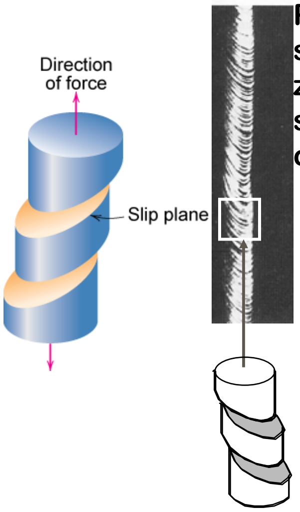
Chapter 7: Dislocations and strengthening mechanisms

- Introduction
- Basic concepts
- Characteristics of dislocations
- Slip systems
- Slip in single crystals
- Plastic deformation of polycrystalline materials

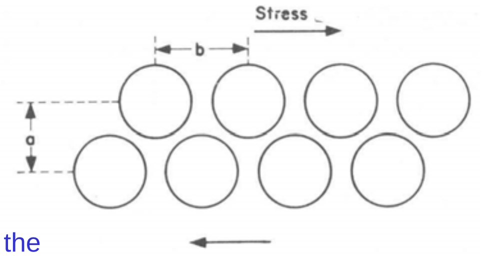


Plastically stretched zinc single crystal.

Theoretical stress

- Theoretical stress (Frenkel in 1926)

$$\tau = \frac{Gb}{2\pi a}\sin\frac{2\pi x}{b}$$



G: shear modulus
b: spacing between atoms in the direction of shear stress
a: spacing of the rows of atoms
x: shear translation

Theoretical stress (*continue*)

- Hook’s law
  assumption: small strain

$$\tau = \frac{Gb}{2\pi a} \times \frac{2\pi x}{b} = G\frac{x}{a} = G\gamma$$

- Theoretical critical shear stress (maximum stress):

$$\tau_{th} = \frac{b}{a}\frac{G}{2\pi}$$

Theoretical & experimental strength

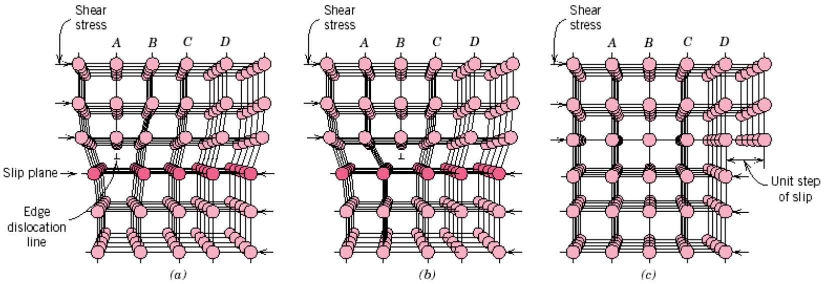
There is much difference between theoretical and experimental strength

Reasons are:

- Defects are present in all perfect crystal
- Dislocation movement makes plastic deformation easier than that predicted by the Frenkel calculation

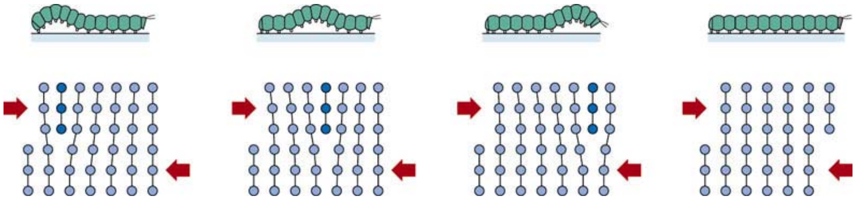
Dislocation motion

- Produces plastic deformation
- Depends on incrementally breaking bonds
- If dislocations don’t move, plastic deformation doesn’t happen!



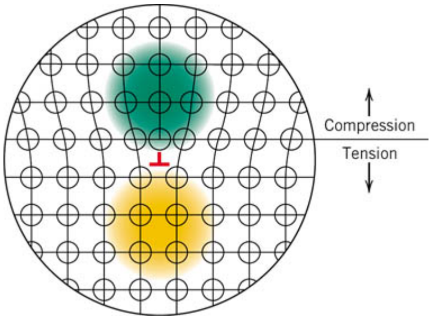
Analogy between caterpillar and dislocation motion

- **Dislocation density**: total dislocation length per unit volume
- 10^3 mm^{-2} for pure metal crystals; 10^9-$10^{10}$$mm^{-2}$ for heavily deformed metals; 10^5-$10^6$$mm^{-2}$ for heat-treated deformed metals



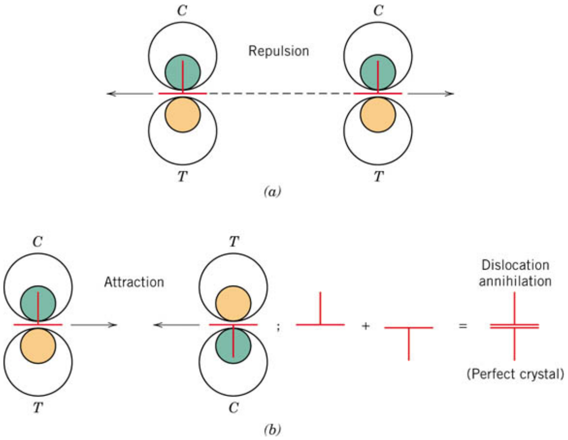
Characteristics of dislocations

- Strain fields: determining the mobility of the dislocations and their ability to multiply
- Compressive, tensile, and shear lattice stains



Dislocation interaction

- Edge dislocation
- Positive sign
- Negative sign

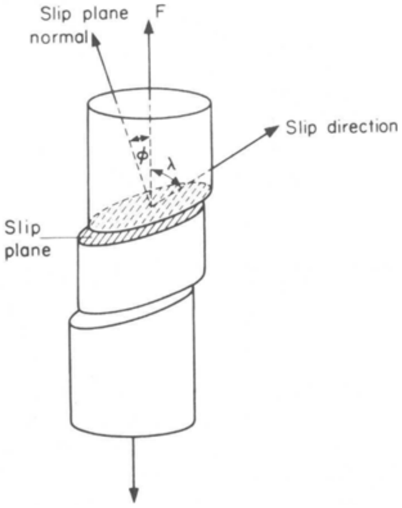


Slip in single crystals

- ☐ Schmid's law

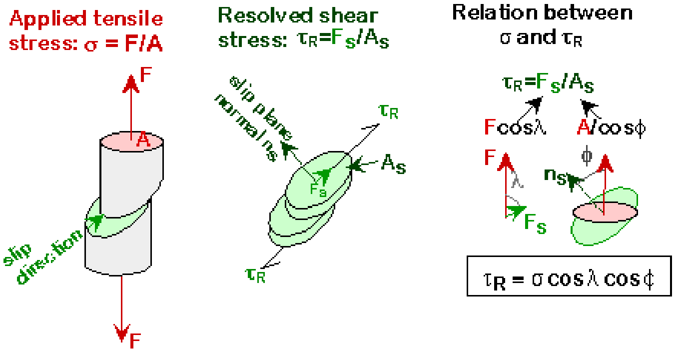
$$\tau = \frac{F}{A}\cos\phi\cos\lambda$$

- ☐ Slip plane: close-packed plane
- ☐ Slip direction: close-packed direction in the planes
- ☐ Slip system: slip planes x slip directions
- ☐ Schmid's factor: $\cos\phi\cos\lambda$



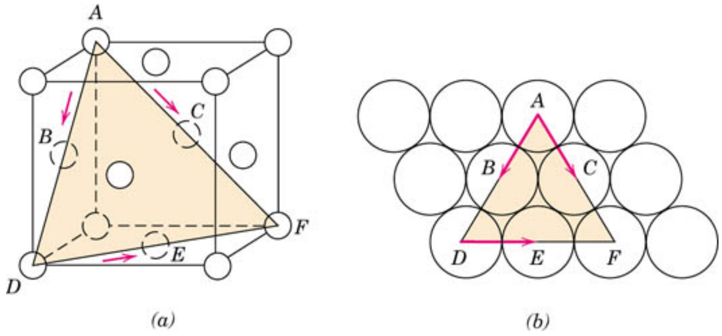
Slip in single crystals (*continue*)

- ☐ Resolved shear stresses
- ☐ Critical resolved shear stress τ_{crss}: minimum shear stress required to initiate slip
- ☐ Resolved shear stress causes crystals slip



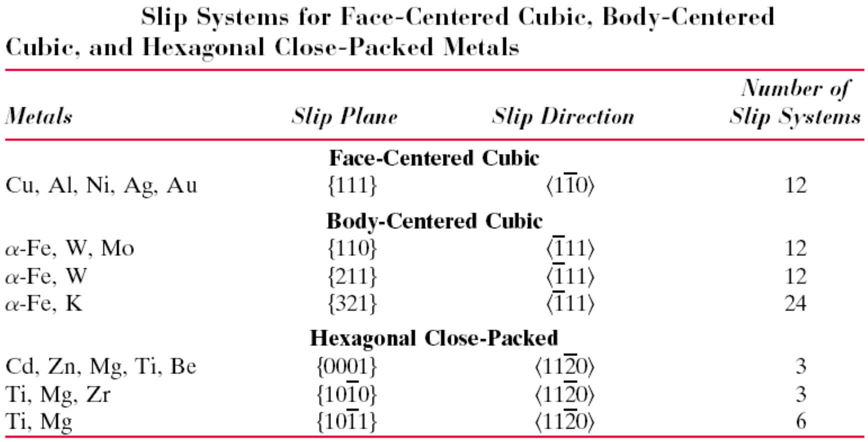
Slip system

- ☐ A {111}<110> slip system for in Fcc unit cell



(a) (b)

Slip planes and directions for common crystal structure



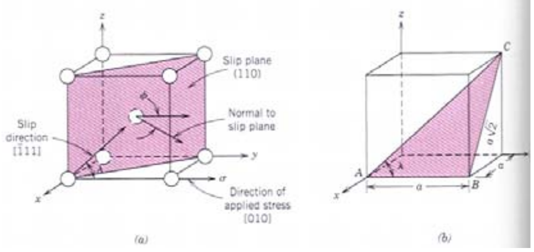
Slip Systems for Face-Centered Cubic, Body-Centered Cubic, and Hexagonal Close-Packed Metals

Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	{111}	$\langle 1\bar{1}0\rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	{110}	$\langle \bar{1}11\rangle$	12
α-Fe, W	{211}	$\langle \bar{1}11\rangle$	12
α-Fe, K	{321}	$\langle \bar{1}11\rangle$	24
	Hexagonal Close-Packed		
Cd, Zn, Mg, Ti, Be	{0001}	$\langle 11\bar{2}0\rangle$	3
Ti, Mg, Zr	$\{10\bar{1}0\}$	$\langle 11\bar{2}0\rangle$	3
Ti, Mg	$\{10\bar{1}1\}$	$\langle 11\bar{2}0\rangle$	6

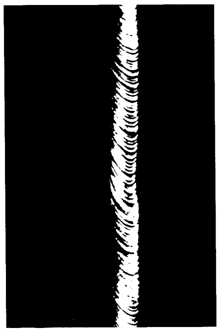
Example

- ☐ Determine the resolved shear stress along (110) plane and in a [111] direction for Bcc iron. Tensile stress is 52 MPa.

$$\tau_R = \sigma \cos\phi \cos\lambda = (52\text{ MPa})(\cos 45^\circ)(\cos 54.7^\circ)$$
$$= 21.3\text{ MPa (3060 psi)}$$



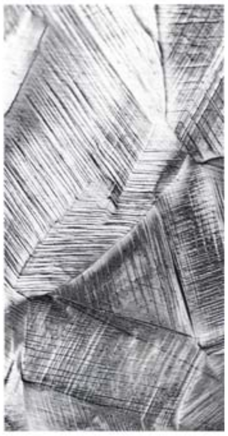
$$\sigma_y = \frac{30\text{ MPa}}{(\cos 45^\circ)(\cos 54.7^\circ)} = 73.4\text{ MPa (10,600 psi)}$$



Slip in a zinc crystal

Plastic deformation of polycrystalline materials

- ☐ Slip planes and directions change from one crystal to another
- ☐ Shear stress varies from one crystal to another
- ☐ Crystal with largest shear stress yields first
- ☐ Other (less favorably oriented) crystals yield later

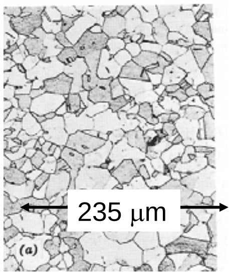


Slip lines on the surface of a polycrystalline specimen of copper

Anisotropy in σ_y

☐ Deformation and slip in polycrystalline materials

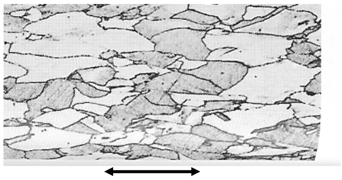
- before rolling



- isotropic

since grains are approx. spherical & randomly oriented.

- after rolling

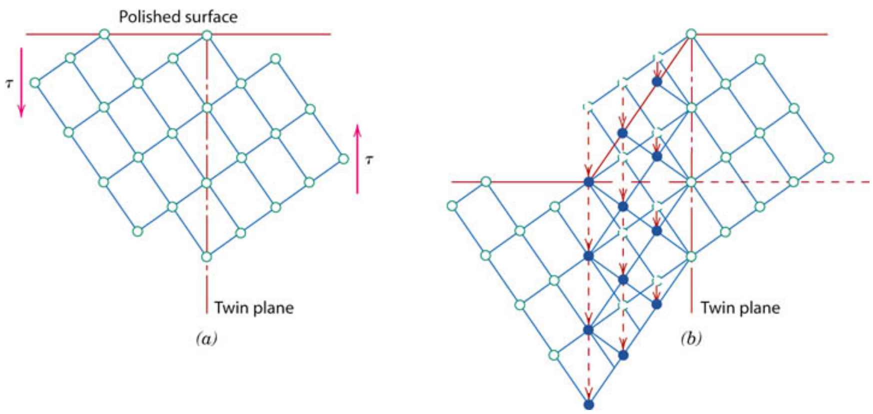


rolling direction

- anisotropic

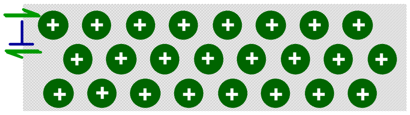
since rolling affects grain orientation and shape.

Deformation by twinning

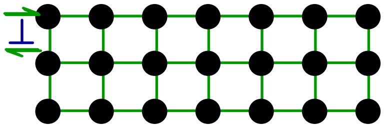


Dislocations & materials classes

- **Metals: Disl. motion easier.**
  - -non-directional bonding
  - -close-packed directions for slip.



- **Covalent Ceramics (Si, diamond): Motion hard.**
  - -directional (angular) bonding



- **Ionic Ceramics (NaCl): Motion hard.**
  - -need to avoid ++ and -- neighbors.