

# Polymer Structure—Organic Aspects (Definitions)

Charles E. Carraher, Jr.

Florida Atlantic University, Boca Raton, FL 33431

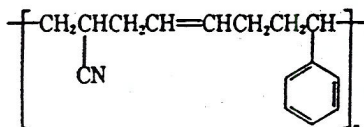
Raymond B. Seymour

Department of Polymer Science, University of Southern Mississippi, Hattiesburg, MS 39406

In the following alphabetical listing, the definitions of key organic-based terms used in characterizing the structure of polymers are provided. Several of the common polymers, some of their uses, as well as their respective structure are also included in the table that follows. The reader should note that the name of the polymer often provides the key to its representative structure. There are, however, names such as polycarbonate that can represent a variety of polymeric materials. In either case, we will cite a representative structure for each.

## acrylonitrile-butadiene-styrene terpolymer (ABS).

Automotive grills, instrument panels, and exterior decorative trim; power tool housings, business machines, television cabinets, molded parts, appliance housings—600,000 tons.<sup>1</sup>



**addition polymers.** Typically formed through the reaction of similar (copolymers) or the same (homopolymers) monomers. Examples are polyethylene, polystyrene, poly(methyl methacrylate), poly(vinyl chloride).

**alternating copolymer.** An ordered copolymer where the units alternate.



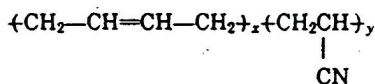
**azeotropic copolymer.** Polymer in which the composition (amount of each comonomer) of the polymer chain is the same as the amount of each comonomer in the reaction mixture.

**biopolymer.** Naturally occurring polymer such as proteins, enzymes, polysaccharides (starch, cellulose) and nucleic acids.

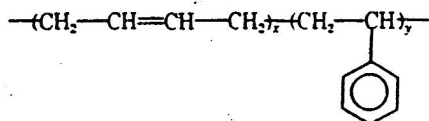
**block copolymers.** Copolymer consisting of long sequences, blocks, of one mer (polymer unit derived from one of the comonomers) followed by long sequences of the second mer.



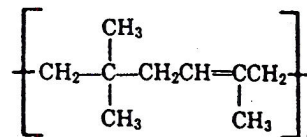
**Buna-N.** Elastomeric copolymer of butadiene and acrylonitrile.



**Buna-S.** Elastomeric copolymer of butadiene and styrene.

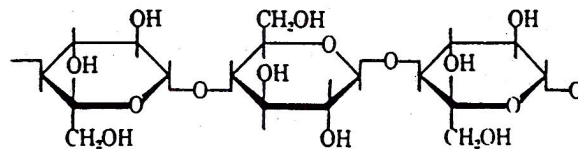


**butyl rubber.** Tire inner tubes, inflatable sporting goods (balls), inner liners of tubeless tires—150,000 tons.



**cellophane.** Regenerated cellulosic film; cellulose, such as derived from dissolving cotton, is precipitated or solvent is allowed to evaporate forming a film.

**cellulose.** Most abundant naturally occurring organic material; main structural material of higher plants; constitutes about one-third of the total mass of higher plants; polymer of D-glucopyranose units linked through  $\beta$  (1-4) bonds; largely linear; major component of paper and paper products; production of ropes; derivatives include cellulose acetates and nitrates, methyl- and ethylcelluloses, and carboxymethylcellulose.



**cellulose acetate.** The ester formed from reaction of cellulose with acetic acid or other acetylating agents. The cellulose may be acetylated to varying degrees. If the majority of OH groups are acetylated, the product is called cellulose triacetate. If an average of two of the three OH groups in each glucose repeating unit is acetylated, the product is called cellulose diacetate.



**cellulose nitrate.** The product obtained by the reaction of nitric acid and sulfuric acid with cellulose; erroneously called nitrocellulose. The product is classified as primary, secondary, or tertiary according to how many groups in each repeating anhydroglucose unit in cellulose are nitrated.



**condensation polymers.** Formed through the reaction of two different functional groups typically producing a by-product such as HCl. Examples are polyamides, polyesters, polyurethanes, proteins, nucleic acids.

**copolymer.** Polymer containing repeating units from two or more monomers.

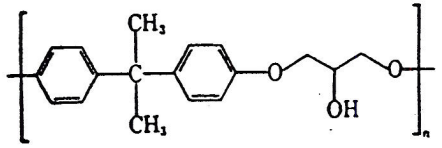
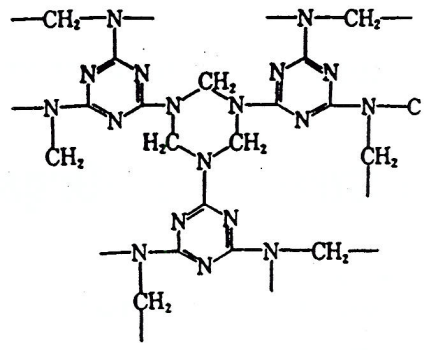


<sup>1</sup> Approximate U.S. annual productions in tons are cited throughout.

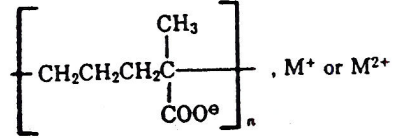
The copolymer may be of a variety of compositions including alternating, block, graft, and branch copolymers.

**xtran.** Extracellular polysaccharide consisting of branched chains of  $\alpha$  (1-6) linked D-glucopyranose units, the branches formed by the presence of 1-2, 1-3, or 1-4 bonds; used as a blood plasma volume extender, emulsion stabilizers in foodstuffs such as ice cream, gels for gel-permeation chromatography.

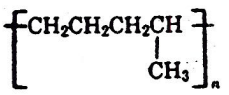
**oxy resins.** Coating for beverages and food, drum and tank liners, varnishes, printed circuit boards, binders for aggregate in the surfacing of floors, adhesives—170,000 tons.



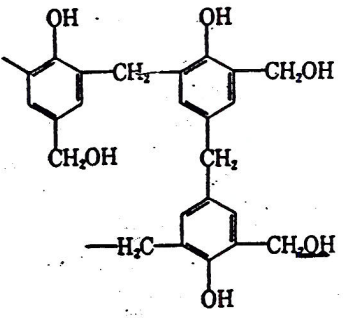
**styrene-methacrylic acid copolymers (ionomers).** Shoe soles, weather stripping.



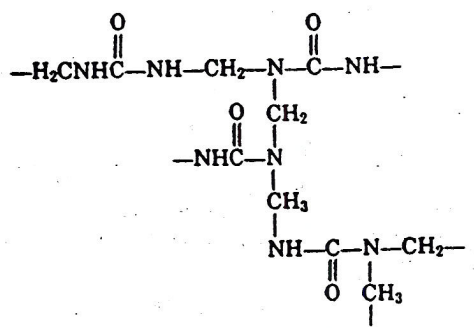
**styrene-propylene elastomers.** Radiator and heater hoses, body and chassis parts, car bumpers, mats, seals, weather stripping, wire and cable insulation, coated fabrics, impact modification, appliance parts—150,000 tons.



**formaldehyde resins.**  
**phenol-formaldehyde (PF).** Plywood adhesive or resin, glass fiber resin, molding compound, distributor caps, fuse boxes—700,000 tons.



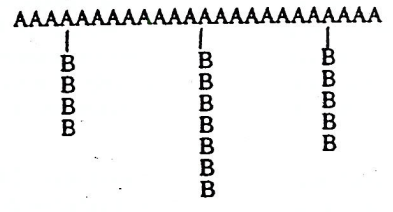
**urea-formaldehyde (UF).** Particle-board binder resin, molding compound, coating, paper and textile treatment—600,000 tons.



**melamine-formaldehyde (MF).** Dinnerware, coating, table tops (Formica)—100,000 tons.

**glycogen.** Main food-reserve polysaccharide of animals; has a multibranching structure with chain lengths of 10-14 glucose units common.

**graft copolymer.** Branched copolymer where the backbone and the branches consist of different building units, mers.

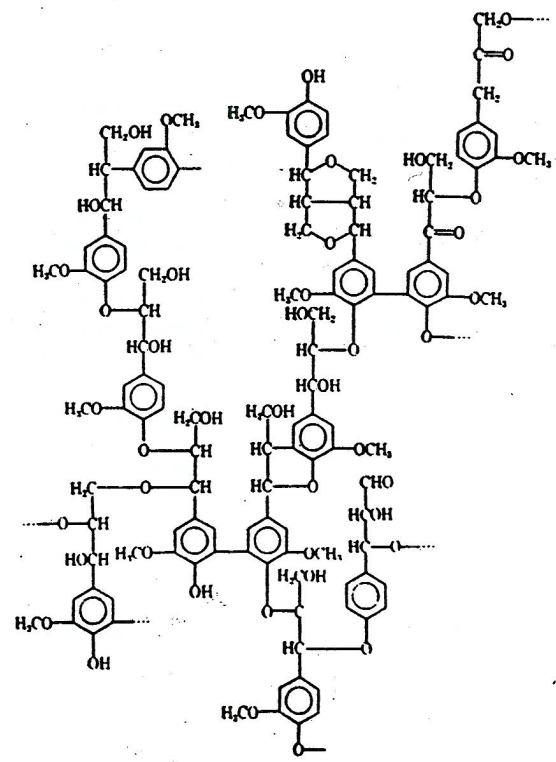


**homopolymer.** Polymer composed of only one repeating unit, in contrast to a copolymer that is made up of two or more different repeating units.

**ideal copolymers.** Copolymer where the units are present in a statistically random order.

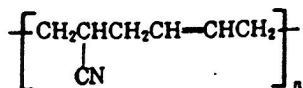


**lignin.** Structural support and adhesive material in plants; constitutes about 25% of wood; used as dispersants and wetting agents; used in oil-well drilling muds, adhesives, road binders, industrial cleaners, leather tanning, manufacture of vanillin, and cement products.

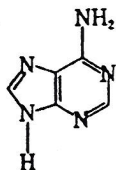




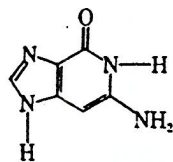
**nitrile rubber (NBR).** Printing tools, footwear, hoses, gaskets, seals, adhesive—80,000 tons.



**nucleic acids.** Consist of the condensation products of nucleoside triphosphates and contain a heterocyclic base (adenine, guanine, thymine, cytosine (DNA); and adenine, guanine, uracil, cytosine (RNA)), a sugar (deoxyribose (DNA); ribose (RNA)), and a phosphate moiety per unit; carry and transmit genetic information, involved in protein biosynthesis.

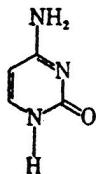


adenine  
(in DNA and RNA)

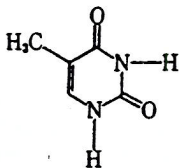


guanine  
(in DNA and RNA)

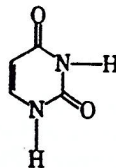
**Pyrimidines**



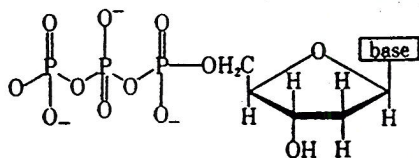
cytosine  
(in DNA and RNA)



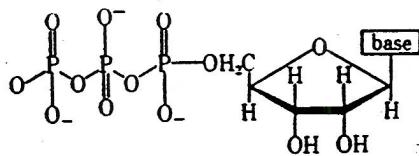
thymine  
(in DNA mainly)



uracil  
(in RNA)



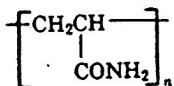
a deoxyribonucleotide  
(monomer of DNA)



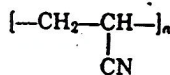
a ribonucleotide  
(monomer of RNA)

**oligomer.** Polymer chain in which the number of repeating units is small, typically 2 to 10.

**polyacrylamide.** Paper treatments, water-treatment coatings, binder for pigments, adhesives, flocculant—50,000 tons.

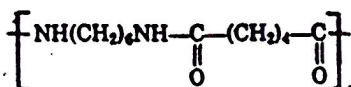


**polyacrylonitrile.** House furnishings, apparel, rug pile, shirts, socks, blankets, simulated fur, craft yarns, draperies—350,000 tons.



**polyamides (nylons).**

*nylons 6,6* and *nylon 6.* Home furnishings, apparel, tire cord, rug fibers, filaments (fishing line and threads)—1,300,000 tons.

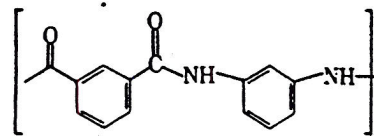


nylon 6,6

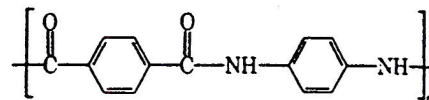


nylon 6

**aromatic polyamides.** heat-resistant clothing, smoke stack filtration, fishing rods, tennis rackets.

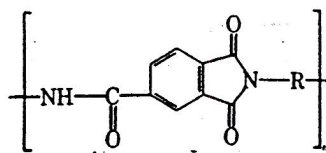


Nomex

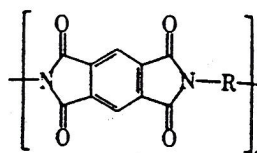


Kevlar

**polyamide imides and polyimides.** film, molded parts, wire enamels.



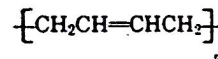
poly(amide imides)



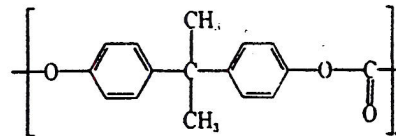
polyimides

**polyblend.** Typically are heterogeneous systems containing a polymer network, matrix in which another polymer is imbedded.

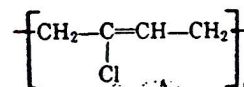
**polybutadiene (butadiene rubber, BR).** Tires, metal can coatings, hoses, belts—400,000 tons.



**polycarbonate (PC).** Glazing, lighting, transportation, appliances, signs, returnable bottles, solar collector application—120,000 tons.

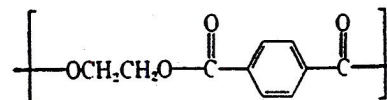


**polychloroprene.** Highway joint seals, bridge mounts, and expansion joints; automotive belts, hoses, and weather stripping; conveyor belts, wire and cable jacketing—120,000 tons.

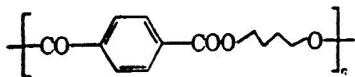


**polyesters.**

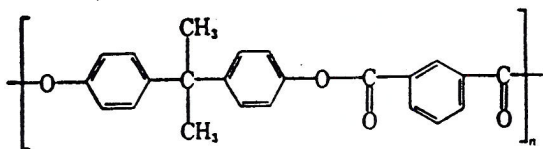
*poly(ethylene terephthalate) (PET).* Apparel, tire cord, magnetic tape, food packaging (including boil-in-bag food pouches), beverage bottles, coatings for microwave and conventional ovens, home furnishings—2,000,000 tons.



*poly(butylene terephthalate) (PBT).* Automotive exterior parts, under-the-hood parts, fuse cases, pump housing, small appliances—25,000 tons.



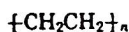
**saturated polyesters.** Appliances, construction, corrosion-resistant products, transportation—500,000 tons.  
**aromatic polyesters.** Abradable seals, plasma coatings.



**lyether (polyoxymethylene; polyacetal).** Molding of telephone components, pump housings, small appliances, mechanical parts—50,000 tons.



**lyethylene (PE).**



**low-density polyethylene (LDPE).** Substantial branching—film, toys, housewares, wire and cable coverings—3,500,000 tons.

**high-density polyethylene (HDPE).** Linear, very little branching—bottles, containers, housewares, film, sheet, pipe and fittings—2,000,000 tons.

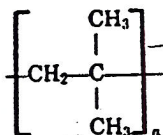
**linear low-density polyethylene (LLDPE).** Moderate branching—films, sheets.

**ultrahigh molecular weight polyethylene (UMWPE).** Packaging, films.

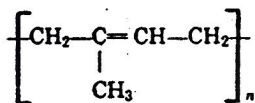
**ly(ethylene glycol) (PEG).** Used in the manufacture of polyurethane foams and polyurethane elastomers, lubricants, thickeners, surfactants, plasticizers—600,000 tons.



**lyisobutylene (PIB).** Lubricating oils, sealants, butyl rubber, blending agents, adhesives—125,000 tons.

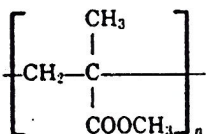


**lyisoprene.** Sporting goods, sealants, caulking compounds, car and truck tires, footwear—75,000 tons.

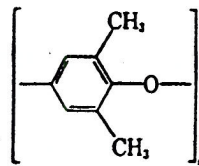


**olymer.** A giant or macromolecule made up of multiple repeating units, such as polyethylene, in which at least 1000 ethylene units  $\left[ \text{CH}_2\text{CH}_2 \right]$  are joined together by covalent bonds. The word is derived from the Greek words meaning “many parts”.

**oly(methyl methacrylate) (PMMA).** Lighting fixtures, automotive lenses, solar panels, signs, glazing—450,000 tons.

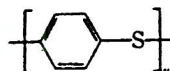


**oly(phenylene oxide) (PPO).** Automotive, appliances, business machines, electrical parts—70,000 tons.

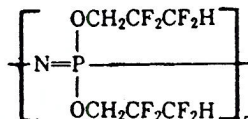


poly(2,6-dimethyl-*p*-phenylene ether)

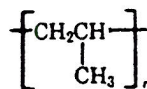
**poly(phenylene sulfide) (PPS).** Electrostatic coatings, electrical and mechanical goods—2,000 tons.



**polyphosphazenes.** Aerospace, medicine, oil exploration.

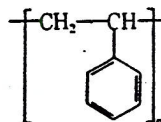


**polypropylene (PP).** Carpet backing, upholstery, fabrics, toys, carpet yarn, interior automobile trim, housewares, packaging—1,800,000 tons.

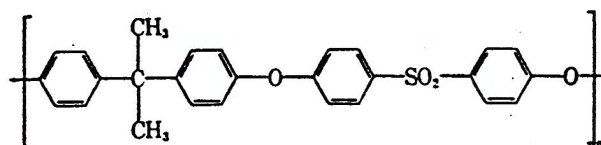


**polysaccharide.** Polymer composed of sugar-type repeating units; includes cellulose, starch, and dextran.

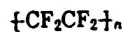
**polystyrene (PS).** Packaging, housewares, recreational products, electronics, toys, appliances, building and construction (insulation), furniture, disposable food containers—1,900,000 tons.



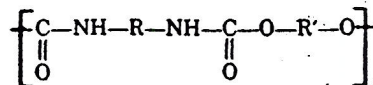
**polysulfone.** Electrical connections, small appliances, mechanical parts—5,000 tons.



**polytetrafluoroethylene (PTFE).** Liners, nonsticking surfaces, components for chemical processing equipment, molded electrical components, bushings, seals, cable insulation—7,000 tons.



**polyurethane.**



**flexible foam.** Transportation, bedding, furniture “stuffing”, carpet backing, packaging—100,000 tons.

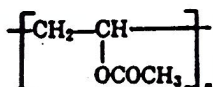
**rigid foam.** Commercial refrigeration, spray-on roof and tank insulation, pipe, building, construction, and cryogenic insulation—300,000 tons.

**elastomers.** Fabric coating, sporting goods, automotive parts, footwear—100,000 tons.

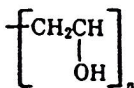
**coatings.** Industrial coatings—40,000 tons.

**poly(vinyl acetate) (PVA).** Labeling, packing, consumer adhesives (white glues), latex paints—400,000 tons.

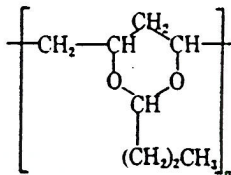




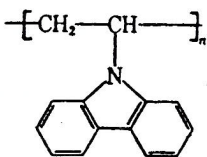
**poly(vinyl alcohol) (PVAL).** Textile and paper treatment—70,000 tons.



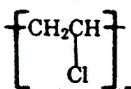
**poly(vinyl butyral) (PVB).** Adhesive in manufacture of laminated safety glass.



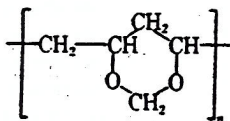
**poly(vinyl carbazole).** Formulation of photopolymer systems, photoconductive material in xerography.



**poly(vinyl chloride) (PVC).** Pool liners, pipe fittings, electrical outlet boxes, roof coatings, automotive bumpers, phonograph records, wire and cable insulation, clear film for meat packing, stretch film—3,000,000 tons.



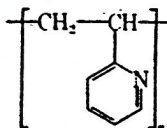
**poly(vinyl formal) (PVF).** Manufacture of enamels for heat-resistance wire insulation



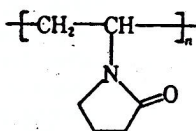
**poly(vinylidene chloride).** Film and sheeting for food packaging, container liners; coatings for paper, fabric and films—90,000 tons.



**poly(vinyl pyridine).** Adhesives to bond textile fibers to natural and synthetic rubbers in the manufacture of tires, rubber goods—14,000 tons.



**poly(vinyl pyrrolidone).** Cosmetics, textile treatment, adhesives, plasma volume extender.



**prepolymer.** Low molecular weight material (oligomer) capable of further polymerization.

**proteins.** Composed of  $\alpha$ -amino acids; play an essential role in all living cells; act as carriers, catalysts (enzymes), chief

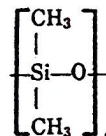
constituents of structural materials such as skin, hair, cartilage, muscle, and bone and in immunological mechanisms.

**random copolymer.** Copolymer where there is no definite sequence of the different mers or building blocks.

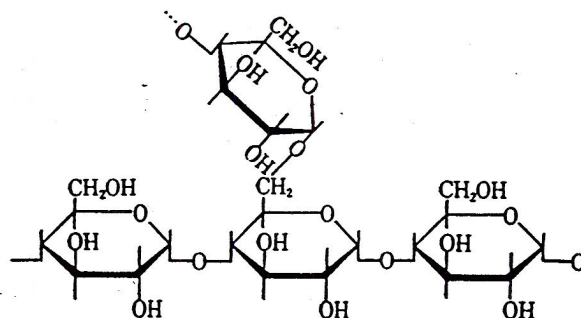
ABAABABAABBABBAB

**rayon—regenerated.** Reprecipitated cellulose in the form of filaments.

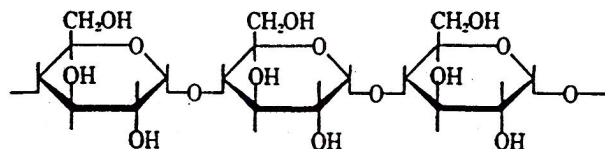
**silicones (siloxanes).** Greases, waxes, dielectric encapsulation, seals, gaskets, caulks, rubber molds, cosmetics, biomedical implants and devices, insulation, glass sizing agents, surfactants, antifoaming agents, hydraulic fluids, heat exchange fluids, masonry additive, water repellents—70,000 tons.



**starch.** Common food-reserve polysaccharide for plants; size, shape, and specific properties vary with botanical source; consists mainly of two components—amylose (which is largely linear chains of  $\alpha$  (1-4)-linked D-glucopyranose units) and amylopectin (highly branched containing chains of glucose units linked by  $\alpha$  (1-4) bonds being cross-linked through  $\alpha$  (1-6) bonding; industrially used in food industry as a thickener and gelling agent for soups, mayonnaise, and many desserts; derivatives used in the textile, paper, and laundry industries; used to make adhesives and in the laundry industry to stiffen and give finish to clothing and household linens.

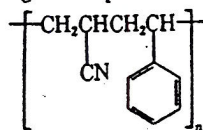


amylopectin—details of branch-point

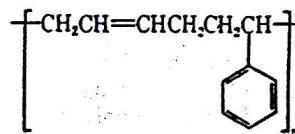


linear amylose

**styrene-acrylonitrile copolymer (SAN).** Manufacture of ABS blends, glass-reinforced dashboard components, blender bowls, dishwasher safe housewares, vacuum cleaner parts, detergent dispensers—60,000 tons.



**styrene-butadiene rubber (SBR).** Foam backing for carpets, adhesive tires—1,400,000 tons.





# Physical Aspects of Polymer Structure

## A Dictionary of Terms

Charles E. Carraher, Jr.

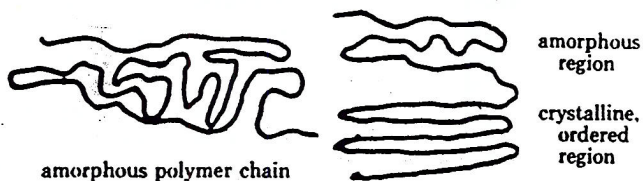
Florida Atlantic University  
Boca Raton, FL 33432

Raymond B. Seymour

University of Southern Mississippi, Hattiesburg, MS 39406

The following terms are commonly used by those working in polymer science to describe the physical features unique to polymers as a class of compounds.

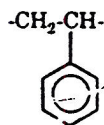
**amorphous.** Noncrystalline polymers or noncrystalline areas in a polymer; polymer chains are arranged in a less-than-well-oriented manner.



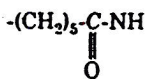
**atactic.** Polymer where there is a random arrangement of the pendant side-chains on each side of the chiro carbon. Thus, for a polymer of general structure  $\text{CH}_2\text{-CHR-}$ , the chain can be represented as



**backbone.** Principal chain in the polymer. For polystyrene



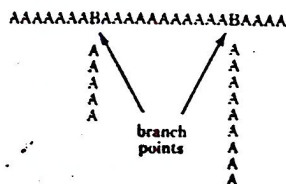
the backbone is simply  $\sim\text{C-C-C-C-C}\sim$ . For nylon-6,



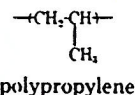
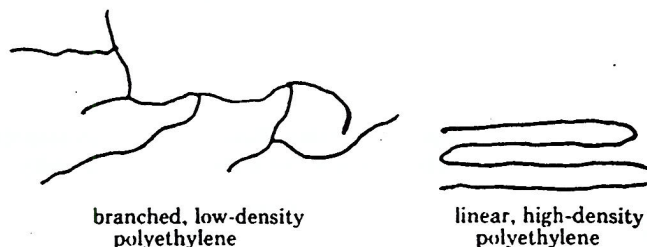
the backbone is  $\sim\text{C-C-C-C-C-C-N}\sim$ .

**bifunctional.** Molecule with two active functional groups. The functional groups can be the same, as in the case of 1,6-hexanediamine, or different, as in the case of alpha-amino acids.

**branch point.** Atom on the polymer chain where additional chain extension occurs, thus producing a branch (like on a tree).



**branched polymer.** Polymer having branches attached to the polymer backbone such as for low-density polyethylene. Polymers having pendant side-groups, such as the methyl groups in polypropylene, are not considered to be branched.



**capping.** Reacting the end-groups of polymer chains to produce an end that may be a stable, nonreactive end-group, or capable of further reaction under specified conditions.

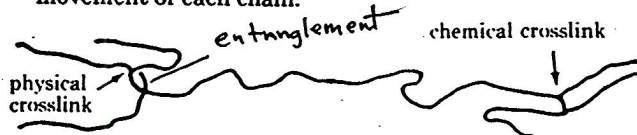
**chain length.** Number of repeating units (mers) composing a chain. Since many polymer mixtures are composed of chains of varying lengths (number of mers), the chain length is often expressed in terms of an average value called the average chain length. For a polymer chain composed of 20 units, as AAAAAAAAAAAAAAAAAAAAAA, chain length is 20. Polymers typically have average chain lengths in excess of 100, often greater than 1000.

**conformer.** Individual shapes produced by changes in the conformation of a polymer; generally the actual average shape of polymer mixture can be pictured as an average of a variety of such conformers.

**contour length.** Fully extended length of a polymer chain; equal to the product of the length of each repeating unit ( $l$ ) times the number of units or mers ( $n$ ), i.e., the full contour length is then  $ln$ . This contour length can be corrected for bond angle (C-C bond angle is about  $109^\circ$ ), for random-walk-associated factors and for steric factors.

**coupling.** Joining together of two polymer chains.

**crosslinks.** Covalent bonds connecting two or more polymer chains or physical entanglement acting to associate the movement of each chain.



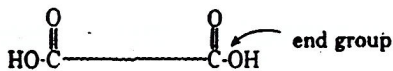
**crystalline polymer.** Polymer with ordered structure that has been allowed to form crystals. Many polymers contain portions that are crystalline and other areas that are amorphous, nonordered; c.f., amorphous.

**crystallites.** Regions of polymer crystallinity.

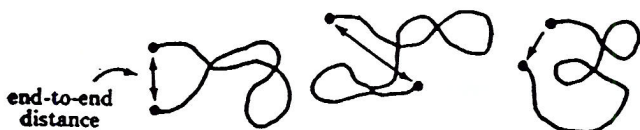
**degree of polymerization.** Number of units, mers, composing a chain. Since polymer mixtures are typically composed of chains of varying lengths, the term average degree of polymerization,  $\overline{DP}$ , is often used with the bar over the  $DP$  designating the value as an average; c.f., chain length.

**end-group.** Groups at the chain ends such as carboxyl group that may occur at the end of polyester chains.



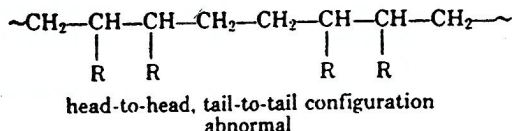
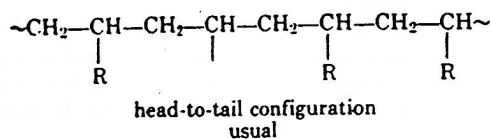


**end-to-end distance.** Distance between end-groups in a polymer chain. Typically, this is reported as an average end-to-end distance.



**functionality.** Number of reactive groups in a molecule (HO-CH<sub>2</sub>-CH<sub>2</sub>-OH, ethylene glycol—two functional groups).

**head-to-tail configuration.** Normal sequence of mers where the pendant groups are regularly spaced.

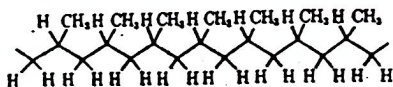


**hydrogen bonding.** Strong secondary valence forces between a hydrogen atom in one molecule and an oxygen, nitrogen, or fluorine atom in another molecule. These forces may also exist between hydrogen atoms in one location and oxygen, nitrogen, or fluorine atoms in another location in the same molecule. Intermolecular hydrogen bonds are responsible for the high strength of fibers. Helices are the result of intramolecular hydrogen bonds. These forces are typically present for fibers derived from nylons and polyesters but are absent for rubbers.



**intermolecular forces.** Secondary, van der Waals forces (including dipole-dipole, hydrogen bonding, and dipole-induced dipole) between different molecules. Intramolecular forces are the same except within the same polymer chain.

**isotactic.** Polymers where the pendant groups are all of the same configurations as in isotactic polypropylene.



**macromolecule.** Large molecule. Typically used interchangeably with the term polymer. Even so, some will use the term "polymer" for a material such as polystyrene that has an exact repeating unit and the term "macromolecule" for natural materials such as hemoglobin, proteins and nucleic acids where a general repeat unit is present (for the latter two) but where there exists some variation such as in the nature of the base for nucleic acids and nature of the alpha substituent for the alpha-amino acid derived units for proteins.

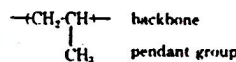
mer. Repeating unit in a polymer chain.

**number-average molecular weight,  $\bar{M}_n$ .** Arithmetical mean value obtained by dividing the sum of the molecular weights by the number of molecules. The basis for determining  $\bar{M}_n$ 's is derived from the realization that for dilute solutions, the activity of the solute in a solution is directly related to its mole fraction as the solute concentration goes to zero. When the activity of an added material is directly related to the mole fraction of material present, the property is referred to as a colligative property. Colligative property methods employed for determining molecular weights includes boiling-point elevation (ebullimetry), freezing-point depression (cryoscopy), osmotic pressure (membrane and vapor phase osmometry), and end-group analysis. Thus any analytic technique that determines the number of moles present in a sample of known weight, regardless of their size, gives a  $\bar{M}_n$ . It is also possible to measure the average molecular weight in terms of the weights, sizes of molecules present in the sample. This latter molecular weight is called the weight-average molecular weight,  $\bar{M}_w$ , and is determined typically by light-scattering photometry. For a mixture of polymer chains of varying lengths,  $\bar{M}_n$  is the first moment in the molecular weight distribution, analogous to the center of gravity in physics. The  $\bar{M}_w$  is the second moment of the distribution corresponding to the radius of gyration. Practically, the  $\bar{M}_n$  can be thought of as simply being related to the probability of drawing out particular lengths of rope from a paper sack containing a mixture of lengths of rope (polymer chains of varying lengths) emphasizing the number of ropes, i.e., the probability of drawing out a short length of rope is the same as the probability of drawing out a long length of rope. If the drawing of rope segments from the bag is dependent on the size of each rope segment (i.e., it is more probable to draw out a long chain compared to a shorter chain), then the probability is referred to as a weight-average property. Mathematically these two probability dependencies can be expressed in terms of  $N_i$ , the number of chains (or rope segments) of weight (or number of repeating units)  $M_i$  as follows:

$$\bar{M}_n = \frac{\sum_{i=1}^{\infty} M_i N_i}{\sum_{i=1}^{\infty} N_i} \quad \bar{M}_w = \frac{\sum_{i=1}^{\infty} N_i M_i^2}{\sum_{i=1}^{\infty} N_i M_i}$$

For homodisperse mixtures of smaller molecules (e.g., camphor, phenylmethylketone, and certain proteins, enzymes, and nucleic acids),  $\bar{M}_n = \bar{M}_w$ . For heterodisperse samples (composed of chains of differing lengths), such as those of almost all synthetic polymers,  $\bar{M}_w > \bar{M}_n$ .

**pendant group.** Nonhydrogen group attached to the main polymer chain or backbone like the methyl group in polypropylene.

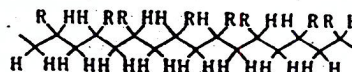


**polydisperse.** Polymer mixture consisting of molecules of different chain lengths.

**polymer.** Giant molecule or macromolecule made up of multiple repeating units joined together by covalent bonds.

**radius of gyration.** Average distance between chain ends and the polymer chains center of gravity, mass.

**syndiotactic.** Ordered polymer where the pendant groups are arranged alternately on each side of the polymer backbone.



**tacticity.** Arrangement of the pendant groups in space such as isotactic, syndiotactic or atactic.



# Polymer Properties and Testing—Definitions

Charles E. Carraher, Jr.

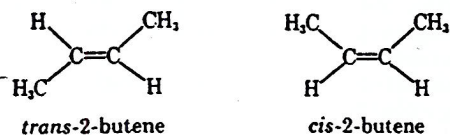
Florida Atlantic University, Boca Raton, FL 33431

Raymond B. Seymour

Department of Polymer Science, University of Southern Mississippi, Hattiesburg, MS 39406

**ASTM.** American Society for Testing and Materials; responsible for checking, compiling and publication of standardized testing procedures; not a governmental agency. (Example: A producer of alabaster glass may say that his product is in fact alabaster glass as defined by ASTM test C162, C-14—an optional test to determine if the glass does in fact diffuse visible light without fiery color and that it is milky white in appearance. A governmental agency responsible for glass may or may not specify that in order for white glass to be called alabaster glass that it must score a certain minimum value in the ASTM test C162, C-14.) The ASTM is composed of over 100 technical committees each responsible for a specific area. For instance, ASTM C-14 is responsible for glass and glass products (thus the C-14 notation above for the alabaster glass); D-6, paper and paper products; D-7, wood; D-11, rubber; D-13, textiles; D-14, adhesives; D-20, plastics; D-23, cellulose and cellulose derivatives; F-9, tires.

**configuration.** Refers to shapes, arrangements related to the actual chemical bonding such as the possible cis and trans configurations of 2-butene.



**conformation.** Refers to arrangements related to rotation about single bonds such as a semirigid rod conformation for proteins versus a random coil conformation of polystyrene in a good solvent.

**calendar.** Machine for producing polymeric sheets; contains counter-rotating rollers.

**casting.** Production of films or sheets generally from concentrated polymer solutions through evaporation of solvent, from melts or by situpolymerization.

**ceiling temperature.** A characteristic temperature above which polymerization does not occur and where the polymer decomposes.

**charge.** Amount of polymer (like 5 kg or 5 g) used in each fabrication cycle.

**cloud point.** Temperature at which a polymer begins to precipitate from solution as the temperature is lowered.

**coextruded film.** Film produced by the simultaneous extrusion of two or more polymers.

**cohesive energy density (CED).** Heat of vaporization per unit volume; used as a means of matching polymers with potential solvents such that a polymer is more apt to be soluble in liquids that have CED's similar to that of the polymer. Since polymers do not vaporize without fragmentation, comparative swelling experiments are often carried out to obtain CED's of polymeric materials. Thus, a few cross-links are introduced into a polymer sample to insure its insolubility. The polymer sample is then divided into samples that are placed in liquids with known CED's. The polymer is assigned a CED corresponding to the CED of the liquid in which the sample shows the greatest swelling.

**cold drawing.** Stretching of a fiber or fibers in one direction; acts to increase tensile strength through alignment of the polymer chains in the direction of the stretching.

**colligative properties.** Properties of a solution that are dependent on the number of solute molecules present and are usually related to the effect of these molecules on vapor pressure lowering.

**commercial polymer range.** Refers to a polymer's molecular weight such that the molecular weight is great enough for the polymer to exhibit good physical properties, such as tensile strength, but not so high as to preclude ready, economical processing.

**composite.** Polymer or mixture of polymers where a foreign material such as reinforcements (fibrous glass, nylon fibers) are dispersed.

**compressive strength.** Measure of resistance to crushing forces.

**creep.** Long-term flow of material under a mild stress, including gravitational forces; also describes the elongation or deformation of a sample after an applied stress is removed.

**critical chain length.** Minimum chain length required for the physical entanglement of polymer chains.

**cross-links.** Covalent bonds connecting two or more mer chains.

**cryometry.** Technique of measuring molecular weight employing the freezing point depression resulting from the presence of molecules such as polymer molecules; molecular weight obtained is referred to as a number-average molecular weight.

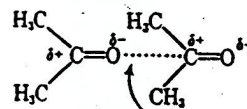
**dielectric constant.** Ratio of the capacitance of a material to that of air or a vacuum; measure of a tendency of a molecule to align itself as an electrical charge is applied; measure of polar nature and "flowability" of a material.

**dielectric voltage.** Maximum applied voltage that can be applied to a material before material destruction, breakdown occurs. Also known as dielectric strength.

**differential scanning calorimetry (DSC).** An instrumental thermal analytical technique in which the difference in the amount of heat absorbed or released by a sample and a standard is measured as the temperature is increased.

**differential thermal analysis (DTA).** A thermal instrumental analytical technique in which the rate of absorption or release of heat by a polymer is compared with that of a standard such as glass or alumina.

**dipole-dipole interactions.** Moderate secondary valence forces between polar groups in different molecules or in different locations in the same molecule.

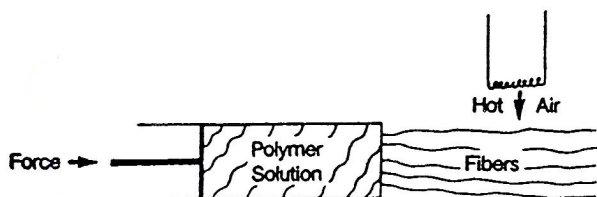


dipole-dipole interactions

**dry spinning.** Process for obtaining fiber by forcing a solution of a polymer through holes in a spinneret followed by evaporating (such as through blowing hot air past the



drying polymer fibers) the solvent from the extruded (fibrous) polymer.



**drying.** Term used to describe the cross-linking of a polymer (typically containing sites of unsaturation). Term used principally by coating technologists.

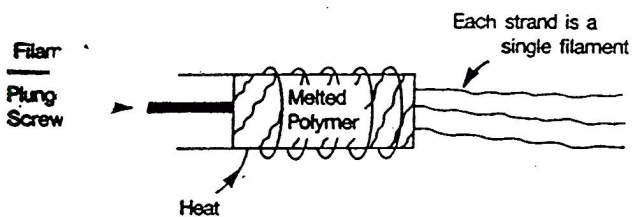
**ebulliometry.** Measure of the number-average molecular weight employing the elevation in the boiling point of a solution containing a polymer compared to the pure liquid itself.

**electrodeposition.** Use of an electric charge to deposit solid or dissolved polymer onto a metal surface; used to coat, paint appliances and automobiles by charging the metal surface with one charge and the coating material with the opposite charge.

**end-group analysis.** Measurement of the number-average molecular weight obtained through determination of the number of end groups per mass of polymer; nature of the end groups must be known.

**extrusion.** Fabrication process in which a heat-softened polymer is forced by a screw through a die; similar to forcing toothpaste through a toothpaste tube.

**filament.** Individual extrudate (extruded material) when a polymer is forced through a hole in a spinneret.



**flexural strength.** Measure of a material's resistance to bending.

**fractionation of polymers.** Separation of polydisperse polymer mixtures into fractions of similar molecular weight.

**glass transition temperature ( $T_g$ ).** A characteristic temperature where the glassy, amorphous regions of polymers become flexible or rubberlike due to the onset of local, segmental motion when the temperature is increased.

**glassy state.** Region where a material is hard, brittle.

**impact strength.** Measure of toughness.

**isotropic.** Having similar properties in all directions. Thus for bulk, amorphous nylon-6,6 properties such as refractive index, tensile strength, toughness are the same regardless of the orientation of the sample. For cold-drawn nylon-6,6 these properties are different (i.e., anisotropic) along the pull axis compared to properties measured at the other angles.

**lamination.** Plying of sheets which can be various materials such as paper, plastic, and wood; construction is much like making a double-decker cheese sandwich; examples include automotive windshields, where the glass is sandwiched about poly(vinyl butyral) and laminated counter-top which sheets of paper are held together by phenolic resins with urea or melamine resins used for the decorative surface and plywood.

**latex.** Stable dispersion of a polymer such as poly(methyl methacrylate) in water.

**melt spinning.** Process for obtaining fibers by forcing molten, melted polymer through holes in a spinneret followed by cooling of the filaments produced.

**modulus.** Ratio of stress (applied force) to strain (elongation, bend); ratio of magnitude of applied force to elongation; a measure of the stiffness of a polymer.

**molding powder or compounds.** Premix of resin and other additives used as the material is added to a mold or extruder.

**osmometry.** Determination of number-average molecular weight from the measure of vapor phase or membrane osmotic pressure differences. (See *number-average molecular weight*.<sup>1</sup>)

**piezoelectric.** Conversion of mechanical forces, such as applied pressure, into electrical energy.

**plasticizer.** A material that reduces the intermolecular forces in polymers permitting the polymer segments to exhibit flexibility. For synthetic polymers this material is usually a nonvolatile additive or may be part of a polymer chain that encourages the formation of amorphous regions. Water serves as a plasticizer in natural polymers. By forming secondary bonds with the polymer chains and spreading them apart, the plasticizer reduces the polymer-polymer chain secondary bonding and provides more room for the polymer segments to slide past one another. Both factors act to provide a softer, more easily deformable, less brittle material.

**power factor (or dissipation factor).** A measure of the energy dissipated per cycle. The actual power absorbed per cycle is the product of the dielectric constant and dissipation factor.

**pultrusion.** Process in which filaments are dipped into (coated with) liquid prepolymer, passed through a die, and subsequently cured, cross-linked.

**rheology.** Science of flow of material.

**rovings.** Multiple untwisted strands of filaments.

**shear (stress).** Deformation in which parallel planes in a material remain parallel but are relatively displaced in a direction parallel to themselves; deformation where polymer chains in a material are displaced relative to one another.

**solubility parameter.** Numerical value equal to the square root of the cohesive energy density; used to predict polymer solubility through trying to match the solubility parameter of the polymer with that of a liquid.

**spinneret.** A plate in which multiple holes have been formed.

**stress.** Force per unit area.

**stress relaxation.** Measure of the relaxation of a stressed specimen with time at constant extension.

**tensile strength.** Resistance to pulling stresses.

**thermogravimetric analysis.** Measurement of the change (normally loss) in weight when a material is heated or temperature is held constant.

**thermoplastic.** Linear or branched polymer which may be softened by heat.

**thermoset plastic.** Network polymer usually obtained by cross-linking a linear polymer; insoluble; does not soften on reheating.

**transfer molding.** A process in which a preheated briquette or preform is forced through an orifice into a heated mold cavity.

**ultracentrifugation.** A high-speed centrifuge employed for the separation of submicroscopic particles such as polymer chains; depending on the type of calculation and experimental procedure used, several types of molecular weight values can be obtained.

<sup>1</sup> Carraher, C. E.; Seymour, R. B. *J. Chem. Educ.* 1986, 63, 418-419.

