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Polymer Chemistry - A Study of Organic Macromolecules

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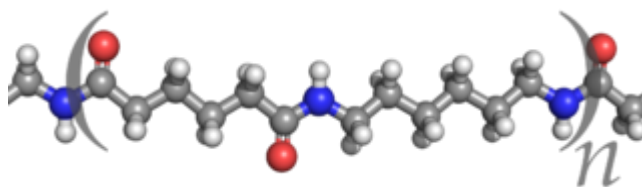
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ABSTRACT: Polymer chemistry is a sub-discipline of chemistry that focuses on the structures of chemicals, chemical synthesis, and chemical and physical properties of polymers and macromolecules. The principles and methods used within polymer chemistry are also applicable through a wide range of other chemistry sub-disciplines like organic chemistry, analytical chemistry, and physical chemistry. Many materials have polymeric structures, from fully inorganic metals and ceramics to DNA and other biological molecules. However, polymer chemistry is typically related to synthetic and organic compositions. Synthetic polymers are ubiquitous in commercial materials and products in everyday use, such as plastics, and rubbers, and are major components of composite materials. Polymer chemistry can also be included in the broader fields of polymer science or even nanotechnology, both of which can be described as encompassing polymer physics and polymer engineering

KEYWORDS: synthesis, physical, molecules, composite, engineering, nanotechnology, plastics, rubbers

I. INTRODUCTION

The work of Henri Braconnot in 1777 and the work of Christian Schönbein in 1846 led to the discovery of nitrocellulose, which, when treated with camphor, produced celluloid. Dissolved in ether or acetone, it becomes collodion, which has been used as a wound dressing since the U.S. Civil War. Cellulose acetate was first prepared in 1865. In years 1834-1844 the properties of rubber (polyisoprene) were found to be greatly improved by heating with sulfur, thus founding the vulcanization process.¹



Portion of backbone of nylon 6,6.

In 1884 Hilaire de Chardonnet started the first artificial fiber plant based on regenerated cellulose, or viscose rayon, as a substitute for silk, but it was very flammable. In 1907 Leo Baekeland invented² the first polymer made independent of the products of organisms, a thermosetting phenol-formaldehyde resin called Bakelite. Around the same time, Hermann Leuchs reported the synthesis of amino acid N-carboxyanhydrides and their high molecular weight products upon reaction with nucleophiles³, but stopped short of referring to these as polymers, possibly due

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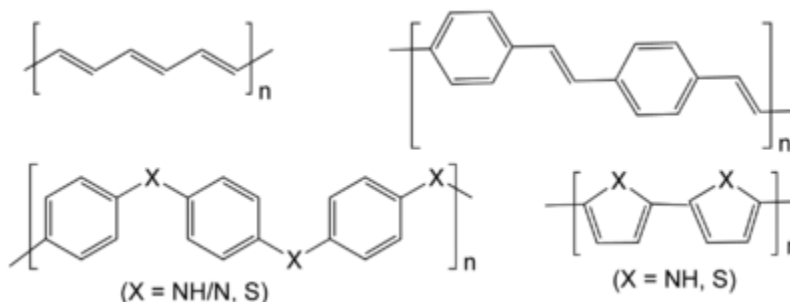
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to the strong views espoused by Emil Fischer, his direct supervisor, denying the possibility of any covalent molecule exceeding 6,000 daltons. Cellophane was invented in 1908 by Jocques Brandenberger who treated sheets of viscose rayon with acid.

The chemist Hermann Staudinger first proposed that polymers consisted of long chains of atoms held together by covalent bonds, which he called macromolecules.⁴ His work expanded the chemical understanding of polymers and was followed by an expansion of the field of polymer chemistry during which such polymeric materials as neoprene, nylon and polyester were invented. Before Staudinger, polymers were thought to be clusters of small molecules (colloids), without definite molecular weights, held together by an unknown force. Staudinger received the Nobel Prize in Chemistry in 1953.⁵ Wallace Carothers invented the first synthetic rubber called neoprene in 1931, the first polyester, and went on to invent nylon, a true silk replacement, in 1935. Paul Flory was awarded the Nobel Prize in Chemistry in 1974 for his work on polymer random coil configurations in solution in the 1950s.²⁷ Stephanie Kwolek developed an aramid, or aromatic nylon named Kevlar, patented in 1966. Karl Ziegler and Giulio Natta received a Nobel Prize for their discovery of catalysts for the polymerization of alkenes. Alan J. Heeger, Alan MacDiarmid, and Hideki Shirakawa were awarded the 2000 Nobel Prize in Chemistry for the development of polyacetylene and related conductive polymers.[8] Polyacetylene itself did not find practical applications, but organic light-emitting diodes (OLEDs) emerged as one application of conducting polymers. Teaching and research programs in polymer chemistry were introduced in the 1940s. An Institute for Macromolecular Chemistry was founded in 1940 in Freiburg, Germany under the direction of Staudinger. In America, a Polymer Research Institute (PRI) was established in 1941 by Herman Mark at the Polytechnic Institute of Brooklyn (now Polytechnic Institute of NYU).⁶

II. DISCUSSION

Polymers are high molecular mass compounds formed by polymerization of monomers. The simple reactive molecule from which the repeating structural units of a polymer are derived is called a monomer. ²⁶A polymer can be described in many ways: its degree of polymerisation, molar mass distribution, tacticity, copolymer distribution, the degree of branching, by its end-groups, crosslinks, crystallinity and thermal properties such as its glass transition temperature and melting temperature.⁷ Polymers in solution have special characteristics with respect to solubility, viscosity, and gelation. Illustrative of the quantitative aspects of polymer chemistry, particular attention is paid to the number-average and weight-average molecular weights²⁵. The study of polymer thermodynamics helps improve the material properties of various polymer-based materials such as polystyrene (styrofoam) and polycarbonate. Common improvements include toughening, improving impact resistance, improving biodegradability, and altering a material's solubility.⁸



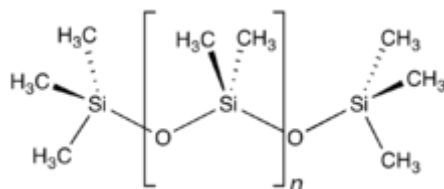
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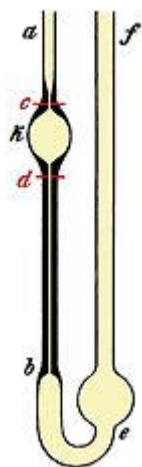
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Structures of some electrically conductive polymers: polyacetylene; polyphenylene vinylene; polypyrrole (X = NH) and polythiophene (X = S); and polyaniline (X = NH/N) and polyphenylene sulfide (X = S).

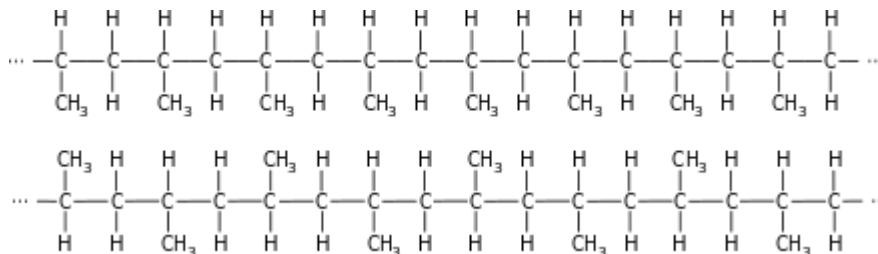


Structure of polydimethylsiloxane, illustrating a polymer with an inorganic backbone.



The viscosity of polymer solutions is a valued parameter. Viscometers such as this are employed in such measurements.

As polymers get longer and their molecular weight increases, their viscosity tend to increase. Thus, the measured viscosity of polymers can provide valuable information about the average length of the polymer, the progress of reactions, and in what ways the polymer branches.⁹



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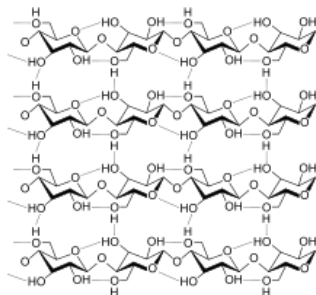
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Segments of polypropylene, showing the slightly different structures of isotactic (above) and syndiotactic (below) polymers.

Polymers can be classified in many ways. Polymers, strictly speaking, comprise most solid matter: minerals²⁴ (i.e. most of the earth's crust) are largely polymers, metals are 3-d polymers, organisms, living and dead, are composed largely of polymers and water¹⁰. Often polymers are classified according to their origin:

- biopolymers
- synthetic polymers
- inorganic polymers

Biopolymers are the structural and functional materials that comprise most of the organic matter in organisms. One major class of biopolymers are proteins, which are derived from amino acids.²³ Polysaccharides, such as cellulose, chitin, and starch, are biopolymers derived from sugars. The polynucleic acids DNA and RNA are derived from phosphorylated sugars with pendant nucleotides that carry genetic information.¹¹



A strand of cellulose showing the hydrogen bonds (dashed) within and between the chains.

Synthetic polymers are the structural materials manifested in plastics, synthetic fibers, paints, building materials, furniture, mechanical parts, and adhesives²². Synthetic polymers may be divided into thermoplastic polymers and thermoset plastics. Thermoplastic polymers include polyethylene, teflon, polystyrene, polypropylene, polyester, polyurethane, Poly(methyl methacrylate), polyvinyl chloride, nylons, and rayon. Thermoset plastics include vulcanized rubber, bakelite, Kevlar, and polyepoxide. Almost all synthetic polymers are derived from petrochemicals.¹²

III. RESULTS

Biopolymers are natural polymers produced by the cells of living organisms. Like other polymers, biopolymers consist of monomeric units that are covalently bonded in chains to form larger molecules.²¹ There are three main classes of biopolymers, classified according to the monomers used and the structure of the biopolymer formed: polynucleotides, polypeptides, and polysaccharides. The Polynucleotides, RNA and DNA, are long polymers of nucleotides. Polypeptides include proteins and shorter polymers of amino acids; some major examples include collagen, actin, and fibrin²⁰. Polysaccharides are linear or branched chains of sugar carbohydrates; examples include starch, cellulose and alginate. Other examples of biopolymers include natural rubbers (polymers

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of isoprene), suberin and lignin (complex polyphenolic polymers), cutin and cutan (complex polymers of long-chain fatty acids) and melanin.¹³

In addition to their many essential roles in living organisms, biopolymers have applications in many fields including the food industry, manufacturing, packaging, and biomedical engineering



In the structure of DNA is a pair of biopolymers, polynucleotides, forming the double helix structure

Some familiar household synthetic polymers include: Nylons in textiles and fabrics, Teflon in non-stick pans¹⁹, Bakelite for electrical switches, polyvinyl chloride (PVC) in pipes, etc. The common PET bottles are made of a synthetic polymer, polyethylene terephthalate. The plastic kits and covers are mostly made of synthetic polymers like polythene, and tires are manufactured from Buna rubbers.¹⁵ However, due to the environmental issues created by these synthetic polymers which are mostly non-biodegradable and often synthesized from petroleum, alternatives like bioplastics are also being considered.¹⁴ They are however expensive when compared to the synthetic polymers (see table)

Brand Name	Polymer	Characteristic properties	Uses
Bakelite	Phenol-formaldehyde resin	High electric, heat and chemical resistance	Insulation of wires, manufacturing sockets, electrical devices, brake pads, etc.
Kevlar	Para-aramid fibre	High tensile strength	Manufacturing armour, sports and musical equipment. Used in the field of cryogenics
Twaron	Para-aramid	Heat resistant and strong fibre	Bullet-proof body armor, helmets, brake pads, ropes, cables and optical fibre cables, etc. and as an asbestos substitute
Mylar	Polyethylene terephthalate film	High strength and stiffness, less permeable to gases,	Food packaging, transparent covering over paper, reflector for rollsigns and

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		almost reflects light completely	solar cooking stoves
Neoprene	Polychloroprene	Chemically inert	Manufacturing gaskets, corrosion resistant coatings, waterproof seat covers, substitute for corks and latex
Nylon	Polyamide	Silky, thermoplastic and resistant to biological and chemical agents	Stockings, fabrics, toothbrushes. Molded nylon is used in making machine screws, gears etc.
Nomex	Meta-aramid polymer	Excellent thermal, chemical, and radiation resistance, rigid, durable and fireproof.	Hood of firefighter's mask, electrical lamination of circuit boards and transformer cores and in Thermal Micrometeoroid Garment
Orlon	Polyacrylonitrile (PAN)	Wool-like, resistant to chemicals, oils, moths and sunlight	Used for making clothes and fabrics like sweaters, hats, yarns, rugs, etc., and as a precursor of carbon fibres
Rilsan	Polyamide 11 & 12	Bioplastic	Used in high-performance applications such as sports shoes, electronic device components, automotive fuel lines, pneumatic airbrake tubing, oil and gas flexible pipes and control fluid umbilicals, and catheters.
Technora	Copolyamid	High tensile strength, resistance to corrosion, heat, chemicals and saltwater	Used for manufacturing optical fiber cables, umbilical cables, drumheads, automotive industry, ropes, wire ropes and cables
Teflon	Polytetrafluoroethylene (PTFE)	Very low coefficient of friction, excellent dielectric properties, high melting, chemically inert	Plain bearings, gears, non-stick pans, etc. due to its low friction. Used as a tubing for highly corrosive chemicals.
Ultem	Polyimide	Heat, flame and solvent resistant. Has high dielectric strength	Used in medical and chemical instrumentation, also in guitar picks
Vectran	aromatic polyester	High thermal and chemical stability. Golden color. Has high strength, low creep, and is moisture resistant	Used as reinforcing fibres for ropes, cables, sailcloth. Also used in manufacturing badminton strings, bike tires and in electronics applications.

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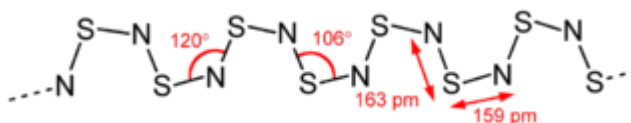
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			Is the key component of a line of inflatable spacecraft developed by Bigelow Aerospace
Viton	Polytetrafluoroethylene (PTFE)	Elastomer	Depends on the grade of the polymer. Viton B is used in chemical process plants and gaskets.
Zylon	poly-p-phenylene-2,6-benzobisoxazole (PBO)	Very high tensile strength and thermal stability	Used in tennis racquets, table tennis blades, body armor, etc.

An inorganic polymer is a polymer with a skeletal structure that does not include carbon atoms in the backbone. Polymers containing inorganic and organic components are sometimes called hybrid polymers, and most so-called inorganic polymers are hybrid polymers. One of the best known examples is polydimethylsiloxane¹⁶, otherwise known commonly as silicone rubber. Inorganic polymers offer some properties not found in organic materials including low-temperature flexibility¹⁸, electrical conductivity, and nonflammability. The term inorganic polymer refers generally to one-dimensional polymers, rather than to heavily crosslinked materials such as silicate minerals. Inorganic polymers with tunable or responsive properties are sometimes called smart inorganic polymers.¹⁷ A special class of inorganic polymers are geopolymers, which may be anthropogenic or naturally occurring.



The inorganic polymer (SN)_x

IV. CONCLUSIONS

Polymer science or macromolecular science is a subfield of materials science concerned with polymers, primarily synthetic polymers such as plastics and elastomers. The field of polymer science includes researchers in multiple disciplines including chemistry, physics, and engineering. This science comprises three main sub-disciplines:

- Polymer chemistry or macromolecular chemistry is concerned with the chemical synthesis and chemical properties of polymers.
- Polymer physics is concerned with the physical properties of polymer materials and engineering applications. Specifically, it seeks to present the mechanical, thermal, electronic and optical properties of polymers with respect to the underlying physics governing a polymer microstructure. Despite originating as an application of statistical physics to chain structures,^[1] polymer physics has now evolved into a discipline in its own right.

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- Polymer characterization is concerned with the analysis of chemical structure, morphology, and the determination of physical properties in relation to compositional and structural parameters.²⁷

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