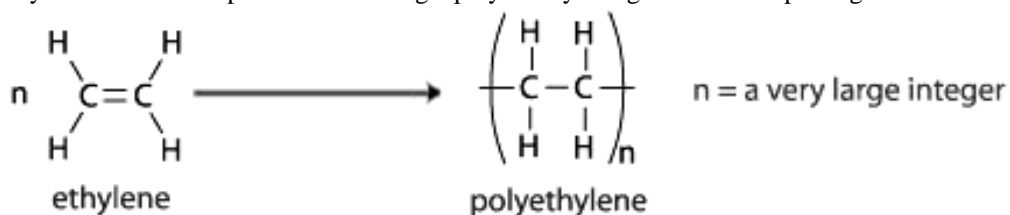


POLYMERS

Introduction

- Polymers are the macromolecules which are formed by the combination of many smaller molecules called monomers.
- Polymerization is the process of forming a polymer by using number of repeating units.



Degree of polymerization

- It is defined as the number of monomers units in a homo polymer.
- Most of the polymers are in the molecular mass range of 5,000 – 2, 00,000.
- But in case of hetero polymer, degree of polymerization (D.P) is defined as the ratio of total molecular weight of a polymer to molecular weight of each repeating unit.
- In the above equation, 'n' is the degree of polymerization.

$$D_p = \frac{\text{Total Molecular Weight of the Polymer}}{\text{Molecular Weight of Monomeric Unit}} = \frac{M_n}{M_o}$$

$$M_n = M_o \cdot D_p$$

$$M_n = \text{Total molecular weight of the polymer}$$

$$M_o = \text{Molecular weight of monomeric unit}$$

$$D_p = \text{Degree of Polymerisation}$$

Functionality

- The number of active bonding sites of a monomer is referred to as its functionality.
- So, the monomer should have two reactive sites (or) bonding sites to form a polymer.

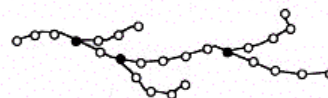
Different types of polymer structure can be obtained based on the functionality of monomeric units.

- Linear or straight chain molecules are formed by the combination of bifunctional monomers which contain two reactive sites
- Branched chain polymers are obtained by the combination of trifunctional monomer and bifunctional monomers.
- Three dimensional network polymers are obtained by the combination of polyfunctional monomers.
- In such polymeric molecules, the movement of monomer units is prevented by strong cross links.

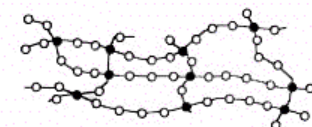
- linear



- branched



- network



Differences between Addition & Condensation Polymerisation

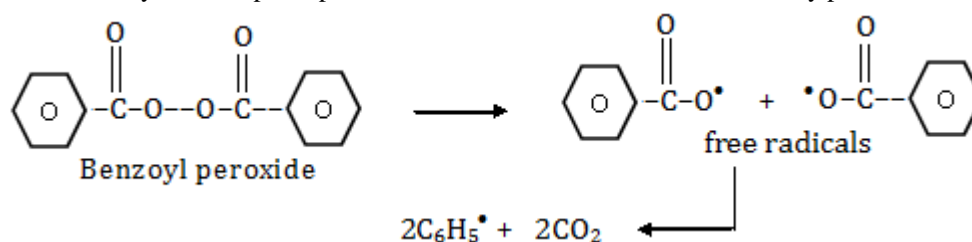
Addition Polymerisation	Condensation Polymerisation
1. Polymer is formed by addition of monomers with out elimination of small molecules.	1. Polymer is formed by two or more monomers by the elimination of small molecules.
2. No by-products are formed.	2. By products are formed.
3. Homo chain polymers, generally thermo plastic is obtained.	3. Hetero chain polymer either thermo plastic or thermo setting can be obtained.
4. Proceeds by chain growth mechanism.	4. Proceeds by step growth mechanism.
5. Weight of polymer is identical with sum of the monomers.	5. Weight of polymer is not identical with sum of the monomers.
$n \begin{array}{c} \text{H} & & \text{H} \\ & \backslash & / \\ & \text{C} = \text{C} \\ & / & \backslash \\ \text{H} & & \text{H} \end{array} \longrightarrow \left(\begin{array}{cc} \text{H} & \text{H} \\ & \\ -\text{C} & - & \text{C}- \\ & \\ \text{H} & \text{H} \end{array} \right)_n$ <p>ethylene polyethylene</p>	$n \begin{array}{c} \text{O} & & \text{OH} \\ & & \\ \text{HO}-\text{C} & - & \text{C}-\text{OH} \\ & & \\ \text{HO} & & \text{OH} \end{array} + n \text{OH}-\text{CH}_2-\text{CH}_2-\text{OH} \longrightarrow \left[\text{O}-\text{CH}_2\text{CH}_2\text{O}-\text{CO}-\text{C}_6\text{H}_4-\text{CO} \right]_n$ <p>Terephthalic acid Ethylene glycol Terylene</p>

Mechanism of polymerization

Free radical polymerization

In this type of polymerization monomer is activated to free radical by any one of the following methods.

- Photo chemical initiation:- By exposing to sunlight free radicals are generated.
- Thermal initiation:- By heating free radicals are generated.
- Radiation initiation:- By exposing to α, β or γ -rays free radicals are generated.
- Chemical initiation:- By using initiators like peroxides free radicals are generated. Benzoyl peroxide or Azo bis isobutyronitrile, persulphates etc are used as chemical initiators. They produce free radicals as



Mechanism of free radical polymerization involves three steps.

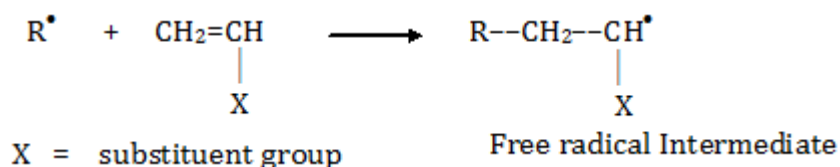
1. Chain initiation:-

It involves two steps.

- Formation of free radicals from the initiator.



- Addition of free radicals to monomer to form a free radical intermediate.



2. Chain propagation:-

Here addition of monomer molecules to the intermediate takes place one by one leads to the formation of macro-radicals.

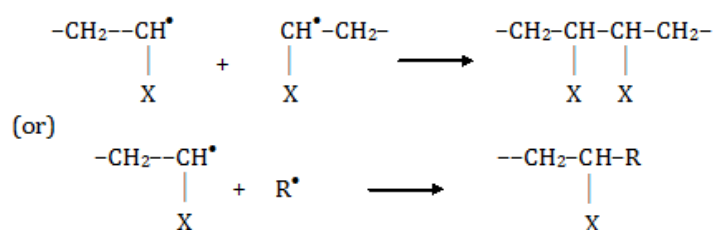


3. Chain termination:-

The growing polymer chain is terminated by many ways.

a) Recombination:-

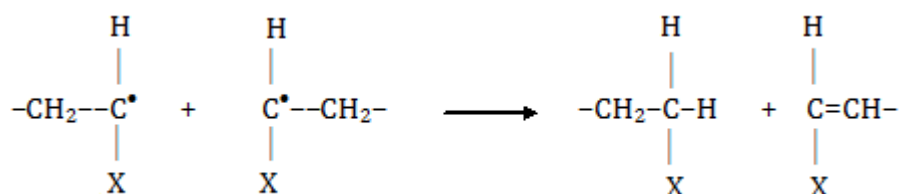
Combination of two free radicals leads to termination.



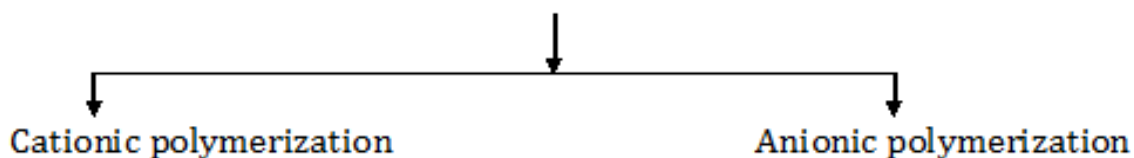
At 60°C poly styrene or Acrylonitrile chains terminate mainly by recombination.

b) Disproportionation:-

Transfer of 'H' atom from one radical to another leads to formation of two macro molecules, one of them with a double bond.



Ionic polymerization



Cationic polymerization:-

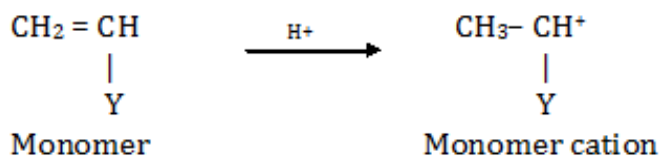
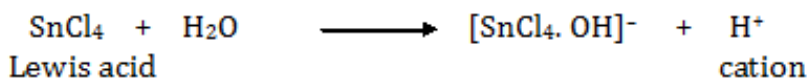
Monomers with electron releasing groups (-OCH₃, -OC₂H₅ & -C₆H₅ etc) undergo cationic polymerization in the presence of Lewis acids like AlCl₃, BF₃, SnCl₄ etc. Cationic polymerization takes place with higher rates even at low temperature.

Mechanism of cationic polymerization:-

It involves three steps.

a) Initiation:-

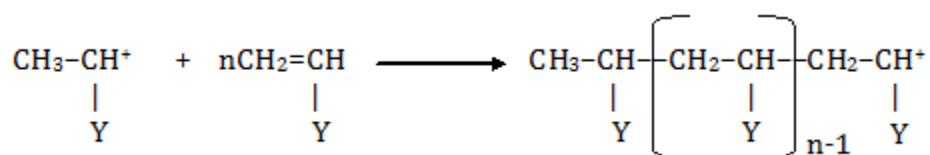
H⁺ ion is produced from Lewis acid and it forms cation with monomer.



Where, Y is electron releasing group.

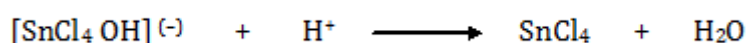
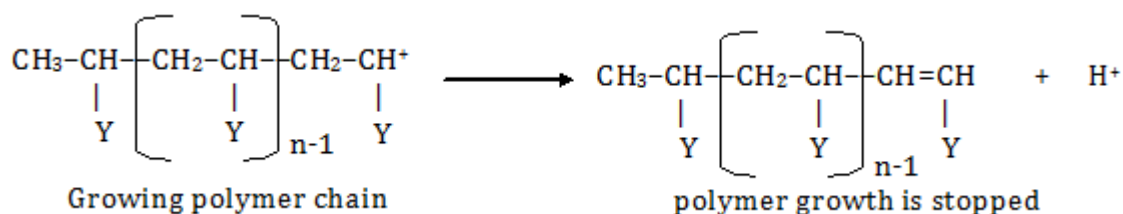
b) Propagation:-

Monomers are added to monomer cation in a sequence and length of polymer chain increases gradually.



c) Termination:-

Growing polymer chain is stopped by removing H⁺ ion from the chain.



Anionic polymerization:-

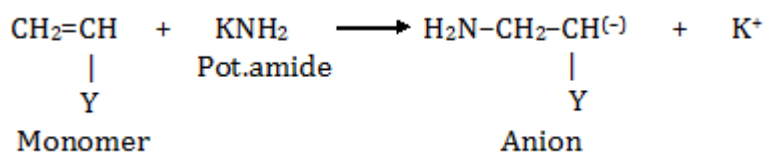
Monomers with electron withdrawing groups (-CN, CH₃COO- and C₆H₅ etc) undergo anionic polymerization in presence of sodium or potassium amide.

Mechanism of anionic polymerization:

It involves 3 stages.

a) Initiation:-

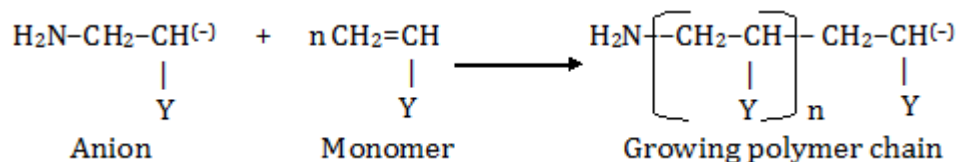
Anion is generated on reaction of potassium amide with monomer.



Y = electron withdrawing group.

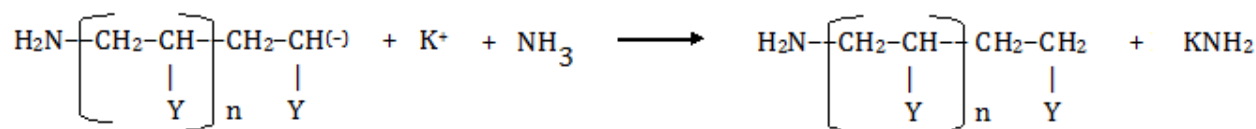
b) Propagation:-

Monomer units are added to anion one after the another and growth of polymer chain is continued.



c) Termination:-

Growing polymer chain is stopped by neutralizing the negative charge on growing chain.



Ziegler – Natta catalysis (or) Co-ordination polymerization:

- ✓ Ziegler Natta catalyst is useful in synthesizing stereo regular polymers commercially.
- ✓ This catalyst is a co-ordination catalyst, consists of two components of catalyst and co-catalyst.

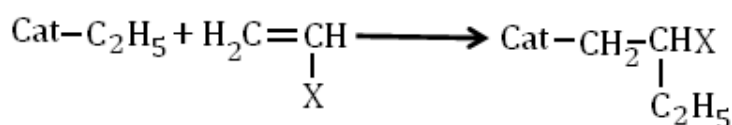
Mechanism:

❖ Preparation:

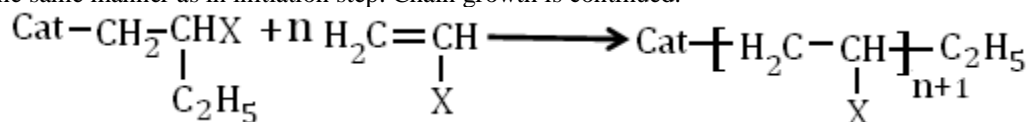
- ★ The active Ziegler – Natta catalyst is formed by chemisorption of aluminium alkyl on TiCl_4 crystal.
- ★ Heating the monomers at 100°C at 10atm in presence of Ziegler Natta catalyst forms stereo regular polymers.

∞ Initiation:

- ★ Monomer forms π -complex with active catalyst by co-ordination bond and with empty orbital of titanium.

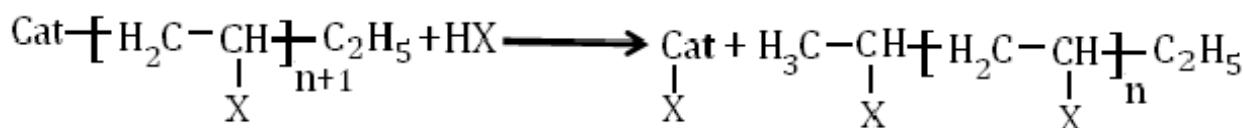


- ∞ **Propagation:** In this step monomers are added one after another in between the metal and ethyl group in the same manner as in initiation step. Chain growth is continued.



∞ Termination:

- ★ The polymer chain is separated from the catalyst by the addition of molecules containing active hydrogen (HX). Chain growth is stopped.



❖ Applications:

- Ziegler Natta catalyst is used for synthesizing the Syndiotactic and Isotactic polymers.
- Co-polymers, like ethylene and propylene are obtained by using Ziegler Natta catalysts, which are excellent elastomers.

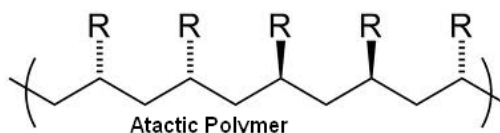
STEREO REGULAR POLYMERS

- ✓ Asymmetric alkenes linked together to form asymmetric carbon chain polymers.

- ✓ The stereo chemical placement of the asymmetric carbons in the polymer chain is called tacticity.
- ✓ Based on the stereo chemical orientation of atoms or groups at asymmetric carbons, the polymers can be classified as
 - a) Atactic
 - b) Syndiotactic (Syntactic)
 - c) Isotactic
- ✓ Tacticity helps in understanding M.P, Solubility and mechanical properties, crystallinity, rigidity of the polymer.

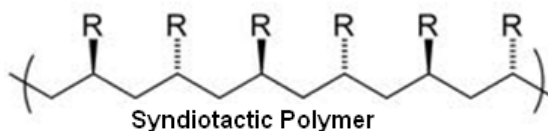
Atactic polymer:

- ♣ In these polymers, the substituents of asymmetric carbons are placed randomly along the chain.
- ♣ The percentage of mesodiads is in between 1 - 99%.
- ♣ Ex: PS, PVC etc.
- ♣ These polymers have low crystallinity, low melting point and mechanically weak due to irregular structure.



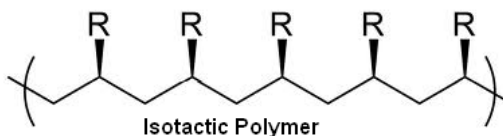
Syndiotactic polymers:

- ♣ The polymers in which the substituents of asymmetric carbon are placed in alternative positions along the macro molecule chain are known as Syndiotactic polymer.
- ♣ The percentage of racemodiads in this polymer is 100%.
- ♣ These polymers have high crystallinity, high melting point and mechanically strong due to the presence of weak interaction forces.



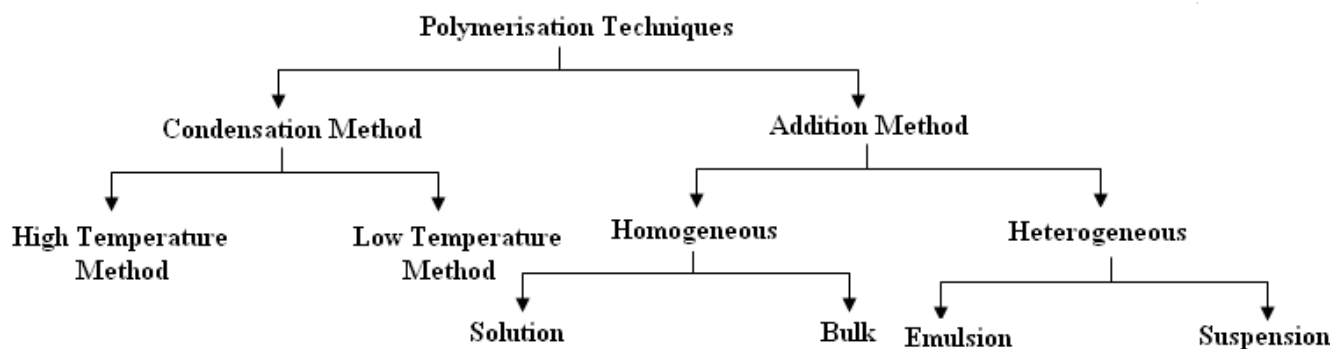
Isotactic polymer:

- ♣ The polymers composed of the substituents of asymmetric carbon on the same side of the polymer chain are known as Isotactic polymers.
- ♣ The Isotactic polymers consist of 100% mesodiads.
- ♣ These polymers have high crystallinity, high melting and mechanically strong due to the presence of weak interaction forces.



- ✓ The polymers which are having tacticity and regular order of arrangement are called stereo regular polymers.
- ✓ Syndiotactic and isotactic polymers are stereo regular polymers.

Methods of polymerization



♣ **Heterogeneous polymerization:**

If the polymerization reaction takes place in more than one phase, it is known as heterogeneous polymerization.

Suspension polymerization

- ☞ It is also known as pearl or bead or granular polymerization.
- ☞ It is the polymerization process that uses mechanical agitations to mixture of monomers in liquid state.
- ☞ In which, the monomers are dispersed as relatively large droplets (0.1 – 1 mm) in liquids.
- ☞ A catalyst is added for initiation of polymerization process, and the suspension is stabilized by adding stabilizer agents ($\text{Al}(\text{OH})_3$, Kaolin).
- ☞ Without adding stabilizer breaking of suspension takes place.
- ☞ Then the polymers are obtained as pearls or spherical beads.
- ☞ Ex: PS, PVC, PMMA

- ☞ **Advantages:**
 - High purity product formed.
 - Process is more economical.
 - Efficient thermal control.
- ☞ **Disadvantages:**
 - It is difficult to control the size of the particle.
 - Applicable to water insoluble monomers.

Emulsion polymerization

- ☞ The most common type of emulsion polymerization is oil – in – water emulsion.
- ☞ In this method, the monomer is dispersed in water phase as fine droplets (10^{-5} to 10^{-6} mm) which are stabilized by adding surfactants like soap or detergents.
- ☞ These surfactants form micelles. When their concentration exceeds critical micelle concentration.
- ☞ The formed micelles dispersed through out the solution.
- ☞ The addition of initiator leads to the activation of reaction in micelles.
- ☞ Due to the formation of polymers, these micelles increase in size.
- ☞ To continue the reaction, monomers diffuse from its droplets to micelle, then the size of the micelle increases.
- ☞ Termination reactions are less likely as the polymerization sites are isolated from each other.
- ☞ Here, high molecular weight polymers can be obtained.
- ☞ Ex: PS, PVC
- ☞ **Advantages:**
 - High molecular weight polymers can be prepared.
- ☞ **Disadvantages:**
 - It cannot be used for condensation, ionic, Ziegler – Natta polymerization processes.
 - It is economically costly.

Properties of polymers

Physical properties:

These properties depend on average molecular weight of a polymer.

For molecular weights < 1000 - oily viscous liquids

For molecular weights 1000 – 10,000- soft, waxy solids

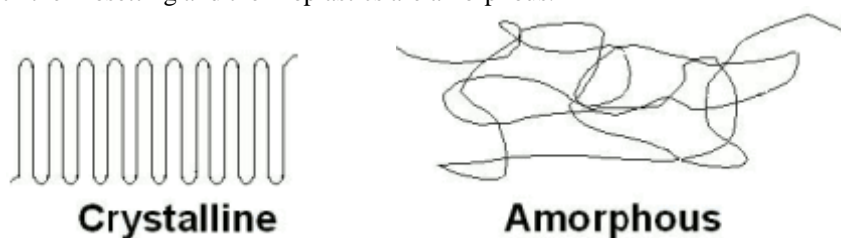
For molecular weights > 10,000 - hard, brittle solids or flexible solids

✍ **Crystallinity:**

- ✓ The orderly arrangement of polymeric molecule is known as crystallinity.
- ✓ The properties like solubility, diffusion, toughness, density and transparency depend on degree of crystallinity.
- ✓ In crystalline polymer, the polymeric molecules are packed close to each other through intermolecular forces of attraction.
- ✓ Thus, these polymers have higher and sharper melting point, greater rigidity, greater density and strength.
- ✓ A completely crystalline polymer tends to acquire brittleness.

✍ **Amorphous state:**

- ✓ Random arrangement of polymer molecules results amorphous state.
- ✓ The intermolecular forces between polymer chains are weak.
- ✓ So, amorphous polymers can be moulded to desired shape.
- ✓ Both thermosetting and thermoplastics are amorphous.



Mechanical properties:

- ✦ **Elasticity:** It is the ability of a material to recover to its initial shape and dimensions when applied stress is removed.
- ✦ **Hardness:** It is the ability of a material to surface deformation, indentation or abrasion.
- ✦ **Dimensional stability:** it is the ability of a polymer to withstand progressive removal of material from its surface as a result of mechanical action of rubbing, scrapping or corrosive nature.
- ✦ **Plasticity:** A material is said to exhibit plasticity if on releasing the applied stress it retains a permanent deformation.
- ✦ **Brittleness:** A brittle material shatters suddenly without noticeable plastic deformation preceding failure.
- ✦ **Ductility:** A ductile material undergoes large irrecoverable deformation before rupture.
- ✦ **Strength:** It is the ability of a material to withstand a gradually applied stress without rupture. These are of three types.
 - **Tensile strength:** It is the stress needed to break a sample.
 - **Compressive strength:** It is the ability of a material to resist crushing when a squeezing force is applied to it.
 - **Impact strength:** It measures the ability of a material to resist sharp blows or shock . or *Impact strength* is the resistance of a material to fracture under dynamic load.

PLASTICS

Introduction:

- ✓ The Word Plastics is derived from Greek Word ‘Plastikos’ meaning capable of being moulded [or] shaped.
- ✓ Plastics can be moulded [or] pressed [or] casted [or] extruded into various shapes like plates, tubes, bottle, boxes, fibers etc.
- ✓ Plastics materials have
 - Sufficient rigidity
 - Mechanical strength
 - Insulation Property
 - Low density
 - Low cost
 - Light weight
 - Resistance to chemicals, corrosion, insect abrasion etc to shape them into desired article.
- ✓ Resin is a part of plastic.
- ✓ It helps in binding the constituent together in the plastic.

Advantages:

1. Recyclable
2. It can be destroyed by burning [incineration]
3. Durable.

Disadvantages:

1. Recycling of plastic is a costly process.
2. Plastic undergo biodegradation after long time.
3. Incineration of plastic causes pollution.
4. Plastics are derived from petrochemicals and their production causes environmental pollution.

5. Plastics are low heat resistance and brittle. They undergo deformation at low temperatures.

Uses:

- **In Packaging industry:** As bags, covers and containers LDPE and HDPE are used.
- **In construction industry:** PVC, HDPE are used as drainage pipes, electrical pipes etc.
- **In automobiles:** Wipers, air intake manifolds, fuel pipe lines, bumpers, brake linings etc.
- **In electronic devices:** TV & Radio cabinets, computers, clocks produced from plastic materials.
- **In house hold purpose:** Around the house, some of the most popular uses are shower heads, dishes, food containers, tooth brushes, pens, skylights, eye glasses, toys, decorative items, carpets, piano keys, buttons, door knobs, luggage suitcases etc.

Differences between Thermo Settings and Thermo Plastics

Thermo Plastics	Thermo Settings
Formed by either addition (or) condensation polymerisation.	Formed by condensation polymerisation.
They are linear (or) branched linked structures.	They are cross linked (or) three dimensional structures.
Polymers chains are held together by weak attractive forces.	Polymers chains are held together by covalent cross links.
They soften on heating and stiffen on cooling.	They don't soften on heating.
They are soluble.	They are not soluble.
They can be remoulded, reshaped and reused.	They cannot be remoulded.
They can be recycled.	They cannot be recycled.
They are tough.	They are brittle.
They have low melting points.	They have high melting points.

Compounding of plastics

- ❖ The process of including various additives into plastic by mechanical means to get a homogeneous mixture is called compounding.
- ❖ By the addition of suitable materials, plastics get desired qualities.
- ❖ Additives are classified into various types based on their role in the plastic.
 - Binders
 - Fillers
 - Plasticizers
 - Stabilizers
 - Colorants
 - Accelerators
 - Fire retardants

Binders:

- ♣ The main purpose of binder is to hold the different constituents together in the material.
- ♣ A binder may compose of 30-100% of the plastic.
- ♣ The binders used may be natural [or] synthetic [or] cellulose derivatives.
- ♣ These are also polymeric materials.
- ♣ Resins are the basic binding materials in the plastics.
- ♣ Binders used also determine the type of process needed to mould the plastic.
- ♣ Plastic are classified based on the type of binder used.
- ♣ **Thermoplastic:**
 - These are prepared in single step process.
 - These plastic are generally amorphous (or) crystalline.

- These are linear (or) branched polymers with weak intermolecular attractive forces.
- These plastics become soft on heating and stiffen on cooling at any time.
- They may be remolded, reshaped and reused.
- They can be recycled.



Thermosettings



Thermoplastics

♣ **Thermosetting:**

- These are normally produced.
- These are cross linked, three dimensional structures.
- Once a product is prepared by heating and moulding, it can't be changed by further heating.
- On excess heating materials undergoes destruction but not become soft.

Fillers:

- ♣ Fillers are cheap organic (or) inorganic materials used to reduce cost of the material (or) to improve certain properties of it.
- ♣ These are two types.

Particulate fillers;

- ♣ They are used to lower the cost of plastic.
- ♣ They also help to increase tensile strength & retention of shape.
- ♣ Ex; Asbestos, clay, silica, talc, lime stone, mica & even wood flour.

Fibrous Fillers:

- ♣ These are mainly used to improve tensile strength, wear, tear & impact resistance.
- ♣ They act like steel in reinforced concrete.
- ♣ Ex; Cotton threads, scrap clothes, nylon poly ester fiber, fiber glass etc.

Plasticizers:

- ★ Some plastics are hard, brittle and glassy with high T_g and melt viscosity.
- ★ It is difficult to prepare products from such plastics.
- ★ Plasticizers are high molecular weight organic compounds which make the plastic soft, flexible and low melt viscosity.
- ★ Ex; Triphenyl phosphate, Phthalic esters, Fatty acid esters etc.

Stabilizers:

- ♣ Many plastics undergo thermal (or) photo chemical degradation during their processing (or) when they are put into use.
- ♣ Stabilizers protect the plastic from such degradation.
- ♣ Natural rubber, PE, esters undergo such degradation.
- ♣ It is prevented by adding anti oxidants like alkyl phenols, naphthols, phenyl salicylate etc.

Colorants:

- ★ These are inorganic (or) organic pigments used to impart pleasing colours to the plastic.
- ★ They don't cause any influence on other properties.
- ★ Ex; Carbon black, anthraquinones, azodyes, phthalocyanines, BaSO_4 , TiO_2 , PbCrO_4 , Fe_2O_3 , Zinc chromate.

Accelerators (or) Catalysts:

- ➔ These are used in the preparation of thermosetting polymers in which cross linked are produced by adding accelerators.
- ➔ Ex; H_2O_2 , Benzoyl peroxide, ZnO , NH_3 etc.

Fabrication of plastics

These are 5 methods of fabrication

Casting:

- ♣ This method is suitable for thermosetting & thermoplastics.
- ♣ Molten plastic material is poured in a suitable mould and it is subjected to curing at 70°C for several hours at atmospheric pressure.
- ♣ The products formed are free from internal stresses and can take high polish.

Blowing:

- ♣ In this process, molten plastic is blown by air (or) steam into a closed mould.

Extrusion:

- ♣ By this method, articles like sheets, pipes, rods, having uniform dimension are prepared.
- ♣ The method is used only for thermoplastics.
- ♣ The material of required composition is forced by a screw conveyor into a heated chamber. Where it softens, and then it is forced through a die having the required shape.
- ♣ The finished product extruded out is cooled by blowing air (or) spraying water.

Lamination:

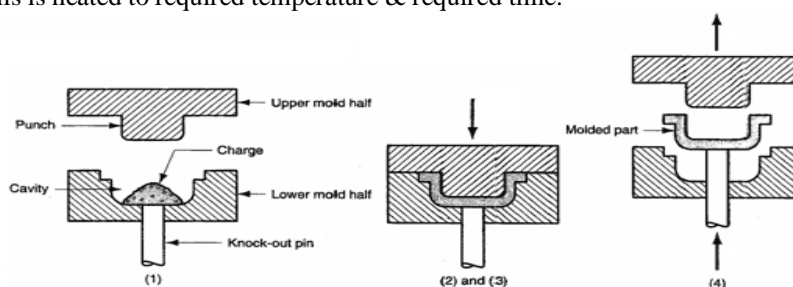
- ♣ Sheets of cloth, paper (or) wood are soaked with resin solvent solution.
- ♣ Such sheets are arranged one over the other till the required thickness is obtained and pressed together by using smooth polished metal sheets to get laminated product.
- ♣ Laminated products have high tensile strength and impact resistance.

Moulding Techniques

- ♣ Moulding is an important method of fabrication.
- ♣ There are several ways of moulding.

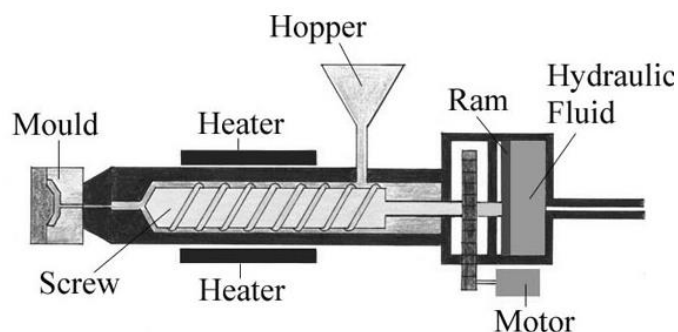
Compression moulding:

- ♦ It is the most common method used for thermosetting polymers.
- ♦ With this process, the material is squeezed into its desired shape with the help of pressure and heat.
- ♦ Plastic powder is mixed with other components & placed in the mould and closed.
- ♦ This is heated to required temperature & required time.



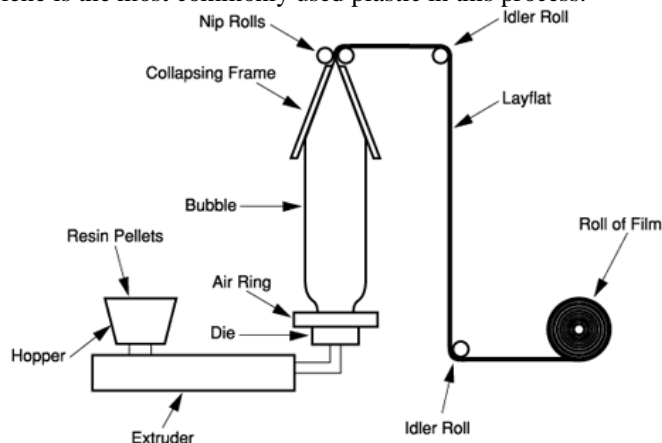
Injection moulding:

- ♦ The plastic material placed in the hopper.
- ♦ Hopper feeds the material to the heated injection unit.
- ♦ This unit is provided with a reciprocating screw.
- ♦ This screw forces the melted plastic through a nozzle into a cold mould.
- ♦ Two halves of the mould is fitted with one another through clamps.
- ♦ When the plastic is cooled and solidified, the halves are opened and plastic moulded article is ejected with the help of ejector pins.
- ♦ Thermosetting polymer can't be moulded by this method.



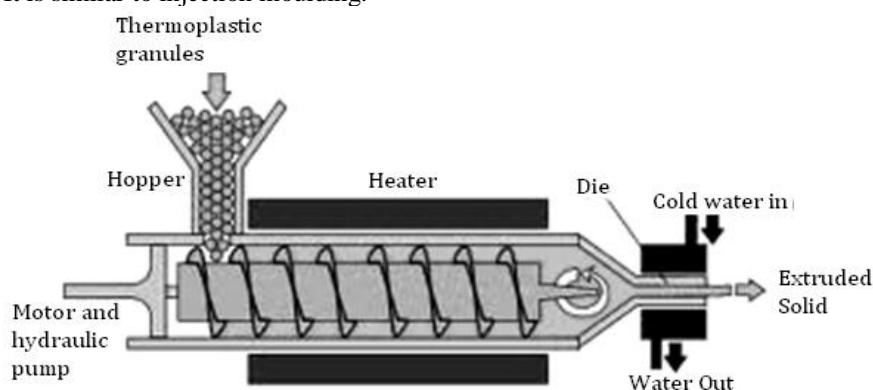
Blown film extrusion moulding:

- ♦ Plastic film is usually produced using a process called 'blown – film'
- ♦ Molten plastic is injected into a blow film machine and blowing air through the molten plastic.
- ♦ This creates a bubble in the molten plastic.
- ♦ The bubble is blown vertically, creating a long bubble like a party balloon.
- ♦ The air is blowing into the outside of the balloon from a cooling ring at the base of the balloon
- ♦ blown air cools the balloon & then a thin film is produced.
- ♦ It is guided through pinched rollers which make the film flatten and it is wound on the roller.
- ♦ The flattened balloon is called lay flat tube.
- ♦ It is used to make carry bags.
- ♦ Polyethylene is the most commonly used plastic in this process.



Extrusion moulding:

- ♦ This method is used to produce continuous sheets, rods, threads, cords and cables.
- ♦ It is similar to injection moulding.



- ♦ Dry plastic material is placed into heated injection chamber.
- ♦ At the end of the chamber, the material is forced out of a small ring opening (or) a die in the shape of the desired finished product.

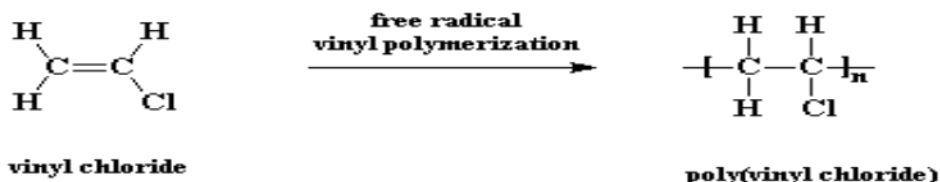
- ♦ Extruded out plastic is placed on a moving conveyor belt for uniform cooling.

Individual polymers

Poly vinyl chloride:

Preparation:

Polyvinyl chloride is prepared by heating a water emulsion of vinyl chloride in presence of benzyl peroxide or hydrogen peroxide in autoclave under pressure.



Properties: Polyvinyl chloride is

- Colourless
- Odourless
- Non-inflammable
- Chemically inert
- Soluble in hot ethyl chloride

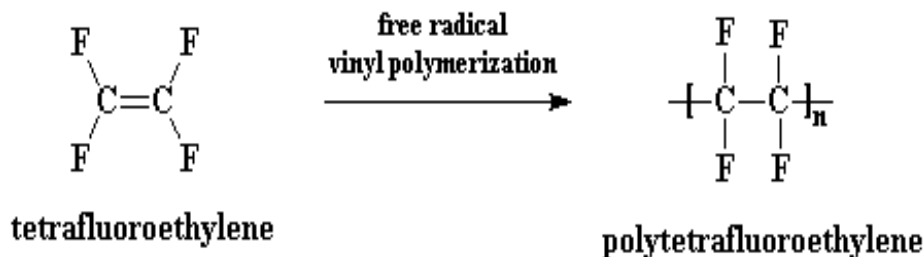
Uses: Used for the preparation of

- Safety helmets
- Light fittings
- Tyres, cycles
- Refrigerator components

Teflon (poly tetra fluoro ethylene ,PTFE) or Fluon:

Preparation:

Poly tetra fluoro ethylene is prepared by polymerization of a water emulsion of tetra fluoro ethylene in presence of Benzoyl peroxide under pressure.



Properties:

- ♦ Due to presence of highly electro negative fluorine atom, very strong attractive forces between different chains.
- ♦ Due to strong attractive forces
 - Teflon is extreme tough
 - High softening point (>350°)
 - High chemical resistance towards all chemicals except hot alkali metal and hot fluorine

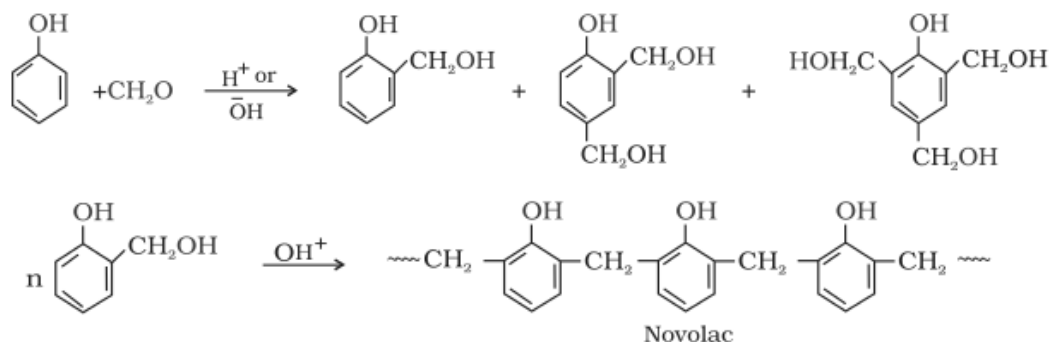
Uses: Used as

- ▲ Insulating material for motors, cables
- ▲ Coatings
- ▲ Impregnating glass
- ▲ Asbestos fibre
- ▲ Clothes
- ▲ Wires
- ▲ Fittings

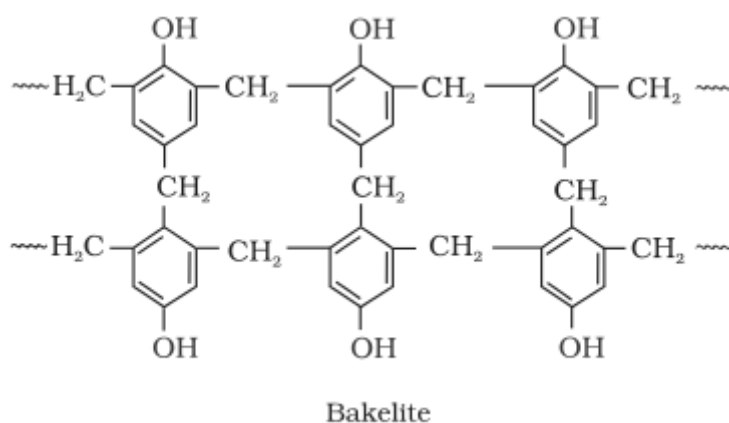
Phenol formaldehyde resins: Bakelite

Preparation:

- These are formed by the poly condensation between phenol and formaldehyde.
- The reaction is catalysed by acid or base.
- The initial product is Novolac (linear product).



- Novolac on heating with formaldehyde forms Bakelite.



Properties: These are

- Rigid
- Hard, resistant to heat
- With stand to high temperature
- Good insulator

Uses: Used for the preparation of
Electrical insulator parts like

- Switches
- Plugs
- Handles

Moulded articles like

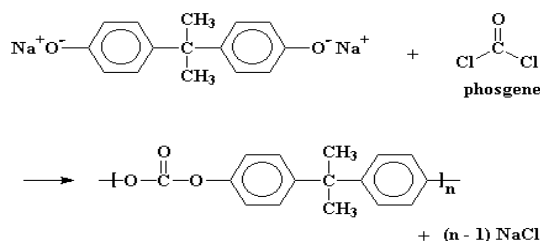
- Telephone parts
- Cabinets for T.V
- Cabinets for radio

Poly Carbonates

Polymers containing **-O-CO-O-** functionality

Preparation:

By the treatment of bisphenol-A with phosgene in presence of sodium hydroxide.



Properties: Polycarbonates

- ✍ Good electrical insulators
- ✍ Heat and flame resistance
- ✍ Easily soluble in organic solvents and alkali solvents
- ✍ Undergo large plastic deformation without cracking
- ✍ Highly transparent to visible light
- ✍ Low scratch resistance

Uses: Used in

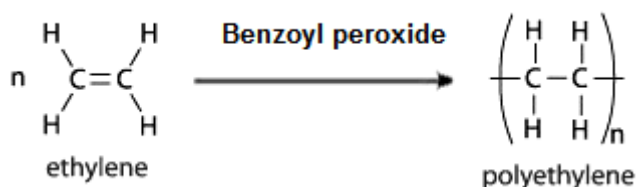
- ✍ Preparation of Compact disc, DVD'S
- ✍ Construction industry
- ✍ Automotive components
- ✍ Aircraft components
- ✍ Manufacture of lenses like sunglasses, eyeglasses

Disadvantages:

- ✍ Polycarbonate containers or bottles used for the storage of food are controversial because their hydrolysis releases bisphenol-A which causes several health hazards.

Polyethylene:**Preparation of LDPE:**

LDPE (low density polyethylene) is prepared by heating ethylene at 100-300°C under high pressure 1500 – 3000 atm in presence of benzoyl peroxide (as initiator) and benzene or chloro benzene (as solvent).

**Properties:** Density range from 918-935 Kg/m³

- Very tough
- Flexible

Uses: Used for the preparation of

- Domestic ware
- Squeeze bottles
- Tubing
- Cold water tanks

Preparation of HDPE:

HDPE (High density polyethylene) is prepared by heating ethylene at approximately 300°C under 1 atm pressure in presence of aluminium based oxide (as Catalyst) and paraffin or cyclo paraffin (as diluting agent).

Properties: Density range from 935 - 965 Kg/m³

- Stronger
- Stiffer

Uses: Used for the preparation of

- Dustbins
- Fluid containers
- Pipes
- Bottle crates
- Sheets, which are employed for tank linings

RUBBERS

✍ Rubber is an elastomer.

✍ A polymer which regains its original shape after removing applied force is called elastomer.

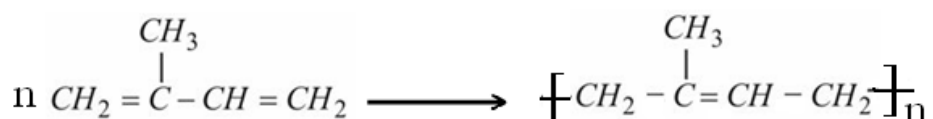
- Natural rubber, Thiokol, neoprene etc.

Characteristics of Elastomers

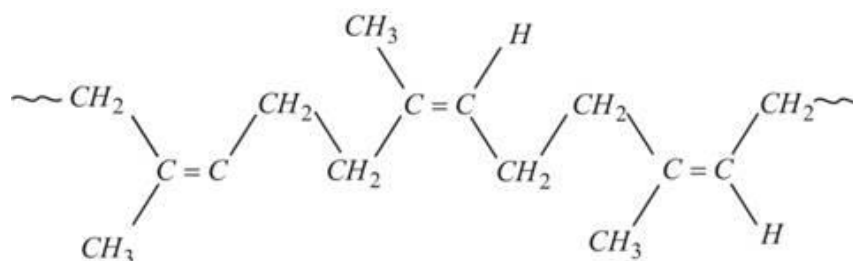
- ✗ Elastomers regain original shape after removing stress.
- ✗ Elastomers are sticky at higher temperatures.
- ✗ Elastomers exist at above glass transition (T_g) temperature.
- ✗ Elastomers absorb moisture.
- ✗ Elastomers have less chemical resistance.
- ✗ Elastomers have weak intermolecular attractions.
- ✗ Elastomers have coiled structures.

Natural Rubber

- ♣ Latex is collected from a tree known as *Hevea brasiliensis*.
- ♣ Latex is a water suspension.
- ♣ Rubber is coagulated by adding acetic acid or formic acid or electrophoresis of suspension.
- ♣ Separated rubber is then further processed.
- ♣ Natural rubber is Cis – poly isoprene formed from isoprene (2 – methyl 1, 3 – butadiene) by the biochemical reaction.

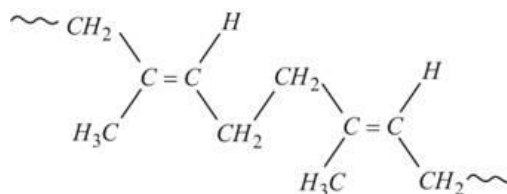


- ♣ The repeating unit is Cis configuration which is responsible for elastic property.
- ♣ The molecular weights of rubber molecules range from 50,000 to 30,00,000.
- ♣ Asia contributes 90% of rubber products. Thailand, Malaysia and Indonesia are major producers of rubber.



Gutta percha:

- It is obtained from mature leaves of *dichopsis gutta* and *palagum gutta* trees.
- Tran's polyisoprene is gutta percha.
- It is crystalline polymer & the chains are very closely packed.
- It leads to the formation of rod like structure.
- It is used to fill dental cavities and to prepare conveyor belts.

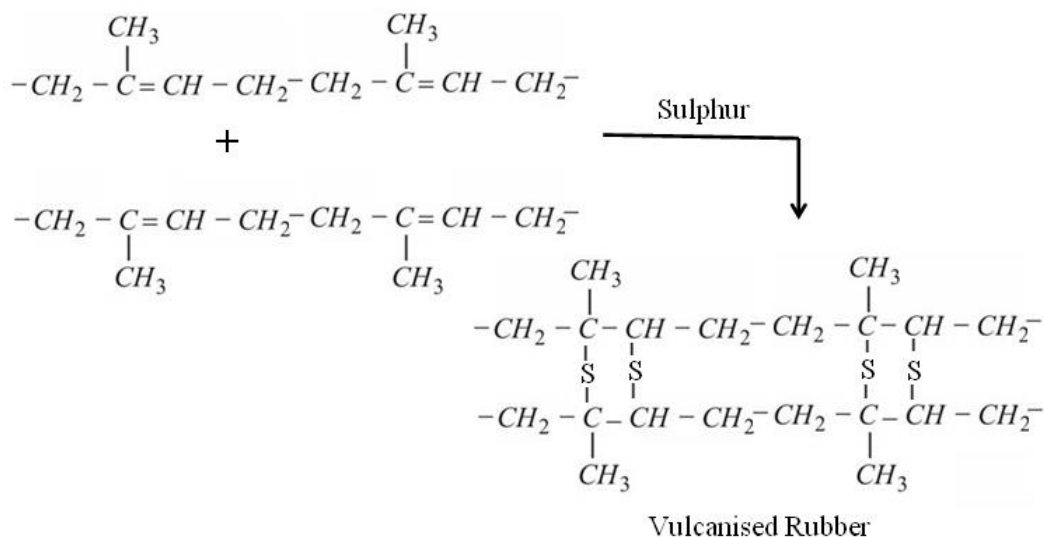


Compounding of rubber

To improve the qualities from rubber, it is mixed with various chemicals like plasticizers, stabilizers, fillers, vulcanizing agents etc is called compounding of rubber.

1) Vulcanization of rubber:

- ♣ To improve the undesirable properties of rubber, it is heated in the presence of sulphur.
- ♣ Heating of rubber in presence of sulphur is called vulcanization.
- ♣ On heating three dimensional cross linkings of the chains through sulphur atoms formed.
- ♣ Rubber becomes stiff.
- ♣ This process converts rubber into insoluble, infusible thermosetting polymer.



2) Accelerators:

- ☞ Vulcanization process is catalyzed by adding accelerators.
- ☞ They reduce the time required for vulcanization.
- ☞ Accelerators may be inorganic or organic.
 - **Inorganic:** Lime, Magnesia, ZnO
 - **Organic:** Aldehydes, Amines, thio carbonates
- ☞ 0.5 to 1% of the accelerator is used.

3) Antioxidants:

- ☞ Antioxidants protect the rubber from oxidation by O₂, ozone and light.
 - Example: Phenyl-naphthylamine, Phenolic substances, Phosphate.

4) Reinforcing agents:

- ☞ They provide strength, rigidity and toughness to the rubber.
 - Example: Carbon black, ZnO, MgCO₃, CaCO₃ and clays.

5) Fillers:

- ☞ The main function of the fillers is to change the physical properties and to reduce the cost.

6) Plasticizers:

- ☞ These are added to impart greater tenacity and adhesion to the rubber.
 - Example: Vegetable oils, Waxes, Stearic acid, Rosin etc.

7) Coloring agents:

- ☞ These are added to impart the desired colour to rubber.

TiO₂, ZnS, BaSO₄ - White
 PbCrO₄ - Yellow
 Ferric Oxide - Red

Sb₂S₃ - Crimson red
 Ultramarine- Blue
 Cr₂O₃ - Green

8) Miscellaneous agents:

- ☞ Baking soda is added to prepare sponge rubber.
- ☞ Silica and pumice are added to cause abrasiveness.
- ☞ Processed rubber is converted into various articles by calendaring (or) injection moulding (or) compressed moulding.

Advantages of vulcanization:

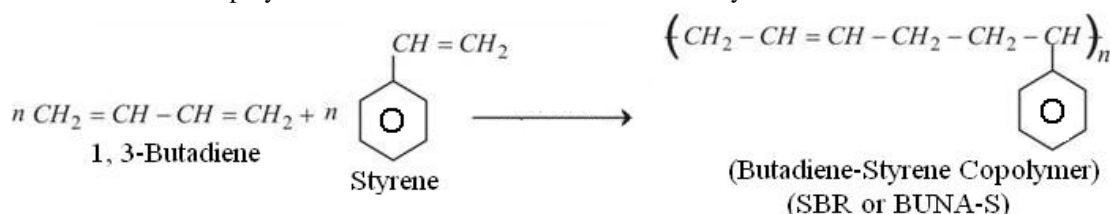
- ✍ Working temperature range is -40°C to 100°C.
- ✍ Tensile strength increases 2000Kg/cm²
- ✍ Water absorption capacity is reduced.

- ✍ Elasticity is reduced.
- ✍ Resilience is improved.
- ✍ Resistance to organic solvents such as benzene, CCl₄, fats and oils.
- ✍ Resistance to abrasion, ageing and reactivity with O₂ and O₃.

Synthetic rubber

Buna –S (or) SBR (styrene butadiene rubber):

- It is prepared by free radical polymerization in the presence of free radical initiator cumene hydrogen peroxide.
- It is a copolymer consists of 75% butadiene and 25% styrene.



Properties:

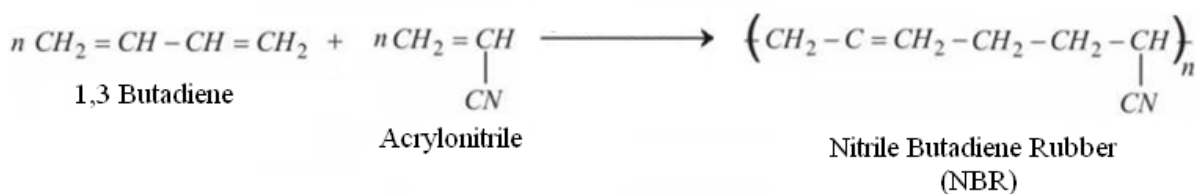
- Excellent abrasion resistance.
- Very tough.
- high load bearing capacity
- Sensitive to oil, waste water and ozone.
- Good electrical properties.
- Poorer resilience than that of natural rubber.

Uses:

- Used for the manufacture of
 - Tyres
 - Shoes heels
 - Shoe soles
 - Gaskets
 - Chewing gums
 - Electrical insulation
 - Floor tiles
 - Foot wear components

Buna –N (or) Nitrile butadiene rubber (NBR):

- It is prepared by free radical polymerization in the presence of free radical initiator cumene hydrogen peroxide.
- It is a copolymer of 75% butadiene and 25% acrylonitrile.



Properties:

- It is oil resistance. If the content of acrylonitrile more than 40% then it is extremely oil resistance.
- Resistant to heat, light and acids.
- High load bearing capacity.
- It has good tensile strength
- It has good abrasion resistance.
- It is less resilient than natural rubber.

Applications:

- Used for the manufacture of
 - Oils
 - Hoses

- Conveyer belts
- Tank lining
- High altitude air craft components
- Used as latex in textile and cloth
- Printing rollers

Polyurethane:

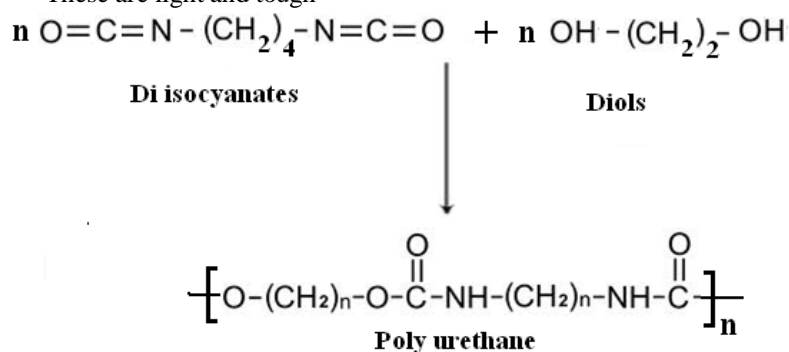
- Polyurethane polymer has urethane (-RNHCOOR-) linkage.

Preparation:

- Polymerization of diols and di isocyanates by addition polymerization gives polyurethane.

Properties:

- High strength
- Good resistance to ozone, oxygen, aromatic hydrocarbons
- These are light and tough



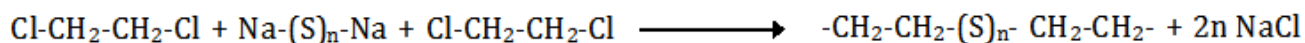
Uses:

- ❖ Used in beading and truck seating
- ❖ Used in thermal insulation
- ❖ Used in foot wear
- ❖ Electronic instruments
- ❖ Structural parts
- ❖ Gel pads
- ❖ Print rollers
- ❖ Flexible plastic - staps, bands

Thiokol (Poly Sulphide rubber):

Preparation:

- ♦ It is obtained by the polymerization of ethylene dichloride with sodium poly sulphide.



Properties:

- ♦ The property of this material depends upon the length of the chain and number of sulphur atoms present in it.
- ♦ With four sulphur atoms per monomer – the product is rubbery.
- ♦ Where as with 2 sulphur atoms per monomer – the product do not act as rubber.
- ♦ It can withstand cold but not heat.
- ♦ It is unaffected by petrol, oil etc.

Uses: It is used for making

- ♦ Hose pipes
- ♦ Linings tanks

Conducting polymers

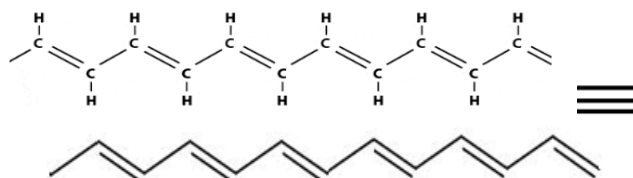
- ♣ Polymers that can conduct electricity are called conducting polymers.
Ex: Poly acetylene, poly aniline, poly pyrrole, poly thiophene, poly quinolene etc.
- ♣ On the basis of their conduction properties conducting polymers are classified into two types
 - ⌘ Intrinsically Conducting Polymers
 - ⌘ Extrinsically Conducting Polymers
- ✎ Intrinsically conducting polymers, which are able to conduct through either
 - ⌘ Conjugation
 - ⌘ Doping
- ✎ Extrinsically conducting polymers that are able to conduct through

- ☞ External Elements Filled
- ☞ Blending

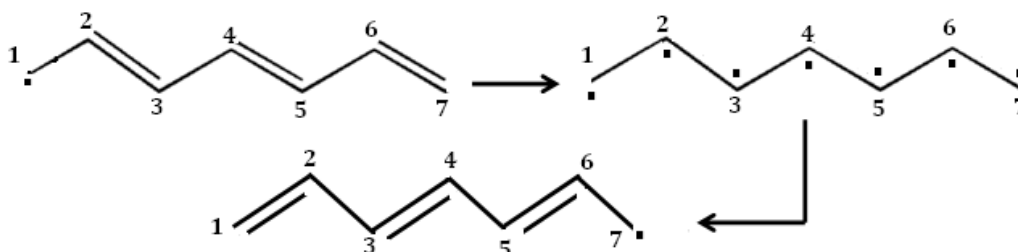
Intrinsically Conducting Polymers:

Conjugation:

- These polymers contain conjugated or delocalized π - e^- pairs in the back bone responsible for conduction.
- The orbital's of conjugated π - e^- form valency band as well as conduction band and they are extended over the entire polymer molecule.
- When current is passed electrons enter conduction band due to shifting of π - e^- .
- Ex; Conduction of poly acetylene due to conjugation.



- When current is passed into poly acetylene, the electron enters the unhybridised P-orbital of carbon atom and moves through the C – C bonds.



Explanation:

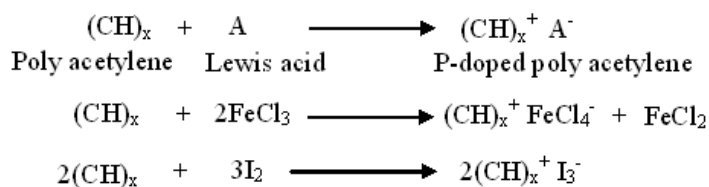
- ◆ When the electron enters the chain, breakage of π - bond takes place and a new π -bond is formed.
- ◆ π -bond between 2&3 is broken and a new π - bond is formed between 1&2.
- ◆ Similarly π -bond between 4&5 is broken and anew π -bond is formed between 3&4.
- ◆ π -bond between 6&7 is broken and a new π - bond is formed between 5&6.
- ◆ A long as current flows in to the polymer this process is continued and there by a conducting path is created in the polymer.

Doped conducting polymers:

- ♣ Polymers can conduct due to doping and by using doping agents or dopants.
- ♣ Doping of conducting polymers can be two different types.
 - p-Doping (or) Oxidative Doping
 - n-Doping (or) Reductive Doping

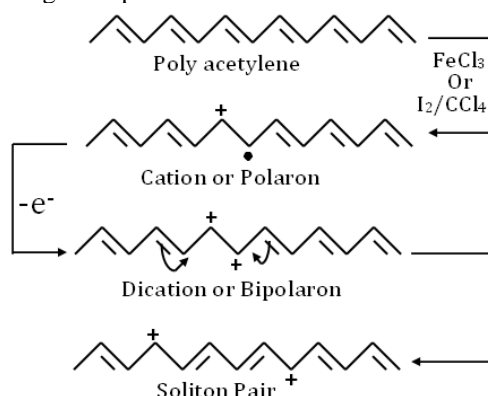
p-Doping (or) Oxidative Doping:

- In this method the polymer is treated with an oxidizing agent like Lewis acid which acts as a dopant.
- Examples of dopants used: FeCl_3 , I_2 etc.



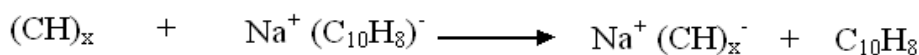
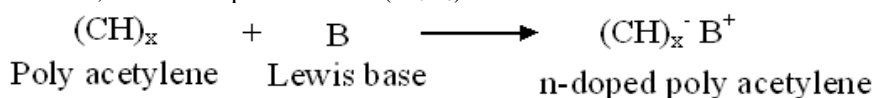
Mechanism of p-Doping:

- ♣ During this process, oxidation of polymer takes place due to dopant and forms a cation called Polaron.
- ♣ On further oxidation of polymer results in the formation of a dication or bipolaron.
- ♣ The charges get separated by forming a soliton pair.
- ♣ The cation occupies the band gap between valency band and conduction band, thereby creating a conducting path.
- ♣ So electrons move through this path.

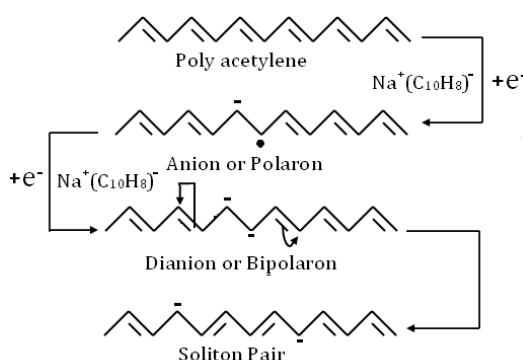


n-Doping (or) Reductive Doping:

- ♣ In this method, the polymer is treated with a reducing agent like a Lewis base which acts as a dopant.
- ♣ Ex; Sodium Naphthalide $\text{Na}^+ (\text{C}_{10}\text{H}_8)^-$



Mechanism of n-doping:



- ♣ During this process, reduction of polymer takes place due to dopant and forms an anion called Polaron.
- ♣ On further reduction of polymer results in the formation of a dianion or bipolaron.
- ♣ The charges get separated to form a soliton pair.
- ♣ The anions occupy the band gap between valency band and conduction band thereby creating a conducting path.
- ♣ So that electrons move through this path.

Extrinsically Conducting Polymers:

- ♣ Some of the polymers conduct electricity due to externally added ingredients to them. They are of two types.
 - Polymers with conductive elements filled

- Blended conducting polymers

Polymers with conductive elements filled:

- ◆ In these polymers, the polymer acts as a 'binder' and holds the conducting element added so that the polymer becomes a conductor.
- ◆ Examples of conductive elements are carbon black, metallic fibers, metallic oxides etc.
- ◆ Minimum concentration of conductive element to be added so that the polymer becomes a conductor is called percolation threshold.
- ◆ The conductive elements added to create a conducting path in the polymer.

Blended conducting polymers:

- ◆ These polymers are obtained by blending a conventional polymer with a conducting polymer.
- ◆ The polymer thus obtained has good chemical, physical, electrical properties and mechanical strength.
- ◆ Ex; 40% pyrrole when blended with a conventional polymer, the combination gives conducting polymer with good impact strength.

Applications of conducting polymers in biomedical devices:

- ★ Conducting polymers are used in preparation of artificial devices like Heart valves, kidneys, and lungs.
- ★ Poly methyl methacrylate is used as bone cement used for some fracture repairs.
- ★ Poly methyl methacrylate is also used for artificial teeth.
- ★ Used in preparation other medical devices include sutures, pins, screws used during surgery on bones, ankles, hands etc.
- ★ They are used to prepare contact lenses which permit O₂ to the eyes. These lenses are called rigid gas permeable lenses (RGP).

Applications of conducting polymers in electronics:

- ☞ They are used in rechargeable batteries.
- ☞ They are used in analytical sensors of p^H, O₂, NO₂, SO₂, NH₃ etc.
- ☞ Used in photo voltaic cells. Ex; Al/polymer/Au.
- ☞ Used in telecommunication systems.
- ☞ Used in transistors and diodes.
- ☞ Used in solar cells.
- ☞ Used as wiring in air crafts and aerospace parts.

NANO MATERIALS

Introduction

- In recent years, nano science and technology have grown rapidly.
- Nano chemistry has wide applications in almost all the fields.
- The word “Nano” means “dwarf” in Greek language.
- Nano is one billionth parts.
- A nano second is one billionth of a second and a nano meter is one billionth of a meter. i.e., $1 \text{ nm} = 10^{-9} \text{ m}$

Examples

- ▲ Size of atom is up to 10 nm.
- ▲ DNA molecules are about 2.5 nm wide.
- ▲ RBC size is 1000 nm.
- ▲ A two meter tall person is two billion nano meters tall.

NANO CHEMISTRY

It is the science of tools, technologies and methodologies for chemical synthesis, analysis and biochemical diagnostics performed in nano litre to fermeto litre level. i.e., Nano = 10^{-9}
fermeto = 10^{-15}

NANO MATERIALS

Nano materials are the materials having components within size less than 100 nm.

Nano particles are the particles having size 1-50nm.

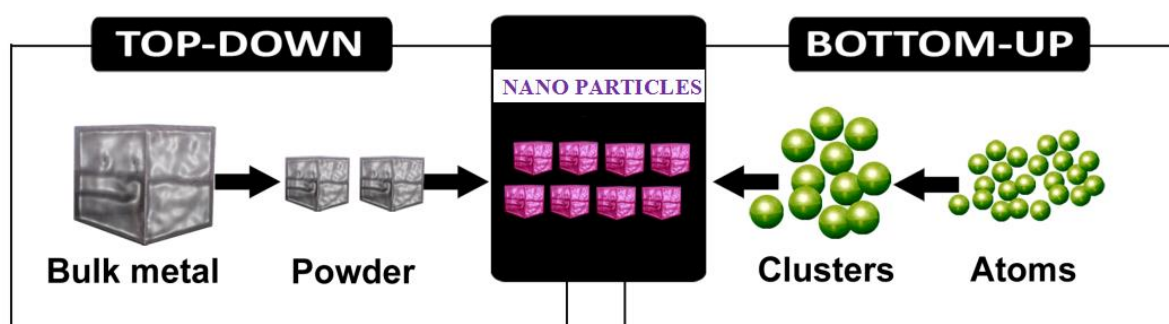
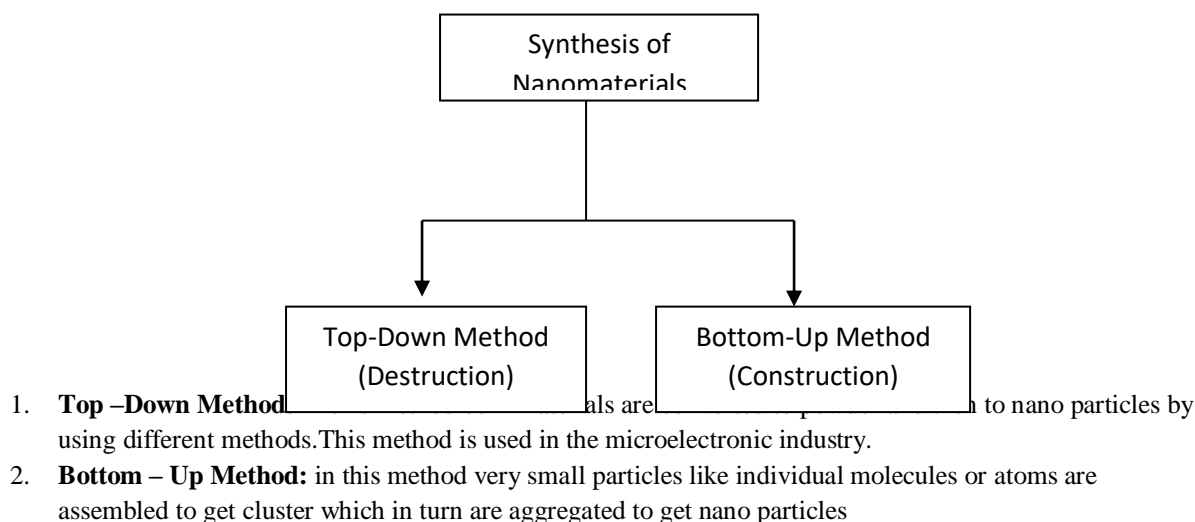
- ▲ Nano materials in one dimension are layers like thin films or surface coatings.
- ▲ Nano materials in two dimensions are tube like nano tubes and nano wires.
- ▲ Nano materials in three dimensions are particles like precipitates, colloids and quantum dots.

Quantum Dot (Three Dimensional Nano Materials)

- ▲ The size of the quantum dot is one billionth of a meter.
- ▲ The key to the quantum dot is in the electrons.
- ▲ Electrons occupy are of two bands (valency band & conduction band) in a crystal.
- ▲ By supplying energy, an electron is excited from valency band (VB) to conduction band (CB).
- ▲ As it moves from one band to the other, it creates a hole which is positively charged.
- ▲ Together, the hole and the electron are referred to as an exciton.
- ▲ The electron and the hole in the exciton normally keep their distance from each other.
- ▲ This is called the exciton Bohr radius.
- ▲ If the crystal is reduced in size, it crowds this gap.
- ▲ Once that happens, it changes the crystals ability to absorb and emit energy.
- ▲ At this point, quantum dot is created.
- ▲ Different colours can be obtained by reducing or increasing the size of the quantum dot.
- ▲ **Applications**
- ▲ Used to track trespassers in restricted areas.
- ▲ Used as light emitting diodes in sign display
- ▲ Used as cell staining for life science.

GENERAL METHODS OF PREPARATION OF NANO MATERIALS

There are basically two major types of approach for the preparation of nanomaterials.



SOL- GEL METHOD

- Sol gel method is bottom up approach for the synthesis of nano materials and it is very long known since 1980.
- A colloid suspended in a liquid is called as **sol**.
- A suspension that keeps its shape is called **gel**.
- Thus sol-gel is suspensions of colloids in liquids that keep their shape.
- The sol-gel formation occurs in different stages.

Step – I: Precursor (metal oxide) undergoes hydrolysis by continuing stirring for 24hrs gives sol.

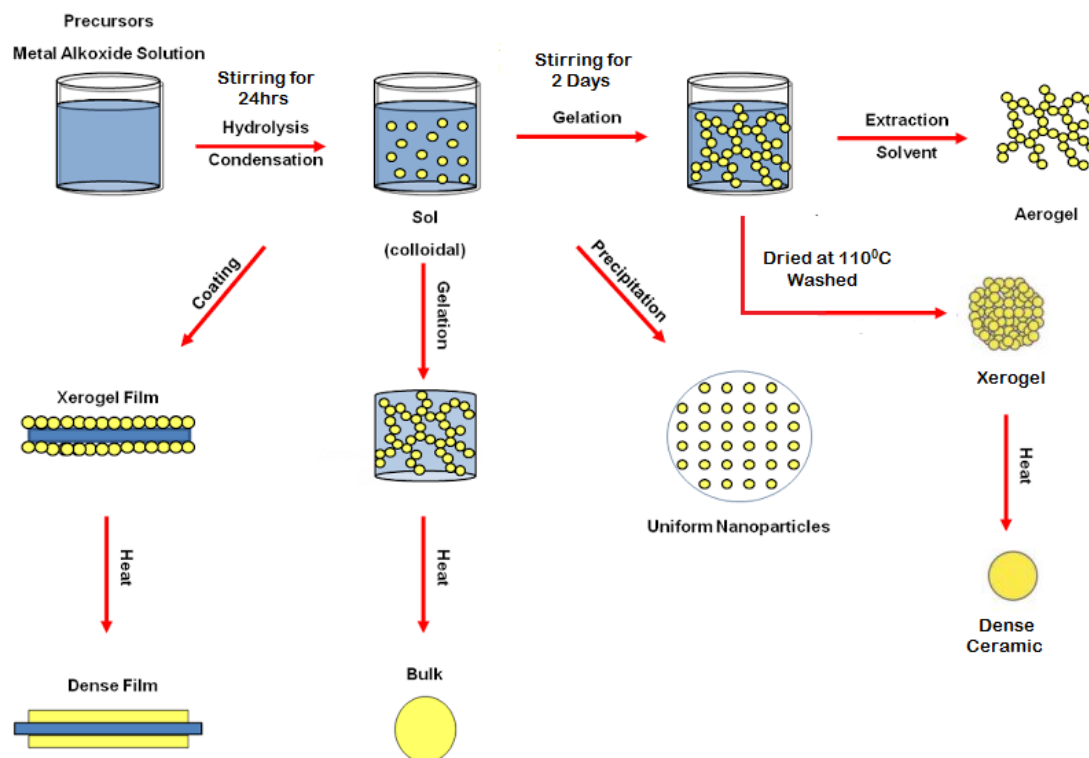
Step – II: On continues stirring for 2 days, sol is converted into gel. This results increase in the viscosity of solution.

Step – III: On drying at 110°C, gel is converted into Xerogel.

Step – IV: On extraction of solvent from the gel produces aerogel.

Step – V: Sol on precipitation uniform nano particles is formed.

Step – VI: Sol is coated on a material and heated, dense layer is formed.



CHEMICAL REDUCTION METHOD

- In this method is also belongs to bottom up approach.
- Metal nano particles are prepared by this method like nano silver particles, nano platinum particles etc.
- General preparation is carried out by mixing metal salt with phase transferring agents and reducing agents.
- Different types of phase transfer agents are used for the preparation of different metal nano particles.

The method involves following steps.

- To the metal salt solution, precursor, stabilizer and reducing agents are added.
- This mixture is allowed to stand for sometime, and then the nano particles are separated out.
- The formed nano particles are purified by centrifugation.
- A dried powder of nano particle is obtained by freeze drying.

For example: Silver nano particles are obtained by following method.

- Metal salt solution - silver nitrate
- Precursor and stabilizer - sodium dodecyl sulphate (SDS)
- Reducing agents – hydrazine hydrate, citrate solution
- This mixture is allowed to stand for sometime, and then the nano particles are separated out.
- The formed nano silver particles are purified by centrifugation.
- A dried powder of nano silver particle is obtained by freeze drying.

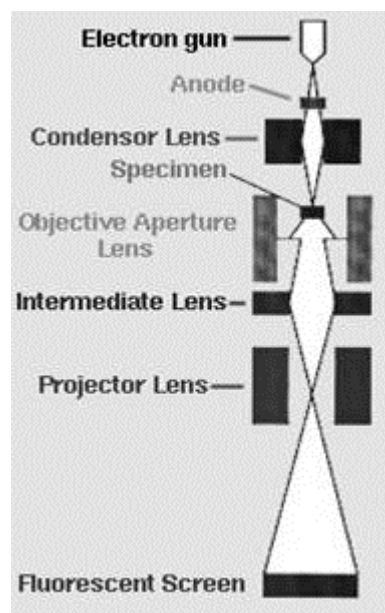
METHODS OF CHARACTERIZATION OF NANO PARTICLES

TEM (Transmission Electron Microscopy)

1. TEM is used for the determination of particle size, size distribution and morphology of the nanoparticles.
2. TEM is a technique whereby a beam of electrons is transmitted through a thin specimen, interacting with the specimen as it passes.
3. An image is formed from the interaction of the electrons transmitted through the specimen; the image is magnified and focused onto fluorescent screen or onto

photographic film, for a record of the sample.

4. Areas of dense material (such as solid nano particles) absorb the electrons and appear as dark areas on the viewing screen.
5. Less dense material (such as coating around the nano particles) allows the electrons to pass through more freely and appear as lighter areas.
6. TEM images can also be used to judge whether good dispersion has been achieved or whether agglomeration is present in the system.



BET (Brunauer Emmett Teller Method)

- ★ This method gives the information about the physical [adsorption](#) of [gas molecules](#) on a [solid surface](#).
- ★ It is an important analytical technique used for the measurement of the specific surface area of a material.
- ★ BET is an extension of the Langmuir theory, which is a theory for monolayer molecular adsorption and the BET theory refers to multi layer molecular adsorption.
- ★ The sample is weighed and placed into a vacuum chamber.
- ★ The sample is degassed and cooled down to a constant temperature by means of an external bath containing liquid nitrogen.
- ★ Other inert gases, such as Ar or Kr, can also be used.
- ★ N₂ gas is admitted and adsorbs on the sample surface.
- ★ The BET theory is then used to determine the amount of gas necessary to form a monolayer on the surface, also called the monolayer capacity.
- ★ From the monolayer capacity, the known surface requirement of a single adsorbate molecule and the mass of the sample, the specific surface area in m²/g can be calculated.

CARBON NANO TUBES (CNTS)

- ✍ Carbon nano tubes were discovered in 1991 by Iijima.
- ✍ Carbon nano tubes are long thin cylinders of carbon.
- ✍ These are large macro molecules that are unique for their size, shape and physical properties.
- ✍ CNTs are allotropes of carbon with a nano structure having a length to diameter ratio greater than 1,00,000.
- ✍ A sheet of graphite rolled into a cylinder. Rolled graphite sheets are called Carbon nano tubes.
- ✍ CNT have very broad range of electronic, thermal and structural properties which vary with the dimensions of tubes.

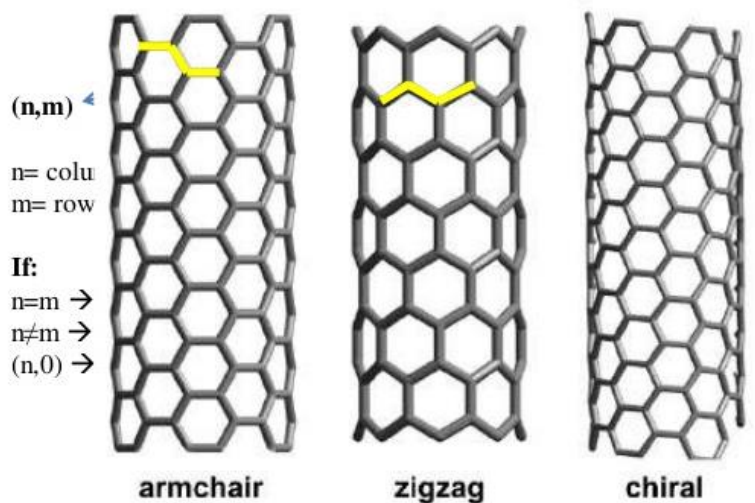
TYPES OF CARBON NANO TUBES

- Carbon nano tubes are lattice structure of carbon atom.
- Each carbon atoms are covalently bonded to each other.
- Depending upon the arrangement of carbon atoms, these are classified into two types.
 - Single walled nano tubes (SWNTs)
 - Multi walled nano tubes (MWNTs)

Single walled nano tubes (SWNTs)

- ♣ SWNT have diameter close to one nano meter
- ♣ It is obtained by wrapping graphene in to seamless cylinder.

- ♣ One atom thick layer of graphite is graphene.
- ♣ One useful application of SWNT's is in the development of first intermolecular field effect transistors (FET).
- ♣ Based on the way the graphene sheet is wrapped SWNT's are three types.
 - a) Zig – Zag
 - b) Arm Chair
 - c) Chiral



Graphene sheet consisting of pair of indices n, m

Arm chair

- If $n=m$ the nano tubes are called armchair.
- The lines of hexagons are parallel to the axis of the nano tube.

Zig – Zag

- If $m=0$ the nano tube are called zig-zag.
- The lines of carbon bonds are down the centre.

Chiral

- Remaing all are Chiral.
- It has twist or spiral around the nano tube.

Multi walled nano tube (MWNTs)

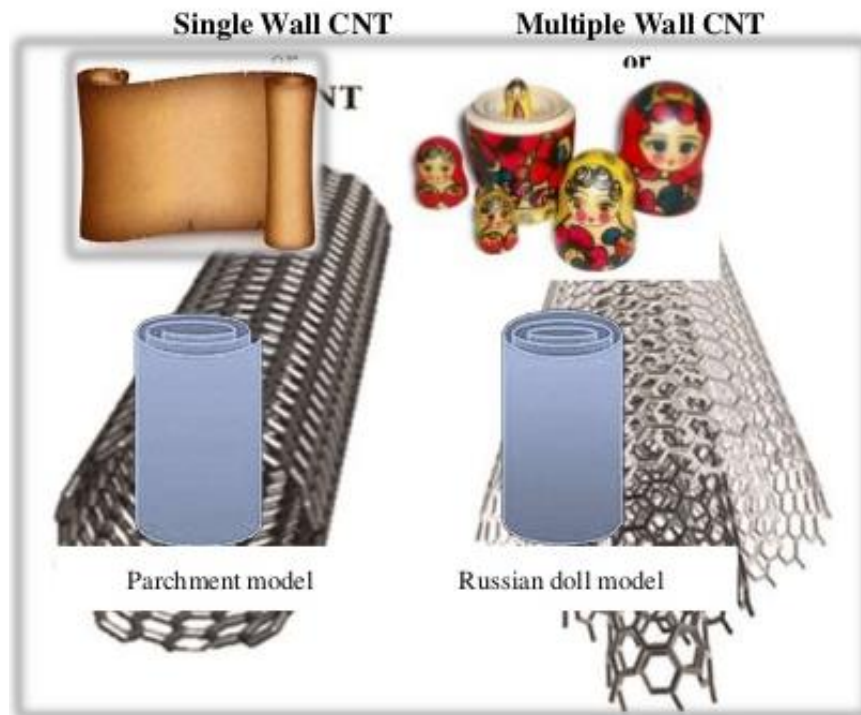
- ✍ It consists of multiple rolled layers of graphite.
 - ✍ These are concentric tubes.
 - ✍ The distance between two layers is 3.3 \AA .
 - ✍ These are two models.
- a) Russian doll model b) Parchment model

Russian doll model

- ✍ Sheets of graphite are arranged in concentric cylinders.
- ✍ A tube is arranged inside the larger tube.

Parchment model

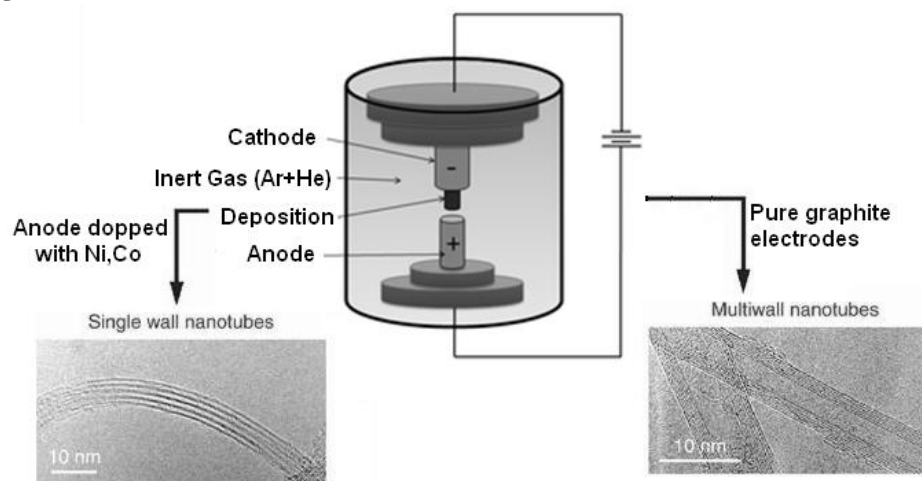
- ✍ A single sheet of graphite is rolled in around itself like a rolled News paper.



SYNTHESIS OF CARBON NANO TUBES

Carbon nano tubes are synthesized by 3 methods.

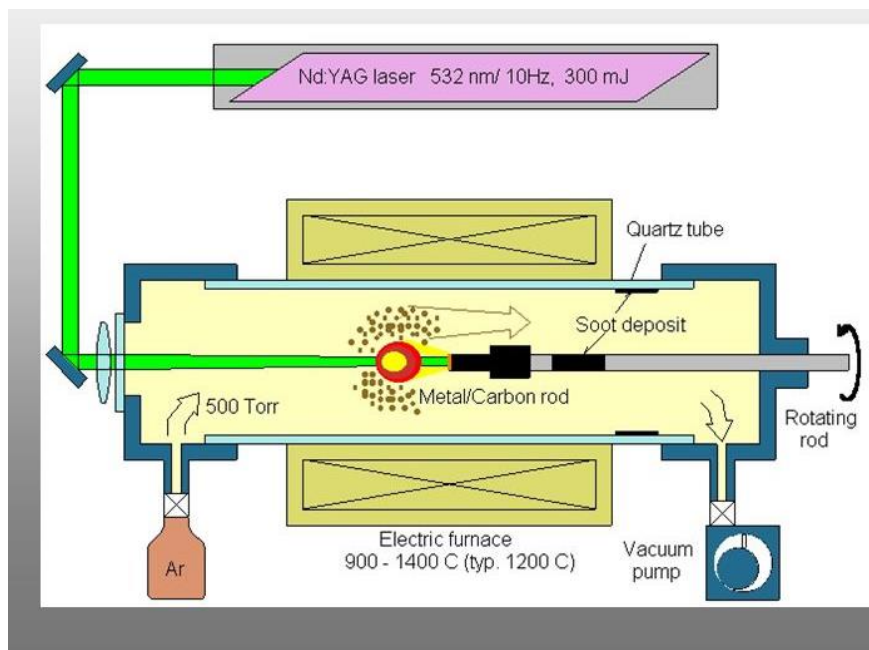
1. Arc Discharge Method



- This is the most common and easiest way of producing CNT.
- This method creates nano tubes through the arc vaporization of two carbon rods placed end to end, separated by 1mm.
- A direct current of 50 to 100 Amps driven by approximately 20 V creates high temperature discharge between the two electrodes.
- The discharge vaporizes one of the carbon rods and forms a small rod shaped deposit on the other rod.
- Size of the nano tubes formed depends up on the mixture of He & Ar gas used in the discharge tube.
- This mixture shows different diffusion co-efficient and thermal conductivities which affect the size of CNTs formed.
- By this method, it is possible to produce SWNTs (or) MWNTs selectively.
- Single walled nano tubes are prepared by anode dopped with Ni, Co.

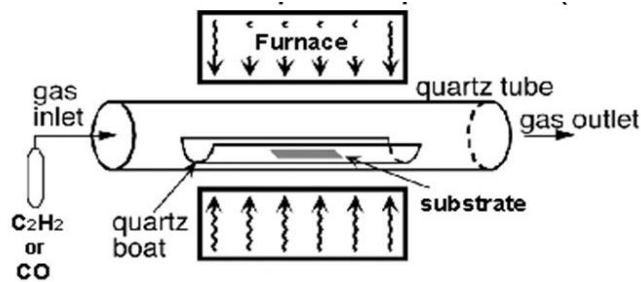
2. Laser Ablation Method

- In 1995, Smalley's group produced CNTs using laser ablation technique.
- In laser ablation technique a high power laser is used to vaporize carbon from a graphite target at high temperature.
- Both SWNTs and MWNTs can be produced.
- To produce SWNTs the catalyst must be added to graphite.
- The laser is focused on the carbon target containing 98.8% graphite, 1.28% cobalt (or) nickel composite placed in 1200°C quartz furnace under argon atmosphere under 500 torr pressure.
- These conditions are achieved for production of SWNTs.
- Argon gas carries the vapour from the high temperature chamber in to water cooled collector position at down stream.
- CNTs produced by this method are purity up to 90%.
- Quantity and quality of CNTs depend on laser power, wave length, temperature, pressure, type of inert gas, type of catalyst.



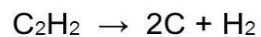
3. Chemical Vapour Deposition Method (CVD)

- CH₄, CO and acetylene gases are used as a source for carbon atoms.
- Using heated coil, the energy is supplied to the gas molecules and carbon atoms are separated by cracking.
- Then the carbon atoms diffuse towards substrate which is heated and coated with Ni or Fe or Co where it will bind.
- By this method, alignment and position of the carbon tubes can be controlled in nano scale.
- Even length of the nano tube is also controlled.
- CVD is a two step process.
- In the first step, transition metal is coated on the substrate by sputtering.
- In the second step, nano tubes are deposited on the specified areas of substrate by thermal annealing or chemical etching of catalyst.
- NH₃ may be used in etching.
- The temperature maintained in this process is 650 – 900°C.
- Yield in this method is 30%.



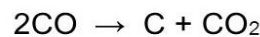
MWCNT

600-800 °



SWCNT

900-1000 °



PROPERTIES OF CARBON NANO TUBES (NANO MATERIALS)

CNTs have unique chemical, optical, electrical and structural properties which are useful in bio sensing and drug delivery systems for treating various diseases.

Mechanical Properties

Strength:

- Carbon nano tubes are the strongest and stiffest materials.
- They possess high tensile strength and Young's modulus.
- This strength is due to $\text{SP}^2 - \text{Sp}^2$ bonding between carbon atoms.
- CNTs are much softer in the radial direction than along the tube axis.

Hardness:

- Super hard material is prepared by compressing SWNTs to above 24 GPa at room temperature.
- The bulk modulus of compressed SWNT was 462 – 546 GPa.

Electrical Properties

- ✓ CNTs are metallic or semi conducting depending on their structure.
- ✓ If $n=m$, the nano tube is metallic.
- ✓ If $n-m$ is multiple of 3, then nano tube is semi conducting.
- ✓ Some nano tubes have higher conductivities than that of copper.

Vibrational Properties

- ✓ Atoms in CNT are continuously vibrating back and forth.
- ✓ **A_{1g} Mode:** It involves in and out oscillations.
- ✓ **E_{2g} Mode:** Here squashing of the tube takes place (Oscillation between sphere and ellipse).

APPLICATIONS OF CARBON NANO TUBES

- The small size, strength and unique properties of these nano materials found greater applications in various fields of engineering.

Engineering Applications

- ▲ Sensors
- ▲ Radiation sources
- ▲ Hydrogen storage media
- They are used as efficient tools for transporting therapeutic molecules.
- CNTs attached with peptides, proteins, nucleic acids, drugs are used to deliver the materials to cells or organs.
- CNTs are used in nano biotechnology and nano medicine.

Applications in Fuel Cell

- ▲ SWNTs are effective as a hydrogen storage material for fuel cell electric vehicles.

- ♠ Electrodes constructed with nano tubes are light weight and thin.
- ♠ They work as good as conventional electrodes.

Applications in Catalysis

- ♠ A catalyst having CNT makes reaction milder, safer and more selective.
- ♠ CNTs are used as catalyst or catalyst additives or catalyst promoter.
- ♠ Oxidized CNT with phosphorous is used as a catalyst for the conversion of butane to butadiene.
- ♠ Some chemical reactions are carried out inside the nano tubes.
 - Reduction of NiO to Ni
 - Reduction of AlCl_3 to Al

Application in Medicines

- ♠ CNTs deliver drugs in low potential to the cancer cells with out damaging other healthy cells.
- ♠ CNTs are useful in selective destruction of cancer cells by IR radiation.
- ♠ A biosensor prepared from SWNT is used for the detection of DNA.