



SOMAIYA
VIDYAVIHAR UNIVERSITY

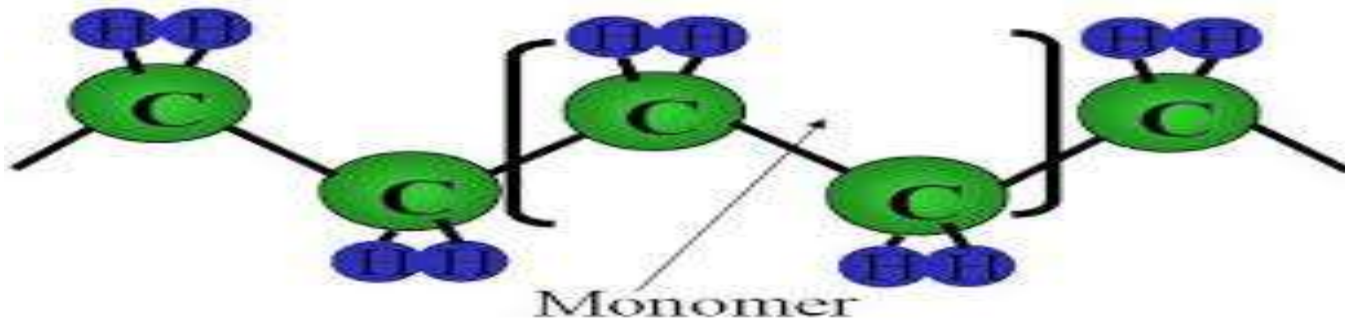
K J Somaiya College of Engineering



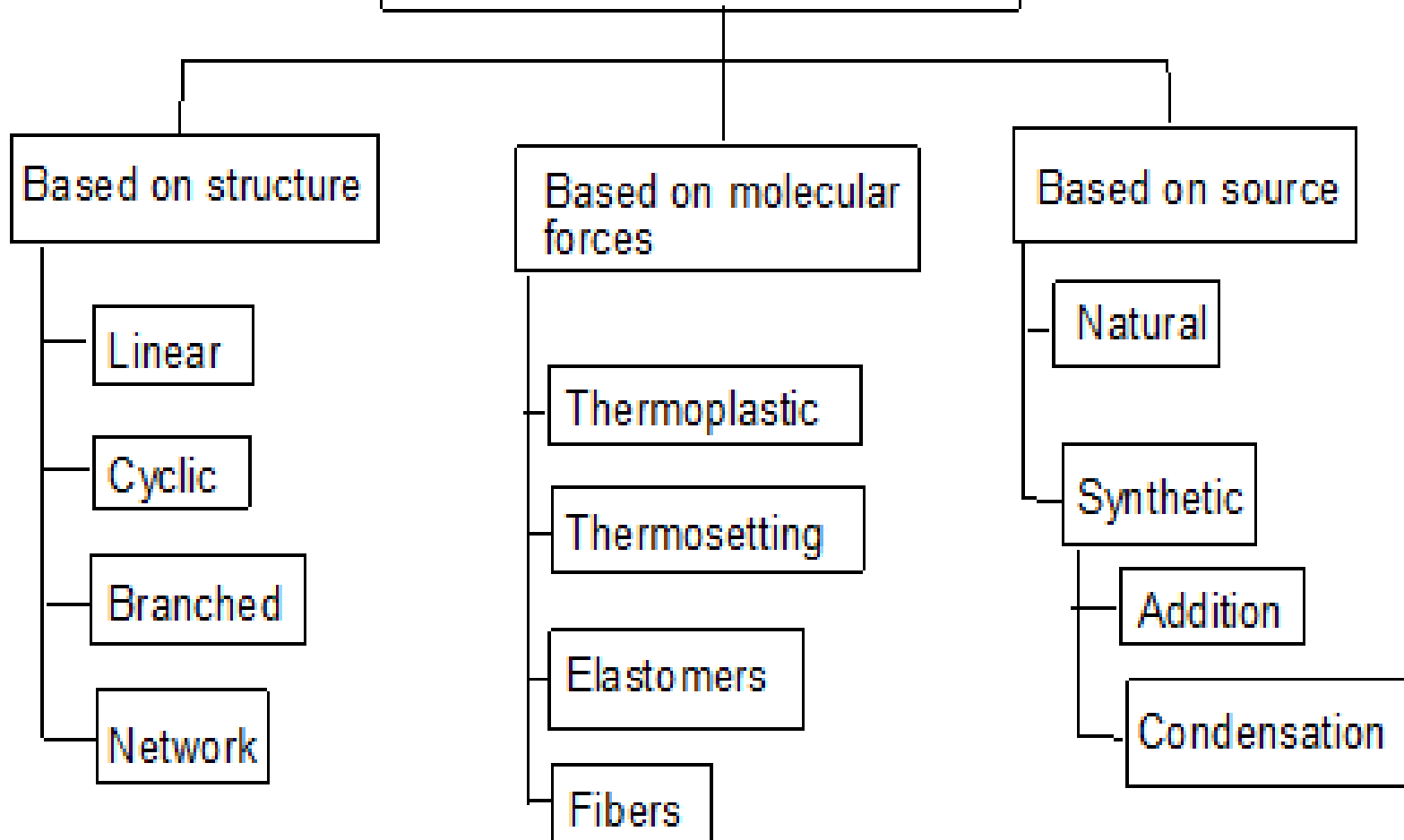
Polymers

Dr. Jitendra Satam

- A polymers are macromolecule with high molecular mass compound ranging from 5000 to one million
- Formed by combination of one or more low molecular weight compounds. The smallest unit from which polymer is obtained is called **monomer**.
- The process by which polymers are obtained is called polymerization
- For e.g. **polyethylene** is obtained by repeating ethylene unit as a result of polymerization.



CLASSIFICATION OF POLYMER



Classification based on source

- **Naturally occurring Polymers:** These occur in plants and animals and are very essential for life e.g. starch, cellulose, amino acids, etc.
- **Synthetic polymers:** These polymers are prepared in laboratory they are man made polymers e.g. plastics, synthetic rubbers, etc.
- **Semi synthetic polymers:** These are derived from naturally occurring polymers by chemical modification. e.g. vulcanized rubber, Cuprammonium silk and Cuprammonium rayon, etc.

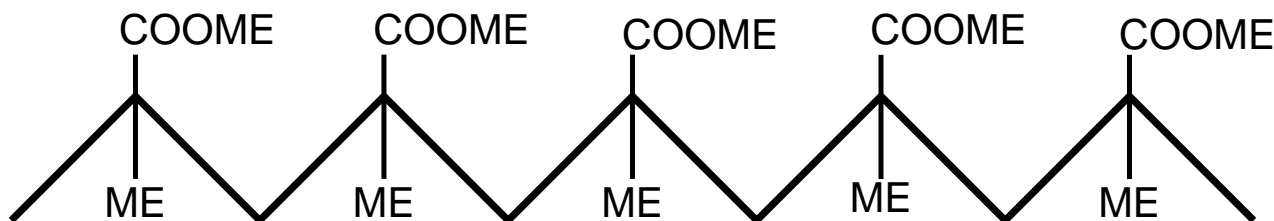
Classification based on Molecular forces

Polymers are classified into four categories based on magnitude of intermolecular forces

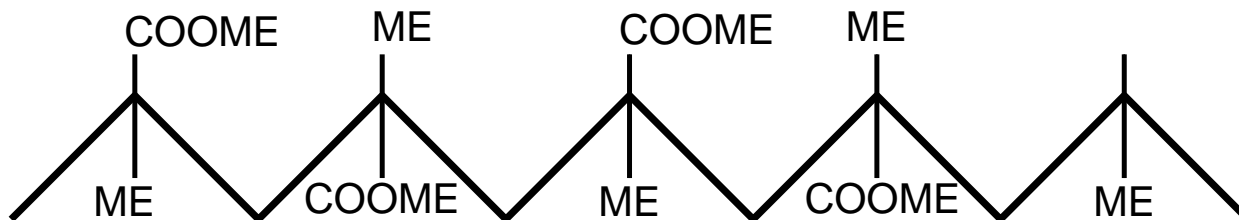
- **Elastomers:** In these polymers, chain are held by weakest intermolecular forces which permits the polymers to be stretched. The polymer regains its original position when forces are released.
- **Fibers:** In these polymers the inter molecular forces are strong due to hydrogen bonding, cross linking, cyclic structure
- **Thermoplastics:** These are polymers for which inter molecular forces between elastomers and fibers. Due to this they can be easily molded by heating.
- **Thermosetting polymers:** Thermosetting polymers undergo chemical changes and cross linking on heating and become permanently hard and infusible.

Classification based on Tacticity

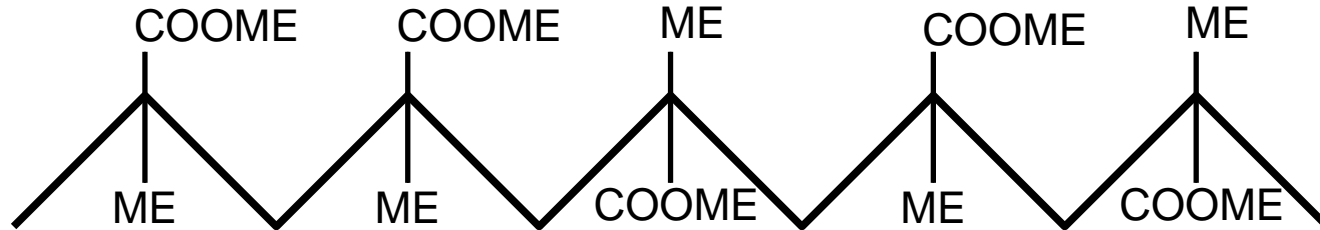
- Isotactic polymers: In isotactic, all the functional group lie on the same side of chain



- Syndiotactic polymers: In syndiotatactic, functional group arrangement is alternate



- Atactic polymers: In atactic, functional group arrangement is random



Every other carbon in the chain is a stereo-center

Classification based on Polymerization method

- Addition Polymerization:** A polymer formed by direct repeated addition of monomers is called addition polymerization. In this types of polymers monomers are unsaturated compounds or derivatives of alkenes.

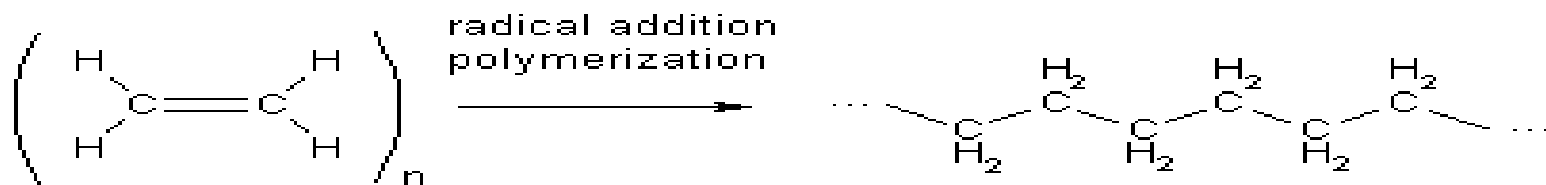
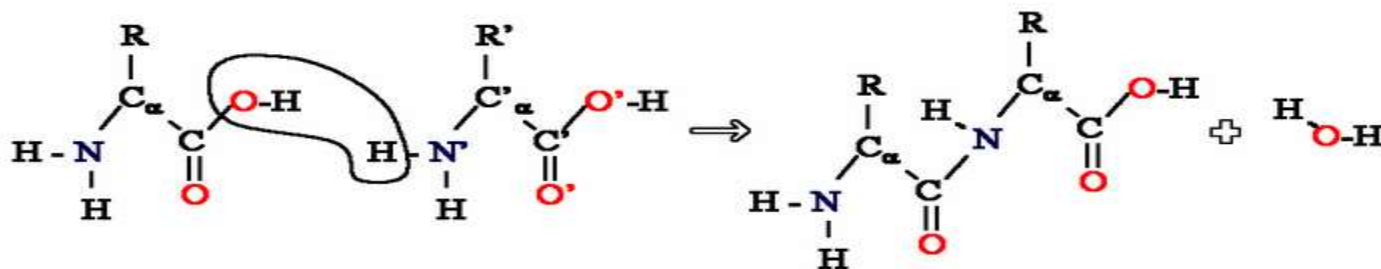


Fig 1: The polymerisation of ethene in to poly(ethene)

- Condensation Polymerization:** Condensation polymerization involves condensation of two different monomers which are normally bi functional group. During the process there is loss of small molecule such as water





	Condensation polymerisation		Additional polymerisation
(1)	It is also known as step growth polymerisation	(1)	It is also known as chain growth polymerization
(2)	It takes place in monomers having reactive functional groups	(2)	It takes place only in monomers having multiple bonds.
(3)	It takes place with elimination of simple molecule like H_2O , NH_3 , HCl etc.,	(3)	It takes place without elimination of simple molecule.
(4)	Repeat units of monomers are different	(4)	Repeat units & monomers are same.
(5)	The polymer is formed in gradual steps	(5)	Reaction is fast and polymer is formed at once.
(6)	The molecular mass of polymer increases throughout the reaction	(6)	There is very little change in the molecular mass throughout the reaction
(7)	Product obtained may be thermosetting/thermoplastic	(7)	Product obtained are thermoplastic
(8)	E.g.:- Bakelite, polyester ,polyamides etc.,	(8)	E.g:-Polyethylene, PVC, poly styrene.

Plastics

- Plastic is a substance that can be easily moulded into a desired shape by the effect of mechanical force & heat.
- In the manufacturing of plastic raw materials like coal, petroleum, cellulose, salt, sulphur, limestone, air, water etc. are used.

Plastics as engineering materials:-

- Low fabrication cost, low thermal & electrical conductivities, high resistance to corrosion, Plastics are resistant to chemicals & solvents
- Plastics reduce noise & vibrations in machines
- Plastics are bad conductors of heat are useful for making handles used for hot objects, most plastics are inflammable.
- Plastics are electrical insulators & find large scale use in the electrical industry.
- Plastics are clear & transparent so they can be given beautiful colors.

Compounding of plastics

The process of mechanical mixing of various additives with polymers (resin) to impart some special properties to the plastics.

The additives gets incorporated with resins to give homogeneous mixture.

The principle **Additives / Ingredients** used in compounding are:

- Resin or Binder
- Fillers or extenders
- Plasticizers
- Pigments or Dyes
- Activators, catalysts or accelerators
- Lubricants
- Stabilizers

1. Resin (Binder)

- Resin is binder which holds the various constituents together
- High molecular weight substances such as, synthetic resins, cellulose derivatives etc.
- Binders influence the properties of plastics
- They also decide the type of treatment during moulding operation
- Eg. LDPE, HDPE, PP, PMMA, Phenol-Formaldehyde resin

2. Fillers or extender

- Fillers reduce the cost of plastic without affecting its original properties
- Imparts better tensile strength, hardness, finish, workability, opacity to the plastic
- Highest % can be up to 50 %, which depends upon type of plastic
- The fillers which increase mechanical strength are known as reinforce fillers
- They also reduce shrinkage and brittleness

Eg. **Organic fillers**: wood powder, cotton pulp, carbon black, graphite, powdered rubber

Inorganic fillers: Asbestos, powdered mica, clays, talc, Zn & Pb oxides, Cd & Ba sulphides, carborundum.

3. Pigments / Dyes

- Imparts desired color
- Organic dyes and inorganic pigments
- Eg. Azo dyes, chromate pigments

4. Catalysts or accelerators

- Used for thermosets to increase the rate of cross-linking
- Acidic or basic catalysts can be used
- Just the small quantities are required
- Eg. Benzoyl peroxide, hydrogen peroxide, metal oxides

5. Plasticizers

- This increase the flexibility and mouldability and decrease brittleness of the materials.
- It also lowers the temperature of moulding operation
- Increase workability and flame proof-ness of plastics
- Only used in thermo-softening plastics
- When they mixed with the resin, they get uniformly distributed between the molecules and reduce intermolecular attraction between original polymer molecules. Thus the plastic becomes flexible.

5. Plasticizers

- They can be added upto 10 %
- Generally liquid plasticizers are used, hence the only disadvantage is, if they are not consistent they could ooze out from the finished product.

Examples

- Cresyl diphenyl phosphate
- Tricresyl phosphate
- Triphenyl phosphate
- Esters of oleic and stearic acids

6. Lubricants

- Especially help during low or room temperature moulding
- This gives the glossy finish to the final product
- As lubricants get dispersed on the surface and occupies a layer between article and mould
- This prevents sticking of an article to the mould and its easier separation from the mould
- Eg. Soaps, waxes

7. Stabilizers

- Improves thermal stability of the plastics
- Generally helps in high temperature moulding operations, where some plastics decompose or gets decolorized
- This could be prevented with the help of stabilizers
- Eg.
 - Diethyl phthalate
 - Adipic acid esters

Molecular Mass of Polymer

- The molecular mass of polymer is an important property of polymer because many important properties are influenced by molecular mass. Polymers with higher molecular mass are tougher and more resistant. Their viscosities and softening temperature are also higher. Thus polymers with desired molecular mass are often required for particular purposes.
- Molecular mass of polymer is not a fixed or constant value like organic compound. Their molecular mass is controlled by polymerization reaction, which in turn depends upon availability of functional group, charge carrier, life time of charge carriers. Because of random nature of growth process, the product of polymerization process is mixture of chains of different length.
- Hence polymers are poly disperse mixture of various molecular mass polymers. Therefore molecular mass of polymers is average molecular mass

Fabrication (Molding) of Plastics

Giving any desired shape to the plastics (granules or powders) by using mould under the application of heat and pressure. A proper method is to be selected depending on the shape and type of resin used. Methods involves partial melting of resinous mass by heating.

In case of **thermo-plasts** molten resin is introduced in die/mould and desired shape could be achieved by compression and further cooling.

In case of **thermo-sets** partially polymerized mass or raw materials are introduced in the die/mould, which further cured at high temperature in the mould itself to achieve desired shape.

Note:

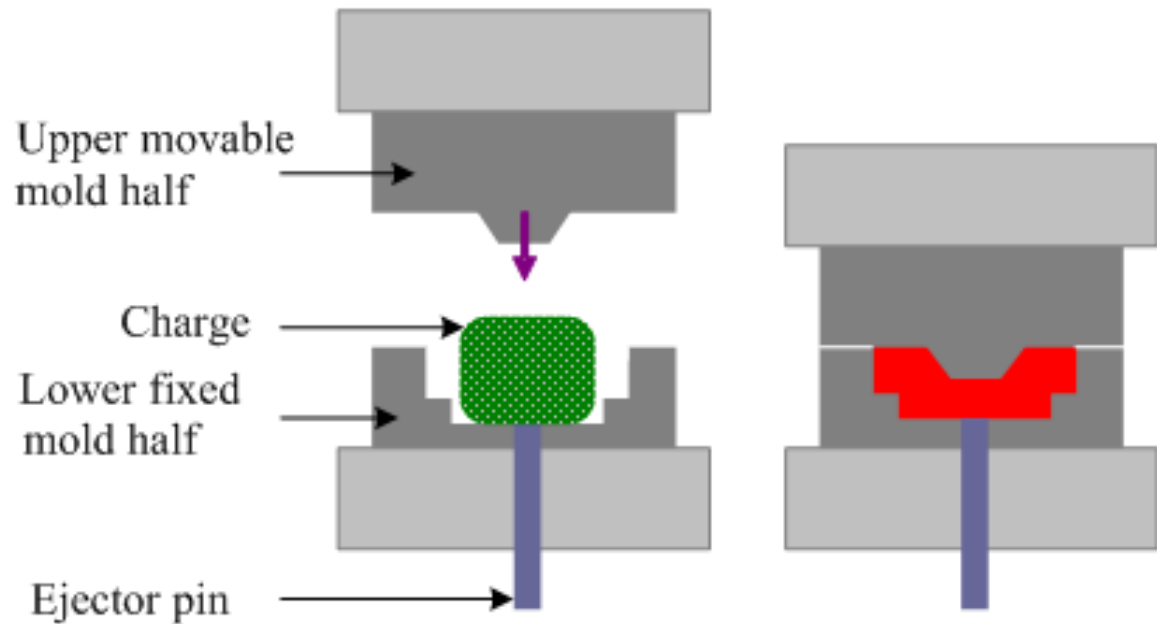
- In case of **thermoplasts**, curing is done at room temperature (low temperature), while in case of **thermosets**, curing is done at high temperature to obtain desired cross-linking

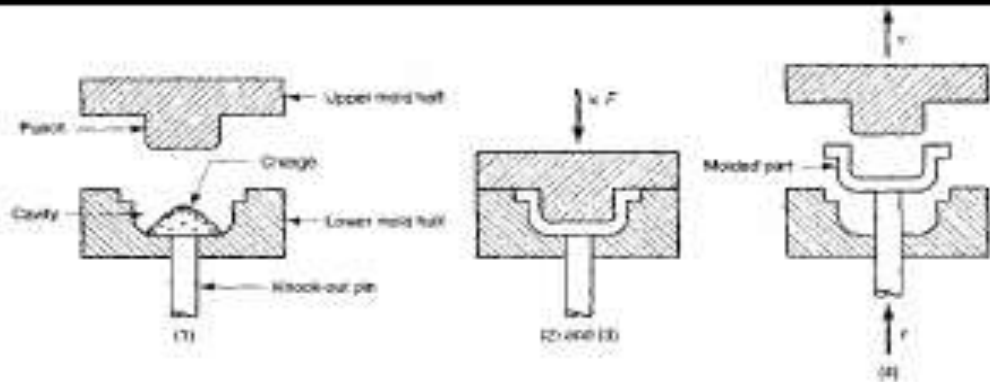
Four important types of fabrication Methods

- Compression Molding : (Suitable for Thermosets / Thermoplasts)
- Injection Molding : (Suitable for Thermoplasts)
- Transfer Molding : (Suitable for Thermosets)
- Extrusion Molding : (Suitable for Thermoplasts)

Compression Molding

1. Common and oldest method for molding thermosetting / thermoplastic materials
2. Compression of raw materials or soften resinous mass is done in the mould/die under heat and pressure
3. Predetermined quantity of raw materials is introduced carefully in the mould, further compressed by hydraulic pressure (2000 to 10000 psi)
4. Molten or soften resinous mass gets filled in the cavity of mould.
5. Curing is done by heating (Thermosetting) or by cooling (Thermoplastics)
6. Finally moulded article is separated from the mould by opening the mould apart.
7. **Applications** : Electric switch boxes, Ash trays, cabinets for radio, television, computers etc.



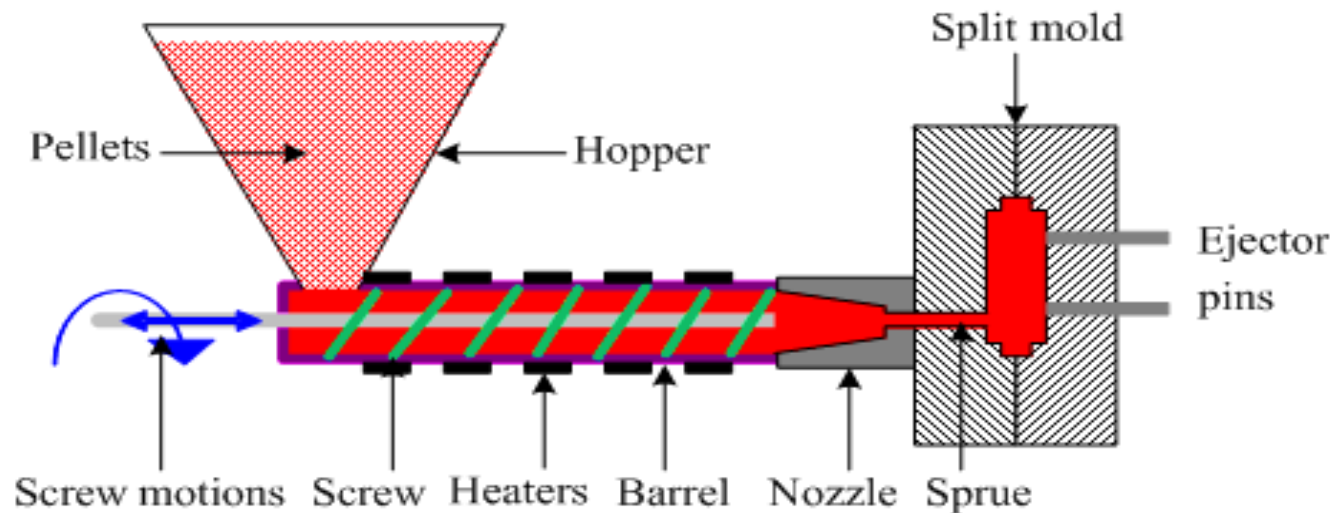


Compression Moulding

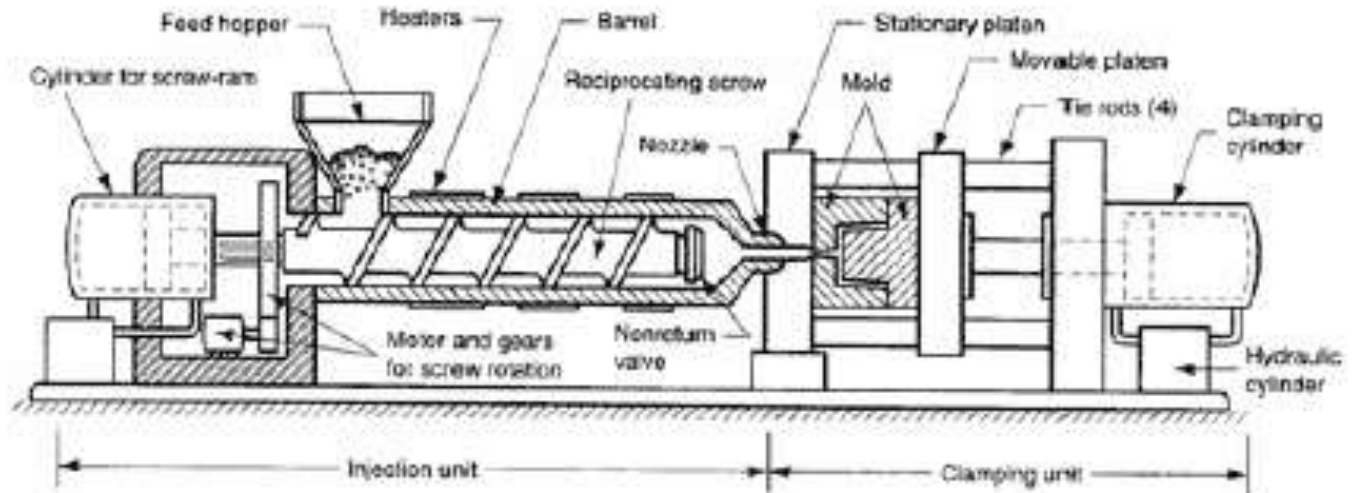
- ❑ This process was the first to be used to form plastics. It involves four steps:
 1. Pre-formed blanks, powders or pellets are placed in the bottom section of a heated mould or die.
 2. The other half of the mould is lowered and is pressure applied.
 3. The material softens under heat and pressure, flowing to fill the mould. Excess is squeezed from the mould. If a thermoset, cross-linking occurs in the mould.
 4. The mould is opened and the part is removed.
- ❑ When **thermoplastics** are used, the mould is **cooled** before removal so the part will not lose its shape.
- ❑ When **thermosets** are used, they may be ejected **while they are hot** and after curing is complete. This process is slow, but the material moves only a short distance to the mold, and does not flow through gates or runners. Only one part is made from each mold.

Injection Molding

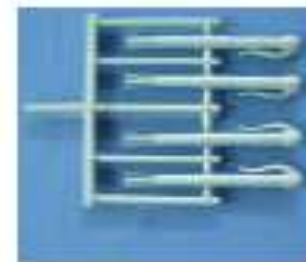
- Especially used for thermoplastic materials
- Powder or granular resin is heated in a cylinder and injected at a controlled rate in a mould
- Piston plunger or screw is used to force the material in mould.
- Pressure upto 1758 kg/cm^2 (125 psi) is used
- Once the article is formed mould is cooled and half mould is opened to remove the finished article.
- Disadvantage of the method is formation of air bubbles or cavities in the articles
- **Applications:** Smaller but large volume articles such as, pen caps, bottle caps, cups, containers, mechanical parts



Injection Moulding



Mobile Phone



Rubber Pen

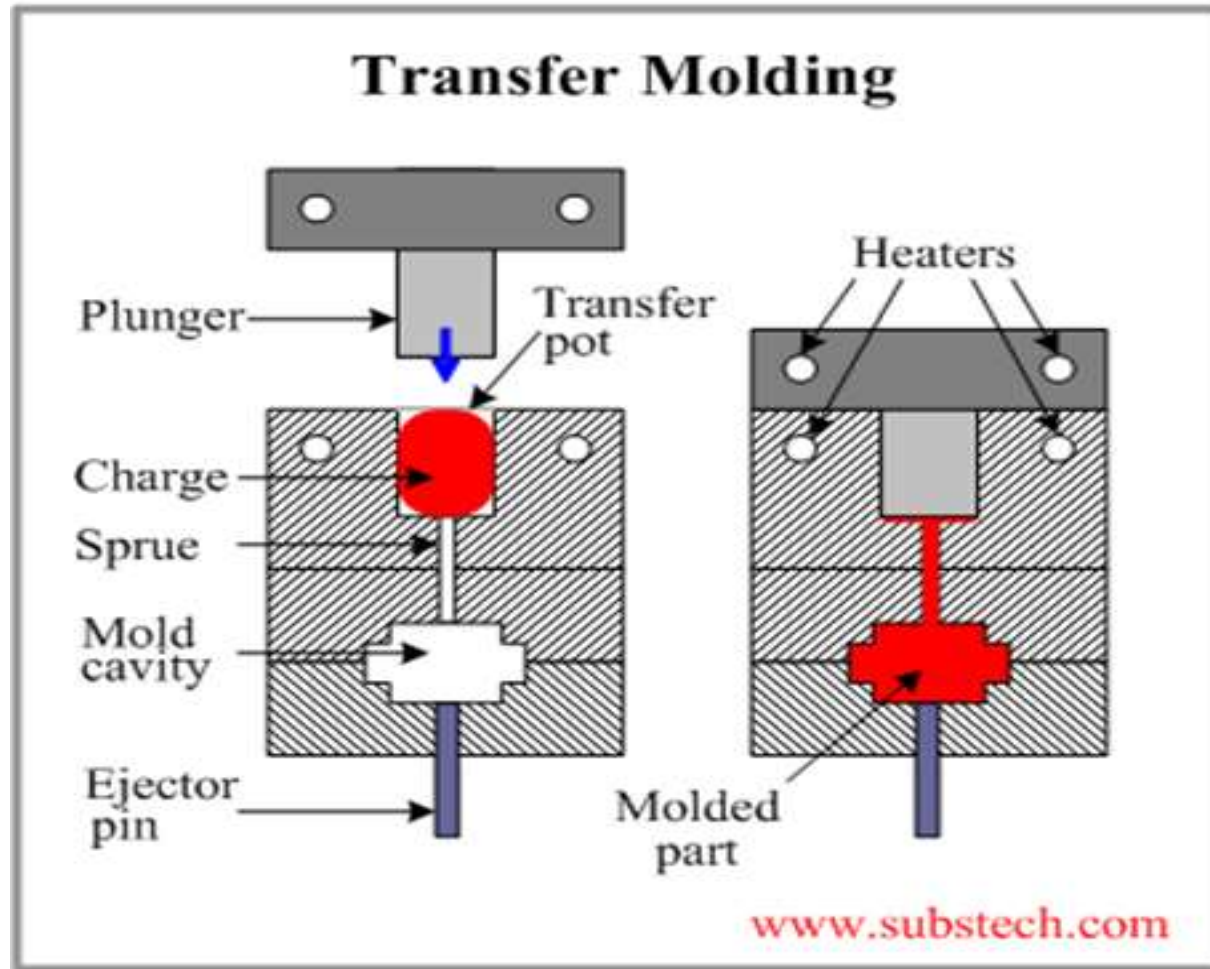
Transfer Molding

- The method combines features of both Compression Molding (hydraulic pressing of molding materials - thermosets) and Injection Molding (ram-plunger and filling the mold through a sprue).
- The method is used especially for molding thermosetting resins (thermosets)
- Products with relatively intricate designs could be fabricated with this method
- Powdered raw materials are heated at certain low temperature to soften and then introduced through an orifice or sprue in the mould
- Then it is cured in the mould at high temperature for certain time
- Finally the moulded article is removed by separation of mould

Advantages:

- Articles with intricate shapes could be designed
- Aerospace and automobile parts, car body, helmets
- The articles produced are blister free
- Fine wires and glass fibers can be inserted in the mould
- Even thick pieces can be cured completely and uniformly

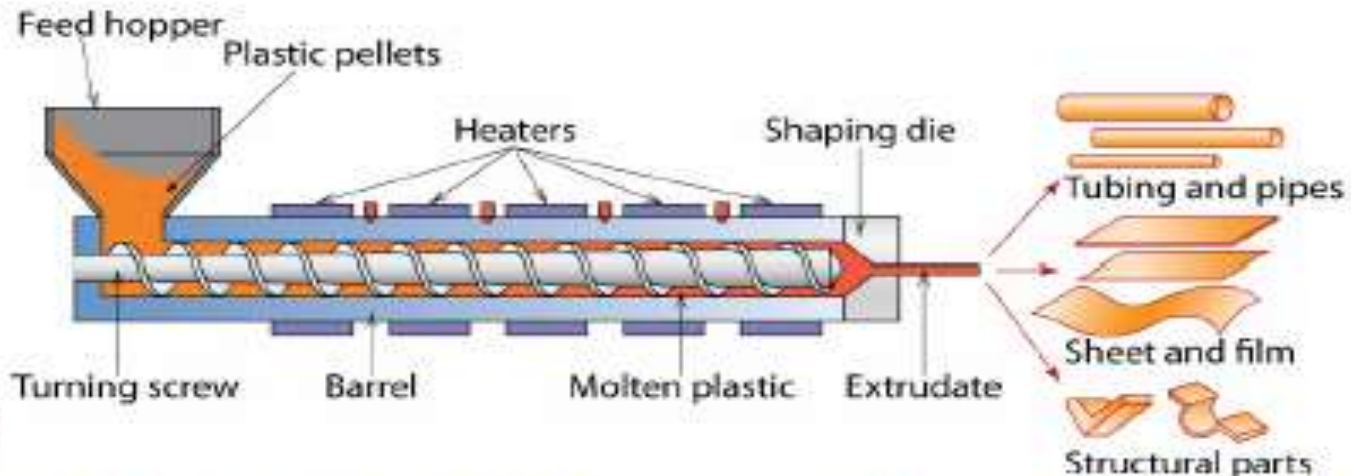
Transfer Molding



Extrusion Molding (Horizontal)

- The method is used for the manufacturing of continuous type of thermoplastic articles with constant cross-section. **Eg. Tubes, rods, strips, insulated electric cables**
- Dry powder or granules of thermoplastic materials are introduced through hopper and further melted by heating.
- There are two types of extrusion moulding:
 1. Vertical extruder moulding
 2. Horizontal extruder moulding
- Molten mass is pushed through the orifice of the die by using screw
- Once the article leaves the orifice, it is allowed to pass through water for solidification
- Proper temperature control of heating chamber and the speed of the screw are the major factors behind successful operation

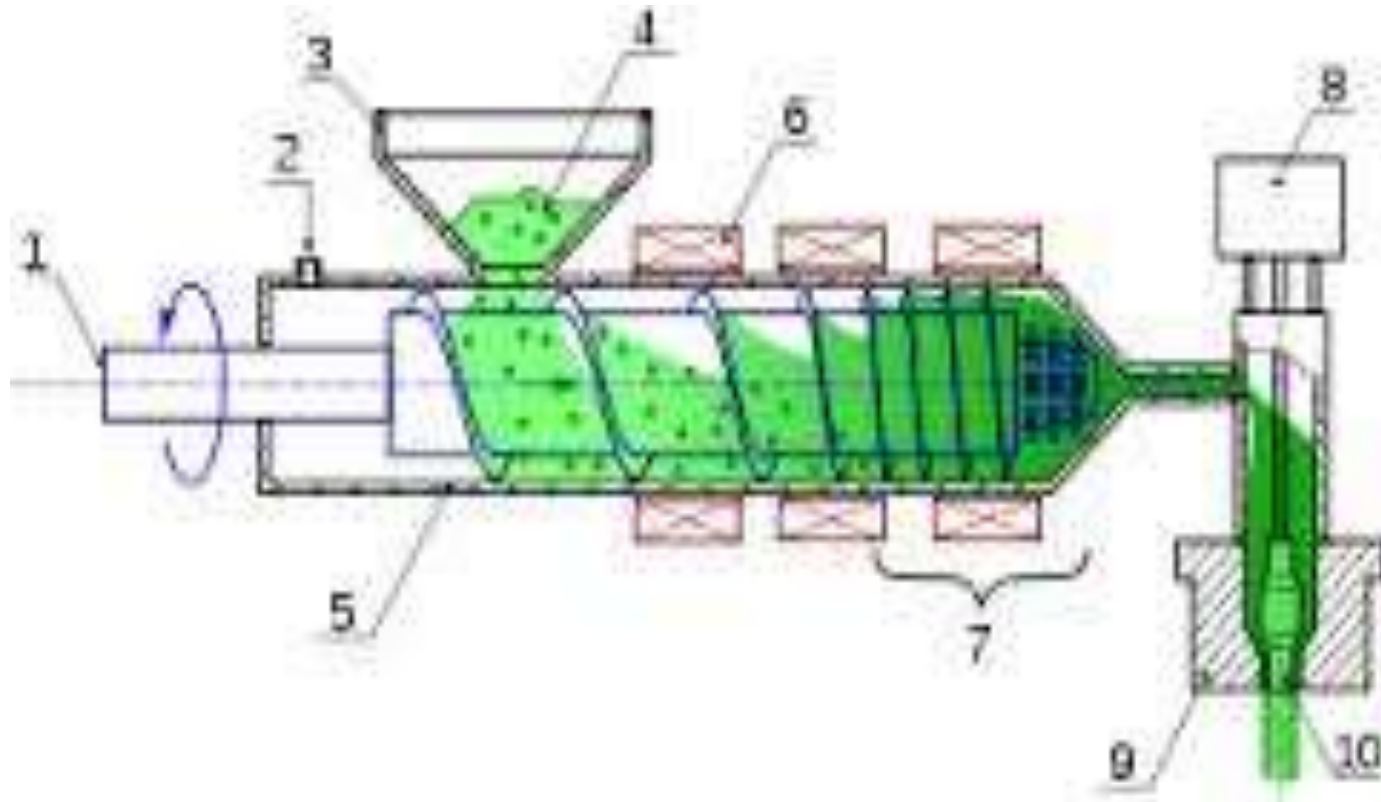
Extrusion Molding (Horizontal)



Extrusion

- ❑ This process makes parts of constant cross section like pipes and rods. liquid polymer goes through a die to produce a final shape. It involves four steps:
 1. Pellets of the polymer are mixed with colouring and additives.
 2. The material is heated to its proper plasticity.
 3. The material is forced through a die.
 4. The material is cooled.
- ❑ An extruder has a hopper to feed the polymer and additives, a barrel with a continuous feed screw, a heating element, and a die holder. An adapter at the end of an extruder blowing air through an orifice into the hot polymer extruded through a ring die produces plastic bags and films.

Extrusion Molding (Vertical)



Synthesis and Applications of Commercially important Polymers

[Preparation, Properties and Uses]

Some Important Polymers

1. **Poly Vinyl Acetate (PVAc): Y**
2. **Poly Methyl Methacrylate (PMMA):Y**
3. **Poly-Paraphenylene Terephthalamide (KEVLAR):Y**
4. **Polylactic acid: Y**
5. **PDMS: Y**

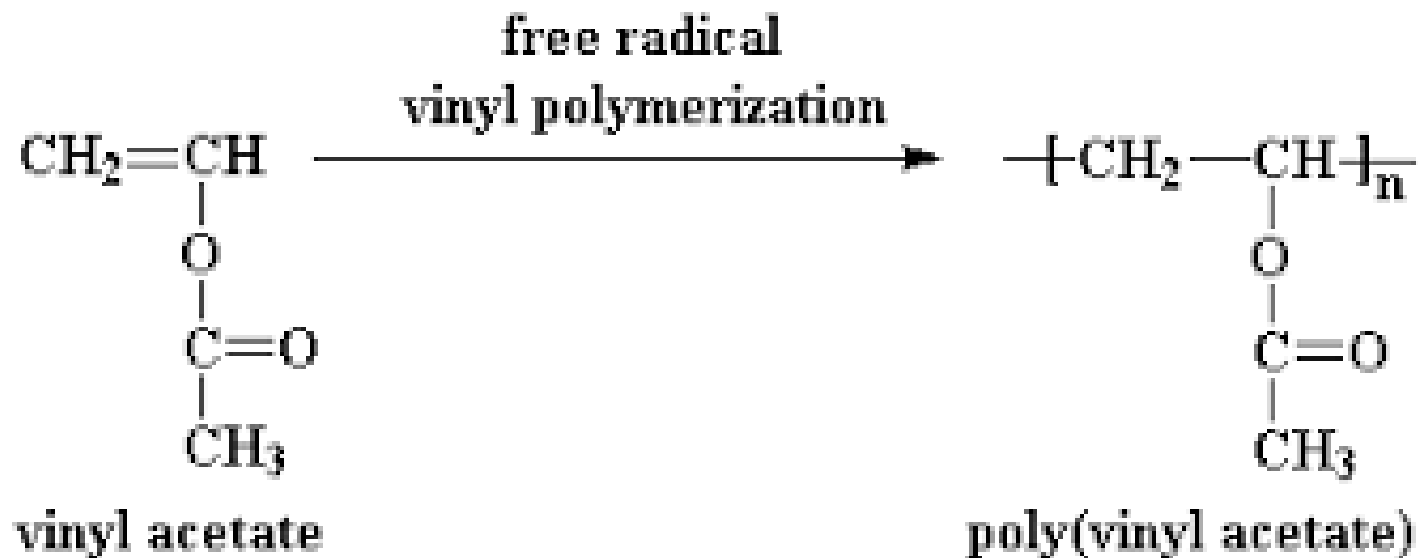
1. Poly Vinyl Acetate (PVAc)

- Polyvinyl acetate is a polymer produced through the combination of several units of monomeric vinyl acetate ($\text{CH}_3\text{COOCH}=\text{CH}_2$).
- The number of units so combined is typically between 100 and 5,000.
- This translates to an average molecular weight between 850 and 40,000.

1. Poly Vinyl Acetate (PVAc)

Preparation:

Vinyl acetate Monomer is prepared by reacting acetylene with anhydrous acetic acid in the presence of a mercurous sulfate catalyst; poly vinyl acetate is prepared by free radical vinyl polymerization as follows:



1. Poly Vinyl Acetate (PVAc)

Properties:

- Polyvinyl acetate is an amorphous polymer
- The hardest of the polyvinyl esters, polyvinyl acetate offers good adhesion to most surfaces.
- Unlike some other thermoplastics, it will not turn yellow.
- Polyvinyl acetate does not cross-link, and it can be dissolved in many solvents other than water.
- One slow-drying formulation combines 5 to 15 percent polyvinyl acetate with ethyl alcohol (ethanol).
- A fast-drying counterpart combines the same amount of polyvinyl acetate with acetone (dimethyl ketone).

1. Poly Vinyl Acetate (PVAc)

USES:

- Emulsified polyvinyl acetate is used in water-based adhesives, including pastes and glues.
- One of the uses for emulsified polyvinyl acetate is in bookbinding, depending upon the necessary lifetime of the book, the polyvinyl acetate chosen will either be co-polymeric or homo-polymeric.
- Polyvinyl acetate offers acceptable gap-filling capability.
- It may be used as a resinous component of latex paints, offering compatibility with a wide-range of other paint chemicals.
- Polyvinyl acetate may be used in the lamination of metal foils.
- Non-emulsified, or waterless, polyvinyl acetate is useful as a thermosetting adhesive.

2. Poly Methyl Methacrylate (PMMA)

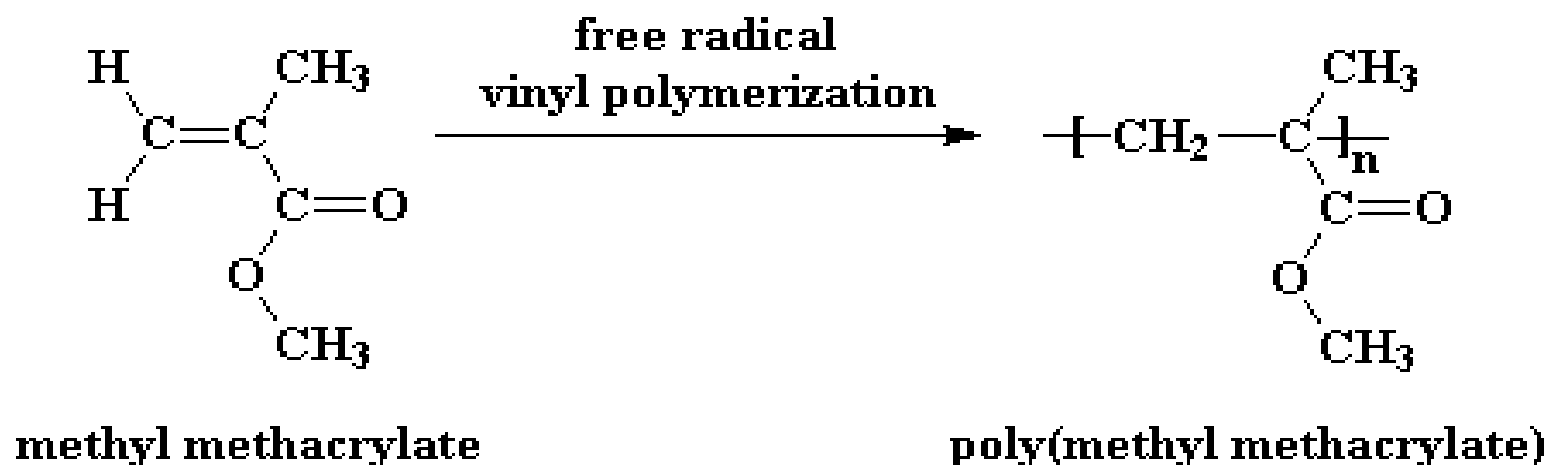
- Poly-(methyl methacrylate) (PMMA), also known as acrylic or acrylic glass as well as by the trade names Crylux, Plexiglas, Acrylite, Lucite, and Perspex
- It is a transparent thermoplastic often used in sheet form as a light-weight or shatter-resistant alternative to glass.
- The same material can be used as a casting resin, in inks and coatings, and has many other uses.

2. Poly Methyl Methacrylate (PMMA)

Preparation:

PMMA is routinely produced by emulsion polymerization, solution polymerization, and bulk polymerization.

It is generally prepared by radical initiation method.



2. Poly Methyl Methacrylate (PMMA)

Properties:

- PMMA is a strong, tough, and lightweight material.
- It has a density of 1.17–1.20 g/cm³, which is less than half that of glass.
- It also has good impact strength, higher than both glass and polystyrene. [PMMA's impact strength is still significantly lower than polycarbonate]
- PMMA transmits up to 92% of visible light (3 mm thickness), and gives a reflection of about 4% from each of its surfaces due to its refractive index (1.4905 at 589.3 nm).
- It filters ultraviolet (UV) light at wavelengths below 300 nm.
- PMMA swells and dissolves in many organic solvents; it also has poor resistance to many other chemicals due to its easily hydrolyzed ester

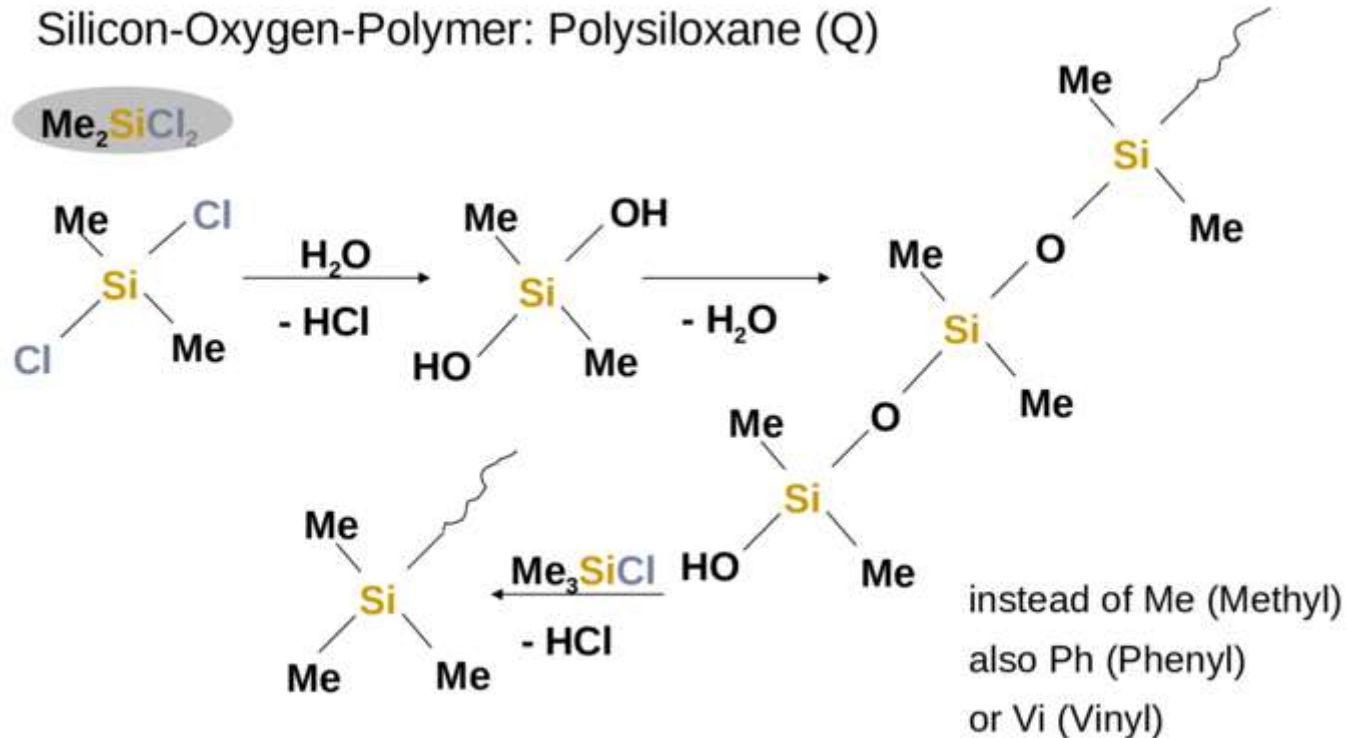
2. Poly Methyl Methacrylate (PMMA)

Uses:

- Being transparent and durable, PMMA is a versatile material and has been used in a wide range of fields and applications such as rear-lights, appliances, and lenses for glasses.
- PMMA is used for building windows, skylights, signs & displays, sanitary ware (bathtubs), LCD screens, furniture and many other applications.
- It is also used for coating polymers based on MMA provides outstanding stability against environmental conditions with reduced emission of VOC.
- Methacrylate polymers are used extensively in medical and dental applications where purity and stability are critical to performance.

3-PDMS

Silicon-Oxygen-Polymer: Polysiloxane (Q)



Properties-

- Good chemical resistance, low water absorption, good electrical properties, & available in flame retardant grade
- Service temperature to about 260 °C to -50 °C
- High molecular weight but not a solid, Ability to spread out on a wide variety of substrates
- Silky, non-tacky, film forming
- Lowest surface shear viscosity and low surface tension
- Lubricating, antifoaming, waterproofing, release properties
- High gas permeability, Excellent dielectric properties
- Very good thermo-oxidative stability, Good chemical inertness and temperature resistance

Uses-

- In the plumbing and automotive fields, silicone grease is often used as a lubricant. In plumbing, the grease is typically applied to O-rings in faucets and valves.
- In the automotive field, silicone grease is typically used as a lubricant for brake components since it is stable at high temperatures, is not water-soluble
- Biomedical applications, electronics applications, adhesives
- 3D-Printing applications, medicines, cosmetics, hair conditioners, contact lenses, mold release agent

4. Poly-Paraphenylene Terephthalamide (KEVLAR)

Poly-Paraphenylene Terephthalamide (KEVLAR):

Poly-paraphenylene terephthalamide (Kevlar) is a heat-resistant and strong synthetic fiber,

Preparation:

Kevlar is synthesized in solution from the monomers 1,4-phenylenediamine (*para*-phenylenediamine) and terephthaloyl chloride in a condensation reaction yielding hydrochloric acid as a byproduct.

4. Poly-Paraphenylene Terephthalamide (KEVLAR)



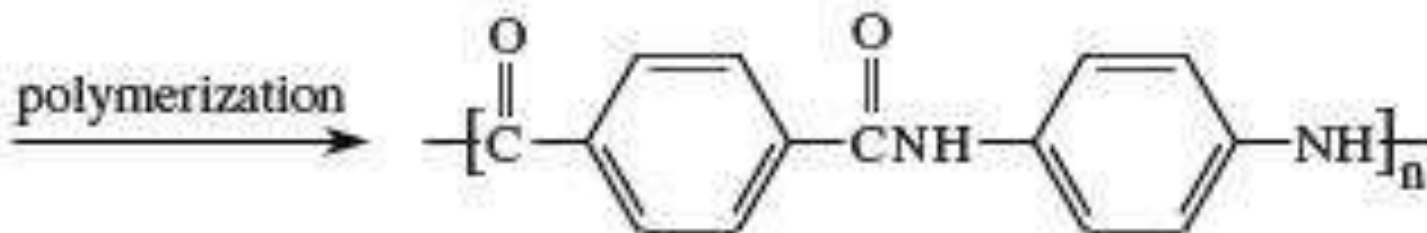
1,4-benzenedicarboxylic acid
(terephthalic acid)

+



1,4-benzenediamine
(*p*-phenylenediamine)

polymerization



Kevlar

4. Poly-Paraphenylene Terephthalamide (KEVLAR)

Properties:

- When Kevlar is spun, the resulting fiber has a tensile strength of about 3,620 MPa, and a relative density of 1.44.
- Kevlar maintains its strength and resilience down to cryogenic temperatures (-196 °C); in fact, it is slightly stronger at low temperatures.
- Kevlar's structure consists of relatively rigid molecules which makes them exceptionally strong
- They are high tensile strength-to-weight ratio; by this measure it is 5 times stronger than steel.



4. Poly-Paraphenylene Terephthalamide (KEVLAR)

Uses:

- Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests,
- It is also used to make modern marching drumheads that withstand high impact.
- Kevlar is a well-known component of personal armor such as combat helmets, ballistic face masks, and ballistic vests.
- It is used for motorcycle safety clothing, especially in the areas featuring padding such as shoulders and elbows.
- Kevlar is often used in the field of cryogenics for its low thermal conductivity and high strength relative to other materials for suspension purposes.

Conducting Polymers

- Generally polymers are insulators because of the absence of free electrons.
- But they can be made conductive in certain cases by the process called doping.
- Two conditions for the polymer to become conducting are:
 1. Polymers should possess conjugated double bonds
 2. Polymer structure has to be disturbed either by adding or removing electrons by the process of doping.
- There are 3 major classes of conducting polymers
 1. Intrinsically conducting polymers
 2. Doped conducting polymers
 3. Extrinsically conducting polymers

1. Intrinsically conducting polymers

This belong to a class of organic materials consist of Conjugated pi-electrons in the backbone of their macromolecules which is responsible for high electrical conductivity.

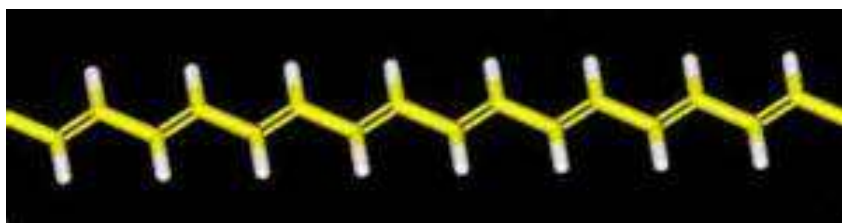
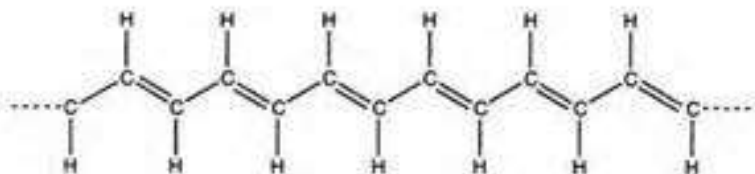
In an electric field, conjugated pi-electrons of the polymer gets excited and can be transported through the solid polymer.

Overlapping of orbitals of conjugated pi-electrons over the entire backbone of the polymer results in the formation of valence bands and conduction bands. This induces conductivity in the presence of electric field.

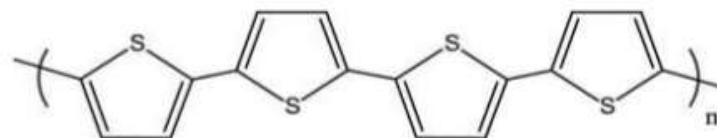
For example:

Poly-acetylene, poly-aniline, poly-pyrrole and poly-thiophene etc.

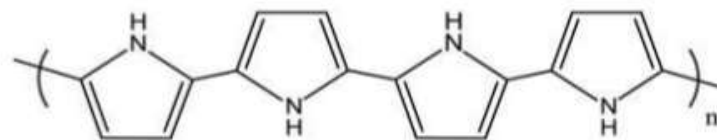
Polyacetylene



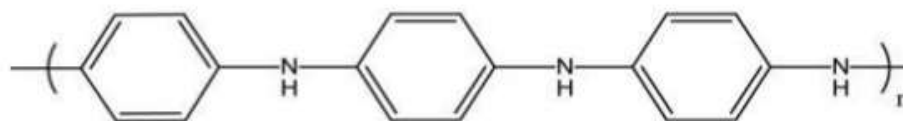
few Common Conducting Polymers



polythiophene



polypyrrole



polyaniline

- Due to their high electrical properties, ICPs are intensively investigated for application in electronics, microelectronics, optoelectronics mainly for areas in aerospace and automobile industries.
- Among the most promising applications of the ICPs are corrosion protection, solid-state charge storage devices, electromagnetic screens, antistatic coatings and gas separation coatings.
- However, poor mechanical properties, environmental sensitivity, moderate stability of electrical properties with temperature significantly limit the industrial applicability of ICPs.

2. (DCP) Doped conducting polymer

While the addition of a donor or an acceptor molecule to the polymer is called "**doping**", the reaction that takes place is actually a redox reaction. The first step is the formation of a cation (or anion), which is called a soliton or a polaron.

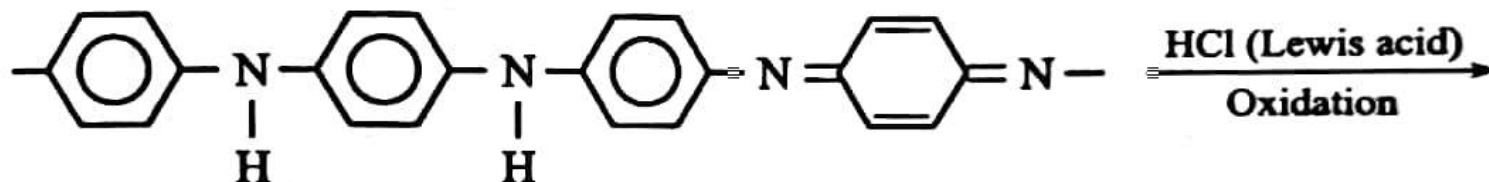
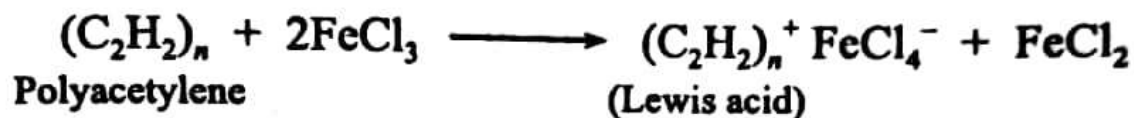


As synthesized conductive polymers exhibit very low conductivities. It is not until an electron is removed from the valence band (**p-doping**) or added to the conduction band (**n-doping**, which is far less common) does a conducting polymer become highly conductive.

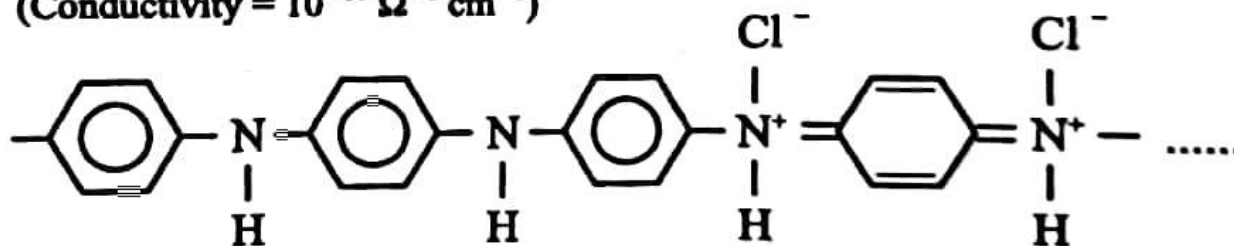
Doping (p or n) generates charge carriers which move in an electric field. Positive charges (holes) and negative charges (electrons) move to opposite electrodes. This movement of charge is what is actually responsible for electrical conductivity.

(DCP) Doped conducting polymer

- This is obtained by exposing a polymer to a charge transfer agent in a gas phase or in solution.
 - Conductivity of ICPs can be increased by creating positive or negative charges on the polymer backbone by oxidation or reduction by the process of doping.
1. **p-doping** involves treating intrinsically conducting polymer with a Lewis acid thereby oxidation takes place and positive charges on the polymer backbone are created. Some common P-dopants are I_2 , Br_2 , AsF_5 , PF_6 etc.

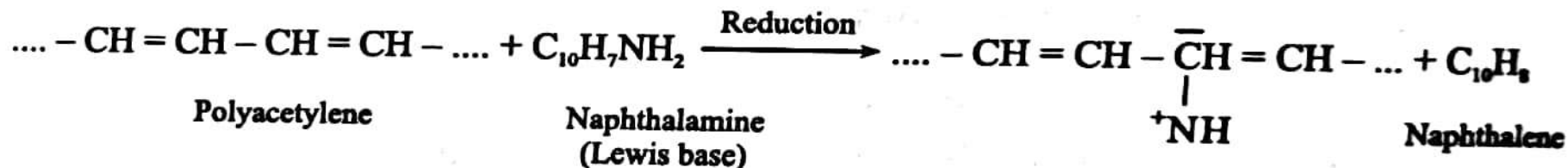
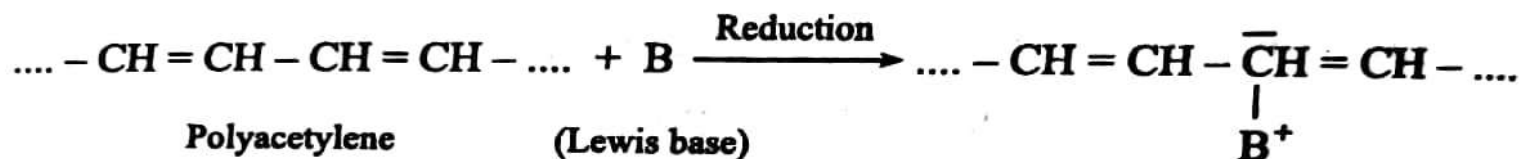


Emeraldine base (a polyaniline)
(Conductivity = $10^{-10} \Omega^{-1} \text{ cm}^{-1}$)



Emeraldine hydrochloride (a salt known as *synthetic metal*)
(Conductivity = $10^3 \Omega^{-1} \text{ cm}^{-1}$)

2. n-doping involves treating intrinsically conducting polymer with a Lewis base thereby reduction takes place and negative charges on the polymer backbone are created. Some common N-dopants are Li, Na, Ca etc.



3. Extrinsically Conducting Polymer

This type of conducting polymers possesses conductivity due to the presence of externally mixed conducting elements or compounds. These are of the following two types:

1. **conductive element filled polymer:** Such polymers contains non-conducting polymers (behaving as binder) holds the conducting elements or compounds (behaving as conducting filler) such as carbon black, metals, metal oxides, etc. Such polymers possesses good bulk conductivity, low cost, light weight, mechanically tough and easily processable.
2. **Blended conducting polymer:** such polymers are obtained by blending conventional polymers with conducting polymers either through physical or chemical process.



Applications of conducting polymers

- In rechargeable light weight batteries
- In optical display devices
- In aircrafts and aerospace components
- In diodes and transistors
- In solar cells

Liquid-crystal polymers (LCPs)

- An Austrian botanist named Friedrich Reinitzer studied a material called as cholesteryl benzoate which showed two distinct melting points. He noticed the change of crystal structure to hazy liquid by increase the temperature of solid sample.
- Later on further heating, the hazy liquid converted to transparent liquid.
- Reinitzer discovered a new phase of matter that is called as liquid crystal phase. Such materials show unique properties and have several new applications in modern technology.
- Liquid-crystal polymers (LCPs) are a class of aromatic polymers. They are extremely unreactive and inert, and highly resistant to fire.
- Liquid crystallinity in polymers may occur either by dissolving a polymer in a solvent (lyotropic liquid-crystal polymers) or by heating a polymer above its glass or melting transition point (thermotropic liquid-crystal polymers).

Liquid-crystal polymers (LCPs)

Liquid-crystal polymers are present in melted/liquid or solid form. In solid form the main example of lyotropic LCPs is the commercial aramid known as Kevlar. Chemical structure of this aramid consists of linearly substituted aromatic rings linked by amide groups. In a similar way, several series of thermotropic LCPs have been commercially produced by several companies. The orientation of molecules in liquid crystal state is intermediate liquid and solid phases. This intermediate state I called as mesogenic state or liquid crystal state. In such materials the properties of a material depend on the direction in which they are measured. The liquid crystalline structure has positional order, orientational order and bond orientational order.

Properties

1. Typically, LCPs have a high mechanical strength at high temperatures, extreme chemical resistance, inherent flame retardancy, and good weatherability.
2. Liquid-crystal polymers come in a variety of forms from sinterable high temperature to injection moldable compounds.
3. LCPs can be welded, though the lines created by welding are a weak point in the resulting product.
4. LCPs have a high coefficient of thermal expansion and are exceptionally inert.
6. They resist stress cracking in the presence of most chemicals at elevated temperatures, including aromatic or halogenated hydrocarbons, strong acids, bases, ketones, and other aggressive industrial substances.
7. Hydrolytic stability in boiling water is excellent. Environments that deteriorate the polymers are high-temperature steam, concentrated sulfuric acid, and boiling caustic materials.

Uses

- Because of their various properties, LCPs are useful for electrical and mechanical parts, food containers, and any other applications requiring chemical inertness and high strength.
- LCP is particularly good for microwave frequency electronics due to low relative dielectric constants, low dissipation factors, and commercial availability of laminates.
- Packaging micro-electro-mechanical systems (MEMS) is another area that LCP has recently gained more attention.
- The superior properties of LCPs make them especially suitable for automotive ignition system components, heater plug connectors, lamp sockets, transmission system components, pump components, coil forms and sunlight sensors and sensors for car safety belts.

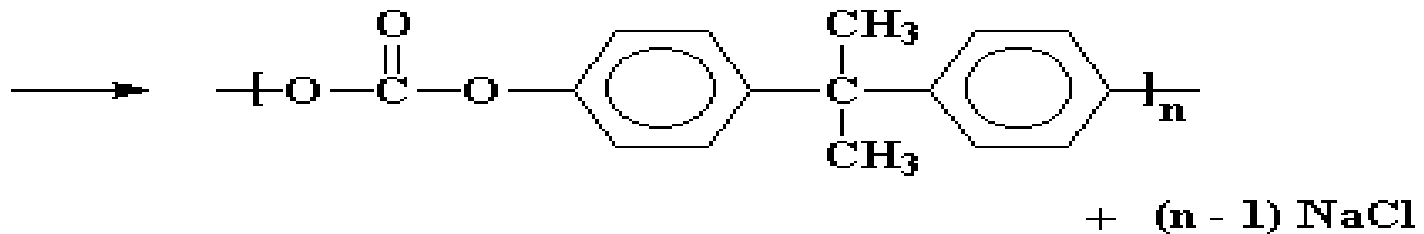
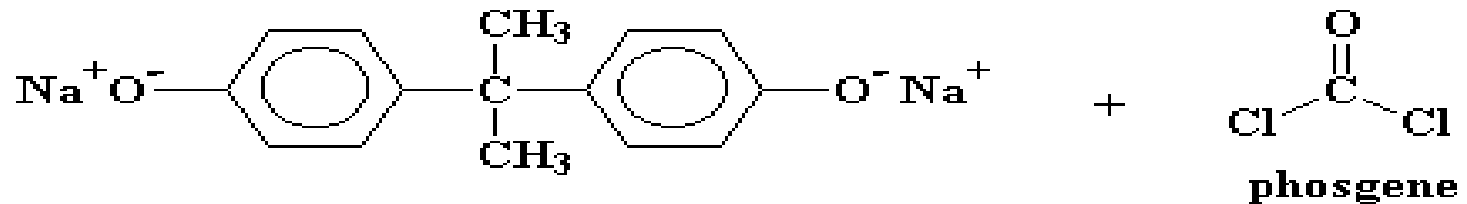
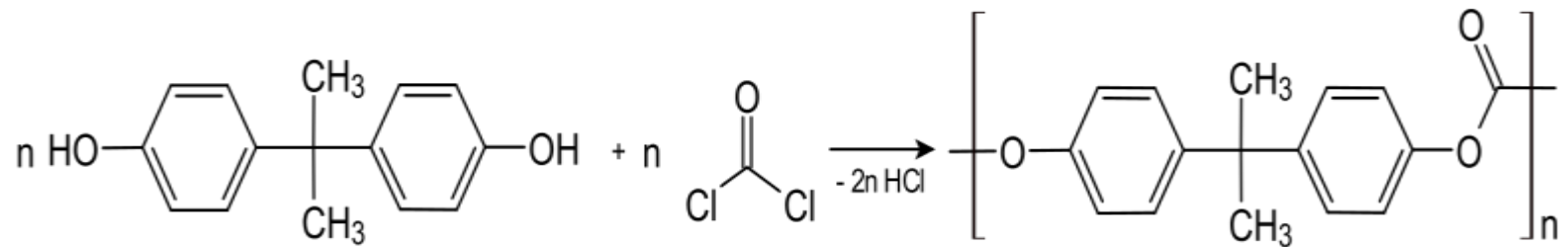
N 3. Poly Carbonates (PC)

Polycarbonates (PC) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. Polycarbonates used in engineering are strong, tough materials, and some grades are optically transparent. They are easily worked, molded, and thermoformed.

Preparation:

- The main polycarbonate material is produced by the reaction of bisphenol-A (BPA) and phosgene COCl_2 .
- The first step of the synthesis involves treatment of bisphenol-A with sodium hydroxide, which deprotonates the hydroxyl groups of the bisphenol-A
- The diphenoxide $[\text{Na}_2(\text{OC}_6\text{H}_4)_2\text{CMe}_2]$ reacts with phosgene to give a chloroformate, which subsequently is attacked by another phenoxide. The net reaction from the diphenoxide is:

3. Poly Carbonates (PC)



3. Poly Carbonates (PC)

Properties:

- Polycarbonate is a durable material. Although it has high impact-resistance, it has low scratch-resistance.
- The characteristics of polycarbonate compare to those of polymethyl methacrylate (PMMA, acrylic), but polycarbonate is stronger and will hold up longer to extreme temperature.
- Polycarbonate has a glass transition temperature of about 147 °C (297 °F; 420 K)
- Unlike most thermoplastics, polycarbonate can undergo large plastic deformations without cracking or breaking.

3. Poly Carbonates (PC)

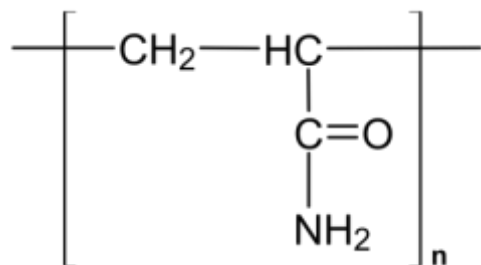
Uses:

- **ELECTRONICS:** Polycarbonate is mainly used for electronic applications that capitalize on its collective safety features. Being a good electrical insulator and having heat-resistant and flame-retardant properties, it is used in various products associated with electrical and telecommunications hardware. It can also serve as a dielectric in high-stability capacitors
- **CONSTRUCTION:** The second largest consumer of polycarbonates is the construction industry, e.g. for dome-lights, flat or curved glazing, and sound walls, which all use extruded flat solid or multiwall sheet, or corrugated sheet.
- **DATA STORAGE:** A major application of polycarbonate is the production of Compact Discs, DVDs. These discs are produced by injection molding polycarbonate into a mold cavity that has on one side a metal stamper containing a negative image of the disc data, while the other mold side is a mirrored surface.
- Due to its low weight and high impact resistance, polycarbonate is the dominant material for making automotive headlamp lenses.

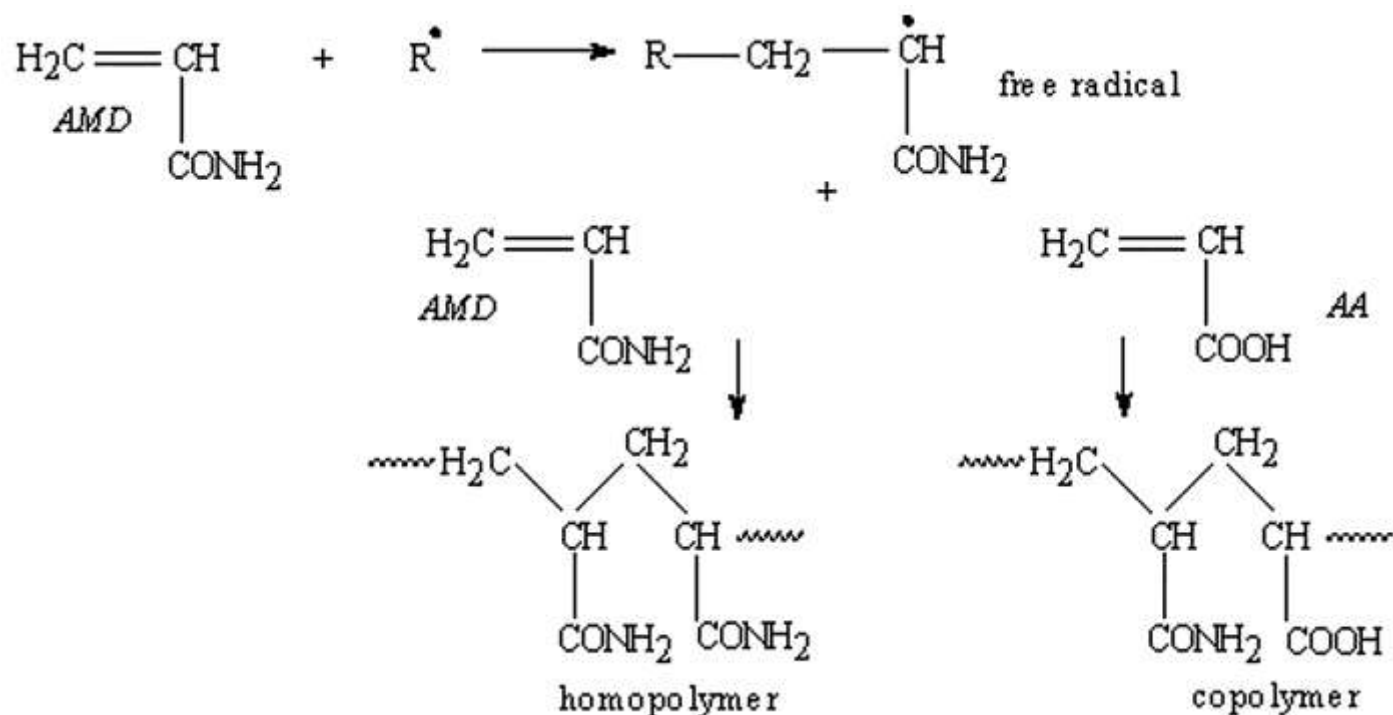
N 5. Polyacrylamide

Preparation:

- Polyacrylamides are water-soluble synthetic linear polymers made of acrylamide or the combination of acrylamide and acrylic acid.
- By chemical co-polymerization of acrylamide (AMD) monomers with a cross-linking reagent (usually *N,N'*-methylenebisacrylamide, Bis), a clear transparent gel is obtained.
- The reaction is started with ammonium persulphate as catalyst.



5. Polyacrylamide



5. Polyacrylamide

Properties:

- Linear polyacrylamide is a water-soluble polymer.
- It is typically non-ionic polymer
- Due to hydrolysis of some amide groups they could convert into carboxylic groups giving polyacrylamide some weak ionic properties.

5. Polyacrylamide

Uses:

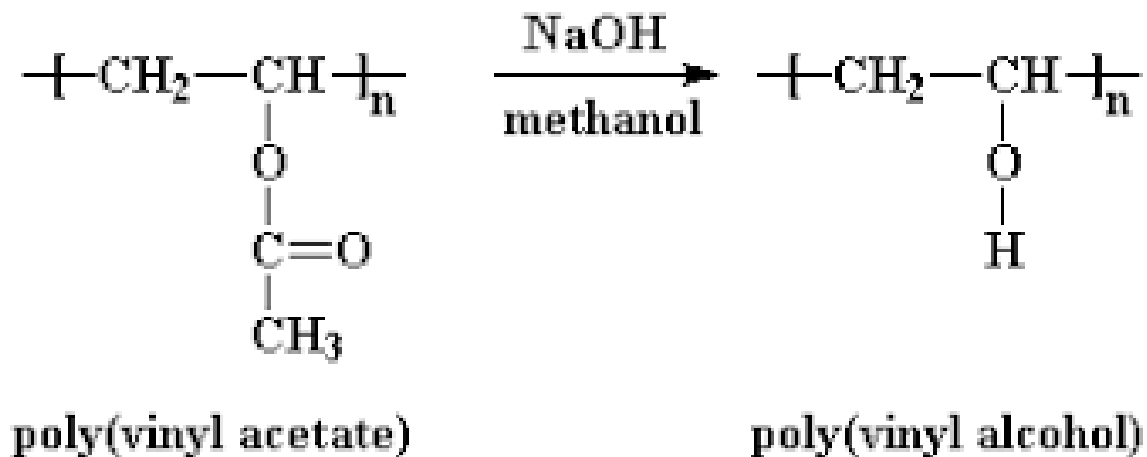
- One of the largest uses for polyacrylamide is to flocculate solids in a liquid. This process applies to water treatment, and processes like paper making and screen printing.
- Polyacrylamide can be supplied in a powder or liquid form, with the liquid form being subcategorized as solution and emulsion polymer. Even though these products are often called 'polyacrylamide', many are actually copolymers of acrylamide
- Another common use of polyacrylamide and its derivatives is in subsurface applications such as Enhanced Oil Recovery

N 6. Poly Vinyl Alcohol (PVA)

Preparation:

- Unlike most vinyl polymer, PVA is not prepared by polymerization of the corresponding monomer
- Polyvinyl alcohol was first prepared in 1924 by hydrolyzing polyvinyl acetate in ethanol with potassium hydroxide.
- Polyvinyl alcohol is produced commercially from polyvinyl acetate, usually by a continuous process. The acetate groups are hydrolyzed by ester interchange with methanol in the presence of anhydrous sodium methylate or aqueous sodium hydroxide. The physical characteristics and its specific functional uses depend on the degree of polymerization and the degree of hydrolysis. Polyvinyl alcohol is classified into two classes namely: partially hydrolyzed and fully hydrolyzed. Partially hydrolyzed PVA is used in the foods.

6. Poly Vinyl Alcohol (PVA)



6. Poly Vinyl Alcohol (PVA)

Properties

- **Polyvinyl alcohol**, also known as *PVOH*, *PVA*, or *PVAL*, is a synthetic polymer that is soluble in water.
- It is effective in film forming, emulsifying, and has an adhesive quality.
- It has no odor and is not toxic, and is resistant to grease, oils, and solvents.
- It is ductile but strong, flexible, and functions as a high oxygen and aroma barrier.

6. Poly Vinyl Alcohol (PVA)

Uses

- Polyvinyl alcohol is often utilized as the raw material for the creation of other resins such as *polyvinyl butyral* (PVB) or *polyvinyl formal* (PVF). (PVB has an adhesive quality and is a water-resistant, plastic film, which is often used to laminate safety glass for vehicles. PVF is commonly used to insulate wires).
- Polyvinyl alcohol is used for coating of medicinal tablets.
- PVA is used in many industries, such as textile, paper industry, and food packaging industry because of its high chemical and thermal stability, and low manufacturing cost.
- **PVA is used in** sizing agents that give greater strength to textile yarns and make paper more resistant to oils and greases.
- It is also employed as a component of adhesives and emulsifiers, as a water-soluble protective film.