# 3.40J / 22.71J
# Modern Physical Metallurgy

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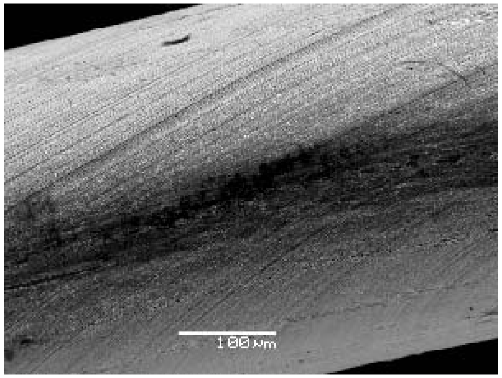
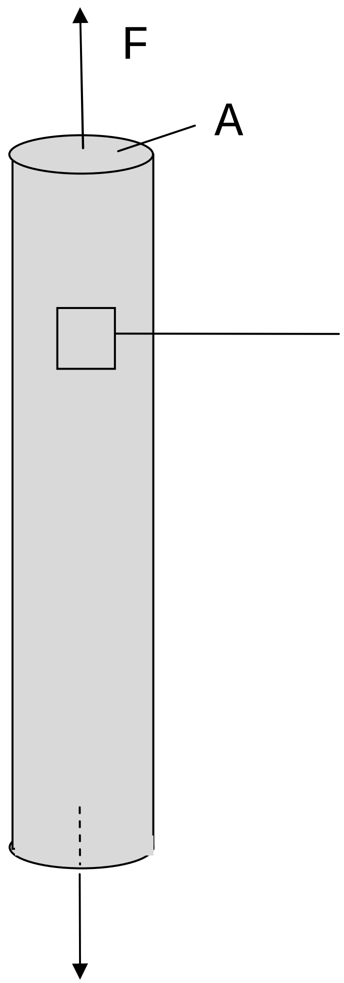
## Lecture 3: Deformation of single crystals, Part II

February 12, 2004




Single crystal Cd, 100% strain

# Single Crystal Deformation: Schmid Factor

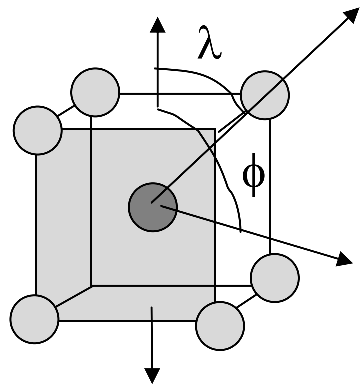



Uniaxial tension:

Stress = $\sigma_e$ = Force/Normal Area = F/A

Strain = $\varepsilon_e$ = $\Delta L/L_i$

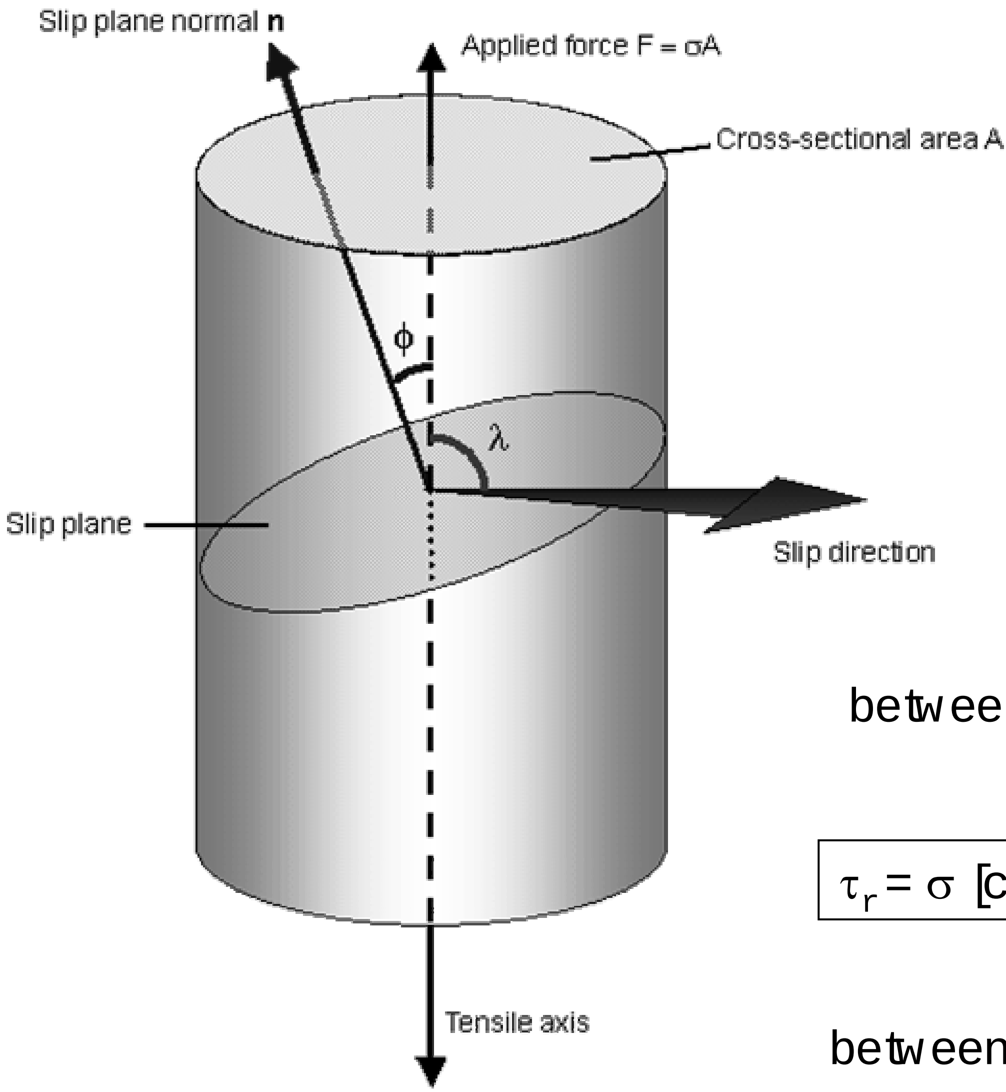
Slip occurs under shear stress $\tau$




Which slip systems are oriented to have maximum shear stress?

$$\tau_R = \frac{\textit{resolved force acting on slip plane}}{\textit{area of slip plane}} = \frac{F\cos\lambda}{A/\cos\phi} = \frac{F}{A}\cos\phi\cos\lambda$$

# Single Crystal Deformation: Schmid Factor




between loading axis and slip direction

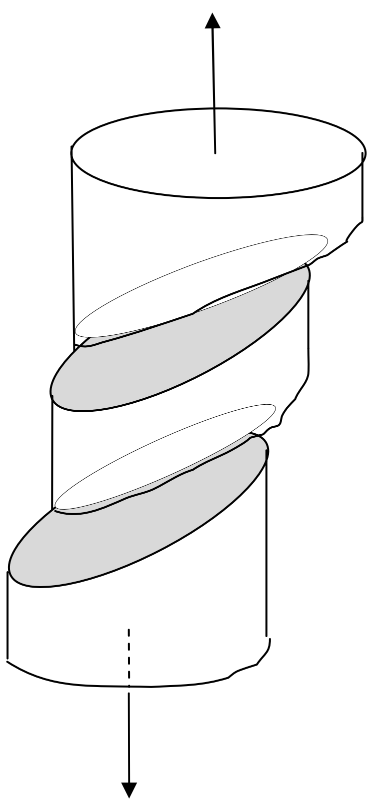
$$\tau_r = \sigma\ [\cos\phi\ \cos\lambda] = \sigma\ [\text{Schmid Factor}]$$

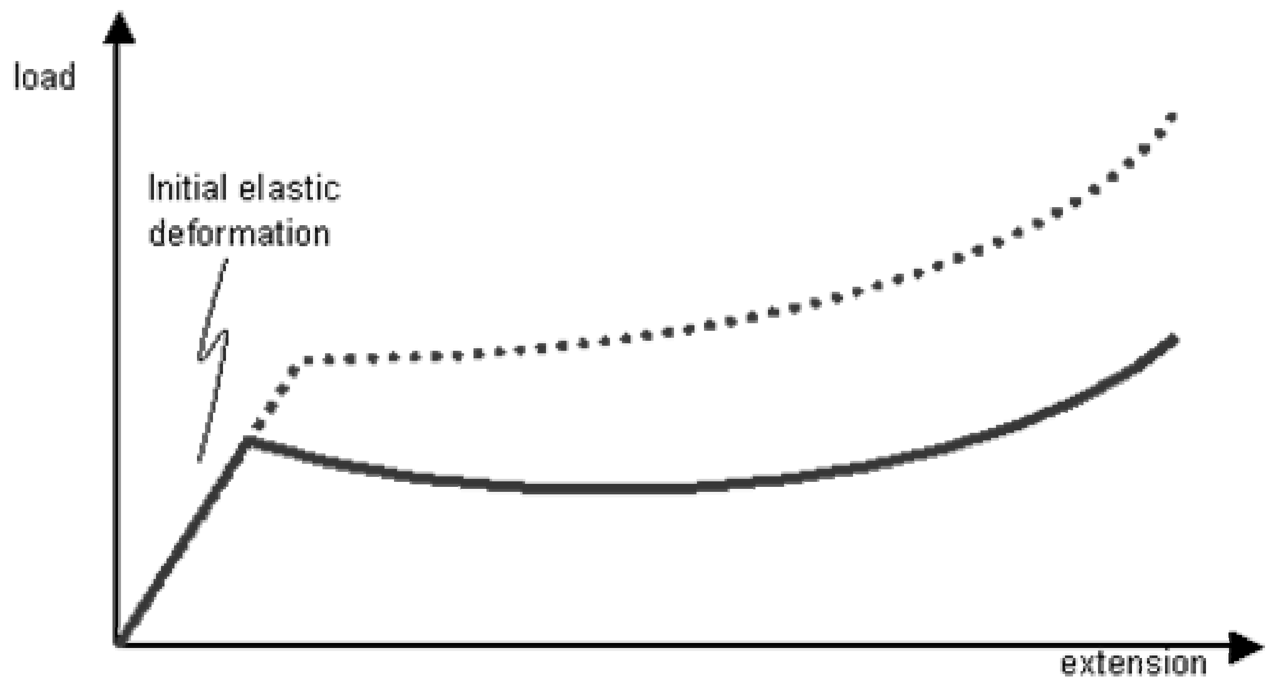
between loading axis and slip plane normal

Single Crystal Deformation: Critical resolved shear stress

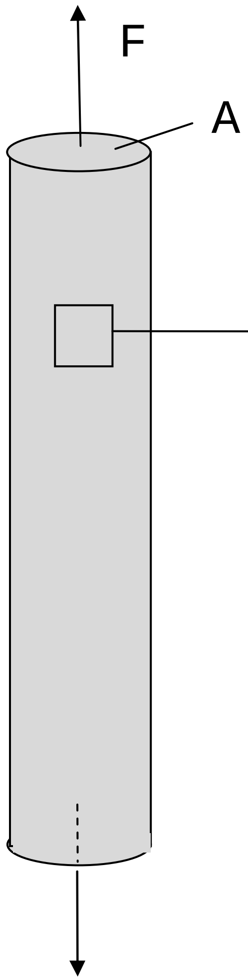
Slip occurs when $\tau_{r,max} = \tau_{crss}$

Yielding or permanent (plastic) deformation occurs when
$\sigma = \tau_{crss}/[\cos\phi \cos\lambda]_{max} = \sigma_y$





# Single Crystal Deformation: Example

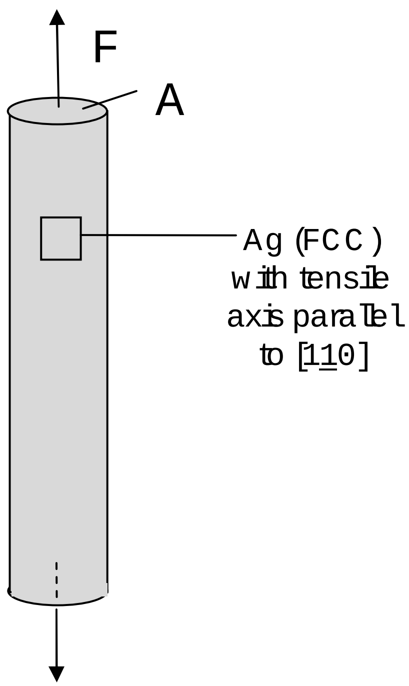



FCC, with tensile axis parallel to [100]

Questions:

1. What is the magnitude of the maximum Schmid factor?
2. If $\tau_{crss}$ = 21 MPa, will applied stress of 45 MPa cause slip?
3. If single crystal has radius of 2 mm, what is the minimum force required to cause slip?

# Single Crystal Deformation: Example




Question:

If $\tau_{crss}$ = 6 MPa, what is the tensile stress required to cause slip on the $(1\bar{1}\bar{1})[0\bar{1}1]$ system?

# OILS Rule: Easy way to calculate Max Schmid Factor for FCC, BCC

OILS stands for zerO Intermediate, Lowest Sign

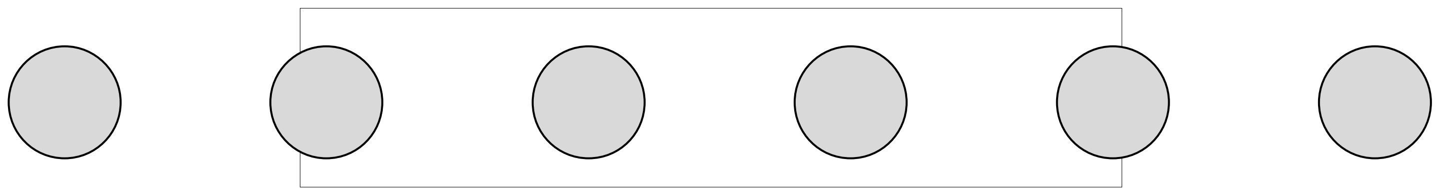
1. Write down the indices of the tensile axis [UVW]
2. Ignoring the signs, identify the highest (H), intermediate (I) and lowest (L) valued indices.
2. The slip direction is the <110> for FCC, with zero in the position of the Intermediate index and the signs of the other two indices preserved.

The slip plane is the {111} for FCC with the signs of the Highest and Intermediate indices preserved, but with the sign of the Lowest index reversed.

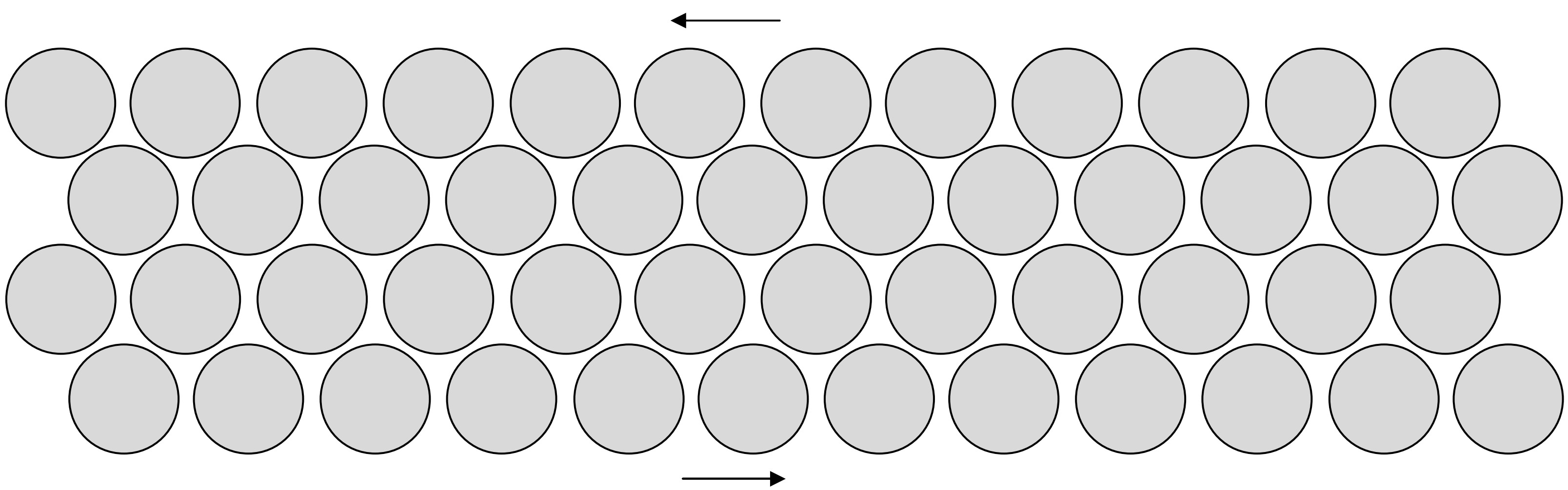
Single Crystal Deformation: Why so weak?

Two kinds of deformation

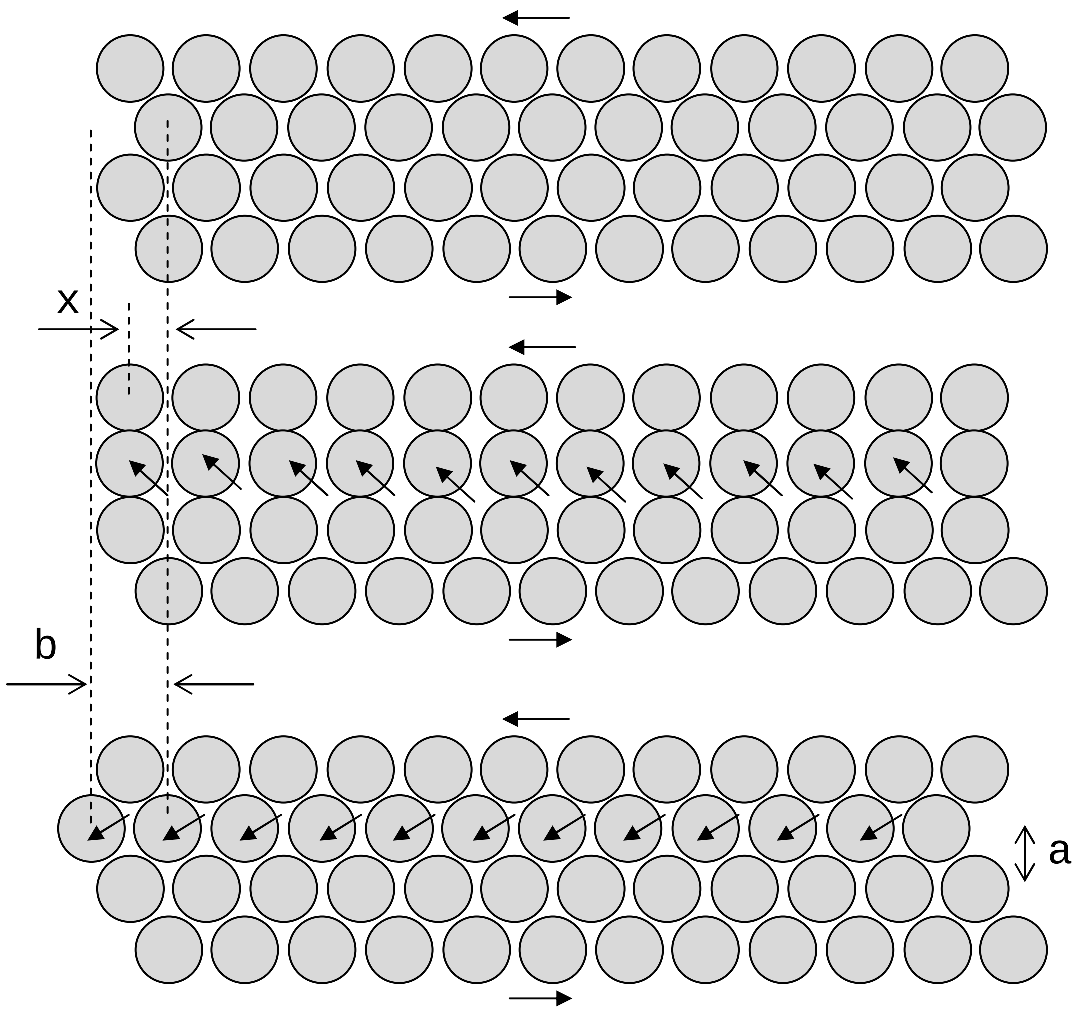
ELASTIC: reversible, bond stretching/shearing



PLASTIC: irreversible/permanent, bond breaking



# Single Crystal Deformation: Why so weak?




How much stress does it take to cause this kind of plastic slip in a crystal?

Single Crystal Deformation: Why so weak?

Two kinds of deformation

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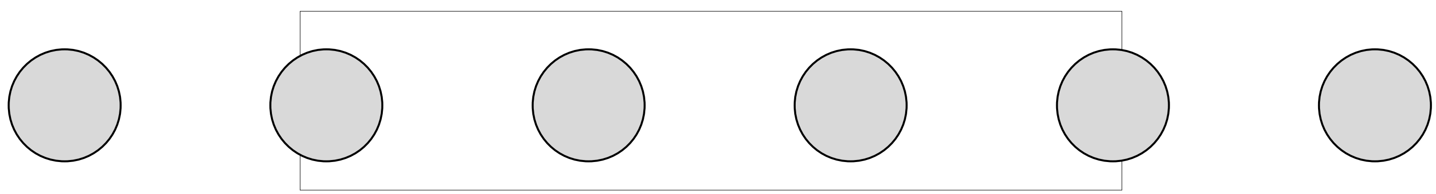
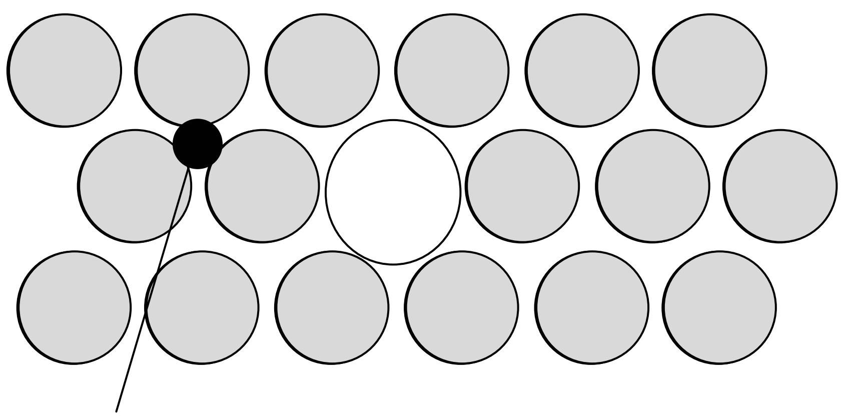


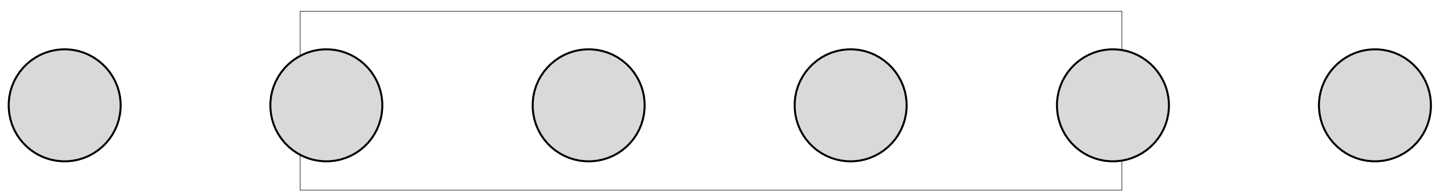
PLASTIC: irreversible/permanent, bond breaking



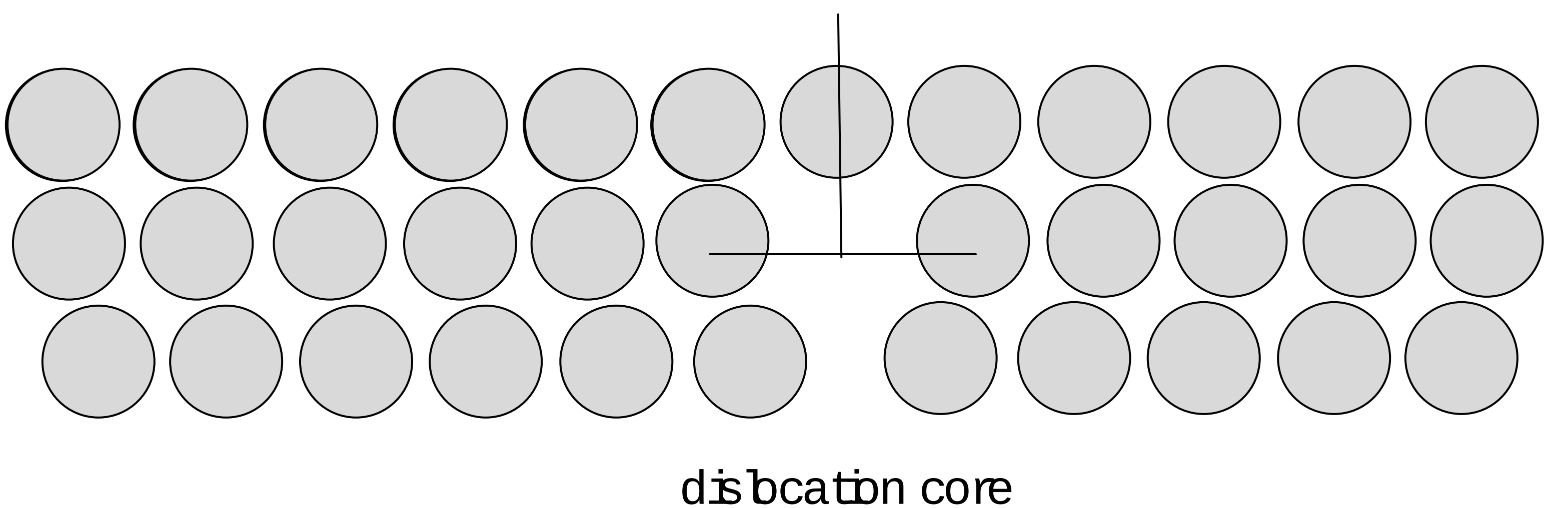
# Single Crystal Deformation: Why so weak?

Two kinds of deformation

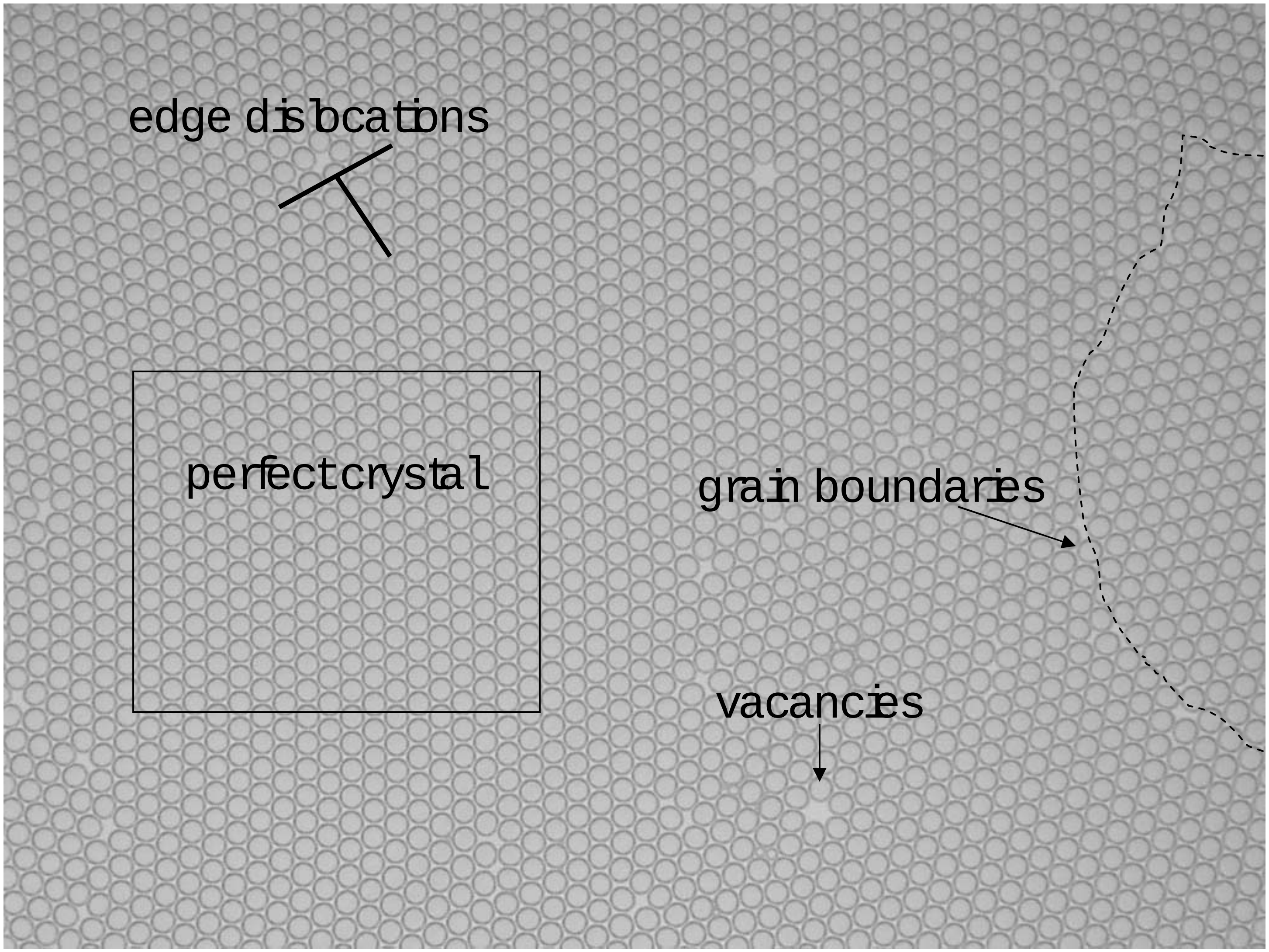
ELASTIC: reversible, bond stretching



PLASTIC: irreversible/permanent, bond breaking



Defects control physical and functional properties of metals




Bragg-Nye Bubble Raft Model [1950s]