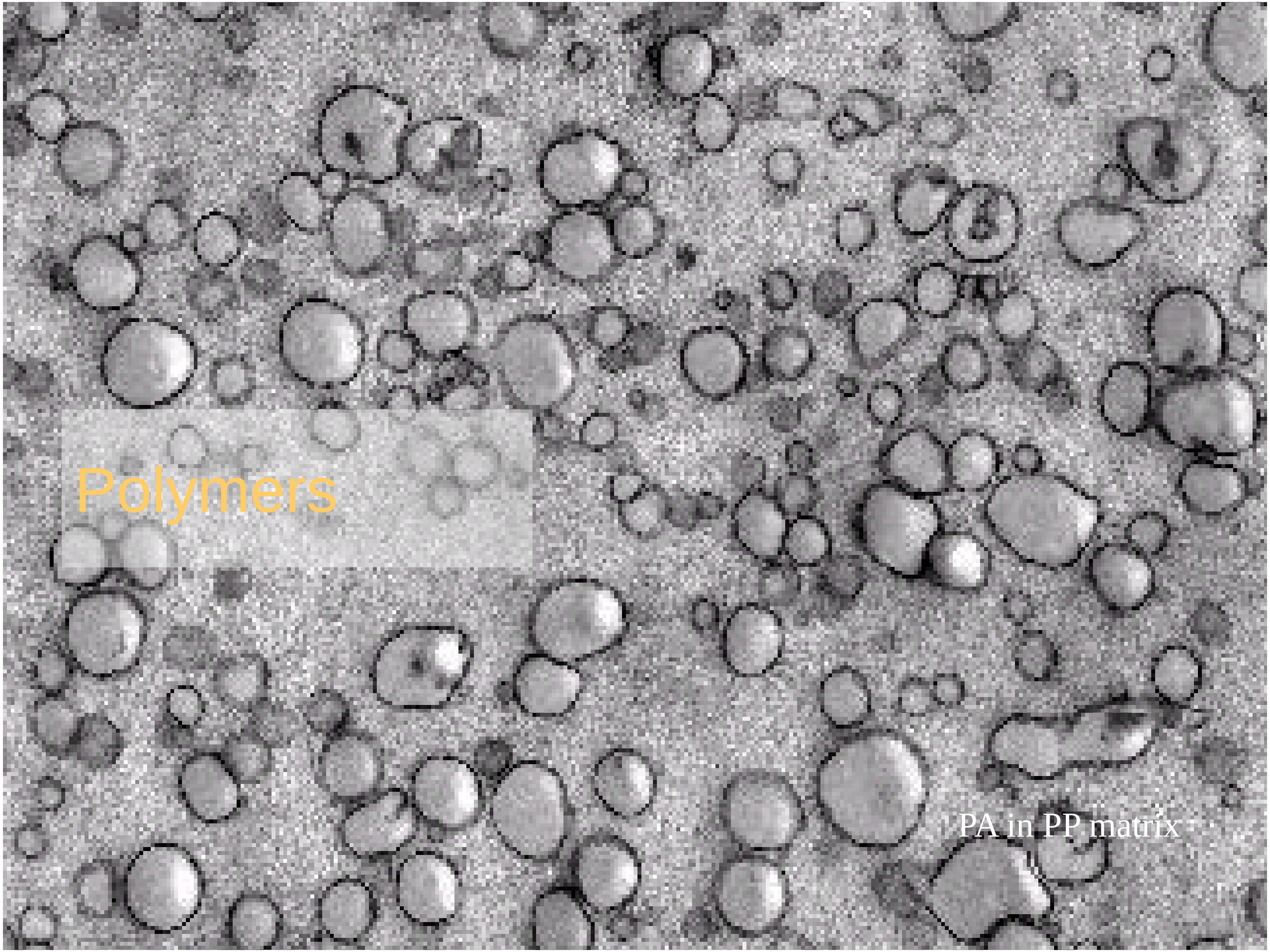
Polymers



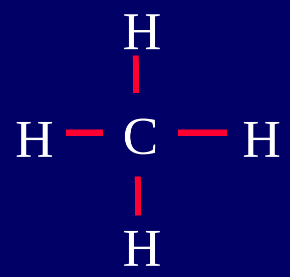
From Natural to Synthetic Polymers

natural: wood, rubber, cotton, wool, leather, silk etc.

↓

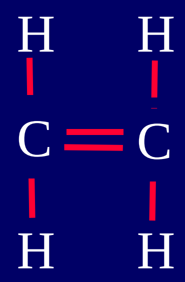
synthesis of small organic molecules, e.g. hydrocarbons

CH_4 (methane)



saturated

C_2H_4 (ethylene)

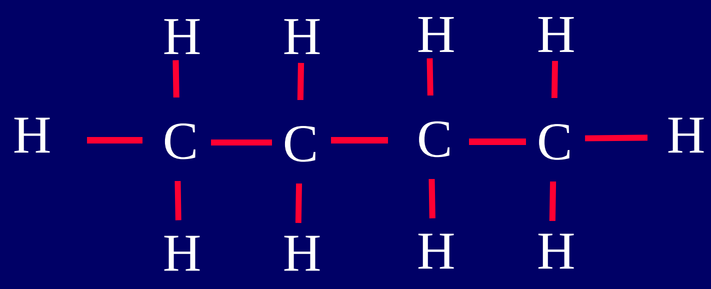


unsaturated
(double, triple bonds)

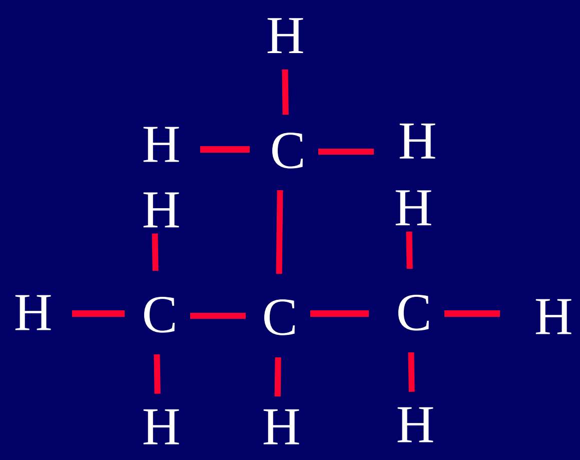
Paraffin Family - Isomerism

C_nH_{2n+2}

e.g. C_4H_{10} (butane)

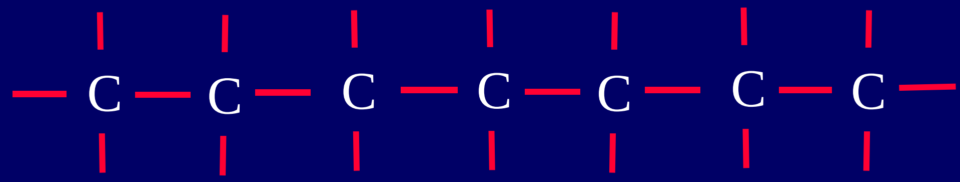


C_4H_{10} (isobutane)



Polymer Macromolecules - Chains

C atoms chain backbone

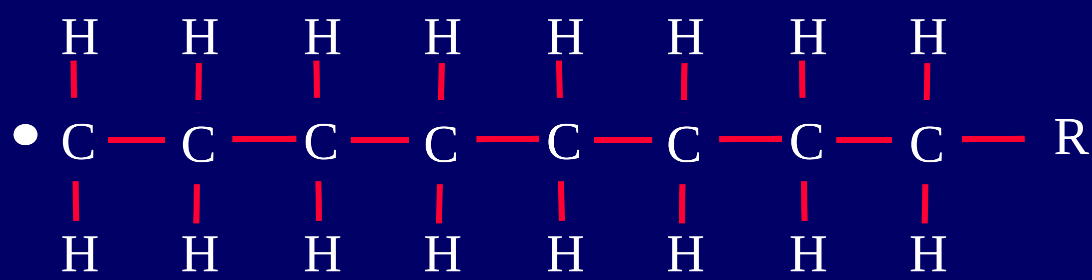


mer: repeated units

mono*mer*s => poly*mer*s

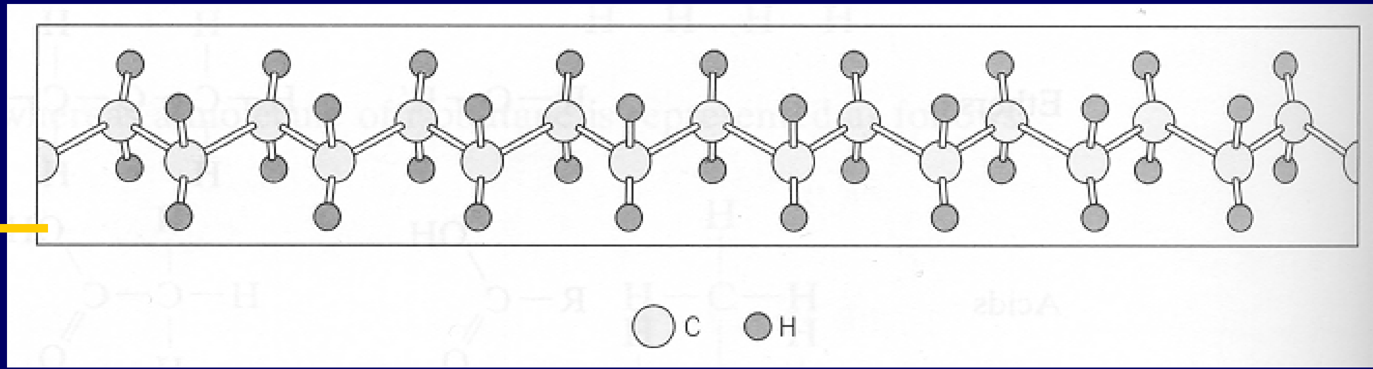
e.g. ethylene C_2H_4
monomer

polymer



Polymerization and Processing

3D structure

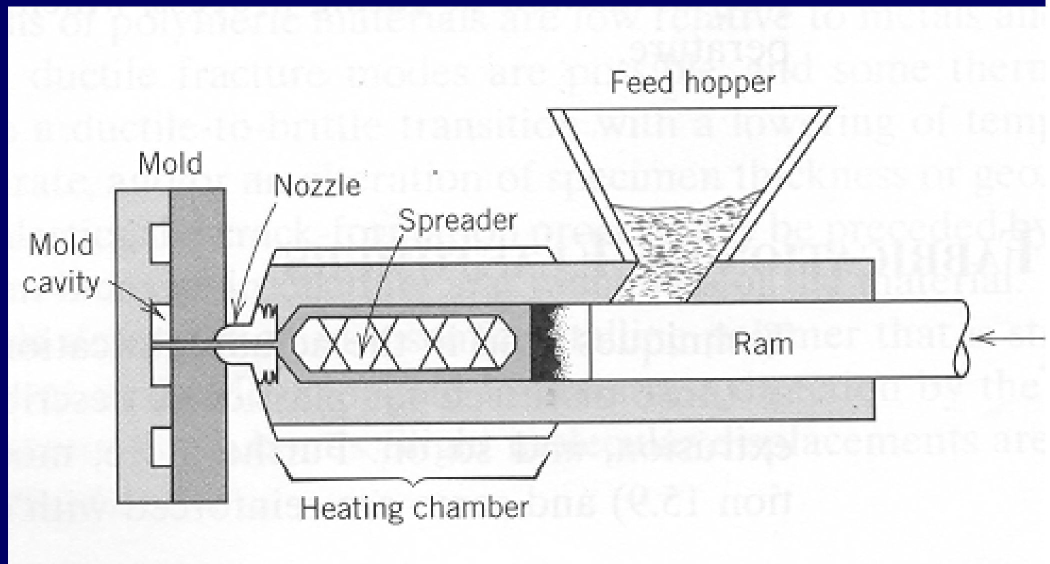


pressure
temperature

extrusion
injection molding (very fast)

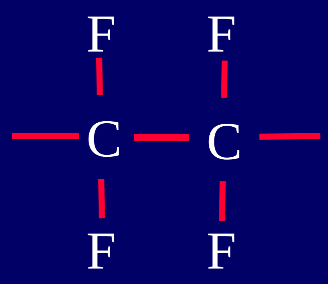
monomers
active initiator
additives (filler,colorants..)

chain growth
termination (R-C-C-R)

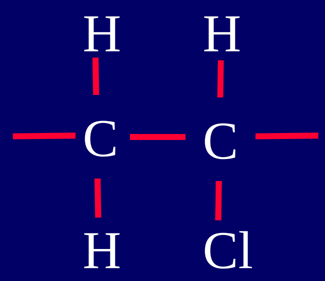


Monomers => Polymers

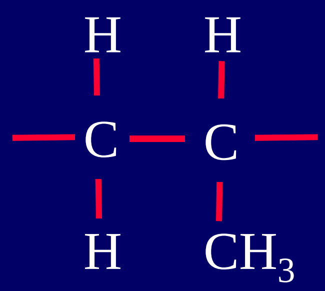
polytretrafluorethylene
PTFE



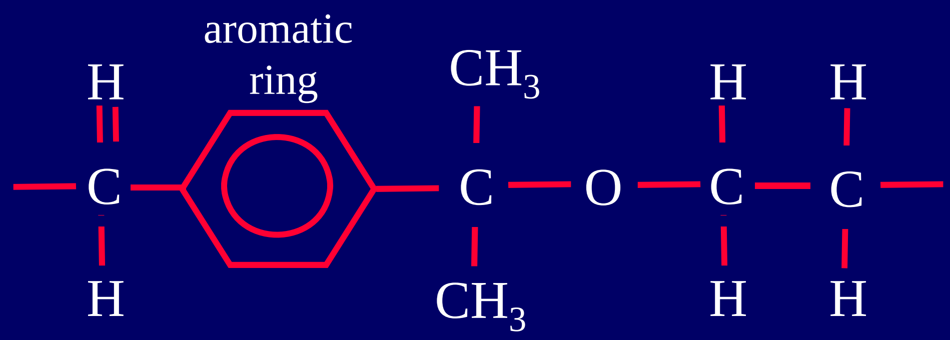
polyvinylchloride
PVC



polypropylene
PP



polyethylene terephtalate
PET



Characteristics: Molecular Weight

chain length ⇔ molecular weight *M*

100g/mole – short chains: liquid state
1000g/mole – waxy solids
>10000g/mole – *high polymers*: solids

degree of polymerization *n*

(average number of mer units in chain)

$$n_{n/w} = \frac{\overline{M}_{n/w}}{\overline{m}}$$

mer molecule weight (homopolymer⇔copolymer)

Characteristics: Molecular Weight

polymerization:
polymer chains of different length – molecular weight

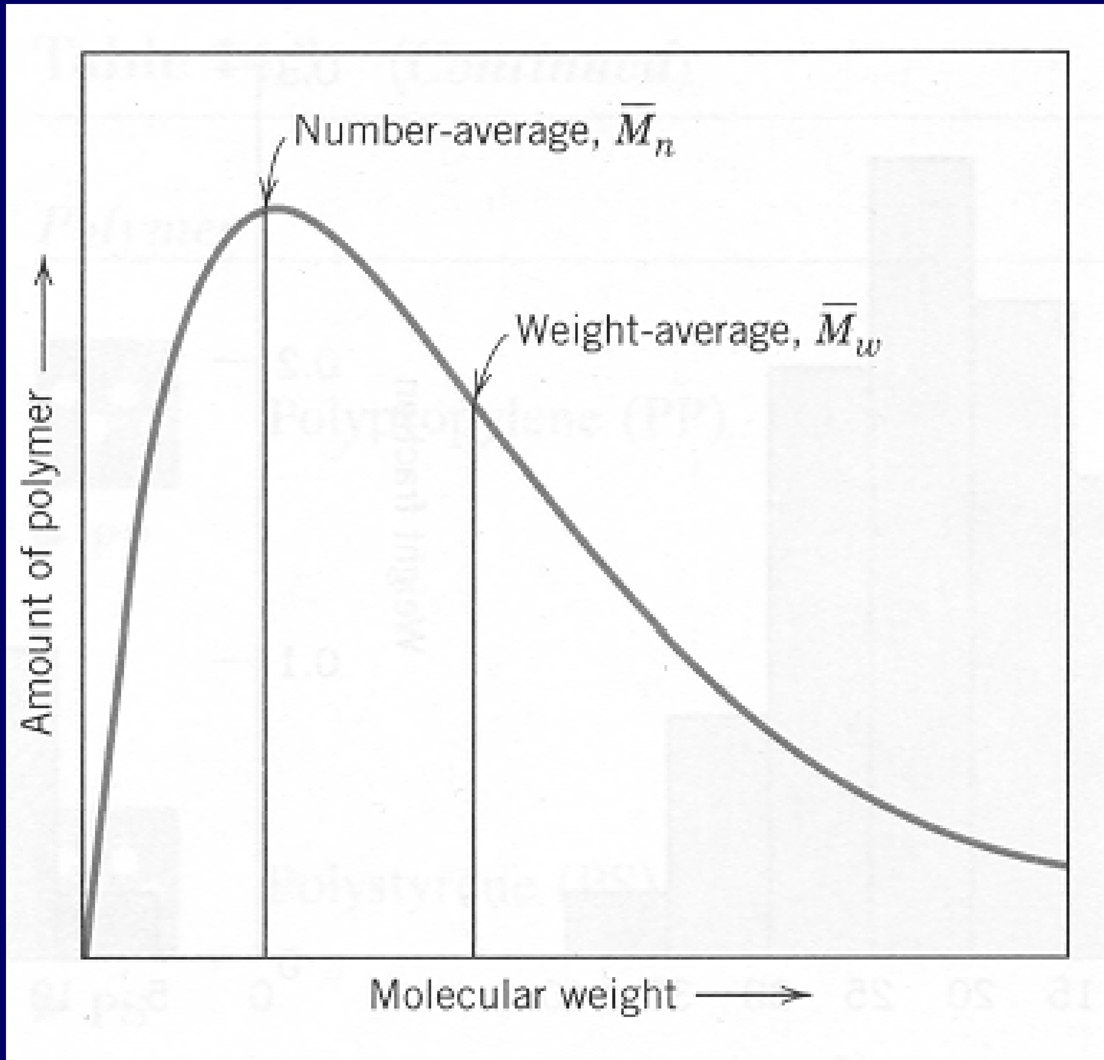
number average molecular weight: $$\overline{M}_n = \sum_i x_i M_i$$

number fraction
(how many polymers of M_i)

weight average molecular weight: $$\overline{M}_w = \sum_i w_i M_i$$

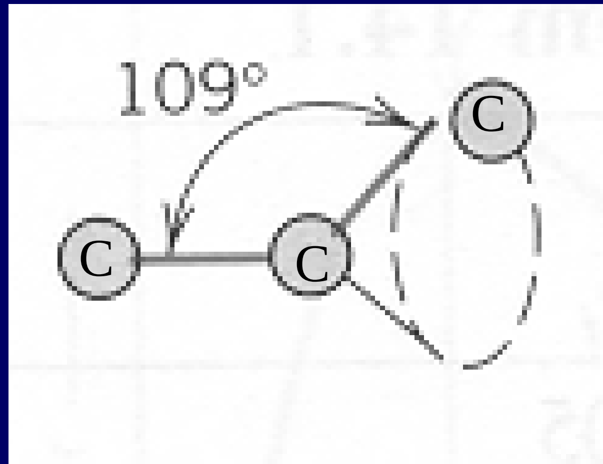
weight fraction
(weight of polymers of M_i)

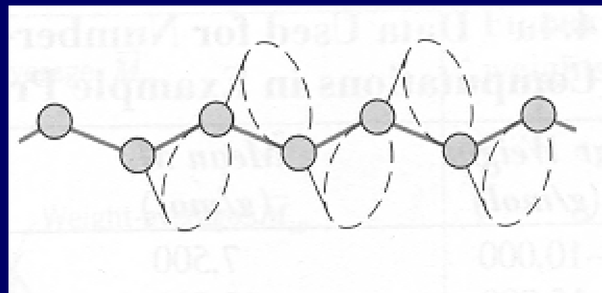
Average Molecular Weight

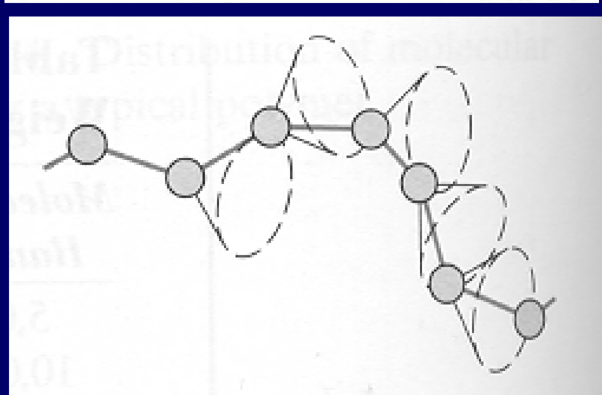


Characteristics: Shape

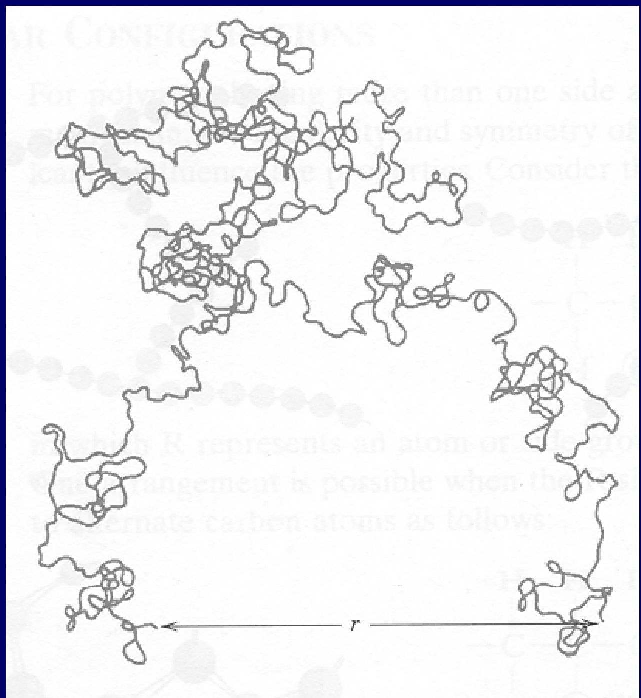
C backbone => 109° angles:





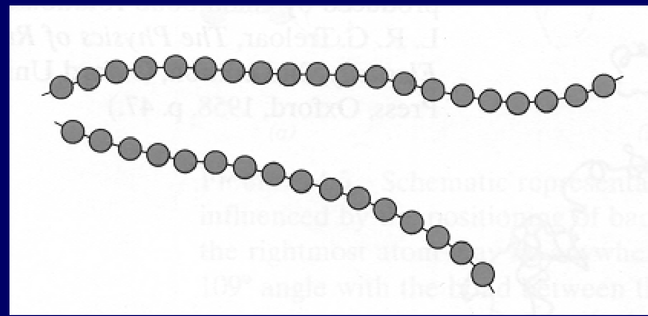


intertwining/coils

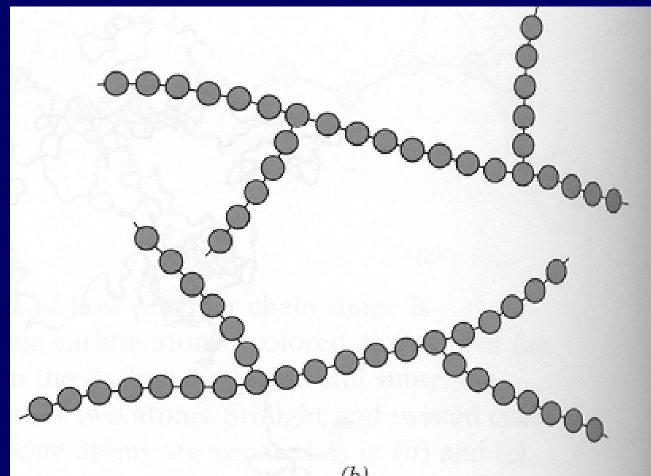


Characteristics: Structure

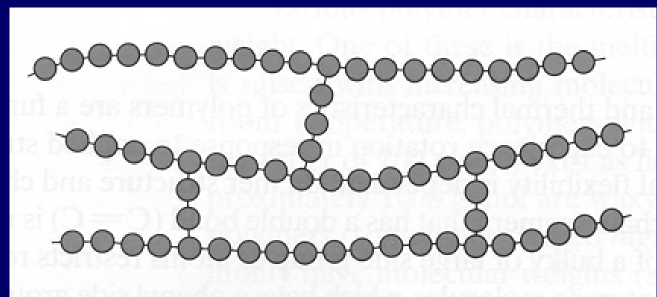
linear polymers
(like spaghettis, e.g. PE,PVC,PS)



branched polymers
(side reactions)

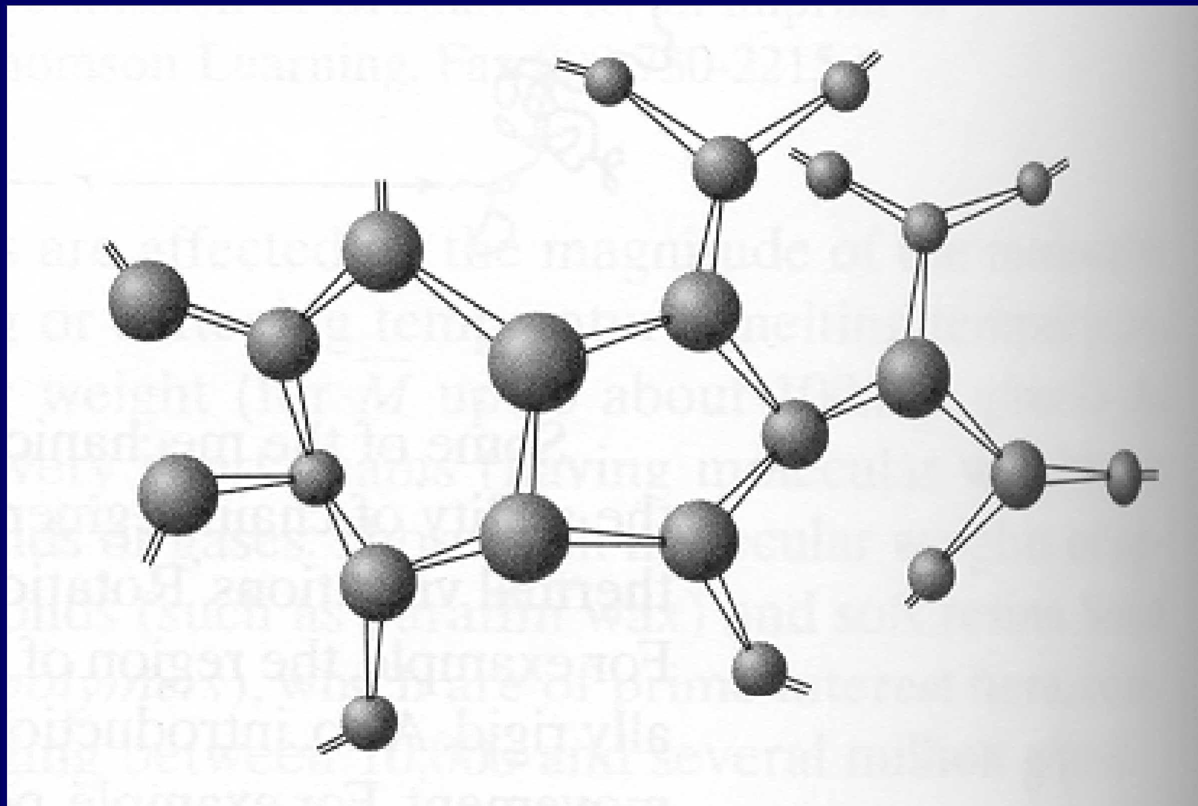


crosslinked polymers
(by addtl. molecules, e.g. epoxies)

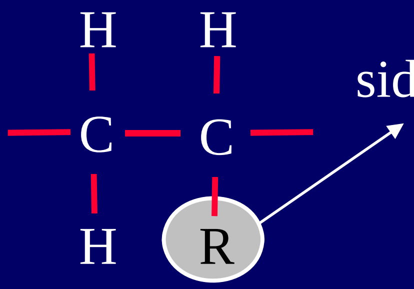


Characteristics: Structure

network polymers
(trifunctional mer units, e.g. epoxies)



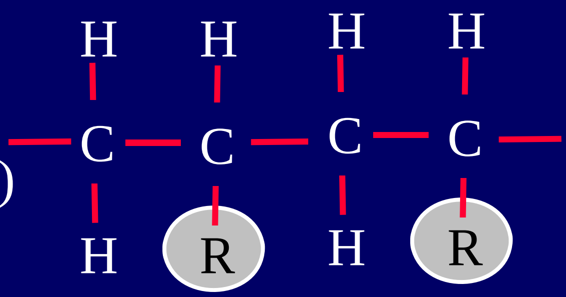
Molecular Configurations



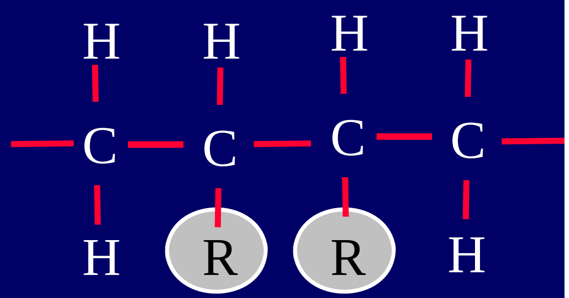
side groups (e.g. Cl, CH_3) => regularity – symmetry=> properties

stereoisomerism
(isotactic, syndiotactic, atactic)

head to tail

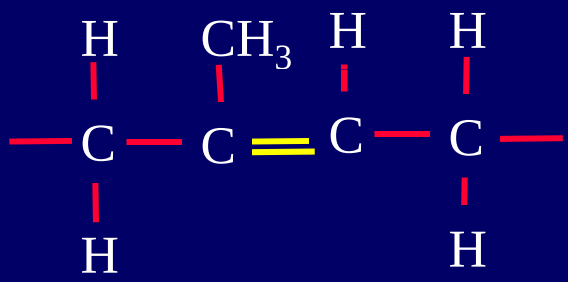


head to head

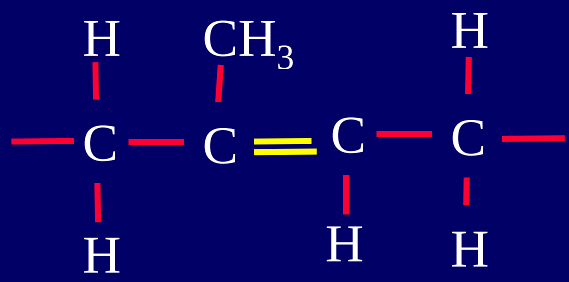


geometrical isomerism
e.g. polyisoprene
cis: natural rubber

cis



trans



Thermoplastic - Thermosetting

when heating

Thermoplastic	Thermosetting
soften liquefy (diminishing secondary bonding forces => fabrication)	crosslinked polymers degradation

- PTFE (e.g. teflon, chemically inert, low friction, T<260°C)
- PA (e.g. nylon)
- PE/PP (bottles, toys, containers)
- Acrylics (PMMA polymethyl methacrylate, transparent)
- Vinyls (floor covering, records)

- epoxies (adhesives)
- polyester (fiberglas, helmets, auto body comp.)

Improving Properties

homopolymers => copolymers

e.g. synthetic rubbers
automobile tires SBR
gasoline hoses NBR

defects
-impurities
-vacancies
mostly at chain ends

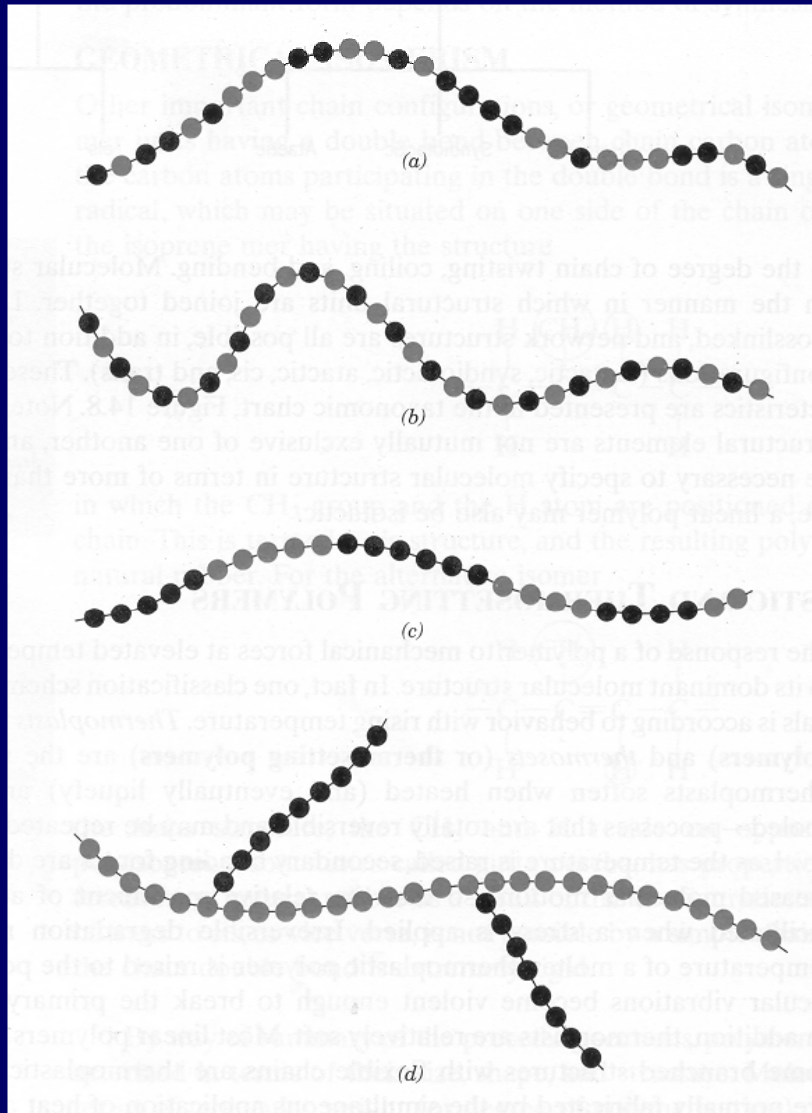
diffusion properties
=> interstitial mechanism
e.g. bottles, membranes

random

alternating

block

graft

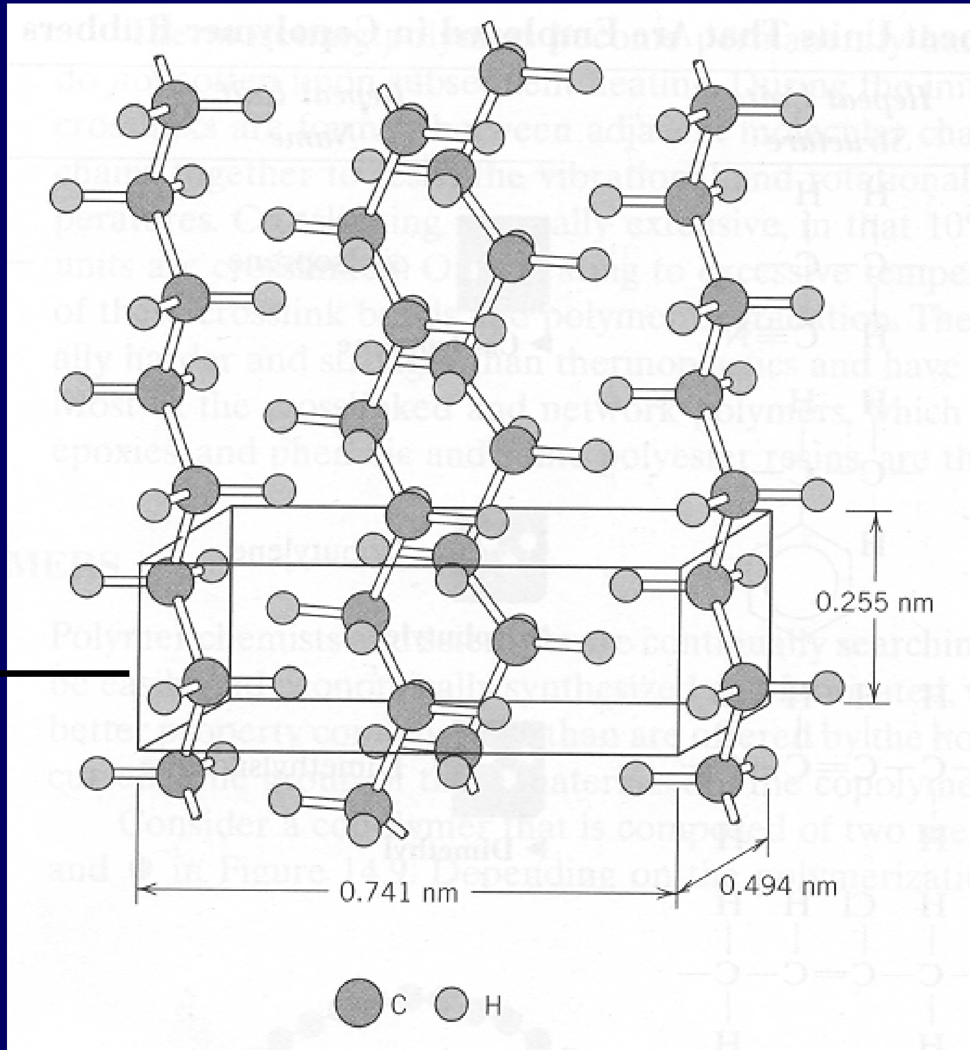


Crystalline Polymers

packing of molecular chains
=> usually not complete

$$\%\text{crystallinity} = \frac{\rho_{\text{cryst}}(\rho_{\text{spec}} - \rho_{\text{amorph.}})}{\rho_{\text{spec}}(\rho_{\text{cryst}} - \rho_{\text{amorph.}})} \cdot 100$$

orthorombic PE
unit cell



depends on
-cooling rate (slow)
-chain configuration (simple)

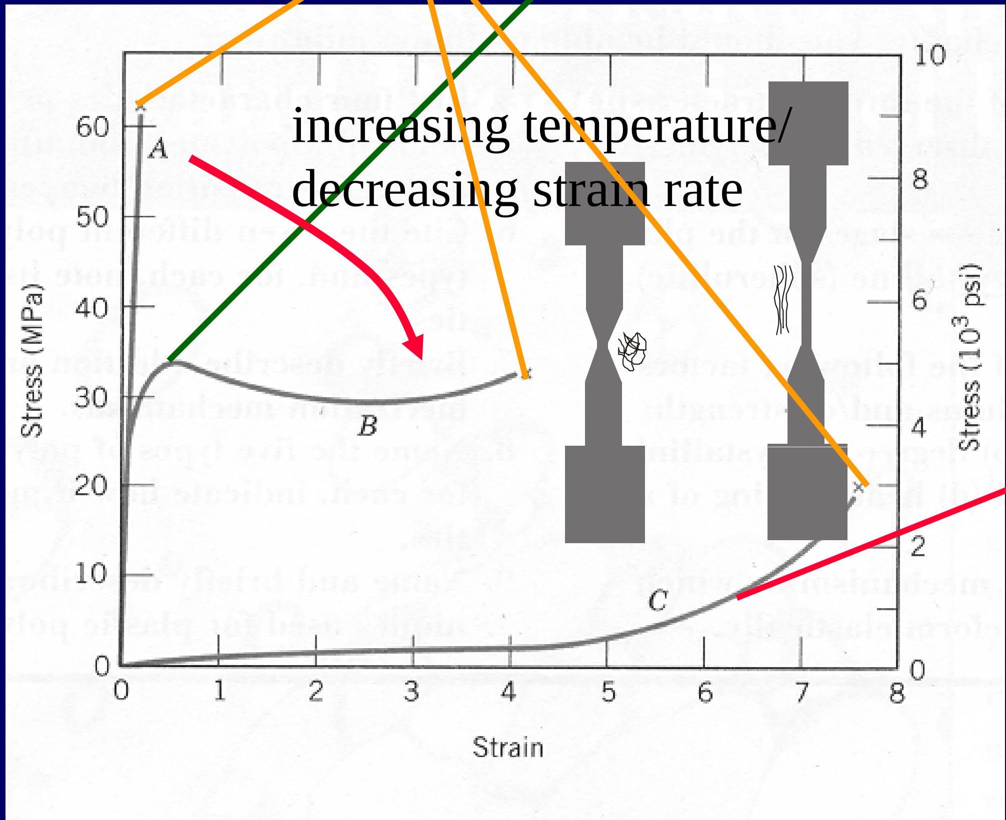
Mechanical Properties of Polymers

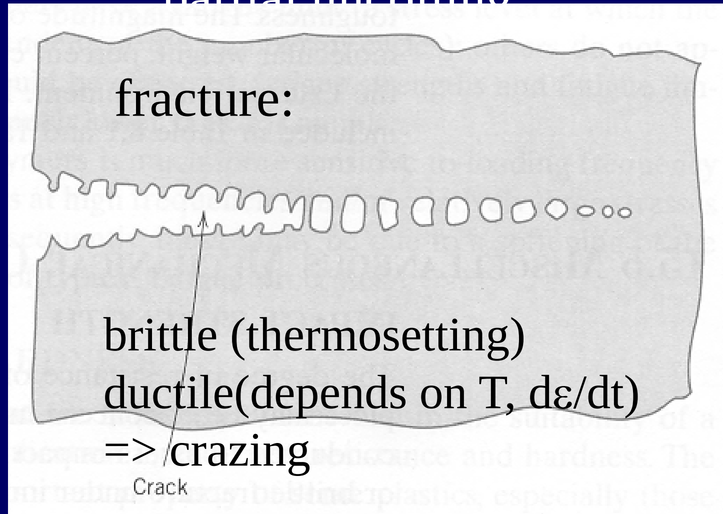
(U)TS – max. 100MPa, E=7...4000MPa

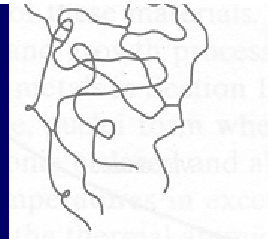
σ_y (necking – chain ordering)

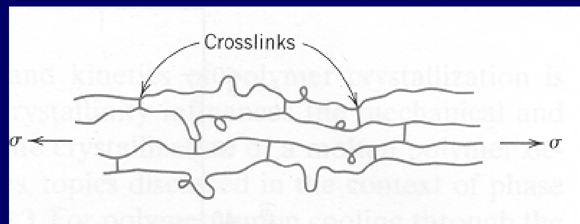
elastomers

partial uncoiling



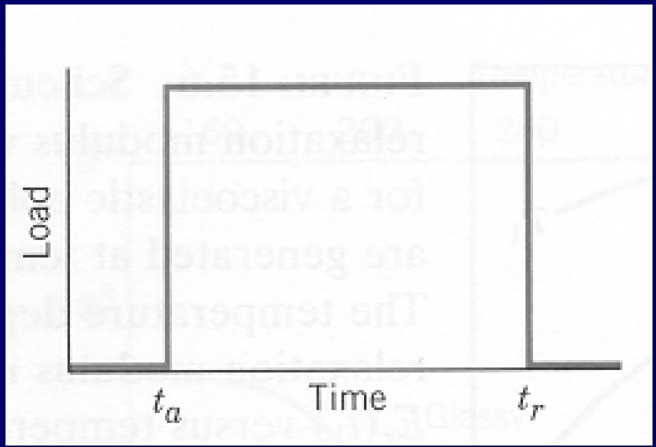


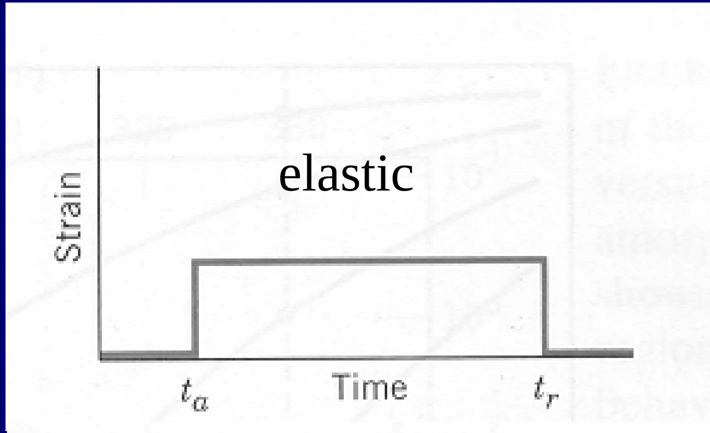


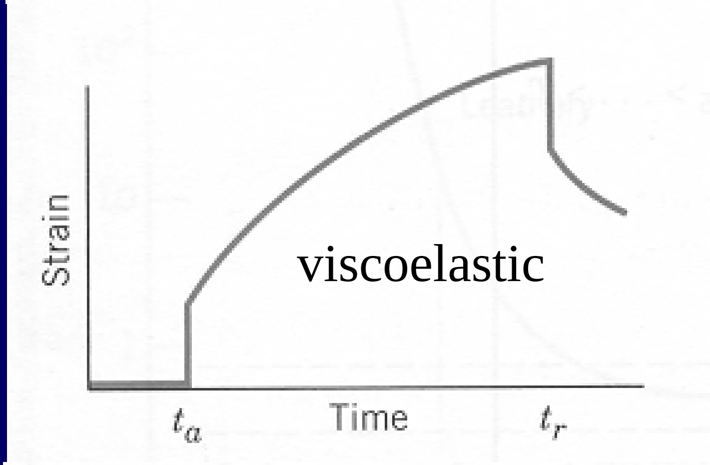


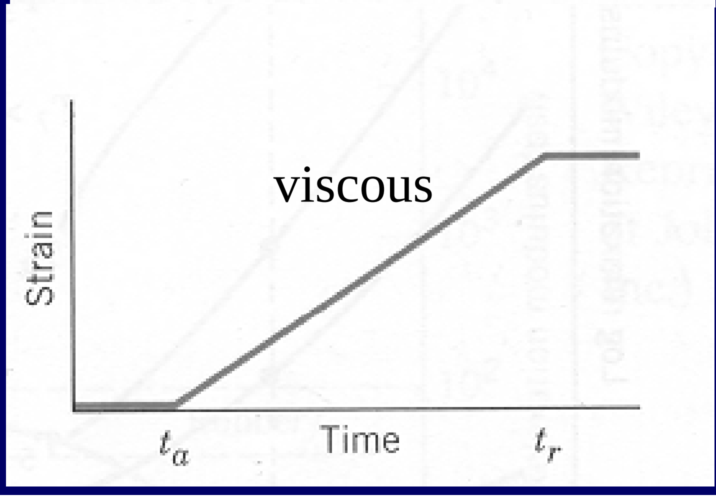
Mechanical Properties of Polymers

mechanical load step









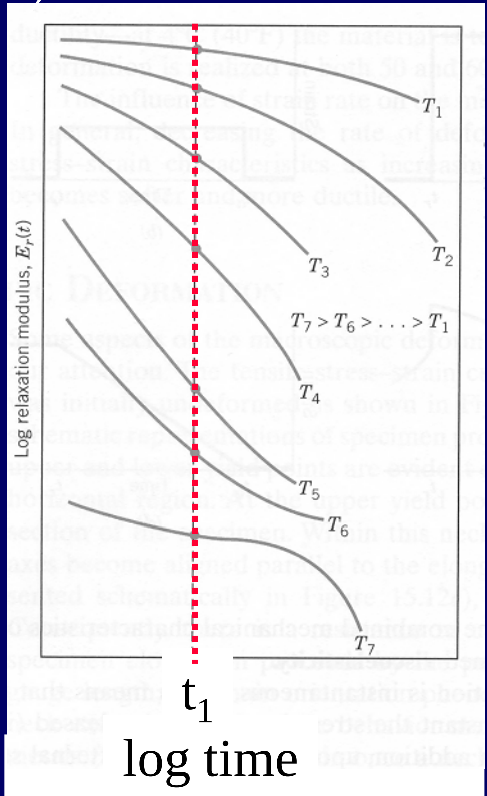
depends on
-strain rate
-temperature
-structure

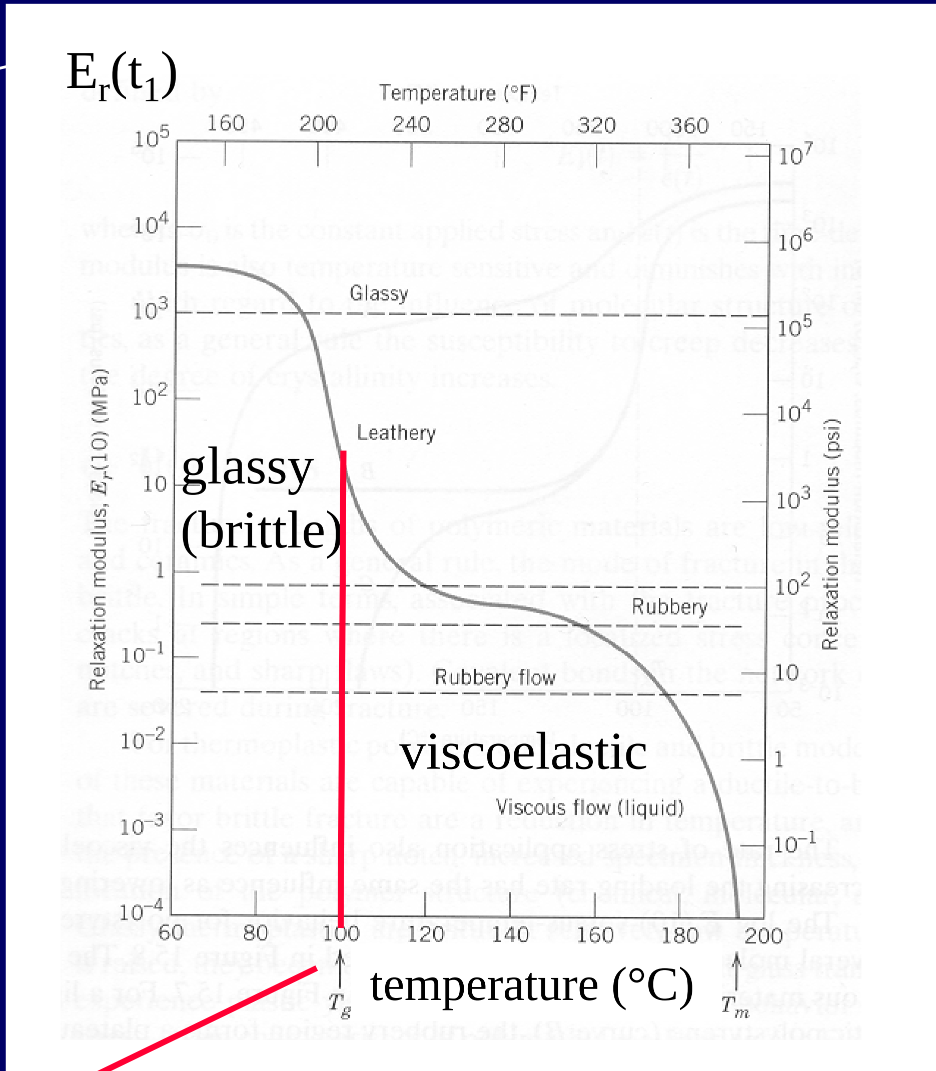
Mechanical Properties of Polymers

load relaxation (ε=const)

relaxation modulus

$E_r(t)=\sigma(t)/\varepsilon_0$





glass transition temperature