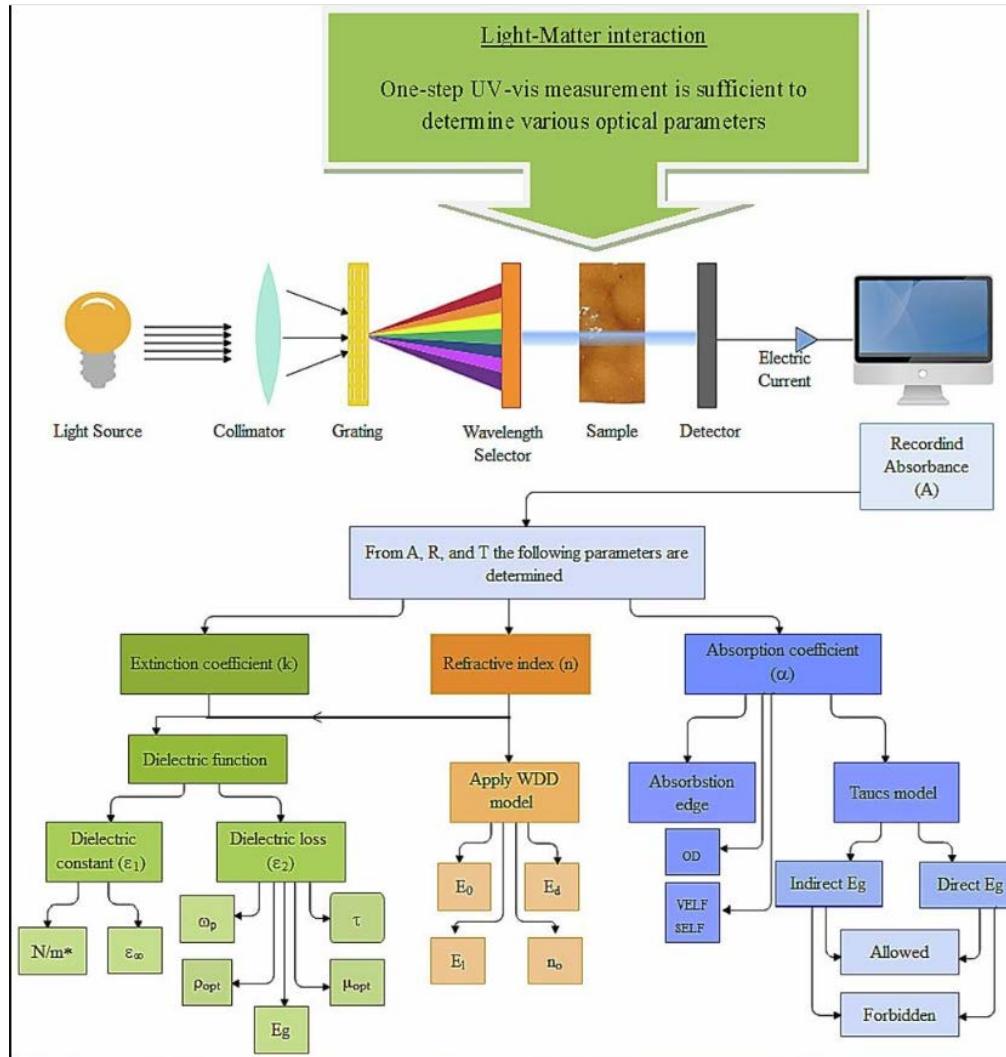


# Properties Of Polymers

## 4. Optical Properties



- **Applications:** Polymer composites with optical properties are used in optoelectronic and energy devices like LEDs, sensors, supercapacitors, and solar cells.
- **Composition:** Made of polymers combined with nano/micro inorganic fillers (metal complexes, semiconductors) to merge optical performance with easy processing.
- **Key Properties:** Refractive index, transparency, dispersion, and absorption coefficient determine their optical functionality.
- **Models & Analysis:** Optical behavior studied using Drude-Lorentz (classical), quantum models, Tauc's model, WD model, and optical dielectric parameters to estimate band gap and refractive index.
- **Findings:** Metal complexes significantly improve optical absorption and reduce band gap compared to ceramic or nanoparticle fillers.

# Properties Of Polymers

## 5. Chemical Properties

- **Chemical Reactivity** Most polymers are chemically stable due to strong covalent bonds. Reactivity depends on functional groups (e.g.,  $-OH$ ,  $-COOH$ ,  $-Cl$ ,  $-NH_2$ ) present in the polymer chain.
- **Resistance to Chemicals** Many polymers resist acids, bases, and solvents, but strong acids/oxidizing agents (e.g.,  $HNO_3$ ,  $H_2SO_4$ ) can degrade them. Solvent resistance varies with polymer polarity (e.g., PVC swells in ketones, while polyethylene resists most solvents).
- **Thermal Decomposition** At high temperatures, polymers undergo chain scission, oxidation, or dehydrogenation, leading to chemical breakdown.
- **Hydrolytic Stability** Some polymers (e.g., polyesters, polyamides) can hydrolyze in the presence of water or steam, especially at high temperature.
- **Oxidative and UV Degradation** Exposure to oxygen or UV light can cause chain cleavage, crosslinking, or formation of free radicals, leading to photo-oxidative degradation.
- **Flammability** Most polymers are combustible; they release smoke and toxic gases on burning. Flame-retardant additives can reduce this.
- **Crosslinking and Chemical Modification** Polymers can undergo crosslinking reactions (e.g., vulcanization of rubber) or be chemically modified to improve strength, thermal stability, or reactivity.

# Properties Of Polymers

## ❖ Properties of Different Types of Polymers

Property	Amorphous Polymers	Crystalline Polymers	Elastomers	Thermosets
<b>Structure</b>	Random, disordered chains	Highly ordered, packed chains	Lightly crosslinked, flexible chains	Heavily crosslinked 3D network
<b>Transparency</b>	Usually transparent	Often opaque	Usually transparent or translucent	Usually opaque
<b>Glass Transition (Tg)</b>	Distinct Tg, no Tm	Tg (if amorphous regions) + sharp Tm	Below room temp (soft, rubbery)	Tg present, no melting (infusible)
<b>Melting Point (Tm)</b>	No sharp Tm	Sharp melting point	No Tm, decompose on heating	No Tm, decompose on heating
<b>Mechanical Properties</b>	Brittle below Tg, soft above Tg	Strong, stiff	Highly elastic, low modulus	Hard, rigid, brittle
<b>Thermal Behavior</b>	Soften and flow on heating (thermoplastic)	Soften then melt on heating (thermoplastic)	Soft, rubbery; degrade at high temp	Cannot melt; degrade on heating
<b>Chemical Resistance</b>	Moderate to good	Excellent	Good resistance to water, solvents	Excellent chemical and solvent resistance
<b>Examples</b>	Polystyrene, PMMA	Polyethylene, Nylon, PET	Natural rubber, SBR	Phenol-formaldehyde, Epoxy resins

# Properties Of Polymers

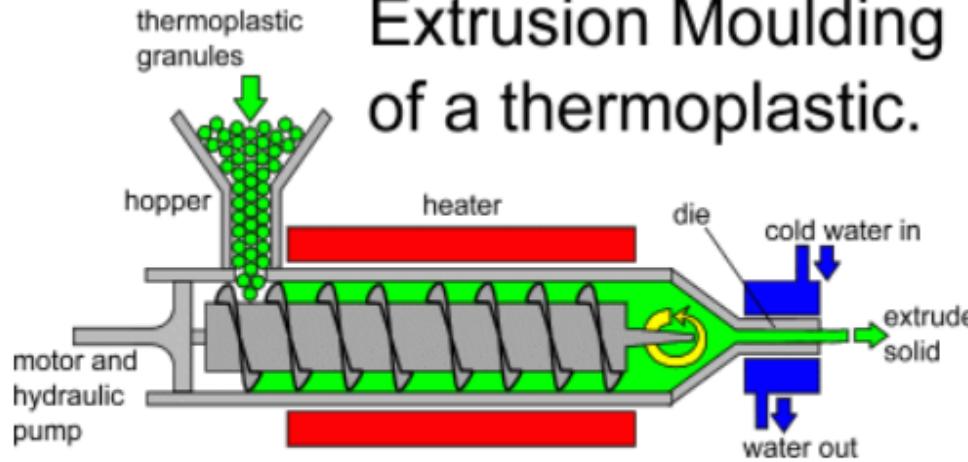
Property	Thermoplastics	Thermosets	Elastomers
<b>Mechanical</b>	Moderate to high strength; ductile or brittle depending on Tg and crystallinity	High rigidity and hardness; brittle after curing	Low modulus, highly elastic (stretch >200%); low strength
<b>Thermal</b>	Soften on heating, remoldable; Tg and Tm distinct	No melting point; decompose on heating; high thermal stability	Soft at room temp; degrade at high temperature
<b>Electrical</b>	Excellent insulators; dielectric constant depends on polarity	Excellent insulators; retain properties at high temperature	Good insulators; used in flexible cables
<b>Optical</b>	Can be transparent (e.g., PMMA, PC); transparency decreases with crystallinity	Generally opaque due to crosslinked structure	Usually translucent or opaque
<b>Recyclability</b>	Recyclable (re-melt and process)	Non-recyclable (crosslinked network prevents melting)	Partially recyclable; some can be reprocessed
<b>Crosslinking</b>	No crosslinking; linear or branched chains	Highly crosslinked network	Lightly crosslinked for elasticity
<b>Examples</b>	Polyethylene, PVC, Nylon, PMMA, Polycarbonate	Epoxy, Phenol-formaldehyde, Melamine resins	Natural rubber, Silicone rubber, SBR

# Properties Of Polymers

Property	Thermoplastics	Thermosets	Elastomers
<b>Tg (Glass Transition)</b>	–50°C to 150°C (e.g., PE: –125°C; PMMA: 105°C)	150°C to 250°C (Epoxy: ~165°C)	–70°C to –50°C (Natural rubber: –70°C)
<b>Tm (Melting Point)</b>	100°C to 300°C (PE: 135°C; Nylon: 265°C)	No melting; decompose above 250°C	No sharp melting; decompose ~200°C
<b>Tensile Strength</b>	20–150 MPa (PE: 20 MPa; Nylon: 80 MPa)	50–200 MPa (Epoxy: ~90 MPa)	5–25 MPa (Natural rubber: ~20 MPa)
<b>Elastic Elongation</b>	20–100%	<5%	200–1000%
<b>Dielectric Constant</b>	2–4 (PE: 2.3; PVC: 3.2)	4–6 (Epoxy: 4.5–5)	2–3 (Silicone rubber: ~2.8)
<b>Thermal Stability</b>	Stable up to 100–200°C	Excellent, >250°C before degradation	Limited (softens >150°C)
<b>Density</b>	0.9–1.4 g/cm <sup>3</sup>	1.1–1.5 g/cm <sup>3</sup>	0.9–1.2 g/cm <sup>3</sup>
<b>Examples</b>	PE, PVC, Nylon, PMMA, Polycarbonate	Epoxy, Phenol-formaldehyde, Urea-formaldehyde	Natural rubber, Silicone, SBR

# Polymer Processing

## Extrusion Moulding of a thermoplastic.



## VARIOUS OF PLASTIC PROCESSING TECHNIQUE

### ❖ What is Polymer Processing ?

- ❑ Polymer processing is the set of methods used to shape and manufacture products from polymers (plastics). It involves converting raw polymer materials into useful forms like films, fibers, sheets, or molded parts by applying heat, pressure, and sometimes chemical additives.

### ❖ Types Of Polymer Processing

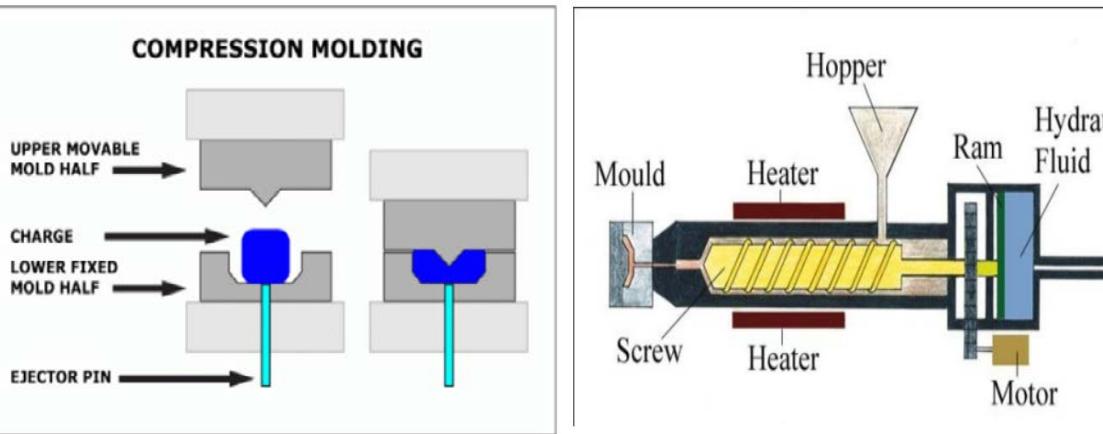
- ❑ Plastics Technology

- ❑ Fiber Technology

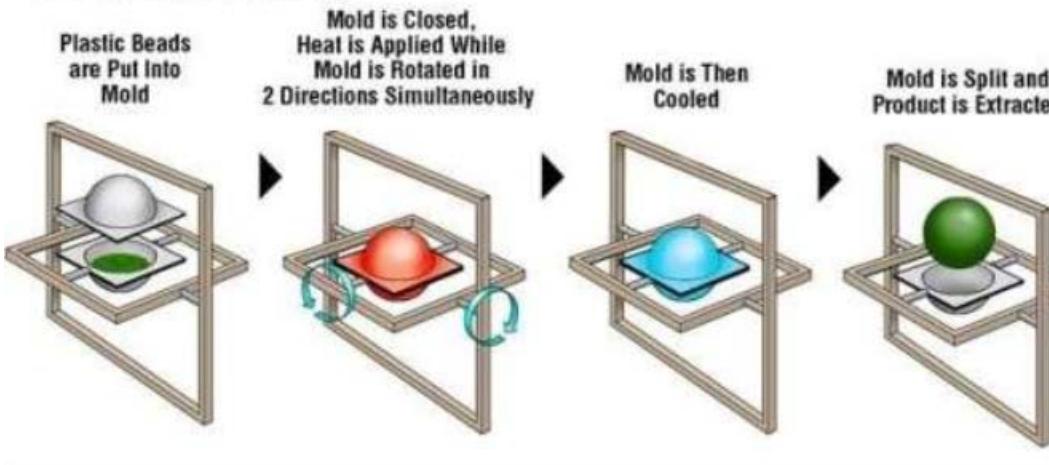
- ❑ Elastomer Technology

# Polymer Processing

## ❖ Polymer Processing – Plastics Technology



### Rotational Molding



❖ Polymer processing converts raw polymers into useful shapes through fabrication methods.

Methods depend on polymer rheology and classification:

- ❑ **Thermoplastics:** Flow on heating, can be remolded.
- ❑ **Thermosets:** Undergo irreversible crosslinking on heating.
- **Common steps:** handling → melting → mixing → forming → devolatilization.

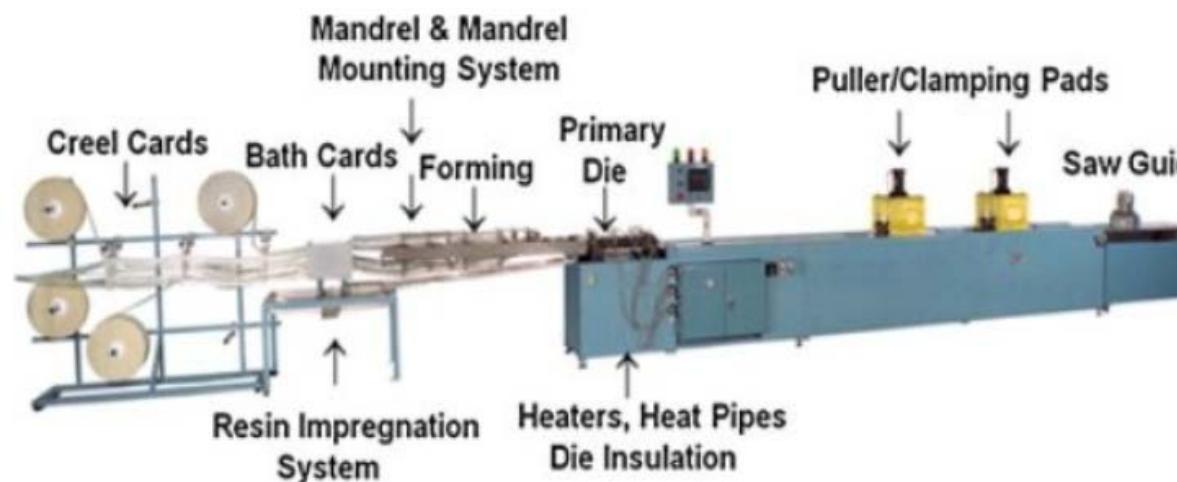
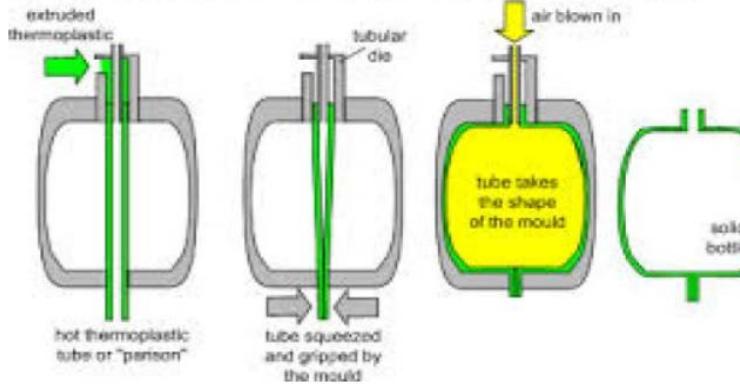
### A. Molding

- ❑ **Compression Molding :** Oldest process; powder placed in heated mold, compressed under pressure.
- ❑ **Injection Molding:** Molten polymer injected under pressure into a cooled mold for quick cycles.
- ❑ **Transfer Molding:** Preheated polymer in pot is transferred into mold (used for thermosets).
- ❑ **Reaction Injection Molding (RIM):** Liquid components react and cure inside mold.
- ❑ **Blow Molding:** For hollow parts (e.g., bottles), inflating hot tube inside mold.
- ❑ **Rotational Molding:** Powdered polymer heated inside a rotating mold to form large hollow parts.

# Polymer Processing

## ❖ Polymer Processing – Plastics Technology

### Extrusion Blow Moulding



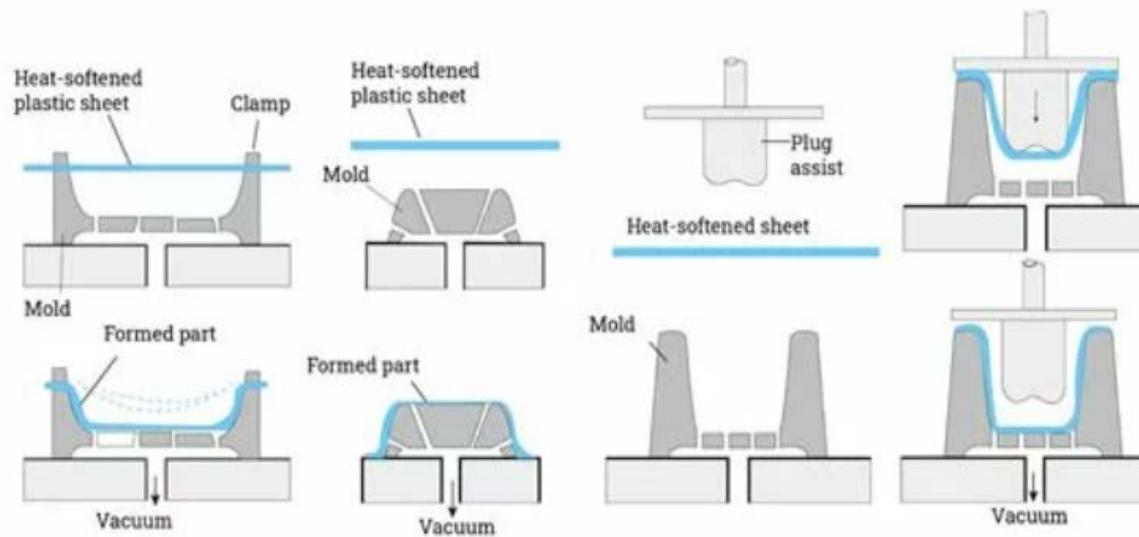
### B. Extrusion

- ❑ Continuous process; polymer melts in screw extruder and is forced through a die.
- ❑ **Products:** rods, pipes, sheets, films.
- ❑ **Variants:** Film Extrusion (blown or cast).Coextrusion (multi-layer films).and Pultrusion
- ❑ **Pultrusion** is similar to extrusion in that it produces continuous cross-sectional profiles. While extrusion relies on press to push unreinforced thermoplastic materials through a short die, pultrusion pulls a variety of reinforced fibers, wetted by thermosetting and/or some thermoplastic resins, through a heated die. Polymerization of the resin occurs as the wetted fibers pass through the die, forming a continuous, rigid profile corresponding to the orifice shape.
- ❑ **Modern extruders:** twin-screw, vented for devolatilization.

# Polymer Processing

## ❖ Polymer Processing – Plastics Technology

### Vacuum Forming Process

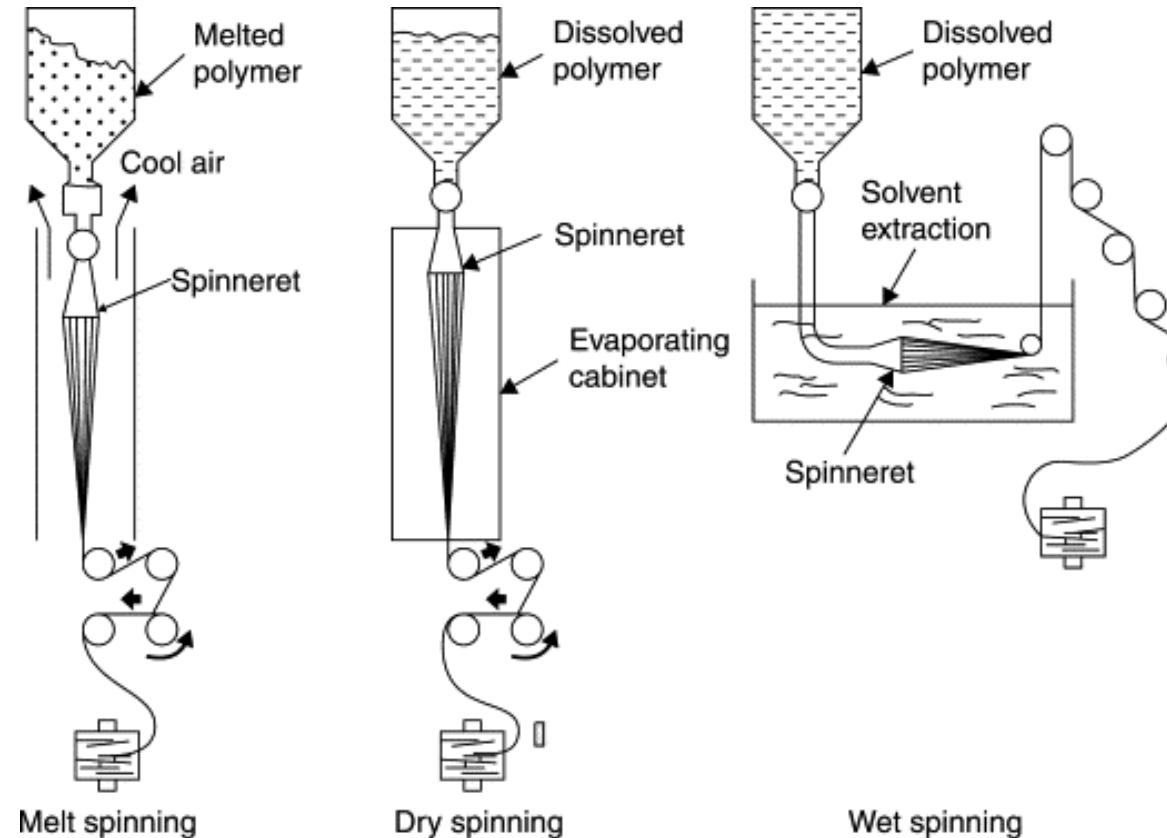


### C. Other Processing Methods

- ❑ **Calendering:** Passing polymer through heated rolls to form sheets/films.
- ❑ **Casting:** Pouring polymer solution or monomer into molds.
- ❑ **Vacuum Forming:** Heating sheet and shaping with vacuum.
- ❑ **Foaming:** Creating cellular structure using blowing agents.
- ❑ **Coating:** Applying polymer films by dipping, spraying, or extrusion.
- ❑ **Laminating:** Bonding layers with adhesives or heat.

# Polymer Processing

## ❖ Polymer Processing – Fiber Technology

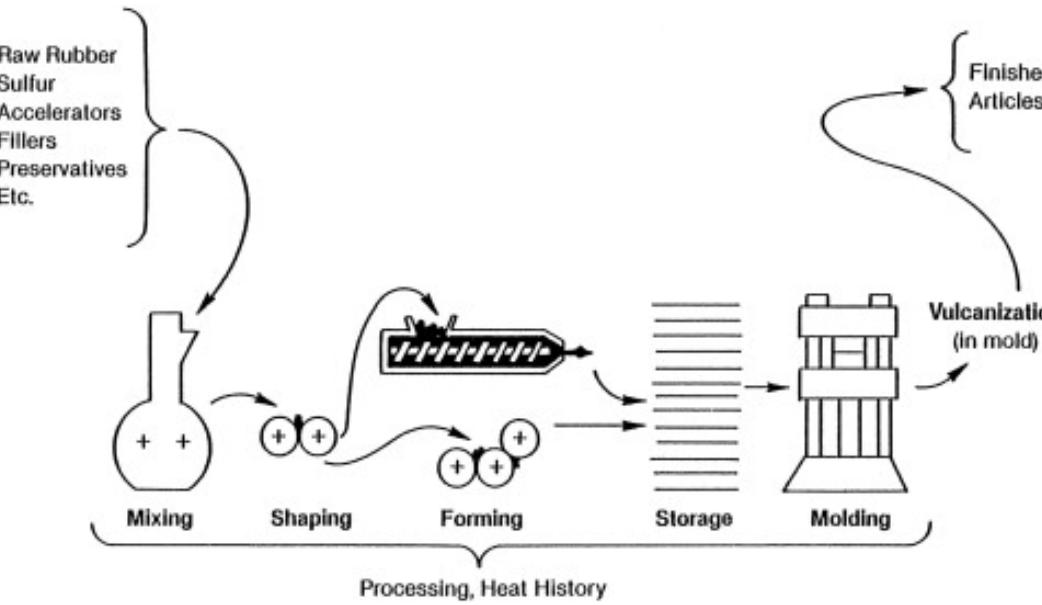


## ❖ Spinning Methods

- **Melt Spinning:** Preferred for polymers that melt without decomposition; produces uniform fibers with circular cross-section.
- **Dry Spinning:** Polymer dissolved in solvent; fiber formed by solvent evaporation.
- **Wet Spinning:** Fiber formed by coagulation in a bath; used for polymers insoluble in common solvents.
- **Other Methods:** For nonfusible polymers (e.g., PTFE), special dispersion and sintering methods are used.

# Polymer Processing

## ❖ Polymer Processing – Elastomer Technology

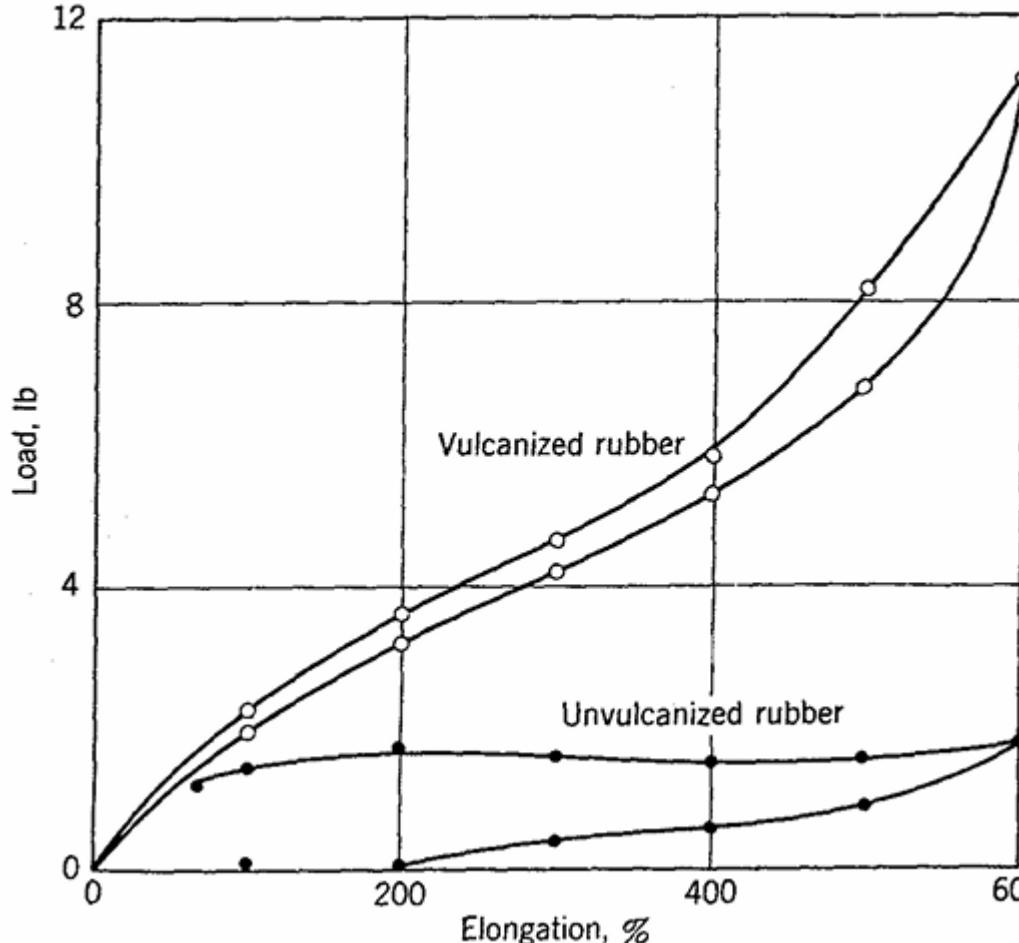


### ❖ 1. Vulcanization

- ❑ Process introducing **crosslinks** into elastomers to transform them from soft thermoplastic masses into strong, elastic, and tough rubber.
- ❑ Commonly uses **sulfur** and heat; accelerated by organic accelerators (e.g., thiazoles, dithiocarbamates).
- ❑ **Accelerators** require **activators** (zinc oxide + fatty acids) to function effectively.
- ❑ Vulcanization can also occur with **nonsulfur systems** (organic peroxides, phenolic resins).
- ❑ Physical changes: ↑ tensile strength, stiffness; ↓ flow, while preserving extensibility.
- ❑ **Optimum cure:** 5–10 parts sulfur per 100 parts rubber; excess leads to overcuring or hard rubber formation (ebonite).

# Polymer Processing

## ❖ Polymer Processing – Elastomer Technology



## 2. Reinforcement

- Vulcanized rubbers often lack sufficient **tensile strength, stiffness, abrasion, and tear resistance**.
- Reinforcing fillers added before vulcanization; main types:
  - Reinforcing fillers:** Carbon black (most important), silica, silicates.
  - Inert fillers:** Clay, talc, whiting, zinc oxide (mainly for processing ease).
- Carbon black improves tensile strength, tear resistance, and abrasion resistance (up to 10x improvement in SBR).
- Reinforcement depends on **particle size** (smaller → stronger), surface condition, and elastomer type.
- High filler loading can increase heat buildup and hysteresis.

Stress-strain curves to 600% elongation and back, typical of unvulcanized and vulcanized natural rubber

# Industrial Polymer

## Definition

- Industrial polymers are synthetic macromolecules produced on a large scale for applications in plastics, fibers, elastomers, and coatings.

## ❖ Key Properties

- Lightweight, high strength-to-weight ratio.
- Resistance to chemicals, solvents, and environmental degradation.
- Tunable properties using fillers, reinforcements, and additives.

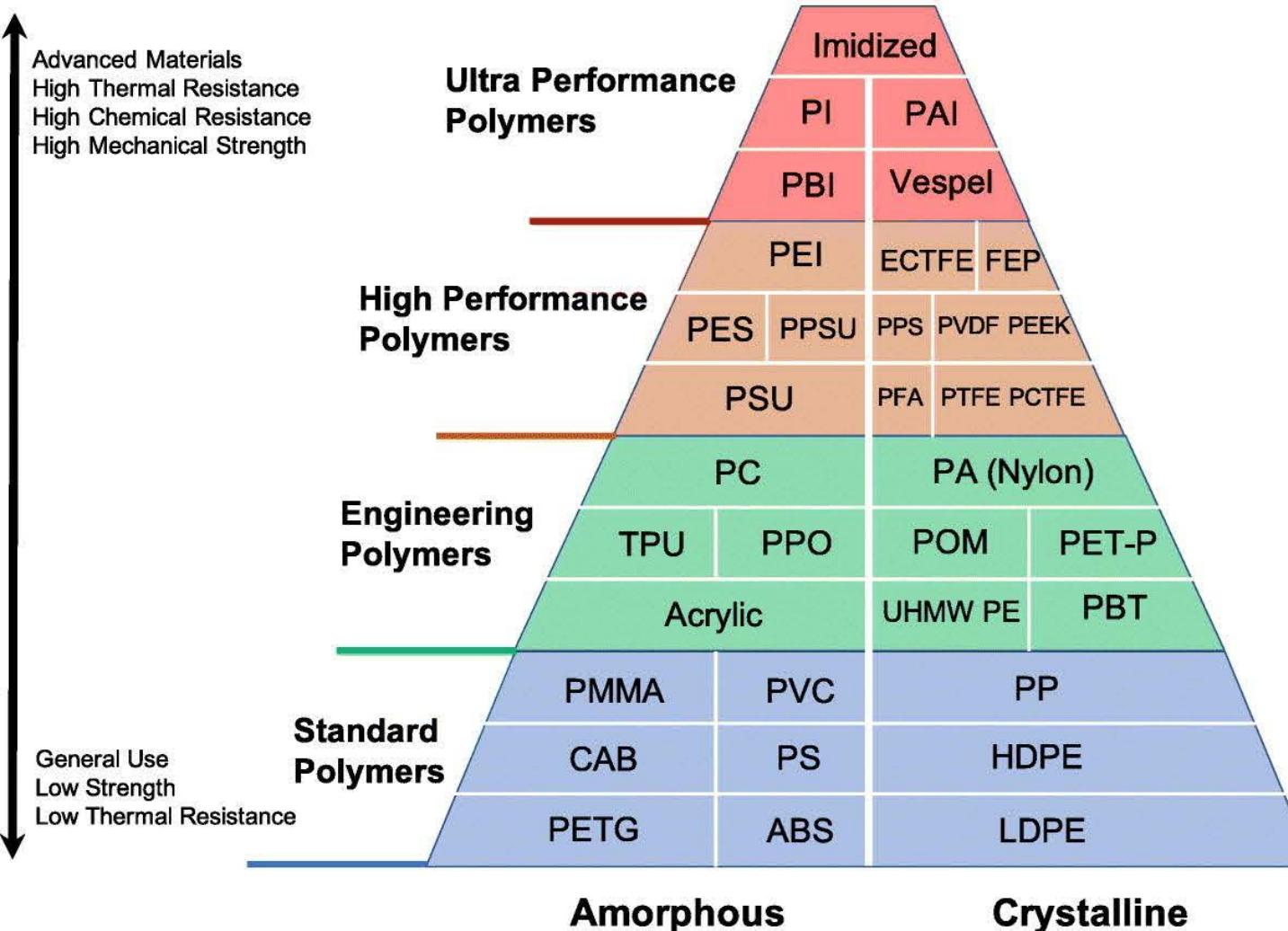
## ❖ Classification & Examples

- **Hydrocarbon Polymers:** Polyethylene, polypropylene, polystyrene.
- **Heterochain Thermoplastics:** Polyesters (PET), polyamides (nylon), polyacetals.
- **Thermosetting Resins:** Phenol-formaldehyde, epoxy resins, polyurethanes.
- **Elastomers:** Natural rubber, SBR, nitrile rubber, neoprene.

## ❖ Applications

- **Automotive:** Tires, gears, dashboards.
- **Construction:** Pipes, insulation, coatings.
- **Electrical/Electronics:** Wire coatings, insulators.
- **Packaging:** Films, bottles (e.g., PET).
- **Textiles:** Nylon, polyester fibers.

# Industrial Polymer

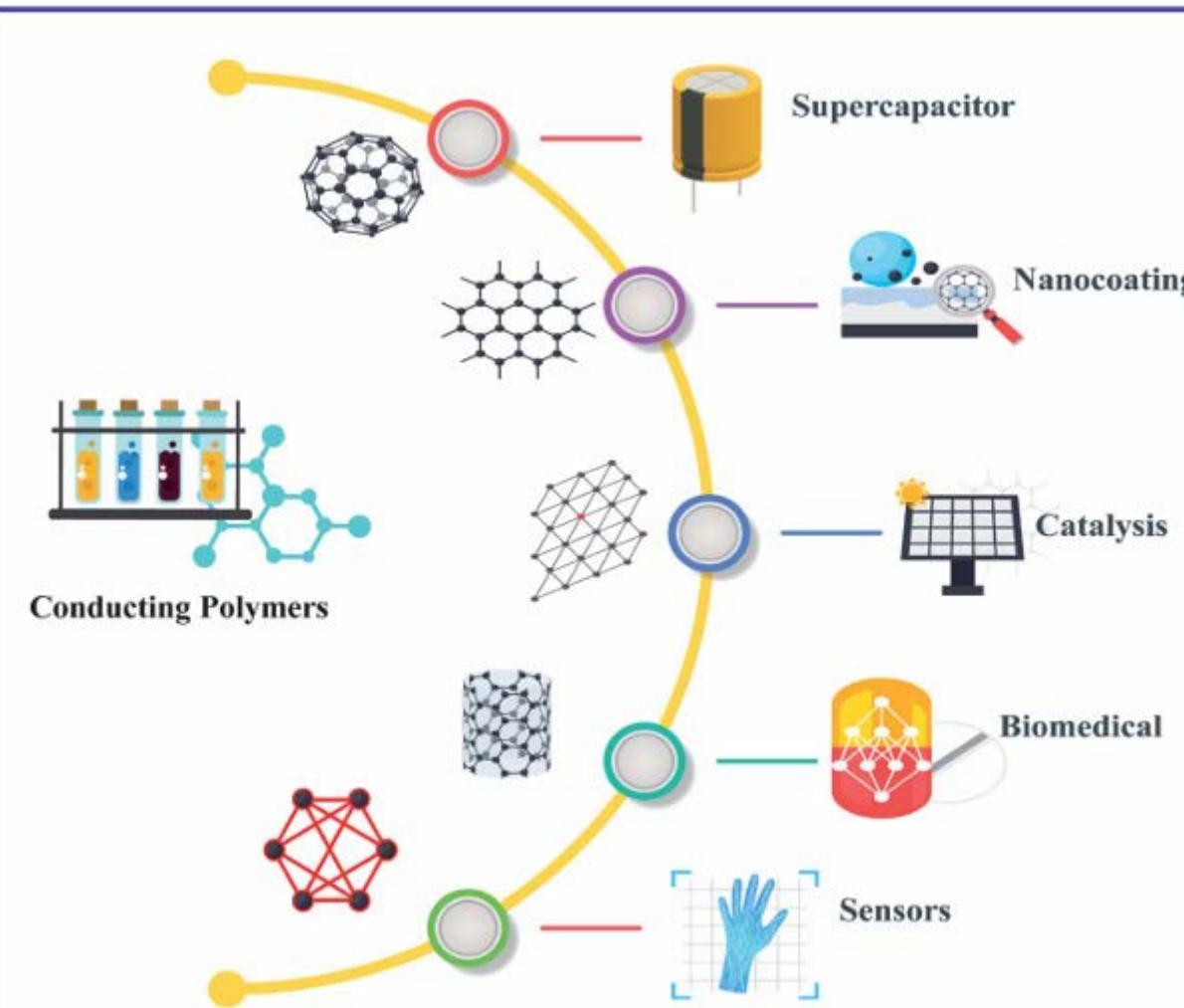


# Industrial Polymer

Polymer	Monomer	Structure	Key Properties	Applications
<b>Polyethylene (PE)</b>	Ethylene ( $\text{CH}_2=\text{CH}_2$ )	Linear $-(\text{CH}_2-\text{CH}_2)-$	High crystallinity, good chemical resistance, low cost, lightweight	Bottles, films, pipes, wire insulation
<b>Polypropylene (PP)</b>	Propylene ( $\text{CH}_2=\text{CH}-\text{CH}_3$ )	Isotactic (highly crystalline)	Lightest major plastic (density 0.905), high stiffness, good heat resistance	Automotive parts, fibers, films, household goods
<b>Polystyrene (PS)</b>	Styrene ( $\text{C}_6\text{H}_5-\text{CH}=\text{CH}_2$ )	Atactic (amorphous)	Transparent, easy to mold, brittle, good electrical properties	Packaging, optical components, disposable items
<b>PVC</b>	Vinyl chloride ( $\text{CH}_2=\text{CHCl}$ )	Linear chain with $-\text{Cl}$ side groups	Flame-resistant, rigid or flexible (with plasticizer), good chemical resistance	Pipes, cables, flooring, profiles
<b>Nylon (Polyamide)</b>	Hexamethylene diamine + adipic acid (Nylon 66)	$-\text{[NH}-(\text{CH}_2)_6-\text{NH-CO-(CH}_2)_4-\text{CO]}-$	High strength, abrasion resistance, good heat resistance, moisture-sensitive	Fibers (carpets, apparel), engineering plastics
<b>Acrylics (PMMA)</b>	Methyl methacrylate	$-\text{[CH}_2-\text{C}(\text{CH}_3)(\text{COOCH}_3)]-$	High optical clarity, weather-resistant, good mechanical strength	Lenses, glazing, signs, lighting panels
<b>Fluoropolymers (PTFE)</b>	Tetrafluoroethylene ( $\text{CF}_2=\text{CF}_2$ )	$-(\text{CF}_2-\text{CF}_2)-$	Exceptional chemical resistance, high melting point, non-stick	Gaskets, seals, non-stick coatings, insulation

# Conducting Polymers

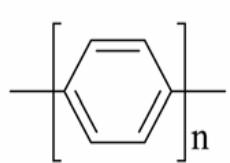
## ❖ Introduction



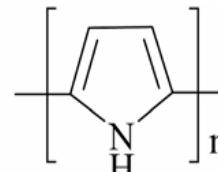
- **Conducting polymers (CPs)** are organic polymers with conjugated  $\pi$ -electron backbones that allow electrical conductivity.
- Initially considered insulators, they can exhibit semiconducting to metallic behavior upon doping.
- **Typical CPs:** Polyacetylene, Polyaniline (PANI), Polypyrrole (PPy), Polythiophenes (PT), Poly(*p*-phenylene), Poly(*p*-phenylene vinylene).
- **Nobel Prize** The 2000 Nobel Prize in Chemistry was awarded to Alan J. Heeger, Alan G. MacDiarmid, and Hideki Shirakawa for the discovery and development of conductive polymers, specifically, polyacetylene.

# Conducting Polymers

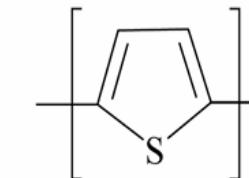
## ❖ Conduction Mechanism



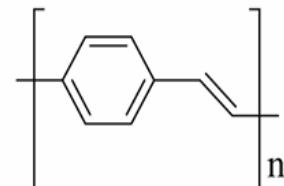
poly(p-phenylene)



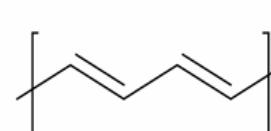
Polypyrrol



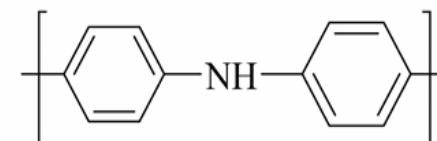
Polythiophene



poly(p-phenylene vinylene)



Polyacetylene



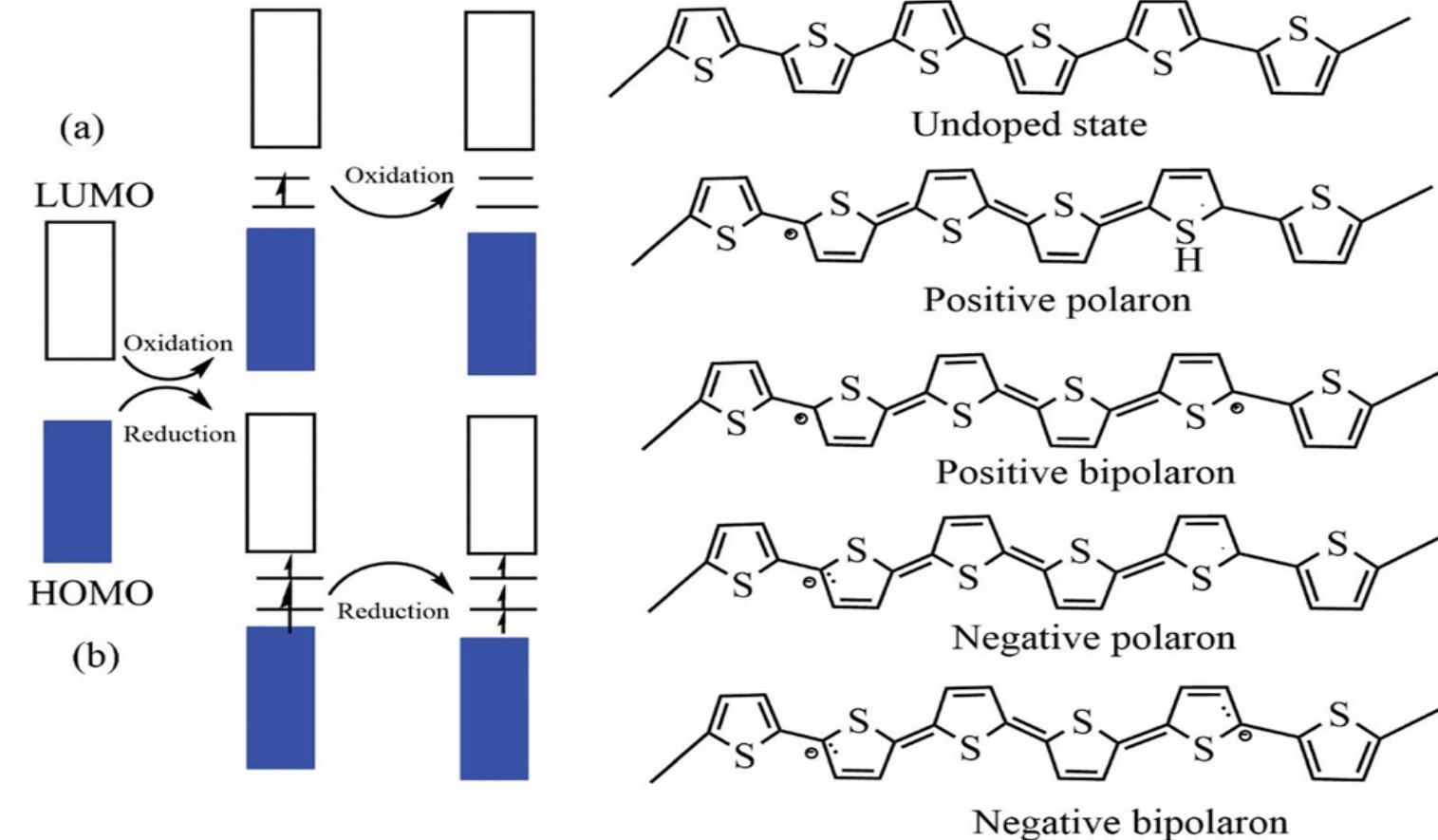
Polyaniline

Structural illustration of different conducting polymers.

- ❑ **Conjugated Backbone:** Alternating single and double bonds allow  $\pi$ -electron delocalization.
- ❑ **Band Structure:** Pristine CPs have a bandgap of **2–3 eV**, behaving like semiconductors.
- ❑ **Doping:**
- ❑ **p-type doping** (oxidation): Removes electrons, forming positive charge carriers (polarons, bipolarons).
- ❑ **n-type doping** (reduction): Adds electrons, creating negative charge carriers.
- ❑ **Charge Carriers:**
- ❑ **Polarons:** Radical cations stabilized by lattice distortion.
- ❑ **Bipolarons:** Two charges in a localized region.
- ❑ **Solitons:** Neutral or charged defects (in polyacetylene).
- ❑ Doping can increase conductivity by **10<sup>10</sup> times**.

# Conducting Polymers

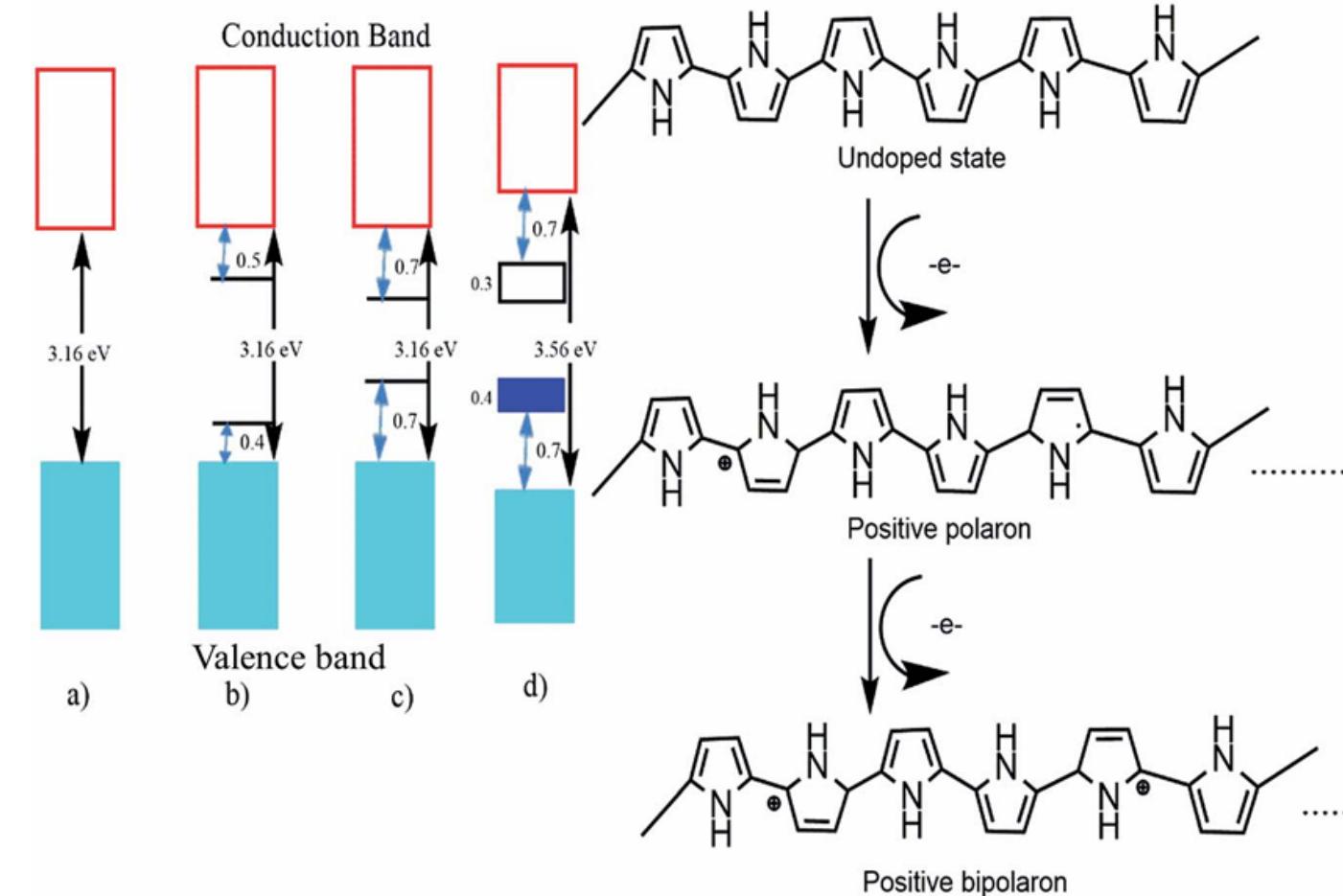
## ❖ Conduction Mechanism



The electronic band and chemical structures of polythiophene (PT) with (a) p-type doping and (b) n-type doping

# Conducting Polymers

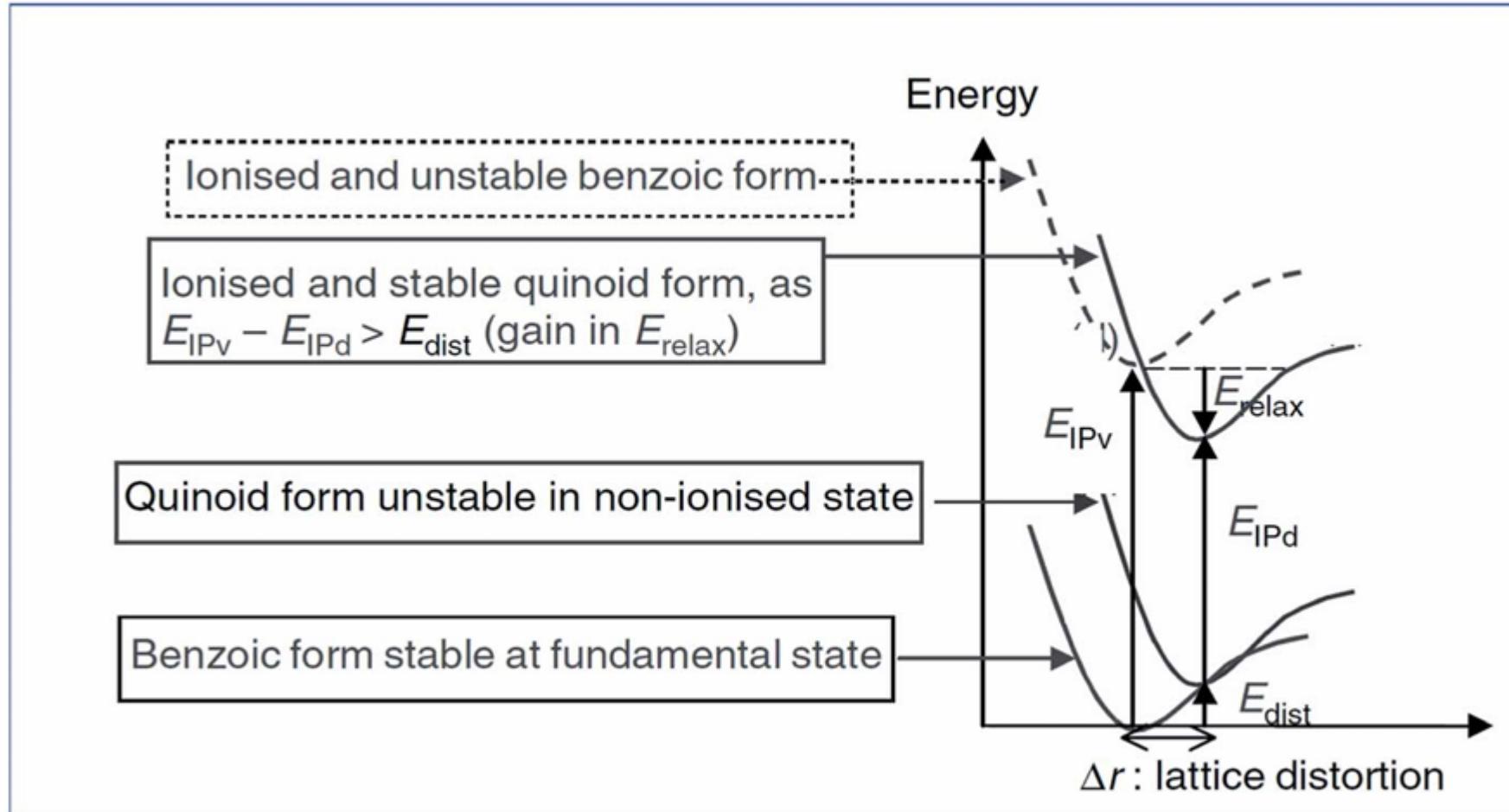
## ❖ Conduction Mechanism



Electronic bands and chemical structures illustrating (a) undoped; (b) polaron; (c) bipolaron; and (d) fully doped states of polypyrrole (PPy)

# Conducting Polymers

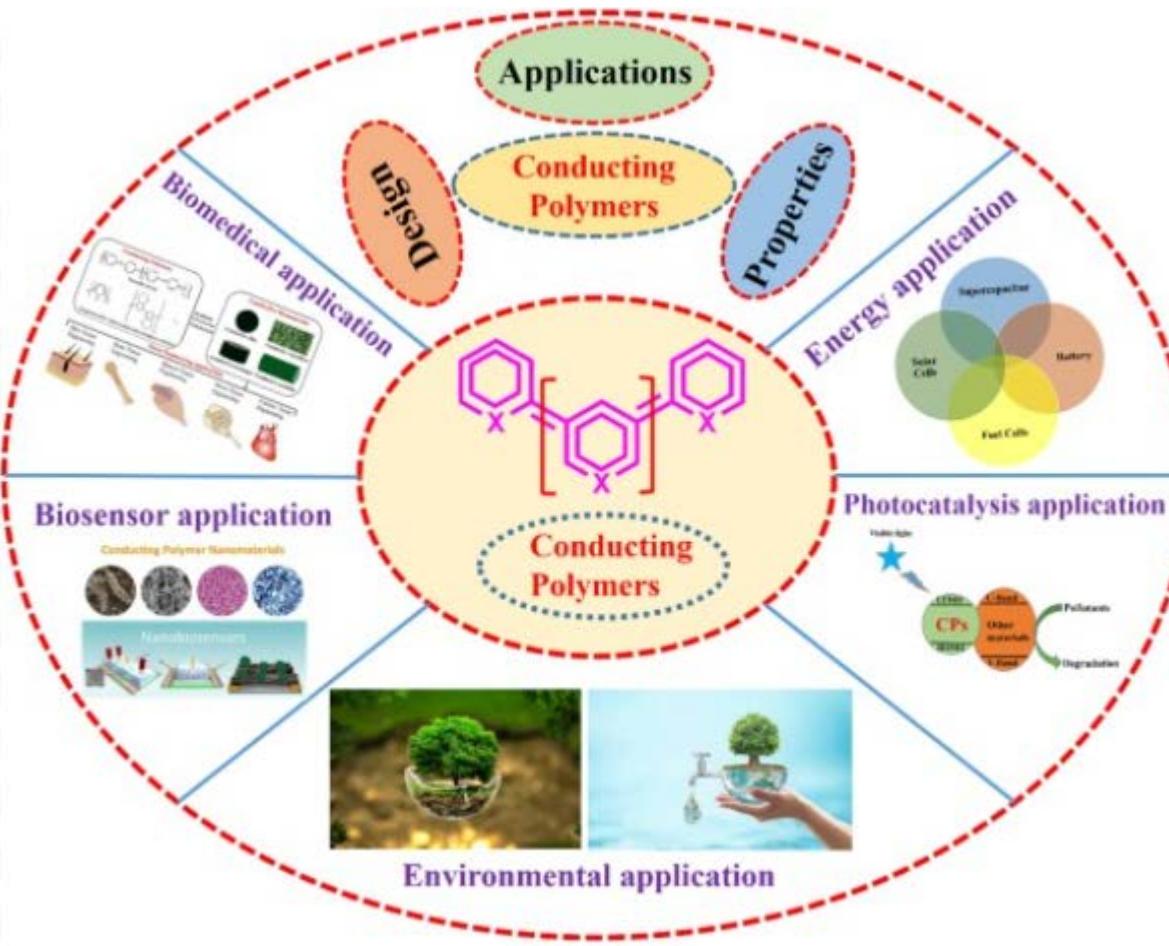
## ❖ Conduction Mechanism



Energy level diagram of the molecular ionization process of poly(p-phenylene)

# Conducting Polymers

## ❖ Applications of Conducting Polymers



### ❑ Energy Storage:

- Supercapacitors and batteries due to redox-active nature and conductivity.

### ❑ Electronics & Optoelectronics:

- OLEDs, OFETs, solar cells, display technology.

### ❑ Sensors & Actuators:

- Gas sensors, biosensors, strain sensors.

### ❑ Corrosion Protection:

- Anticorrosion coatings via anodic protection.

### ❑ Biomedical Applications:

- Drug delivery, neural interfaces, tissue engineering.

### ❑ Wearable Devices:

- Smart textiles, stretchable electrodes, flexible circuits.