Plastics

Polymer structures

UNIVERSITY OF LISBON
INTERDISCIPLINARY STUDIES
ON SUSTAINABLE ENVIRONMENT AND SEAS

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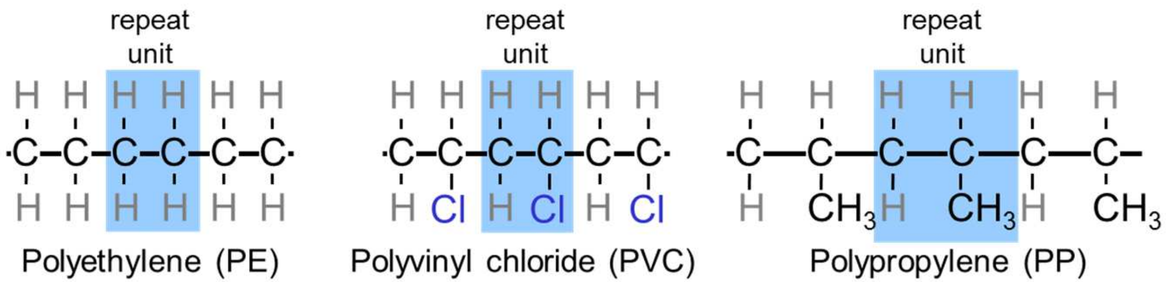
Co-funded by the Erasmus+ Programme of the European Union

Polymer structures

What is a polymer?

Poly mer

many repeat unit

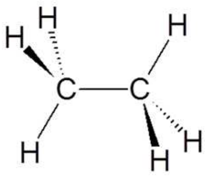


Adapted from Fig. 14.2, *Callister 7e.*

Polymer Composition

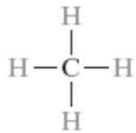
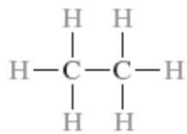
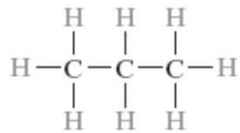
Most polymers are hydrocarbons
- i.e. made up of H and C

- Saturated hydrocarbons
  - Each carbon bonded to four other atoms



C_nH_{2n+2}

Table 14.1 Compositions and Molecular Structures for Some of the Paraffin Compounds: C_nH_{2n+2}

Name	*Composition*	*Structure*	*Boiling Point (°C)*
Methane	CH_4		−164
Ethane	C_2H_6		−88.6
Propane	C_3H_8		−42.1
Butane	C_4H_{10}		−0.5
Pentane	C_5H_{12}		36.1
Hexane	C_6H_{14}		69.0

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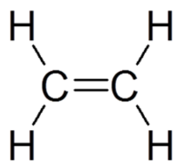
Unsaturated Hydrocarbons

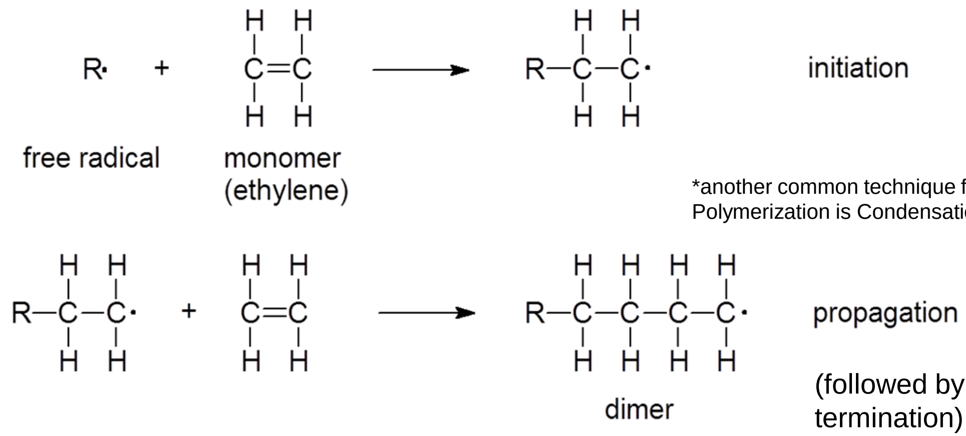
- Double & triple bonds relatively reactive – can form new bonds
  - Double bond – ethylene or ethene - C_nH_{2n}



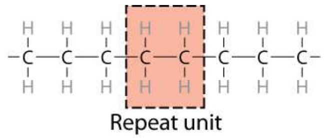
    - 4-bonds, but only 3 atoms bound to C's
  - Triple bond – acetylene or ethyne - C_nH_{2n-2}

$$H-C\equiv C-H$$

Addition Polymerization*



*another common technique for Polymerization is Condensation



polyethylene

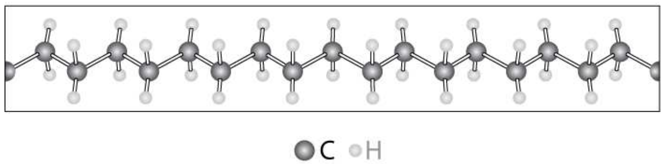


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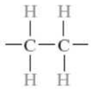
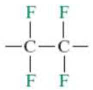
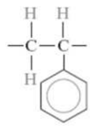
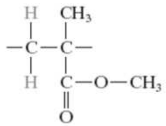
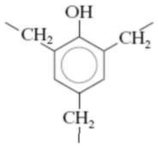
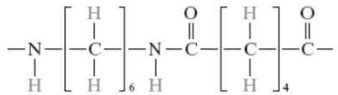
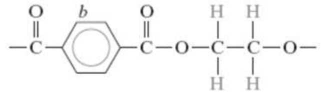
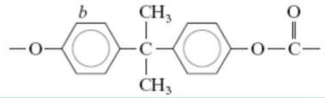
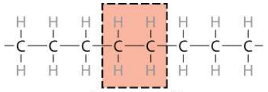
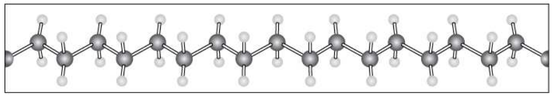
Table 14.3 A Listing of Repeat Units for 10 of the More Common Polymeric Materials

Polymer	*Repeat Unit*
Polyethylene (PE)	
Poly(vinyl chloride) (PVC)	
Polytetrafluoroethylene (PTFE)	
Polypropylene (PP)	
Polystyrene (PS)	
Poly(methyl methacrylate) (PMMA)	
Phenol-formaldehyde (Bakelite)	
Poly(hexamethylene adipamide) (nylon 6,6)	
Poly(ethylene terephthalate) (PET, a polyester)	
Polycarbonate (PC)	



Repeat unit



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Common Polymers

Polymer Names

- Every polymer has three levels of names:
  - IUPAC name – based in chemical structure (e.g. – Poly p-phenylene terephthalamide)
  - Abbreviated Name (e.g. – PPTA)
  - Trade names (e.g. – Kevlar (DuPont) or Twaron (Teijin)

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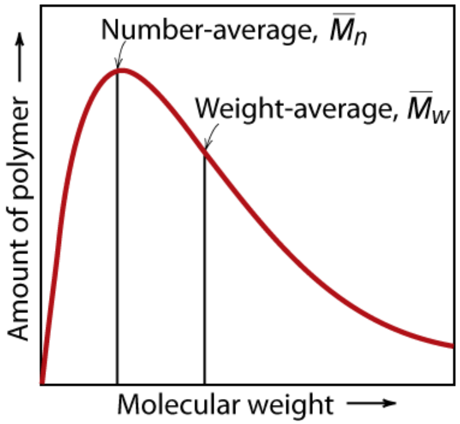
Some useful notions

- Molecular weight, M_i: Mass of a mole of chains.

Lower M higher M

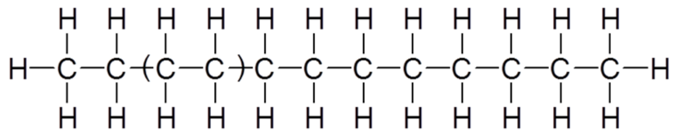


Adapted from Fig. 14.4, *Callister 7e.*

Polymer properties depend on the average molecular weight, configuration, etc.

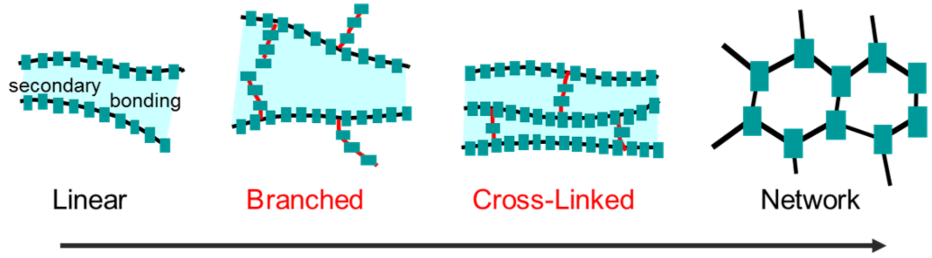
Degree of Polymerization, *n*

***n* = number of repeat units per chain**



$n_i = 6$

- Covalent chain configurations and strength:



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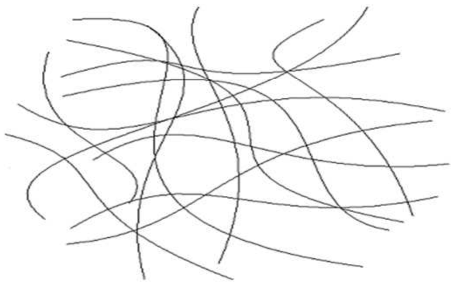
Thermoplastic Polymers

- Flows like viscous liquids when heated and does so through several reheatings

- Weak Van der Waals interactions between chains

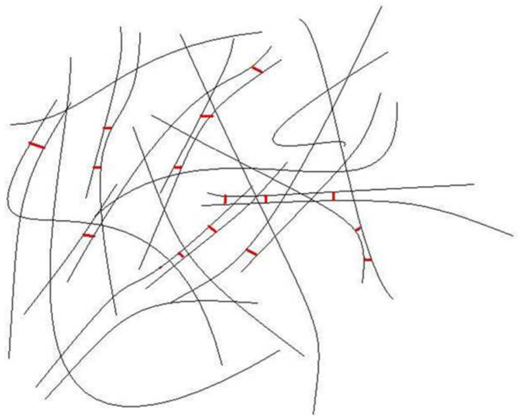


Thermoset Polymers

- Cannot be remelted or recycled

- Stronger bonding between adjacent chains

- More resistant to degradation but harder to recycle



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Polymers are the chemist's contribution to the materials world. The fact that most are derived from oil (a nonrenewable resource) and the difficulty of disposing of them at the end of their life (they don't easily degrade) has led to a view that polymers are environmental villains. There is some truth in this, but the present problems are soluble. Using oil to make polymers is a better primary use than just burning it for heat; the heat can still be recovered from the polymer at the end of its life. There are alternatives to oil; polymer feed stocks can be synthesized from agricultural products (notably starch and sugar, via methanol and ethanol). And thermoplastics—provided they are not contaminated—can be (and, to some extent, are) recycled.

Thermoplastics soften when heated and harden again to their original state when cooled. This allows them to be molded to complex shapes. Some are crystalline, some amorphous, some a mixture of both. Most accept coloring agents and fillers, and many can be blended to give a wide range of physical, visual, and tactile effects. Their sensitivity to sunlight is decreased by adding UV filters, and their flammability is decreased by adding flame retardants. The properties of thermoplastics can be controlled by chain length (measured by molecular weight), by degree of crystallinity, and by blending and plasticizing. As the molecular weight increases, the resin becomes stiffer, tougher, and more resistant to chemicals, but it is more difficult to mold. Crystalline polymers tend to have better chemical resistance, greater stability at high temperature, and better creep resistance than those that are amorphous. For transparency, the polymer must be amorphous; partial crystallinity gives translucency.

Thermosets. If you are a do-it-yourself type, you have Araldite in your toolbox—two tubes, one a sticky resin, the other an even stickier hardener. Mix and warm them and they react to give a stiff, strong, durable polymer, stuck to whatever it is put on. Araldite is an epoxy resin. It typifies *thermosets*: resins that polymerize when catalyzed and heated; when reheated they do not melt, they degrade. Polyurethane thermosets are produced in the highest volume; polyesters come second; phenolics (Bakelite), epoxies, and silicones follow, and, not surprisingly, the cost rises in the same order. Once shaped, thermosets cannot be reshaped. They cannot easily be recycled.

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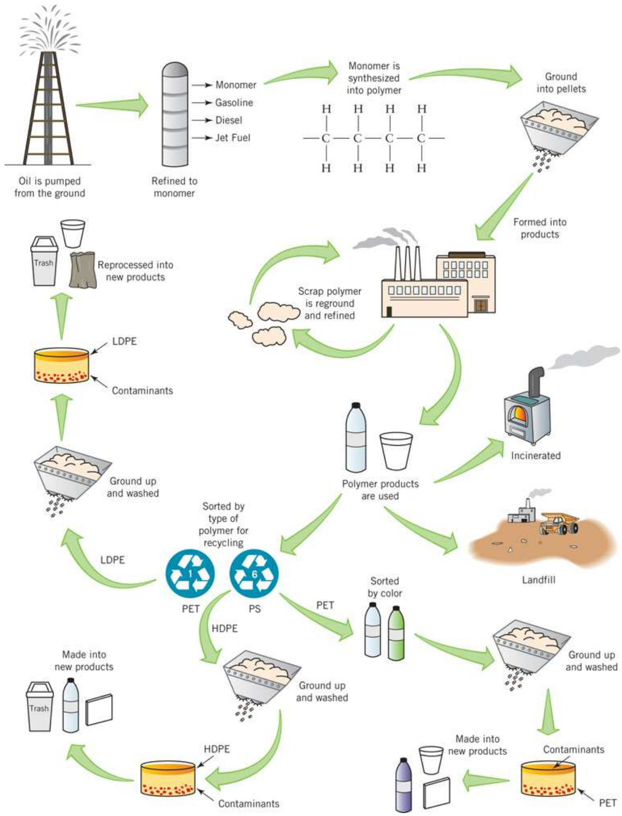
Polymeric Lifecycle



Recycling Challenges

- Need to sort by hand
- Collection and gathering issues
- Presence of coloring agents, plasticizers, and other additives

Composites

Many of the issues that were discussed for Polymers apply to Composites as well, namely to PMCs, Polymer Matrix Composites

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In summary

- Polymer composition, synthesis, naming
- Some basic notions which affect behaviour: degree of polymerization, molecular weight
- Thermoplastic, thermoset, recycling

References / Source Material

Materials Science and Engineering: an Introduction: William D. Callister Jr., David G. Rethwisch, John Wiley & Sons, New York

Essentials of Modern Materials Science and Engineering, James A. Newell, John Wiley & Sons, New York.

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