Diffusion

Diffusion - Mass transport by atomic motion

Mechanisms

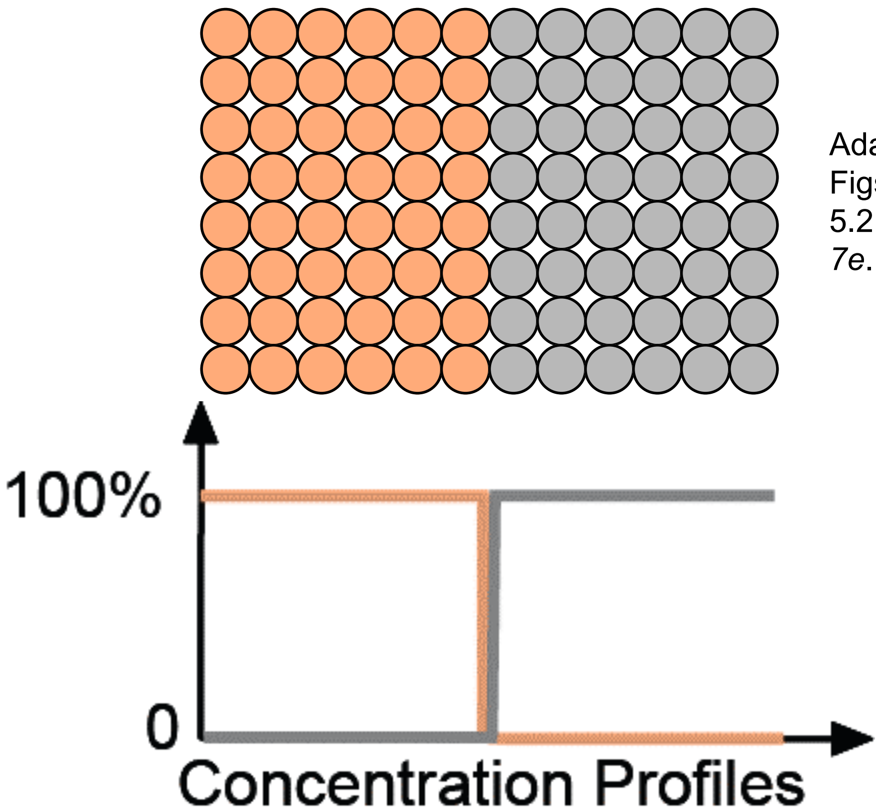
- Gases & Liquids – random (Brownian) motion
- Solids – vacancy diffusion or interstitial diffusion

Interdiffusion: In an alloy, atoms tend to migrate from regions of high conc. to regions of low conc.

Self-diffusion: In an elemental solid, atoms also migrate.

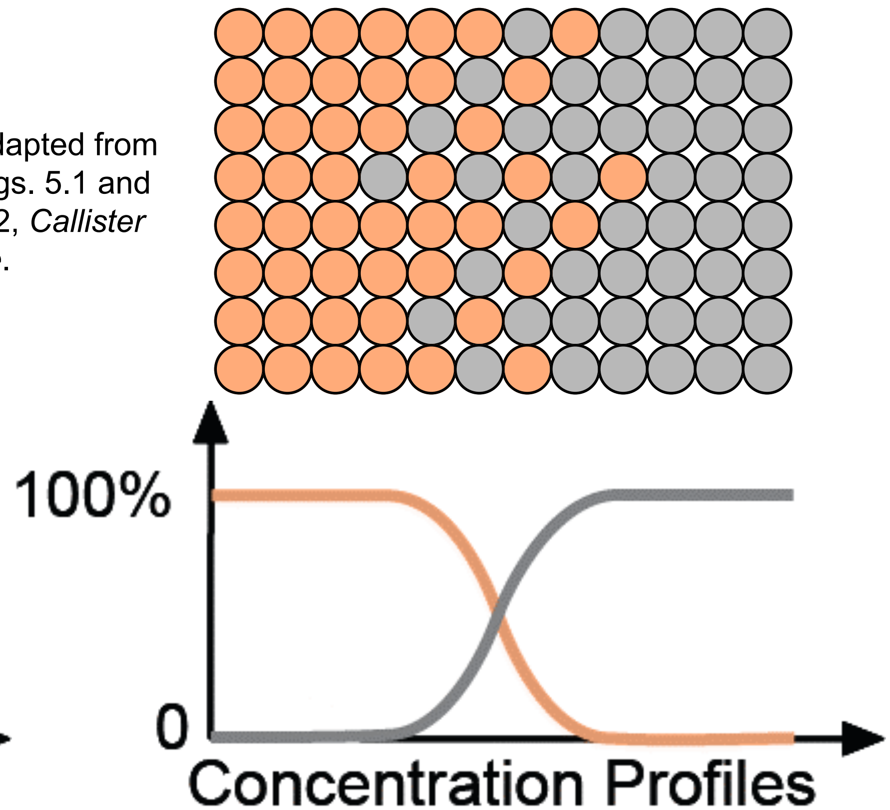
Interdiffusion

Initially



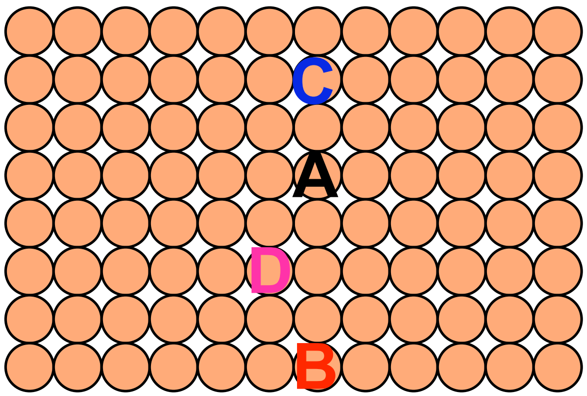
Adapted from Figs. 5.1 and 5.2, *Callister 7e*.

After some time

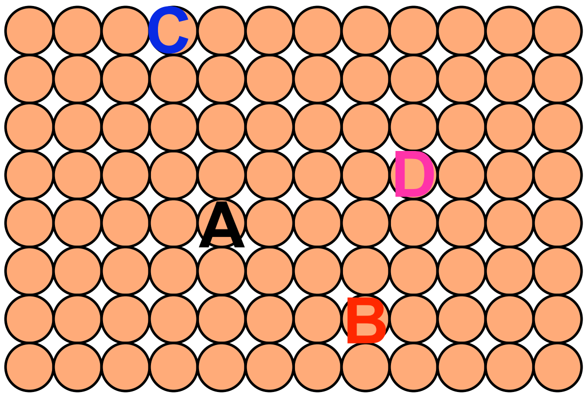


Self-diffusion

Label some atoms



After some time

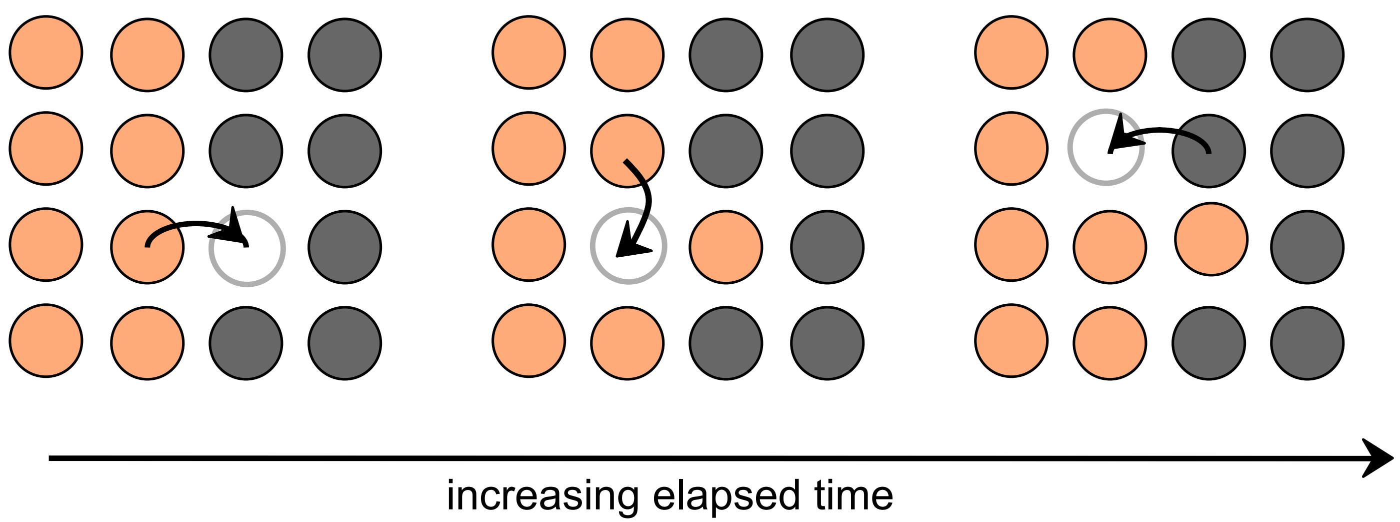


Diffusion mechanisms

Conditions:

Vacancy Diffusion:

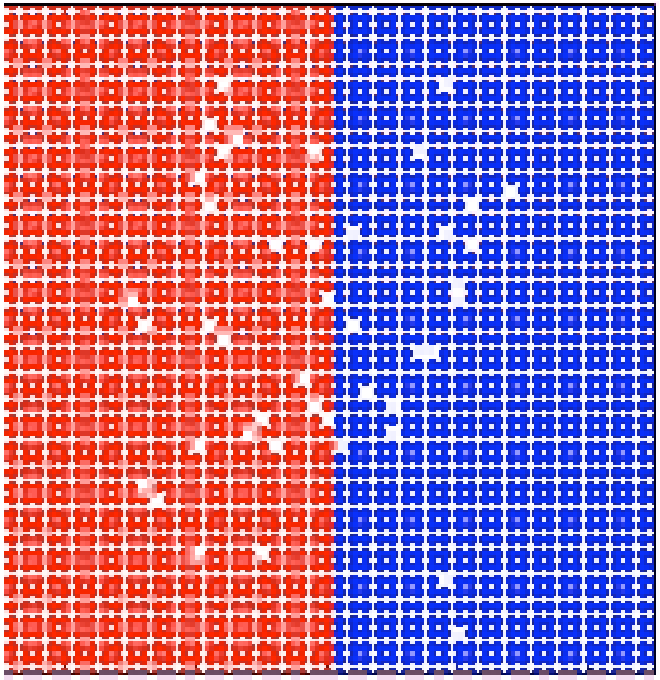
- atoms exchange with vacancies
- applies to substitutional impurities atoms
- rate depends on:
  - --number of vacancies
  - --activation energy to exchange.



Diffusion simulation

• Simulation of interdiffusion across an interface:

• Rate of substitutional diffusion depends on:
  --vacancy concentration
  --frequency of jumping.



(Courtesy P.M. Anderson)

Diffusion flux

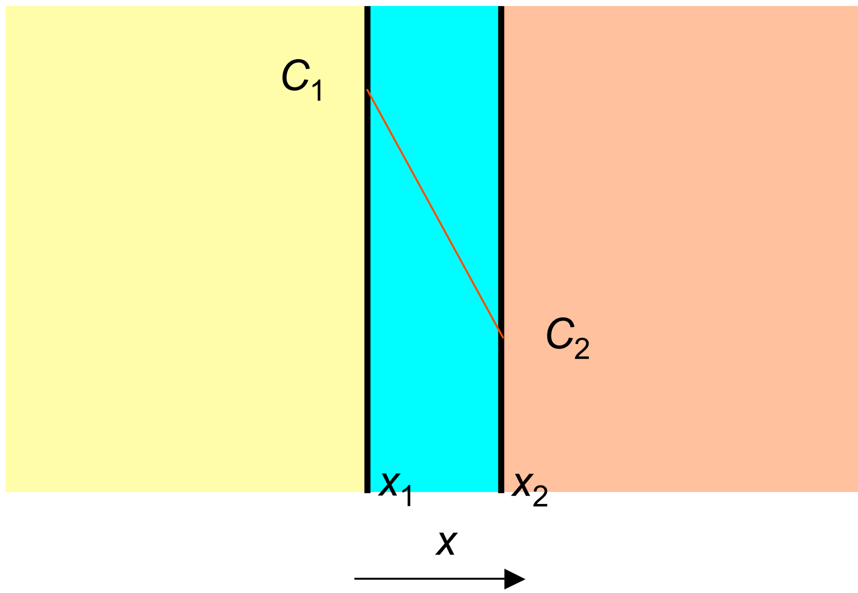
How do we quantify the amount or rate of diffusion?

Measured empirically

- Make thin film (membrane) of known surface area
- Impose concentration gradient
- Measure how fast atoms or molecules diffuse through the membrane

Steady-state diffusion

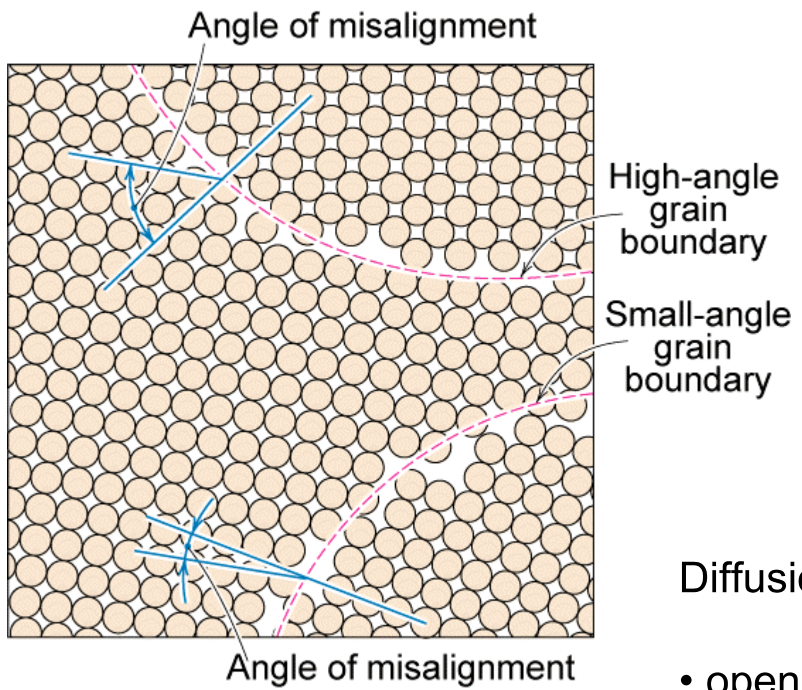
Flux proportional to concentration gradient = $\dfrac{dC}{dx}$



Diffusion and temperature

- Diffusion coefficient increases with increasing *T*.

Diffusion paths



Diffusion FASTER for...

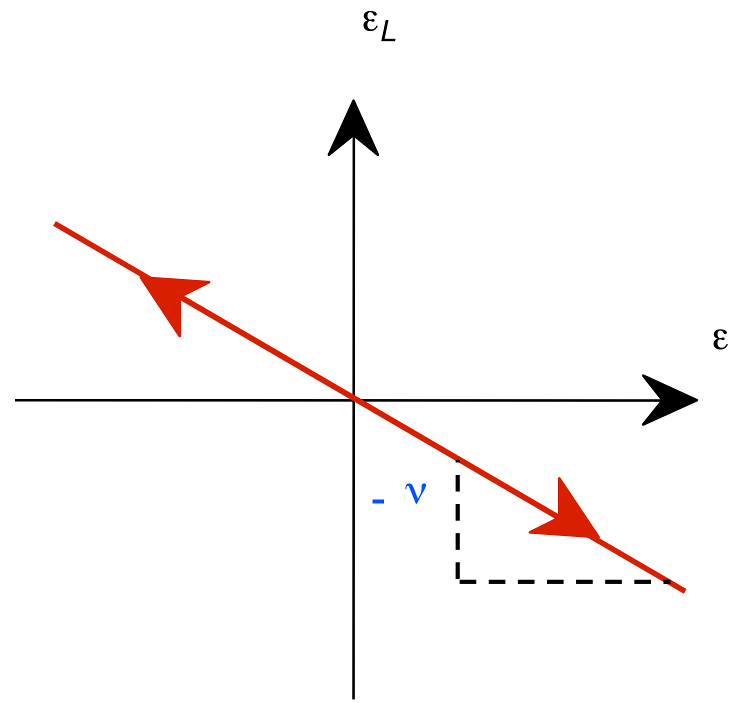
- open crystal structures
- materials w/secondary bonding
- smaller diffusing atoms
- lower density materials

Diffusion SLOWER for...

- close-packed structures
- materials w/covalent bonding
- larger diffusing atoms
- higher density materials

Elastic properties of materials

- **Poisson's ratio, ν:**

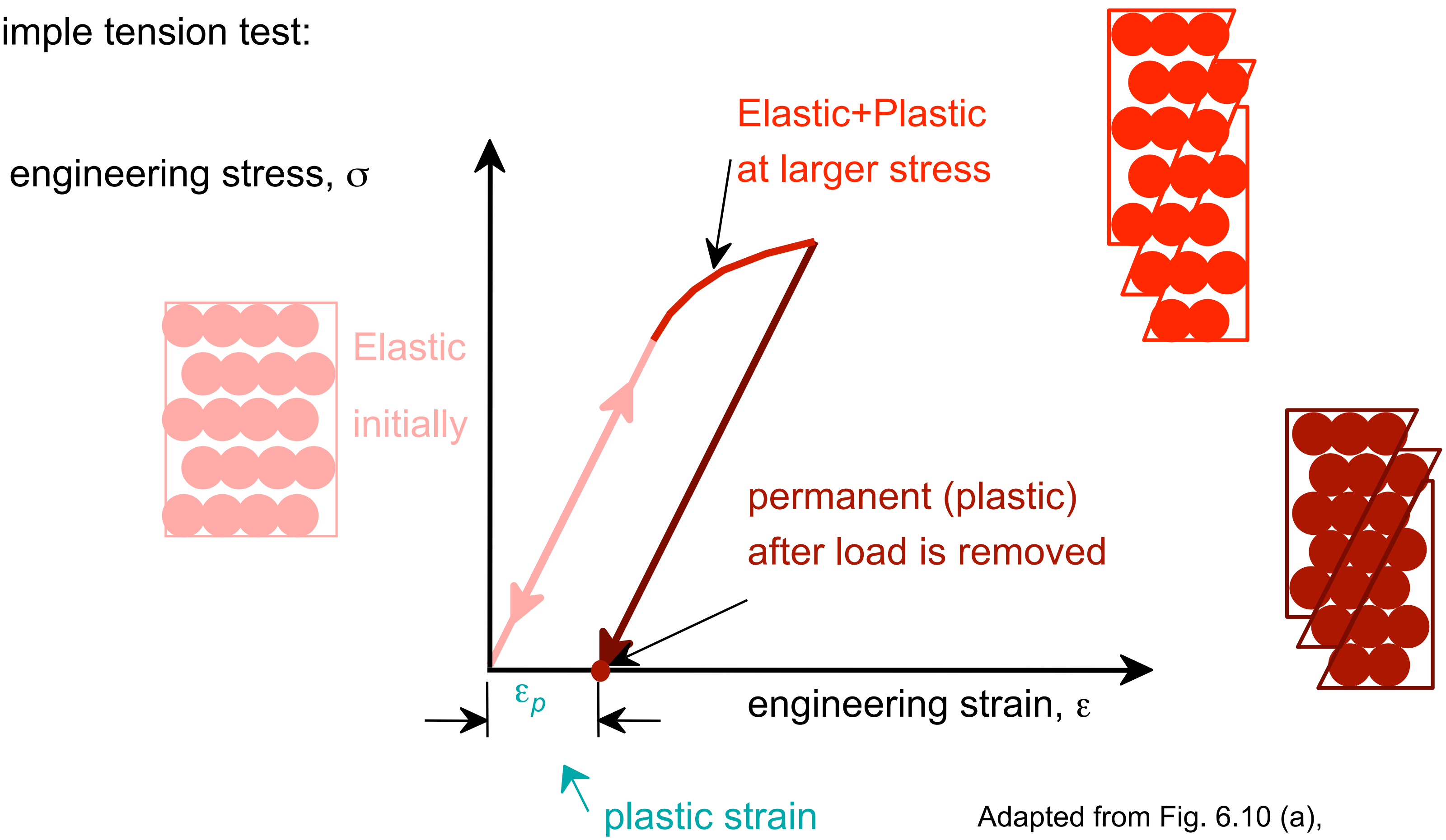


–ν > 0.50 density increases

–ν < 0.50 density decreases
(voids form)

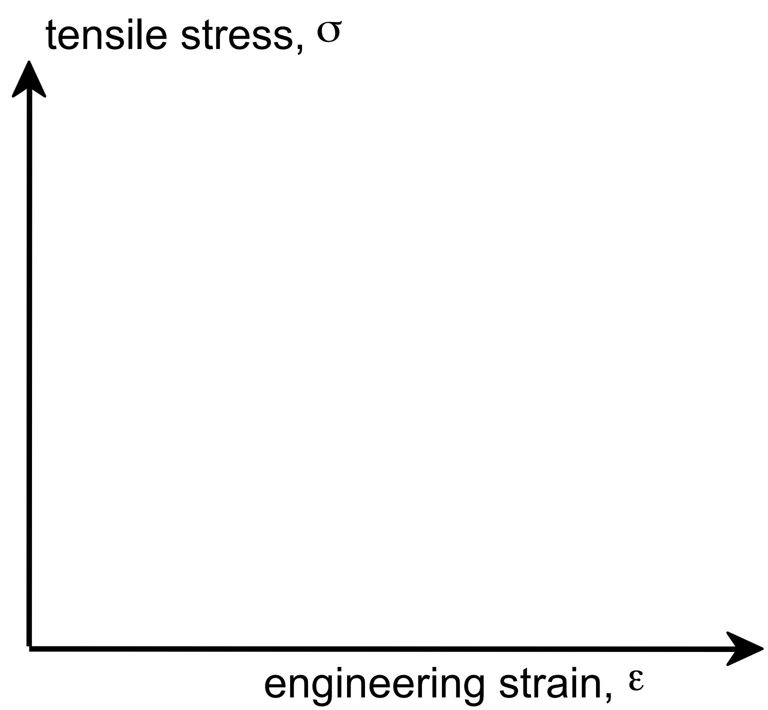
Plastic deformation

- Simple tension test:



Adapted from Fig. 6.10 (a), *Callister 7e.*

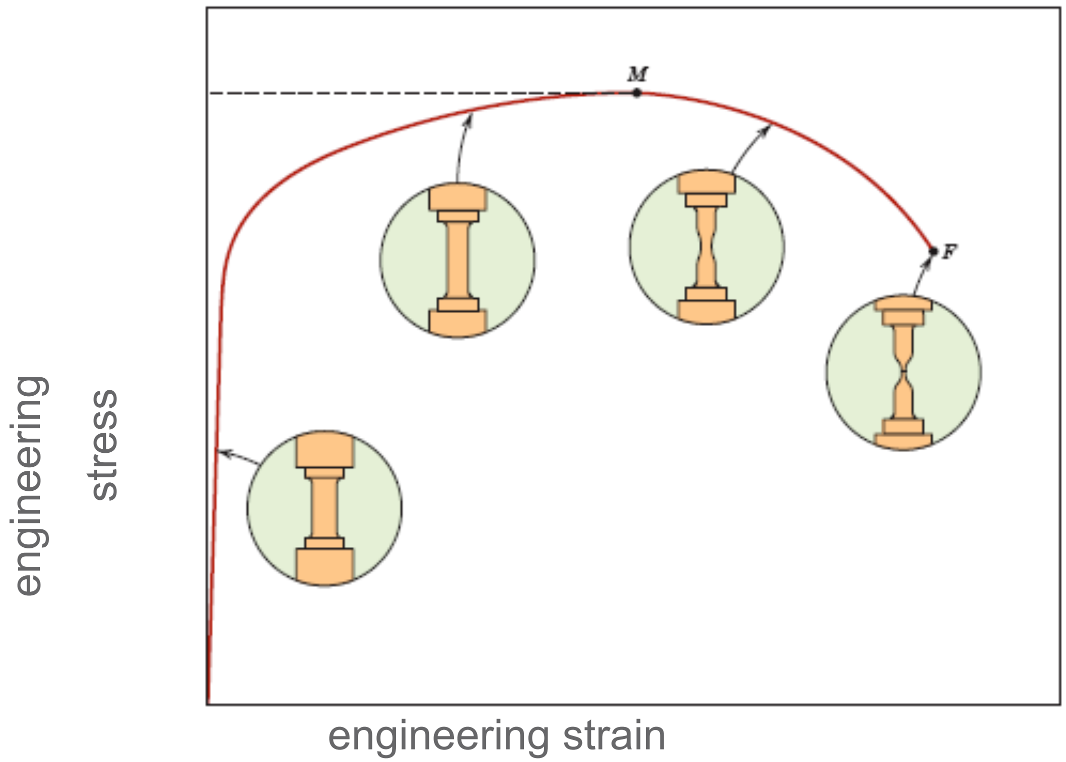
Yield strength, σ_y



Adapted from Fig. 6.10 (a), *Callister 7e.*

Tensile strength, TS

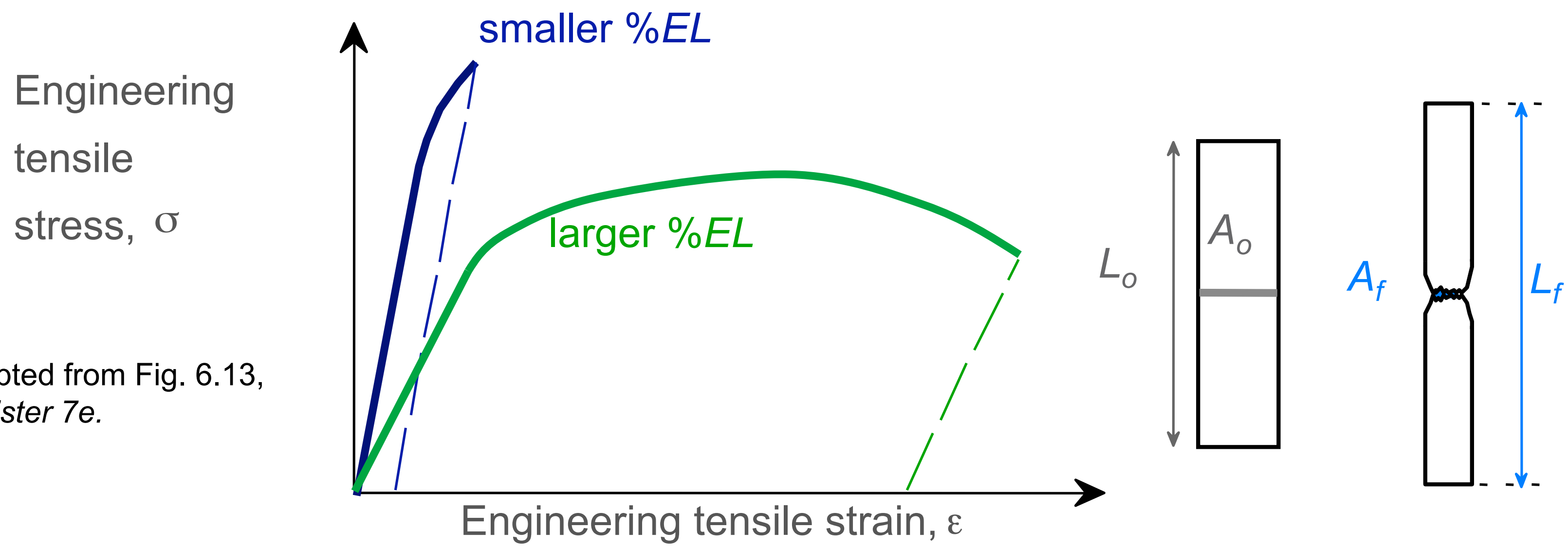
- Maximum stress on engineering stress-strain curve.



- Metals: occurs when noticeable necking starts.
- Polymers: occurs when polymer backbone chains are aligned and about to break.

Ductility

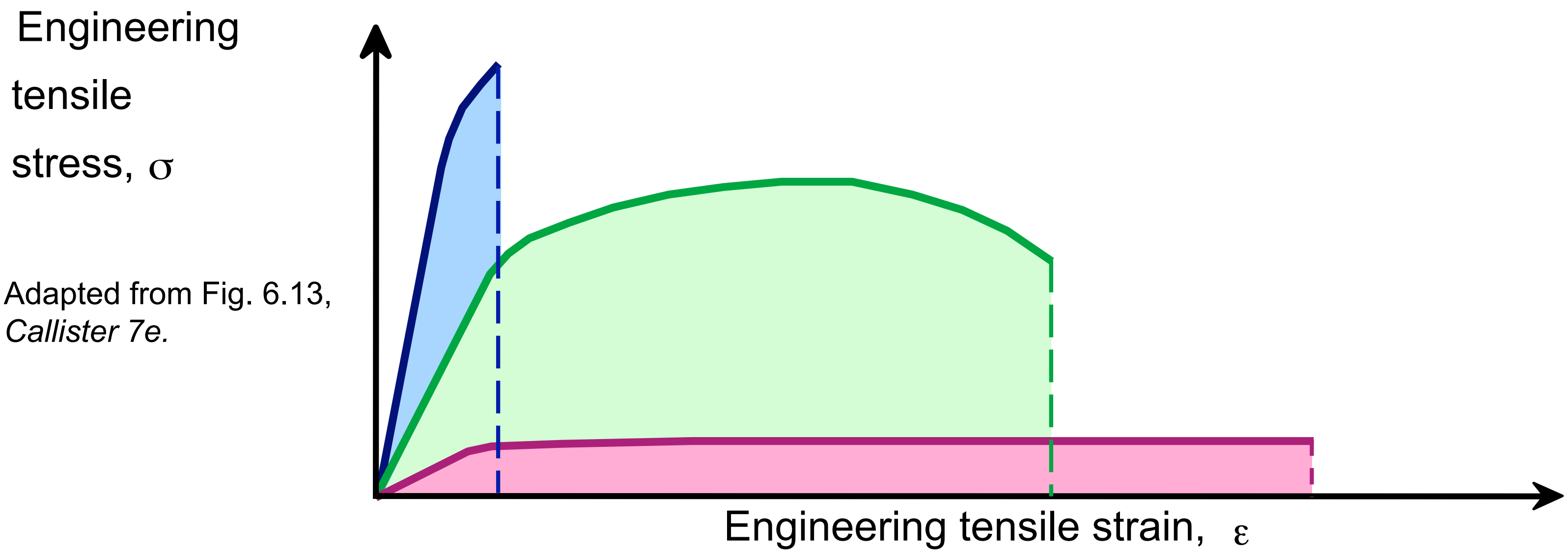
- Plastic tensile strain at failure:



Adapted from Fig. 6.13, *Callister 7e.*

Toughness

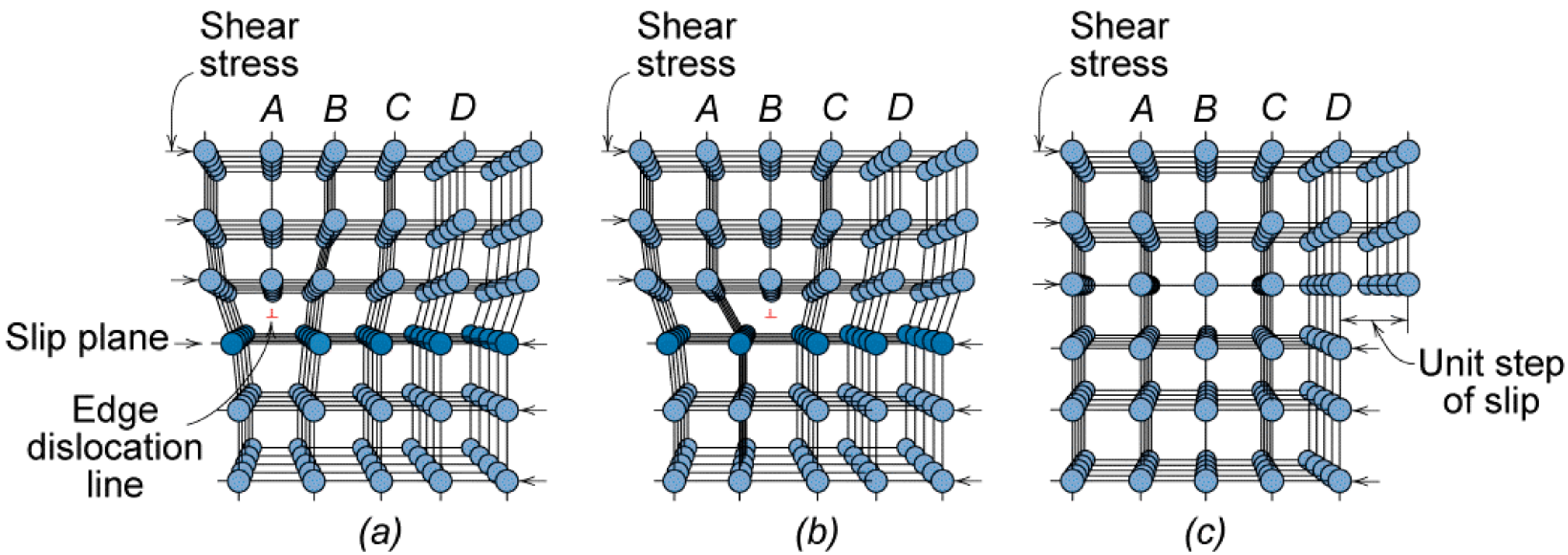
- Energy to break a unit volume of material
- Approximate by the area under the stress-strain curve.



Adapted from Fig. 6.13, *Callister 7e.*

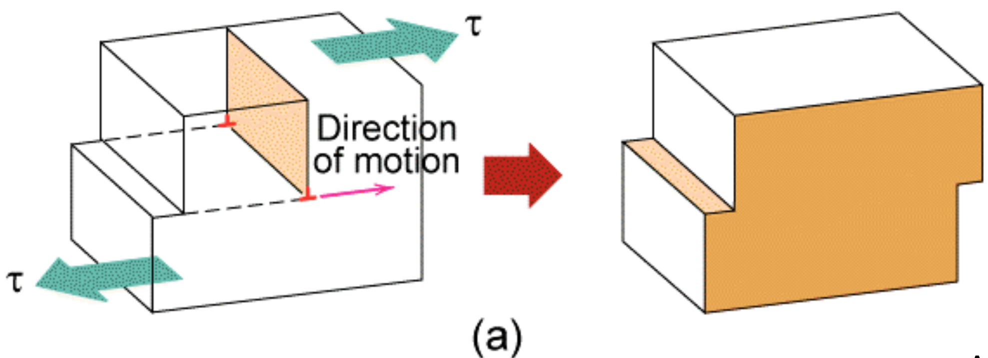
Dislocation and plastic deformation

- Cubic & hexagonal metals - plastic deformation by plastic shear or slip where one plane of atoms slides over adjacent plane by defect motion (dislocations).



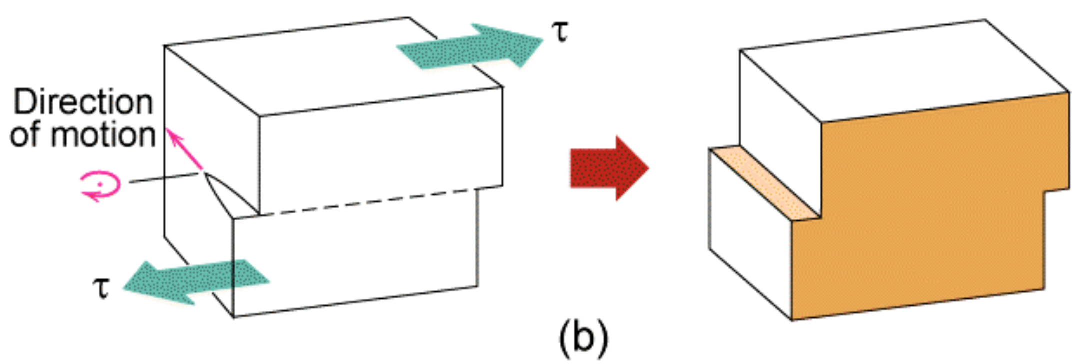
Adapted from Fig. 7.1, *Callister 7e.*

Dislocation motion



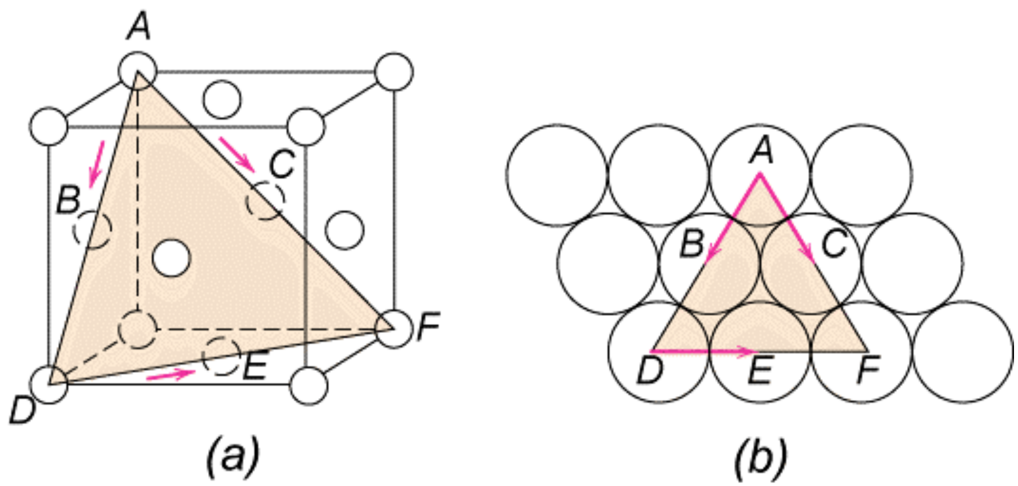
Edge dislocation

Adapted from Fig. 7.2,
Callister 7e.



Screw dislocation

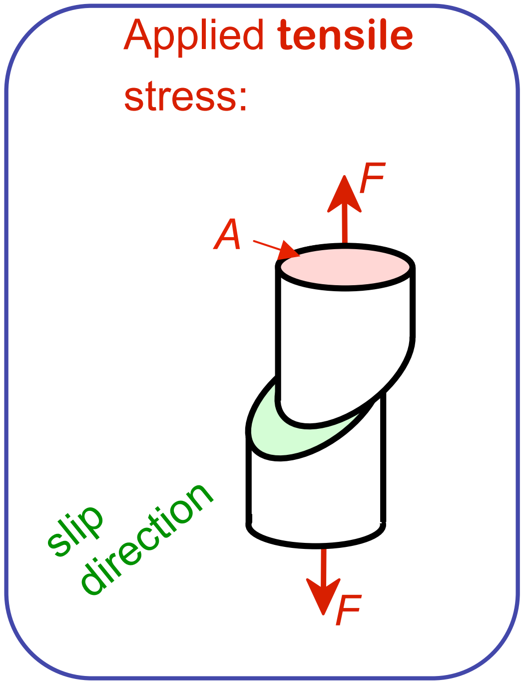
Deformation mechanisms

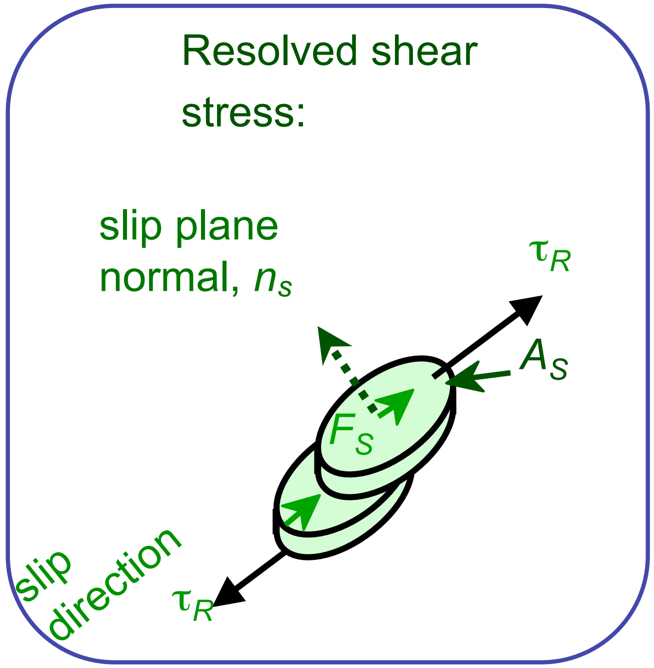


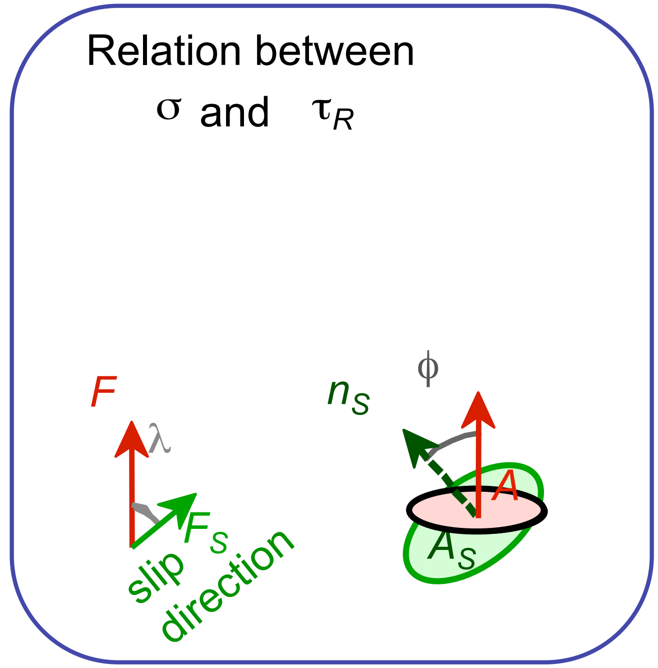
Adapted from Fig. 7.6, *Callister 7e.*

Slip in single crystals

- Crystals slip due to a resolved shear stress, τ_R.
- Applied tension can produce such a stress.



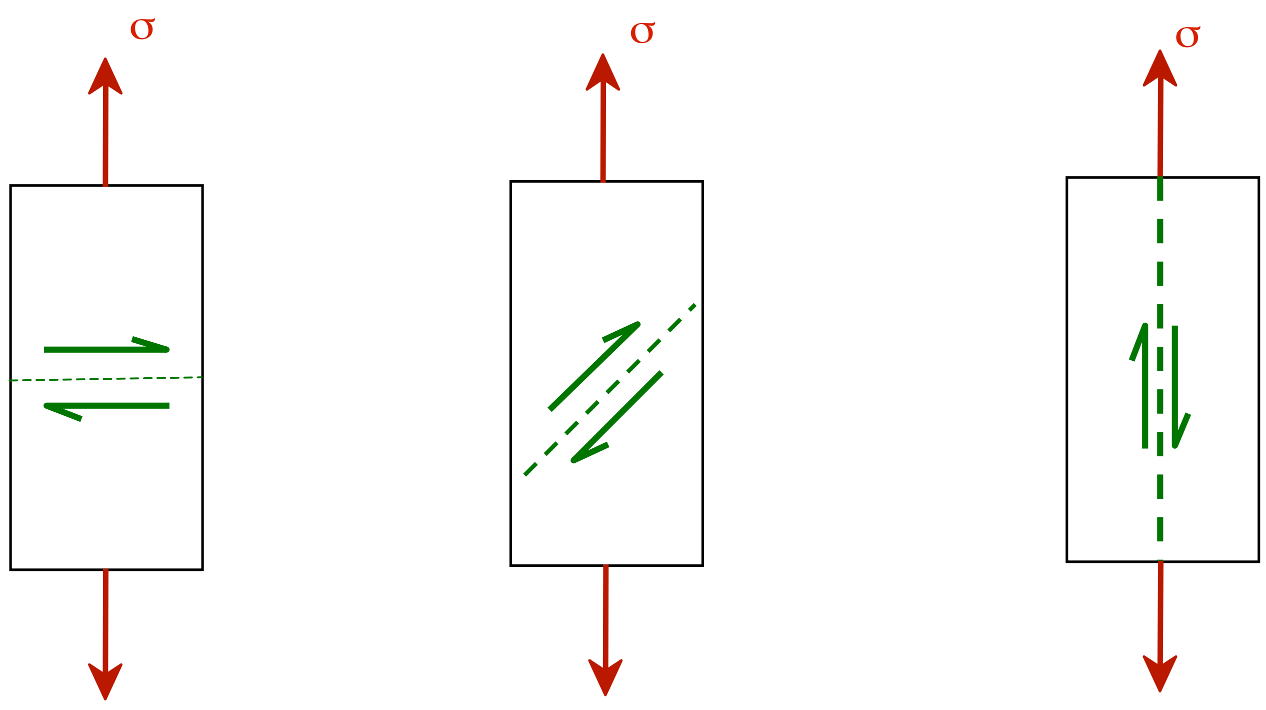




Critical resolved shear stress

- Condition for dislocation motion:

- Crystal orientation can make it easy or hard to move dislocation



Slip motion in polycrystals

- Stronger - grain boundaries pin deformations

- Slip planes & directions (λ, ϕ) change from one crystal to another.

- τ_R will vary from one crystal to another.

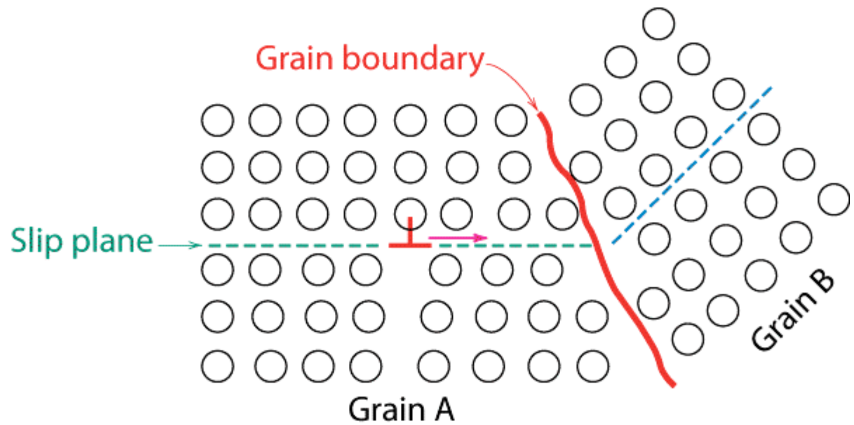
- The crystal with the largest τ_R yields first.

- Other (less favorably oriented) crystals yield later.

Adapted from Fig. 7.10, *Callister 7e.* (Fig. 7.10 is courtesy of C. Brady, National Bureau of Standards [now the National Institute of Standards and Technology, Gaithersburg, MD].)

Strategies for strengthening: grain size reduction

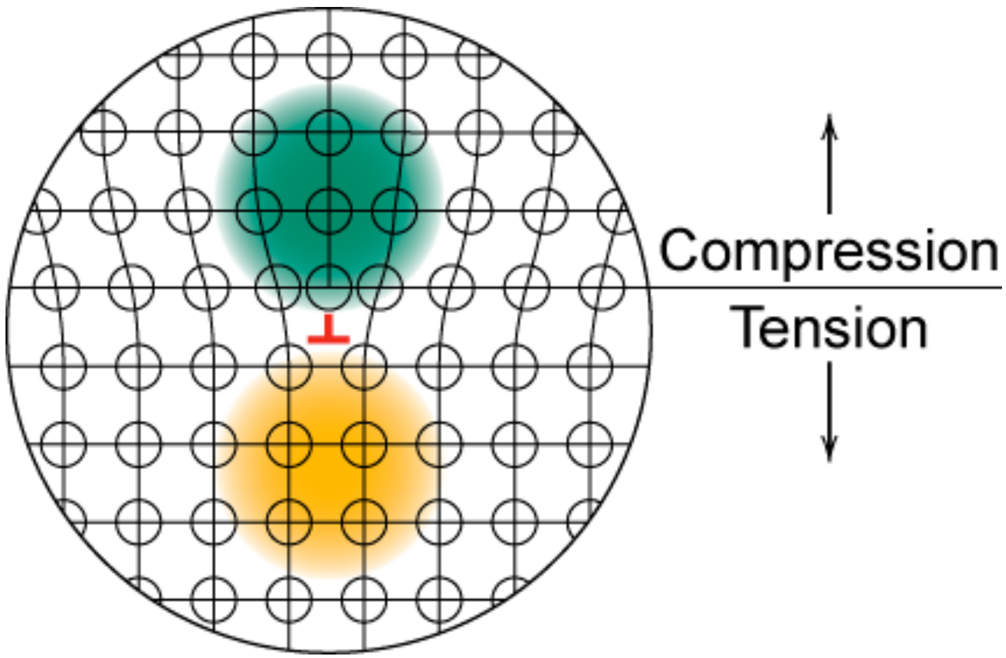
- Grain boundaries are barriers to slip.
- Barrier "strength” increases with increasing angle of misorientation.
- Smaller grain size: more barriers to slip.



Adapted from Fig. 7.14, *Callister 7e.*
(Fig. 7.14 is from *A Textbook of Materials Technology*, by Van Vlack, Pearson Education, Inc., Upper Saddle River, NJ.)

- Hall-Petch Equation:

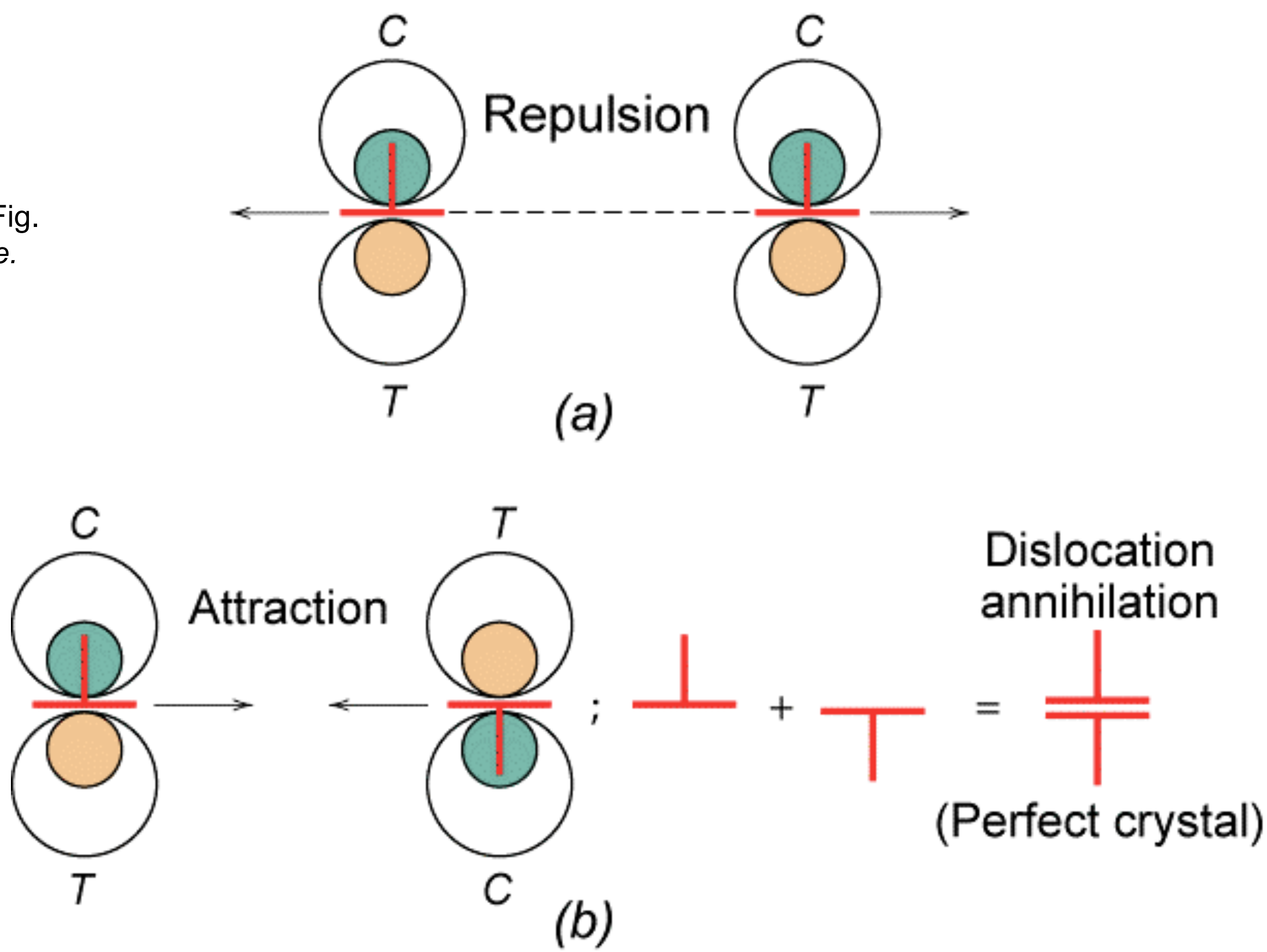
Strategies for strengthening: solid solutions



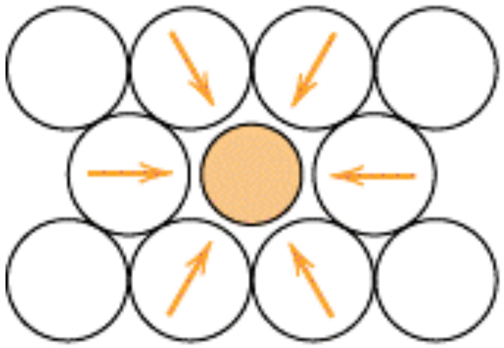
Adapted from Fig. 7.4, *Callister 7e.*

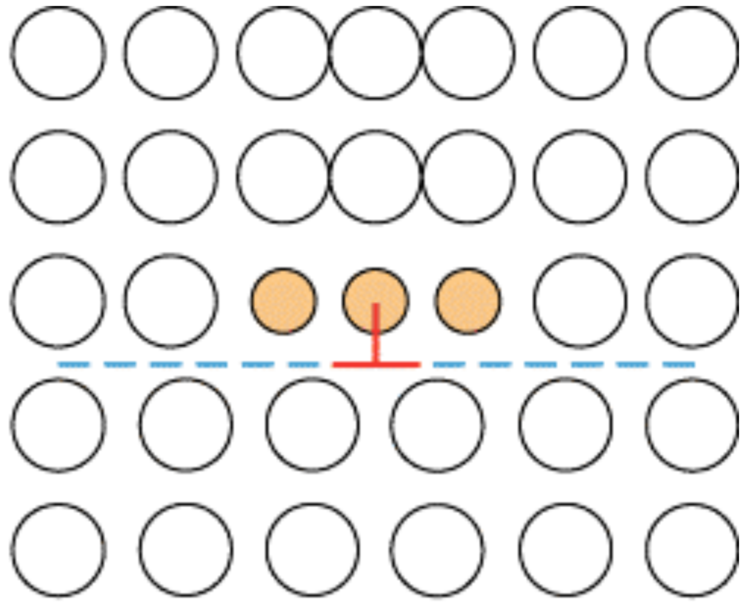
Effects of stress at dislocations

Adapted from Fig. 7.5, *Callister 7e.*



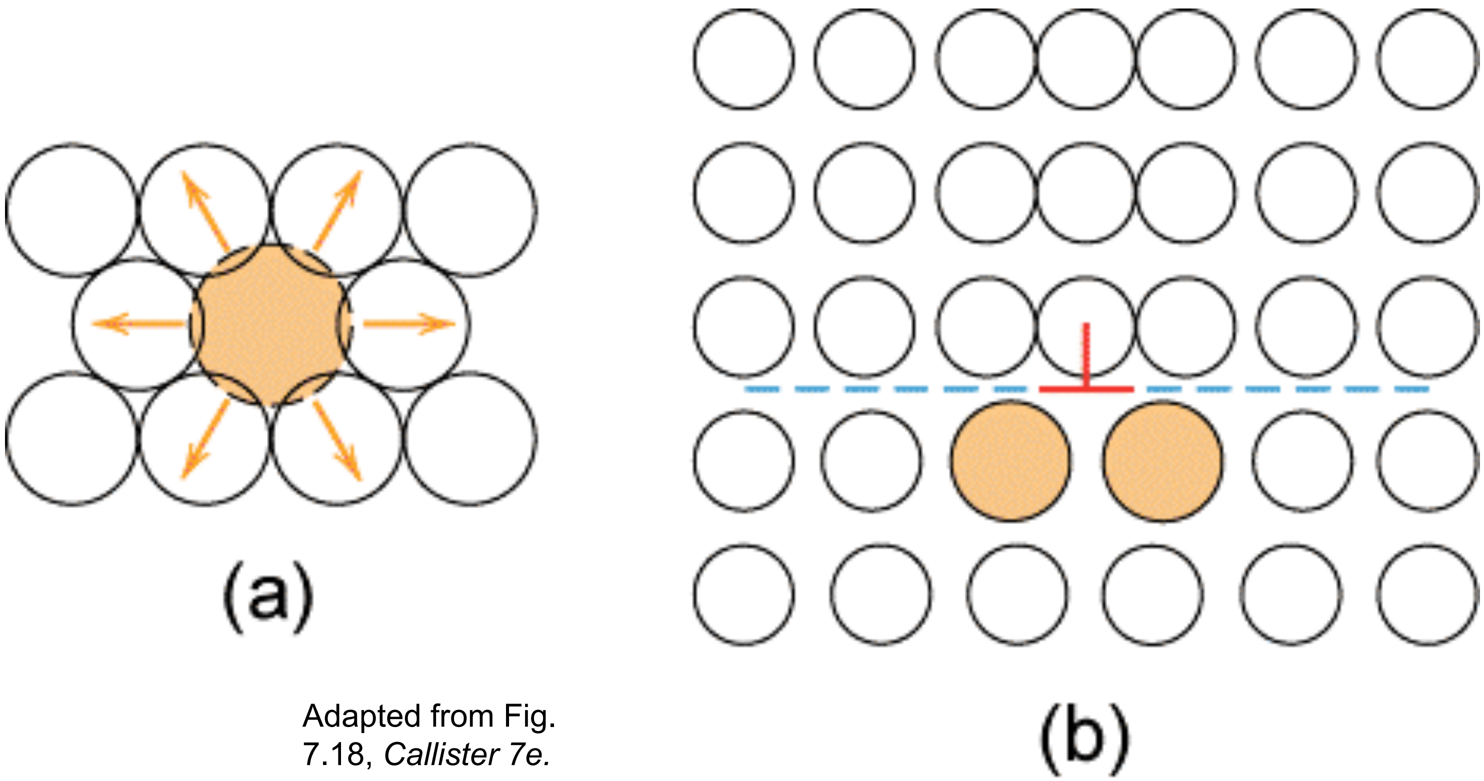
Strengthening by alloying





Adapted from Fig. 7.17, *Callister 7e.*

Strengthening by alloying

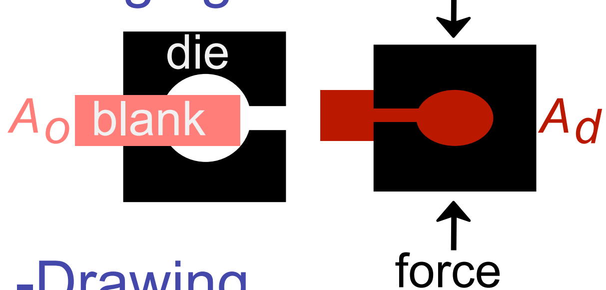


Adapted from Fig. 7.18, *Callister 7e.*

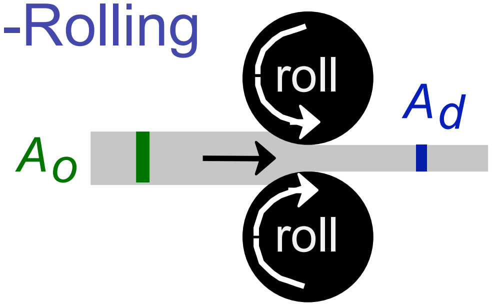
Strategies for strengthening: Cold work (%CW)

- Room temperature deformation.
- Common forming operations change the cross sectional area:

-Forging

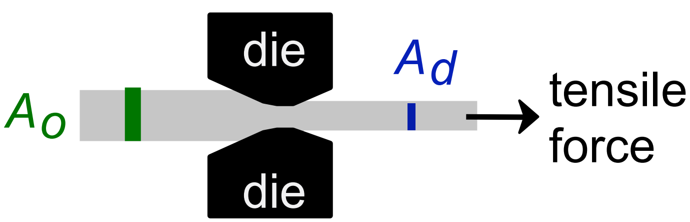


-Rolling

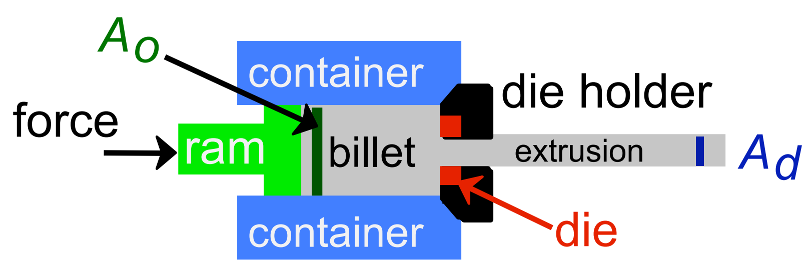


Adapted from Fig. 11.8, *Callister 7e.*

-Drawing

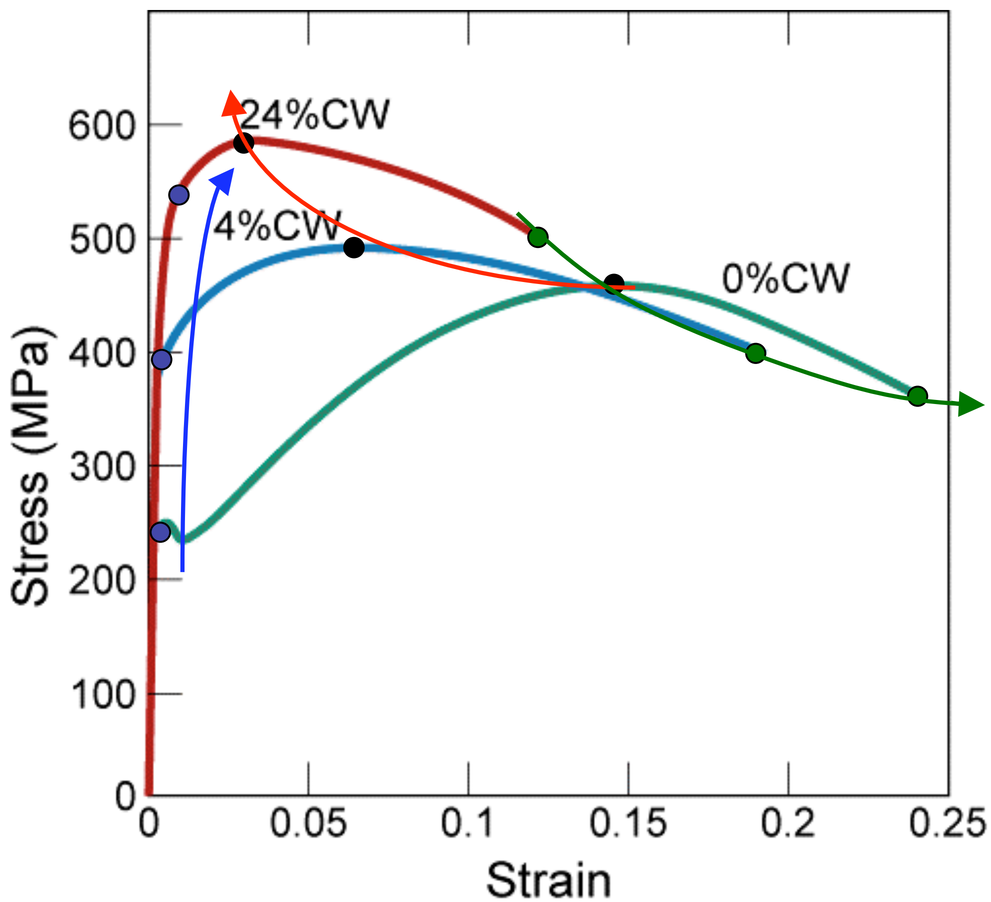


-Extrusion



Impact of cold work

As cold work is increased



Adapted from Fig. 7.20, *Callister 7e.*