재료의 기계적 거동
(Mechanical Behavior of Materials)

Lecture 8 – Dislocations
(Defects and Properties)

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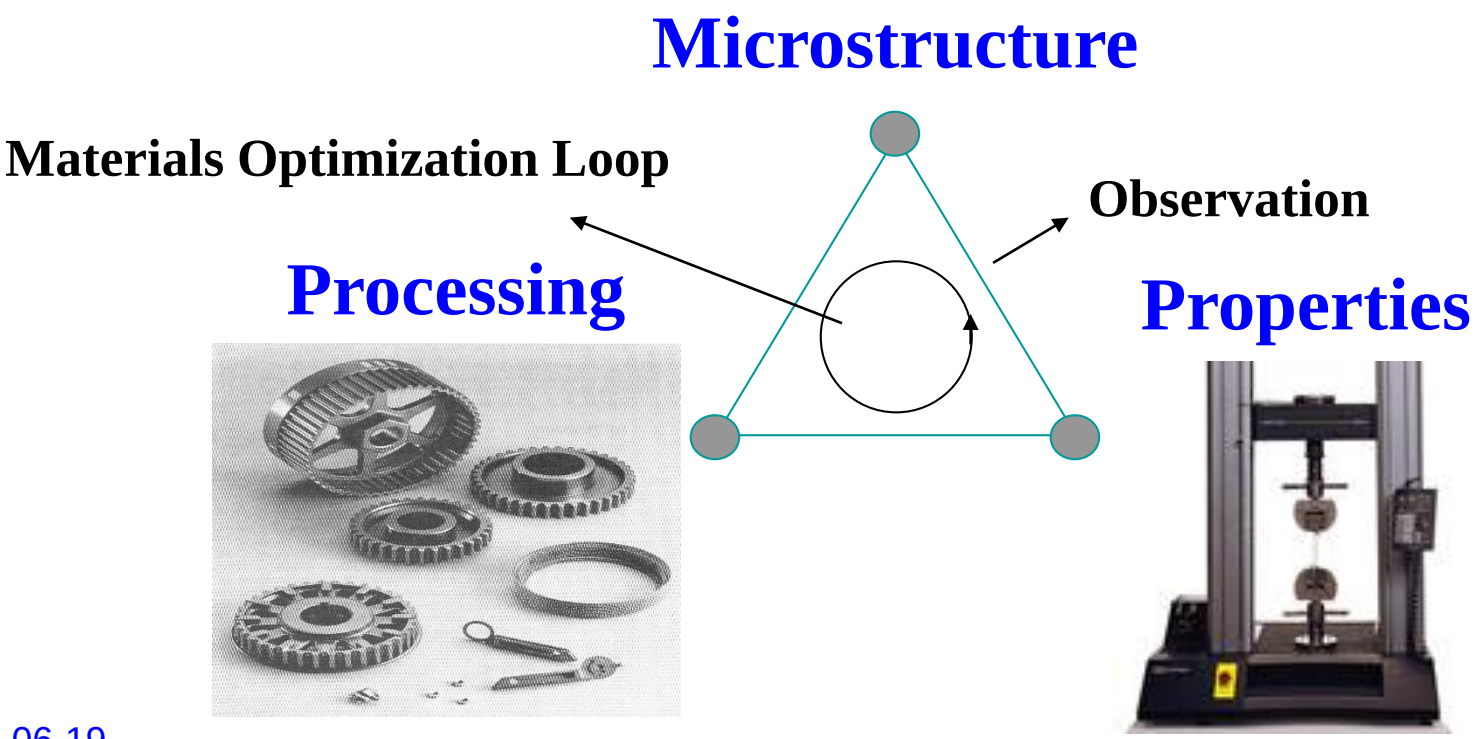
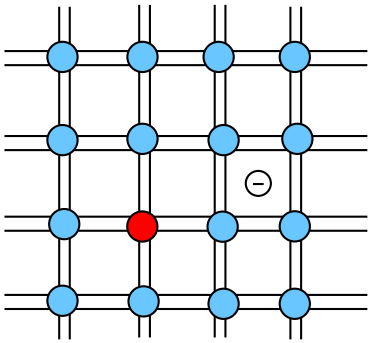
Why study defects in materials?

- Defects are present in all materials.
- It is defects that make materials much more interesting !
- Defects affect microstructures and properties of materials.
- Processing controls the presence and concentration of defects.



Point defects – the other properties

- Impurity doping in semiconductors
- Colors of ionic crystals
  - Fe & Ti in Sapphire
  - Cr 3+ in red Ruby



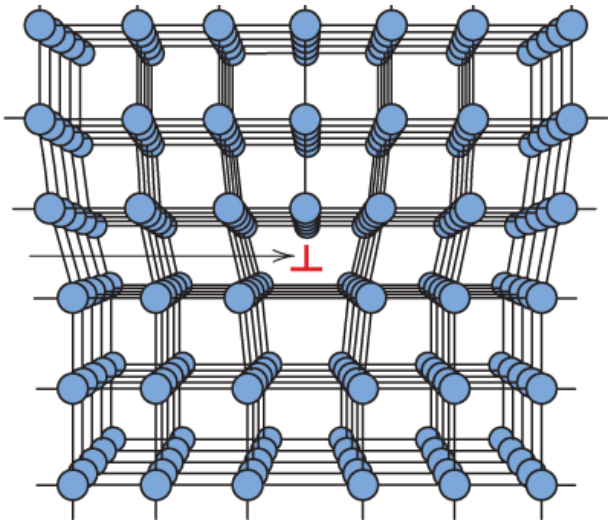
● = Semiconductor atoms

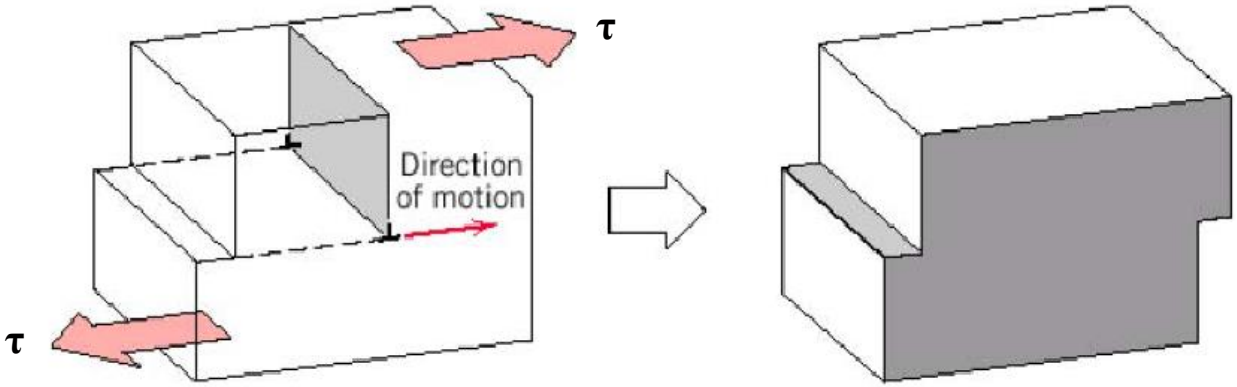
● = Impurity atom with three valence electrons

⊖ = Extra electron from impurity atom

Line defects (one dimension)

❖ **Edge Dislocation**

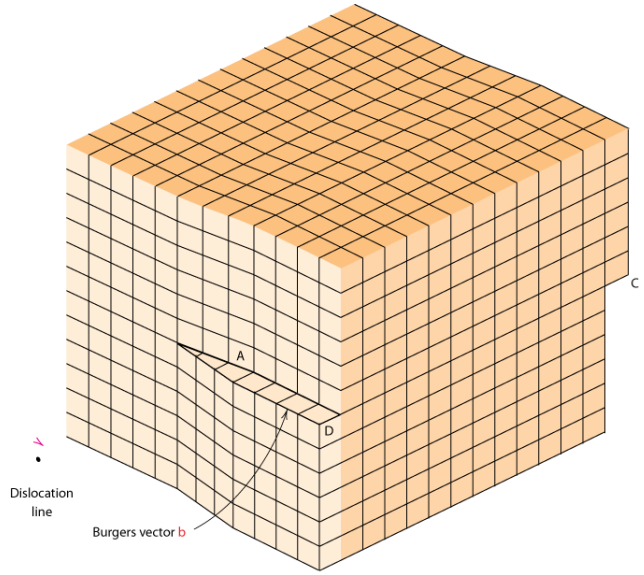


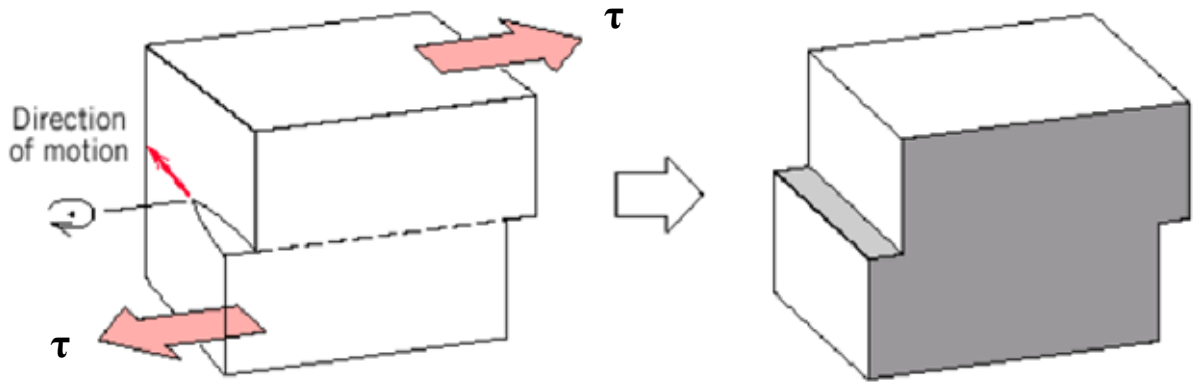


Edge dislocation line moves parallel to applied stress

Line defects (one dimension)

❖ **Screw Dislocation**

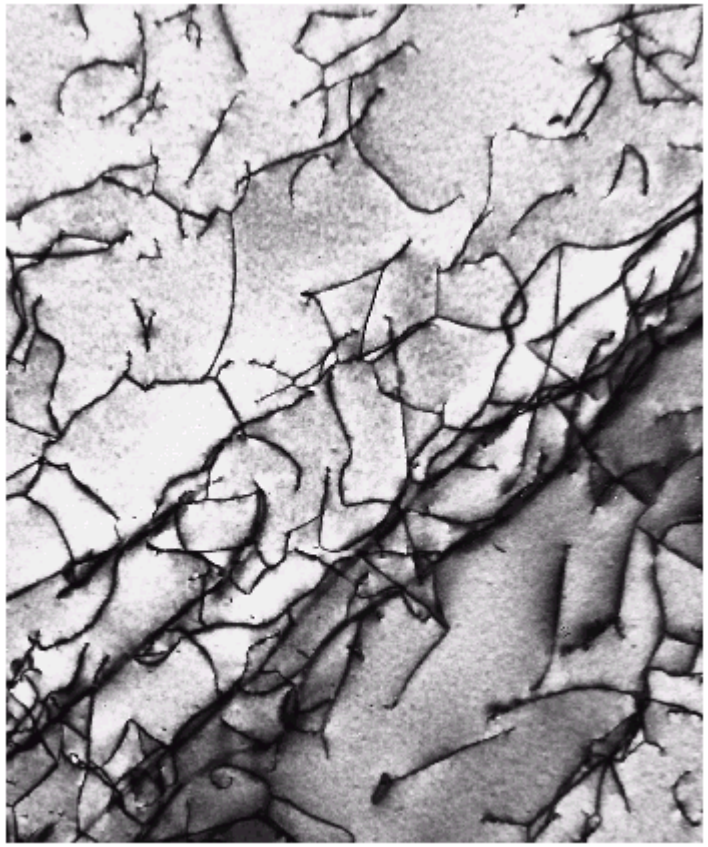




Screw dislocation line moves perpendicular to applied stress

Dislocation

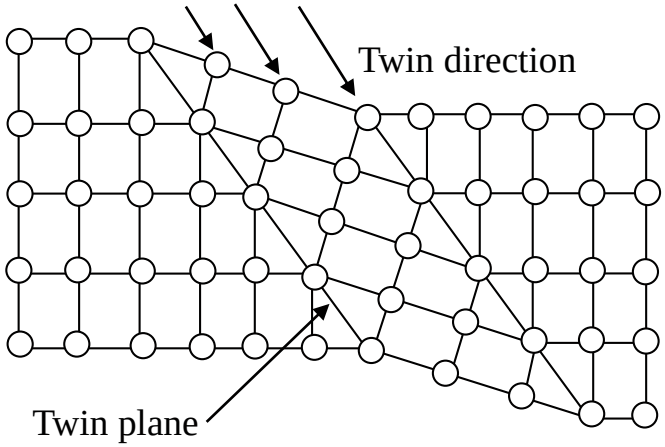
Dislocations are visible in electron micrographs



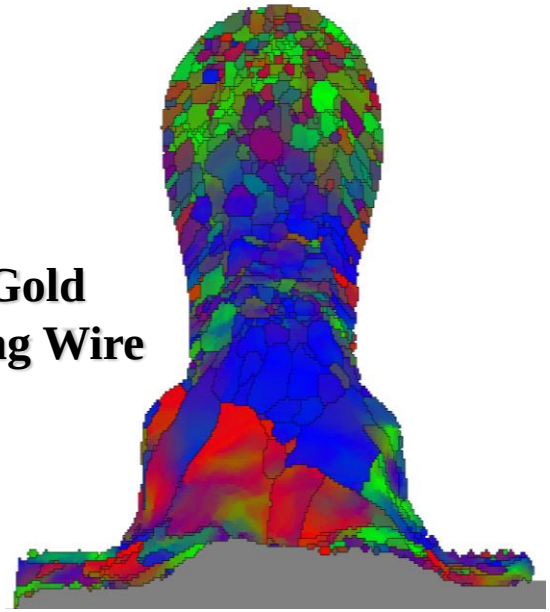
Adapted from Fig. 4.6, *Callister 7e.*

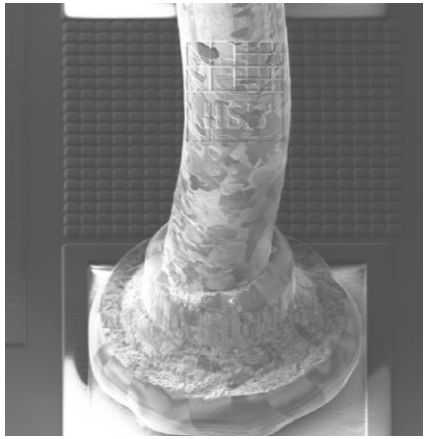
Planar defects (two dimension)

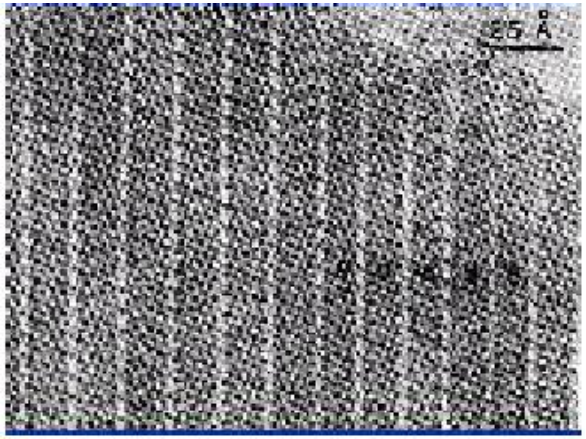
- Grain boundaries
- Twin boundaries
- Stacking faults
- Phase boundaries



MKE Gold Bonding Wire

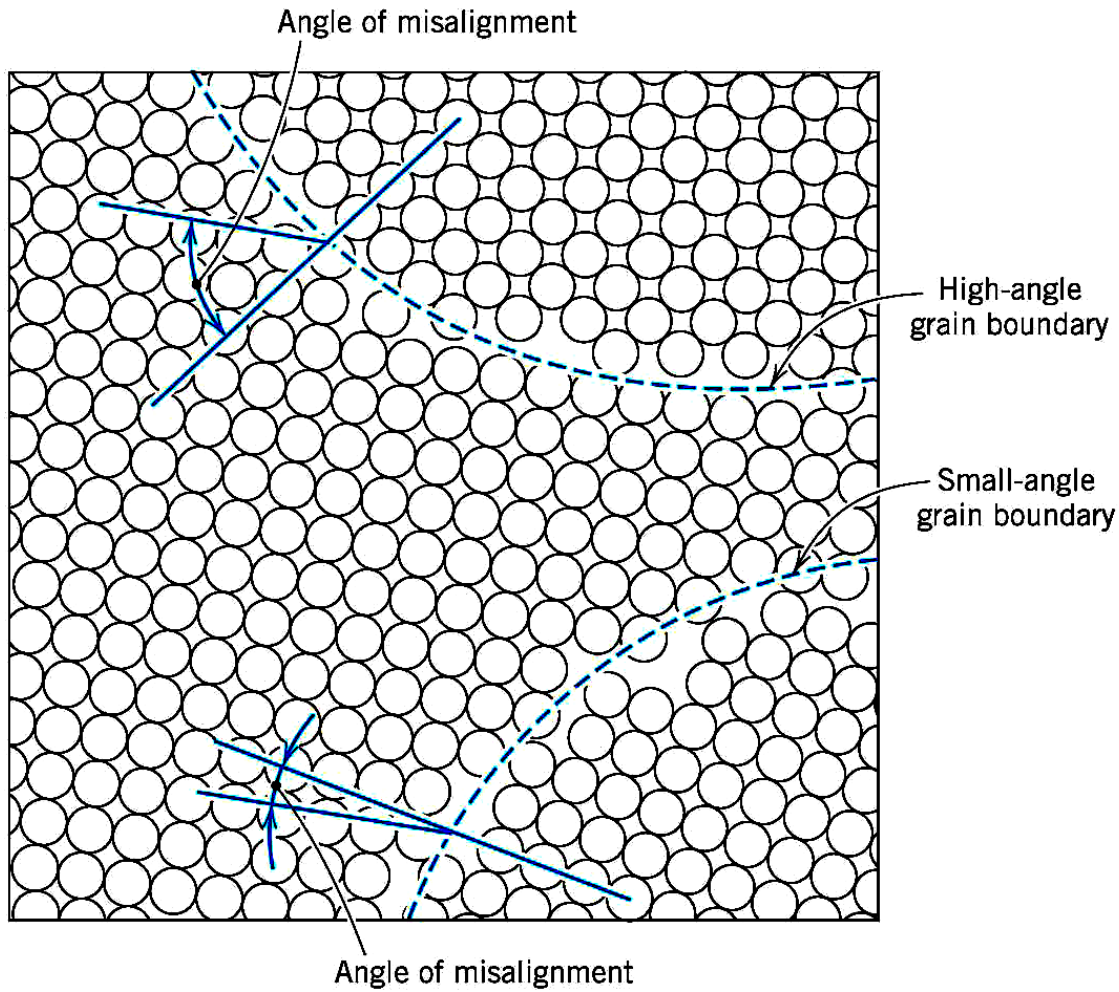


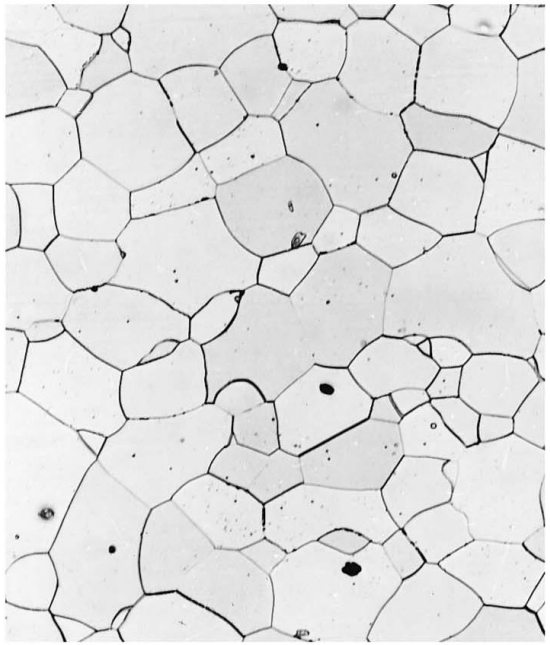




Stacking Fault

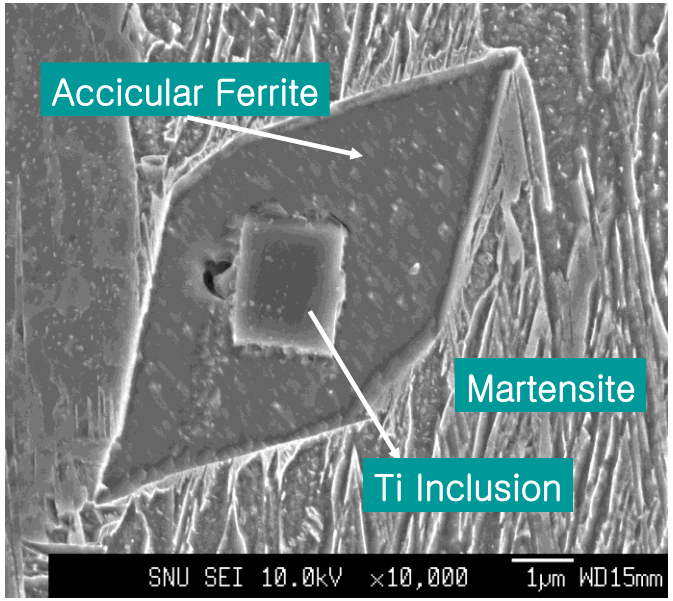
Grain Boundary

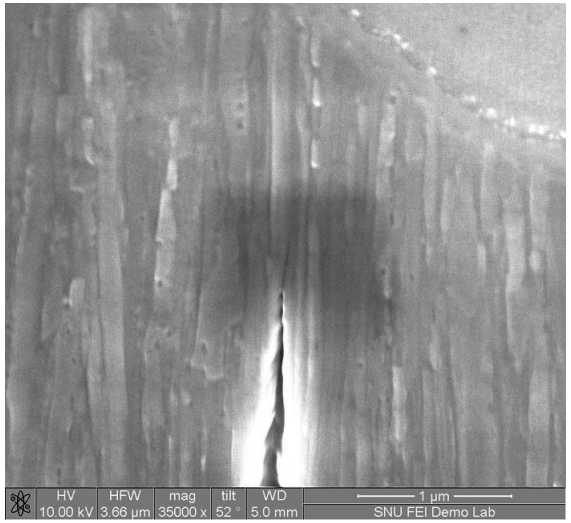




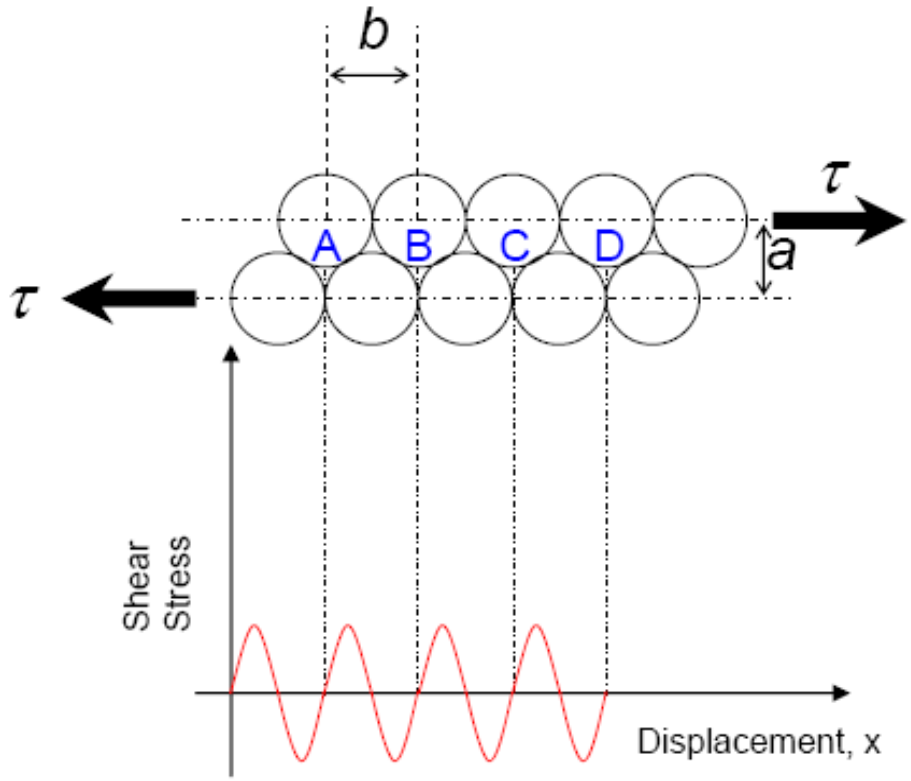
Bulk defects (three dimension)

- Voids
- Cracks
- Inclusions





Theoretical strength of a perfect crystal



$$\tau_{\max} = \frac{Gb}{2\pi a} \cong \frac{G}{2\pi}$$

$$\tau_{\max} \cong \frac{G}{30}$$

$$\tau = \tau_{\max} \sin\left(\frac{2\pi x}{b}\right), \gamma = \frac{x}{a}$$

Theoretical Strength & Experimental Strength

Material	τ_{th} (= $G/30$) (10^9 N/m^2)	τ_{exp} (10^6 N/m^2)	τ_{exp}/τ_{th}	τ_f (10^6 N/m^2)*
Ag	1.0	0.37	0.00037	20
Al	0.9	0.78	0.00087	30
Cu	1.4	0.49	0.00035	51
Ni	2.6	3.2	0.0070	121
α-Fe	2.6	27.5	0.011	150

There is much difference between theoretical and experimental strength.

The reasons are:

1. Defects are present in all perfect crystals.
2. One type of defects, called dislocation, moves during plastic deformation and makes plastic deformation easier than predicted by the Frenkel calculation.

* Whisker is close to the theoretical strength.

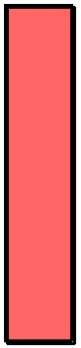
Dislocation

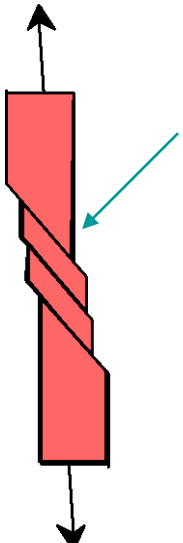
Dislocations:

- are line defects,
- cause slip between crystal plane when they move,
- produce permanent (plastic) deformation.

Schematic of a Zinc (HCP):

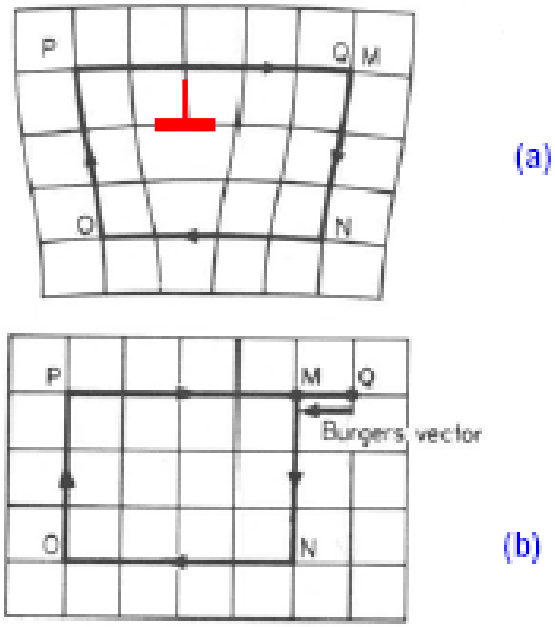
- before deformation
- after tensile elongation





Burgers circuit & Burgers vector

- Burgers circuit: any close loop contains dislocations by an atom to atom path
- Burgers vectors: the vector required to complete the circuit in a perfect crystal; the direction of atom displacement

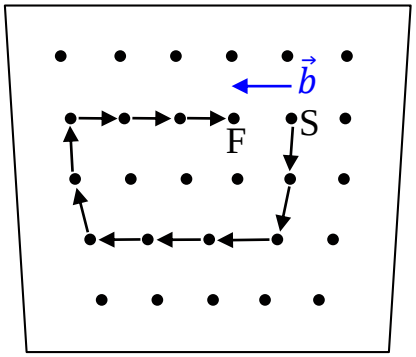


(a) Burgers circuit round an edge dislocation
(b) the same circuit in a perfect crystal

Edge Dislocation

The Burgers vectors for given dislocations never change!

Burgers circuit & Burgers vector



Burgers vector : closure failure of Burgers circuit.

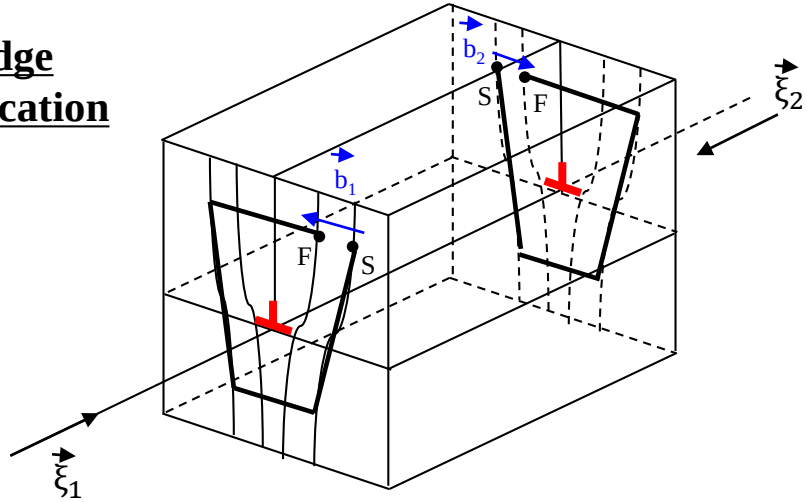
drawn from Start(S) to Finish(F)

RH / SF convention.

(circuit must be drawn around dislocation line.)

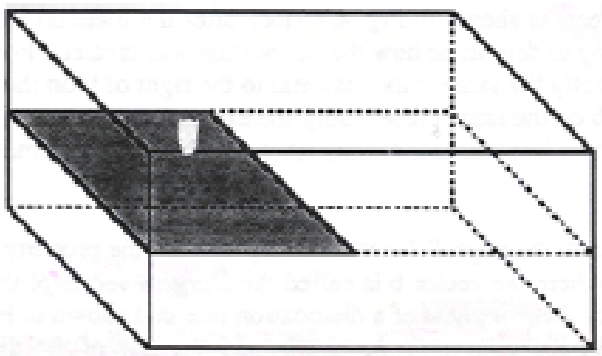
Character of Dislocation based on vector Description

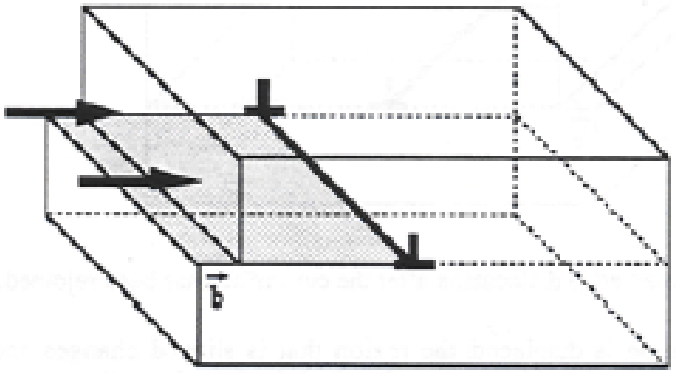
Edge Dislocation



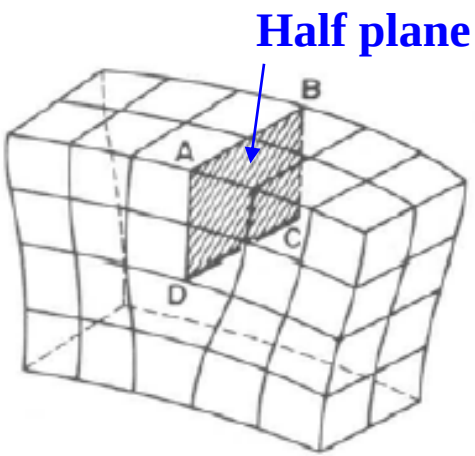
Geometry of dislocation: edge dislocation

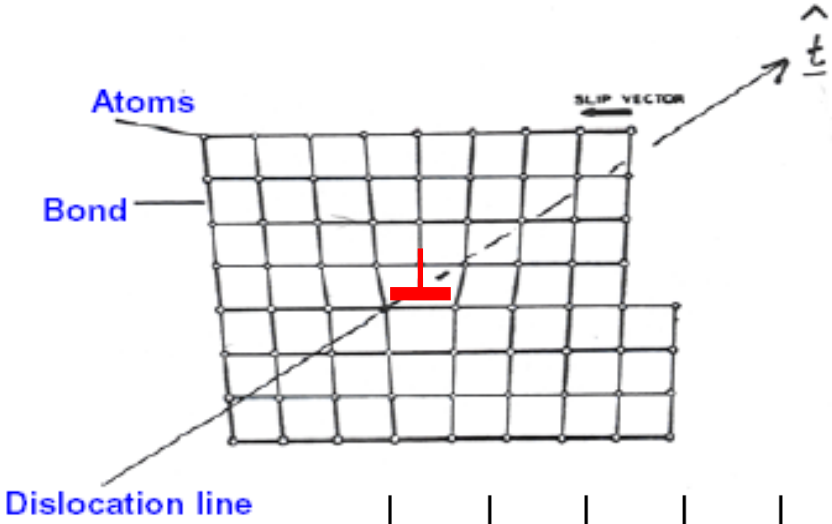
- Slip plane: where slip occurs.
- Dislocation line: boundary between the slipped and unslipped part of a crystal
- Slip plane contains both Burgers vectors and dislocation line
- Edge dislocation: dislocation line is perpendicular to Burgers vector



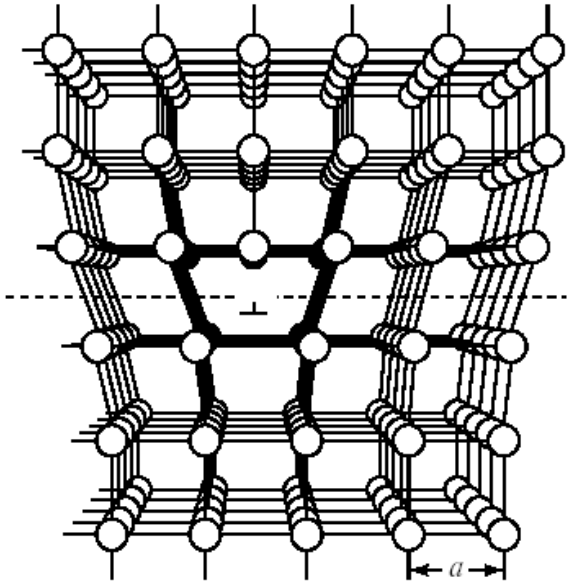


Model of an edge dislocation



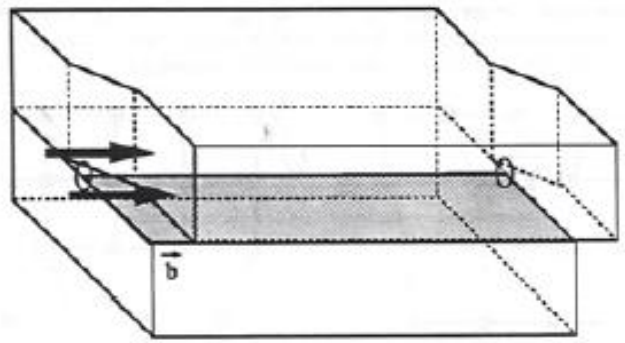


Symbols:
⊥: Positive edge dislocation
T : Negative edge dislocation

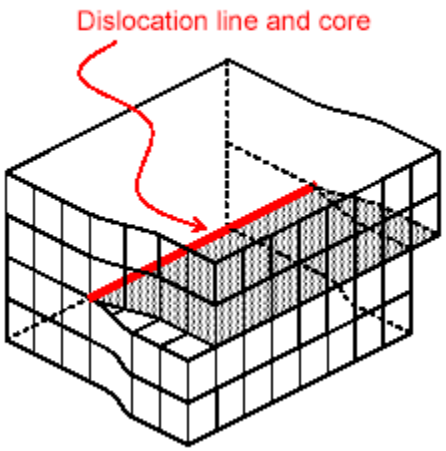


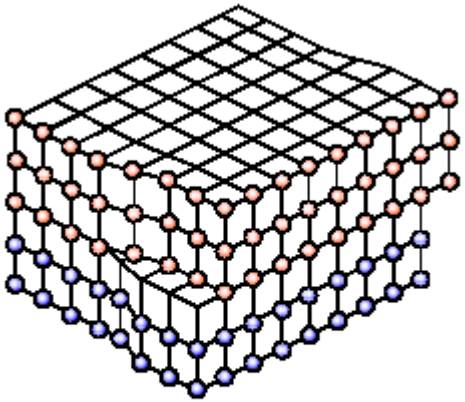
Geometry of dislocation: screw dislocation

- Screw dislocation: the dislocation line is parallel to Burgers vector



Screw dislocation



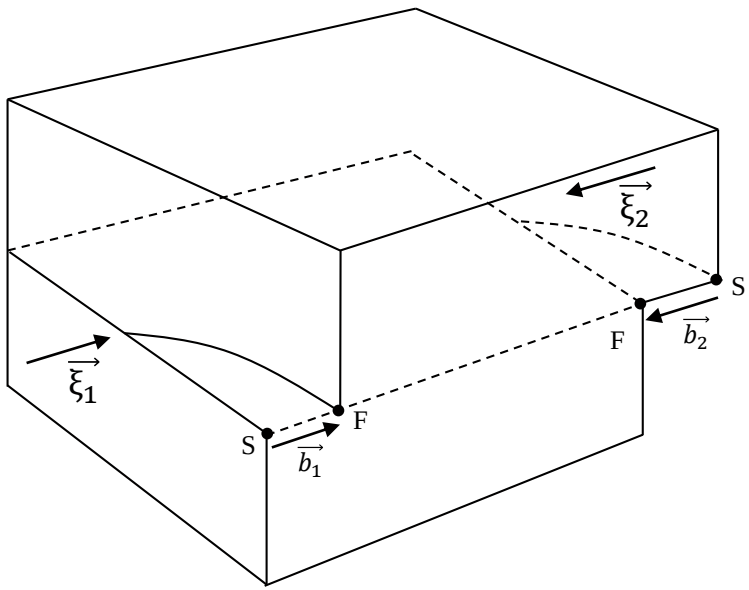


Atoms below slip plane

Atoms above slip plane

Burgers circuit & Burgers vector

Screw Dislocation



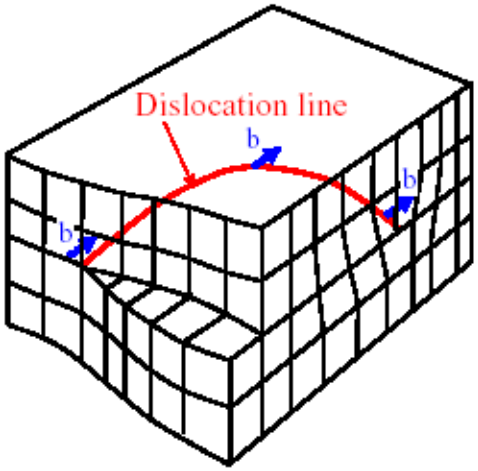
$\vec{\xi} \cdot \vec{b}$ = positive for RHS.

Neither $\vec{\xi}$ nor $\vec{b}$ unique.

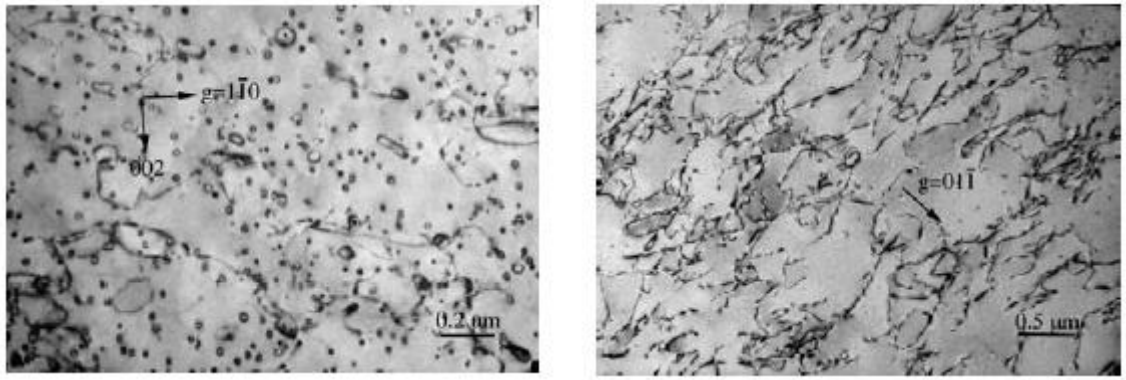
$\vec{\xi} \cdot \vec{b}$ = negative for LHS.

Characteristics of dislocations

Dislocation Characteristic	Type of Dislocation		
	Edge	Screw	**Mixed**
Slip direction	// to *b*	// to *b*	Not // to *b*
Relation between dislocation line and *b*	⊥	//	Not // or ⊥
Direction of line movement relative to *b*	//	⊥	// and ⊥



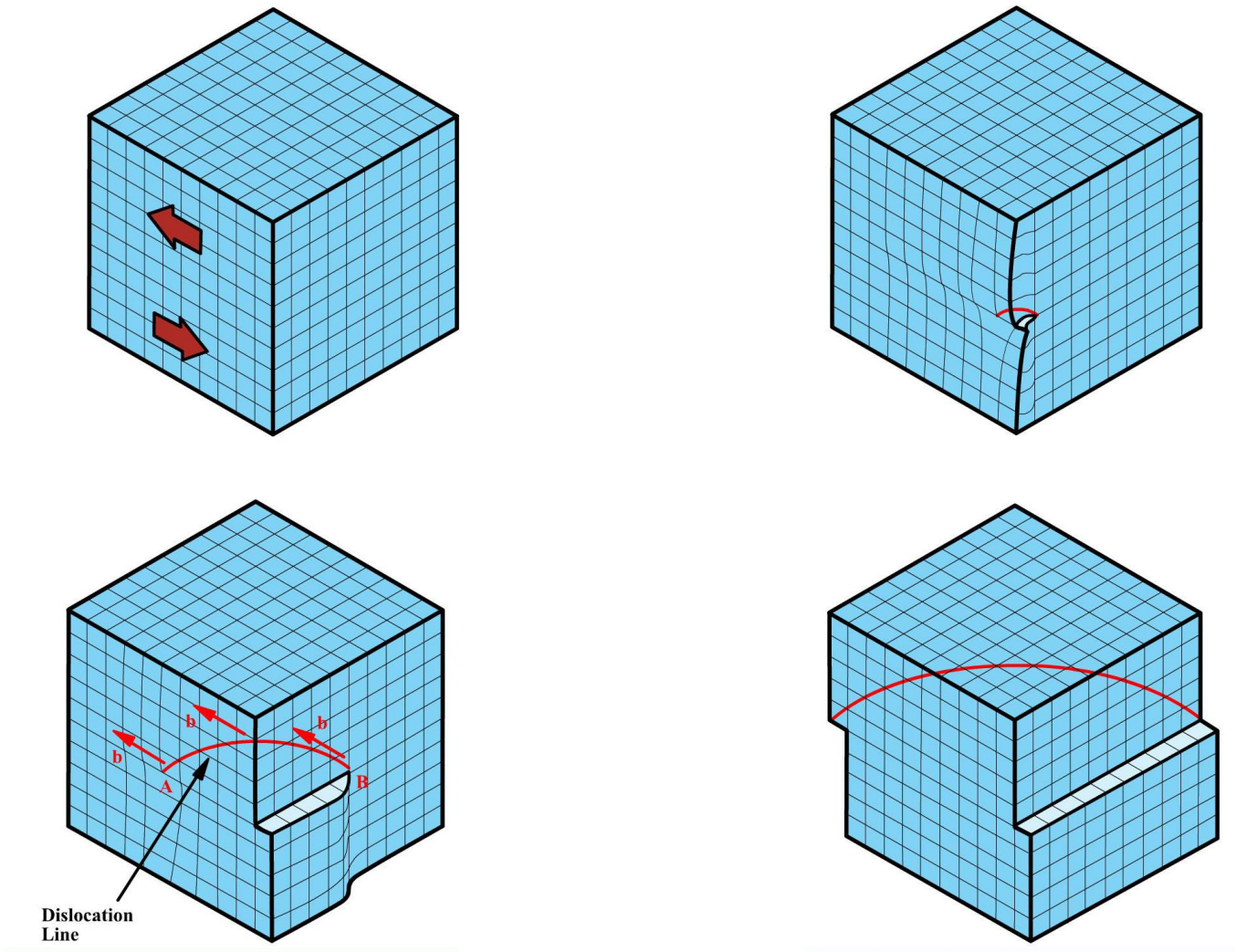
Mixed dislocation



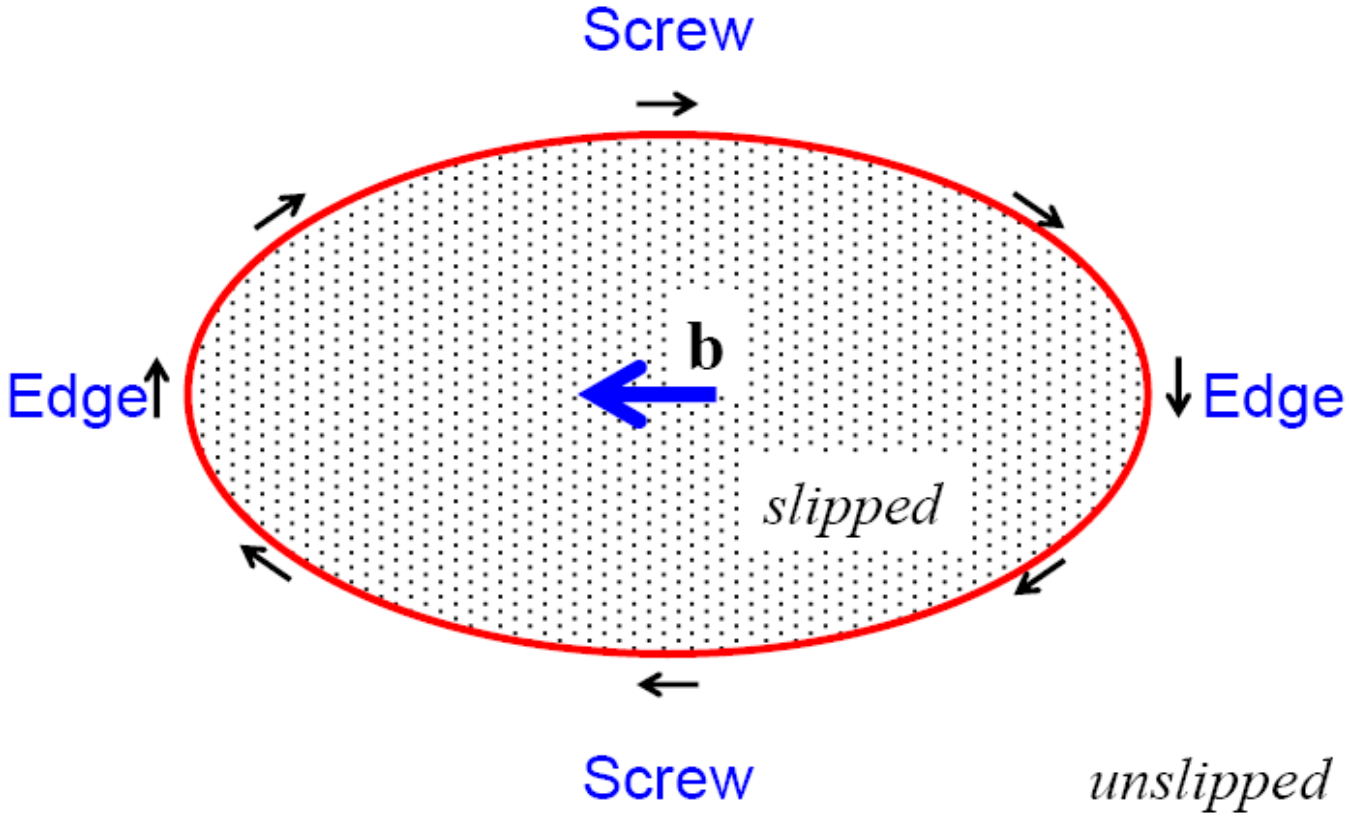
Dislocations imaged in NiAl-0.5Zr single crystals deformed at elevated temperatures.

Most dislocations are curved.

Motion of Mixed Dislocations



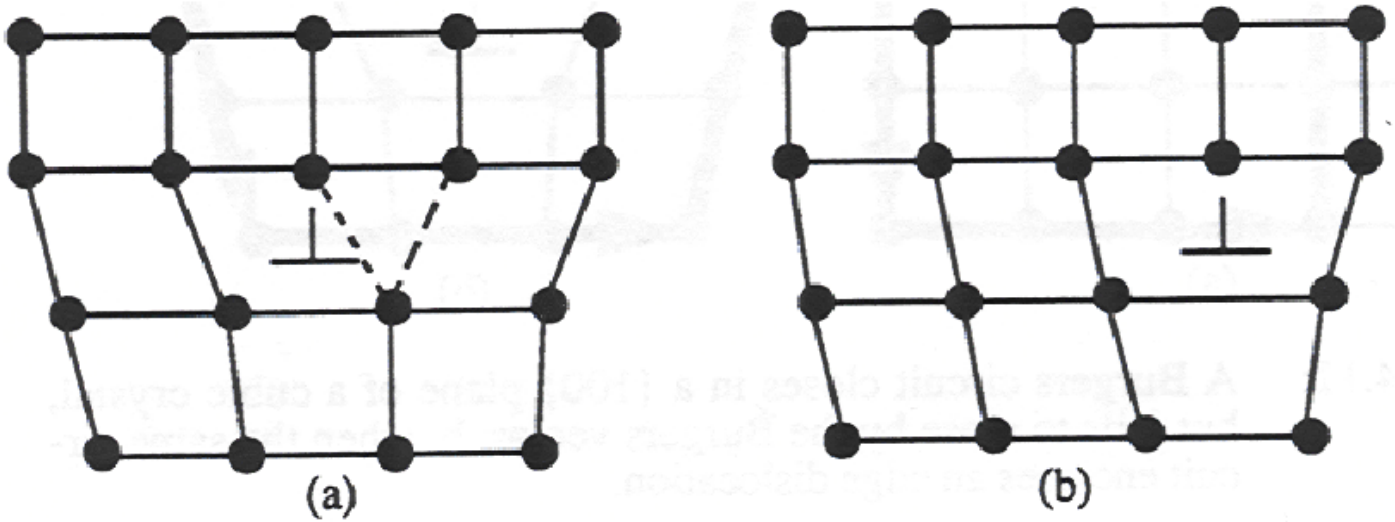
Dislocations move via slip



Schematic representation of a *dislocation loop*

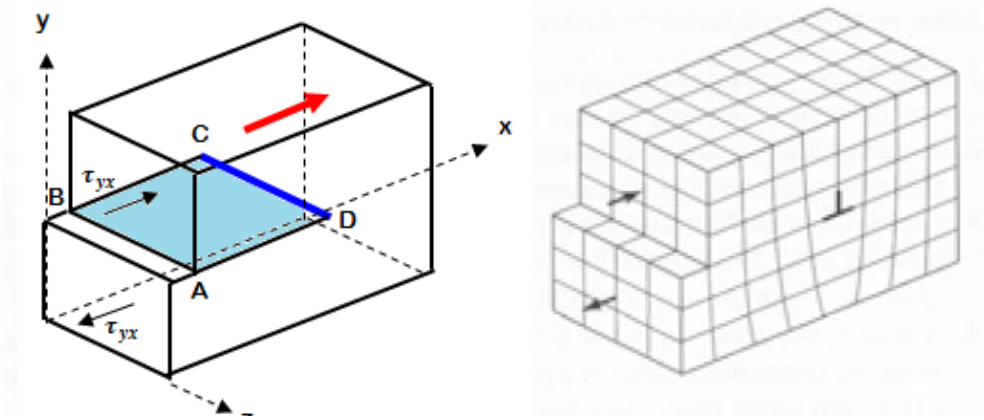
Movement of Dislocations

- Glide--conservative motion: dislocation moves in the surface which contains both its line and Burgers vector

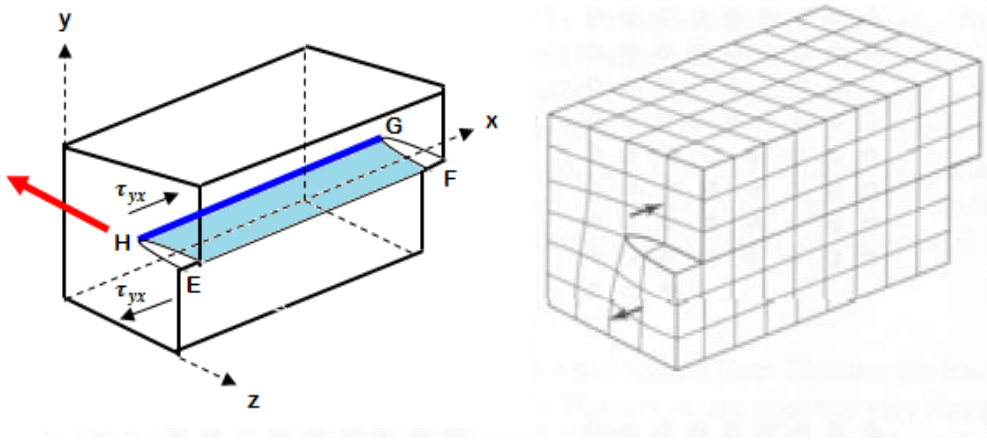


Movement of Dislocations (glide)

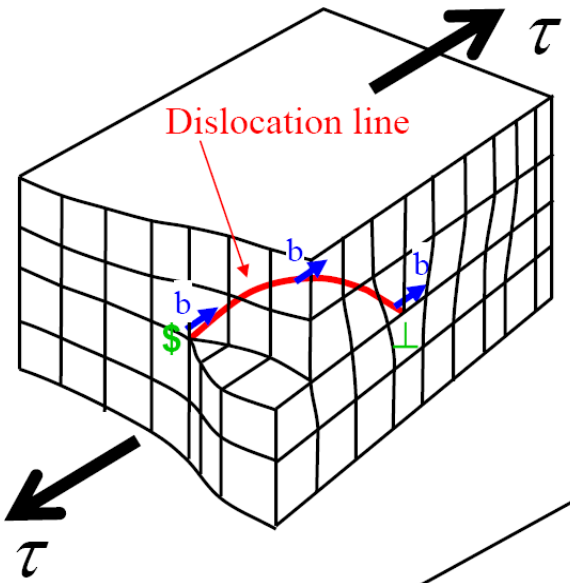
Edge ⊥
moves
this way



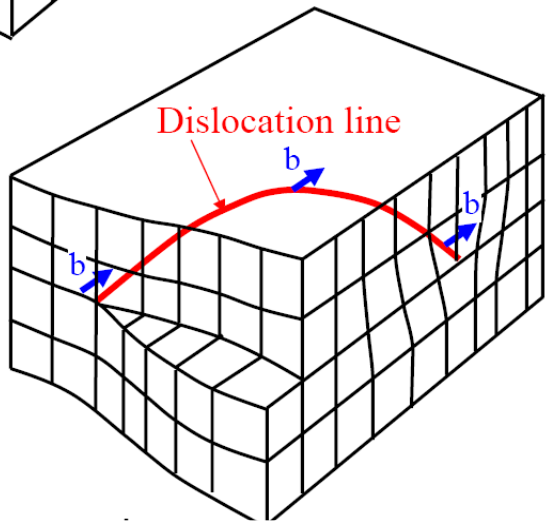
Screw ⊥
moves
this way

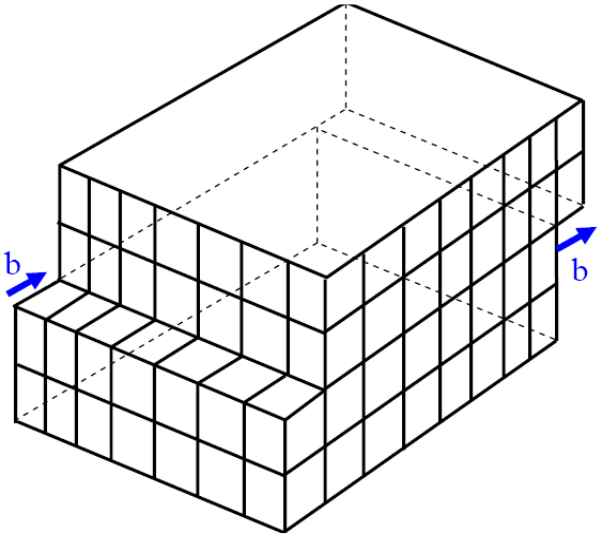


Movement of Dislocations (glide)



Process of slip by expansion of a dislocation loop in a slip plane.

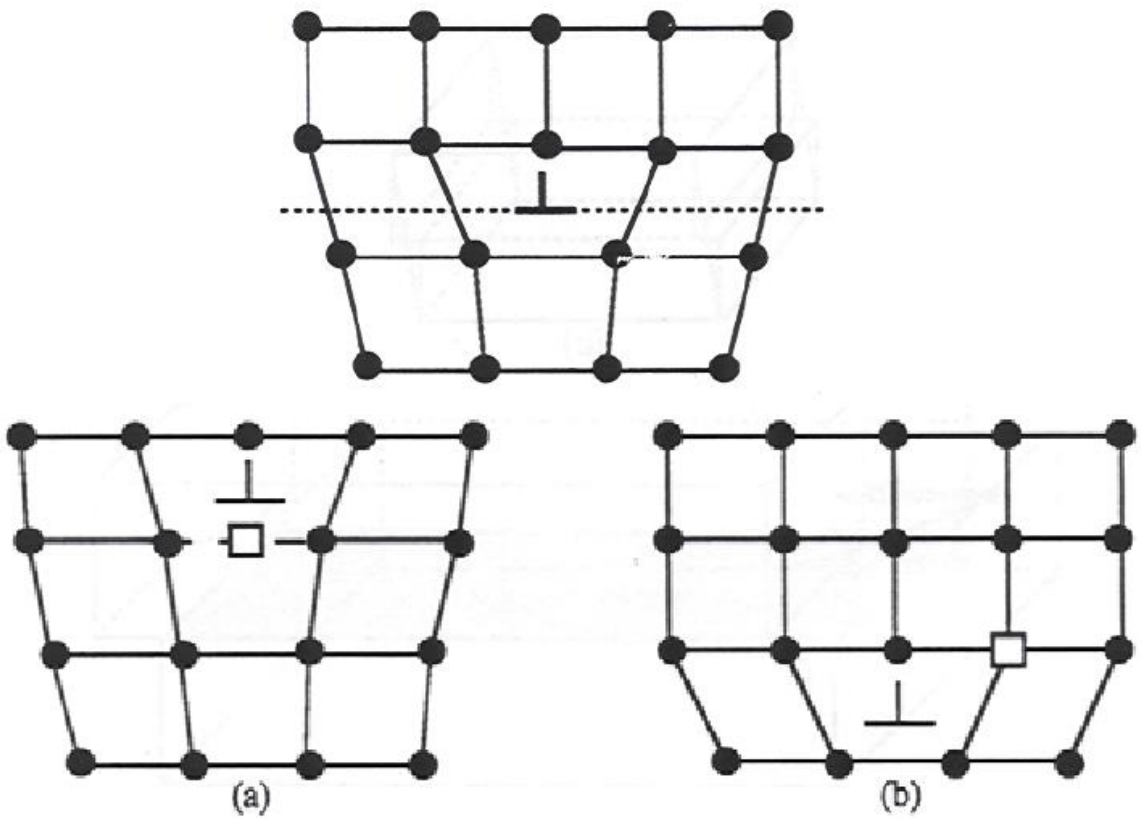




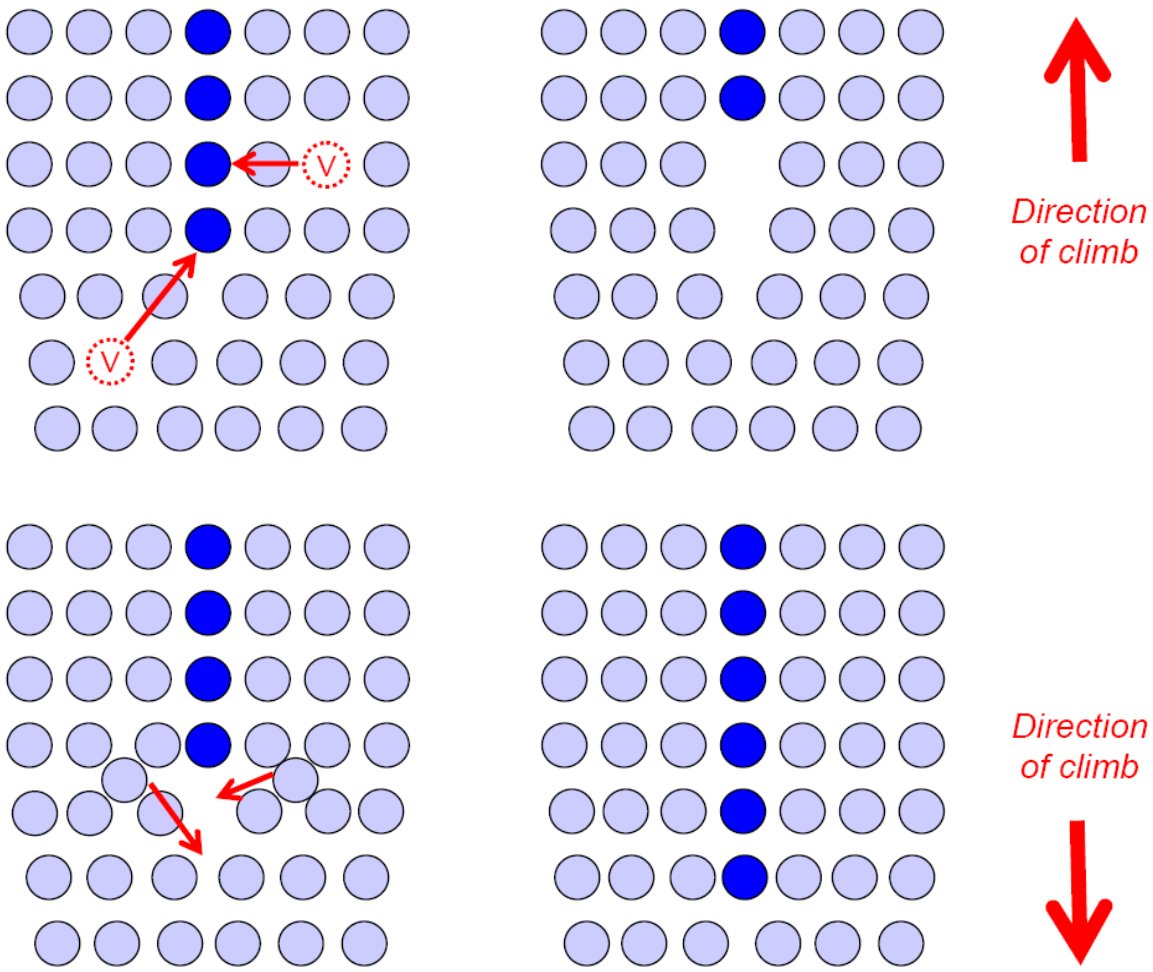
- Edge, screw, and mixed segments move.
- Final shear of crystal is produced by edge and screw dislocations.

Movement of Dislocations

- Climb-- non-conservative motion: dislocation moves out of the glide surface normal to the Burgers vector



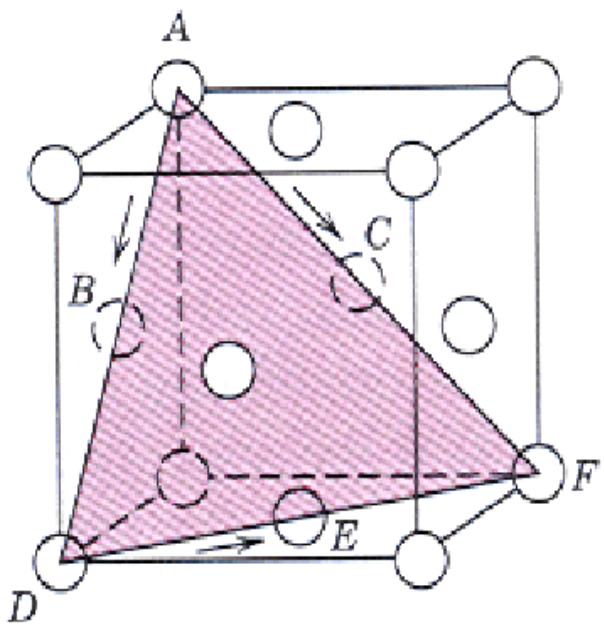
Movement of Dislocations (climb)



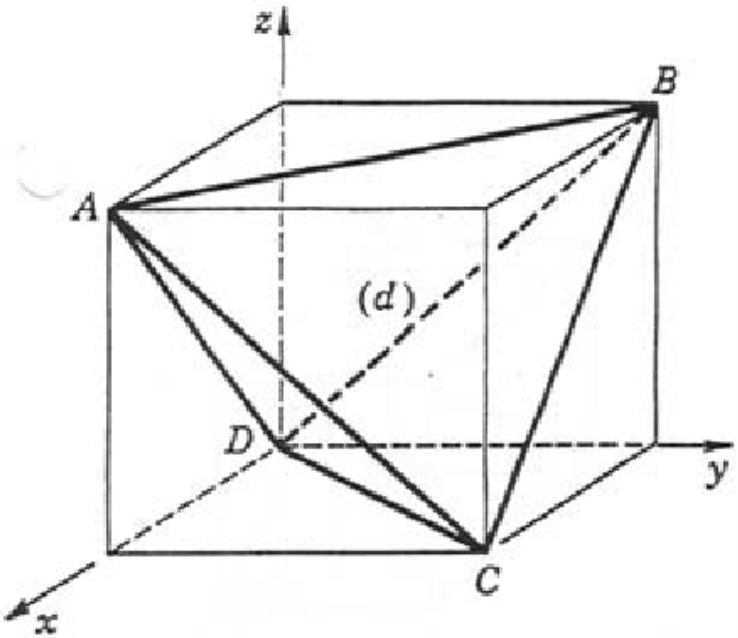
Vacancies or Atoms diffuse to bottom of dislocation line.

Acting slip system in FCC

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

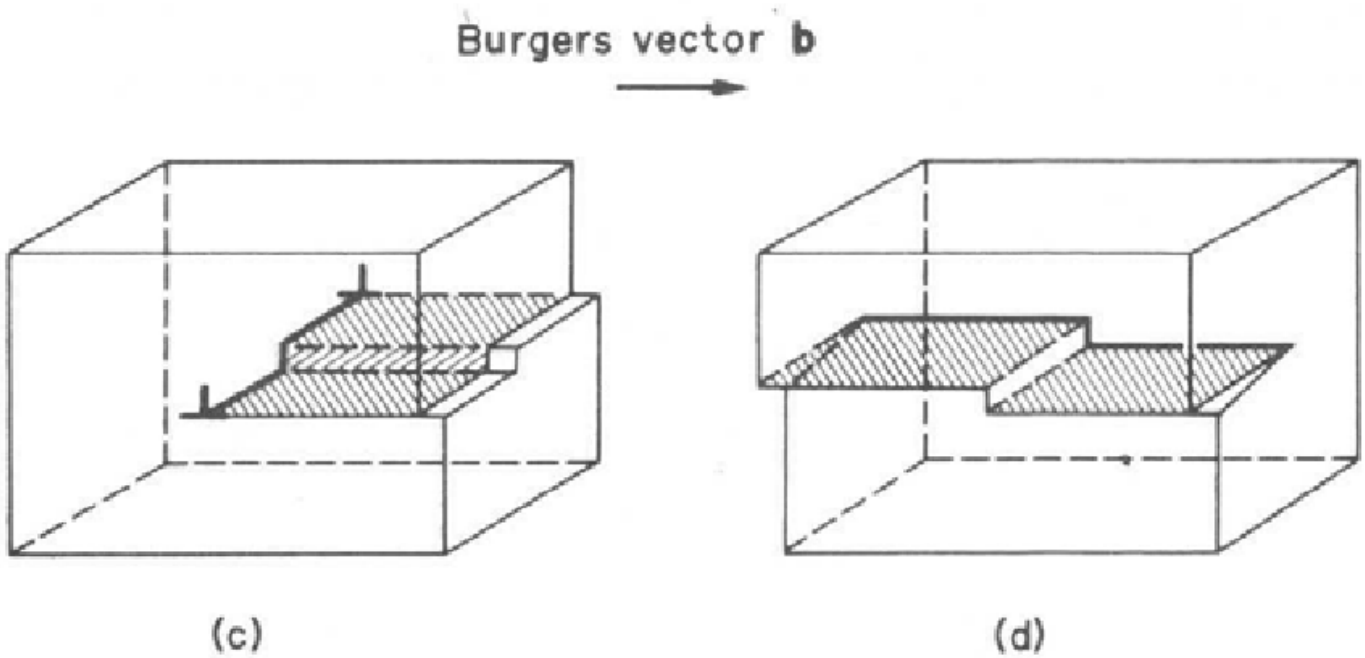


(a)



Jogs

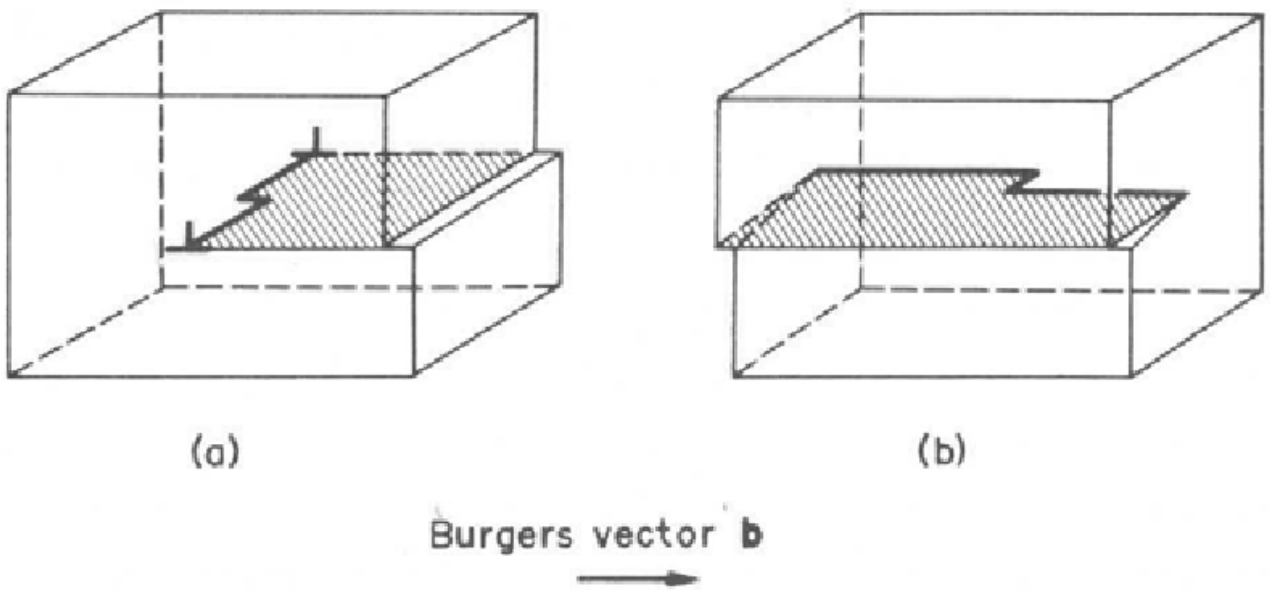
- Jogs on edge dislocations do not impede glide
- Jogs on screw dislocations have edge character and impede glide



The jogs in (c) edge and (d) screw dislocations

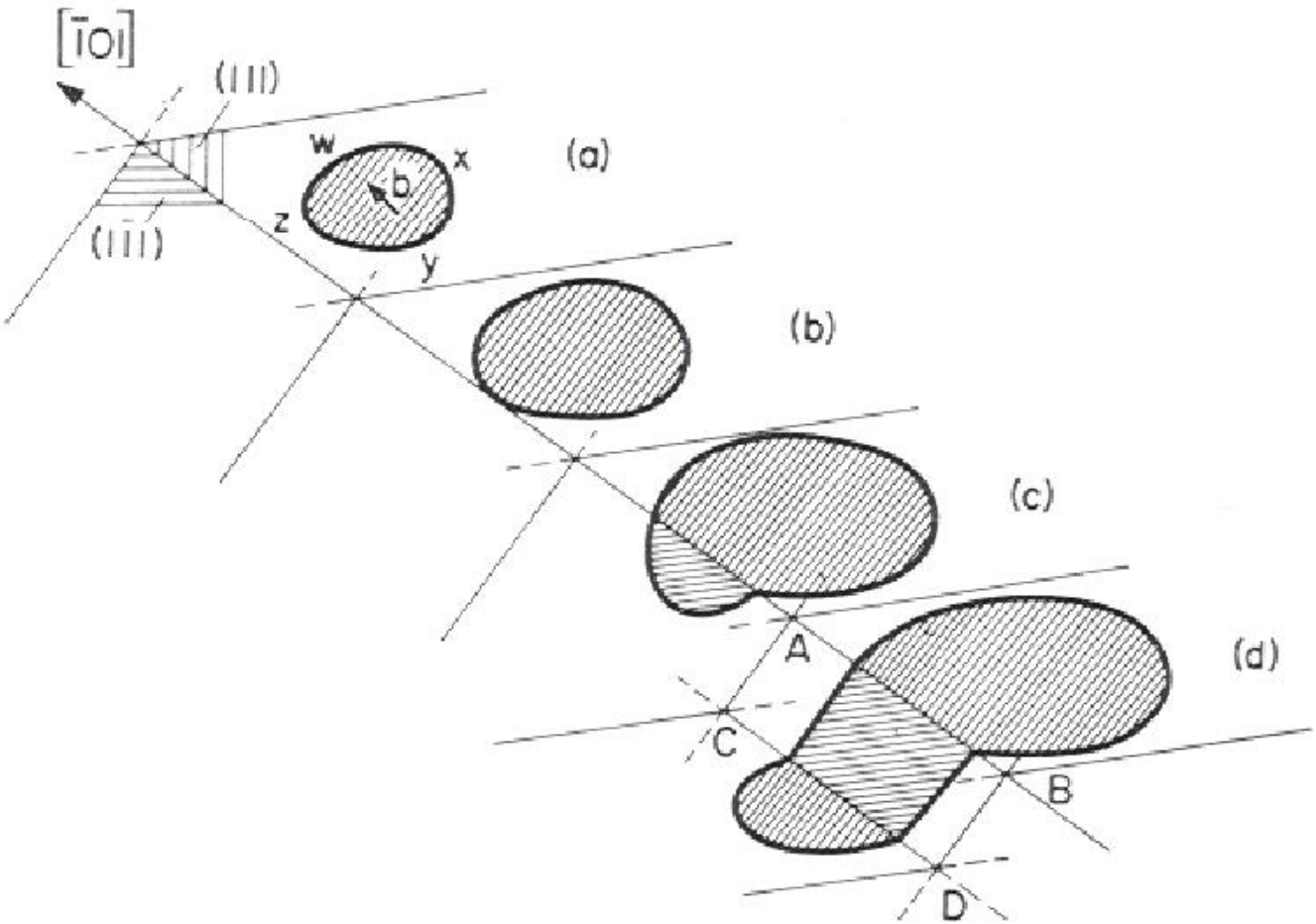
Kink

- Kinks: steps on the dislocation which displace it on the same slip plane
- Kinks in edge and screw dislocations do not impede glide of the dislocation



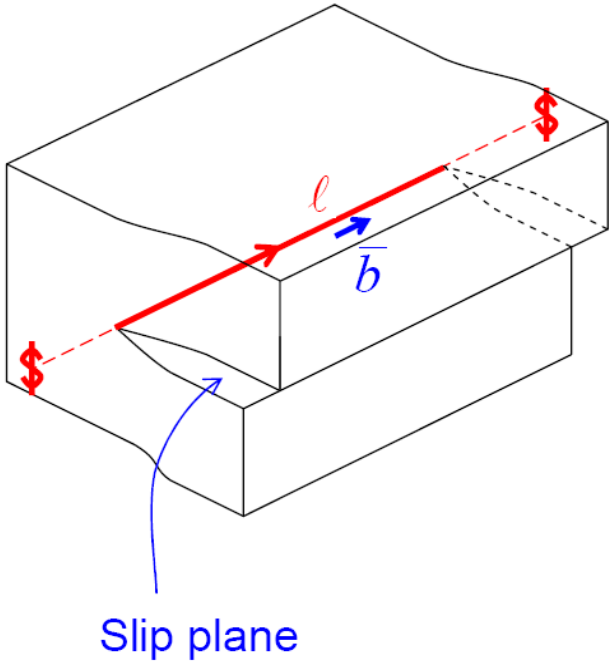
The kinks in edge (a) and screw (b) dislocations

Cross slip

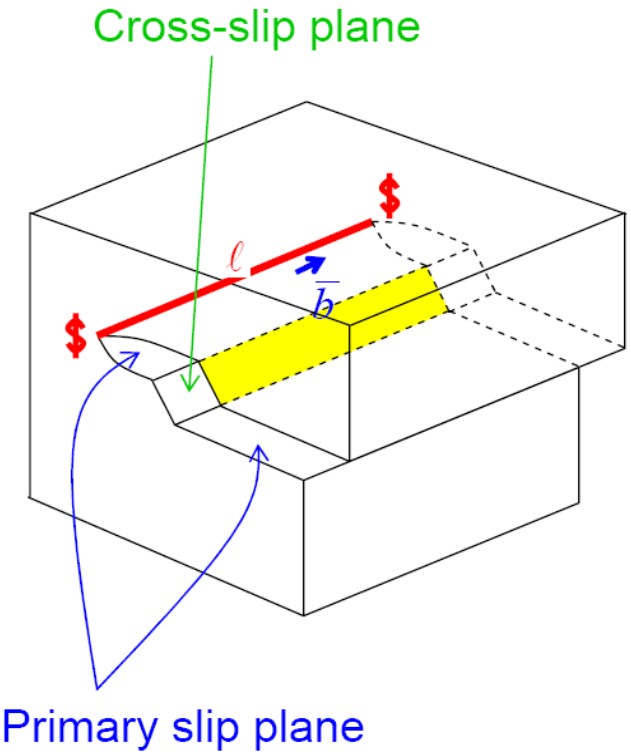


Cross slip

Slip

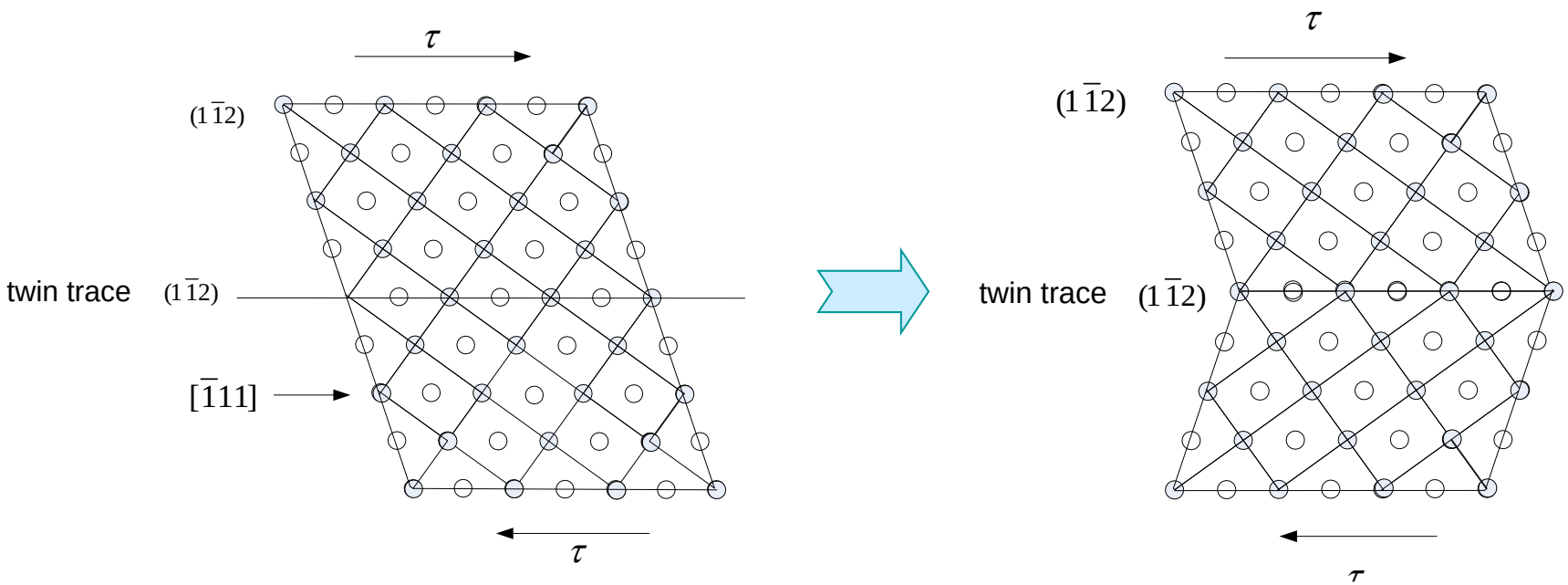


Cross-Slip



Screw dislocations can cross-slip
Edge dislocations cannot

Twinning



- Twinning unassisted by dislocation motion requires cooperative and simultaneous motion of a number of atoms

: theoretical twinning stress is high

: believed associated with dislocation motion

: requires cooperative dislocation displacements