Chapter 14 & Chapter 15: Polymer Structures and Properties

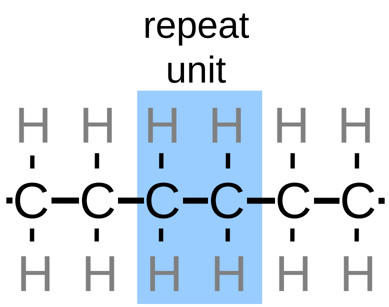
ISSUES TO ADDRESS...

- What are the general structural and chemical characteristics of polymer molecules?
- How is the crystalline state in polymers different from that in metals and ceramics ?
- What are the tensile properties of polymers and how are they affected by basic microstructural features?

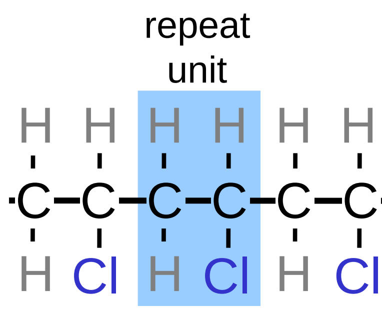
What is a Polymer?

Poly — mer

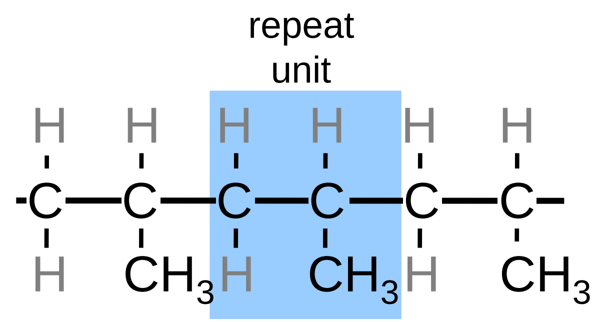
many — repeat unit



Polyethylene (PE)



Poly(vinyl chloride) (PVC)



Polypropylene (PP)

Adapted from Fig. 14.2, *Callister & Rethwisch 8e.*

Ancient Polymers

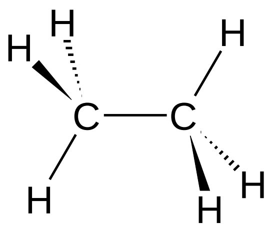
- Originally natural polymers were used
  - Wood
  - Cotton
  - Leather
  - Rubber
  - Wool
  - Silk

- Oldest known uses
  - Rubber balls used by Incas
  - Noah used pitch (a natural polymer) for the ark

Polymer Composition

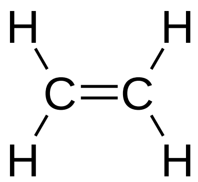
Most polymers are hydrocarbons
– i.e., made up of H and C

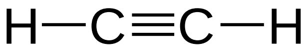
- Saturated hydrocarbons
  - Each carbon singly bonded to four other atoms
  - Example:
    - Ethane, C_2H_6



- Unsaturated hydrocarbons

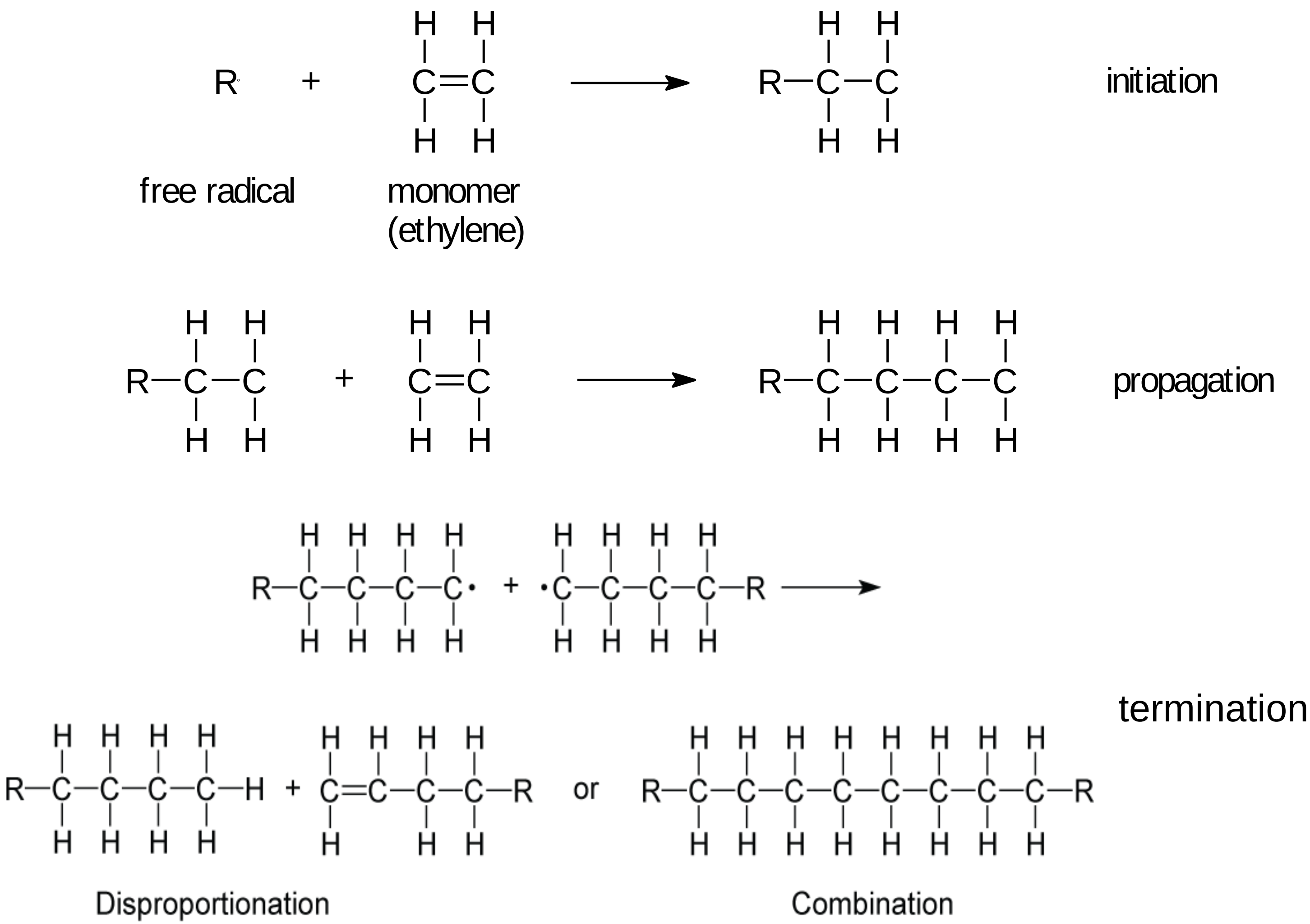
- Double & triple bonds somewhat unstable – can form new bonds
  - Double bond found in ethylene or ethene - C_2H_4
  - Triple bond found in acetylene or ethyne - C_2H_2



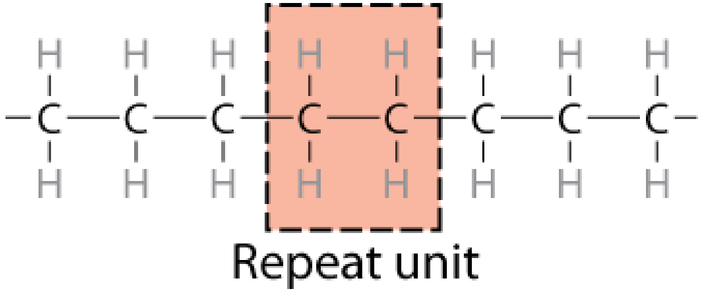


Polymerization and Polymer Chemistry

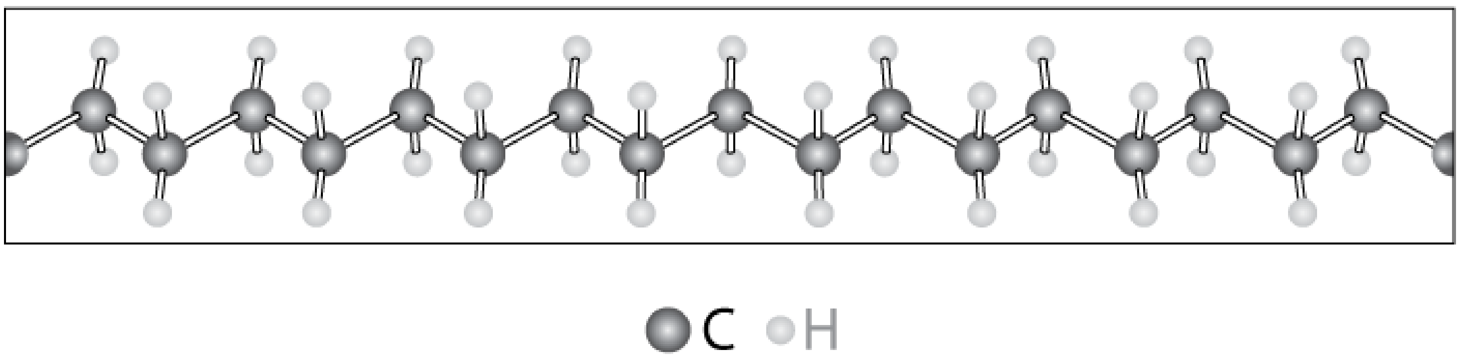
- Free radical polymerization



Chemistry and Structure of Polyethylene

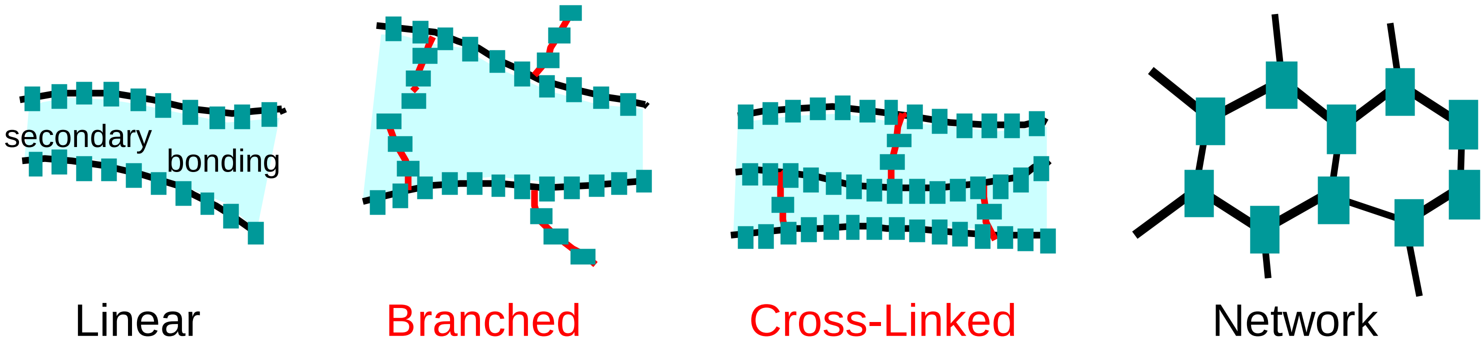


Adapted from Fig. 14.1, *Callister & Rethwisch 8e.*



Note: polyethylene is a long-chain hydrocarbon
- paraffin wax for candles is short polyethylene

Molecular Structures for Polymers

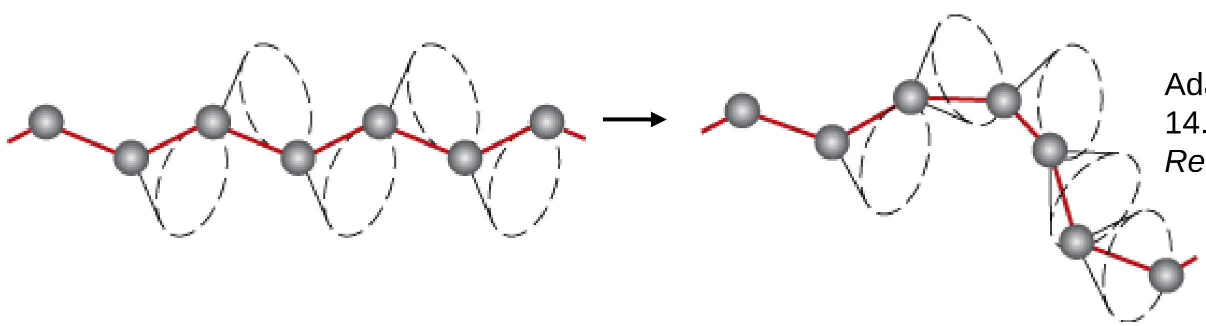


Adapted from Fig. 14.7, *Callister & Rethwisch 8e.*

Polymers – Molecular Shape

Molecular Shape (or Conformation) – chain bending and twisting are possible by rotation of carbon atoms around their chain bonds

– note: not necessary to break chain bonds to alter molecular shape



Adapted from Fig. 14.5, *Callister & Rethwisch 8e.*

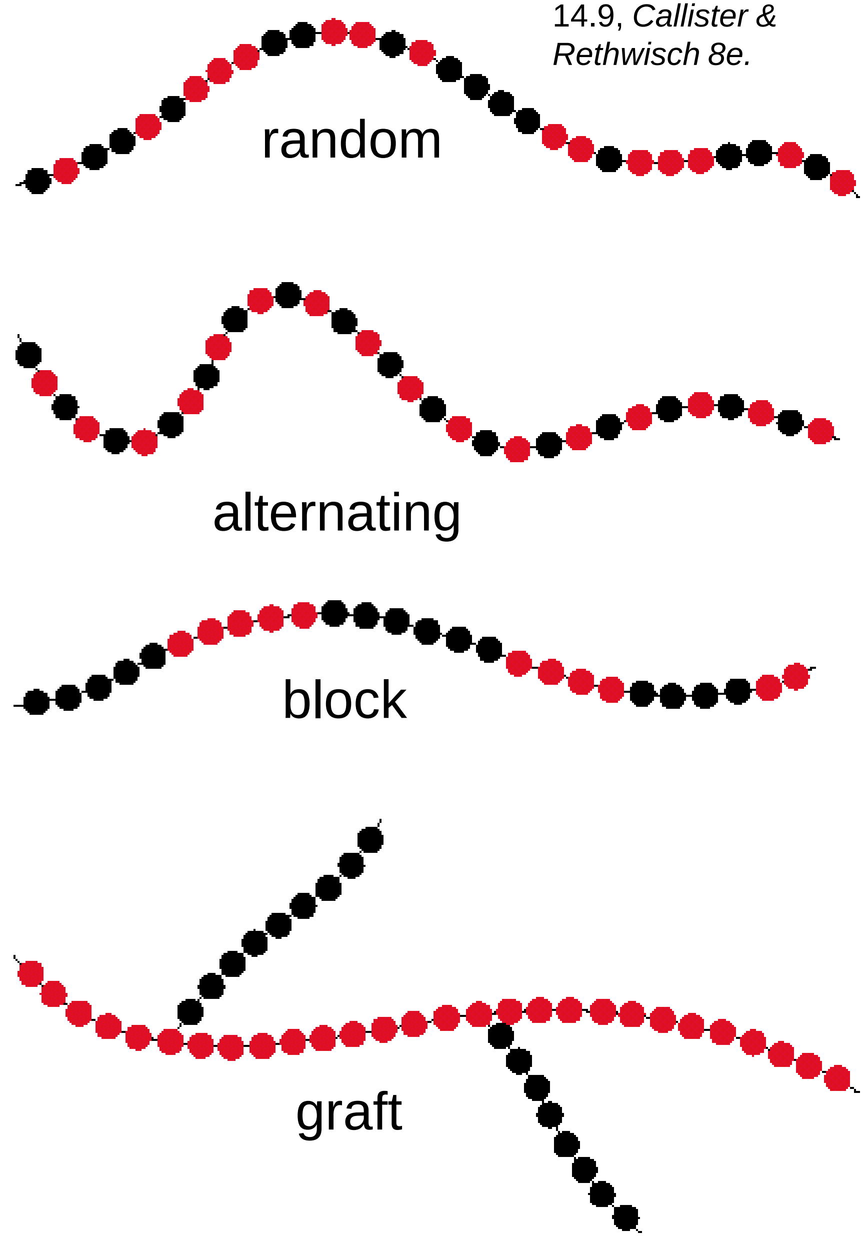
Copolymers

two or more monomers polymerized together

- random – A and B randomly positioned along chain
- alternating – A and B alternate in polymer chain
- block – large blocks of A units alternate with large blocks of B units
- graft – chains of B units grafted onto A backbone

A –   B –

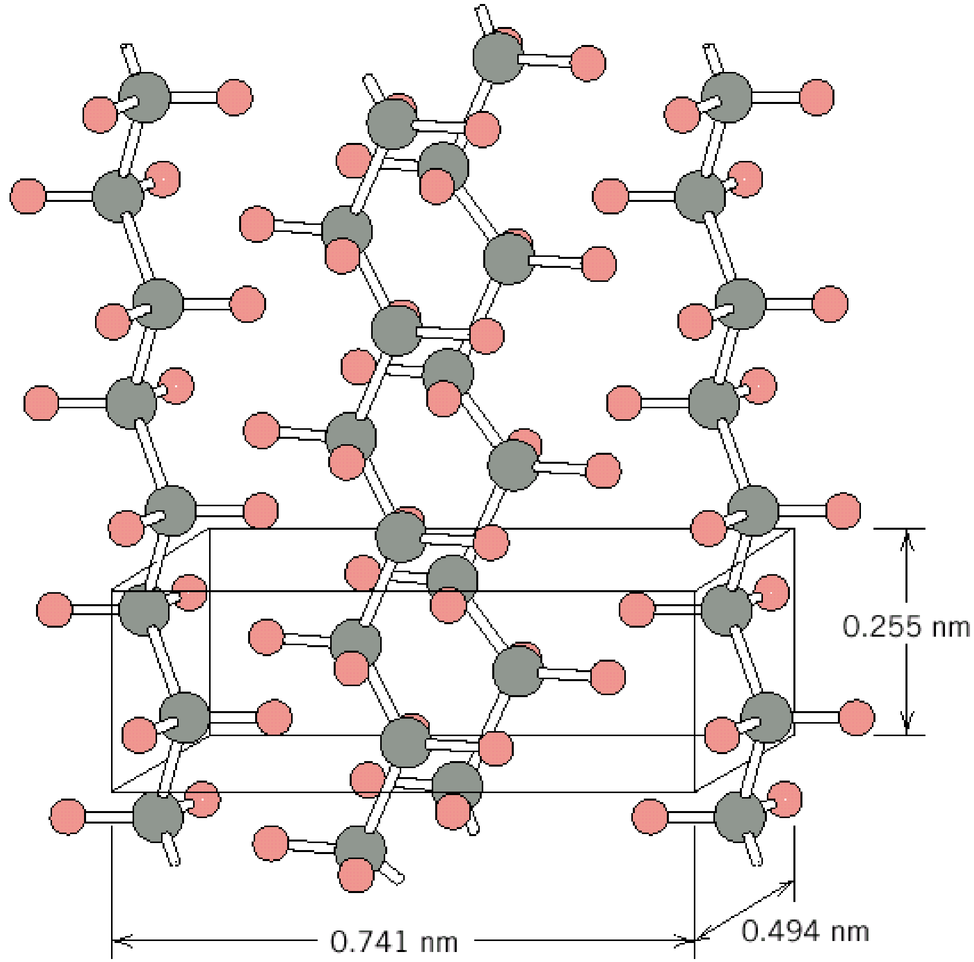
Adapted from Fig. 14.9, *Callister & Rethwisch 8e.*



Crystallinity in Polymers

Adapted from Fig. 14.10, *Callister & Rethwisch 8e.*

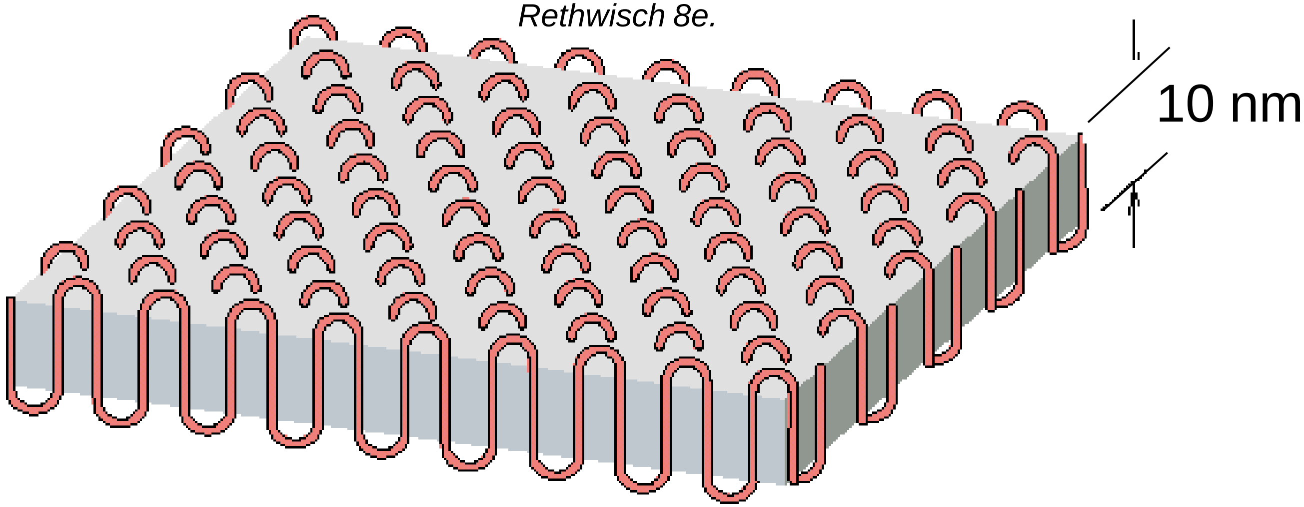
- Ordered atomic arrangements involving molecular chains
- Crystal structures in terms of unit cells
- Example shown
  - polyethylene unit cell



Polymer Crystallinity

- Crystalline regions
  - thin platelets with chain folds at faces
  - Chain folded structure

Adapted from Fig. 14.12, *Callister & Rethwisch 8e.*

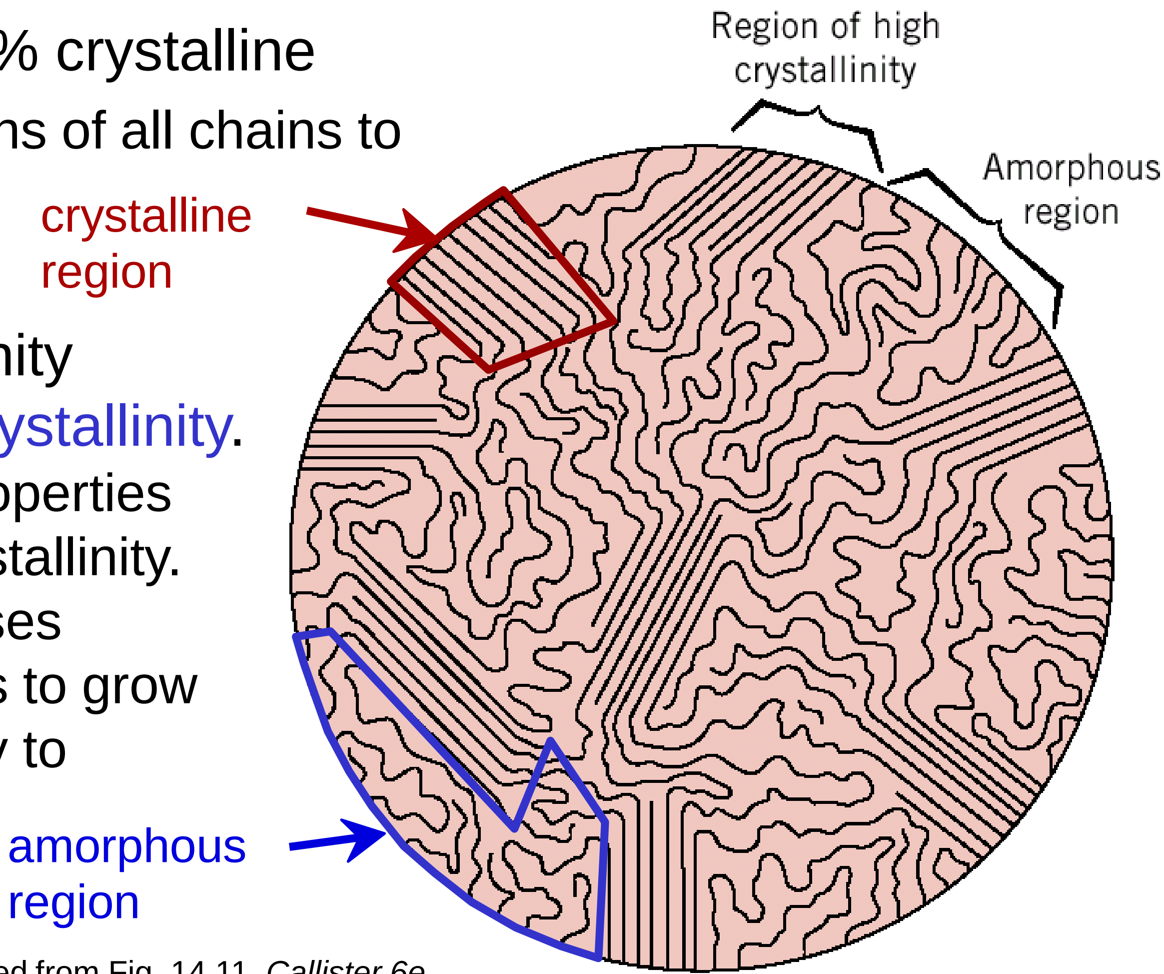


Polymer Crystallinity (cont.)

Polymers rarely 100% crystalline

- Difficult for all regions of all chains to become aligned

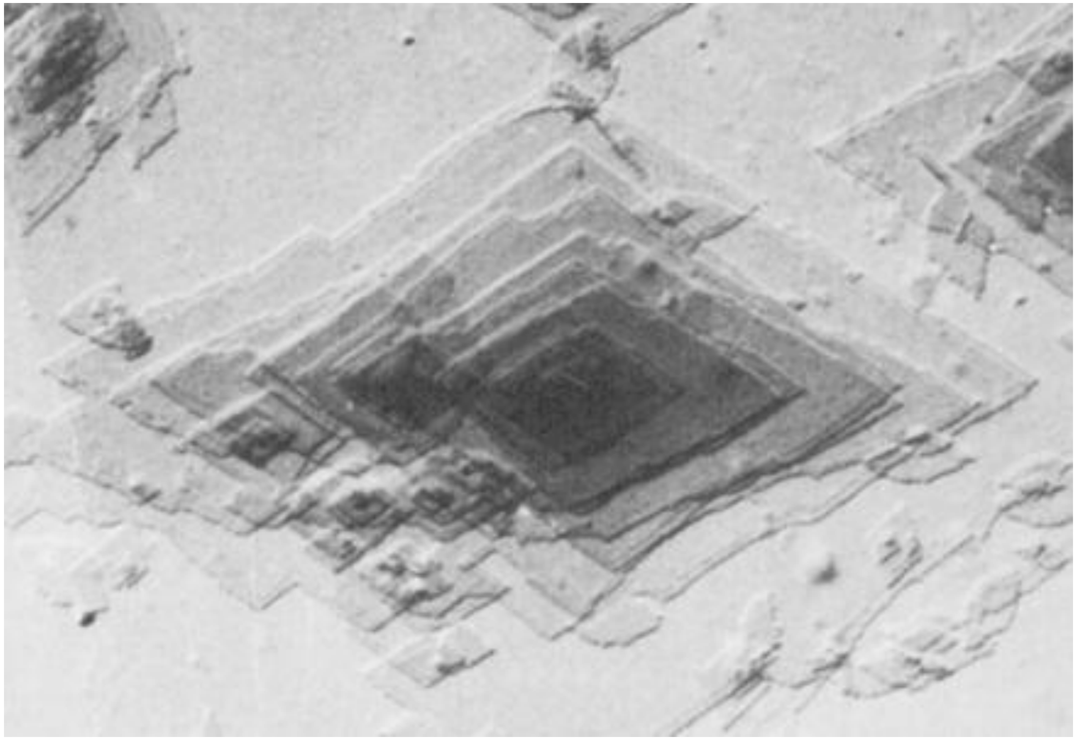
- Degree of crystallinity expressed as % crystallinity.
  -- Some physical properties depend on % crystallinity.
  -- Heat treating causes crystalline regions to grow and % crystallinity to increase.



Adapted from Fig. 14.11, *Callister 6e.* (Fig. 14.11 is from H.W. Hayden, W.G. Moffatt, and J. Wulff, *The Structure and Properties of Materials*, Vol. III, *Mechanical Behavior*, John Wiley and Sons, Inc., 1965.)

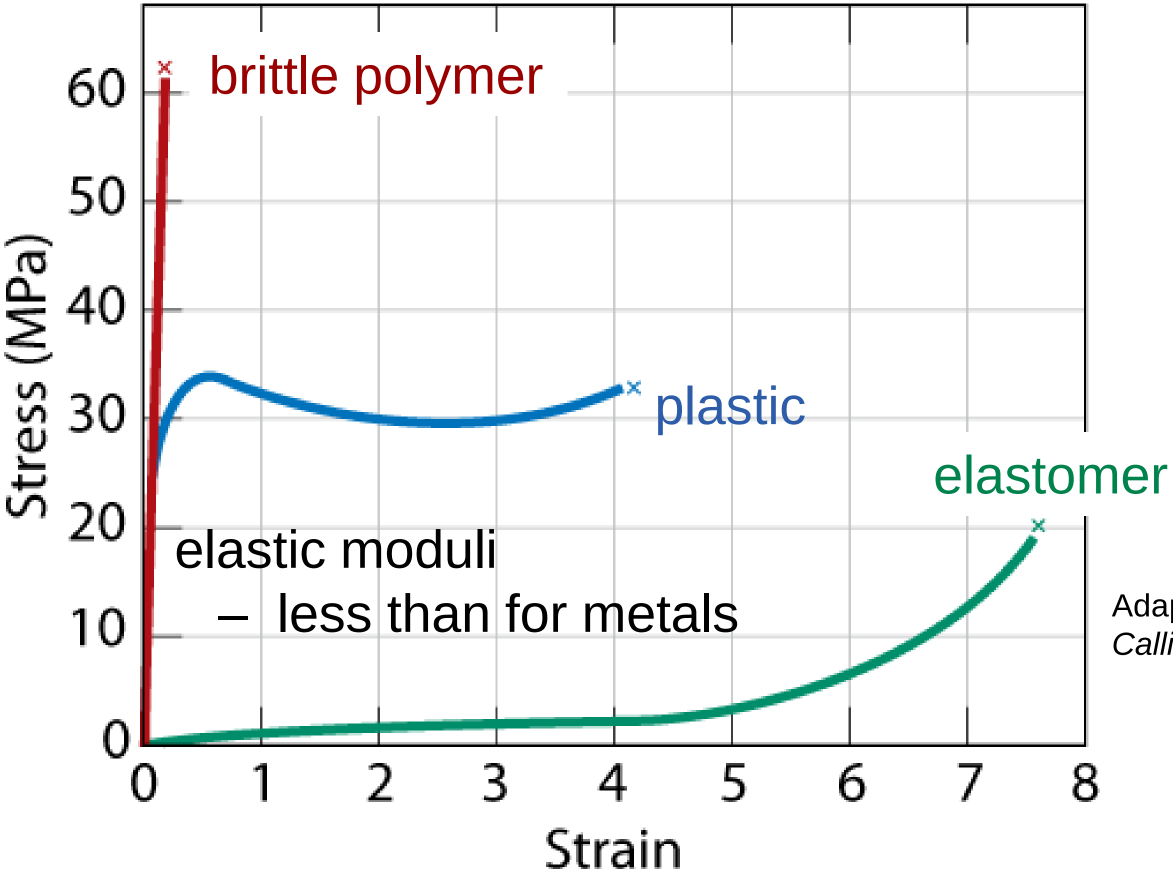
Polymer Single Crystals

- Electron micrograph – multilayered single crystals (chain-folded layers) of polyethylene
- Single crystals – only for slow and carefully controlled growth rates



Adapted from Fig. 14.11, *Callister & Rethwisch 8e.*

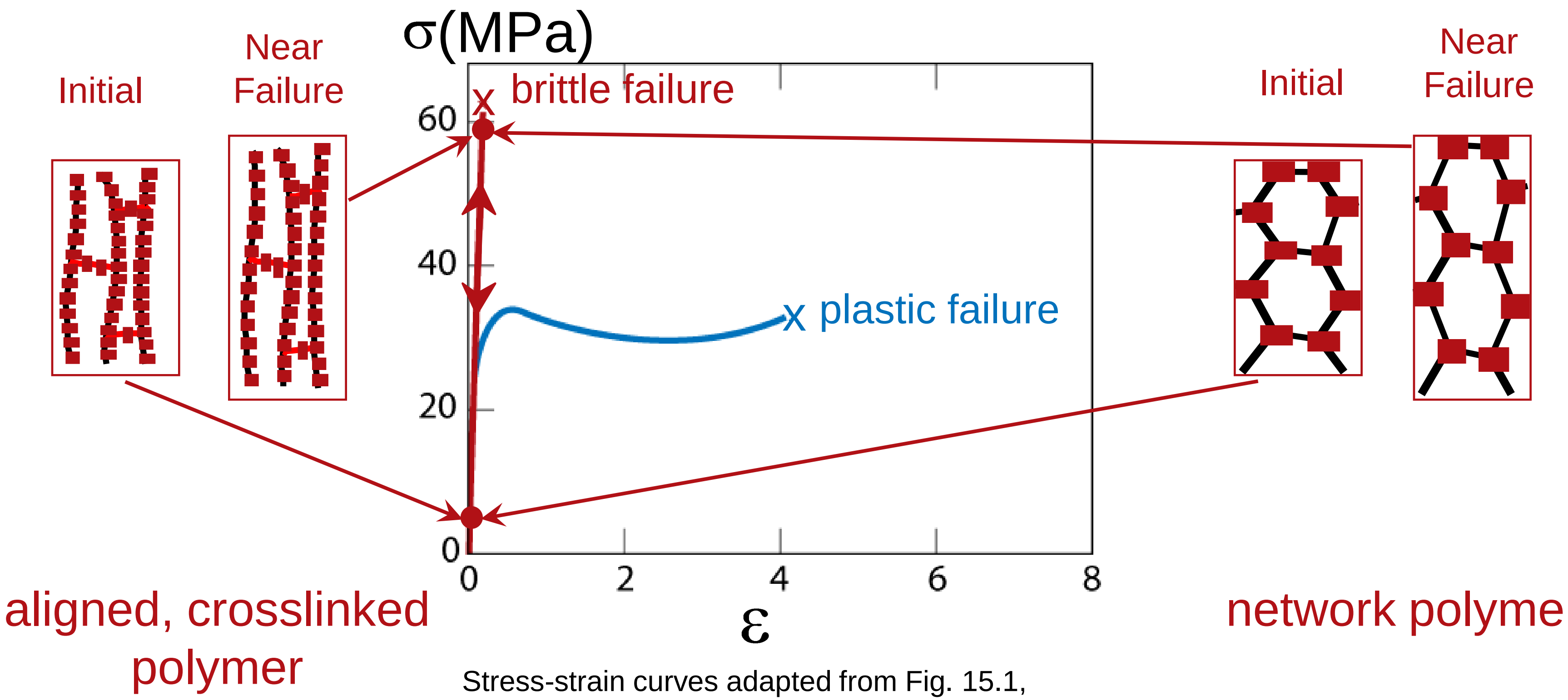
Mechanical Properties of Polymers – Stress-Strain Behavior



Adapted from Fig. 15.1, *Callister & Rethwisch 8e*.

- Fracture strengths of polymers ~ 10% of those for metals
- Deformation strains for polymers > 1000%
  - for most metals, deformation strains < 10%

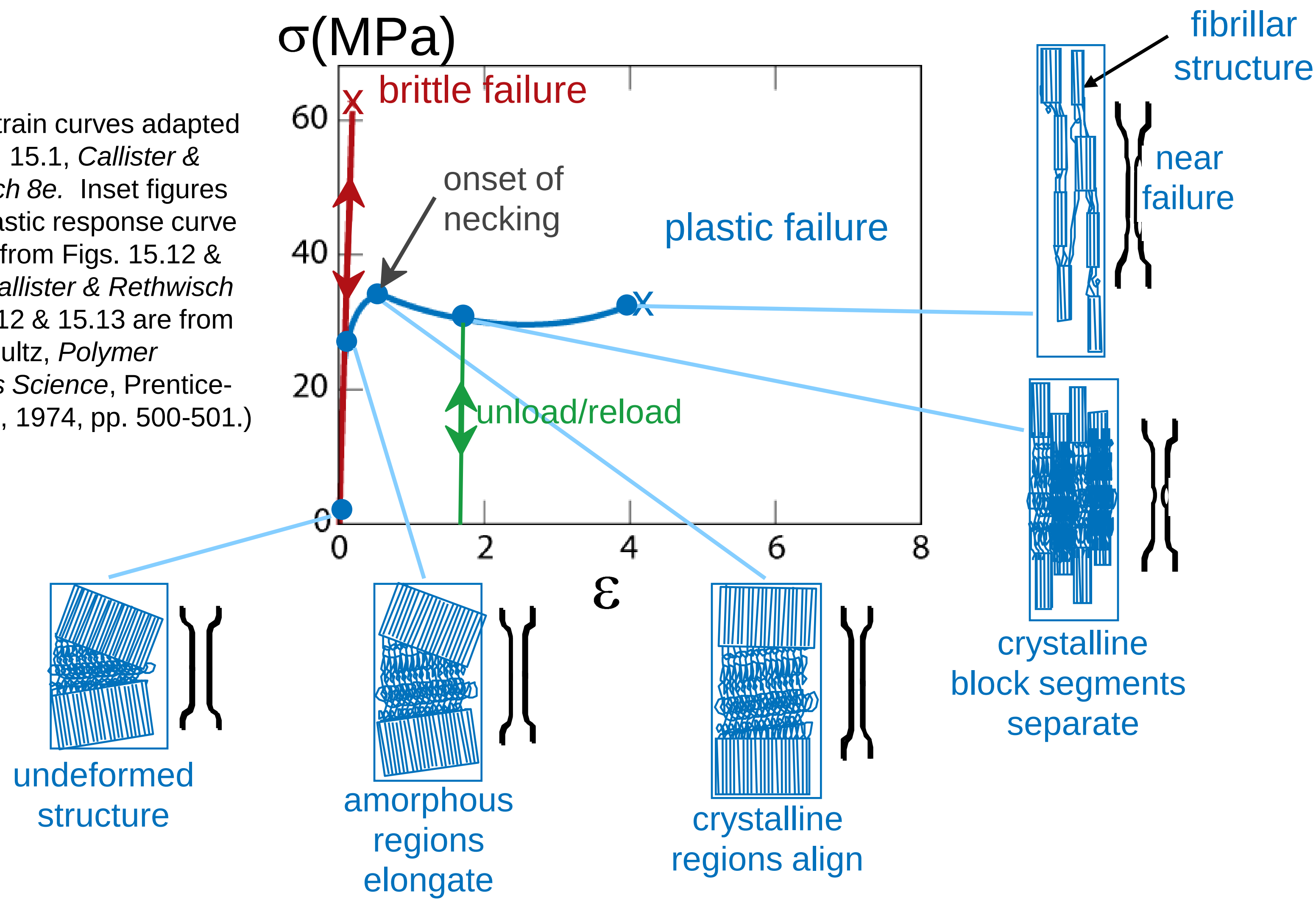
Mechanisms of Deformation—Brittle Crosslinked and Network Polymers



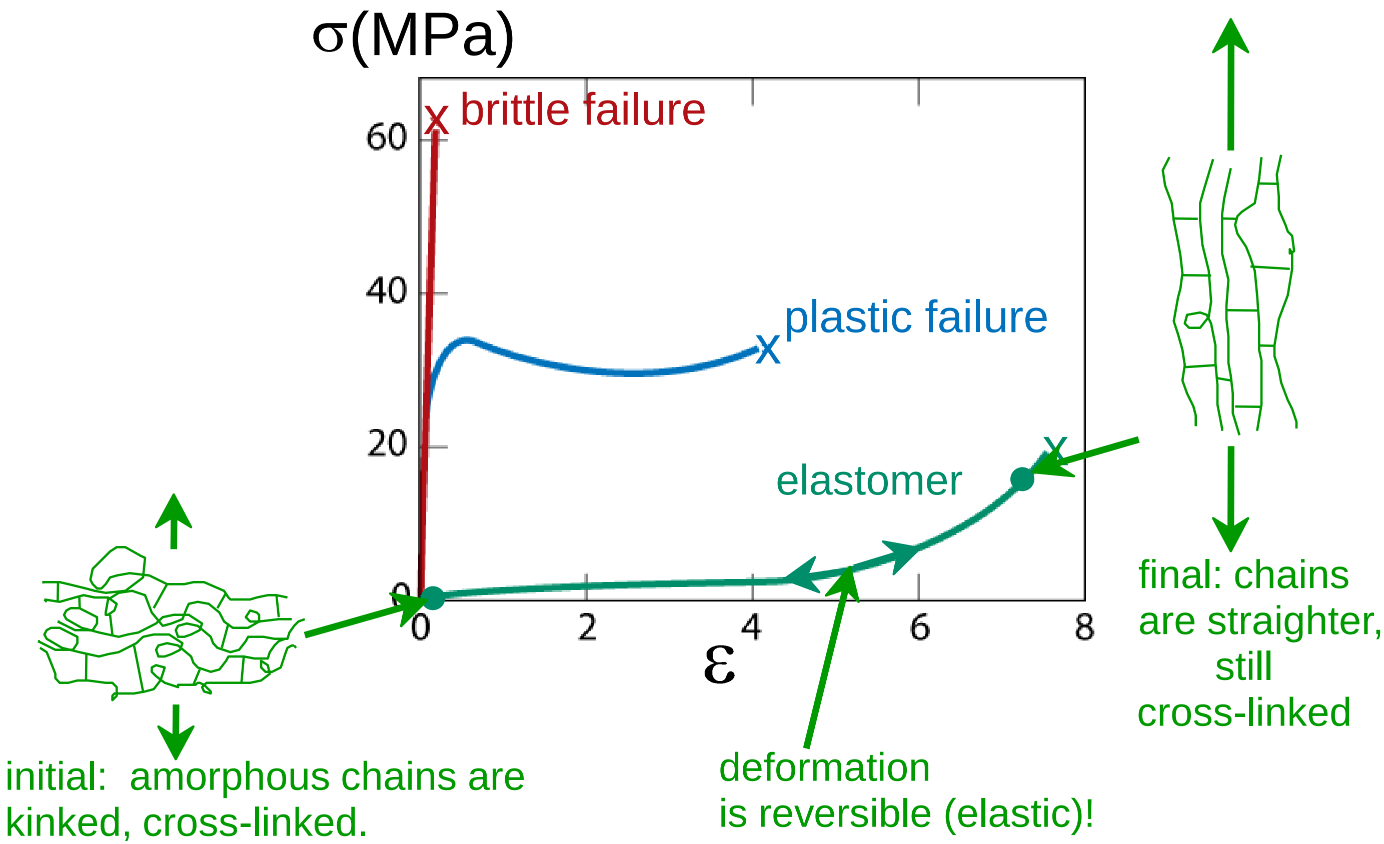
Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.*

Mechanisms of Deformation — Semicrystalline (Plastic) Polymers

Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.* Inset figures along plastic response curve adapted from Figs. 15.12 & 15.13, *Callister & Rethwisch 8e*. (15.12 & 15.13 are from J.M. Schultz, *Polymer Materials Science*, Prentice-Hall, Inc., 1974, pp. 500-501.)



Mechanisms of Deformation—Elastomers



Stress-strain curves adapted from Fig. 15.1, *Callister & Rethwisch 8e.* Inset figures along elastomer curve (green) adapted from Fig. 15.15, *Callister & Rethwisch 8e*. (Fig. 15.15 is from Z.D. Jastrzebski, *The Nature and Properties of Engineering Materials*, 3rd ed., John Wiley and Sons, 1987.)

- Compare elastic behavior of elastomers with the:
  - -- brittle behavior (of aligned, crosslinked & network polymers), and
  - -- plastic behavior (of semicrystalline polymers)
  - (as shown on previous slides)