Introduction to Modern Biomaterials

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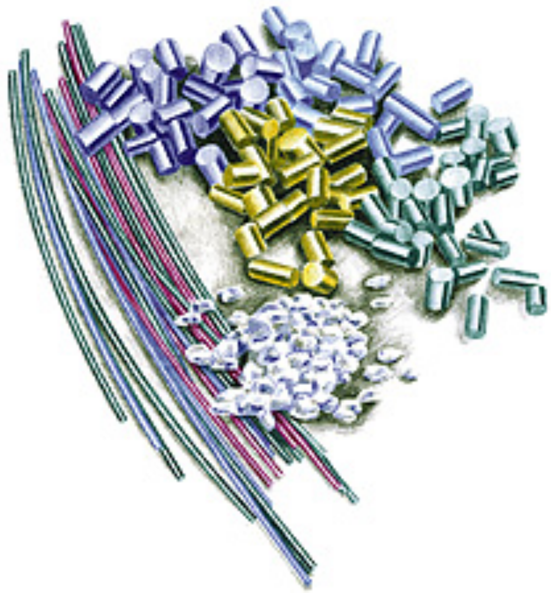
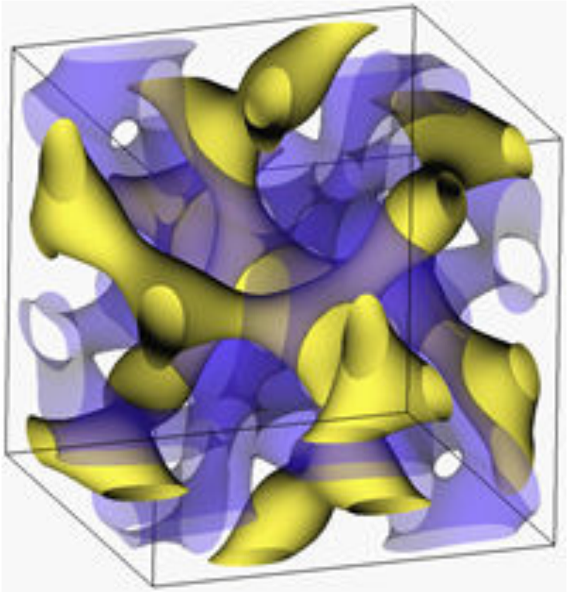
Polymeric Materials - Part I

What is a Polymeric Biomaterial?





What is a polymer?

- The word is from Greek roots “poly” meaning many and “meros” meaning parts .
- Many scientists prefer the word “macromolecule”.
- If one discounts the end uses, the differences between all polymers, whether natural or synthetic, are determined by the intermolecular and intramolecular forces that exist between the molecules within the individual molecules and by the functional groups they contain.

Polymers

- If we disregard metals and inorganic compounds, we observe that practically everything else in the world is polymeric.
- This includes the protein, nucleic acid and sugars that make up all cells and their extracellular matrix, the fibers in our clothing, the food that we eat, the elastomers in our tires, the paint, plastic wall and floor coverings, our foam insulation, dishes, furniture of our homes, etc.

How are they used?

Polymeric Biomaterials are used in a Broad Range of Products

MEDICAL PLASTIC MARKET FORECAST TO CROSS 2.6 BILLION POUNDS BY 2004- Worldwide

- Plastic usage in the healthcare field encompasses several distinct markets-including disposable or single use biomaterials.
- Predominant are applications for medical devices and related products and packaging.

Medical Plastics Market

- Non-disposables comprise slightly over 50% of total volume.
- Commodity thermoplastics currently dominate the market with a little under 50% of total volume, having a consumption level of 956 million pounds in 1999.
- Almost 80% of polymers used in the medical industry are represented by **PVC, polypropylene and polystyrene.**

Medical Plastics Market

- Major nondisposable markets include testing/diagnostic equipment, surgical instruments and related equipment, prostheses/implants, dental/ophthalmic devices;
- Disposable products include syringes, kits, labware, tubing, blood bags, utensils, gloves, trays, catheters, thermometers, etc.

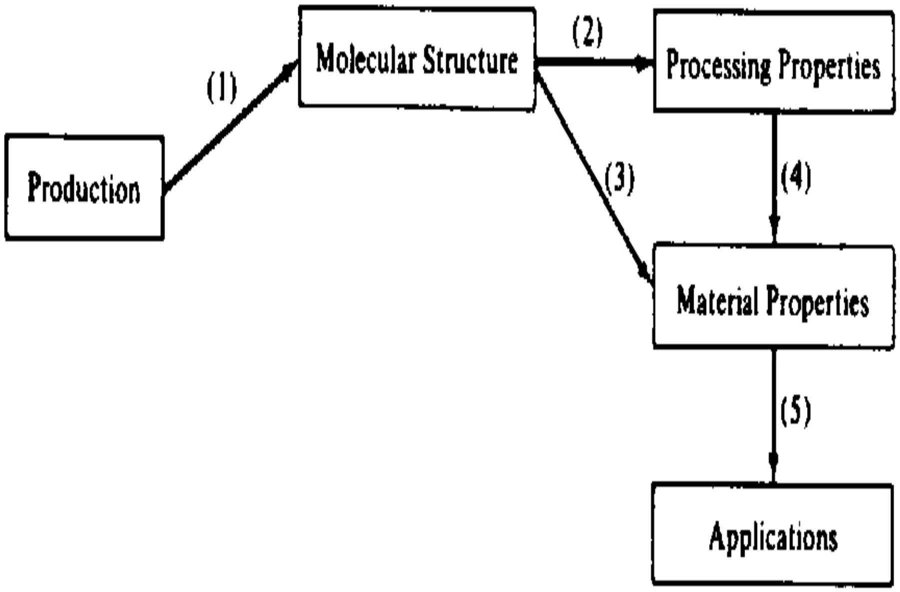
Polymer Science and Processing Technology

Successful product design requires a knowledge of:

- the requirements of the final product;
- the behavior of polymeric materials;
- commercial polymer processing technology; and
- relevant cost and market factors.

Polymer Science and Processing Technology

- At the heart of polymer science and technology is molecular structure.
- It dictates not only final product properties, but the type of polymer synthesis and the potential processing methods.



Learning Resource

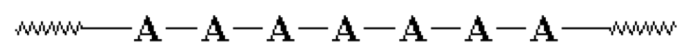
The Macrogalleria

www.psrc.usm.edu/macrog/index.htm

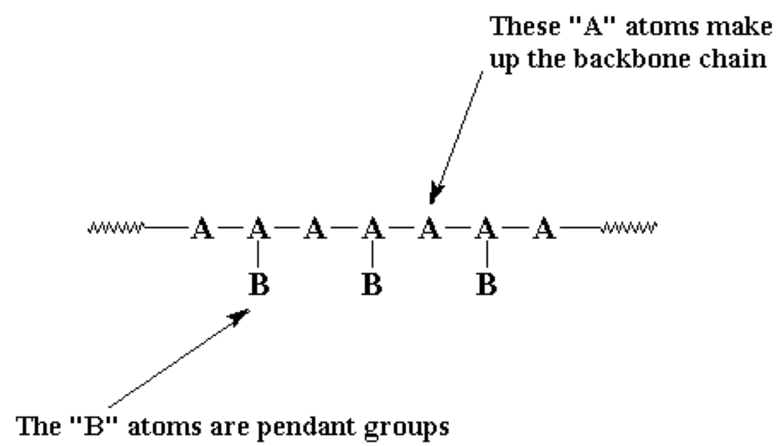
Read through levels 2-5

Molecular Arrangement of Polymers

- Most polymers are large linear macro-molecules.
- This chain is called the *backbone*.
- Normally, some of these atoms in the chain will have small chains of atoms attached to them. These small chains are called *pendant groups.*
- Pendant chains normally have just a few atoms, but the backbone chain usually has hundreds of thousands of atoms.

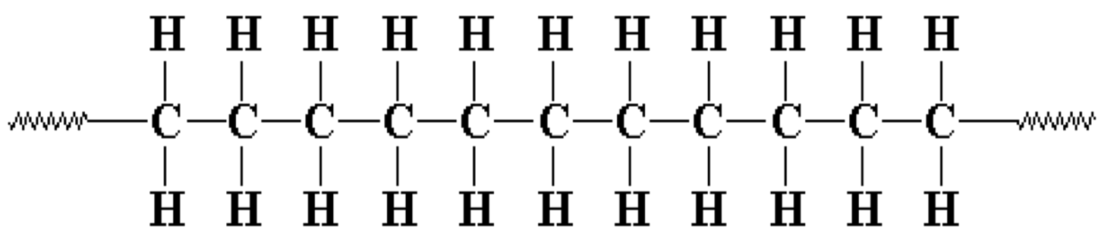


a linear polymer made of "A" atoms



The Structure of Polymers

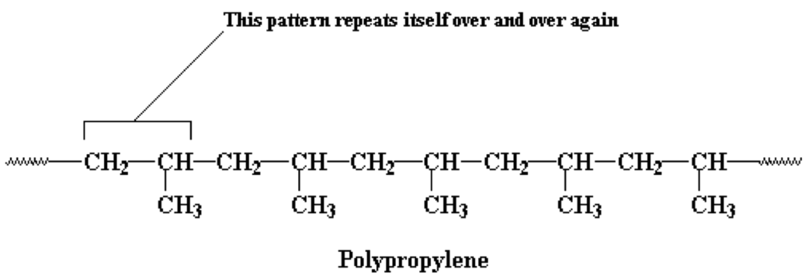
- Below is a diagram of polyethylene, the simplest polymer structure

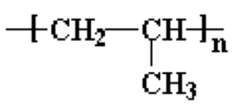


- There are polymers that contain only carbon and hydrogen.
- These are referred to as hydrocarbons-exs. Polypropylene, polybutylene, polystyrene, and polymethylpentene

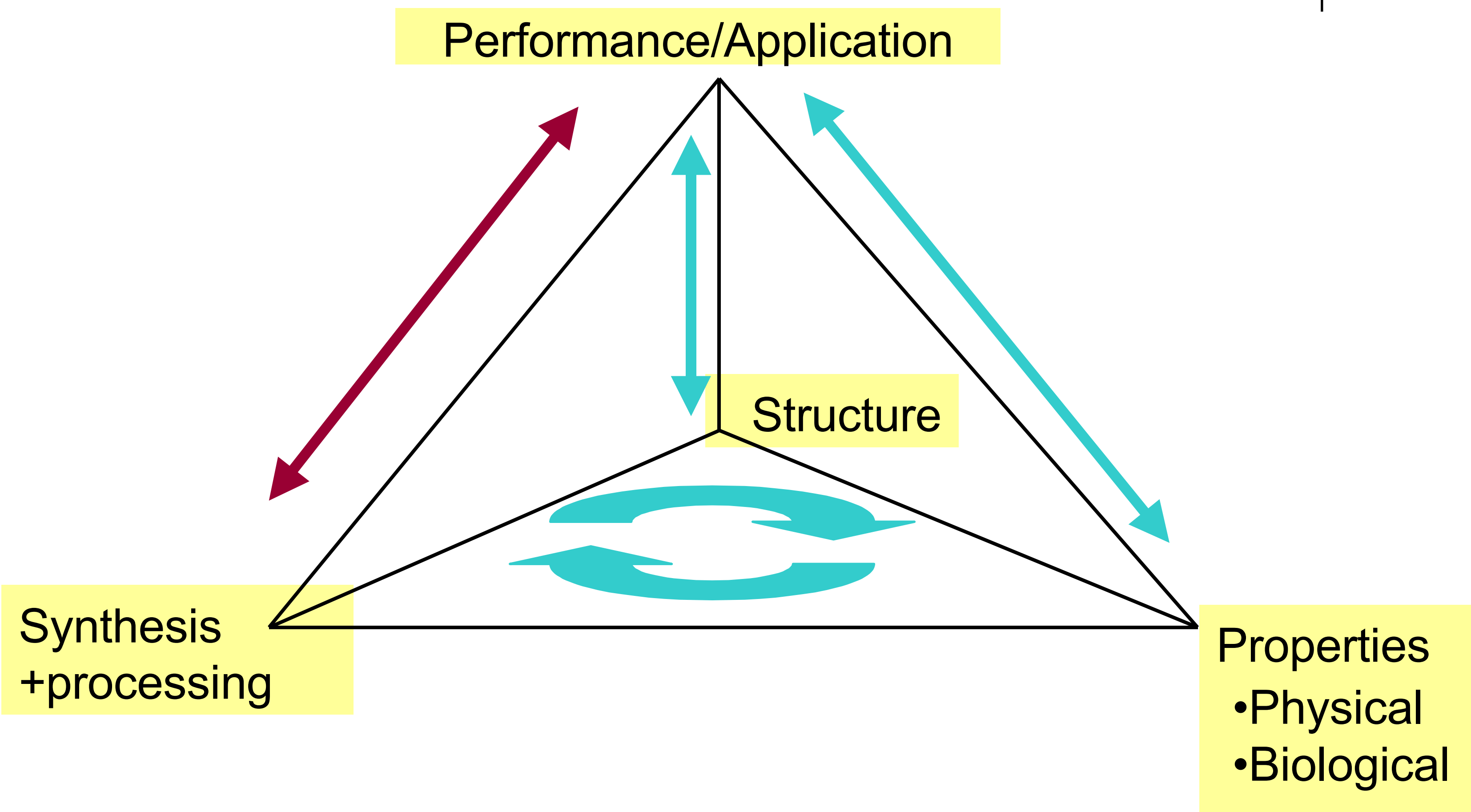
Polymers have a Repeating Structure

- We like to think that the atoms that make up the backbone of a polymer chain come in a regular order, and this order repeats itself all along the length of the polymer chain.
- For example, in polypropylene, the backbone chain is made up of just two carbon atoms repeated over and over again.





Material Science Logic



Basics of Polymer Structure

- What distinguishes polymers from other organic compounds is molecular weight and dimension?

TABLE 1.1 Properties of the Alkane Series

Number of Carbons in Chain	State and Properties of Material	Use, Dependent on Chain Length
1–4	Simple gas	Bottled gas for cooking
5–11	Simple liquid	Gasoline
9–16	Medium-viscosity liquid	Kerosene
16–25	High-viscosity liquid	Oil and grease
25–50	Simple solid	Paraffin wax candles
1000–3000	Tough plastic solid	Polyethylene bottles and containers

The Structure of Polymers

- Even though the basic makeup of many polymers is carbon and hydrogen, other elements can also be involved.
- Oxygen, chorine, fluorine, nitrogen, silicon, phosphorous, and sulfur are other elements found in the molecular makeup of polymers.
- Polyvinyl chloride (PVC) contains chlorine.
- Nylon contains nitrogen.
- Teflon contains fluorine.
- Polyester and polycarbonates contain oxygen.

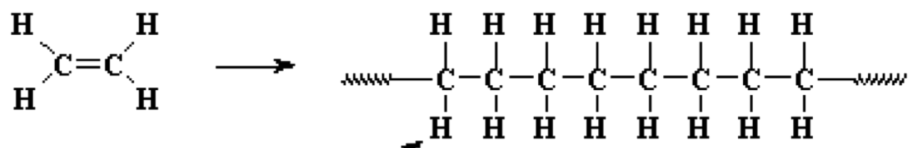
The Structure of Polymers

- There are also some polymers that, instead of having a carbon backbone, have a silicon or phosphorous backbone.
- These are considered inorganic polymers.
- Polysiloxanes (Silicones) and Polyphosphazenes

Vinyl Polymers

- Vinyl polymers are polymers made from *vinyl monomers*; that is, small molecules containing carbon-carbon double bonds.
- They make up largest family of polymers.
- Let's see how we get from a vinyl monomer to a vinyl polymer using for an example the simplest vinyl polymer, polyethylene.

Polyethylene



This can get tedious to draw, so we often use shorthand like this.

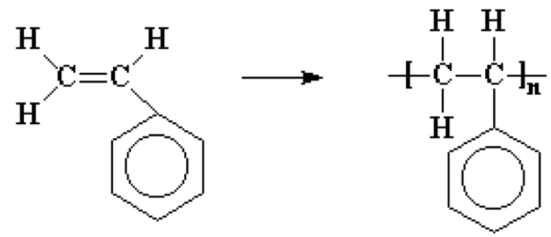
(Note: A line drawn between two atoms represents a pair of electrons shared by those atoms, which constitutes a chemical bond. Two lines represent two pairs of shared electrons, a double bond.)

And when we're feeling really lazy we just draw it like this:

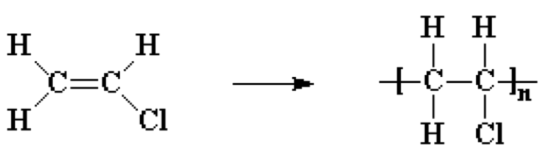
$$CH_2{=}CH_2 \longrightarrow -\!\!\left[CH_2\text{-}CH_2\right]\!\!-_n$$

Vinyl Polymers

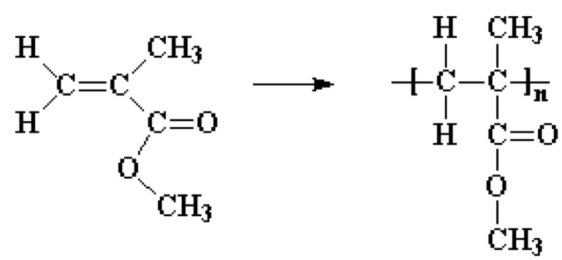
polypropylene



polystyrene



polyvinylchloride



polymethylmethacrylate

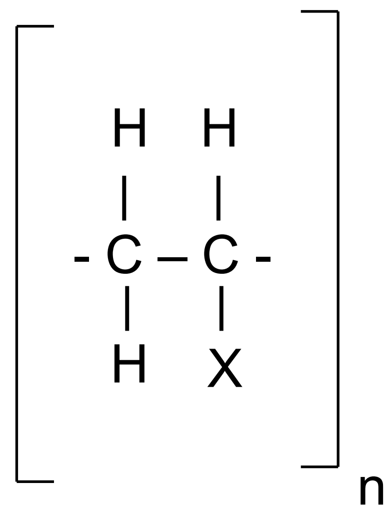
PTFE

polytetraflouroethylene

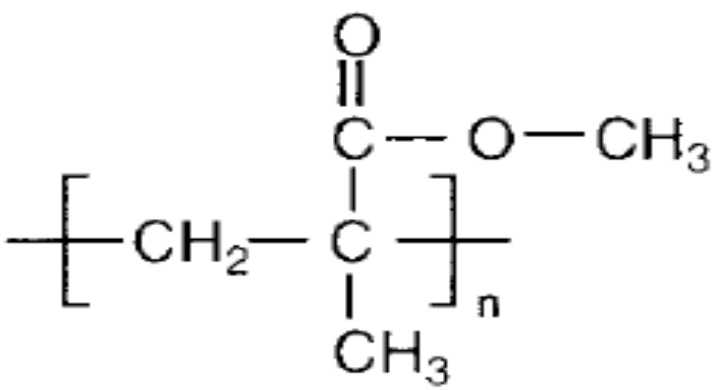
Other Carbon Chain Polymers

Homopolymer

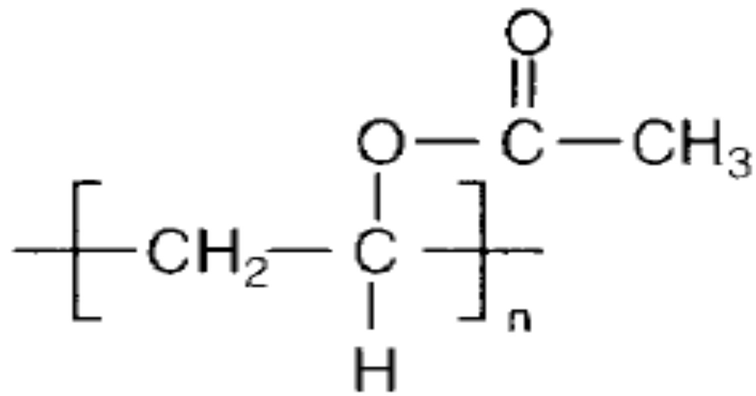
- If X=H then polyethylene
- If X = CH3 then polypropylene
- If X = Cl then polyvinylchloride
- If X = Benzene ring then polystyrene



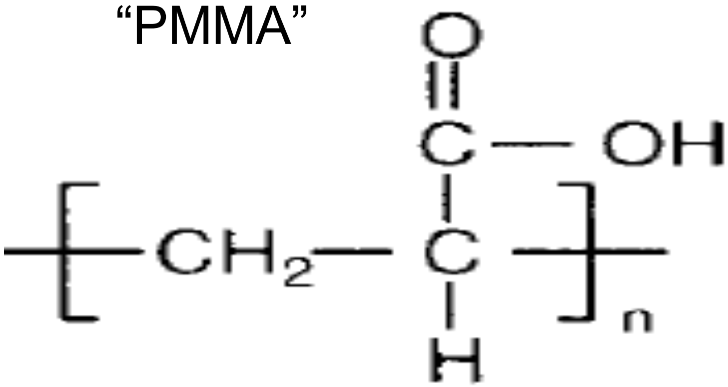
Chemical Structure of Some Common Polymers



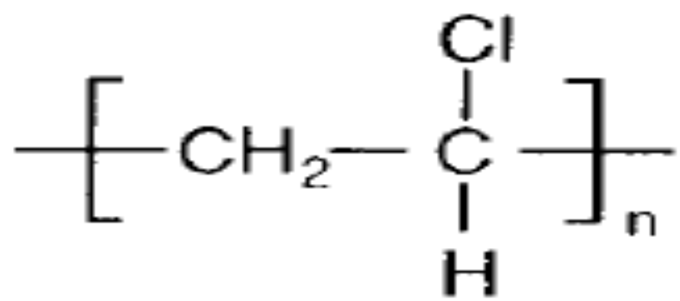
Poly(methylmethacrylate) "PMMA"



Poly(vinylacetate) "PAVc"

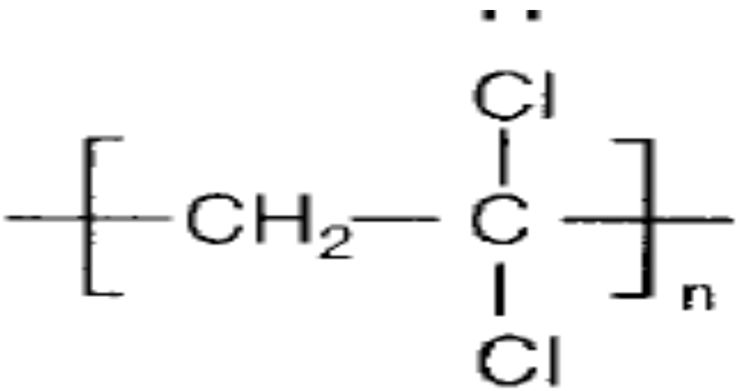


Poly(acrylate) "PAA"

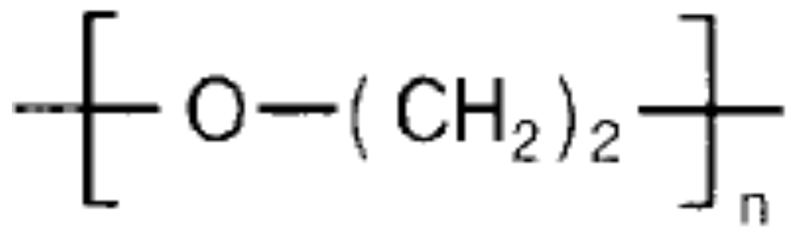


Poly(vinylchloride) "PVC"

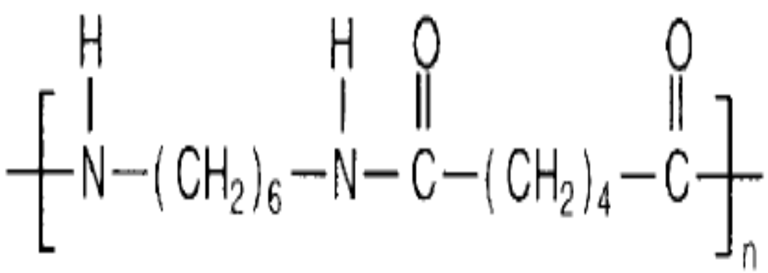
Chemical Structure of Some Common Polymers



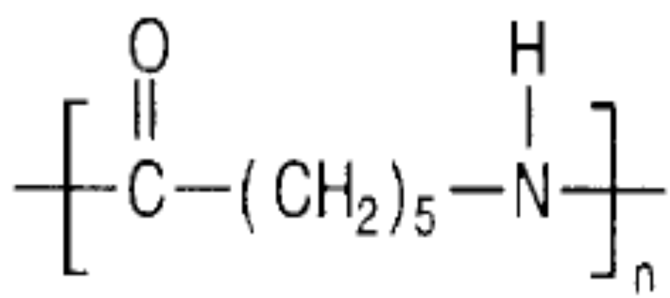
Poly(vinylidene chloride)“PAVc”



Poly(ethylene oxide)“PEO”

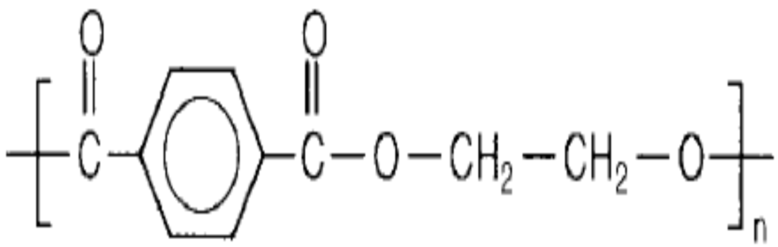


Poly(hexamethylene adipamide)
“Nylon 6,6”

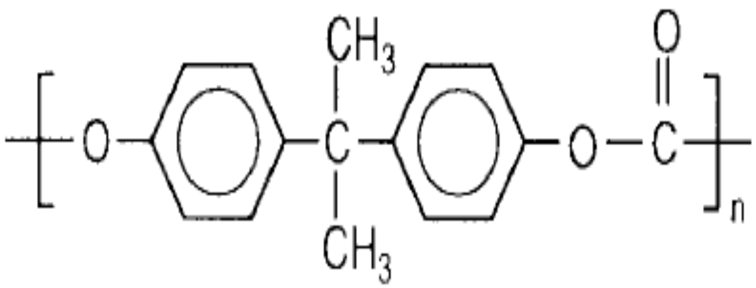


Poly(caprolactam) “Nylon”

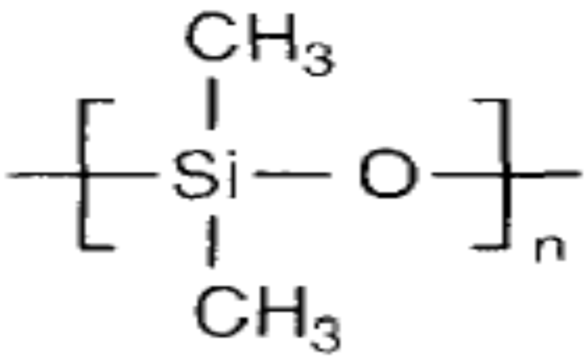
Chemical Structure of Some Common Polymers



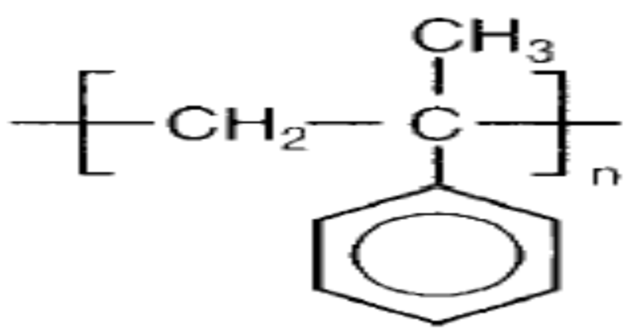
Poly(ethylene terephthalate)"PET"



Poly(carbonate)



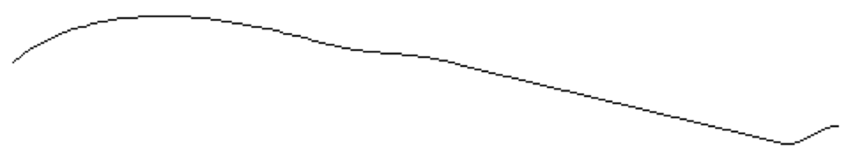
Poly(dimethyl siloxane)



Poly(methyl styrene)

Classification- Chain Architecture: Linear Structures

- Many thermoplastic polymers are built so their molecules consist of many thousands of atoms arranged into long linear chains. But they don't have to be long straight chains.

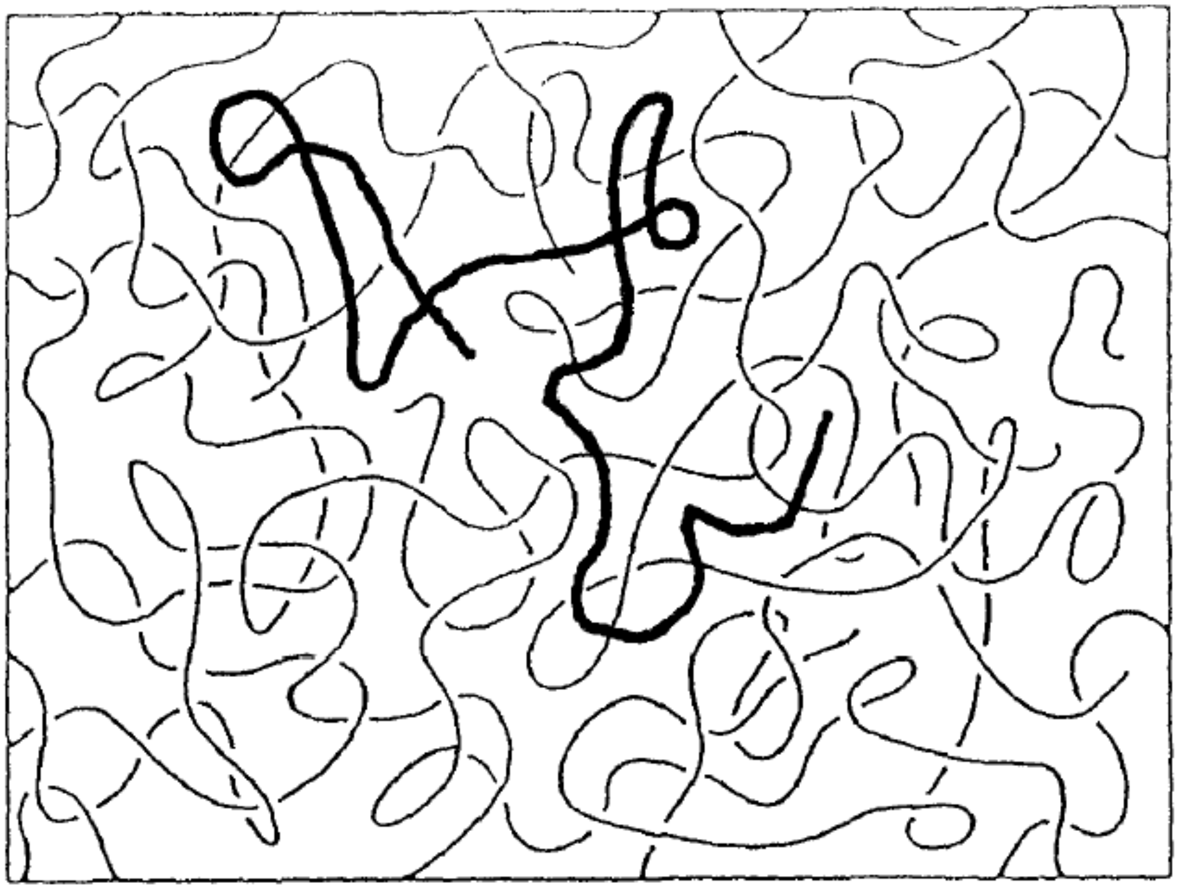


a linear polymer

Polymer Structure

- Also we know that each such carbon to carbon bond allows full rotation in both molecules, so that in reality the chains are seldom extended to their full contour length but are present in many different shapes, or conformations.

Illustration of the random coil model. One chain is marked boldly.

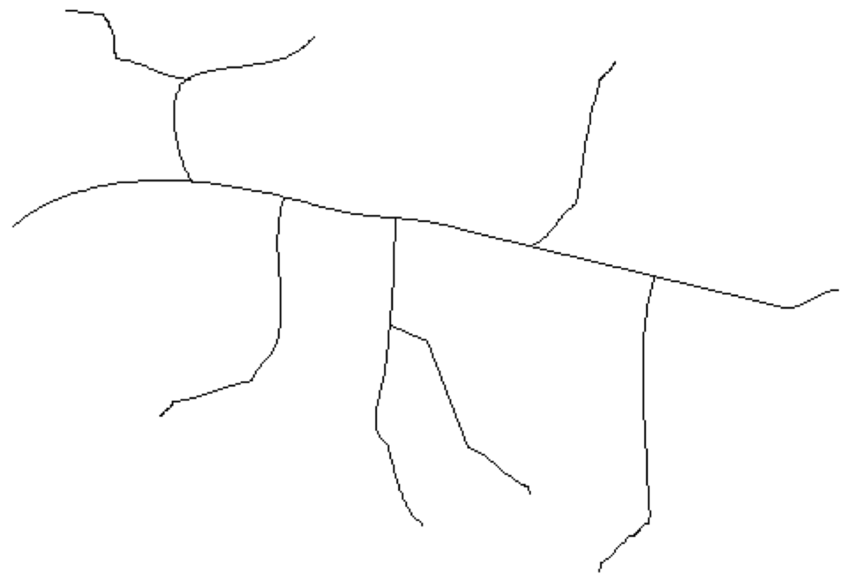


Consequences of the random coil model

- Crystallization strongly impeded by chain entanglement-only partial crystallization or glassy state upon cooling of a melt
- Entanglement gives rise to very high viscosity of polymer melts
- Entropic restoring force upon stretching of a chain- *entropy elasticity* of elastomers

Branched Polymers

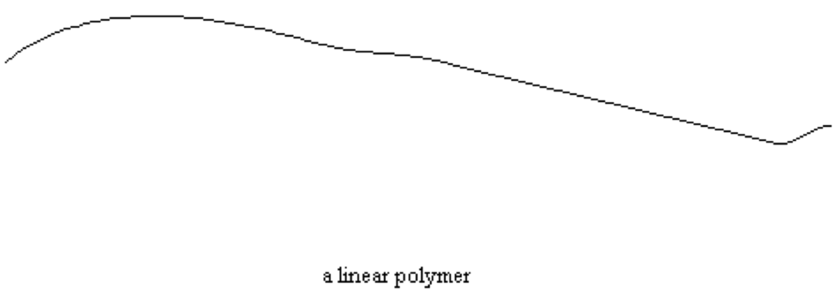
- Not all polymers are linear in this way. Sometimes there are chains attached to the backbone chain which are comparable in length to that backbone chain.
- Some thermoplastic polymers, like polyethylene, can be made in linear or branched versions.
- This gives them a 2-D quality.



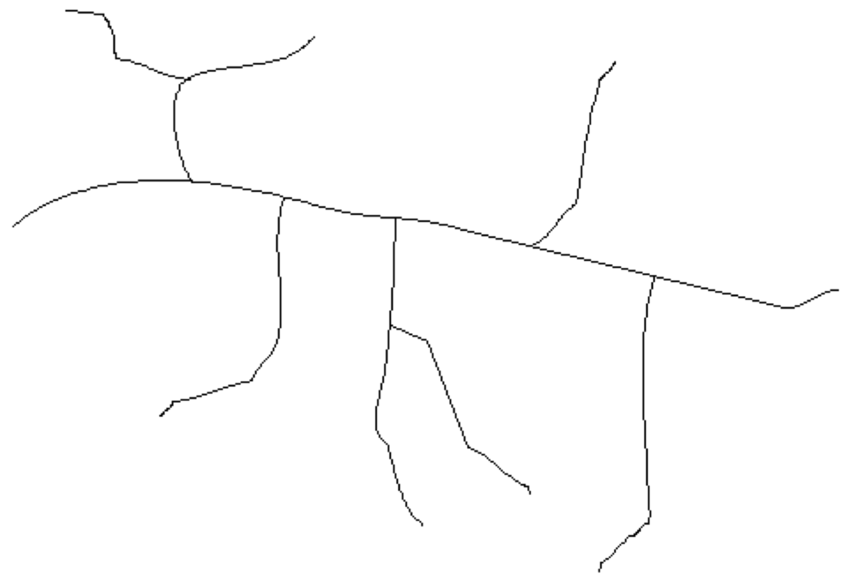
a branched polymer

HDPE vs LDPE

HDPE



LDPE



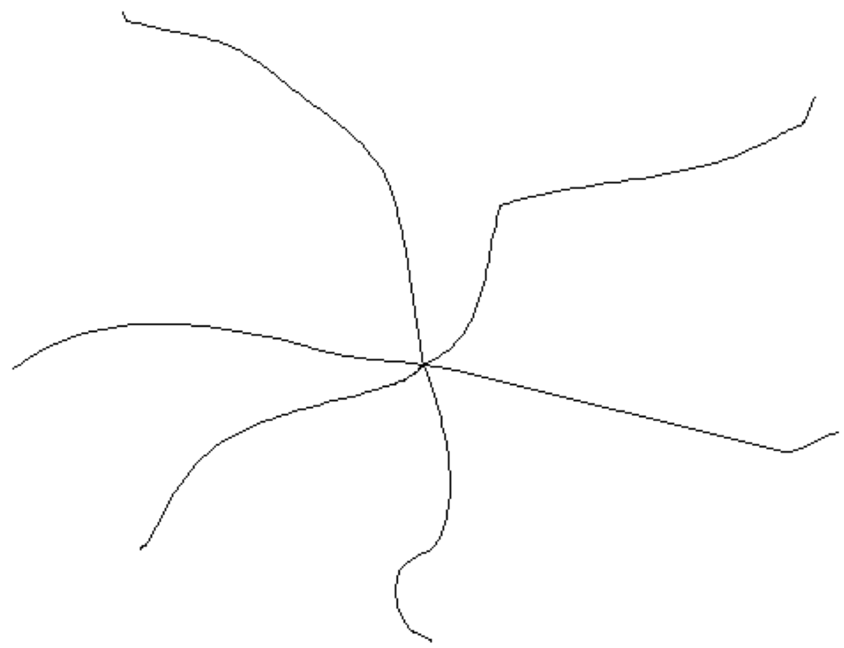
The branching increases the volume and thus reduces the density of the polymer.

Other Linear Polymers

- Proteins are linear polymers that consist of all levo-isomers of amino acids.
- In contrast, the building blocks of starch and cellulose are d-glucose and are joined by both condensation through both alpha and beta acetal groups.

Star Polymers

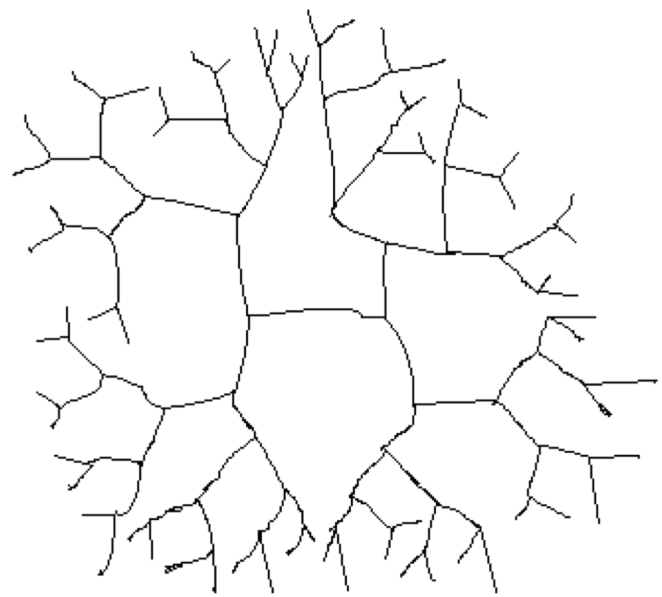
- Sometimes the ends of several polymer chains are joined together at a common center.
- Polymers like this are called *star polymers*.
- They're often used as additives or as coating materials.



a star polymer

Dendrimer

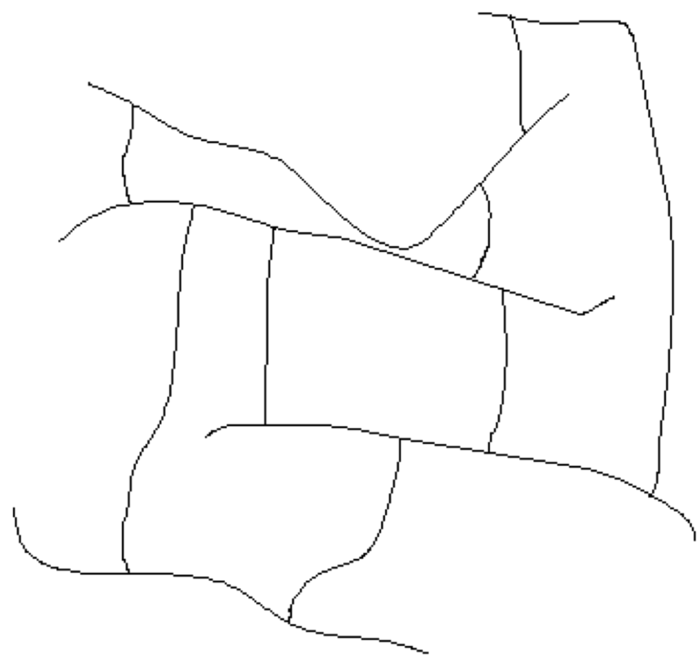
- Sometimes there is no backbone chain at all.
- Sometimes a polymer is built in such a way that branches just keep growing out of branches and more branches grow out of those branches.
- These are called *dendrimers*, from the ancient Greek word for "tree".



a dendrimer

Cross-linked Polymers

- Sometimes, *both* ends of the branch chains are attached to the backbone chains of separate polymer molecules.
- If enough branch chains are attached to two polymer molecules, it can happen that *all* of the polymer backbone chains in a sample will be attached to each other in a giant 3-D network.
- This is what happens in certain hydrogels, polyelectrolytes, rubber, silicone and certain polyurethanes.



a crosslinked polymer

Types of Polymers

- Thermosets
- Thermoplastics

Thermosets and Thermoplastics — Classification based on Processing

- Elastomers – Classification based on mechanical properties
- Hydrogels- Classification based on chemical properties
- Polyelectrolytes-Classification based on chemical properties
- Natural-Classification based on origin
- Biodegradable-Classification based on biostability

Learning Resources

www.msm,cam.ac.uk/

University of Cambridge

Department of Materials Science and Metallurgy

Teaching: DoITPoMS Project

Library of Teaching and Learning Packages for Materials Science

www.msm.cam.ac.uk/doitpoms/tlplib/index.php

THE GLASS TRANSITION IN POLYMERS **(required reading)**