Introduction to Dislocations

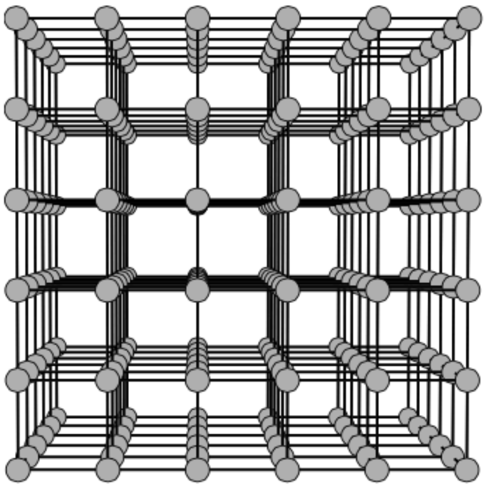
Plastic Deformation in Crystalline Materials

Kamyar Davoudi

Lecture 6

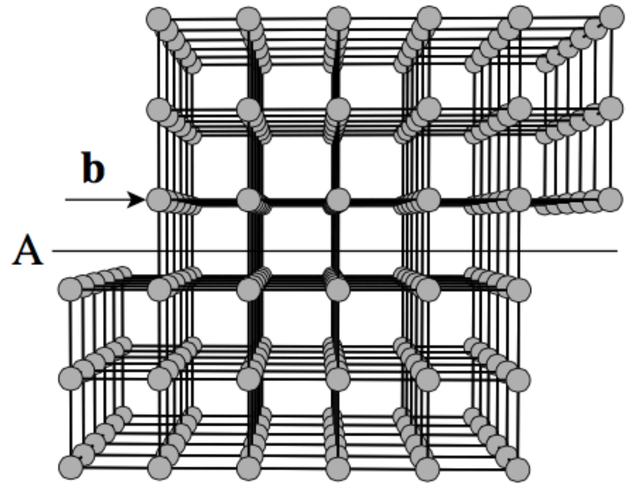
Fall 2015

Dislocations



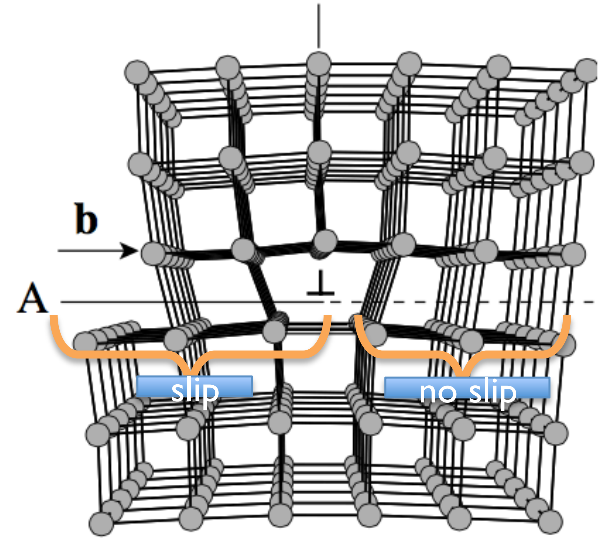
(a)

Perfect Crystal



(b)

A half crystal has been displaced by lattice vector ***b*** along the cut plane A. This does not change the atomic structure inside the crystal. If we assume the two half crystals have sled over each other, in the first lecture we showed that the theoretical shear stress will be ~ $\mu/10$ which is much larger than the observed value.

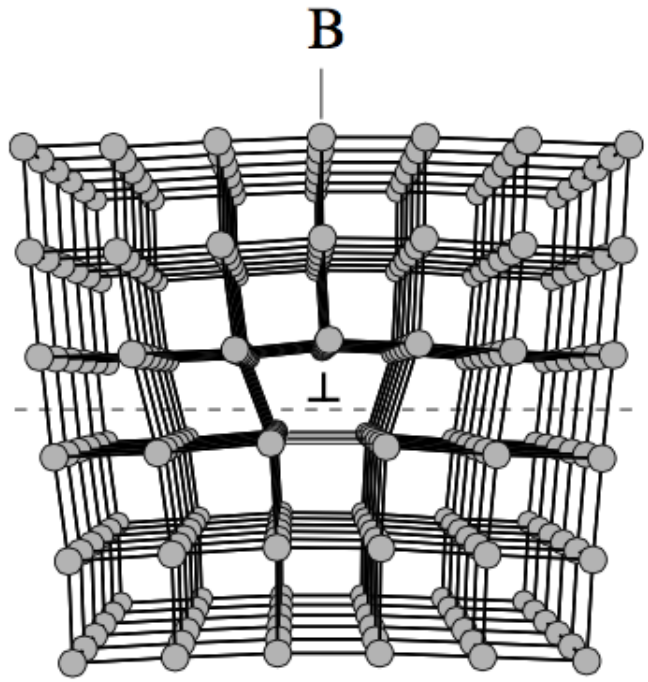


(c)

Because the theoretical shear strength is much larger than the measured shear strength, the concept of dislocations was postulated. Now instead of assuming that two half crystals have sled over each other, we assume a dislocation, which is the boundary between the slipped and un-slipped areas, sweeps along the cut plane A.

[figures from Bulatov & Cai, *Computer Simulations of Dislocations*, Oxford University Press, 2006.]

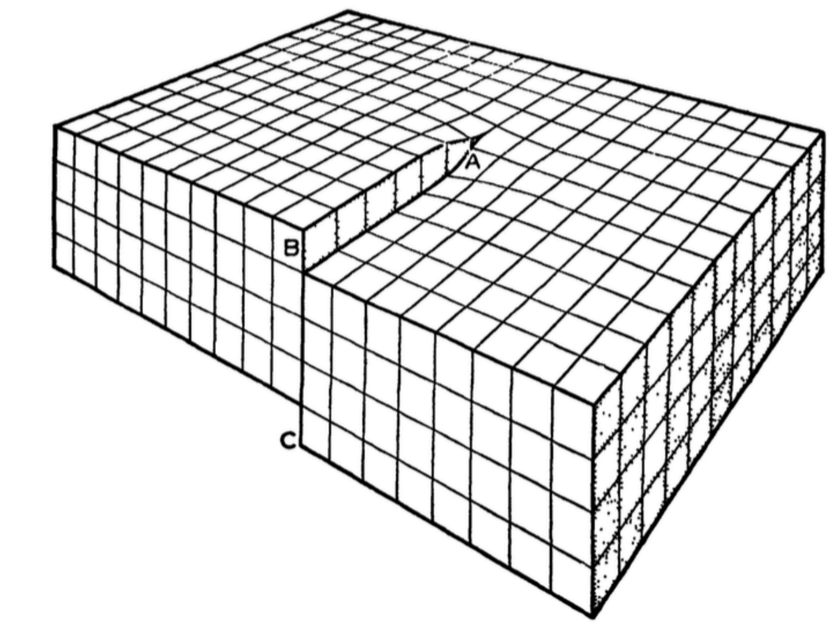
Edge Dislocations



One type of dislocations is edge dislocations. Here we can assume a half plane is inserted in a perfect crystal or a half plane is removed from a perfect crystal. Note that the extra half plane is not unique. In this figure, we are dealing with a simple cubic structure.

[figure from Bulatov & Cai, *Computer Simulations of Dislocations*, Oxford University Press, 2006.]

Screw Dislocation



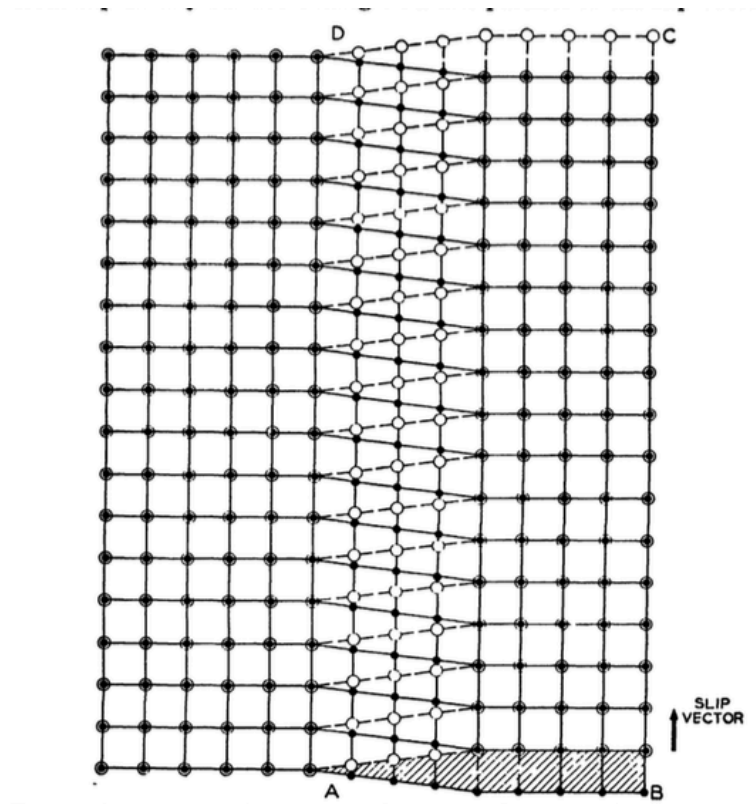
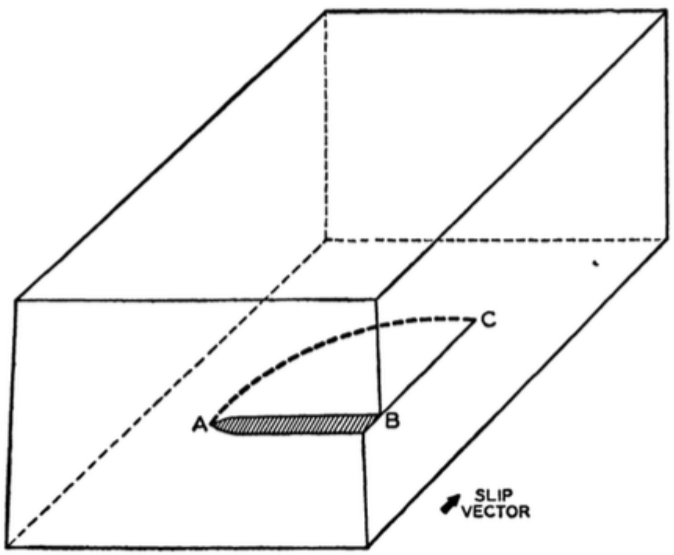


FIG. 2.3 Arrangement of atoms around the screw dislocation shown in Figs. 2.1 and 2.2. The plane of the figure is parallel to the slip plane. *ABCD* is the slipped area and *AD*, the dislocation. The open circles represent atoms in the atomic plane just above the slip plane and the solid circles, atoms in the plane just below the slip plane.

[Read, W.T., *Dislocations in Crystals*, McGraw Hill, 1953.]

Mixed Dislocations



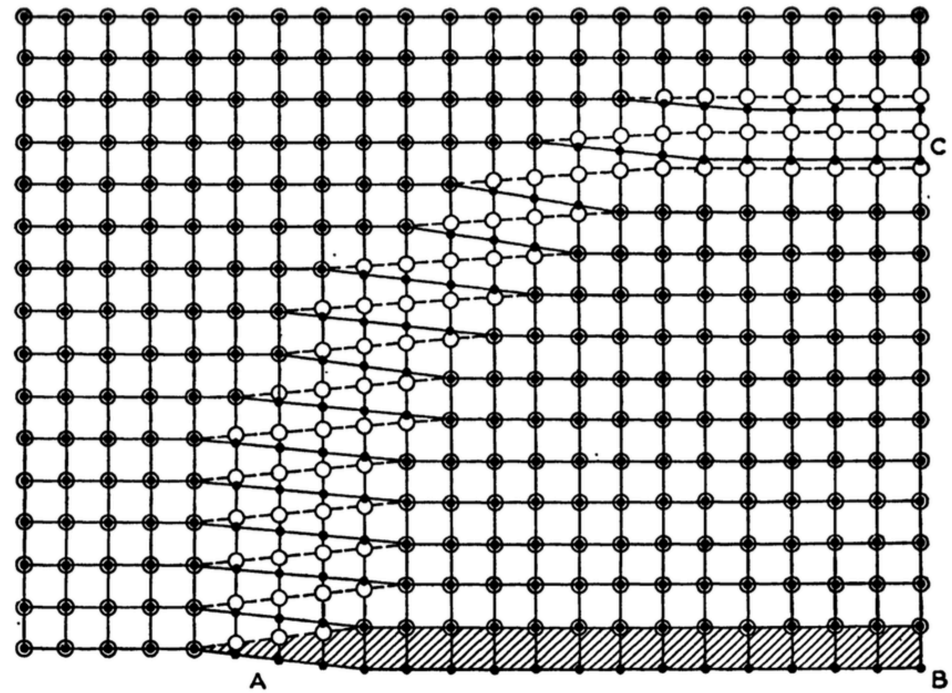


FIG. 2.5 Arrangement of atoms for the curved dislocation shown in Fig. 2.4. Open circles represent the atomic plane just above the slip plane; closed circles represent the atoms just below.

[Read, W.T., *Dislocations in Crystals*, McGraw Hill, 1953.]

Dislocations Simulated by a Bubble Raft

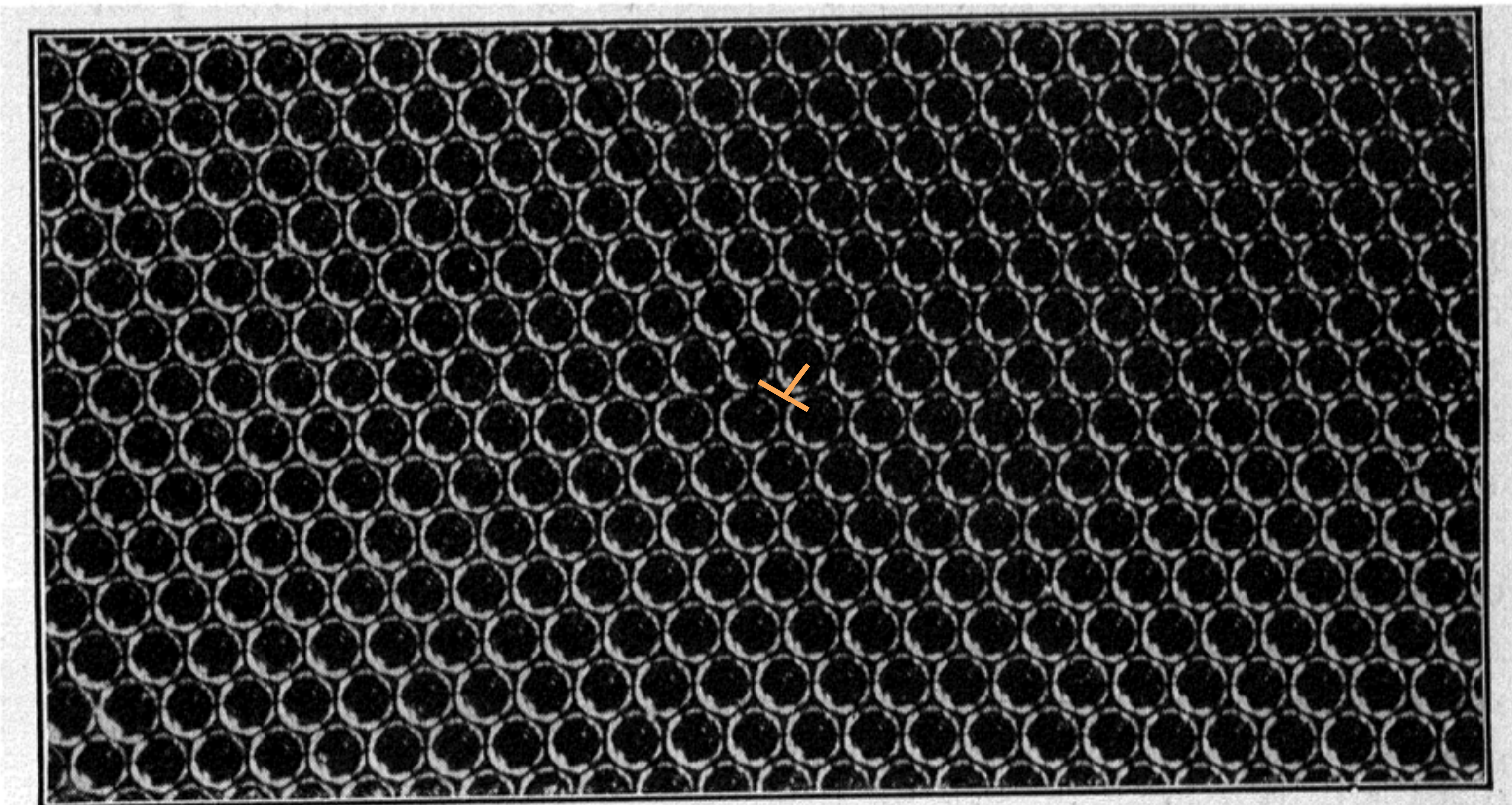
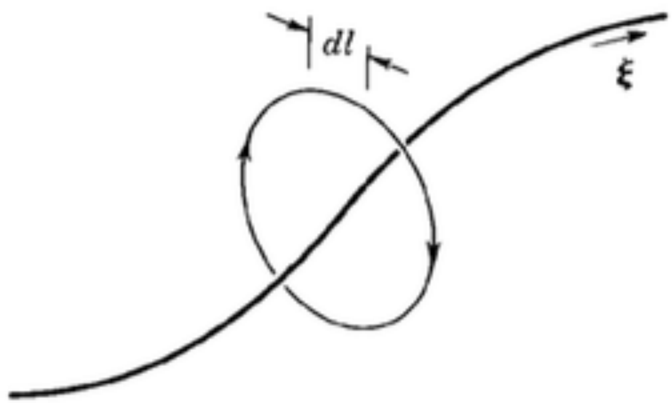
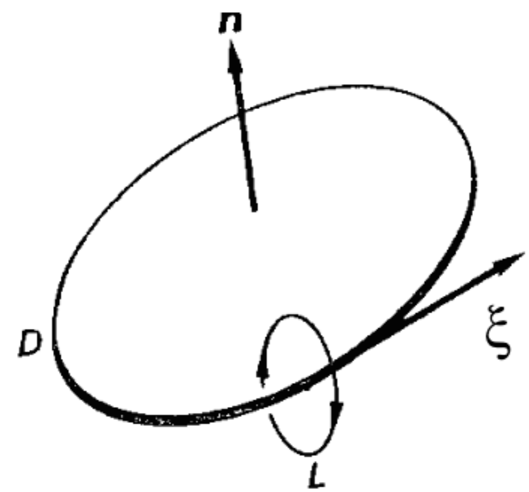


FIG. 2.11 A dislocation in the bubble model. The relatively soft bubbles—1.9 mm in diameter—give a narrow dislocation (after Bragg and Nye, 1947).

[Read, W.T., *Dislocations in Crystals*, McGraw Hill, 1953.]

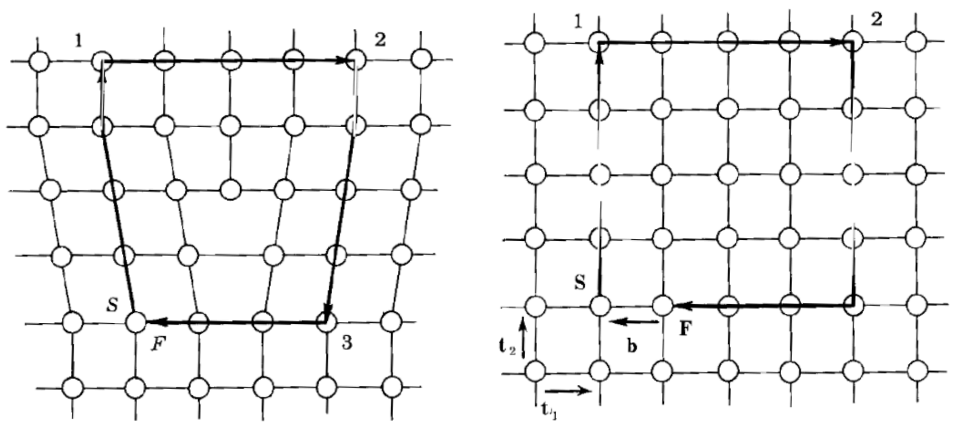
Line Direction



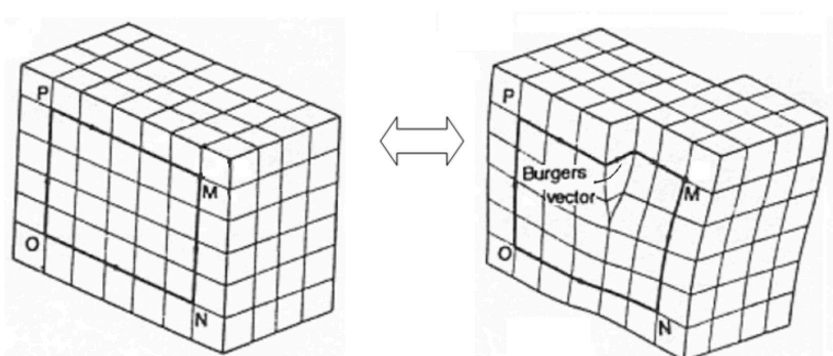


Line direction $\boldsymbol{\xi}$ is a unit vector tangent to the dislocation line.

Burgers Vector



FS/RH convention when line direction $\underline{\xi}$ points into the paper.
For edge dislocations: $\vec{b} \perp \hat{\xi}$



For screw dislocations: $\vec{b} \parallel \hat{\xi}$

Relation between ***b*** and ***u***?

$$\boldsymbol{b} = \oint \mathrm{d}\boldsymbol{u}$$

or

$$b_i = \oint \mathrm{d}u_i = \oint \frac{\partial u_i}{\partial x_k} \mathrm{d}x_k$$

[figures from Hirth & Lothe, *Theory of Dislocations*, and here]

Edge and Screw Dislocations

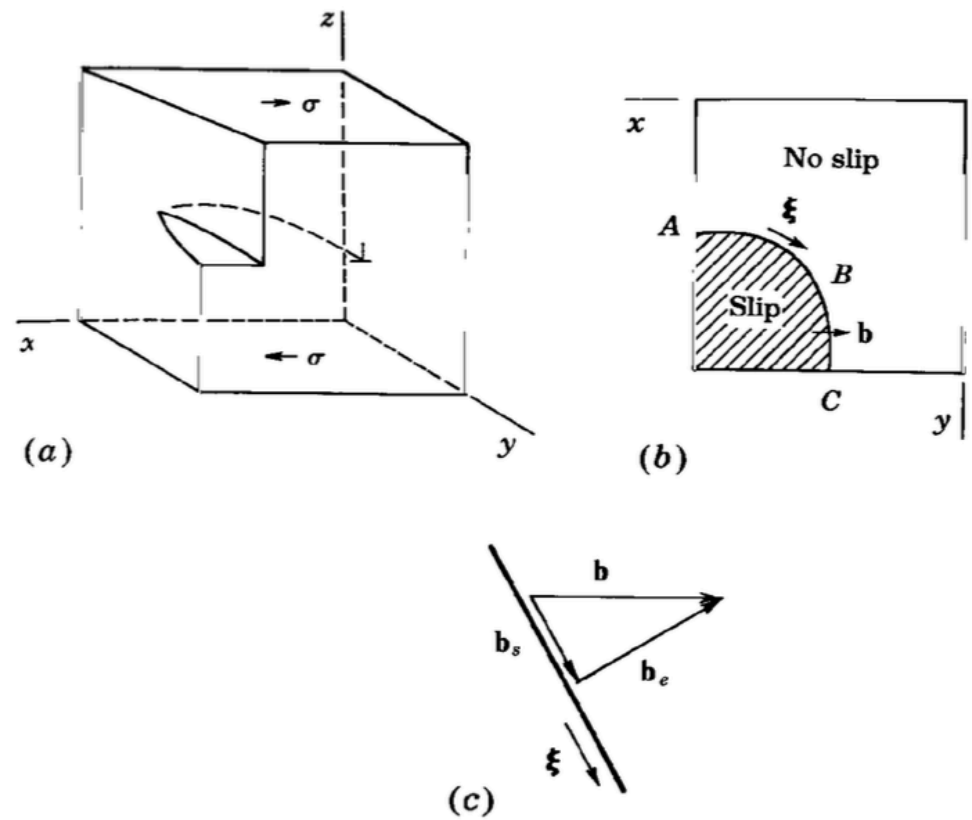
- For screw dislocations: $\vec{b} \perp \hat{\xi}$
- For screw dislocations: $\vec{b} \parallel \hat{\xi}$

- Edge component:

$$\vec{b}_e = \vec{\xi} \times \left(\vec{b} \times \vec{\xi}\right)$$

- Screw component:

$$\vec{b}_s = \left(\vec{b} \bullet \vec{\xi}\right)\vec{\xi}$$

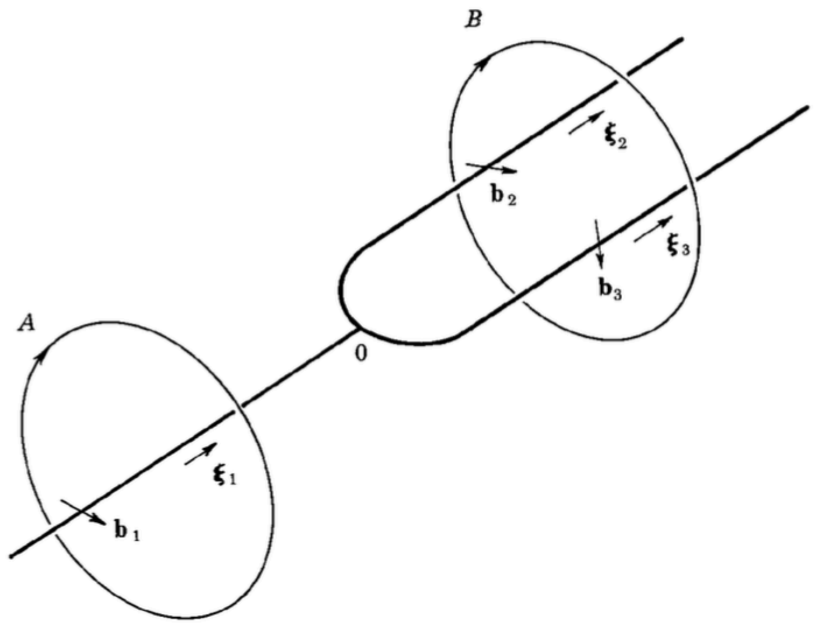


[Hirth & Lothe, *Theory of Dislocations,* Wiley, 1982]

Termination of Dislocations

- A dislocation cannot end within an otherwise perfect crystal, but must terminate at
  - Free surface
  - Another dislocation
  - Grain boundary
  - Some other defects
- Proved by Nabarro with formal elasticity theory

Kirchhoff's law



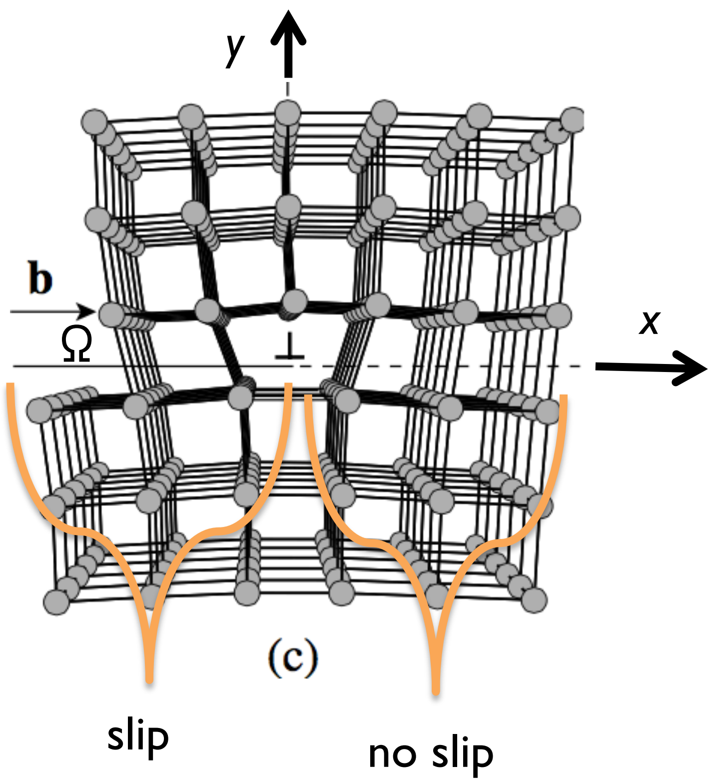
$$\vec{b}_1 = \vec{b}_2 + \vec{b}_3$$

Axiom: Suppose N dislocations meet at a node. If all the ξ are taken as positive taken from the node, we will have

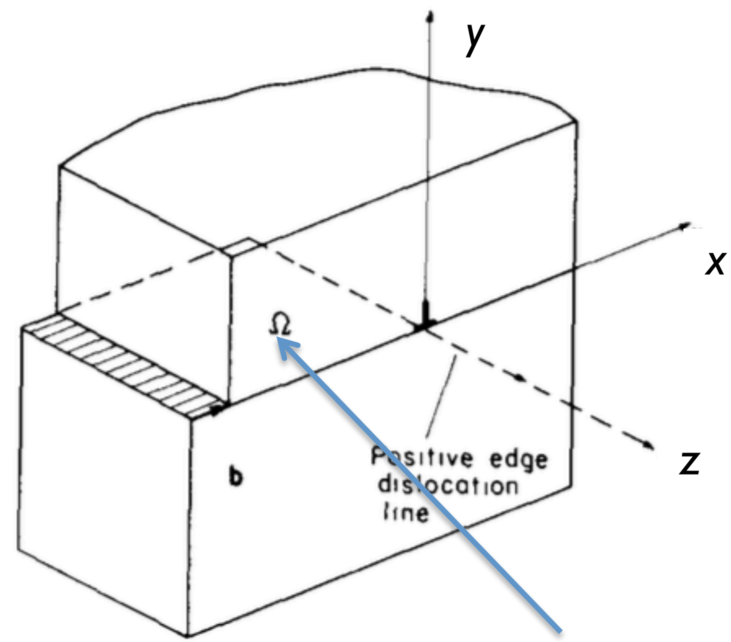
$$\sum_{i=1}^{N} \vec{b}_i = 0$$

[Hirth & Lothe, *Theory of Dislocations,* Wiley, 1982]

Plastic Strain around Edge Dislocartion



(c)

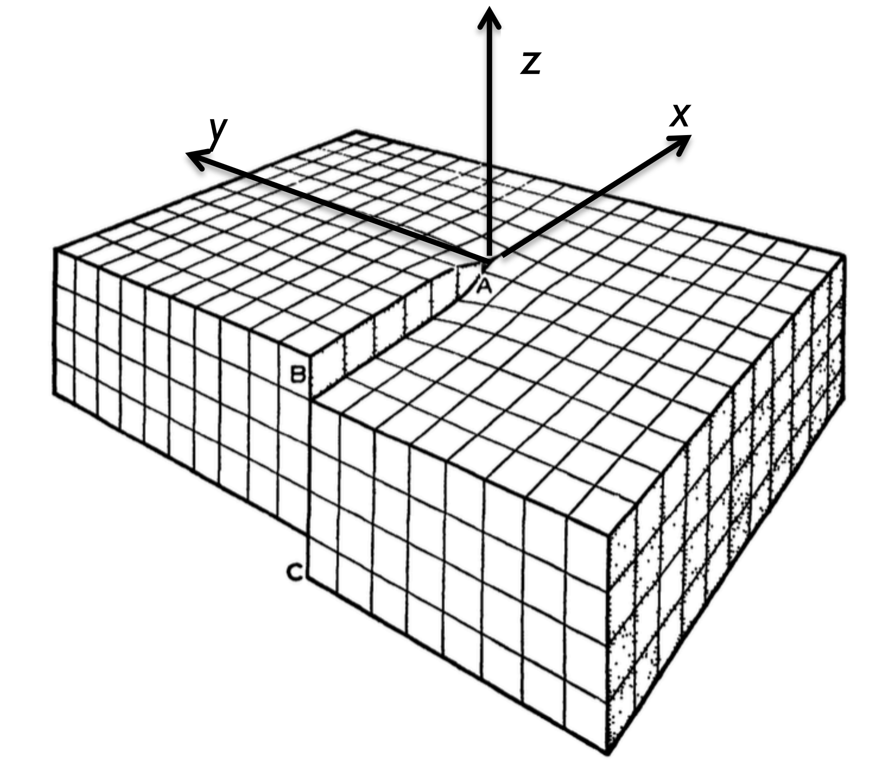


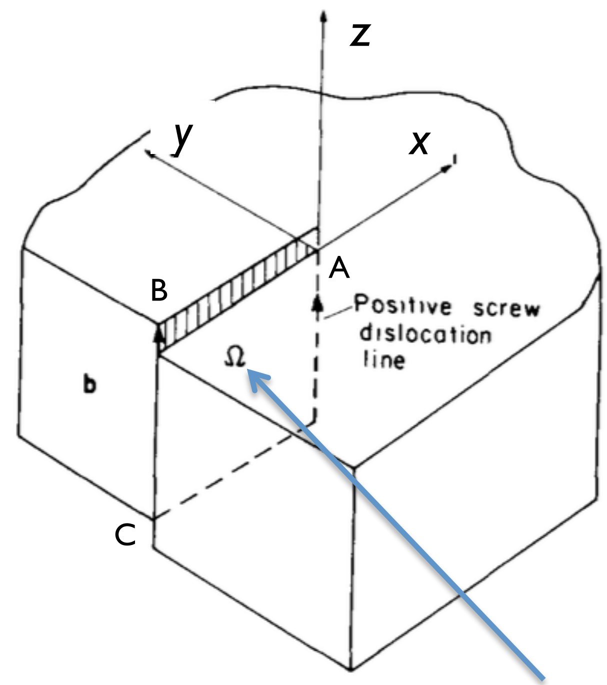
Plastic strain on half plane Ω

$$\varepsilon^{p}_{xy} = \frac{1}{2} b \; \delta(y) H(-x)$$

[figures from Bulatov & Cai, *Computer Simulations of Dislocations*, Oxford University Press, 2006, AND Mura, Micromechanics of Defects in Solids, 2nd ed, Springer, 1987]

Plastic Strain around Screw Dislocation



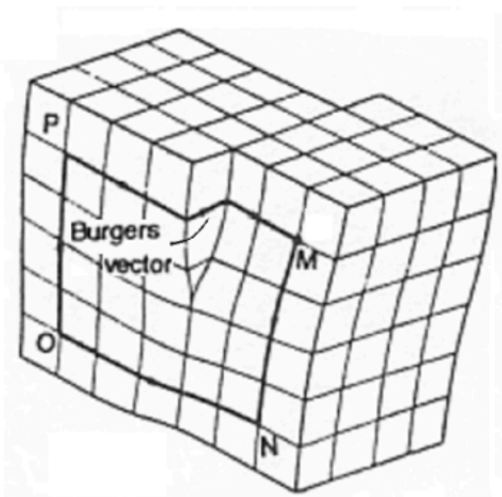


Plastic strain on half plane Ω

$$\varepsilon^{p}_{yz} = \frac{1}{2} b \ \delta(y) H(-x)$$

[figures from Read, *Dislocations in Crystals*, McGraw Hill, 1953, AND Mura, Micromechanics of Defects in Solids, 2nd ed, Springer, 1987]

Elastic Fields around Screw Dislocation



$$u_z = \frac{b}{2\pi}\theta = \frac{b}{2\pi}\left\{\tan^{-1}\left(\frac{y}{x}\right) + \frac{\pi}{2}\mathrm{sgn}(y)\left[1-\mathrm{sgn}(x)\right]\right\}$$

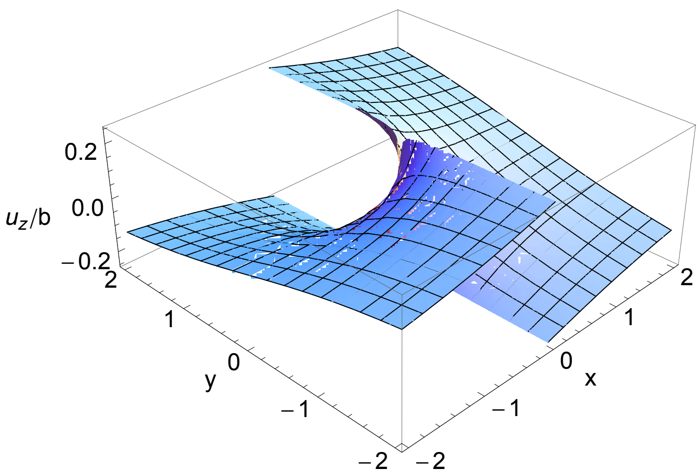
$$E_{rr} = \frac{\partial u_r}{\partial r} \qquad E_{\theta\theta} = \frac{1}{r}\frac{\partial u_\theta}{\partial \theta} + \frac{u_r}{r} \qquad E_{zz} = \frac{\partial u_z}{\partial z}$$

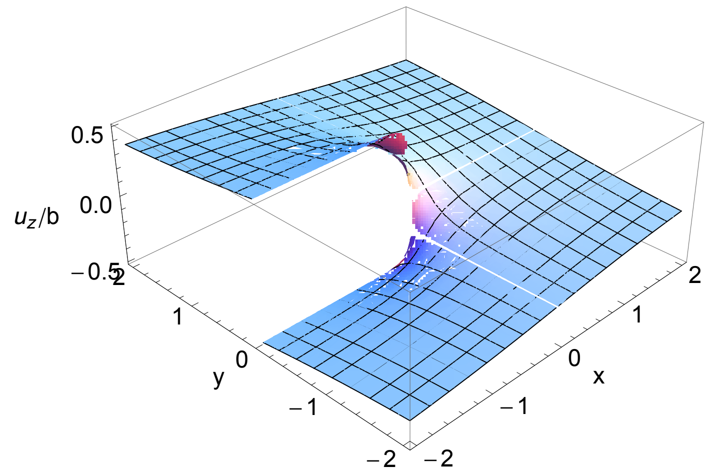
$$E_{r\theta} = \frac{1}{2}\left[\frac{1}{r}\frac{\partial u_r}{\partial \theta} + \frac{\partial u_\theta}{\partial r} - \frac{u_\theta}{r}\right] \qquad E_{\theta z} = \frac{1}{2}\left(\frac{\partial u_\theta}{\partial z} + \frac{1}{r}\frac{\partial u_z}{\partial \theta}\right)$$

$$E_{zr} = \frac{1}{2}\left(\frac{\partial u_z}{\partial r} + \frac{\partial u_r}{\partial z}\right),$$

$$\varepsilon_{z\theta} = \frac{b}{4\pi r} \quad \Rightarrow \quad \varepsilon_{xz} = -\frac{b}{4\pi}\frac{y}{r^2}, \qquad \varepsilon_{xy} = \frac{b}{4\pi}\frac{x}{r^2}$$

Importance of Additional Terms





$$u_z = \frac{b}{2\pi} \tan^{-1}\left(\frac{y}{x}\right)$$

$$u_z = \frac{b}{2\pi} \left\{ \tan^{-1}\left(\frac{y}{x}\right) + \frac{\pi}{2} \operatorname{sgn}(y) \left[1 - \operatorname{sgn}(x)\right] \right\}$$

$$\partial_x \tan^{-1}\left(\frac{y}{x}\right) = -\frac{y}{r^2} + \pi \operatorname{sgn}(y)\, \delta(x),$$

$$\partial_y \tan^{-1}\left(\frac{y}{x}\right) = \frac{x}{r^2}$$

$$\partial_y \operatorname{sgn}(y) = 2\, \delta(x).$$

$$\varepsilon_{zx} = \varepsilon_{zx}^{(e)} + \varepsilon_{zx}^{(p)} = \frac{1}{2} \partial_x u_z = \frac{b}{4\pi} \frac{-y}{r^2}$$

$$\varepsilon_{zy} = \varepsilon_{zy}^{(e)} + \varepsilon_{zy}^{(p)} = \frac{1}{2} \partial_y u_z = \frac{b}{4\pi} \left[\frac{x}{r^2} + 2\pi H(-x) \delta(y) \right]$$

Further Reading

1. Bulatov, V., Cai, W., *Computer Simulations of Dislocations*, Oxford University Press, 2006.
2. Hirth, J.P., Lothe, J., *Theory of Dislocations*, 2nd ed., Wiley, 1982.
3. Hull, D., Bacon, J.D., *Introduction to Dislocations*, 5th ed., Butterworth-Heinemann, 2011.
4. Read, W.T., *Dislocations in Crystals*, McGraw Hill, 1953.
5. Weertman, J., Weertman, J., *Elementary Dislocation Theory*, Oxford University Press, 1992.