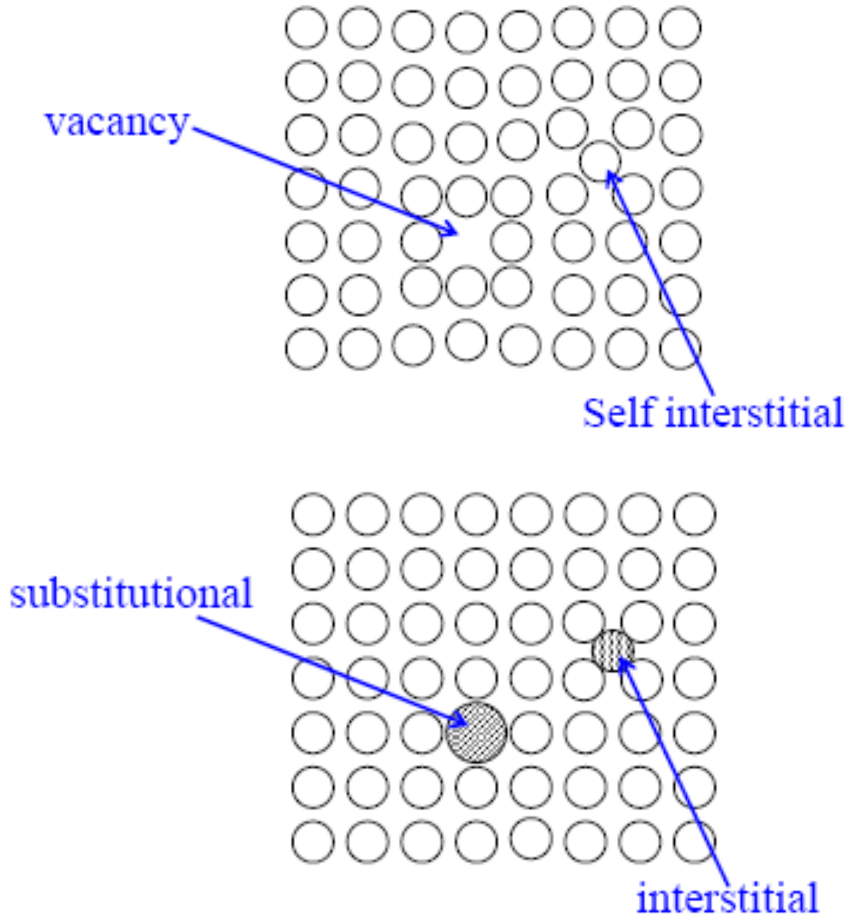
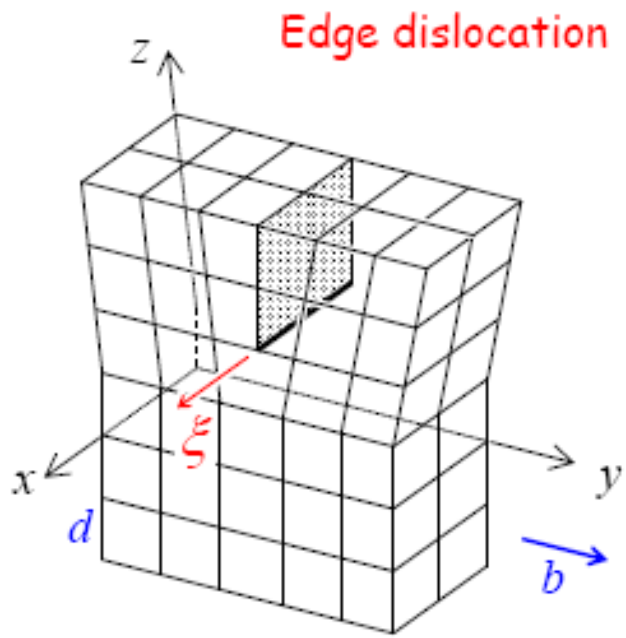
Imperfections in Crystals

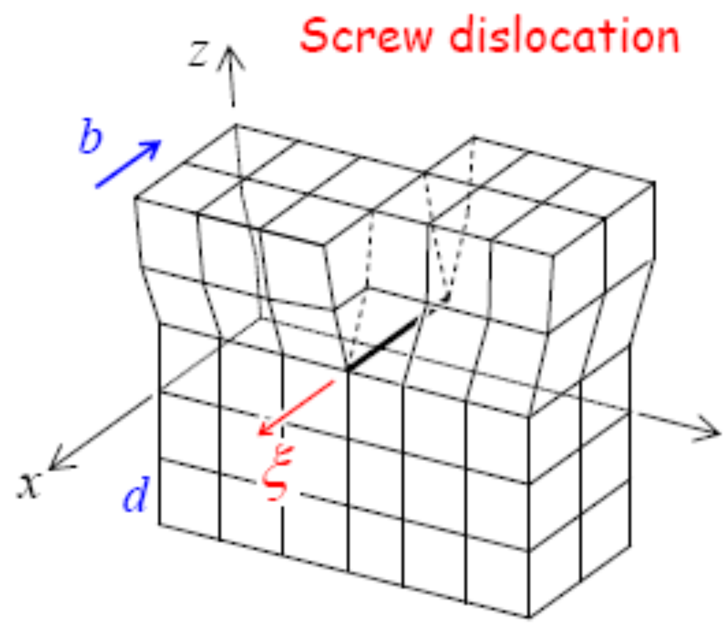
- Point defects (0-D):
  - Vacancy, impurity, interstitial and substitutional atoms.



Imperfections in Crystals

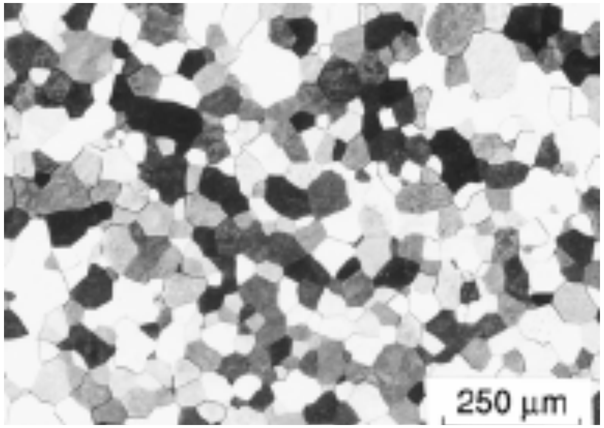
- Line Defects (1-D):
  - Dislocations (Linear defects around which atoms are "dislocated" from their equilibrium lattice positions).

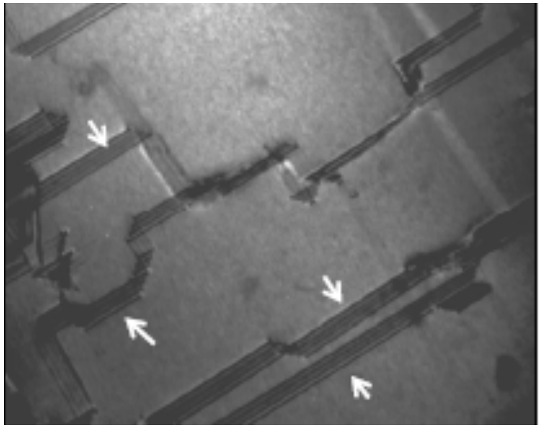


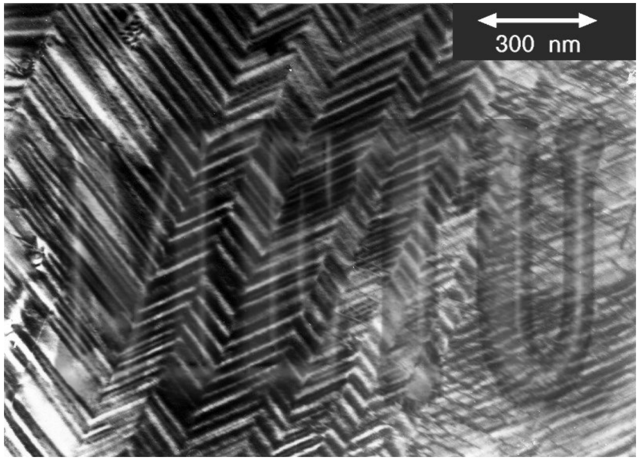


Imperfections in Crystals

- Planar Defects (2-D):
  - Grain boundaries, twin boundaries, stacking faults.

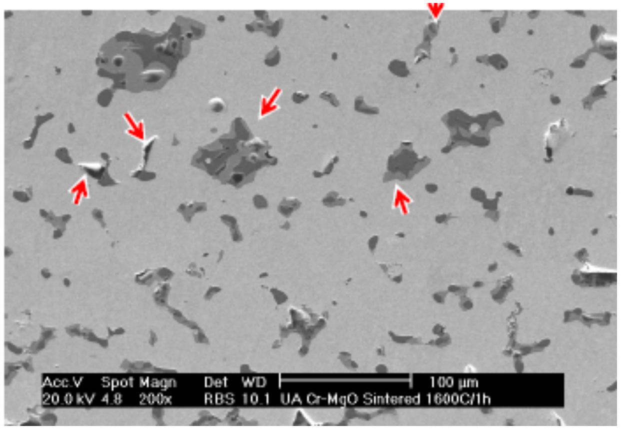


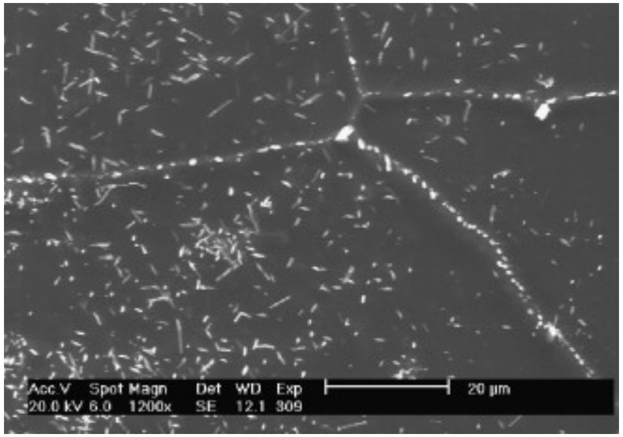


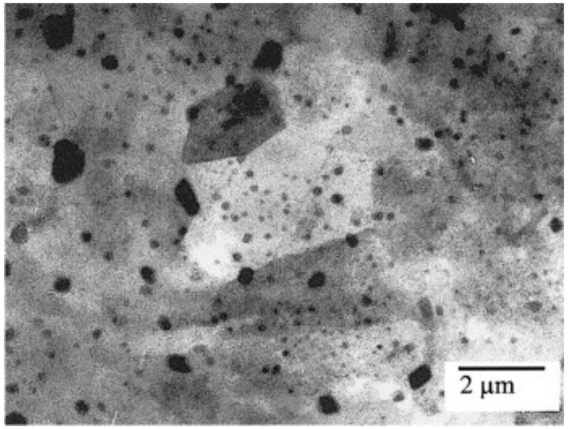


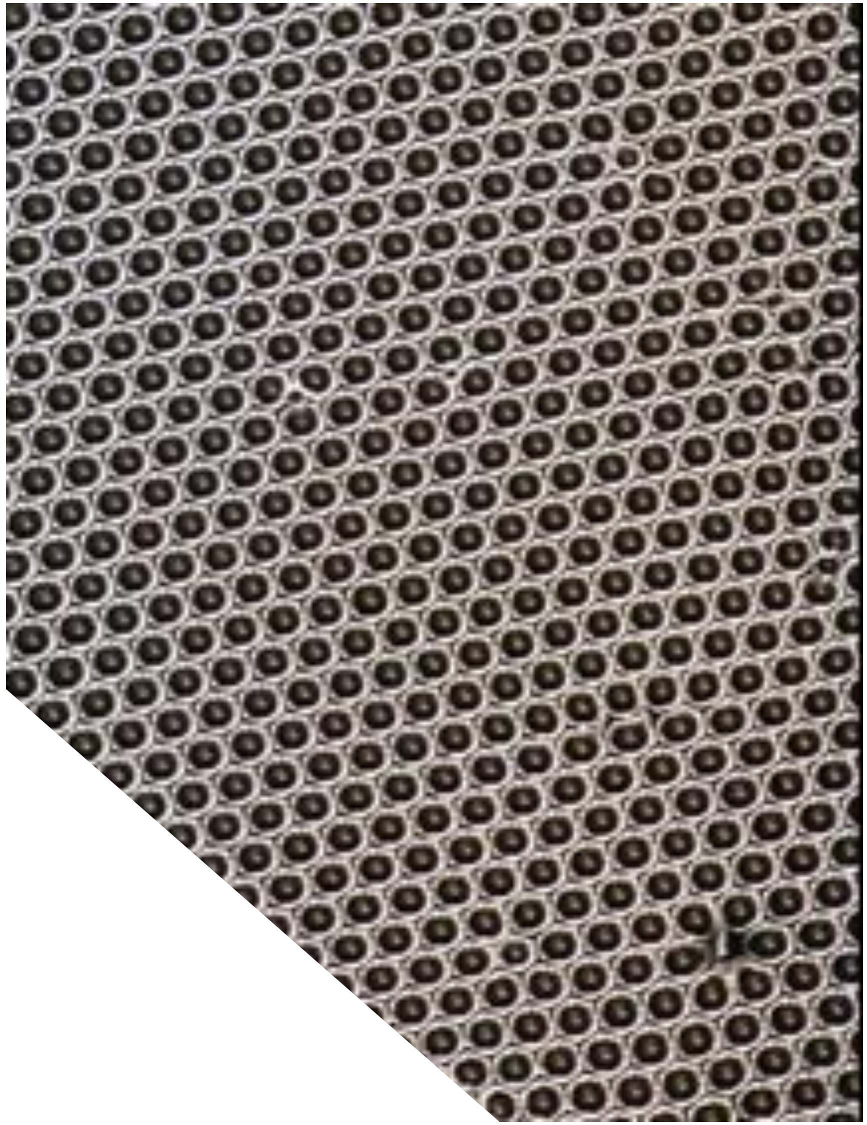
Imperfections in Crystals

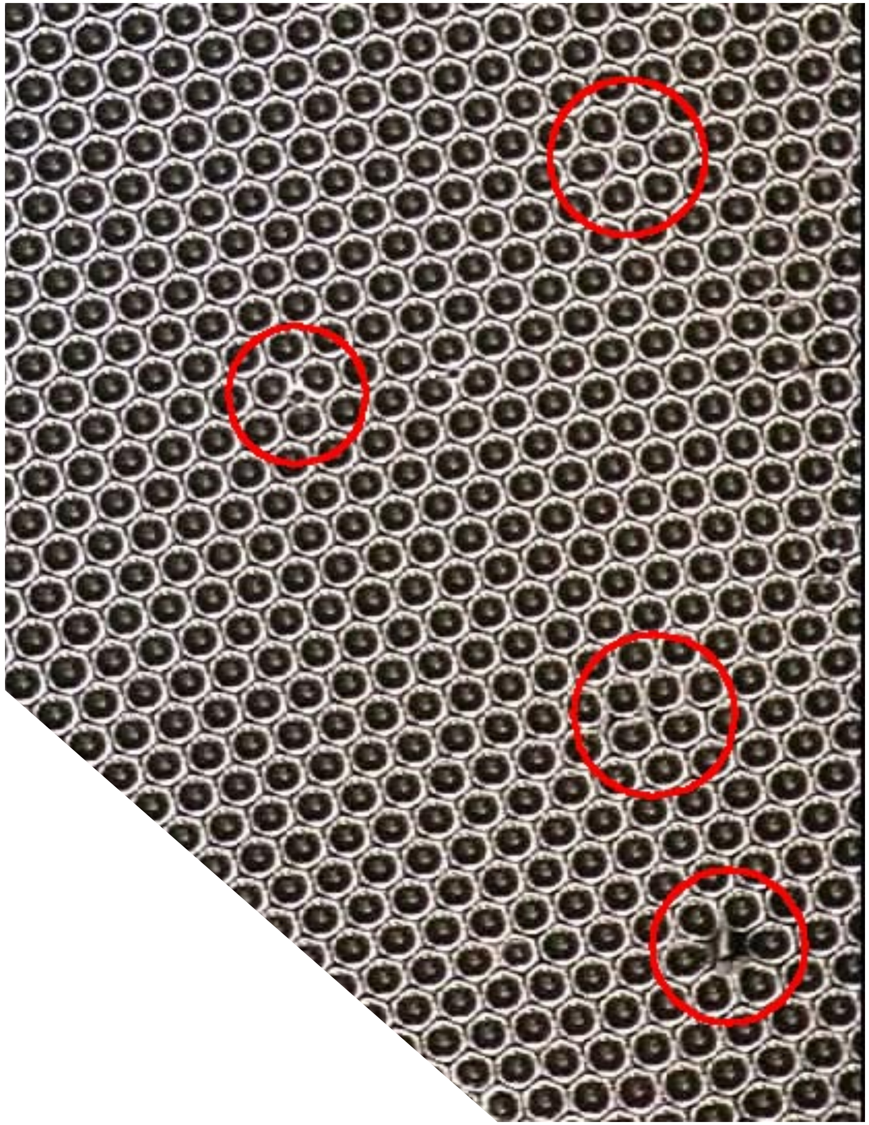
- Volume Defects (3-D):
  - ➢ Voids, inclusions, precipitates, dispersed particles.

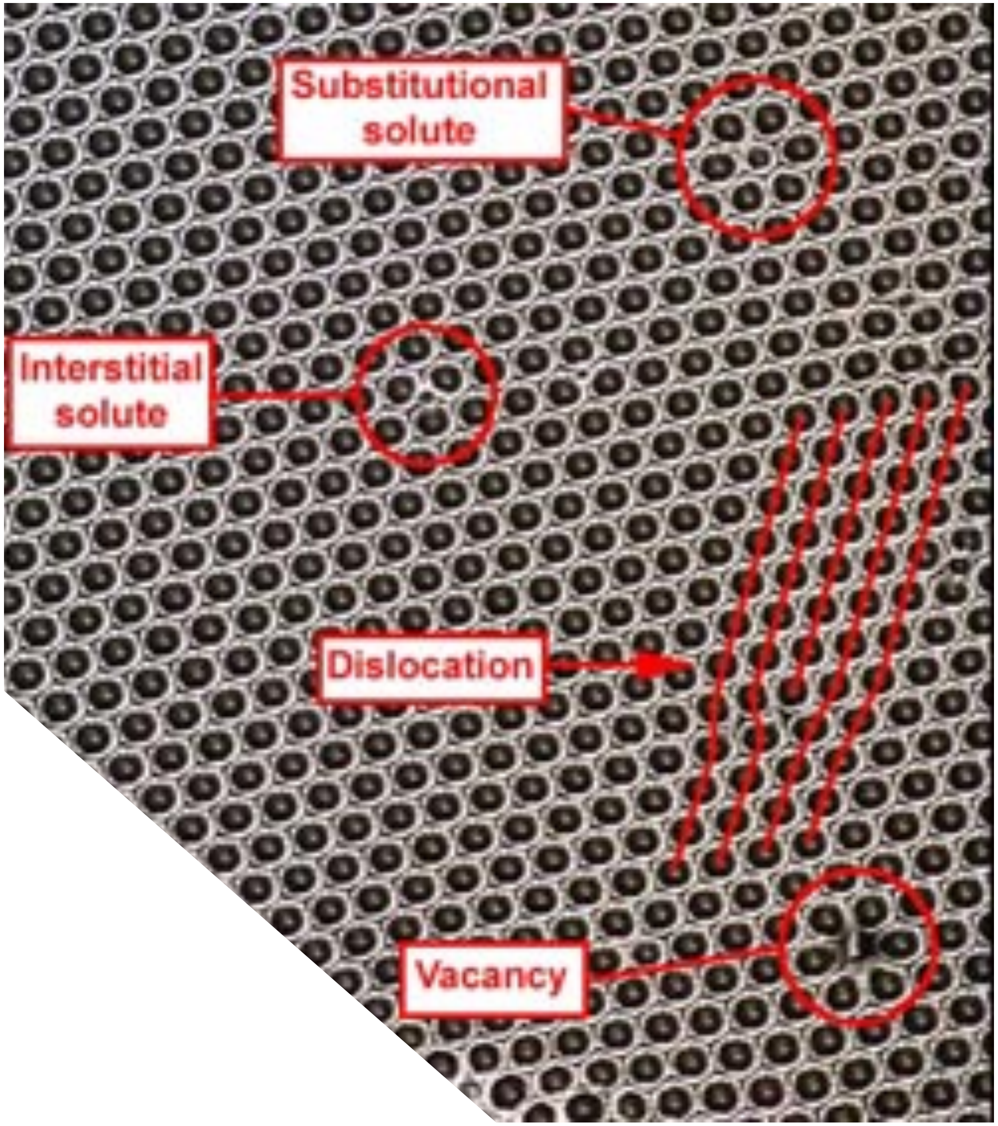


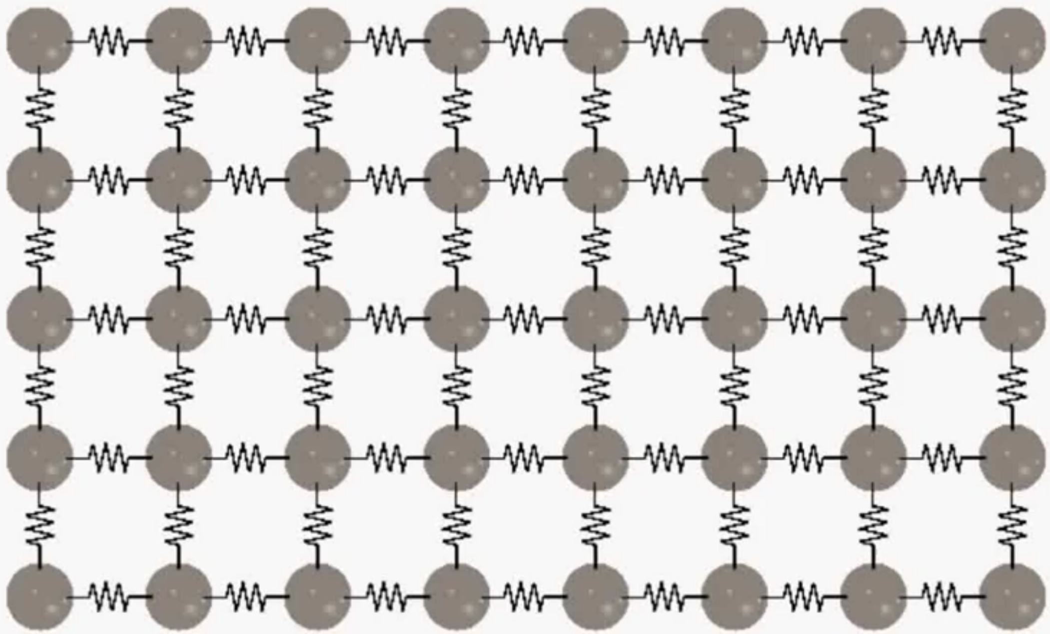








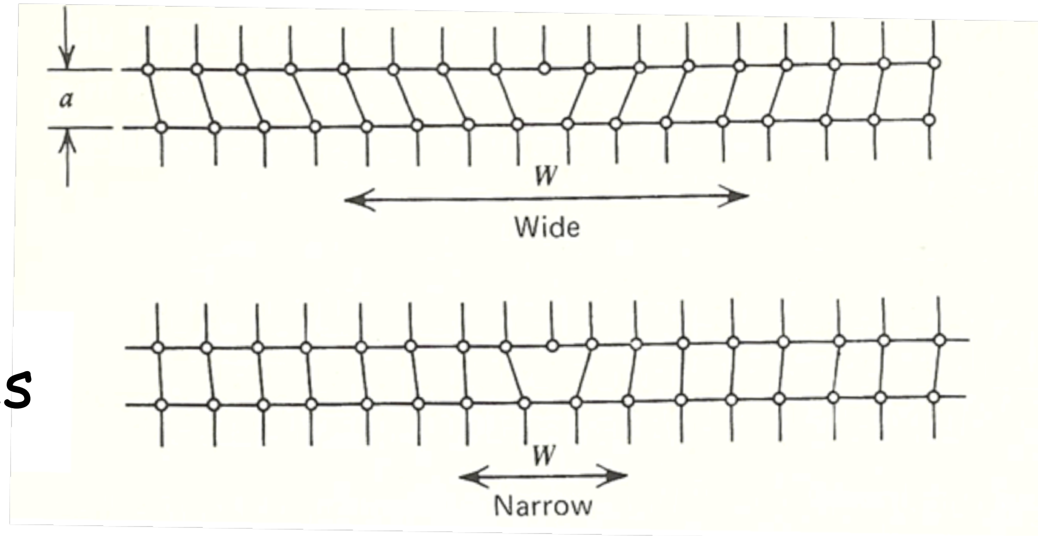

Substitutional solute
Interstitial solute
Dislocation
Vacancy



Slip by Dislocation Movement

fcc and hcp metals

bcc metals & ceramics



Magnitude of Peierls stress depends on w.

- If w ↓, interfacial energy ↓,

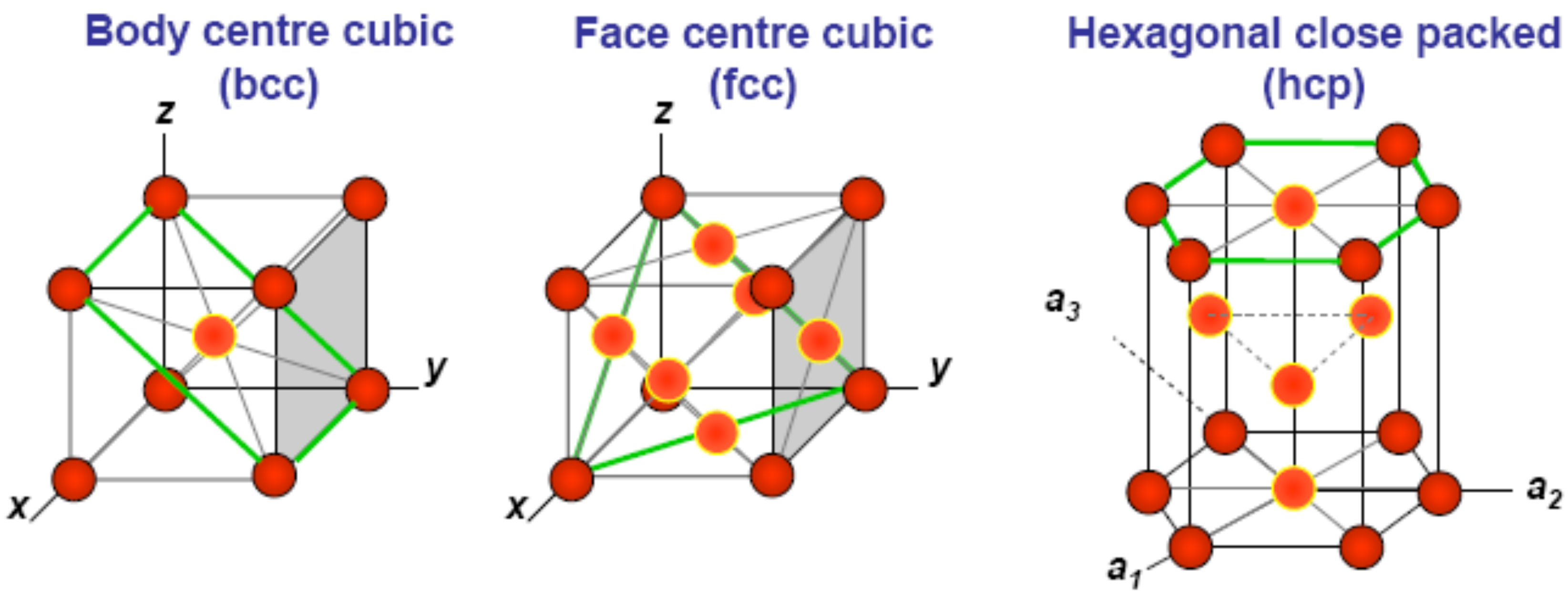
  elastic energy ↑.

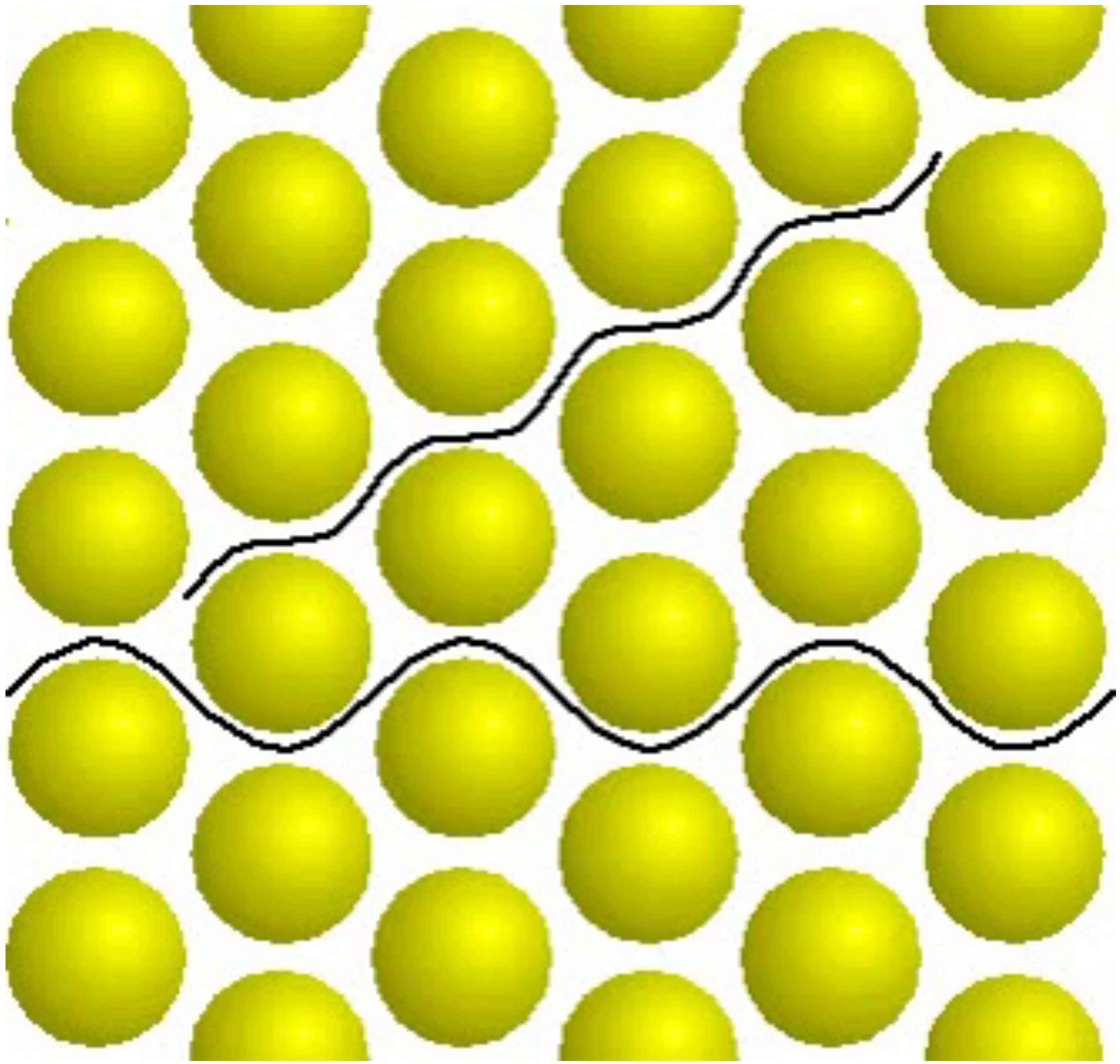
$$\tau_p \approx \frac{2G}{1-\upsilon}\exp\left(-\frac{2\pi w}{b}\right)$$

- When the crystal is complex without highly close-packed planes, dislocations tend to be immobile causing brittleness.

Slip Plane

- Plastic deformation is generally confined to the low-index planes, which has higher density of atom per unit area.
- The planes of greatest atomic density are also the most widely spaced planes for the crystal structure.





Slip Systems for FCC, BCC and HCP

FCC and BCC have at least 12 active slip systems

↓

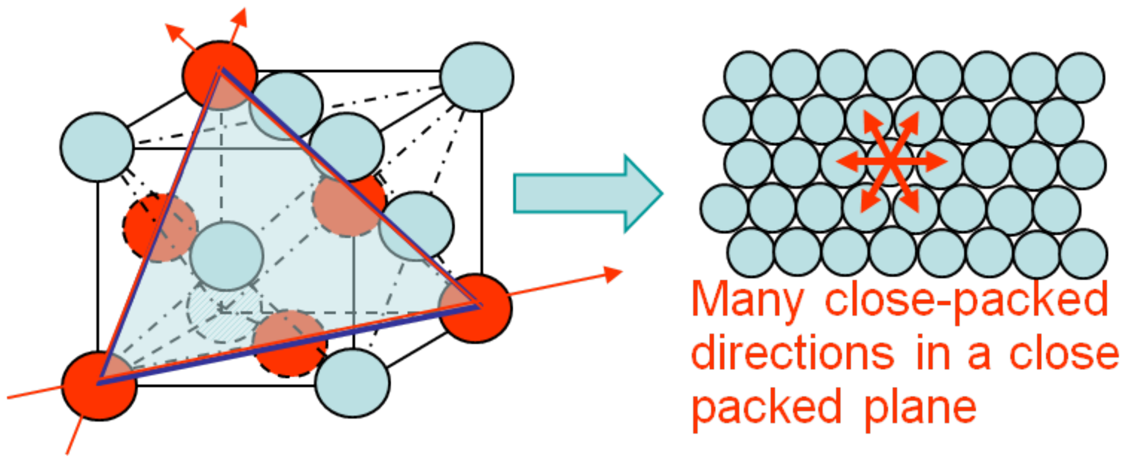
Extensive plastic deformation

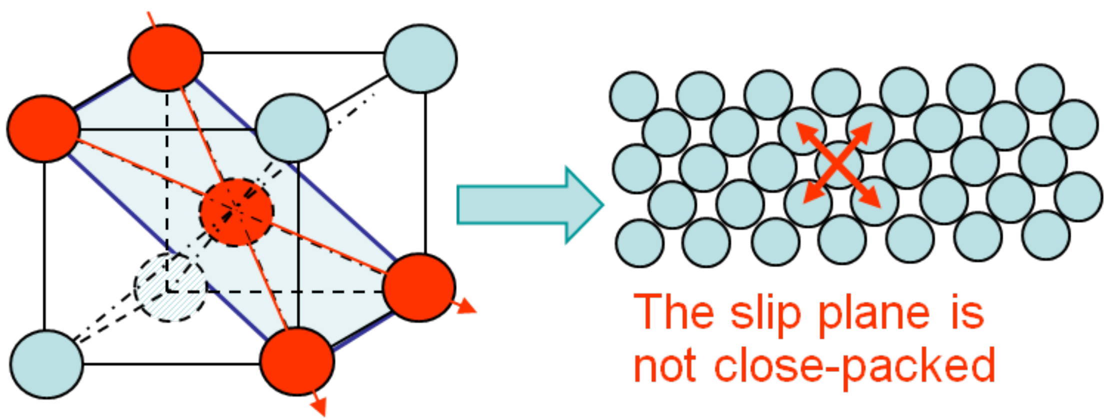
↓

Ductile

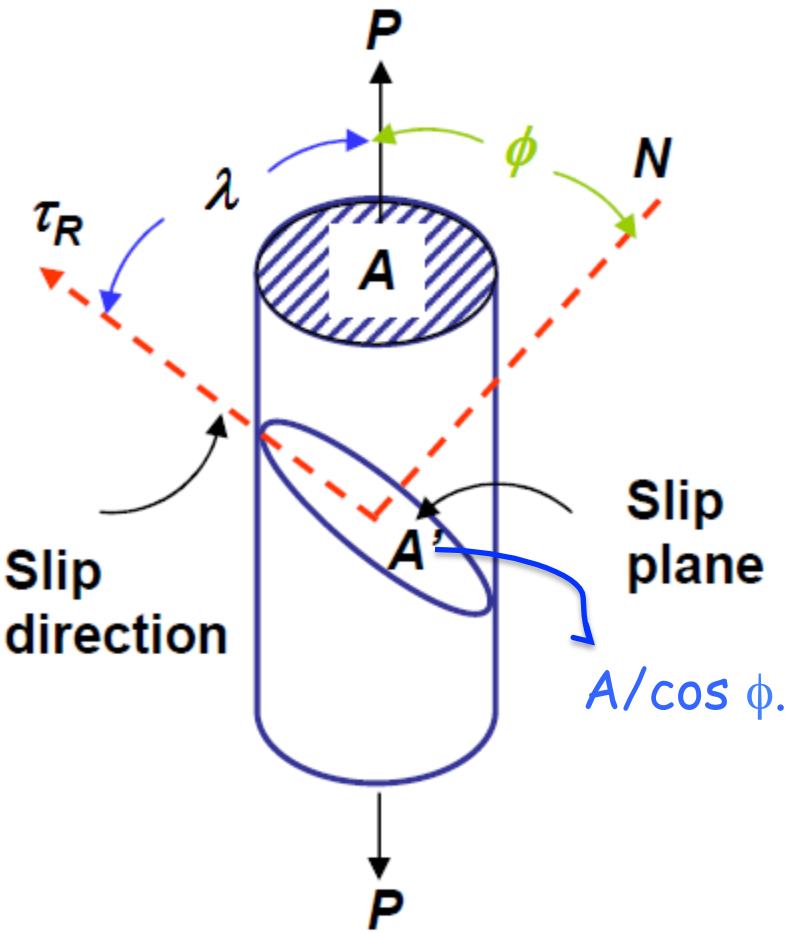
Metals	*Slip Plane*	*Slip Direction*	*Number of Slip Systems*
	Face-Centered Cubic		
Cu, Al, Ni, Ag, Au	$\{111\}$	$\langle 1\bar{1}0 \rangle$	12
	Body-Centered Cubic		
α-Fe, W, Mo	$\{110\}$	$\langle \bar{1}11 \rangle$	12
α-Fe, W	$\{211\}$	$\langle \bar{1}11 \rangle$	12
α-Fe, K	$\{321\}$	$\langle \bar{1}11 \rangle$	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

Slip Systems for FCC, BCC and HCP





Critical Resolved Shear Stress



The resolved shear stress:

$$\tau_R = \frac{P\cos\lambda}{A/\cos\phi} = \frac{P}{A}\cos\phi\cos\lambda$$

$\phi = \lambda = 45^o$ ⇨ τ_R is max.

$\phi = 0$ or $\lambda = 0$ ⇨ $\tau_R = 0$.

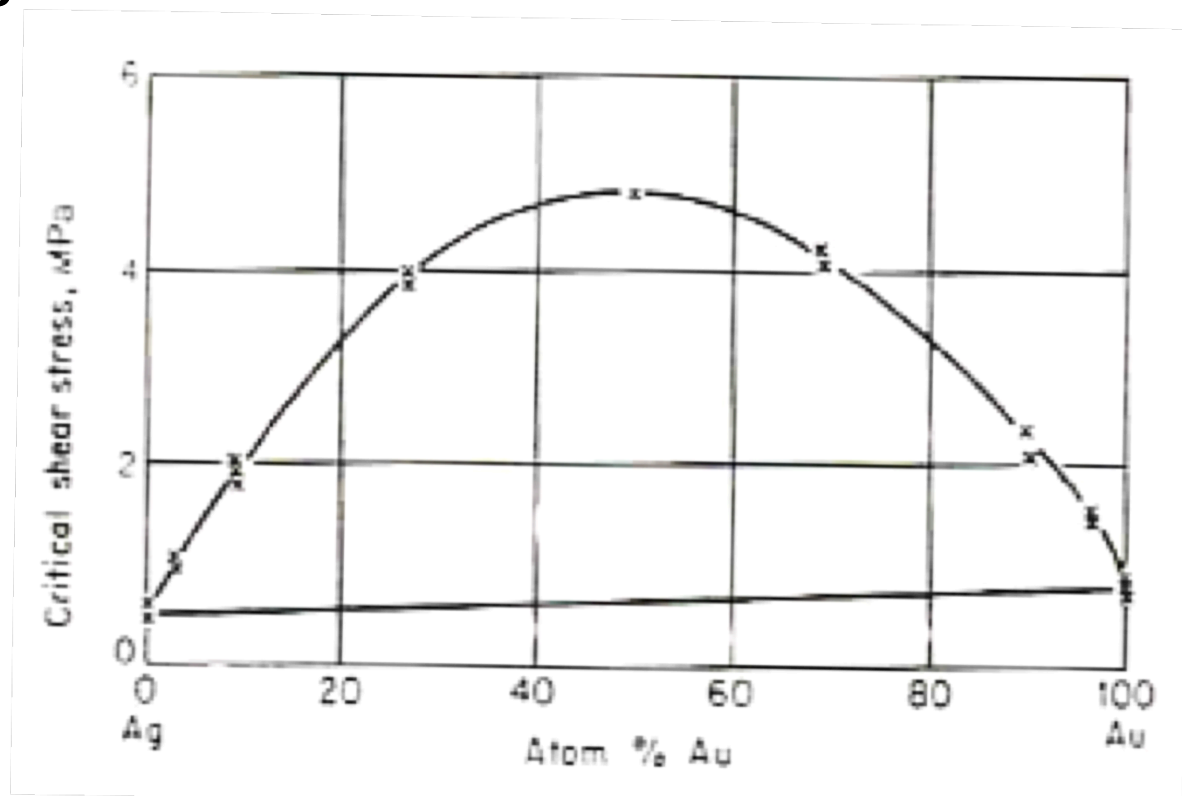
Slip occurs when $\tau_R \geq \tau_{CRSS}$

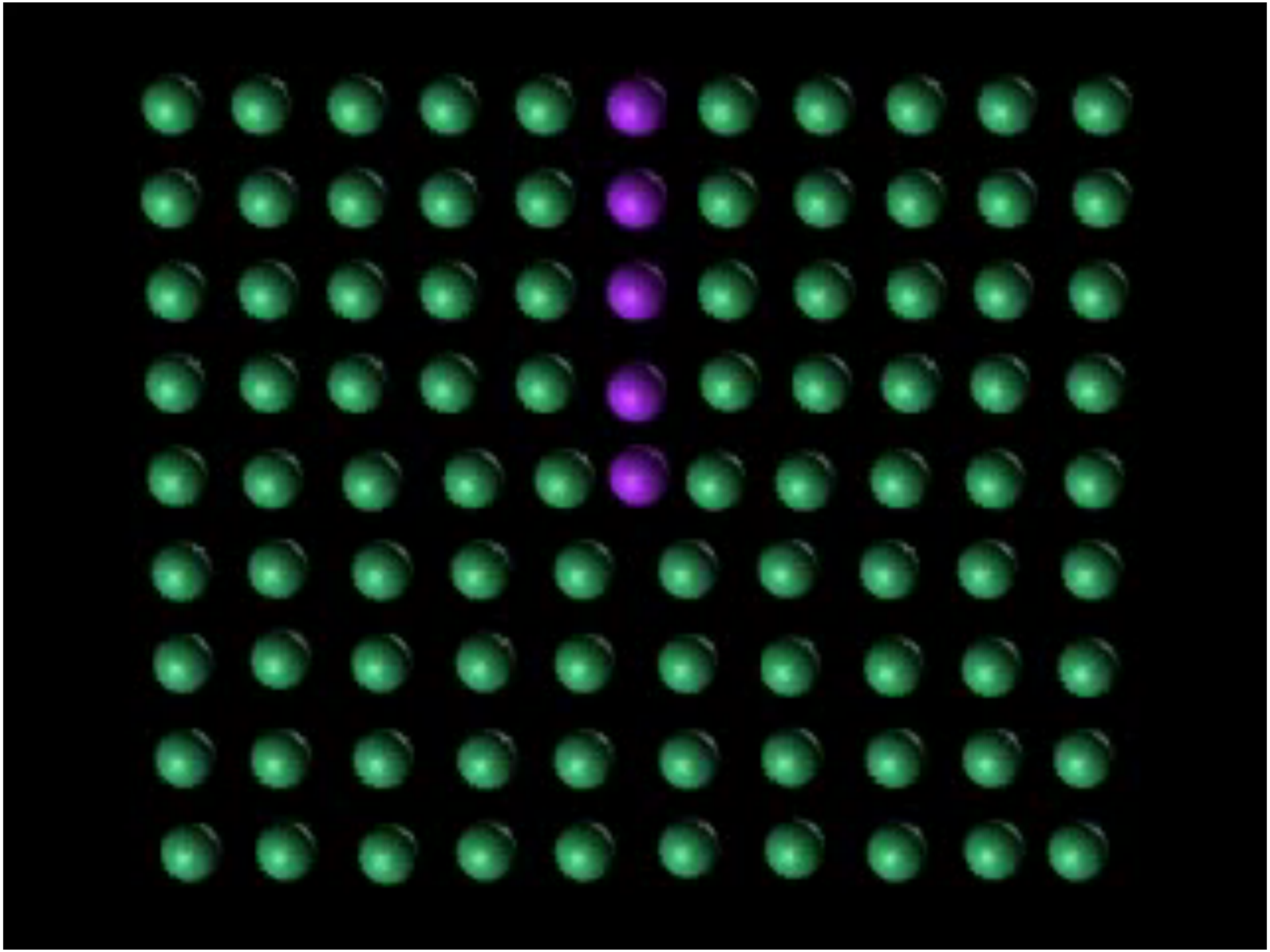
HW: Determine the tensile stress that is applied along $[1\bar{1}0]$ axis of a silver crystal to cause slip on the $(1\bar{1}\bar{1})[0\bar{1}1]$ system. CRSS is 6 MPa.

CRSS in Real Metals

Defects
Vacancies
Impurity atoms
Alloying elements

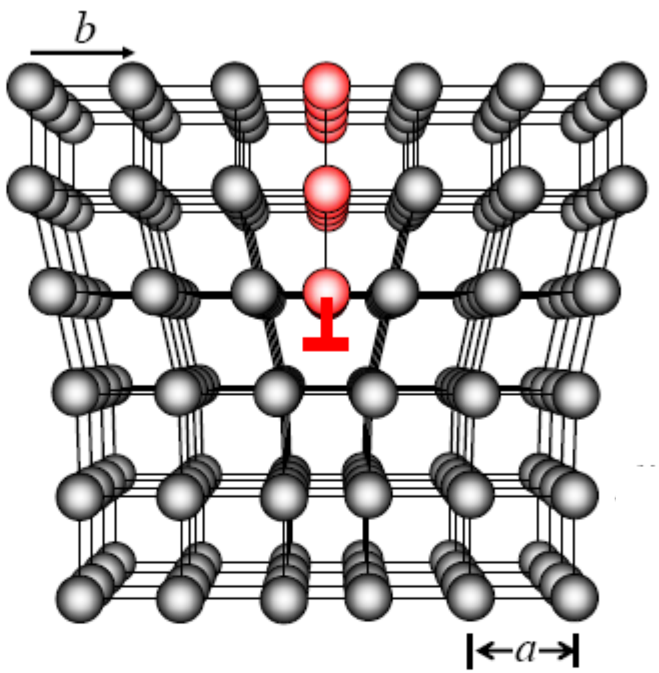
Critical resolved shear stress





Types of Dislocation

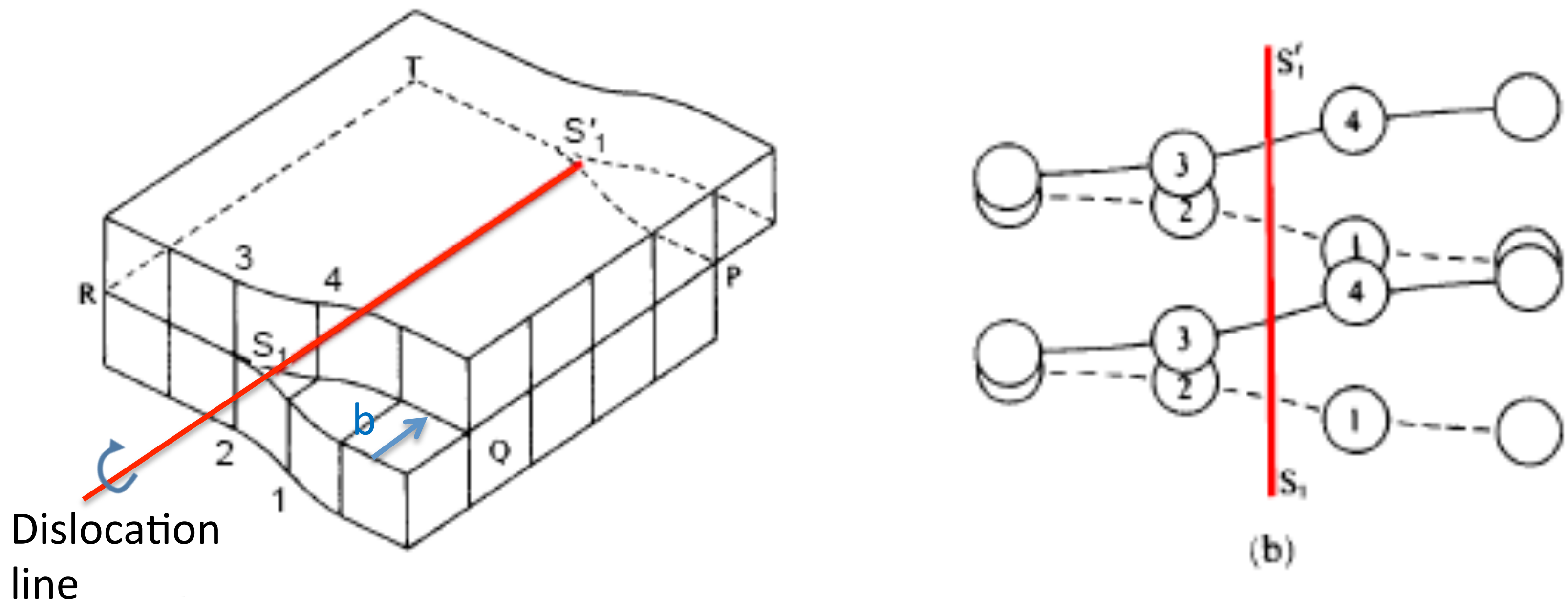
- Edge dislocation: Linear defect that centers around the line, which is defined along the end of the extra portion of a plane of atoms (half plane).

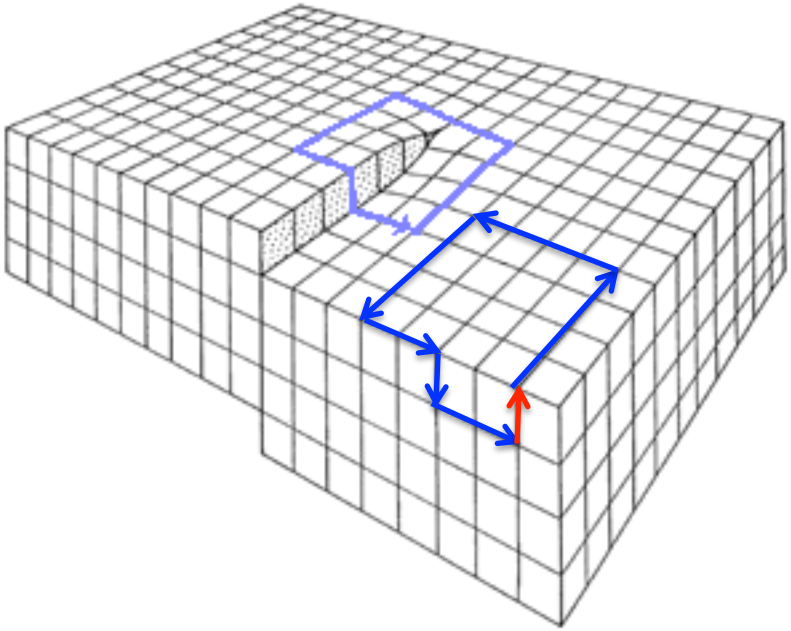


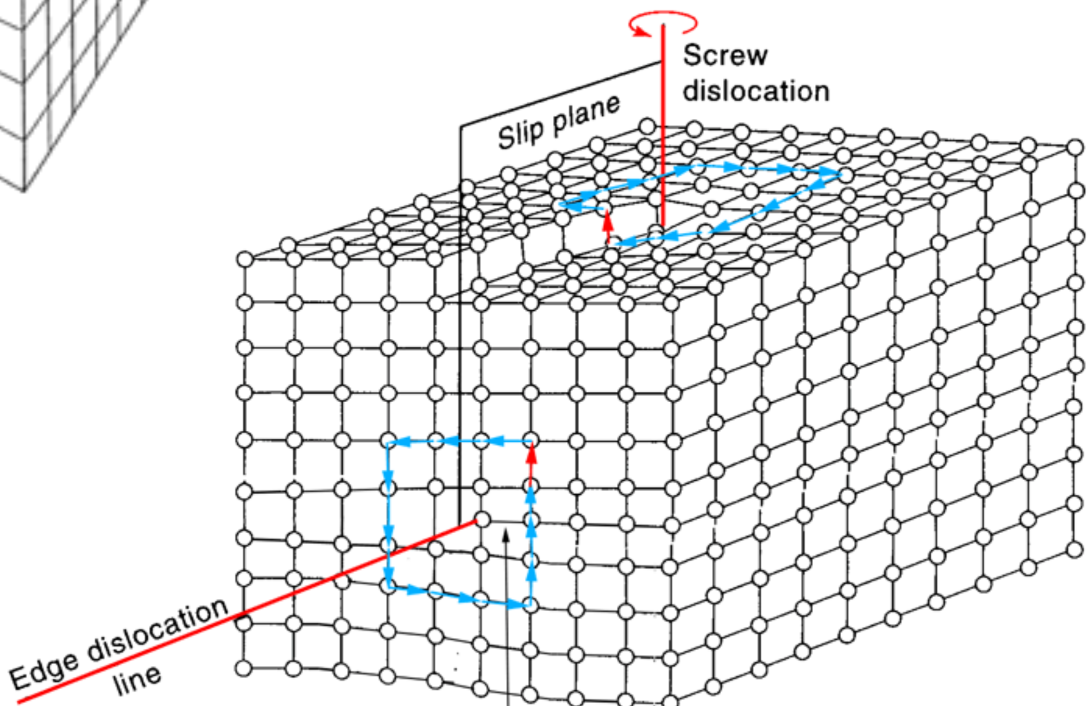
- Atoms above dislocation line are squeezed together (compressive), while those below are pulled apart (tensile), causing localized lattice distortion.
- The amount of displacement (Burgers vector, b) of the dislocation is always perpendicular to the dislocation line.

Types of Dislocation

- Screw dislocation may be thought of as being formed by applying a shear stress to produce a distortion.
  - ➢ The dislocation line is parallel to its Burgers vector, b or slip vector.






Screw
dislocation
Slip plane
Edge dislocation
line
Extra row
of atoms

Characteristics of Dislocations

Dislocation Characteristic	Type of Dislocation	
	Edge	Screw
Slip direction	Parallel to b	Parallel to b
Relation between dislocation line and b	Perpendicular	Parallel
Process by which dislocations can leave slip plane	Climb	Cross-slip

- Dislocations can terminate at free surfaces, or at grain or phase boundaries; but never within the crystal.
- Dislocations must form closed loops or networks with branches that terminate at a surface.
- The junction point within a network is called a node.