reshaped It becomes hard and decomposed on heating. These are cross linked polymers They are formed by condensation polymerisation They are hard, strong and brittle

Natural rubber is an elastic material obtained from the sap (latex) of the rubber tree. The latex is treated with a dilute solution of formic acid or acetic acid, when coagulation of rubber particle takes place. Chemically natural rubber is a linear polymer of **isoprene** (2-methyl1,3- butadiene)

Natural rubber is a soft gummy and sticky mass. It has low tensile strength, and low elasticity.

Vulcanisation is the process of heating natural rubber with sulphur (3-5%) at a temperature of 110-140^{o}C. Vulcanisation improves the elasticity and tensile strength of natural rubber. During vulcanisation the sulphur atoms bridges or crosslinks between rubber chains.

Merits of vulcanisation-

1. Vulcanisation helps in preventing the slippage of rubber chains on application of stress.
2. It makes rubber less sensitive to temperature changes.
3. It increases elasticity and tensile strength.
4. It increases the resistance of rubber to oxidation, abrasion, wear and tear, water and organic solvents.
5. Vulcanisation increases the electrical resistance of rubber.

Common Polymers, Monomers and uses

Polyethene	Ethene	Buckets, containers, bottles, pipes, toys, packaging material
PVC	Vinyl chloride	Sheets, rain coats, dolls, pipes, table cloths, Vinyl floorings
Bakelite	Phenol and formaldehyde	Combs, fountain pen, binding glue, handles of utensils, Electrical switches etc
Nylon-6,6	Hexamethylene diamine and adipic acid	Carpets, ropes, tyre cords, fabrics, bristles for brushes etc.
Buna -S	Butadiene and styrene	Hoses, tyres, floor tiles, shoe soles etc
Buna – N	Butadiene and vinyl cyanide	Conveyer belts, fuel tanks, hoses, printing rollers

NANOCHEMISTRY

Nanomaterials are materials with any one external dimension in the range of 1nm - 100 nm

Nano chemistry is the study of materials of the size 1 to 100nm range (1nm = 10^{-9}meter).

Nanotechnology is the synthesis, analysis, and characterization of materials at the nano scale (1-100nm)

Examples of some nano sized materials are

DNA width ≈ 2nm, H – atom = 0.1nm, Bucky ball = 1nm, Carbon nano tube ≈ 1.3nm

Zero Dimensional (0D) nanomaterials - Nanomaterials with all the three dimension (length, breadth and thickness) in the nanoscale range is called Zero Dimensional (0D) nanomaterials. Eg- Quantum dots, Fullerene etc.

One Dimensional (1D) nanomaterials - Nanomaterials with any two dimension in the nanoscale and the third dimension in the macro scale (above 100 nm) is called One Dimensional (1D) nanomaterials. Eg- Carbon nanotubes (CNT), nano wires etc.

Two Dimensional (2D) nanomaterials - Nanomaterials with any one dimension in the nanoscale and the other two dimension in the macro scale (above 100 nm) is called Two Dimensional (2D) nanomaterials. Eg- Nano sheets, nano coatings etc.

Carbon nanotubes are allotropes of carbon. (CNTs- are also known as buckytubes). A carbon nanotube is a structure which seems to be formed by rolling a sheet of graphite into the shape of a cylindrical tube. The two varieties of carbon nanotubes are

- **SWNT – S**ingle walled carbon nanotube- it consists of a single cylinder of graphite sheet
- **MWNT** – Multi walled carbon nanotube – it consists of multiple concentric nanotube cylinders.

Fullerene- Fullerenes are allotropes of carbon consisting of spheroidal molecules of carbon with composition C_{2n} (where n ≥ 30). The most common member of this category is Buckminster fullerene with formula $\mathbf{C_{60}}$.

Graphene – Graphene is a one atom thick layer of graphite. It is a two-dimensional crystal of carbon atoms arranged in a honeycomb lattice.

Applications of Nano materials

1. Due to large surface area nanomaterials act as better catalyst. Eg.TiO_2, Al_2O_3, and ZrO_2
2. Tumors can be detected, located and treated with very high accuracy
3. DNA mapping of new born child
4. Nanoparticles are used to identify protein-protein interaction.
5. Targeted drug delivery in the body.
6. Bio-compatible joint replacements.
7. Carbon nanotubes are used as heat conductors.
8. Carbon nanotubes are used in solar cells.

Module IV, ELECTROCHEMISTRY & CORROSION

Oxidation may be defined as a process in which an atom or an ion loses one or more electrons.
Reduction may be defined as a process in which an atom or an ion gains one or more electrons.
A chemical reaction in which both oxidation and reduction occur simultaneously is called **redox reaction. Eg**

$$2Mg + O_2 \longrightarrow 2MgO$$

(Oxidation $Mg \longrightarrow Mg^{2+} + 2e^-$ & Reduction $O + 2e^- \longrightarrow O^{2-}$)

Conductors - Substance which allow the passage of electric current through them are called conductors. Eg. Metals, graphite, ionic compounds in fused state or in dissolved state.

Insulators - Substance which does not allow the passage of electric current through them are called insulators. Eg. glass, wood, paper etc.

Conductors have been broadly classified into **Metallic conductors & Electrolytic conductors** (Electrolytes)

Metallic conduction	**Electrolytic Conduction**
Conductance is due to the movement of free electrons	Conductance is due to movement of ions
No chemical change take place	Chemical change (Electrolysis) take place
No transfer of matter	transfer of matter in the form of ions
Conductance decreases with increase of temperature	Conductance increases with temperature
Eg. Metals and their alloys	Eg. Ionic compounds

Electrolytes are the substances which conduct current in the molten state or in the aqueous solution state. Eg. NaCl, KOH, HCl etc

Non electrolytes are the substances which do not conduct electricity in the fused state or in the aqueous state. Eg sugar, urea, alcohol etc

Strong Electrolytes - Electrolytes that dissociates almost completely in to ions even at moderate concentration are called strong electrolytes. Eg. strong acids and bases (HCl, NaOH etc)

Weak electrolytes- Electrolytes which dissociates into ions partially at moderate concentrations are called weak electrolytes. Eg. weak acids and bases (Acetic acid, Sodium carbonate etc)

Electrolysis is the process of decomposition of an electrolyte by the passage of electricity through it. The apparatus used for electrolysis is called **electrolytic cell**.

Faraday's First law of electrolysis – The first law states that the mass of a substance deposited or liberated at an electrode is proportional to the quantity of electricity passed. Mathematically it can be written as

$\mathbf{W \propto Q}$, **or,** $\mathbf{W = ZQ}$, where W is the mass of substance, Q is the quantity of current in coulomb and Z is the electrochemical equivalent of the substance. (**$Q = I \times t$, one ampere current flowing for one second)**

$W = ZQ$ When $Q = 1$, then $W = Z$

So, ***Electrochemical equivalent Z of a substance is defined as the mass of the substance deposited or liberated by the passage of one coulomb of electricity through the electrolytes.***

(On Faraday of charge is 96500 Coulomb. It is the charge carried by 1 mole of electrons)

Faraday's Second law of electrolysis – The second law states that when same quantity of current is passed through different electrolytes, the mass of mass of substance deposited is directly proportional their chemical equivalents. Mathematically it can be written as , **W1 α E1 , and W2 α E2** , where W1 and W2 are the mass of substance 1 and substance 2, E1 and E2 are the equivalent weights of substance 1 and substance 2).

And, $\frac{W_1}{W_2} = \frac{E_1}{E_2}$

Applications of electrolysis – 1. Electroplating, 2. Electrolytic refining of metals 3. Anodizing, 4. Production of metals, 5. Production of non metals, 6. Production of compounds like NaOH, KOH etc.

Electroplating - The process of coating a superior (Noble) metal on an inferior metal (base metal) by passing electric current is called electroplating.

Electroplating of mild steel spoon with Nickel – In the electrolytic cell nickel plate is taken as the anode and the steel spoon is placed as the cathode. Electrolyte is the solution of nickel sulphate. When current is passed, the anode nickel dissolved in the solution and got deposited over the steel spoon.

Anode Reaction - Ni (metal) → Ni^{2+} + 2 e^- (Oxidation)

Cathode Reaction - Ni^{2+} + 2e^- → Ni (Reduction)

Electrolytic refining of metal is the process of purifying a metal by electrolysis.

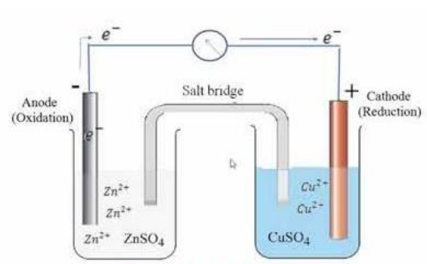
Electrolytic refining of copper – Impure copper is taken as anode and a pure strip of copper is taken as cathode. Copper sulphate is used as the electrolyte. When current is passed through the electrolytic cell impure copper dissolves in the electrolyte as copper ions (Cu^{2+}) and moves towards the cathode. At the cathode copper ions deposited as copper atom.

Anode Reaction - Cu → Cu^{2+} + 2 e^- (Oxidation)

Cathode Reaction - Cu^{2+} + 2e^- → Cu (Reduction)

Electrochemical Cell (Galvanic Cell or Voltaic cell) - The device in which chemical energy is converted into electrical energy is called Galvanic cell. Eg Daniel Cell

Daniel cell consists of Zinc rod dipped in zinc sulphate solution and copper rod dipped in copper sulphate solution. The two solutions (two half cells) are connected externally by a metallic wire to a galvanometer and internally by a salt bridge.



Daniell Cell

Electrode reactions are,

Anode, $Zn_{(s)}$ → $Zn^{2+}_{(aq)}$ + 2e-

Cathode, $Cu^{2+}_{(aq)}$ + 2e- → $Cu_{(s)}$

Overall reaction

$Zn_{(s)}$ + $Cu^{2+}_{(aq)}$ → $Zn^{2+}_{(aq)}$ + Cu

Distinction between Galvanic cell and Electrolytic cell

Galvanic cell	Electrolytic cell
Chemical energy is converted to electrical energy	Electrical energy is converted into chemical energy
Electrical energy is produced by a redox reaction.	Electrical energy is required for the redox reaction
Anode is negative and Cathode is positive	Anode is positive and cathode is negative
Salt bridge is generally used	No salt bridge is required

Primary cells – These are the cells in which the redox reaction occurs only once. The chemical reaction in these cells is not reversible. Eg Daniel cell, Dry cell, Mercury cell etc.

Secondary Cell – These are the cells in which the chemical reaction taking place can be reversed by passing electricity. They can be used again and again. Eg Nickel Cadmium Cell, Lead storage battery etc.

Fuel cells – Fuel cells are galvanic cells in which chemical energy of combustion of fuel is converted to electrical energy. Eg. Hydrogen – Oxygen fuel cell

Electromotive Force (emf) – A galvanic cell is made up of two half cells namely oxidation half cell (anode) and reduction half cell (cathode). The difference in potential of two half cells (cathode and anode) of a cell is known as emf of cell. **or** **EMF = $E_{cathode}$ - E_{anode}**

Eg. EMF of Daniel cell = E_{Cu} - E_{zn} = + 0.34 - (- 0.76) = 1.1V

Electrochemical series - Electrochemical series is an arrangement of elements or electrodes in the increasing order of their standard reduction potentials.

Corrosion – It is the process of decay of metals due to the attack of atmospheric gases on the surface of the metal. Eg Rusting of iron.

Factors affecting corrosion - 1. Purity of metal, 2. Presence of air and moisture, 3. Presence of electrolytes, 4. Temperature, 5. Presence of acidic gases, 6. pH of the medium,

Prevention of Corrosion (or Rusting) - The important methods to prevent (or to minimize) corrosion are

1. Barrier protection – In this method, suitable coating film is placed between the metal and the surrounding air. The coating may be metallic, non-metallic and organic in nature.

(a) Metallic coating – The metal can be protected by coating with a less active metal or by coating with a more active metal. Coating of Tin over iron article is an example of protecting a metal by coating with less active metal. Coating iron articles with Zinc is the example of protecting a metal by coating with more active metal. The more active zinc undergo decay while the iron article is protected. Coating of iron articles with zinc metal is called **Galvanization**. The method of protecting a metal article by covering with a more active metal is called **Sacrificial Protection**

(b) Non-metallic coating – This include protecting a metal by coating with phosphate, chromate or Oxide film.

(c) Organic coating –Plastic, Rubber etc can be coated over metal articles to protect from corrosion.

2. Electrical Protection (Cathodic Protection) - In this method the metal article is connected to a more active metal like Magnesium through a wire. The more active metal is damaged, while the less active metal article is protected.

3. Antirust solution – Alkaline solutions of phosphate or chromate is applied over the metal articles to prevent corrosion. The alkaline solution removes the H^+ ions from the medium and hence corrosion is not occurred.