

Industrial Polymers



Plastics

Commodity plastics

<i>Type</i>	<i>Abbreviation</i>	<i>Major uses</i>
Low-density polyethylene	LDPE	Packaging film, wire and cable insulation, toys, flexible bottles, housewares, coatings
High-density polyethylene	HDPE	Bottles, drums, pipe, conduit, sheet, film, wire and cable insulation
Polypropylene	PP	Automobile and appliance parts, rope, cordage, webbing, carpeting, film
Poly(vinyl chloride)	PVC	Construction, rigid pipe, flooring, wire and cable insulation, film and sheet
Polystyrene	PS	Packaging (foam and film), foam insulation, appliances, housewares, toys



Engineering plastics

<i>Type</i>	<i>Abbreviation</i>	<i>Chapter where discussed</i>
Acetal ^a	POM	11
Polyamide ^b	—	13
Poly(amideimide)	PAI	13
Polyarylate	—	12
Polycarbonate	PC	12
Polyester ^c	—	12
Polyetheretherketone	PEEK	11
Polyetherimide	PEI	11
Polyimide	PI	13
Poly(phenylene oxide)	PPO	11
Poly(phenylene sulfide)	PPS	11
Polysulfone ^d	—	11

^a Common name for polyformaldehyde. Abbreviation refers to poly(oxymethylene).

^b Principally nylons 6 and 66.

^c Principally poly(ethylene terephthalate) (PET) and poly(butylene terephthalate) (PBT).

^d Several types marketed.



Thermosetting plastics

<i>Type</i>	<i>Abbreviation</i>	<i>Typical uses</i>	<i>Chapter where discussed</i>
Phenol–formaldehyde	PF	Electrical and electronic equipment, automobile parts, utensil handles, plywood adhesives, particle board binder	14
Urea–formaldehyde	UF	Similar to PF polymers; also treatment of textiles, coatings	14
Unsaturated polyester	—	Construction, automobile parts, boat hulls, marine accessories, corrosion-resistant ducting, pipe, tanks, etc., business equipment	12
Epoxy	—	Protective coatings, adhesives, electrical and electronics applications, industrial flooring, highway paving materials, composites	11
Melamine–formaldehyde	MF	Similar to UF polymers; decorative panels, counter and table tops, dinnerware	14



Fibers

Synthetic fibers

Type	Description
Cellulosic	
Acetate rayon	Cellulose acetate
Viscose rayon	Regenerated cellulose
Noncellulosic	
Polyester	Principally poly(ethylene terephthalate)
Nylon	Includes nylon 66, nylon 6, and variety of other aliphatic and aromatic polyamides
Olefin	Includes polypropylene and copolymers of vinyl chloride, with lesser amounts of acrylonitrile, vinyl acetate, or vinylidene chloride ($\text{CH}_2 = \text{CCl}_2$) (copolymers consisting of more than 85% vinyl chloride are called <i>vinyon</i> fibers)
Acrylic	Contain at least 80% acrylonitrile; included are <i>modacrylic</i> fibers comprising acrylonitrile and about 20% vinyl chloride or vinylidene chloride



Rubber (elastomers)

Synthetic rubber

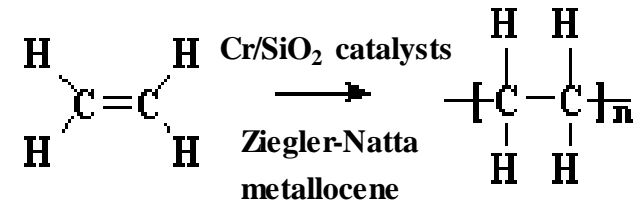
<i>Type</i>	<i>Description</i>
Styrene–butadiene	Copolymer of the two monomers in various proportions depending on properties desired; called SBR for styrene-butadiene rubber
Polybutadiene	Consists almost entirely of the <i>cis</i> -1,4 polymer
Ethylene–propylene	Often abbreviated EPDM for ethylene-propylene-diene monomer; made up principally of ethylene and propylene units with small amounts of a diene to provide unsaturation
Polychloroprene	Principally the <i>trans</i> -1,4 polymer, but also some <i>cis</i> -1,4 and-1,2 polymer; also known as <i>neoprene</i> rubber
Polyisoprene	Mainly the <i>cis</i> -1,4 polymer; sometimes called “synthetic natural rubber”
Nitrile	Copolymer of acrylonitrile and butadiene, mainly the latter
Butyl	Copolymer of isobutylene and isoprene, with only small amounts of latter
Silicone	Contains inorganic backbone of alternating oxygen and methylated silicon atoms; also called polysiloxane (Chap. 15)
Urethane	Elastomers prepared by linking polyethers through urethane groups (Chap. 13)



Polyolefin

High-Density Polyethylene

: Relatively opaque form of polyethylene having a dense structure with few side branches off the main carbon backbone.

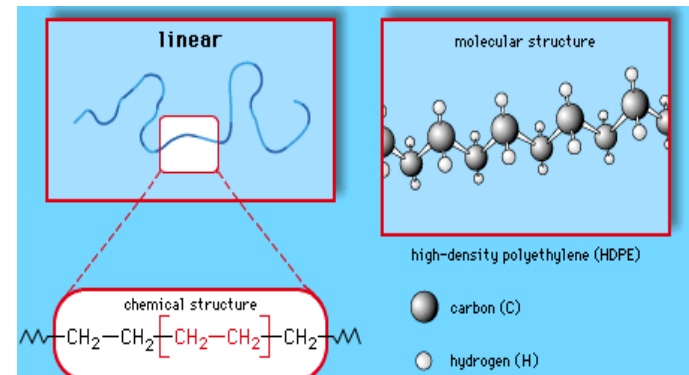


Properties

- Hard and opaque plastic (crystalline structure)
- Higher thermal stability than that of LDPE
- Stronger mechanical properties
(Higher Intermolecular forces than that of LDPE)

Uses & Applications

- Pipe, toys, bowls, buckets, milk bottles, crates, tanks, and containers.



Polyolefin

Low-Density Polyethylene

: many side branches off the main carbon backbone and a less closely packed structure than that of HDPE

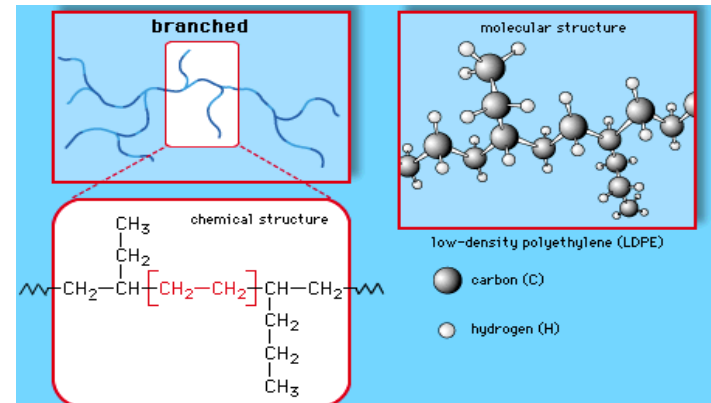


Properties

- Semi-rigid
- Good chemical resistance
- Translucent
- Low water absorption
- Low cost

Uses & Applications

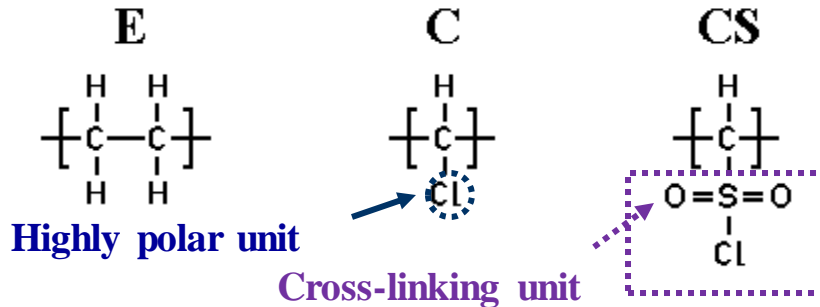
- Dispensing bottles, wash bottles, tubing, and laboratory equipment.



Polyolefin

Chlorosulfonated polyethylene

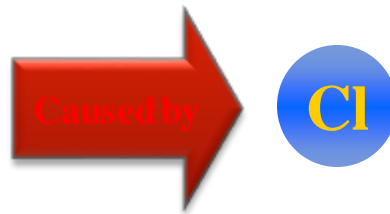
CSPE chloro'sulfonated'poly'ethylene (EE)



- Random chlorination of PE (25-45% Cl)
- Incorporation of infrequent chlorosulfonic groups (SO₂Cl) as preferred cross-linking sites

Properties

- Good resistance to ozone, heat, flame, chemicals and solvents
- Low temperature flexibility
- Heat-ageing resistance



Uses & Applications

- ✓ Hose products, roll covers, tank linings, wire and cable covers, footwear, and building products



Polyolefin

Ethylene copolymer series

Ethylene vinyl acetate (EVA)

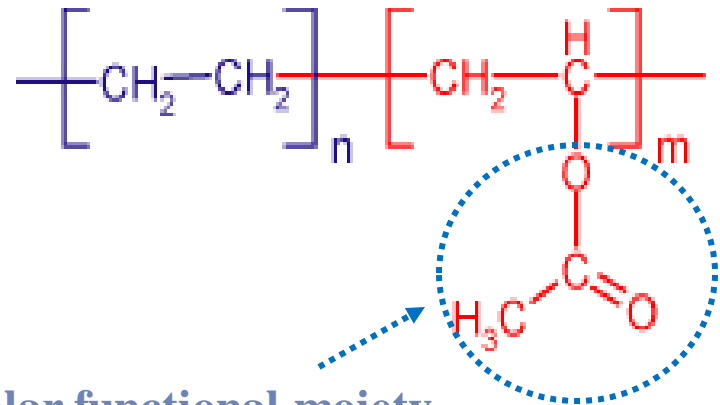
- EVA based hot-melts are able to fulfill various requirements in applications such as packaging, bookbinding or label sticking

✓ Polar functionality promotes adhesion to polar substrates (paper, polyester, wood, and leather)

✓ Low crystallinity gives it a low melting point and excellent low temperature toughness.

✓ Applications

: packaging, adhesives, wire, cable and health care.



Polar functional moiety

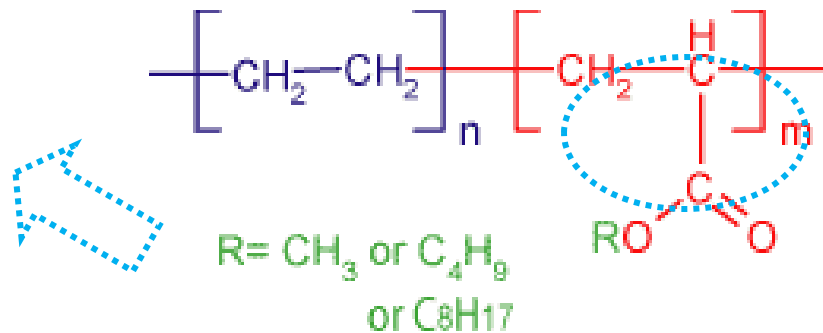
Polyolefin

Ethylene copolymer series

Ethylene - Acrylic Ester copolymers

Key benefits of ethylene acrylic ester copolymers

Acrylic ester decreases the crystallinity of the polymer



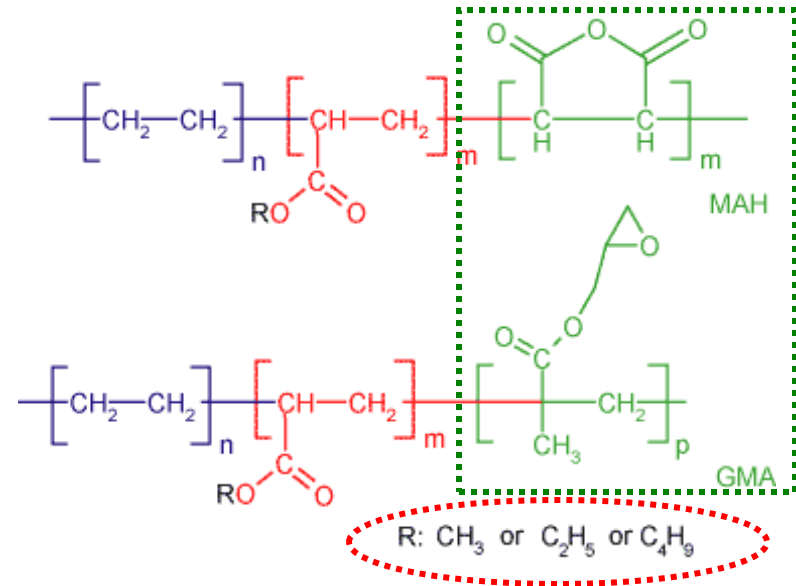
- Excellent thermal stability
- Excellent adherence to many substrates (polyethylene, polystyrene, polypropylene, OPP, etc.)
- Good chemical resistance
- Good elastic properties
- Excellent mechanical behavior at low temperature

Polyolefin

Ethylene copolymer series

Ethylene acrylic ester terpolymers

- They can be divided into several product families depending on the acrylic ester type
(methyl, ethyl or butyl acrylate)
- **Third monomer**
 - MAH : maleic anhydride
 - GMA : glycidyl methacrylate.
- **The roles of third monomer**
 - Increase final adhesion properties
 - Heat resistance or long term ageing properties.



Acrylic Ester	➔	Low to high content Thermal stability - Flexibility - Polarity
MAH or GMA	➔	Middle to high content Reactivity - Adhesion
Main reactivity with chemical groups		
MAH	➔	OH, NH ₂ ...
GMA	➔	COOH, OH, NH ₂ ...

Polyolefin

Ionomers

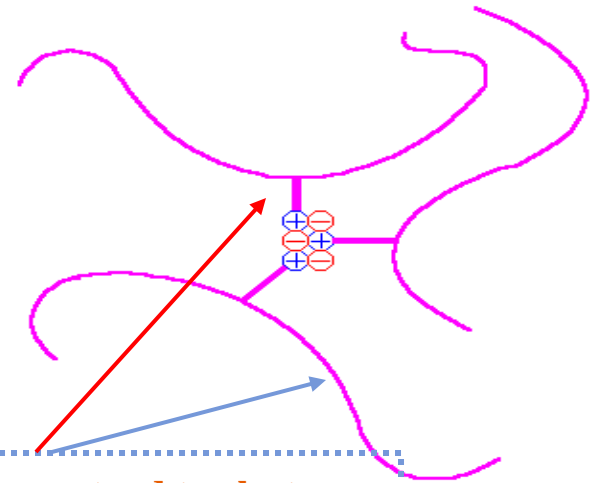
: An ionomer is an **ion containing polymer**.

It is more than just a polymer with ionic groups.

We call any old polymer with ionic groups a **polyelectrolyte**

Characteristics :

- ✓ special kind of polyelectrolyte.
- ✓ containing both nonionic repeat units and small amounts of **ion containing repeat units less than 15%** of polymer
- ✓ not crosslinked polymer
- ✓ a type of **thermoplastic** called a **reversible crosslinker**

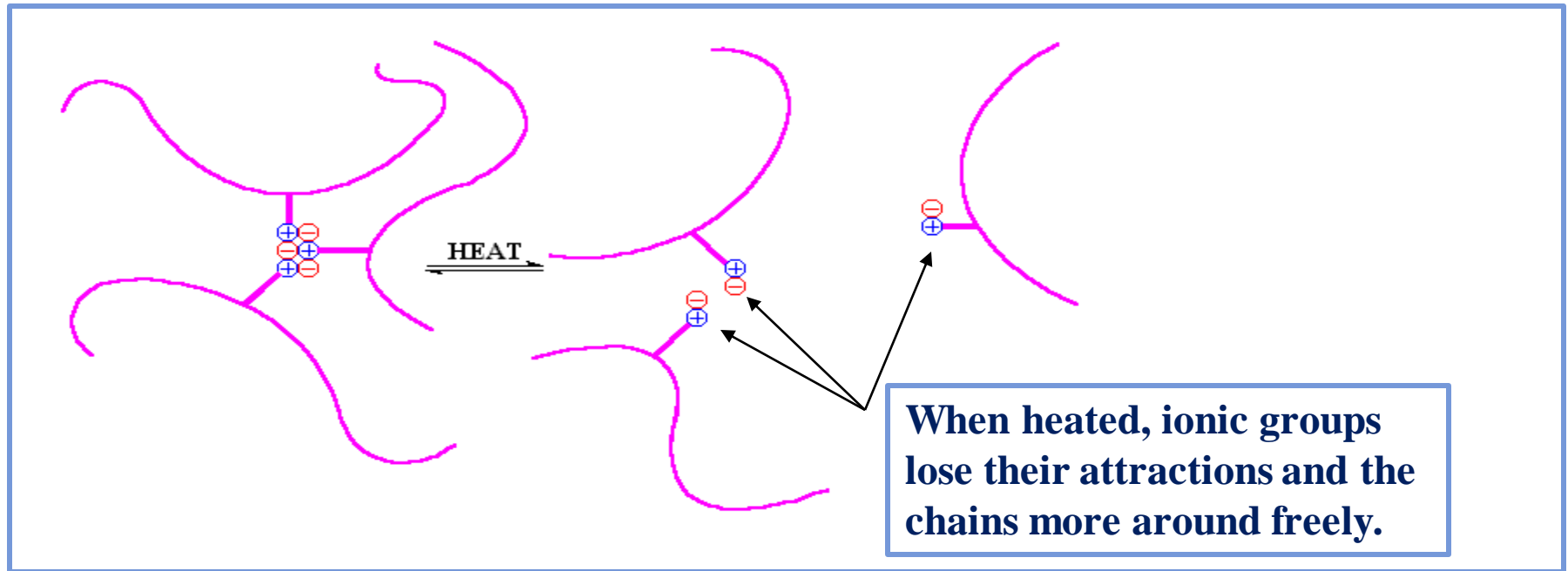


The polar groups tend to cluster together, away from the nonpolar polymer backbone chains

Polyolefin

Ionomers

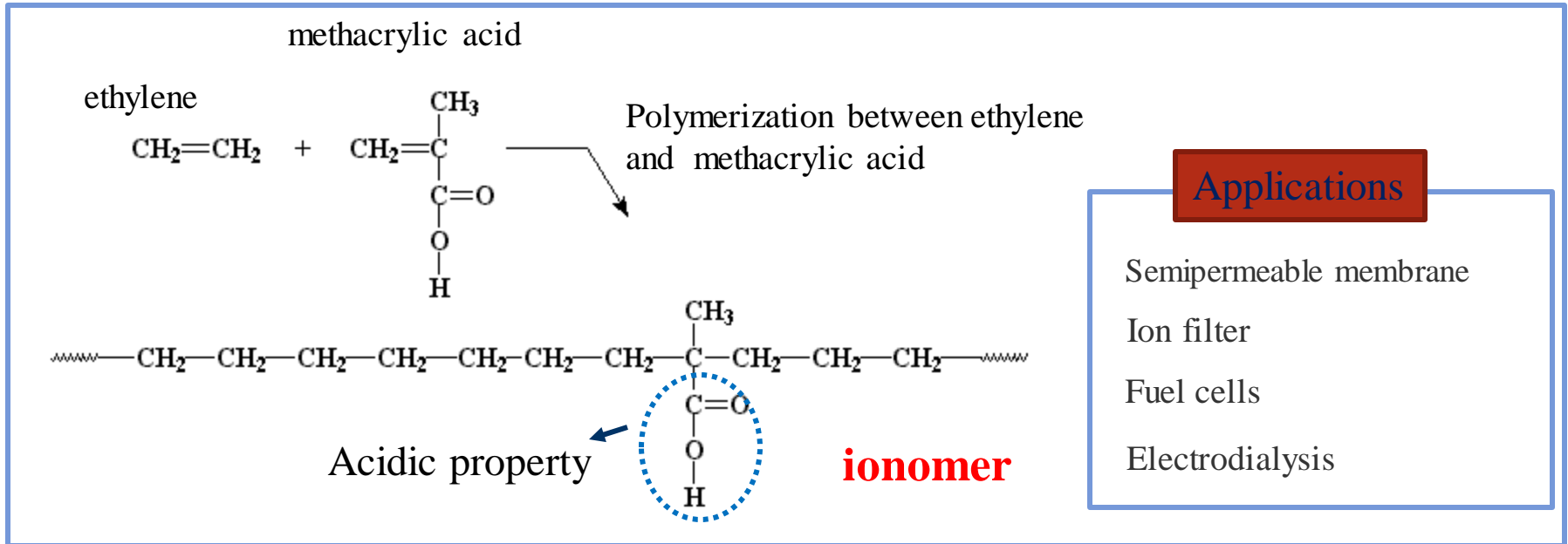
Reversible crosslinking behavior of ionomers



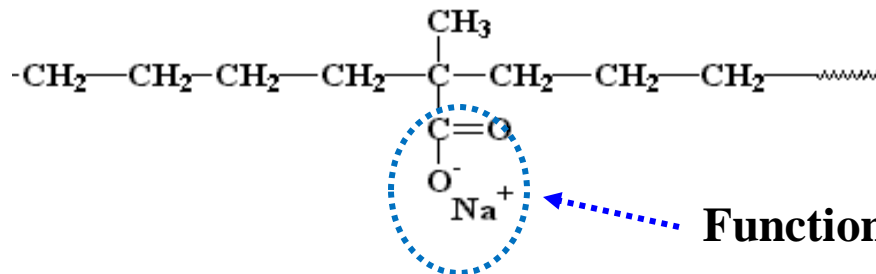
This phenomenon allows for a polymer with the properties of an elastomer and the processability of a thermoplastic. These ionomers are sometimes known as **thermoplastic elastomers**

Example:

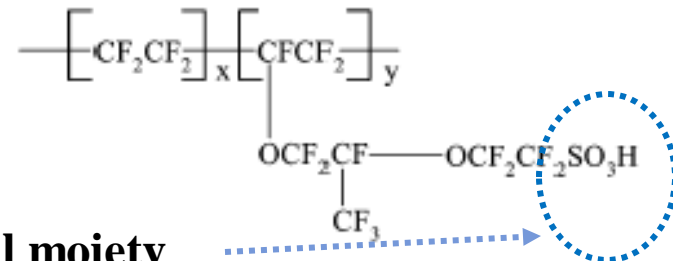
Poly(ethylene-co-methacrylic acid)



Dupon : Sulyn TM



Dupon : Nafion TM



Polyolefin

Ethylene propylene rubber

EP rubber (EPR), poly(ethylene-co-propylene)

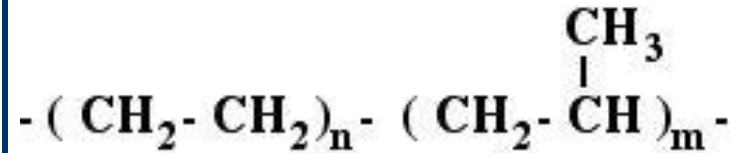
: A random copolymer of ethylene and propylene. A rubbery noncrystalline material

Properties

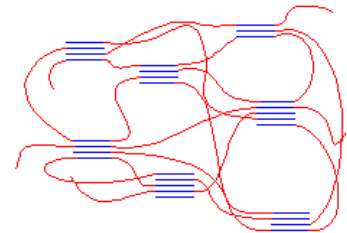
- ✓ Glass transition temperature: -50 deg.C
- ✓ Non-polar elastomers
- ✓ Good electrical resistivity
- ✓ Resistance to polar solvents
(i.e., water, acids, alkalies, ketones, alcohols)

Applications

radiator, appliance hose, tubing, belts, electrical insulation, roofing membrane, rubber mechanical goods



High-voltage tape



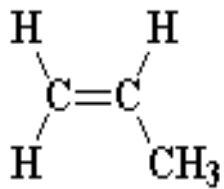
Rubber mechanical goods



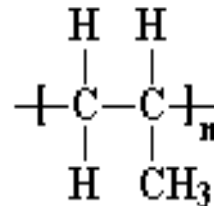
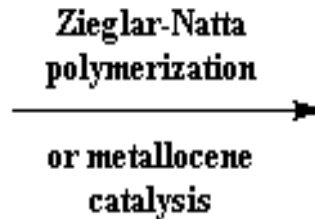
Polyolefin

Polypropylene (PP)

Synthesis



propylene



polypropylene

Characteristics

- Crystallinity and Young's modulus : Intermediate level of LDPE and HDPE
- Melting point : 160 deg. C
- Color : translucent, opaque

: A thermoplastic polymer, used in a wide variety of applications

including →

Food packaging, ropes, textiles

Thermal pants and shirts made for the military

Laboratory equipment, automotive components

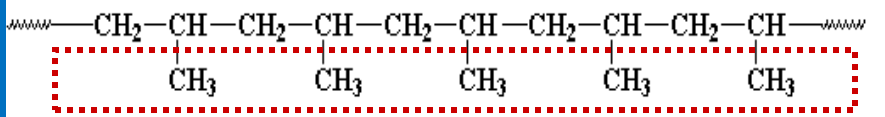
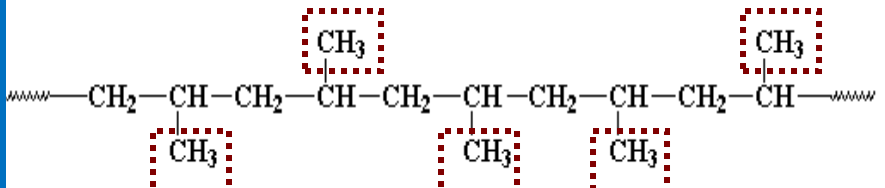
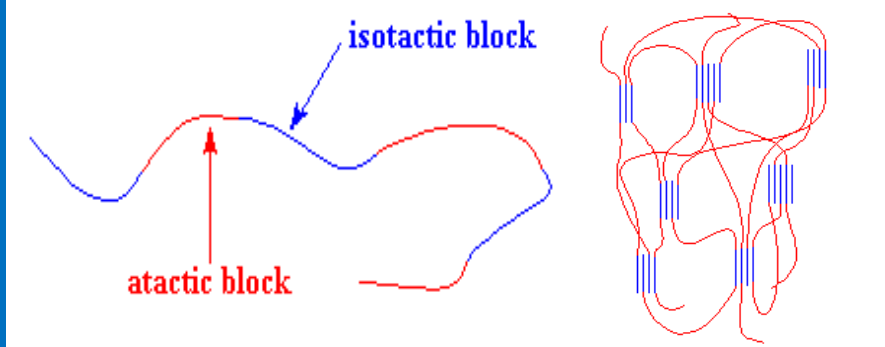
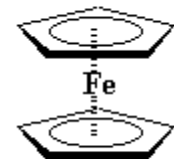
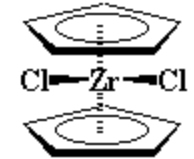
Its resin identification code :



Polyolefin

Polypropylene (PP)

Crystallographic properties:

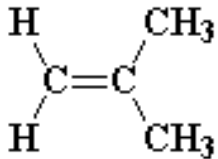
Structure	Synthesis method	Properties
 <p style="text-align: center;">Isotactic polypropylene</p>	<p>Ziegler-Natta polymerization (titanium chloride catalyst)</p> <p>Other isotactic polymer</p> $\left[\begin{array}{c} \text{CH}_2\text{CH}_3 \\ \\ -\text{CH}_2\text{CH}- \end{array} \right]_n \quad \left(\begin{array}{c} \text{CH}_3 \\ \\ -\text{CH}_2\text{CH}- \end{array} \right)_n$ <p>Poly-1-butene Poly(4-methyl-1-pentene)</p>	<p>Hard crumps of crystalline polymer</p>
 <p style="text-align: center;">atactic polypropylene</p>	<p>Radical polymerization (i.e., initiator : AIBN)</p>	<p>Soft rubber</p>
	<p>Metallocene catalyst</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;">  <p>ferrocene</p> </div> <div style="text-align: center;">  <p>bis-chlorozirconocene</p> </div> </div>	<p>Thermoplastic elastomer</p>



Polyolefin

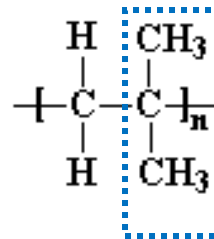
Poly isobutylene (butyl rubber)

Synthesis



isobutylene

- Radical polymerization
- Cationic addition pmz
- Anionic addition pmz



polyisobutylene

Characteristics

- Synthetic rubber
- Thermoplastic elastomer
- Gas impermeable polymer
 - Enable gas storage
- Color : light yellow elastic semi-solid

: PIB, used in many applications requiring an airtight rubber

including

- Liners for tubeless tyres
- Inner tubes
- Inner tubes for footballs, basketballs etc
- Stoppers for medicine bottles
- In sealants and adhesives
- O-rings
- Joint replacements (biomedical)
- Chewing gum



Gas mask

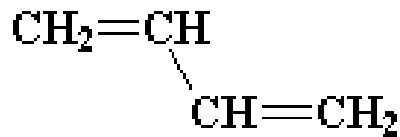
Rubber grove



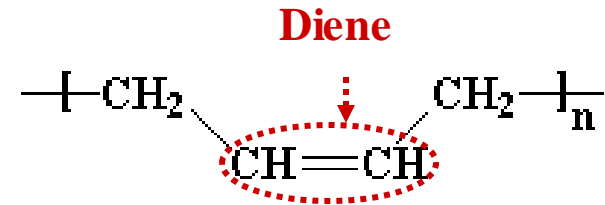
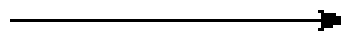
Diene Elastomers

Poly butadiene

Synthesis



Ziegler-Natta
polymerization



Characteristics

- First invented synthetic rubber
- Stands up to cold temperatures
- Low T_g, typically below -90 deg. C
- Excellent abrasion resistance (cured PB)
- Low rolling resistance (cured PB)

Uses & Applications

- Car parts (belt, hoses, gaskets..)



- Golf ball (core, shell)



- ✓ Low T_g also leads to poor wet traction properties, so polybutadiene is usually blended with other elastomers like **natural rubber or styrene-butadiene rubber** for tread compounds.

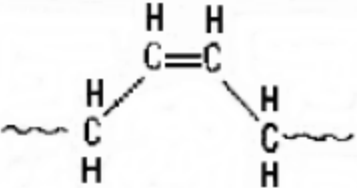
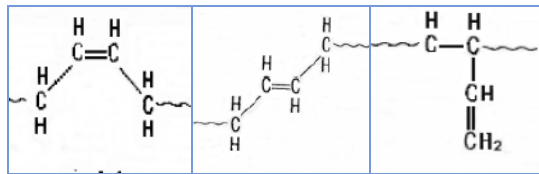
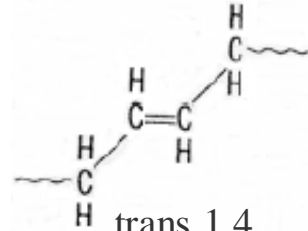


Diene Elastomers

Polybutadiene

Stereoregular properties (cis-, trans-)

“ When we synthesis the polybutadiene, the alkyl lithium and transition metal catalysts make very different products”

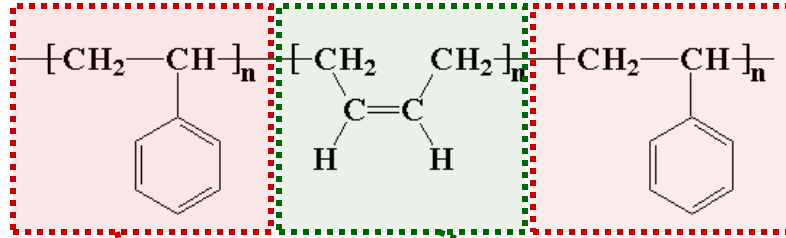
Catalyst	Ziegler catalyst (La, Nd, Ni)	Alkyl lithium based catalyst	Transition metal
Conformation Ratio (%)	 <p>Cis 1,4 (>95%)</p>	 <p>Cis 1,4 (40%) trans 1,4 (50%) Vinyl (10%)</p>	 <p>trans 1,4 (>90%)</p>
Properties	<ul style="list-style-type: none"> ▪ Good green strength ▪ Excellent cut growth resistance 	<ul style="list-style-type: none"> ▪ Less thermal stability due to Vinyl unit. 	<ul style="list-style-type: none"> ▪ Crystalline polymer ▪ Melting point : 80 deg.C
Application	Golf ball core	Plastic modification, blend	Golf ball shell



Diene Elastomers

SBS rubber

Poly(styrene-butadiene-styrene)



polystyrene
block

polystyrene
block

polybutadiene
block

Tough hard plastic

Gives SBS its durability

Rubbery

Gives SBS its rubber-like properties

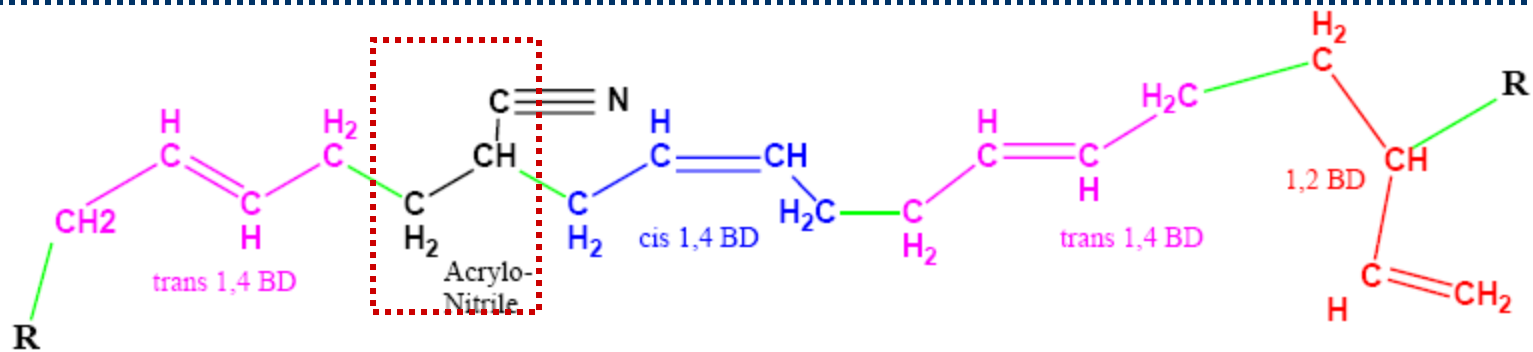
- **Uses:** Thermoplastic elastomer, tires, shoe soles
- **Monomers:** Styrene and Butadiene
- **Polymerization:** Living anionic polymerization
- **Morphology:** Amorphous
- **Tg:** - 55 deg. C (vulcanized)



Diene Elastomers

Nitrile rubber (ABR)

Synthetic rubber copolymer of acrylonitrile and butadiene



Highly polar unit →

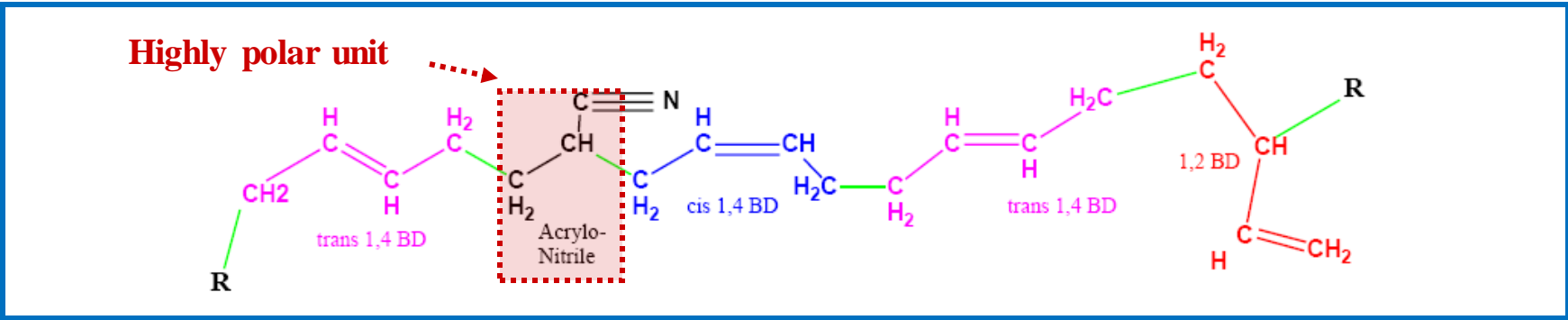
- ✓ Good resistance to aliphatic and aromatic fuels, oils, and solvents
- ✓ Poor electrical properties
- ✓ Poor low-temperature flexibility

Properties:

- Morphology: Amorphous
- Ability to withstand a range of temperatures from -40°C to $+120^{\circ}\text{C}$
- Uses: Extreme automotive applications, fuel, oil handling hoses, seals and grommets



Diene Elastomers Nitrile rubber (NBR)



NBR Properties-Relationship to Acrylonitrile Content

NBR with Lower Acrylonitrile Content

- Processability →
- Cure Rate w/Sulfur Cure System →
- Oil/Fuel Resistance →
- Compatibility w/Polar Polymers →
- Air/Gas Impermeability →
- Tensile Strength →
- Abrasion Resistance →
- Heat-Aging →

- ← Cure Rate w/Peroxide Cure System
- ← Compression Set
- ← Resilience
- ← Hysteresis
- ← Low Temperature Flexibility

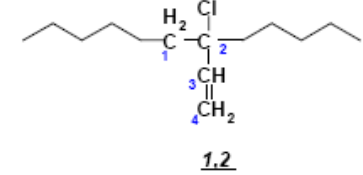
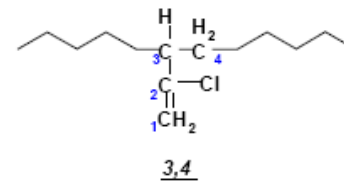
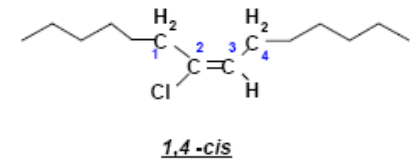
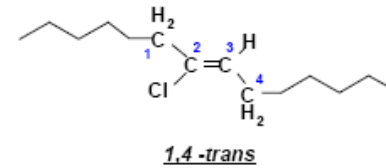
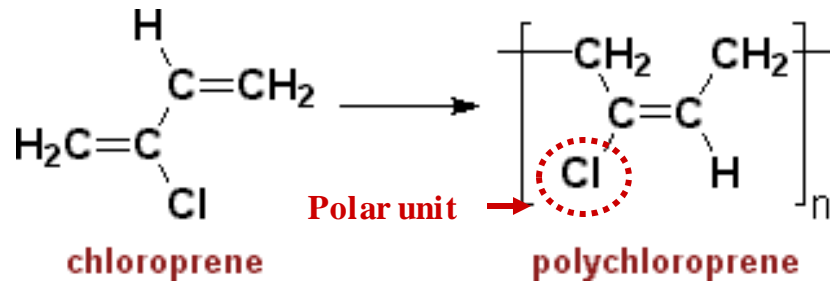
NBR with Higher Acrylonitrile Content



Diene elastomers

Neoprene

◆ Polychloroprene (CR), Neoprene™ (Dupont)



- First synthetic elastomer to be a **hit commercially**
- Good **mechanical strength**
- High **ozone and weather resistance**
- Good **aging resistance** ▪ **Low flammability**
- Good **resistance toward chemicals**
- Moderate **oil and fuel resistance**
- **Adhesion** to many substrates



But.....

Expensive..



Hanyang Univ.

Styrene polymers

Polystyrene

History

Polystyrene was accidentally discovered in 1839 by **Eduard Simon**, an apothecary in Berlin, Germany. About 80 years went by before it was realized that heating of styrol starts a chain reaction which produces macromolecules, following the thesis of German organic chemist **Hermann Staudinger** (1881 - 1965). This eventually led to the substance receiving its present name, polystyrene. The **I.G. Farben** company began manufacturing polystyrene in Ludwigshafen, Germany, about 1931. Success was achieved when they developed a reactor vessel that extruded polystyrene through a heated tube and cutter, producing polystyrene in pellet form. Public support of initial development during **World War 2** (1939-1945) has made polystyrene a large volume low-price plastic in the United States.

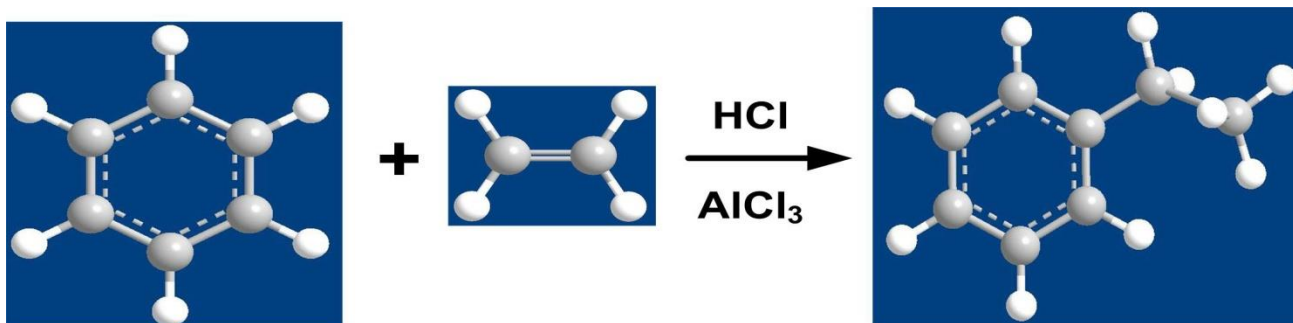
Mechanism

Styrene is one of the most Important industrial chemicals-more than 6 billion lb is produced each year. Then starting material for the commercial synthesis of styrene is ethyl-benzene, produced by Friedel-Crafts alkylation of benzene. Two-step synthesis of styrene monomer from benzene and ethylene mekaes it a reasonably low-cost raw material.



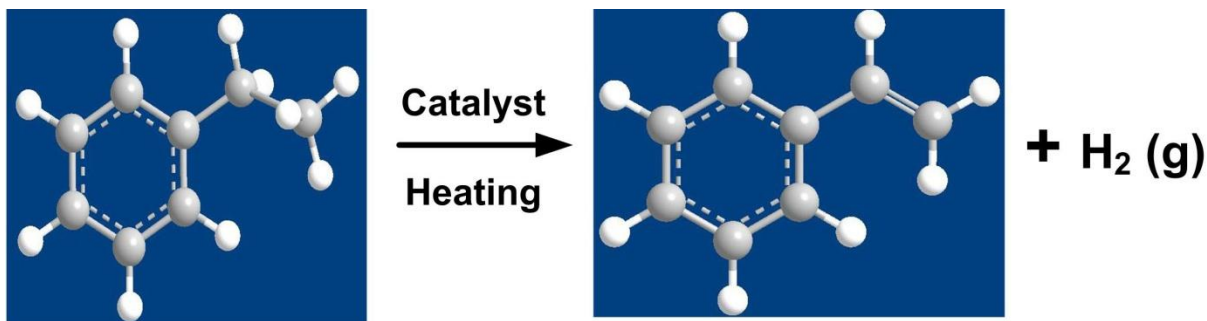
Styrene Polymers

Polystyrene



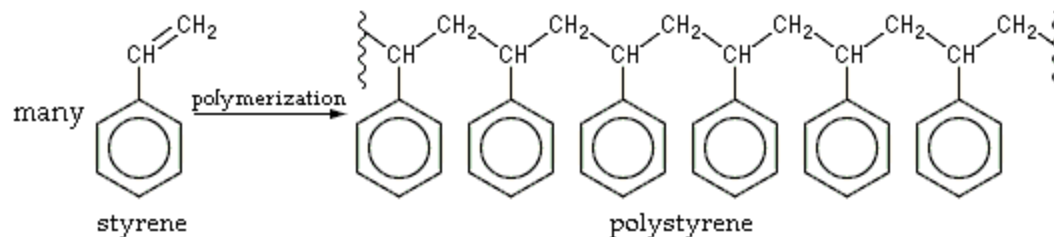
Ethylbenzene

Ethylbenzene is then dehydrogenated in the presence of a catalyst (zinc oxide or chromium oxide) to produce styrene.



Styrene 90-92% yield

Most styrene is polymerized to the familiar plastic, polystyrene, through free radical vinyl polymerization.



Styrene Polymers

Polystyrene

- Properties and uses

Electrical conductivity (σ)	10^{-16} S/m *silver 63.01×10^6
Thermal conductivity	0.08 W/(m·K) *silver 429
Glass temperature	95 °C
Melting point	240 °C
Decomposition	\pm 2000 years

The phenyl group on every second carbon atom in the main-chain of PS has a rigid, bulky configuration, producing sufficient steric hindrance to make the the polymer molecule very inflexible at room temperature.

At high temperature, atomic vibrations increase sufficiently to make the molecule quite flexible. → it is available to process molding.

Easy processability, rigidity, clarity and low price combine to support major applications in molded and thermoformed packaging containers and lids, housewares, toys, signs, closures, brushes, interior wall tiles, radio, and television cases.



Styrene Polymers

Polystyrene

• Polystyrene Foam

Styrofoam is a trademark name for polystyrene thermal insulation material, manufactured by Dow Chemical Company.

Properties

- Low-density closed-cell structure, containing primarily air, provides very good thermal insulation, and is widely used in flotation application and construction material.
- ability to absorb energy when crushed by impact provides excellent protection for delicate mechanisms and food stuffs, and is heavily used in packaging.

Nontoxicity and water resistance support major use in packaging of many foods, particularly in meat-trays.

Problems

- not easily recyclable due to its light weight and low scrap value.
- very long time to decompose in the environment and it is to cause starvation in birds and other marine wildlife. Now, over 20 US cities have banned polystyrene food packaging, including Oakland CA on Jan 1st 2007.



Styrene Polymers

Polystyrene

Foam Board often known as Fome-cor, Foam-core.

EXPANDED polystyrene which is most often found as a packaging material.

Blue Foam of "Styrofoam" is actually a trade name of DOW extruded polystyrene.



About PVC

Of all the synthetic thermoplastics used today, polyvinyl chloride (PVC) is probably the one with the oldest pedigree. Vinyl chloride monomer (VCM) was first produced by Regnault in France in 1835 and its polymerization was recorded in 1872 by Baumann, who exposed sealed tubes containing vinyl chloride to sunlight. The earliest patents for PVC production were taken out in the USA in 1912 and pilot plant production of PVC began in Germany and the USA in the early 1930's.

The industrial production of PVC using emulsion and suspension techniques was taking place in Britain, Germany and the USA by 1939. Total production reached 50,000 tons by 1945, and in the course of the following years, increased rapidly.

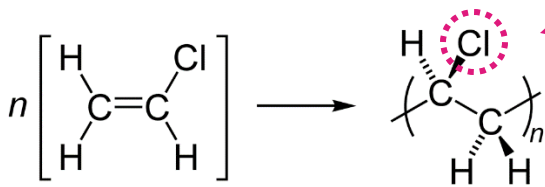
PVC is now the second most used plastic in the world.



Vinyl Halide polymers

PVC

► Properties



- The chlorine atom on every second carbon in the main-chain of polyvinyl chloride produces polarity.
- The large negative chlorine atoms also cause some steric hindrance and electrostatic repulsion, which reduce the flexibility of the polymer chain.
- So PVC have high rigidity and strength coupled with brittleness, fair heat deflection temperature, good electrical resistance, and high solvent resistance.



▶ Application

- Building panels, siding, windows, rainwater gutter and downspouts.
- Pipe, fittings, and conduit, particularly for water and for chemical processing.
- Blow-molded bottle.
- Thermoformed sheet for packaging.
- In Europe for magnetic tape.



About Plasticized PVC

Plasticized PVC has been one of the most economically and technically important plastics materials since the 1950s. As a result, examples are present in many international museum collections, as clothing and footwear, furniture, electrical insulation, flexible toys, storage and packaging materials. Many plasticized PVC formulations are designed to function for less than 20 years; this is a short lifetime for a museum object.

▶ Properties

- The Plasticized Polyvinyl Chloride is softened by the addition of major proportions of compatible, nonvolatile, liquid plasticizers.
- The products has softness, flexibility, and even extensibility and gradual elasticity.
- PPC outperforms rubber in process ability, wide range of mechanical properties, flame resistance, transparency and color possibilities, resistance to chemical and aging.
- In textiles and paper, wear resistance, flame resistance, impermeability, resistance to soiling.
- It outperforms leather in easy processing and quality control, wear resistance, color, moisture resistance.

Vinyl Halide polymers

PPC

▶ Application

- Furniture and auto upholstery and interior wall coverings.
- In outdoor clothing, rainwear, shoes, and baby pants.
- In tablecloths, shower curtains, and closet accessories.
- In electrical wire and cable insulation
- In packaging film, especially for meat, poultry, fresh fruit, and vegetables.
- In dolls and inflatable toys.
- In sporting goods such as balls and swimming pool liners.
- In garden hose and medical tubing.
- In weather-stripping and water stops.
- In auto mat and in stationery supplies.

This PVC photograph pocket has cockled and distorted due to loss of plasticizer since 1975



About Plasticized PVC

Polyvinylidene chloride is a polymer derived from vinylidene chloride.

Ralph Wiley, a Dow Chemical lab worker, accidentally discovered polyvinylidene chloride in 1933. While cleaning laboratory glassware, Wiley came across a vial he could not scrub clean. Dow researchers made this material into a greasy, dark green film, first called "Eonite" and then Saran.

The military sprayed Saran on fighter planes to guard against salty sea spray and carmakers used it for upholstery. Dow later got rid of the Saran's green color and unpleasant odor.

The most popularly known use of polyvinylidene chloride came in 1953, when Saran Wrap, a plastic food wrap was introduced. In 2004, however, the formula was changed to Low density polyethylene out of environmental concerns about the chloride.

In packaging, polyvinylidene chloride is also applied as a water-based coating to other plastic films such as biaxially-oriented polypropylene (BOPP) and polyester (PET). This coating increases the barrier properties of the film, reducing the permeability of the film to oxygen and flavors and thus extending the shelf life of the food inside the package.

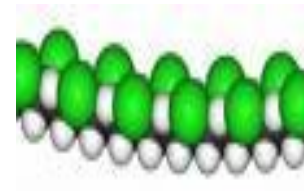
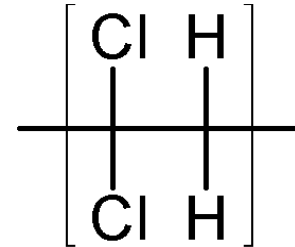


Vinyl Halide polymers

Polyvinylidene Chloride

► Properties

- Symmetrical substitution of two chlorine atoms on every second carbon in the main-chain provides a regular zigzag chain structure.
- High strength, high melting point, and especially outstanding impermeability to oil, grease, water vapor, oxygen, and carbon dioxide.



▶ Application

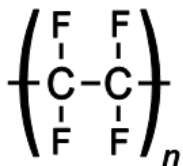
- Packaging film (impermeable barrier protection)
- Outdoor furniture



Vinyl Halide polymers

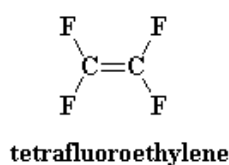
Polytetrafluoroethylene

► Properties

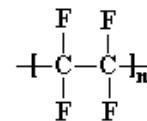


- The fluorine atoms in polytetrafluoroethylene account for most of its unusual properties.
- Flame resistance, high thermal and chemical stability.
- High electro negativity, small diameter, and high-density, and low surface tension
- low adhesion, and low coefficient of friction.

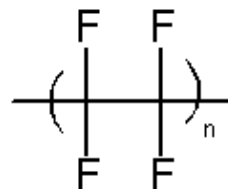
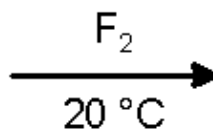
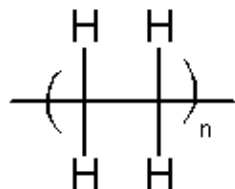
• PTFE is a vinyl polymer, and its structure, if not its behavior, is similar to polyethylene. Polytetrafluoroethylene is made from the monomer tetrafluoroethylene by free radical vinyl polymerization.



free radical
vinyl polymerization



polytetrafluoroethylene



or it may be produced by the direct substitution of hydrogen atoms on polyethylene with fluorine, using polyethylene and fluorine gas at 20 °C



Vinyl Halide polymers

Polytetrafluoroethylene

▶ Application

- Insulating electrical wiring in high-temperature environments; motors, locomotives, aircraft engines, missiles, and spacecraft.
- Lighting fixtures, stoves, and oven.
- Switches, controls, and computers.
- Heating cable for pipe tracing in chemical plants and refineries.
- Gasket, seals, packing, bearings, and cooking utensils
- Electrical insulators for radar and television.
- Lining pipe, fittings, valves, and pump in industrial plant and hydraulic and fuel hose in aircraft, truck, buses, and trains.



Vinyl Halide polymers

Fluorinated Ethylene/Propylene copolymer

About FEP



FEP is chemically a copolymer of hexafluoropropylene and tetrafluoroethylene. It can be described as a fluoropolymer resin having most of the excellent physical, chemical and electrical properties of PTFE fluoropolymer resin but with the ability to be processed using conventional thermoplastics processing equipment. End products of FEP are known for their excellent chemical resistance, superior electrical properties and high service temperatures of up to 200° C (400° F). In addition, FEP provides outstanding low temperature toughness and unique flame resistance.



Vinyl Halide polymers

Fluorinated Ethylene/Propylene copolymer

► Properties

- Copolymerization of tetrafluoroethylene with some hexafluoropropylene produces irregularity in the polymer molecule, making it less rid-like and less crystalline, lowering melting point and melt viscosity, and thus improving process ability.

► Application

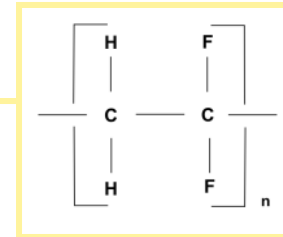
- Capacitors, printed circuits, multiconductor cable, mold liners, flexible belting for food and chemical plants, and shrink tubing on rolls for conveyors, textile finishing, offset printing, paper-making and wax handling.



Vinyl Halide polymers

Polyvinylidene Fluoride

About PVDF



PVDF is a specialty plastic material in the fluoropolymer family; it is used generally in applications requiring the highest purity, strength, and resistance to solvents, acids, bases and heat and low smoke generation during a fire event. Compared to other fluoropolymers, it has an easier melt process because of its relatively low melting point. It has a relatively low density (1.78) and low cost compared to the other fluoropolymers. It is available as piping products, sheet, tubing, films, plate and an insulator for premium wire. It can be injection molded and welded and is commonly used in the chemical, semiconductor, medical and defense industries, as well as in lithium ion batteries. A fine powder grade, KYNAR 500 PVDF, is also used as the principal ingredient of high-end paints for metals. These PVDF paints have extremely good gloss and color retention, and they are in use on many prominent buildings around the world



► Properties

- With alternating hydrogen and fluorine atoms, polyvinylidene fluoride has better process ability.
- Less thermal and chemical resistance than the precious fluoropolymers.
- Strength is higher, melting point lower, dielectric constant and loss higher, and resistance to solvents much less.

► Application

- Chemical piping, valves, pumps and large ducts
- Electrical wire insulation in aircraft, computers, oil well, and heat-shrinkable insulating tubing for electronics resistors
- Exterior metal siding such as aluminum and galvanized panels for stores and industries.



Polyolefin

Ethylene copolymer series

◆ Ethylene vinyl acetate (EVA)

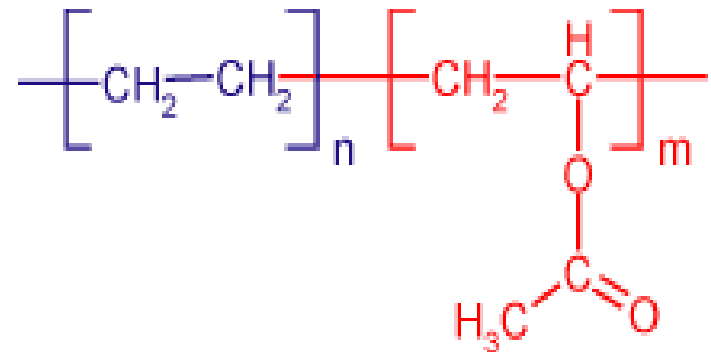
- EVA based hot-melts are able to fulfill various requirements in applications such as packaging, bookbinding or label sticking

✓ Polar functionality promotes adhesion to polar substrates (paper, polyester, wood, and leather)

✓ **Low crystallinity gives it a low melting point and excellent low temperature toughness.**

✓ Applications

: packaging, adhesives, wire, cable and health care.



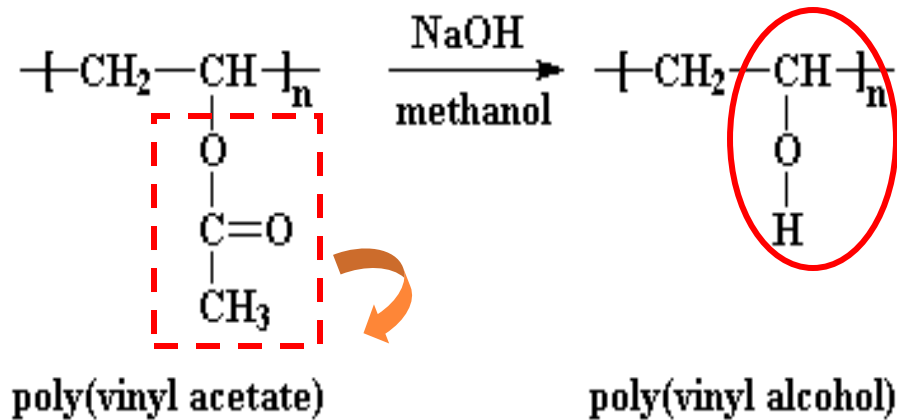
Polar functional moiety



Polyvinyl alcohol & its derivatives

Polyvinyl alcohol

; (PVOH, PVA, or PVAL) is a water-soluble synthetic polymer.



The hydroxyl group provides high polarity and hydrogen-bonding, which make it *infusible but soluble in water and resistant to oils, fat and greases.*

Leaving of acetate groups in the polymer molecule is sufficient to decrease regularity and packing and increase flexibility and solubility.

Properties

- Excellent film forming, emulsifying, and adhesive properties.
- It is resistant to oil, grease and solvent.
- High tensile strength, flexibility, as well as high oxygen and aroma barrier



Applications

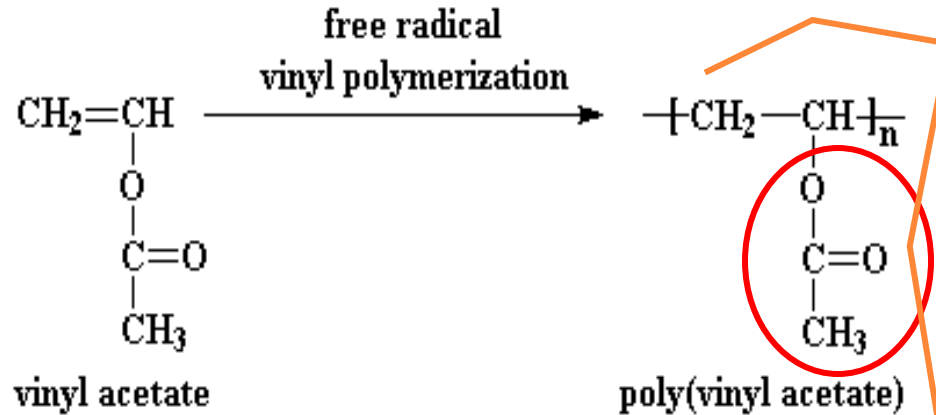
- Aqueous thickeners and dispersing agents in emulsion .
- Adhesive for paper and paperboard in packaging.
- Water-soluble film useful for packaging.
- A fiber reinforcement in concrete.
- A Surfactant for the formation of polymer encapsulated nanobeads.



Polyvinyl alcohol & its derivatives

Polyvinyl acetate

; *Polyvinyl acetate or PVA is a rubbery synthetic polymer.*



The ester groups and active hydrogen atoms provide moderate polarity and hydrogen-bonding, permitting easy fusion, solubility, plasticization, emulsification and adhesion to a wide range of substrates.

The size & shape of acetate side-chains provide sufficient steric hindrance to make the polymer stiff at R.T.

Polyvinyl alcohol & its derivatives

Polyvinyl acetate

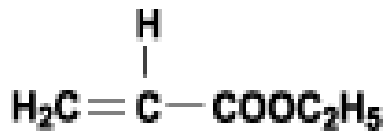
Applications

- Adhesives, films, lacquers, inks, latex paints, and paper sizes.
- Book making and book arts.
- Used in emulsion paints and as a precursor for poly(vinyl alcohol) manufacture: a component of chewing gum, drinking straws, and adhesives.
- Used to protect cheese from fungi and humidity.

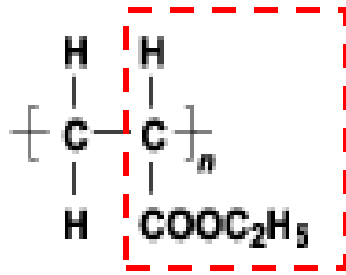


Acrylic polymers

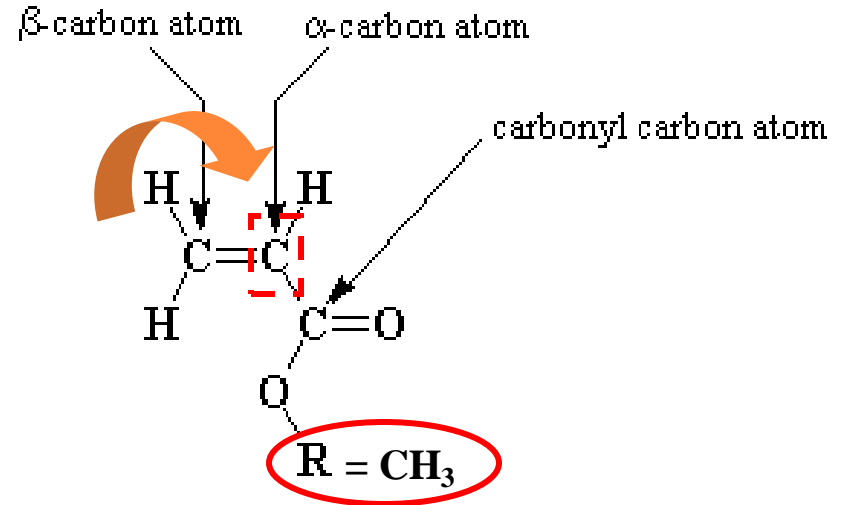
Ethyl acrylate polymers



Ethyl acrylate



Poly(ethyl acrylate)



- *The flexible carboethoxy side-chains* push the molecules apart without restricting rotation and it produces **high molecular flexibility**.
- *The random atactic configuration of successive asymmetric carbon atoms* prevents crystallization and produces a random amorphous coil.

Properties

- A hard, transparent polymer with high optical clarity, high refractive index.
- Having good resistance to the effects of light and aging.



Acrylic polymers

Ethyl acrylate polymers

Applications

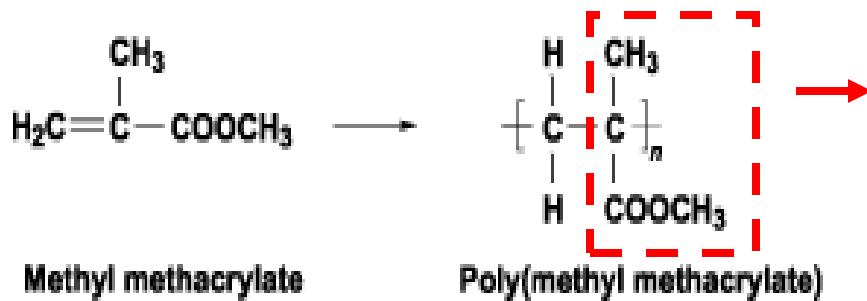
- Latex paints for wood, wallboard, and masonry in homes.
- Aqueous latexes formed by the emulsion polymerization of methyl methacrylate with other monomers are useful as water-based paints and in the treating of textiles and leather.
- Lenses, signs, indirect lighting fixtures, transparent domes and skylights, and protective coatings.



Acrylic polymers

Polymethyl Methacrylate

Prepared by radical polymerization of the methyl ester of methacrylic acid.



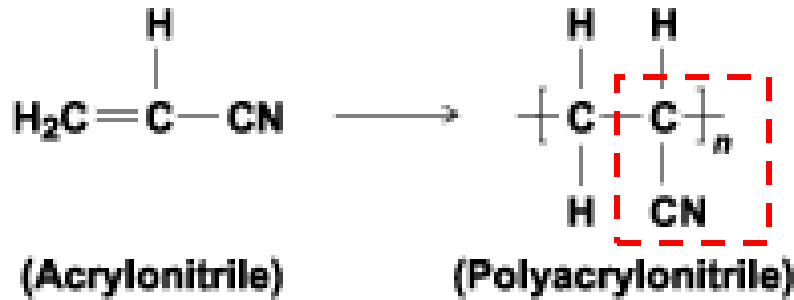
- *Quaternary substitution on every second carbon atom in the main-chain provides steric hindrance, making the polymer molecule more rigid at ordinary temp.*
- *Random configuration of the asymmetric carbon atoms produces a amorphous structure which provides high transparency to visible.*

Application

- Tough rubbery products.
- Plastic optical fiber.
- Glass replacement.
- Plasticizing or softening components of copolymers.



Acrylic polymers



Polyacrylonitrile

- *The highly electronegative nitrile groups exert so much mutual electronic repulsion that they force the molecule into an extended, stiff, rod-like conformation.*

- *These rod-like structure permits orientation and crystallization to produce strong fiber.*
- *The hydrogen-bonding between adjacent chain produces high strength, infusibility and resistance to moisture and solvents.*

Properties

- Hard, relatively insoluble, and high-melting materials.

Applications

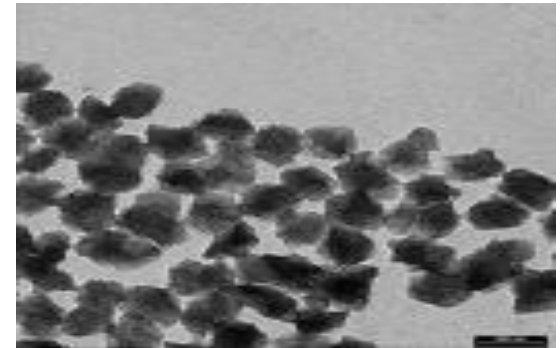
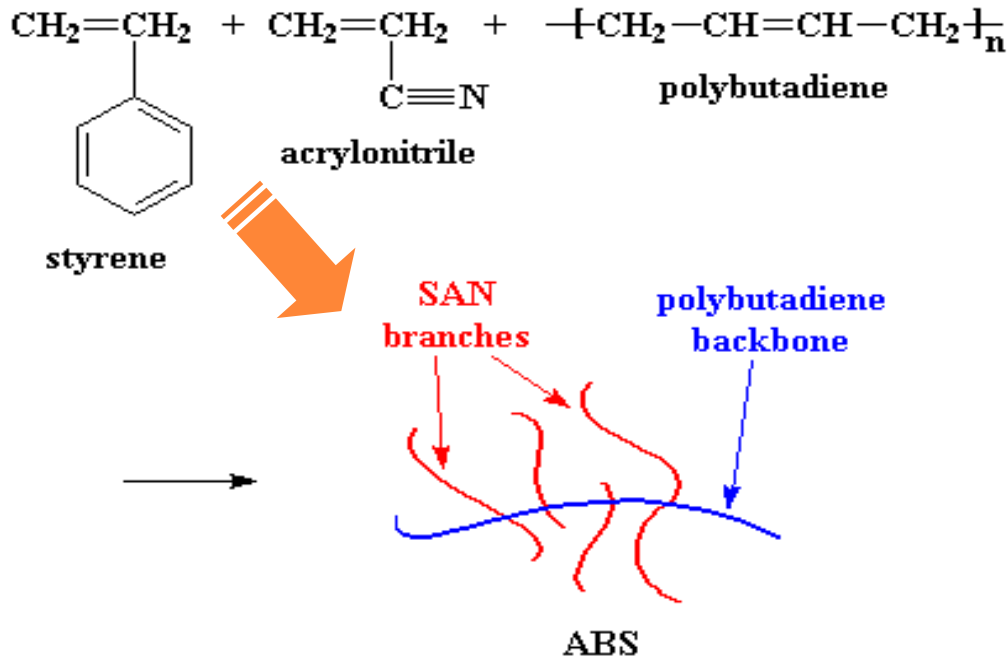
- Copolymers. (It falls into three groups: fibers, plastics, and rubbers.)
- Major use in wool-like applications such as sweaters, blankets, and carpeting.



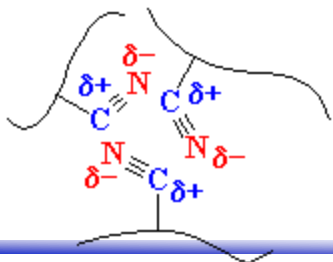
Acrylic polymers

Polyacrylonitrile

One of the examples of the copolymers of polyacrylonitrile



- Very strong and lightweight.
- Strong enough to be used to make automobile body parts, but so light.
- Using plastics like ABS makes automobiles lighter, uses less fuel, therefore they pollute less.



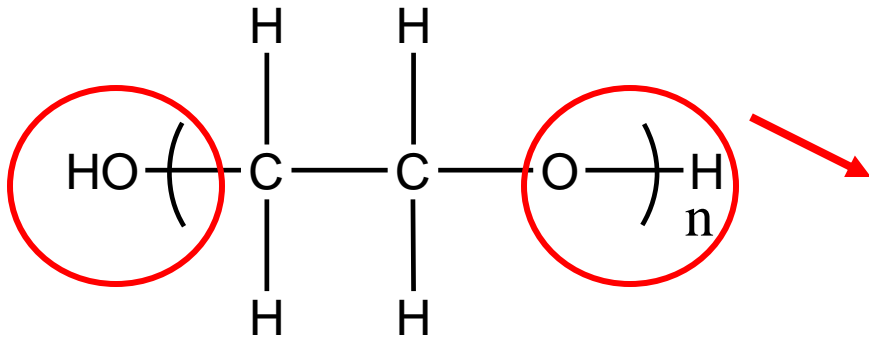
- *It is stronger plastic than polystyrene because of the nitrile groups of its acrylonitrile units.*
- *Nitrile groups are very polar, so they are attracted to each other.*



Aliphatic polyethers

Polyethylene Oxide

An organic compound without ring structures, i. e. with a straight chain arrangement of carbon and, possibly, other atoms ; as compared with the closed chains of the aromatic compounds.



The oxygen atoms which alternate regularly with ethylene units provide high polarity and hydrogen-bonding and it make the polymers are completely soluble in water and organic solvents.

- ▶ While the low-molecular-weight polymers are used as fluids and thickeners, the solid high-molecular-weight polymers find use in textile warp sizes, pharmaceutical, and water-soluble films.



Aliphatic polyethers

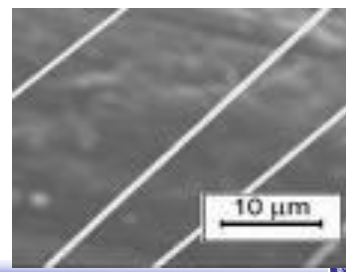
Polyethylene Oxide

Properties

- The most commercially important polyethers.
- PEG and PEO are liquids or low-melting solids, depending on their molecular weights.
- Both are prepared by polymerization of ethylene oxide.

Applications

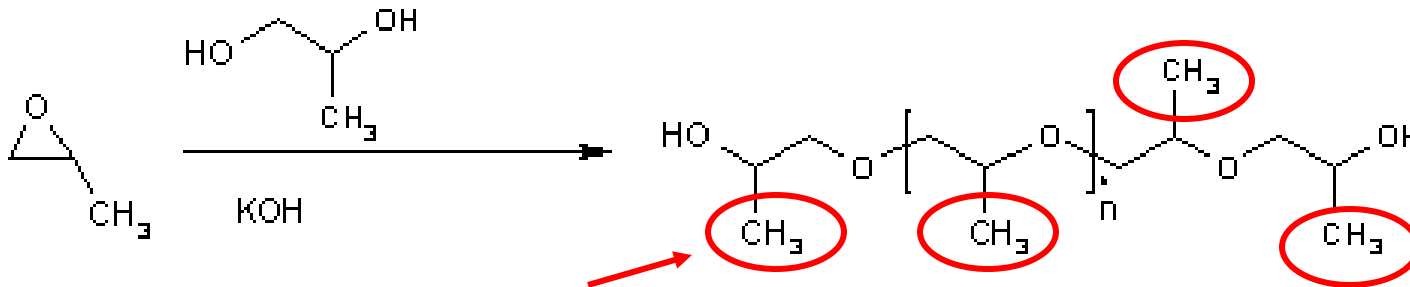
- Brightening effect and adhesion enhance in electroplating and electroplating.
- Cleaners, detergents and soaps with low toxicity solvent properties.
- In cosmetics and personal care bases.
- Dimensional stabilizer in wood working operations.
- Dye carrier in paints and inks and heat transfer fluid formulation.



Aliphatic polyethers

Polypropylene Oxide

; Produced by anionic ring-opening polymerization of propylene oxide.



The additional methyl groups make these polymer less hydrophilic and create asymmetric carbon atoms which configuration can lead to either amorphous or crystalline materials.

Properties

- Many properties in common with polyethylene glycol.
- Solubility in water decreases rapidly with increasing molar mass.

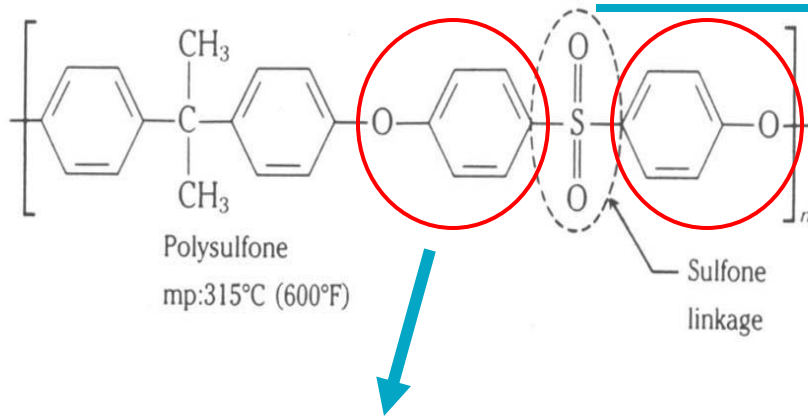
Applications

- Used in many formulations for polyurethanes.
- Used as a rheology modifier.



Aliphatic polyethers

Polysulfone



- The sulfur atoms* in this oxidation state make *the polymer quite polar and thus hydrophilic* as much of the fouling in water comes from hydrophobic organic particles, they are not attracted to the polysulfone.
- The pH and temperature ranges are wide for using this polymer.*

The phenylene rings within the chain restrict rotation of the polymer chain. => **High strength and rigidity.**

Properties

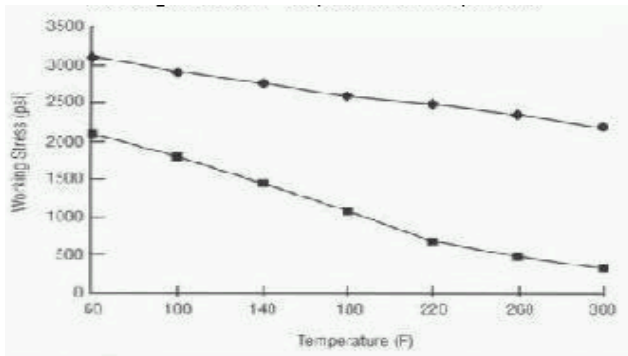
- Excellent resistance to inorganic acids & bases.
- Withstands repeated exposure to steam sterilization.
- Excellent resistance to hot water.
- Good thermal properties.



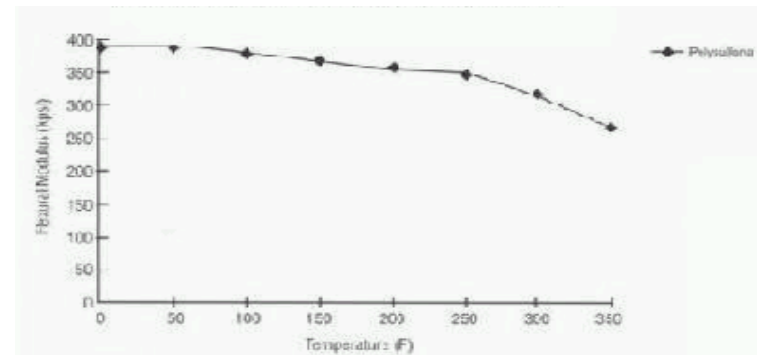
Applications

- Membranes. (drinking and ultra-pure waters, gas separation, food & beverage)
- Medical. (surgical trays, nebulizers, humidifiers)
- Food service. (microwave, beverage and food dispensers, milking machine)
- Plumbing. (hot water fittings, manifolds, mixer tap cartridges)

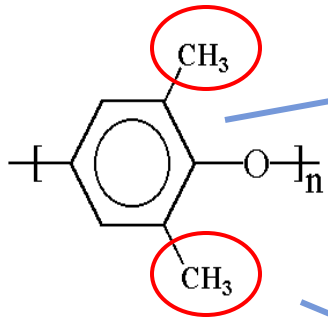
* Working stress vs Temperature



* Flexural modulus vs Temperature



Aliphatic polyethers *Poly (2,6-dimethyl phenylene oxide)*



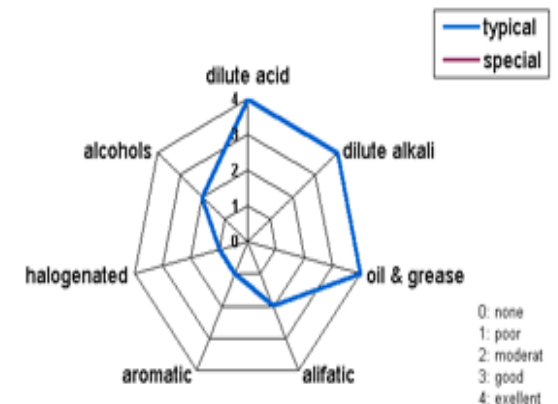
Because of repeating phenylene rings, PPO create steric hindrance to rotation within the molecule and electronic attraction of resonating electron systems in adjacent molecule.

The symmetrical structure has no unbalanced polarity, high molecular Rigidity. The low polarity also produces very low water absorption

Properties

- High dimensional and thermal stabilities.
- Unusual resistance to acids and bases.
- Processable on conventional extrusion and injection molding equipment.
- Excellent dimensional stability, low moisture absorption
- High mechanical and dielectric strength.
- Rigid, opaque, difficult to process.

PPO, resistance to liquids



Aliphatic polyethers *Poly (2,6-dimethyl phenylene oxide)*

Applications

- Coffee pot and washing m/c parts.
(where high temperature and moisture are critical)
- Replacement for die castings, drink vending machines.
- Microwave components.



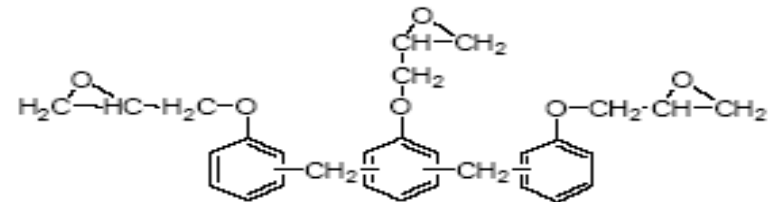
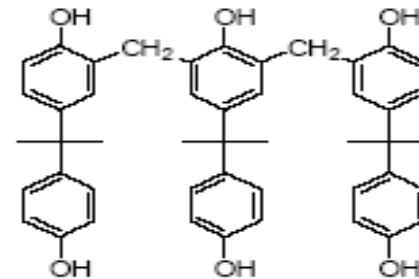
Aliphatic polyethers

Applications

- Adhesives, coatings, plastics modifiers.



Phenoxy resins



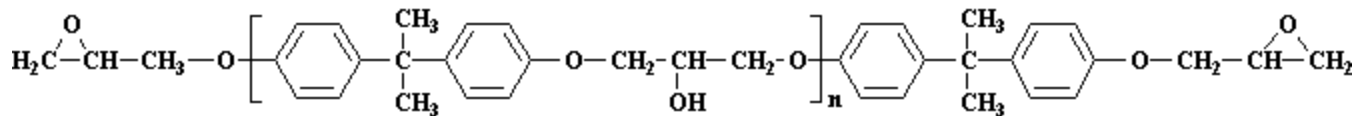
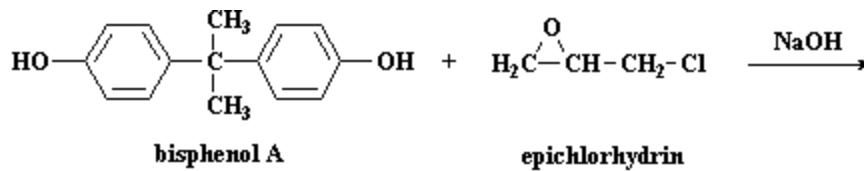
Properties

- High molecular weight but very linear in structure.
- Tough and ductile.
- Pendant hydroxyl groups promote wetting and bonding to polar substrates and fillers.
- **Phenoxy resins** are chemically similar to epoxy resins but **they contain no epoxy groups and have higher molecular weights, and are true thermoplastics.** However, the presence of many free hydroxyl groups permits cross-linking with isocyanates, anhydrides, triazines and melamine.

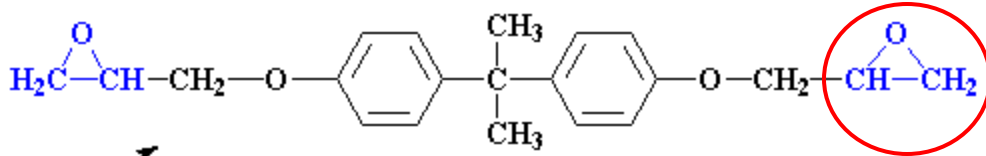


Aliphatic polyethers

Epoxy resins

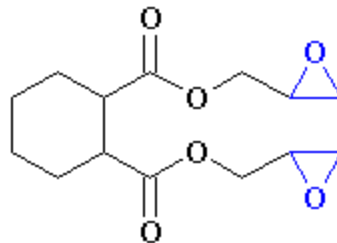
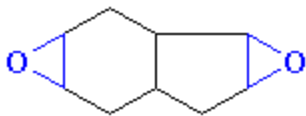


Produced from a reaction between epichlorohydrin and bisphenol-A



This is a small molecule diepoxy. You can think of it as the polymer shown above with a degree of polymerization of one. Some other diepoxy small molecules are shown below.

1. Oestrogenic activity
2. Alteration of male reproductive organs
3. Early puberty induction
4. Shortened duration of breast feeding
5. Pancreatic cancer



Aliphatic polyethers

Epoxy resins

Properties

- Excellent mechanical property..
- Good electrical insulating property.
- Heat, chemical resistance.

Applications

- Coating & paints & adhesive.
- Electrical systems and electronics.
- Industrial tooling and composites.
- Consumer and marine applications.
- Aerospace applications.

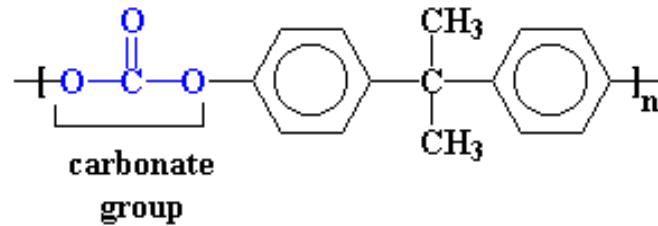


POLYESTERS

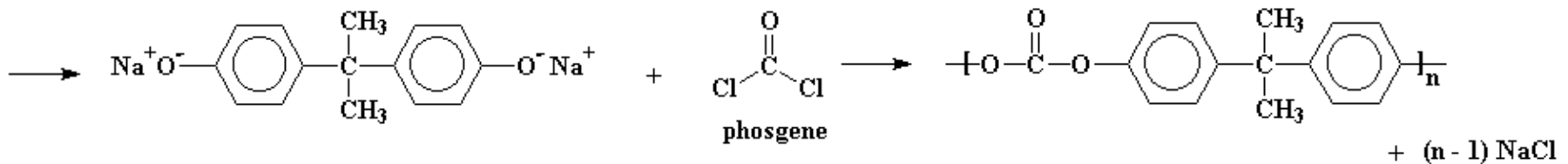
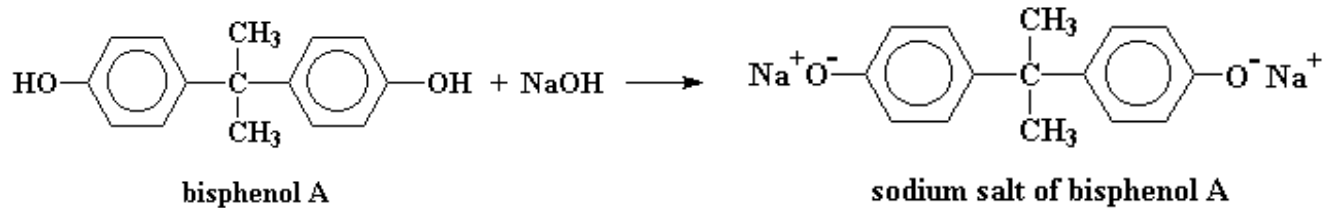
Polycarbonate

Polycarbonate : PC

➤ What is PC??



➤ Polymerization



POLYESTERS

Polycarbonate

➤ Characteristics

- The overlap of resonant **phenyl groups from adjacent chains** produces some degree of **intermolecular attraction**
 - > High melting point (T_m : 267°C, T_g : 150°C) & melt viscosity
 - ✓ Difficult melt processing
 - ✓ High rigidity and strength
 - ✓ High deflection temp.
 - ✓ Good electrical properties
- The flexibility of the **carbon-oxygen single bonds** permits some **molecular flexibility**
 - > High impact strength
 - > But molecular mobility is not sufficient to insure this unambiguously and impact strength are very sensitive to thickness and other specific design considerations



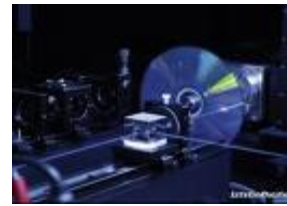
POLYESTERS

Polycarbonate

➤ Application



Building materials



Electric parts



Water Bottle



Film



Automobile part



Diffusion panel

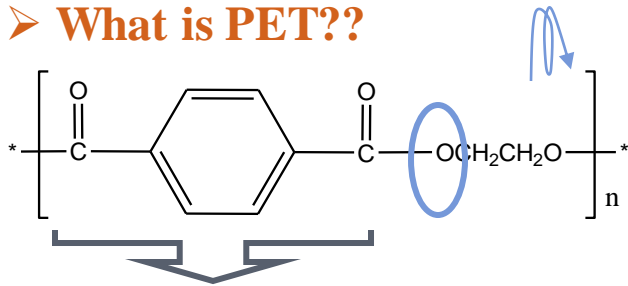


POLYESTERS

PET

Poly(Ethylene Terephthalate) : PET

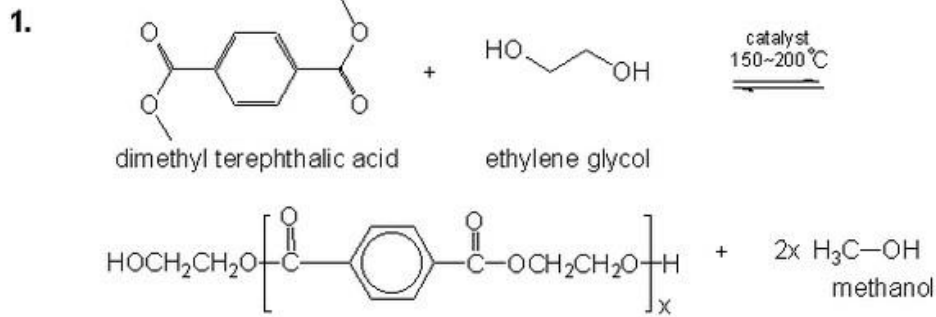
➤ What is PET??



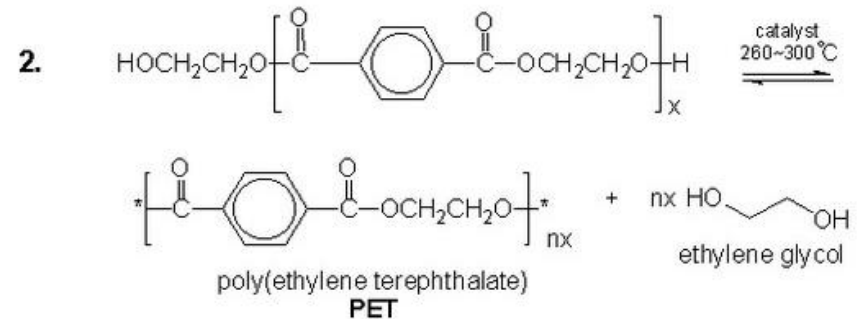
Large flat rigid bulky unit

➤ Polymerization

< Esterification >



< Condensation >



POLYESTERS

Polycarbonate

➤ Characteristics

- **The benzene rings** are bulky and rigid, and resonate with the carbonyl groups
- Their resonance creates some overlap and attraction between adjacent chains
- The regular structure crystallize quite readily despite its bulkiness
 - ✓ High modulus, strength, melting point, electrical quality
 - ✓ $T_g : 70^{\circ}\text{C}$, $T_m : 260^{\circ}\text{C}$
 - ✓ moisture and solvent resistance
- **The ethylene glycol** units are very flexible
- Provide sufficient molecular mobility for melt processing, stretching and orientation above the T_g
- Flexibility in fibers & films down to very low temp.

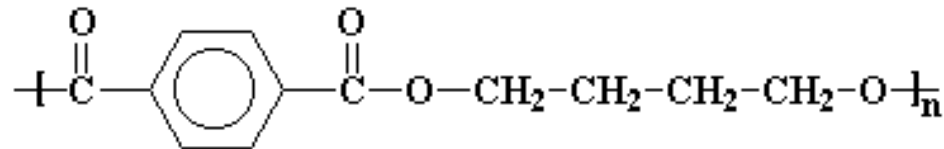


POLYESTERS

PBT

Poly (butylene terephthalate) : PBT

➤ What is PBT??



poly(butylene terephthalate)

➤ Characteristics

- **The benzene rings** are bulky and rigid, and resonate with the carbonyl groups
- Crystallization time of PBT is shorter than that of PET → Short cycle!!
- The regular structure crystallize quite readily despite its bulkiness
 - ✓ **Engineering plastics**
 - ✓ **Mechanical properties** : resistance to moisture, strain and abrasion
 - ✓ **T_g : 65°C , T_m : 225°C**

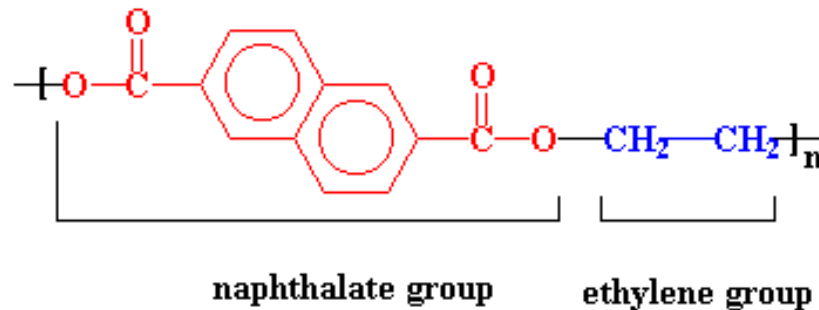


POLYESTERS

PEN

Poly (ethylene 2,6-naphthalate) : PEN

➤ What is PEN??



➤ Characteristics

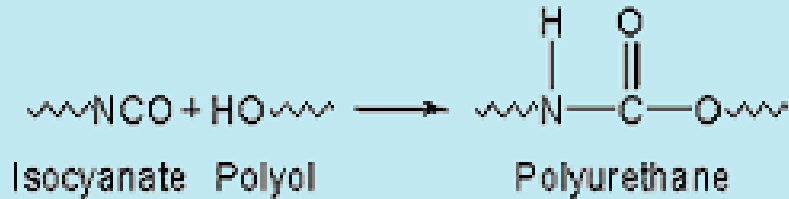
- Rigid and flat naphthalene ring → Superior mechanical properties than that of PET
 - ✓ T_g : 117°C , T_m : 262°C
 - ✓ Crystallization rate is seven times slower than PET
 - ✓ Melt viscosity about ten times larger than PET



POLYURETHANES

PU

➤ What is Polyurethane (PU)??



➤ Characteristics

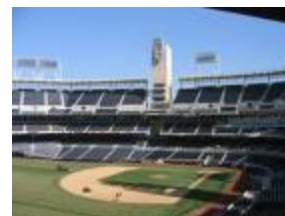
- PU form very rapidly when low-viscosity liquid reactants are mixed at room temp.
 - > easily poured or sprayed from low-cost equipment and converted directly into finished form
- Easy control of structure & properties over a wide range
- The aliphatic polyol, and especially polyether, portions of the finished polymer contribute flexibility and elasticity
- The urethane groups contribute polarity and hydrogen-bonding to prevent creep and improve strength and elasticity
- controlled cross-links
 - ✓ increased strength & elasticity
 - ✓ at high concentration can actually produce rigidity
 - ✓ the foam structure provides cushioning, insulating, and low-density properties in the finished products



POLYURETHANES

PU

➤ Application



POLYURETHANES

PU

Flexible Foams : Largest use of PU

➤ Characterization

- Long aliphatic polyether blocks provide **high flexibility**
- Urethane group polarity and hydrogen-bonding, and controlled mild cross-linking, provide **strength and resilience**
- The low density and high air content of the **open-celled foam** provides **softness and resilience**

➤ Application



Furniture cushioning



Auto seat cushioning



Bedding,
both mattresses



carpet



Rigid Foams : Second largest use of PU

➤ Characterization

- High-functionality polyether, and high-functionality polyisocyanates as well, produce sufficient cross-linking to immobilize the molecules and make the structure entirely rigid at room and even elevated temp.
- When foamed with low-boiling fluorocarbon gases, contained in a closed-cell foam structure, thermal conductivity is exceptionally low.
- The closed cell structure, easily poured into any type of cavity, has great buoyancy and considerable rigidity /weight ratio, making it useful in flotation and structural applications as well.

POLYURETHANES

PU

Rigid Foams : Second largest use of PU

➤ **Application**



POLYURETHANES

Elastomers

➤ Characterization

- Long flexible aliphatic diols, with moderate trifunctionality for cross-linking, can be mixed with diisocyanate
- The long aliphatic polyesters & polyethers provide softness and flexibility
- The urethane groups provide polarity and hydrogen-bonding
- the mild cross-links provide stronger intermolecular bonding together providing high strength, elasticity, abrasion resistance.
- provide chemical resistance

➤ Application

Shoe heels & soles



Solid tires & wheels
for industrial trucks



POLYURETHANES

Fibers

➤ Characterization

- Fibers prepared from block copolymers of aliphatic polyurethanes and aromatic polyureas combine the softness and flexibility.
- Microcrystallization of the aromatic polyureas, and sometimes add covalent cross-linking -> strong & elastic.
- “Spandex” fibers : superior in **strength** and in **resistance to abrasion, heat, light, and ozone.**

➤ Application



outerwear



Swimming suits



POLYURETHANES

Coatings

➤ Characterization

- Coatings made of PU have all the same advantage of flexibility, toughness, abrasion resistance, and chemical resistance
- Their main limitations are processing, light-stability, and cost

Adhesives



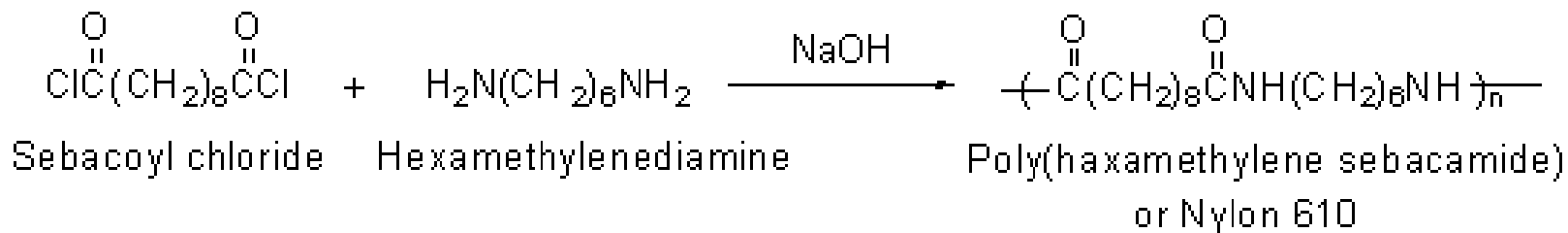
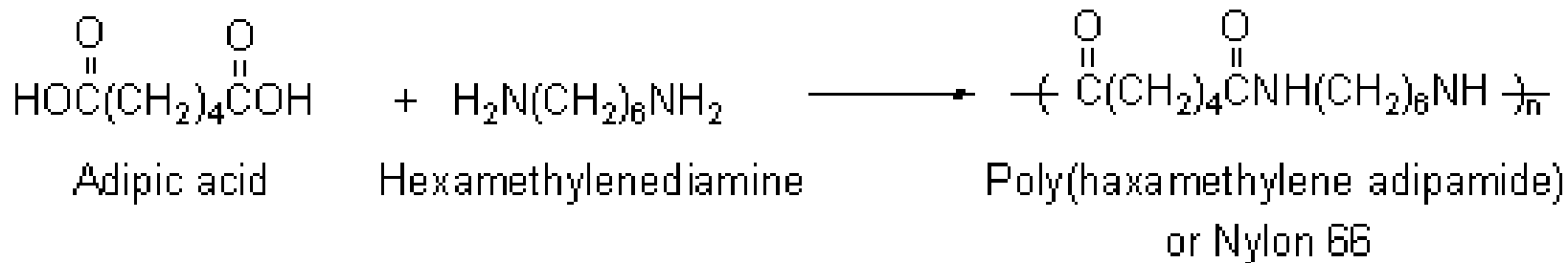
- Adhesive applications derive from the low viscosity and high polarity of the starting materials -> provide good wetting & penetration of the substrate
- Easy room-temp. polymerization & cure
- Reactivity in situ which may involve reactive sites on the substrate as well
- Varied structure and polarity of the finished polymer, providing many sources of bonding to the substrate
- High cohesive strength of the final PU layer itself



POLYAMIDE

Nylon

➤ Polymerization



POLYAMIDE

POLYAMIDES

➤ Characterization

	Nylon 6	Nylon 66	Nylon 610
Tensile strength (kg/cm ²)	800	750	500
Elongation (%)	65	90	90
Rigidity (kg/cm ²)	27,000	28,000	18,000
specific gravity	1.14	1.14	1.09

▪ Amide group

- ✓ Crystalline intermolecular force
- ✓ Good rigidity, High strength
- ✓ Heat deflection temp., chemical resistance

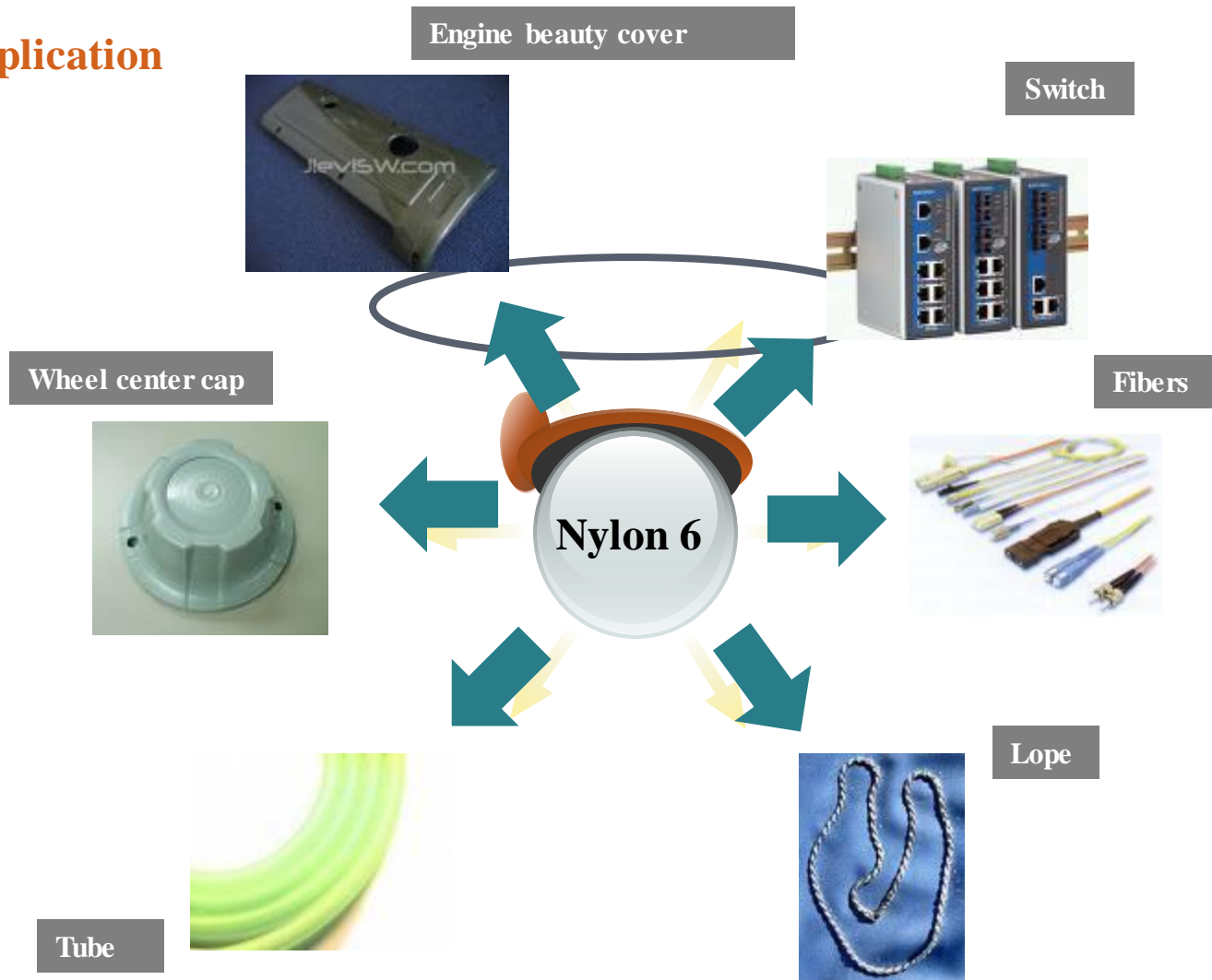
▪ Aliphatic chain : flexibility

- ✓ Low melt viscosity, Easy processability
- ✓ Good orientation by stretching of fibers and films
- ✓ Enhance strength, contributes impact resistance



POLYAMIDE

➤ Application



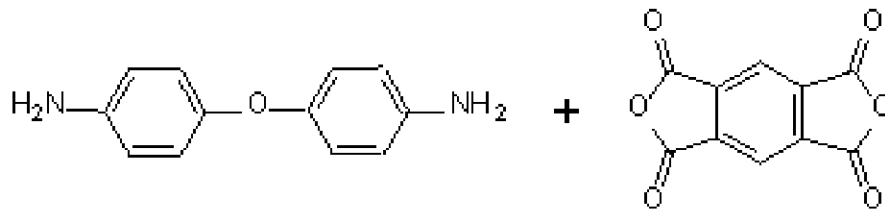
POLYAMIDE

➤ Application

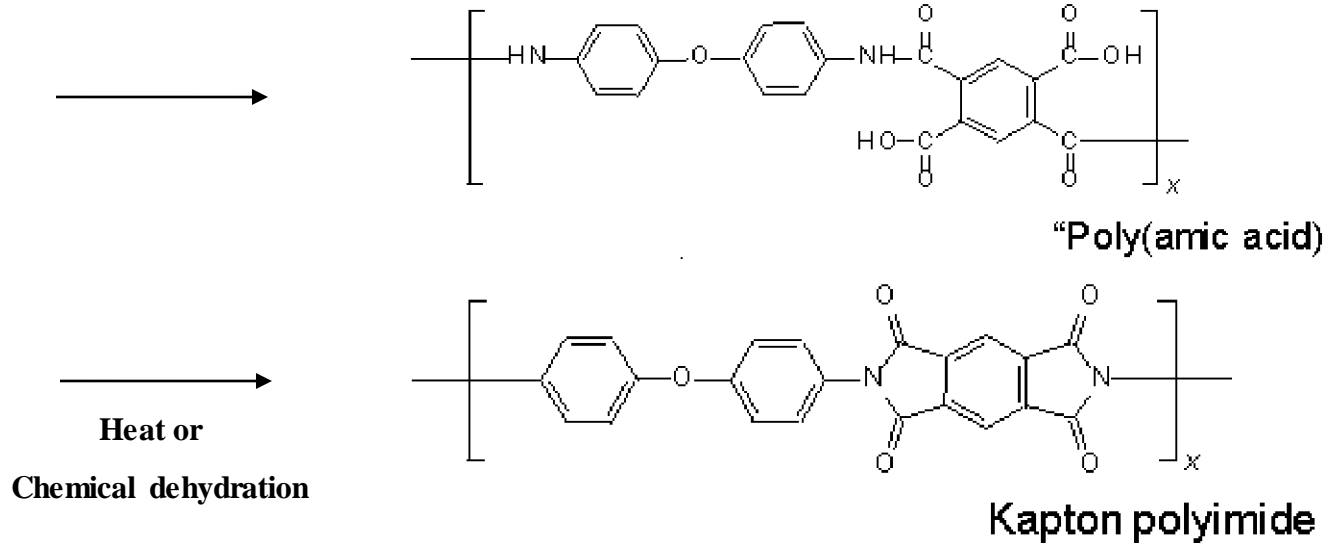


HIGH-TEMPERATURE HETEROCYCLES

Polyimide (Kapton)



➤ Polyimide has **high temperature rigidity and stability** because of its carbon-nitrogen, carbon-oxygen bonds. (extended possibilities for resonance structures)



HIGH-TEMPERATURE HETEROCYCLES

➤ Characteristics

- Multiple ring structures make quite inflexibilities → Long flat planar structures
- Resonance, Polarity, hydrogen bonding → crystalline intermolecular forces, high T_m .
- Very rigid, creep resistant, and almost infusible and insoluble
- Great problems in fabrication and even in the polymerization reaction

➤ Applications

- magnet-wire enamels, impregnated glass cloth, wrapping film for high-temperature motors, high-temperature bearings, gaskets, etc.

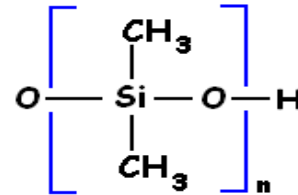


SILICONES

Poly dimethyl siloxane

➤ Characteristics

- Silicon-oxygen bond provides high heat and chemical stability, and also provides good rubbery elasticity.
- Methyl groups → low polarity and surface tension, high lubricity, water repellency
- Good electrical resistance



➤ Applications

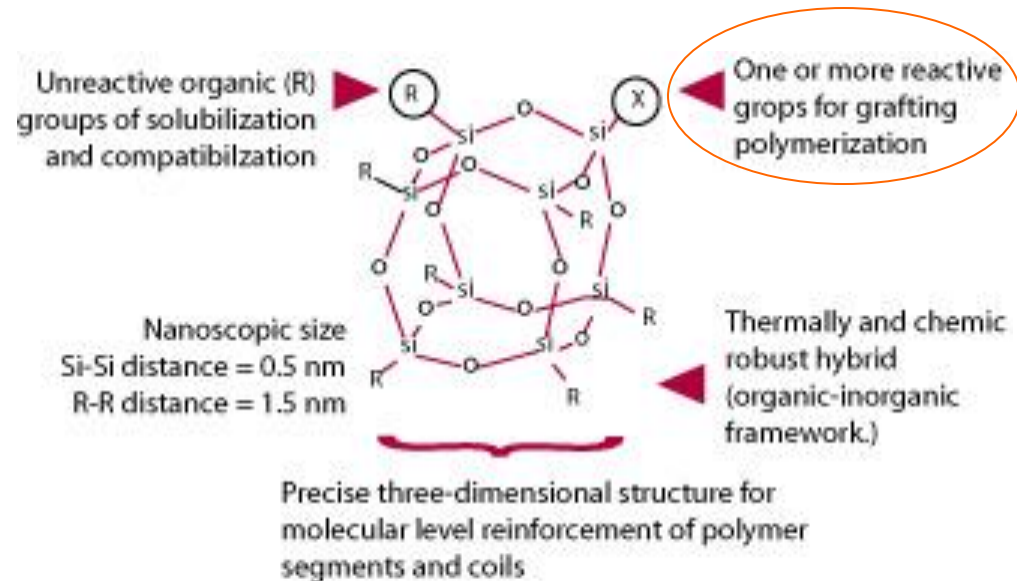
- Potting and encapsulating electrical and electronic components
- Sealants, roof coatings, spark plug connectors, oven door seals, oxygen houses
- Space suits, medical equipment, body implants
- Engine heat barriers, motor slot liners, etc.



SILICONES

Cubic Silsesquioxanes (POSS)

- Polyhedral Oligomeric Silsesquioxane
- Nanostructured **chemical** technology
: can be easily functionalized with a variety of organic materials
- Properties Enhancement
 - Improved mechanicals
 - Viscosity reduction
 - Increased HDT
 - Decreased dielectric
 - Increased gas permeability
 - Retainment of opticals
 - Improved fire retardancy



(Source: Hybridplastics)