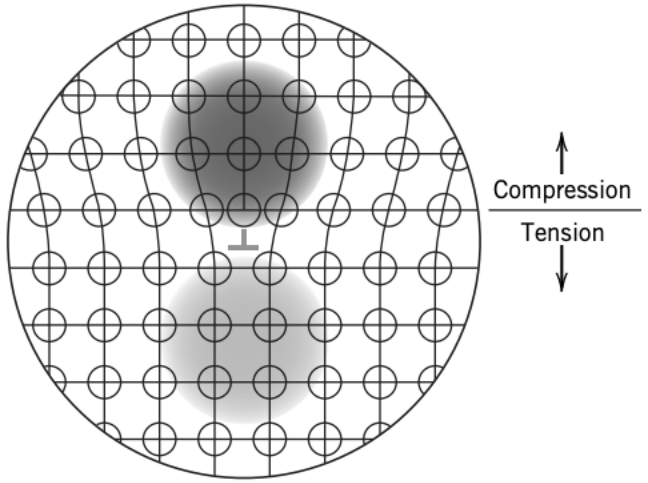
Dislocation and Strengthening of Materials

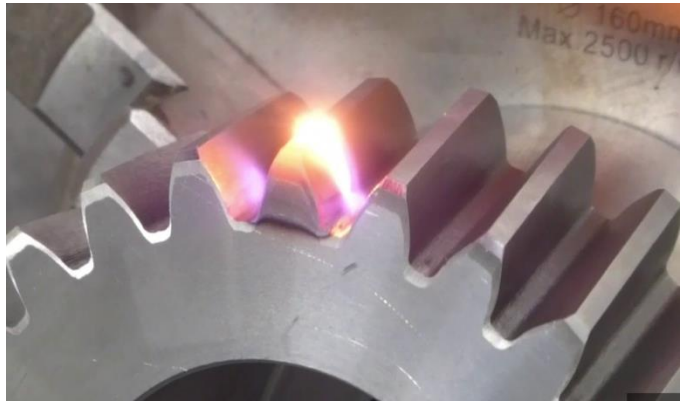
Kuntal Talit
Postdoctoral Research Associate @ Nowadnick Group
University of California, Merced

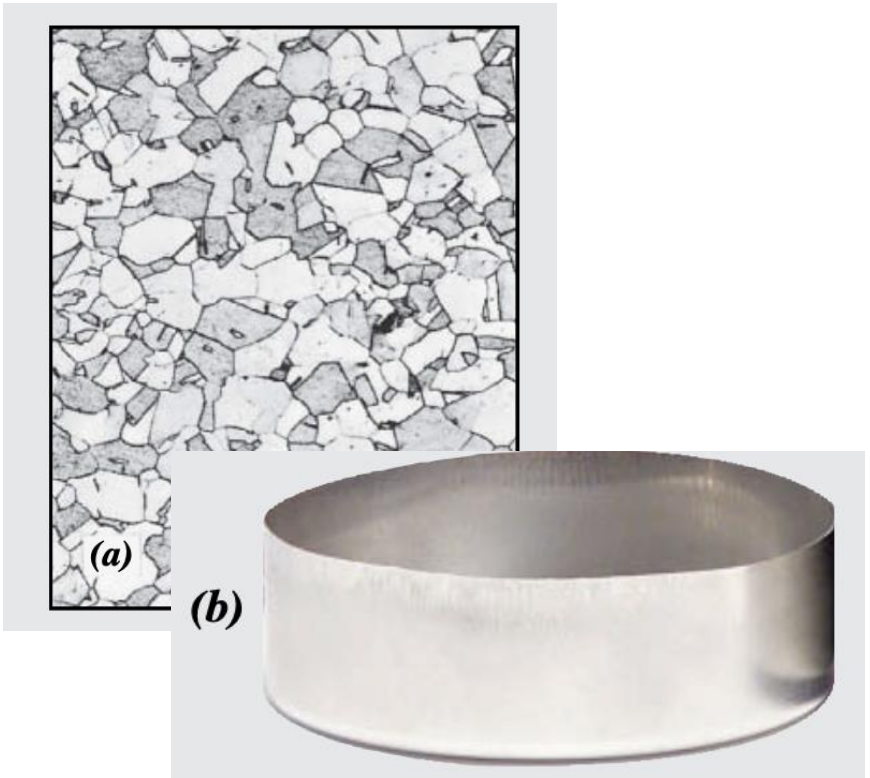


first. further. forward.

WHY STUDY Dislocations and Strengthening Mechanisms?







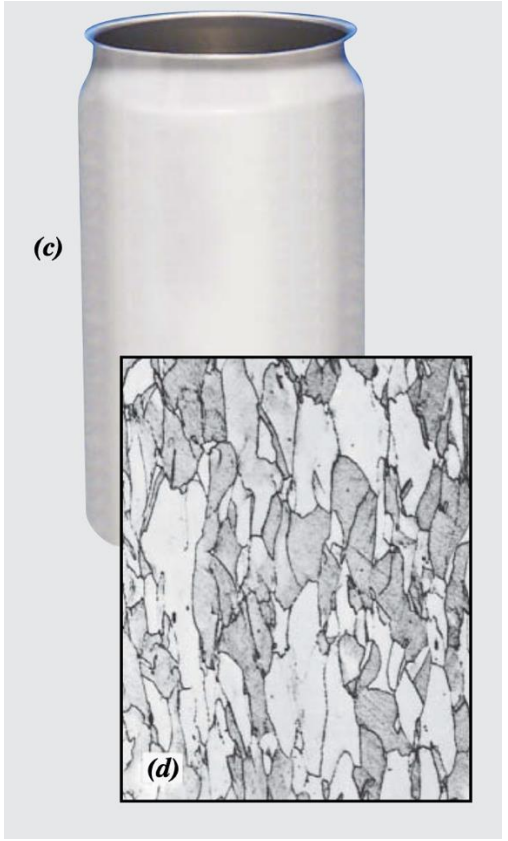


Image: Callister

Learning Objectives

Scan Me

By the end of this class, you would be able to:

1. **Identify** and **describe** edge, screw, and mixed dislocations.
2. **Describe** how plastic deformation occurs through dislocation motion.
3. **Explain** strain fields around dislocations and their interactions.
4. **Define** slip systems, including slip planes and directions, and their roles in crystal structures.
5. **Explain** how grain boundaries impede dislocation motion to influence material strength.
6. **Compare** grain size reduction, solid solution alloying, and strain hardening as strengthening mechanisms.
7. **Apply** knowledge of dislocations and strengthening mechanisms to suggest material treatments for improving strength in engineering applications.

Basic Concepts of Dislocations



Dislocation: A linear defect

Types of dislocation in materials

- Edge dislocation
- Screw dislocation
- Mixed dislocation

A TEM image of a Ti alloy in which the dark lines are dislocations, 50,000x

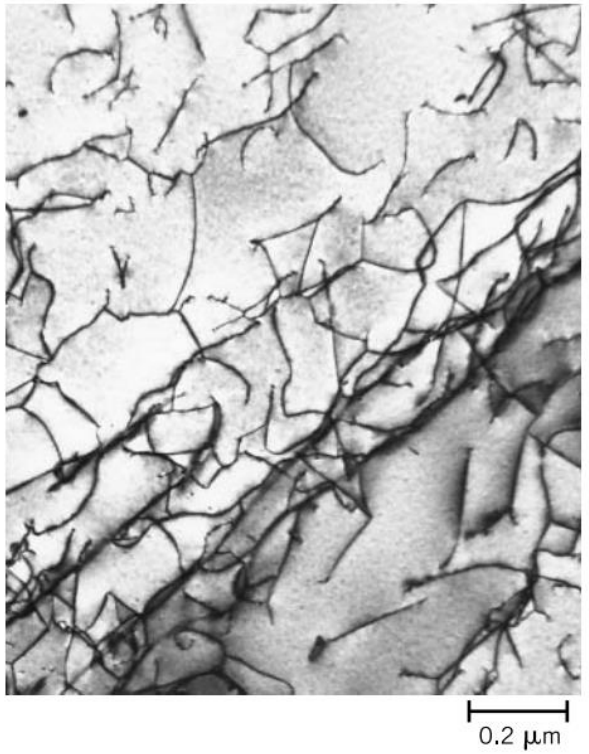
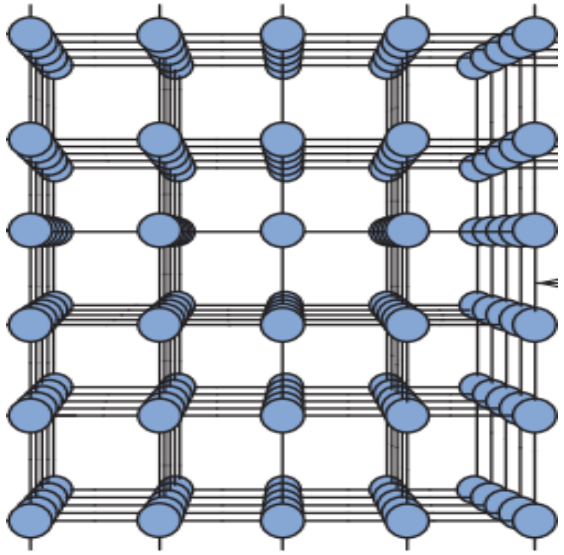
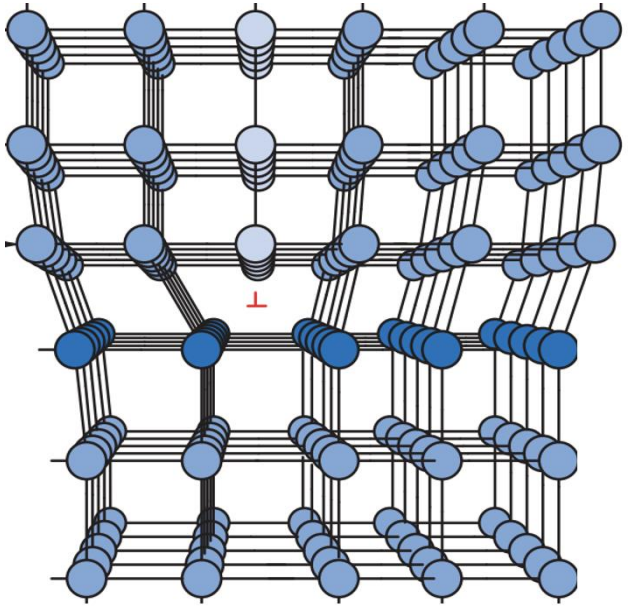
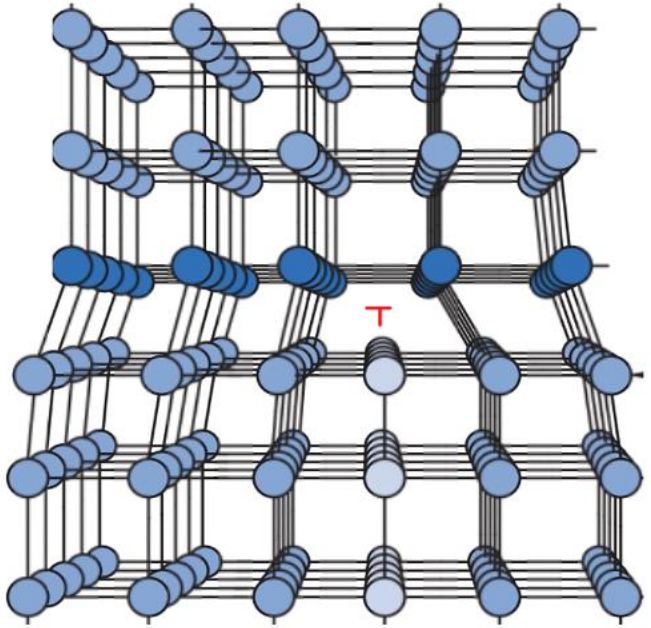


Image: Callister

Edge Dislocation



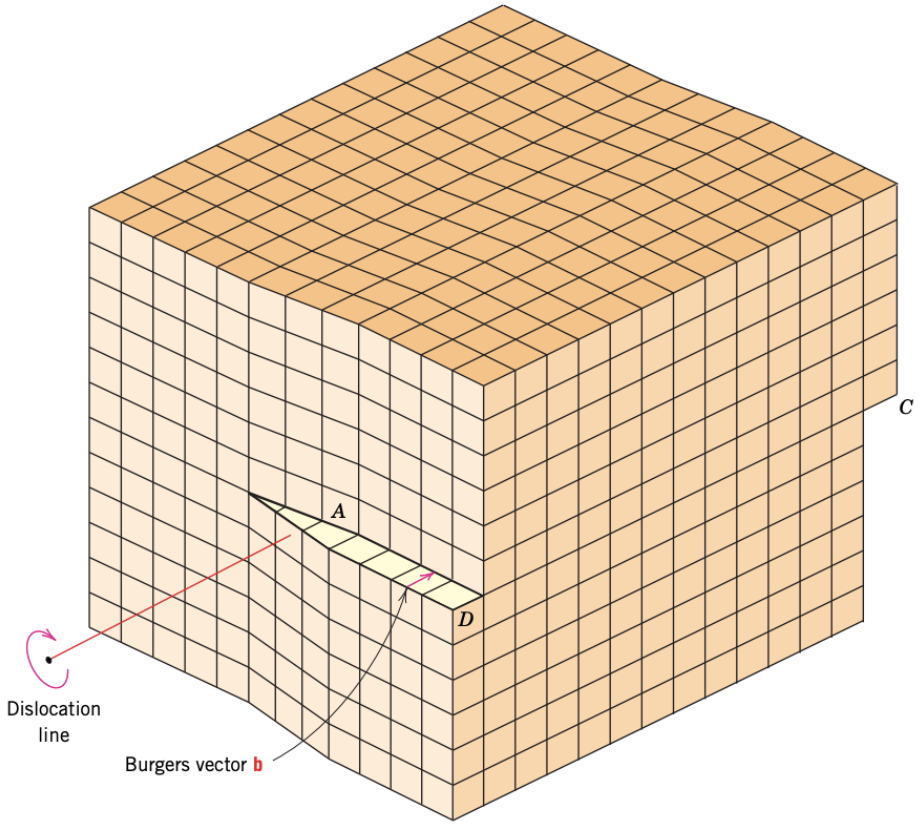


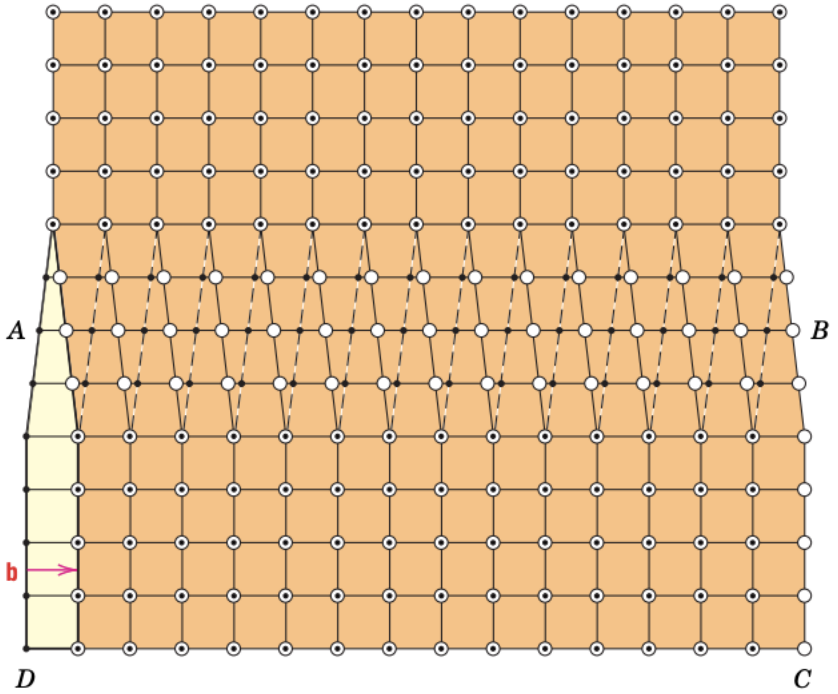


- Dislocation line
- Dislocation plane or slip plane
- Burgers vector (**b**) is perpendicular to dislocation line

Image: Callister

Screw Dislocation

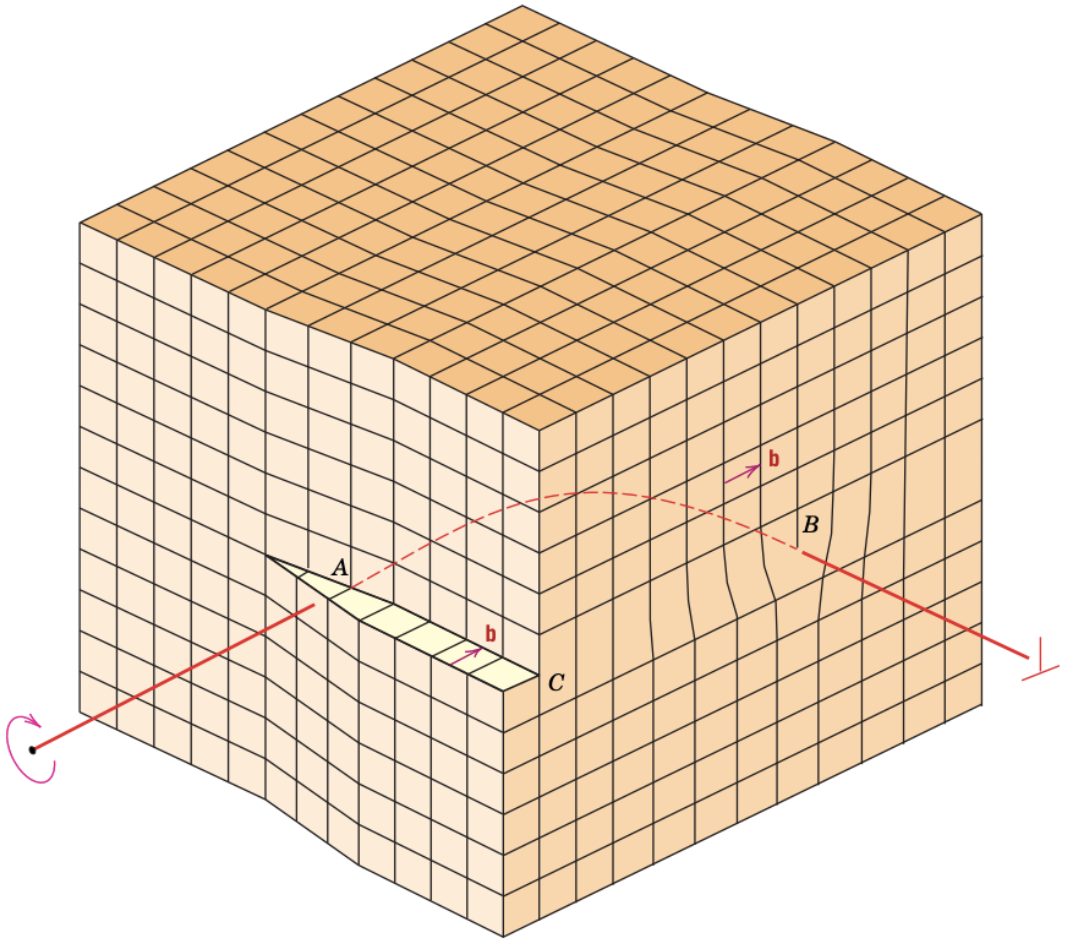




- Burger vector is parallel to the dislocation line

Image: Callister

Mixed Dislocation



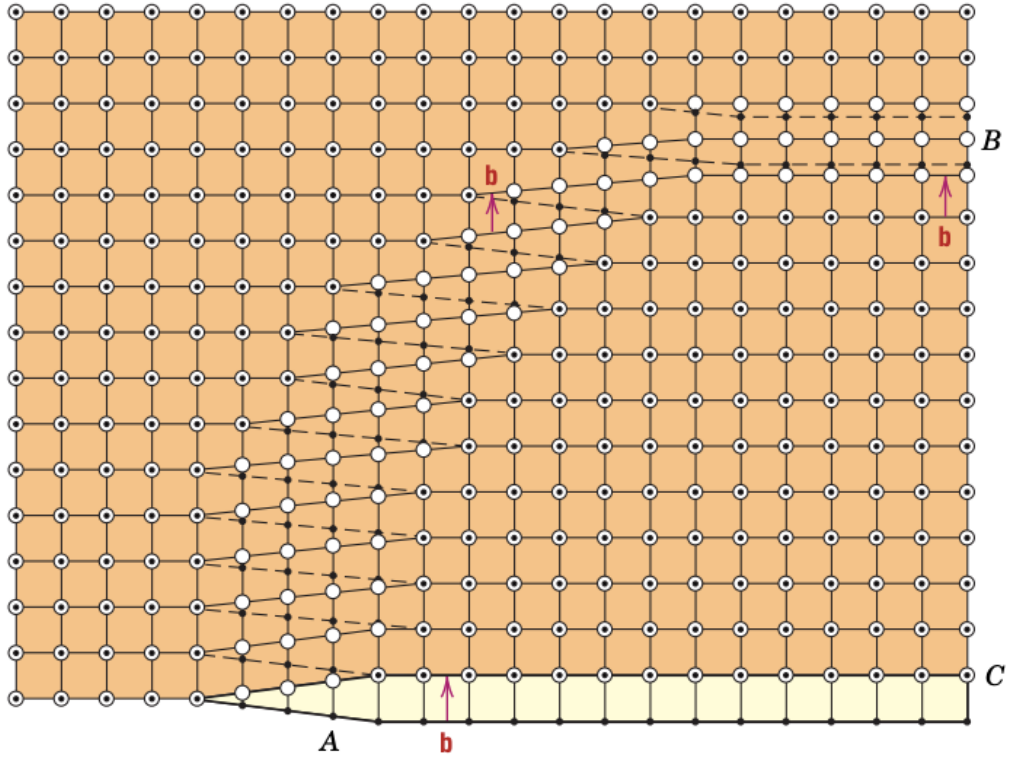
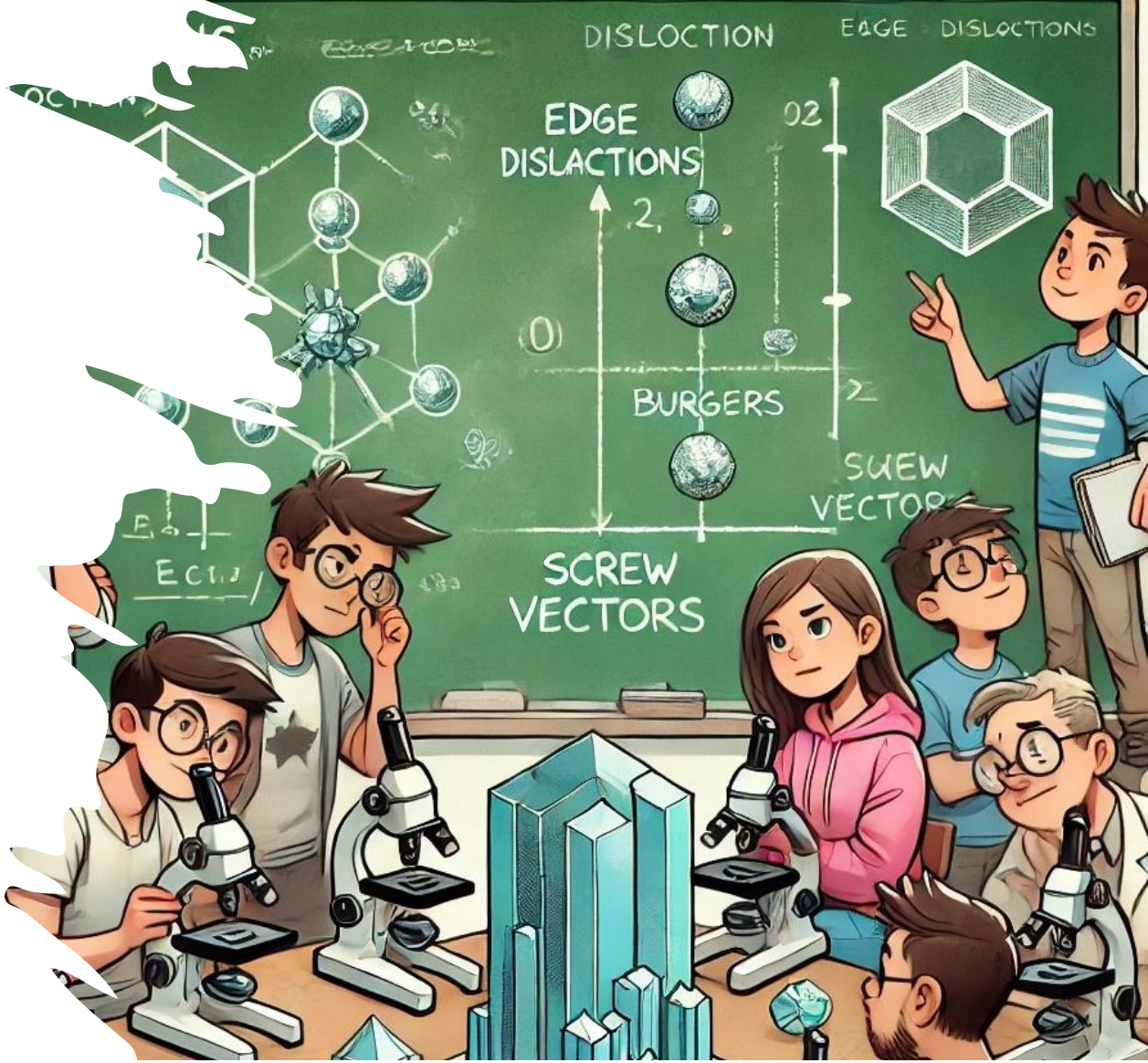


Image: Callister

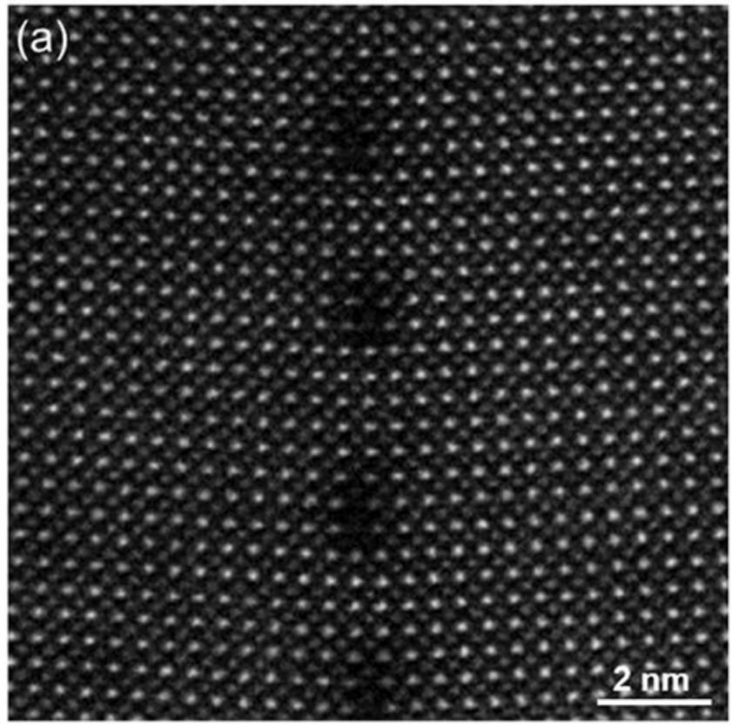
Group Activity-1

- Work in groups to identify Edge dislocation, screw dislocation and mixed dislocations in the work sheets provided
- Draw Burgers vector (**b**) for each case.

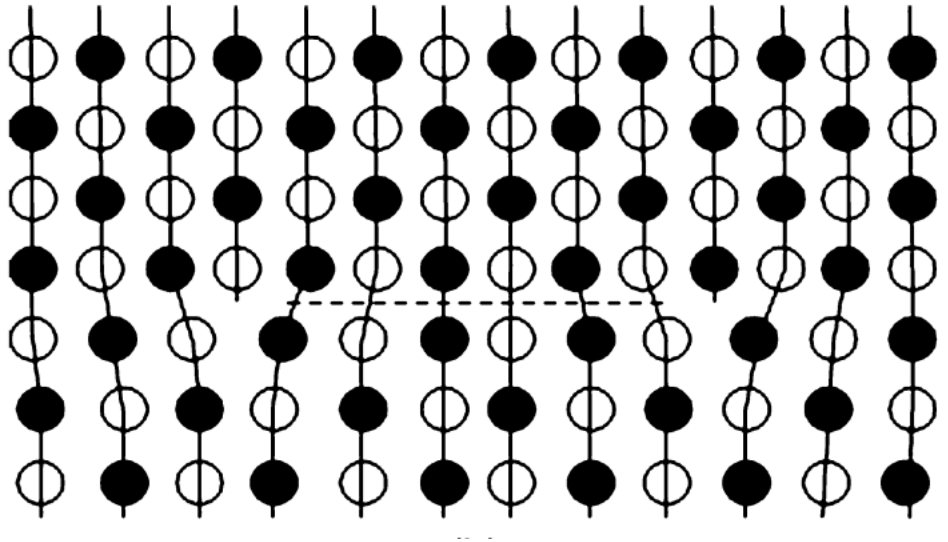


Question-1

[001] atomic-resolution dark-field STEM image of dislocations on a small-angle grain boundary of $SrTiO_3$ taken at an accelerating voltage of 200 kV.

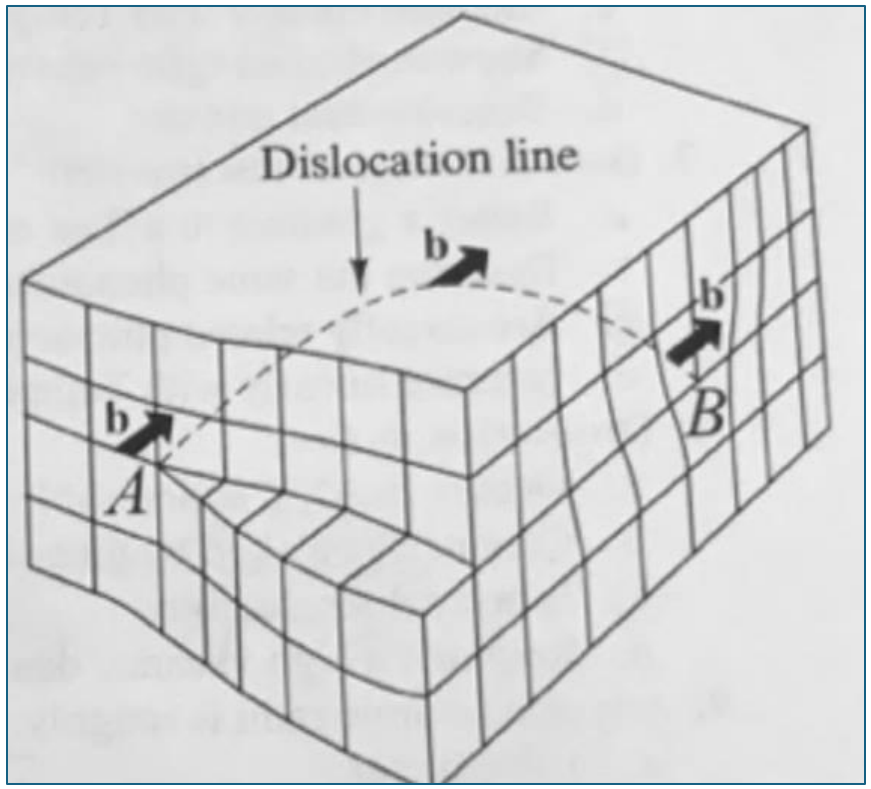


Picture: jeol.com



1. Find all the edge dislocations in figure 1 & 2.
2. Draw Burgers vectors in each case.

Question-2



1. What type of dislocation are there at point A and at point B?

2. In which case the Burgers vector is parallel to the dislocation line?

3. If each block in the picture represents a cubic lattice with lattice constant **a,** what is the value of the Burger vector?

Question-3



Atomic-resolution high-angle annular dark-field (HAADF) image taken along [1120] $MgZn_2$

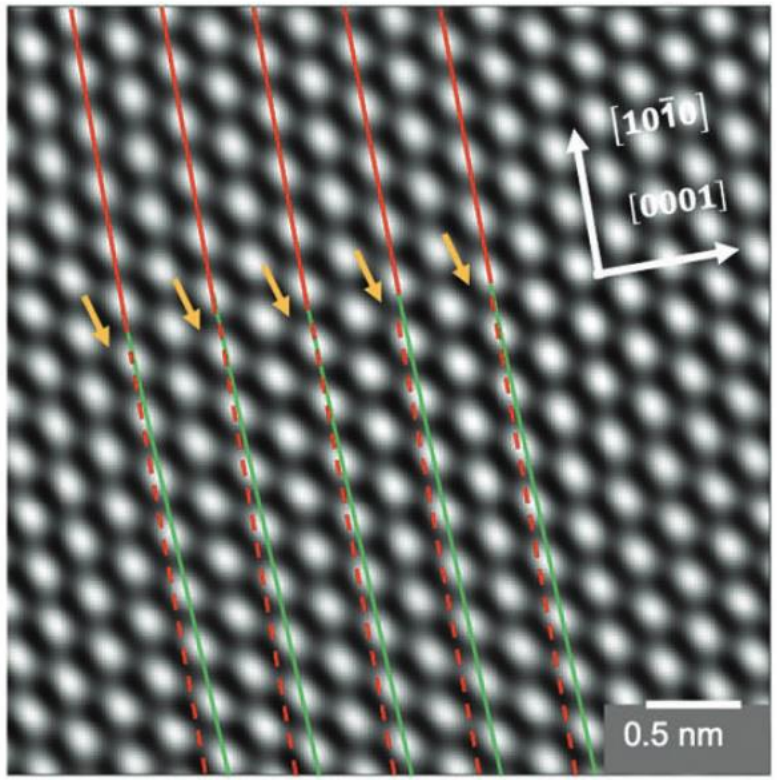
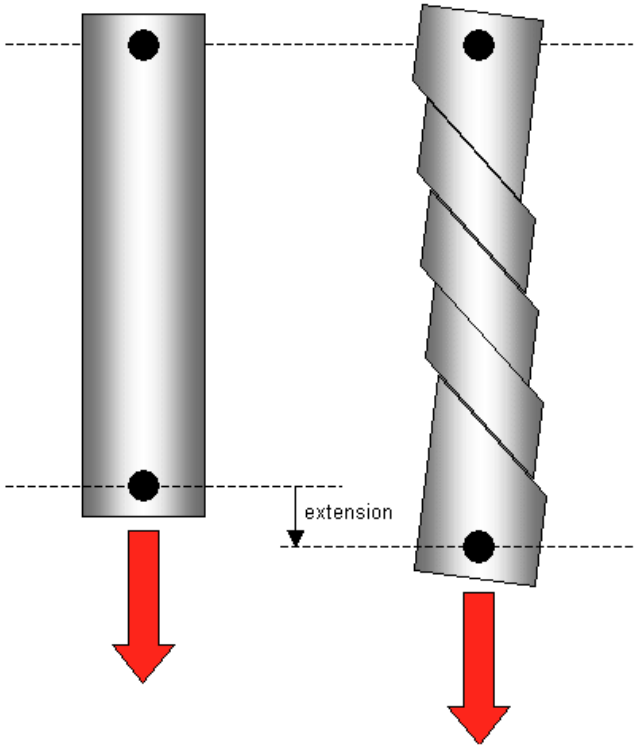
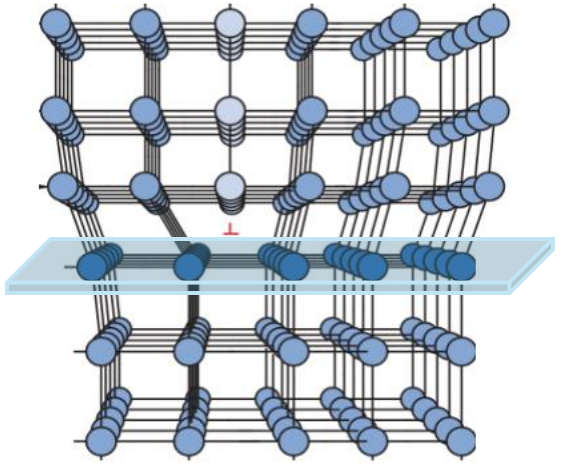


Figure: S. Moniri et al., Small, 16, 1906146 (2020)

1. What type of dislocation is this and why?

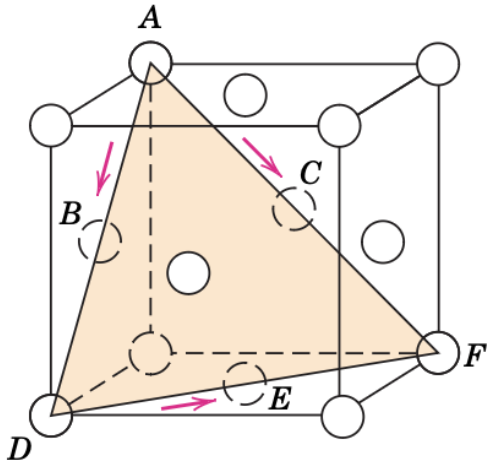
Slip System



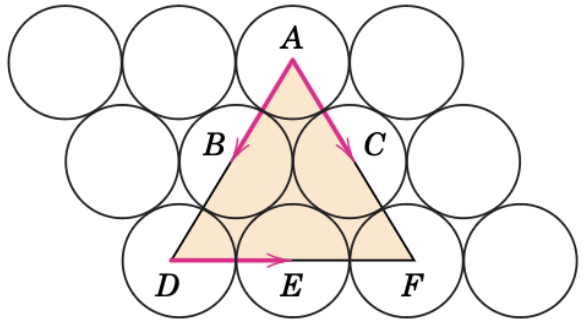


Slip Plane

Slip plane in FCC crystal



(a)



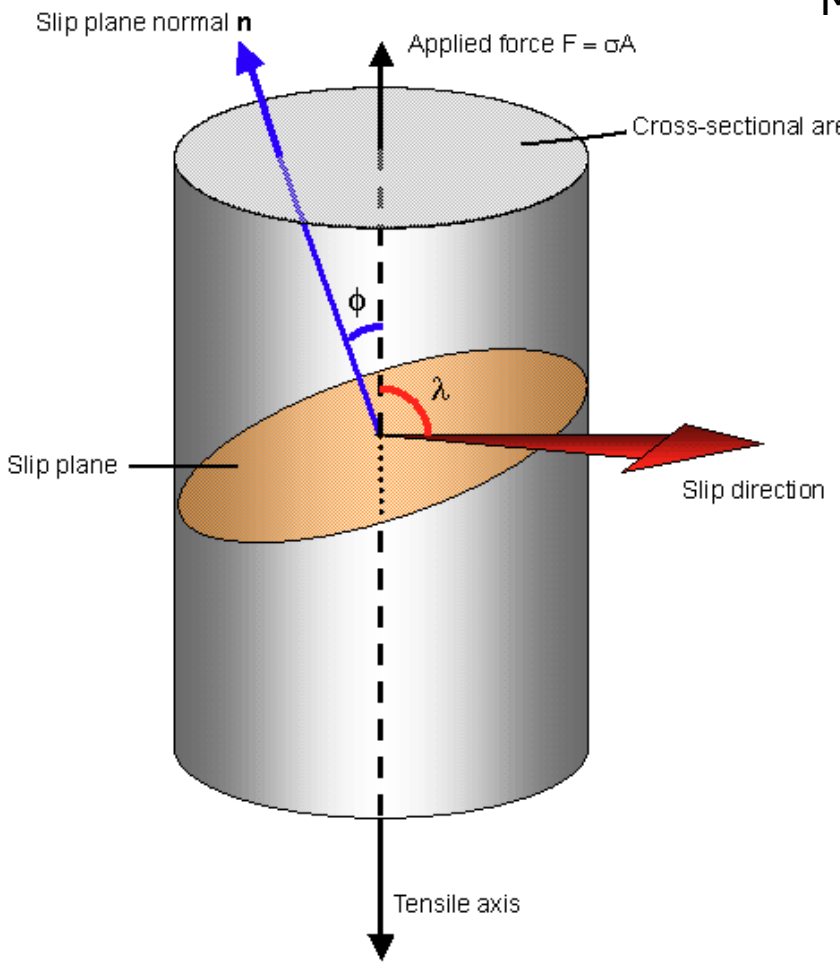
(b)

How many?

12

Most closely packed planes

The critical resolved shear stress: **Schmid's Law**



Minimum shear stress required to initiate slip

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

$$\tau_C = \sigma_y \cos\varphi \cos\lambda$$

Minimum stress necessary is at $\phi = \lambda = 45^o$

$$\sigma_y = 2\tau_c$$

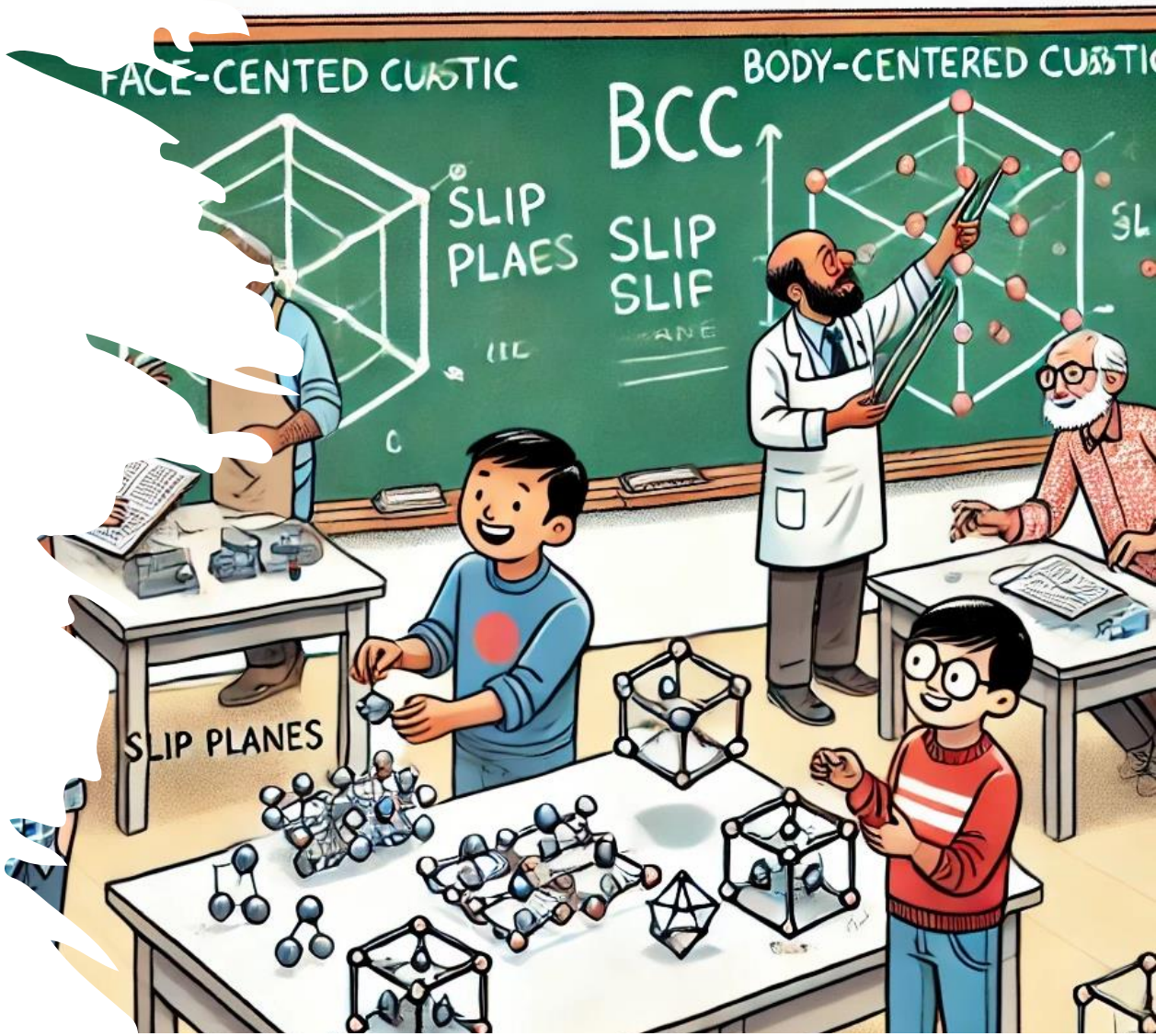
first. further. forward.

Image: Callister

Group Activity-2

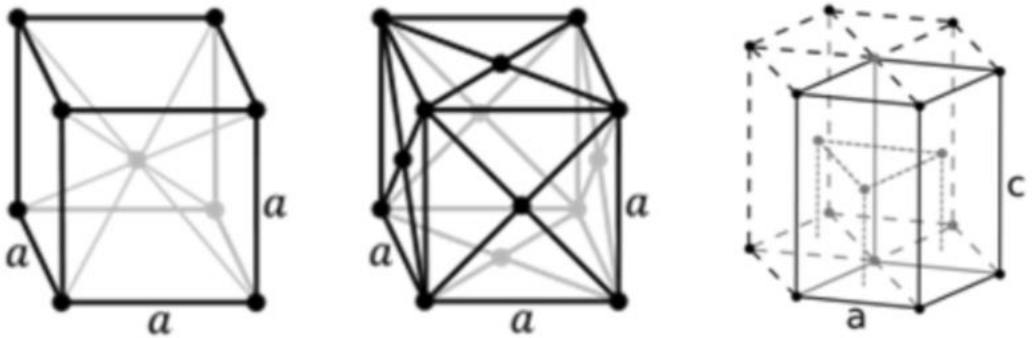
- Find slip planes and slip directions for the crystal systems provided in the work sheet.

- Count the total number of slip planes for a particular crystal structure asked in the work sheet.



Question-1

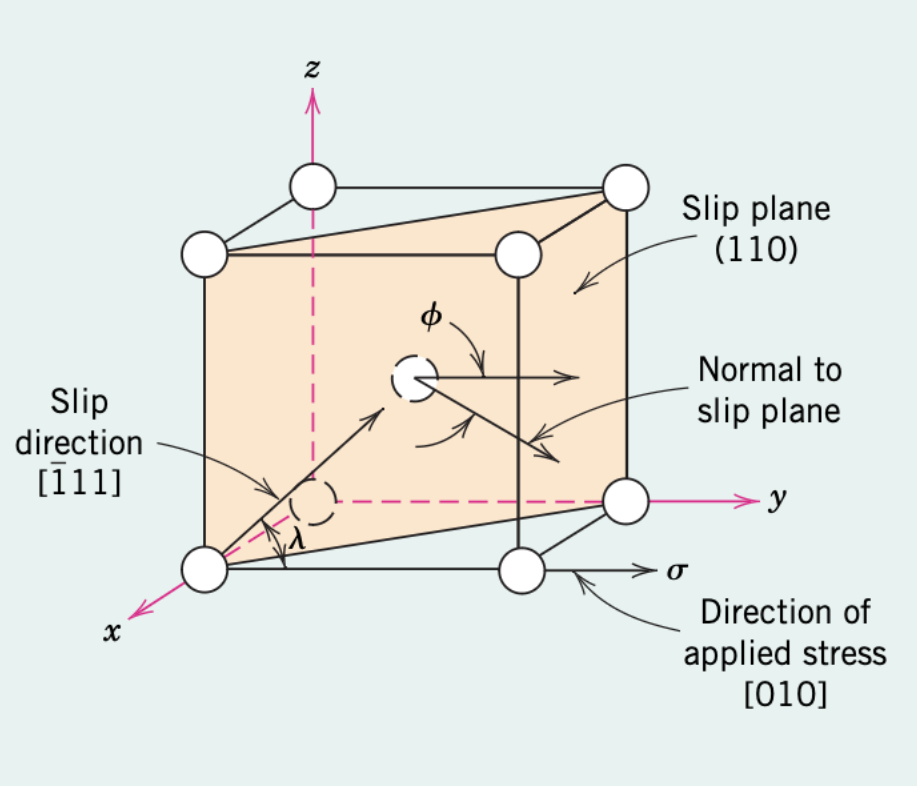
Fill the table below for these crystal systems:



bcc fcc hcp

Crystal system	Slip planes	Slip directions	Number of slip systems

Question-1: Answer



Major Slip Systems in the Common Metal Structures

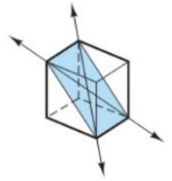
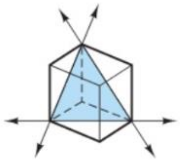
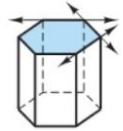
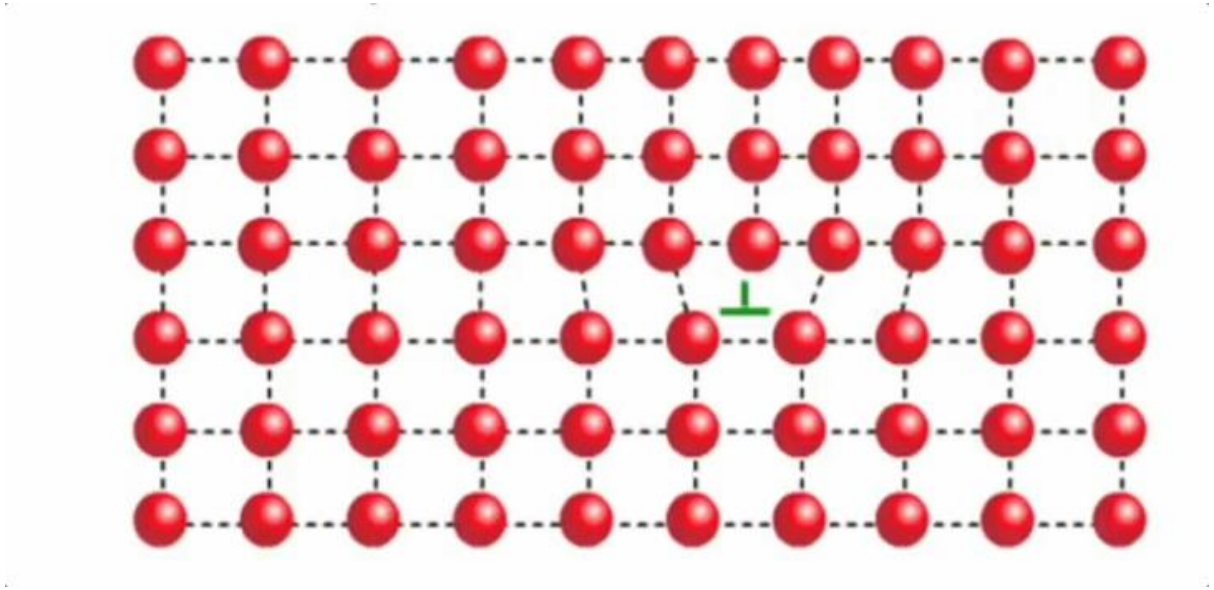
Crystal structure	Slip plane	Slip direction	Number of slip systems	Unit-cell geometry	i Examples
bcc	{110}	$\langle \bar{1}11 \rangle$	$6 \times 2 = 12$		α-Fe, Mo,W
fcc	{111}	$\langle 1\bar{1}0 \rangle$	$4 \times 3 = 12$		Al, Cu, γ-Fe, Ni
hcp	(0001)	$\langle 11\bar{2}0 \rangle$	$1 \times 3 = 3$		Cd, Mg, α-Ti, Zn

Image: Callister

Dislocation Motion



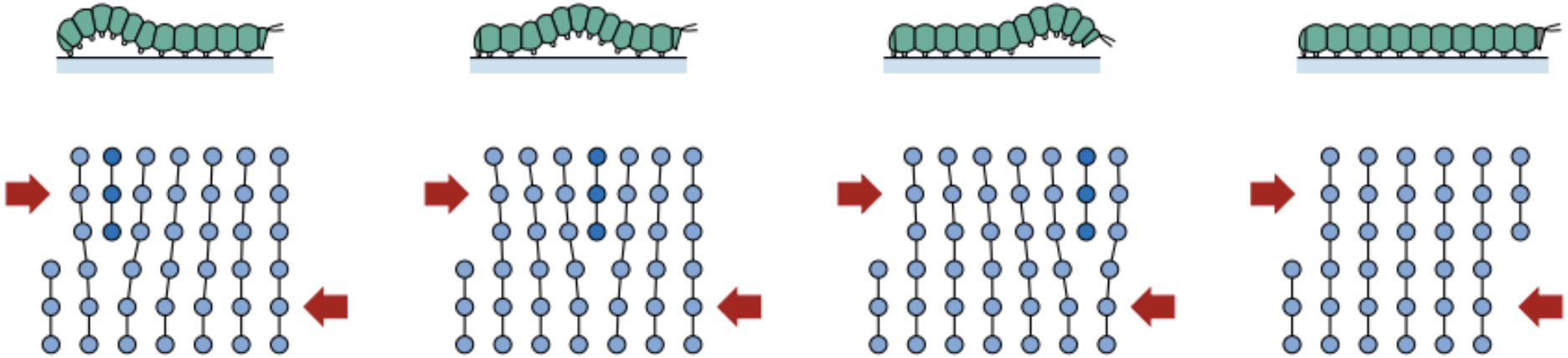
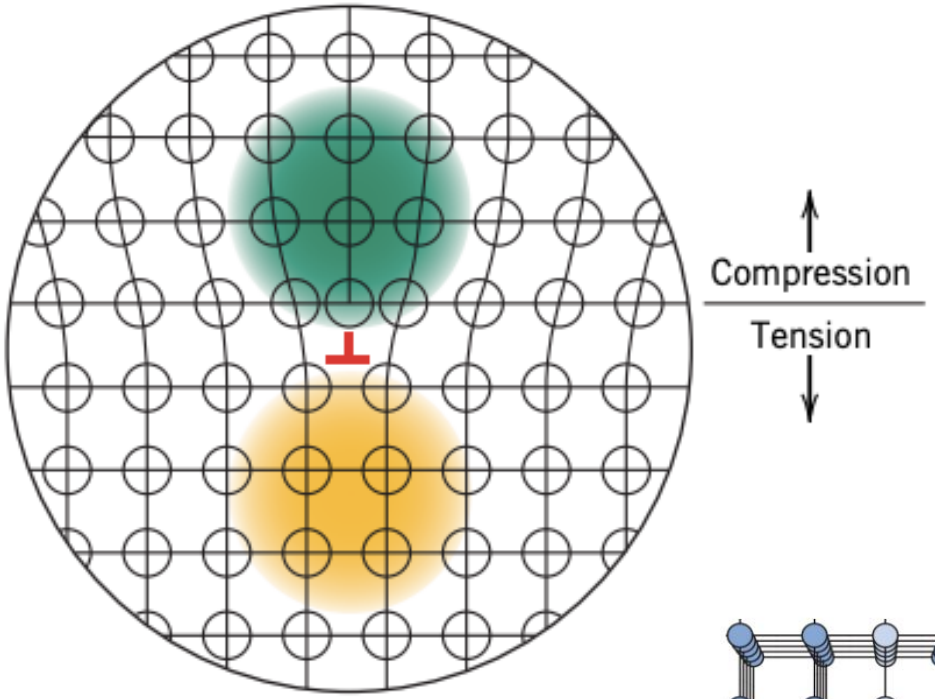
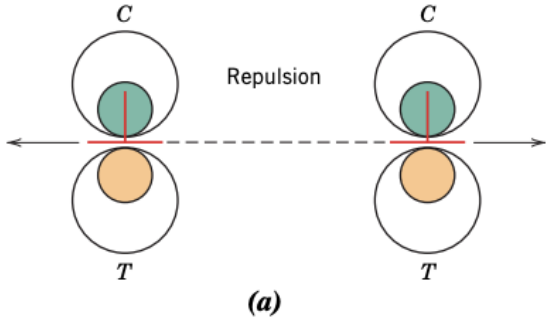
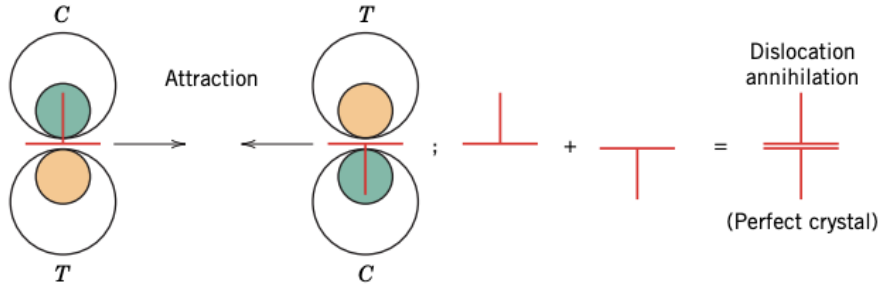


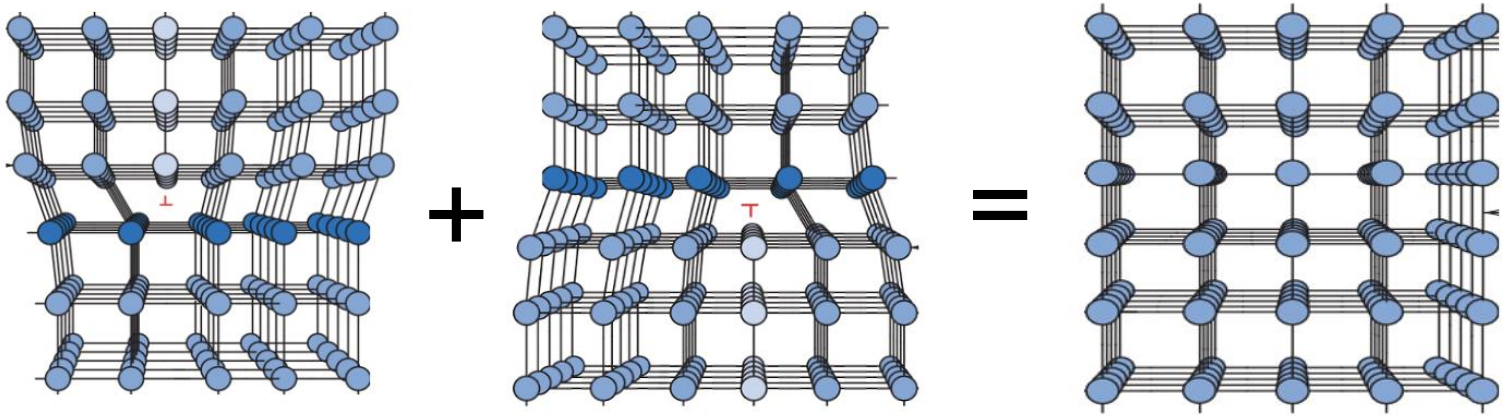
Image: Callister

Strain Field in Dislocation









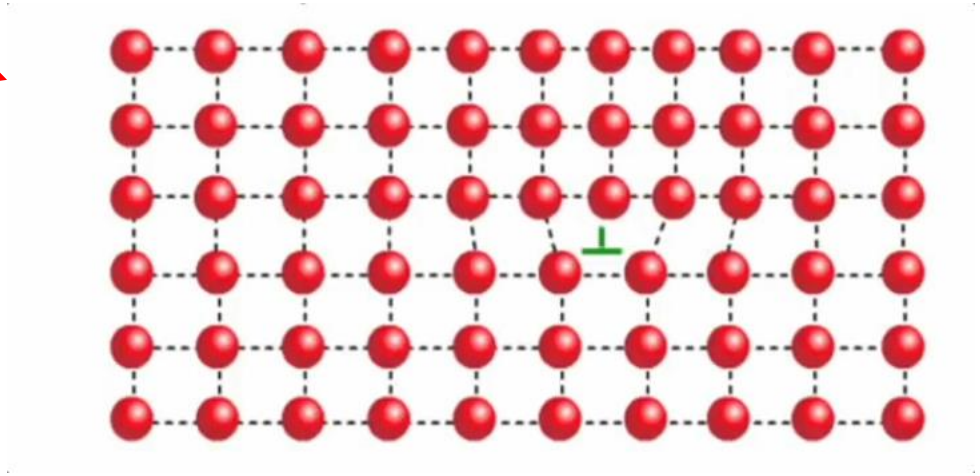
first.
further.
forward.

Image: Callister

Strengthening Materials



Keep the expected stress below the yield stress all the time



STOP dislocation movement **STOP** yielding

first. further. forward.

Image: Callister

Strengthening methods

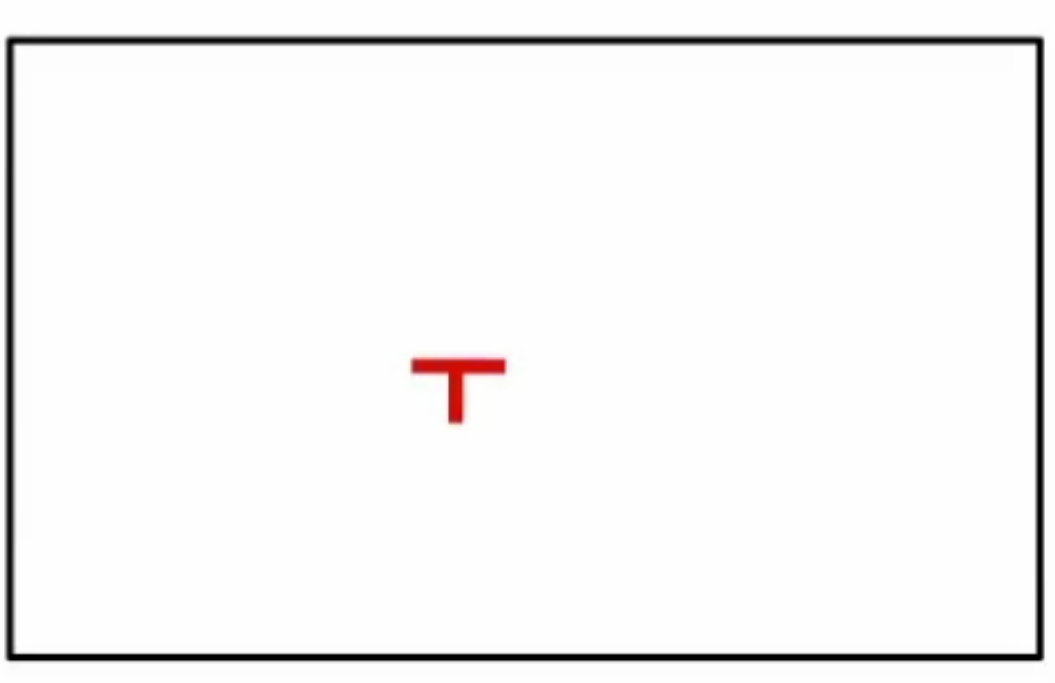
- Cold working (a. k. a. work hardening, strain hardening)
- Grain size refinement
- Alloying
    - Solid solution strengthening
    - Precipitation hardening (a. k. a. age hardening)

Dislocation and work hardening



$$\%\ Cold\ Work = \frac{\left(A_0 - A_{final}\right)}{A_0} \times 100\ \%$$

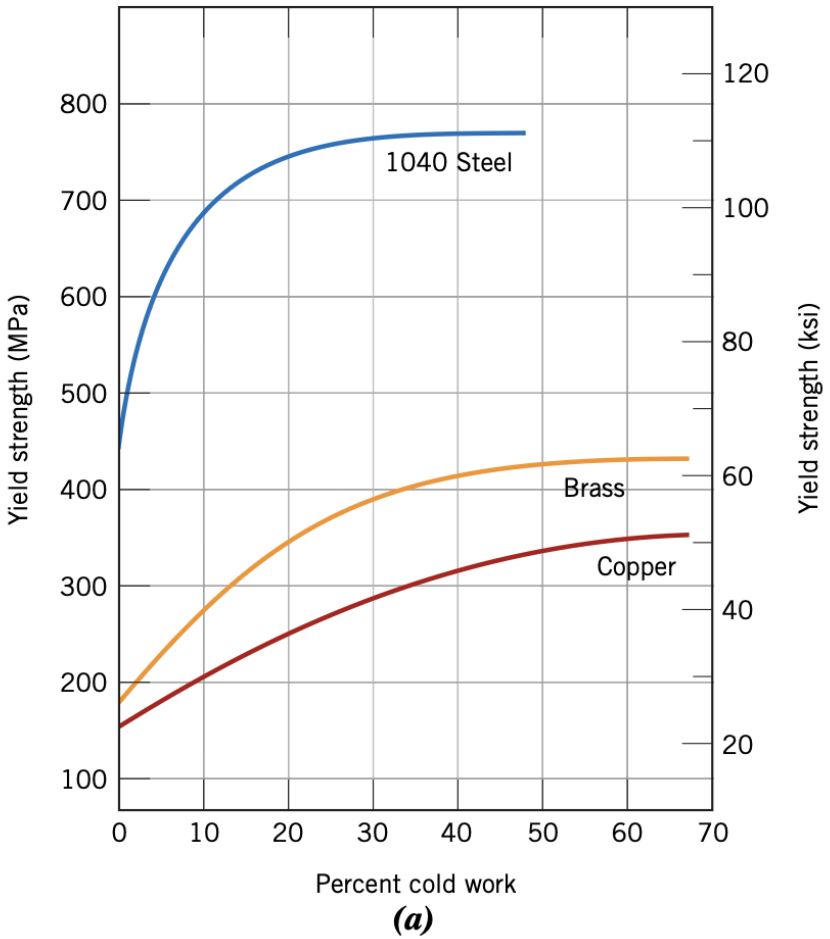
Add **more** dislocations



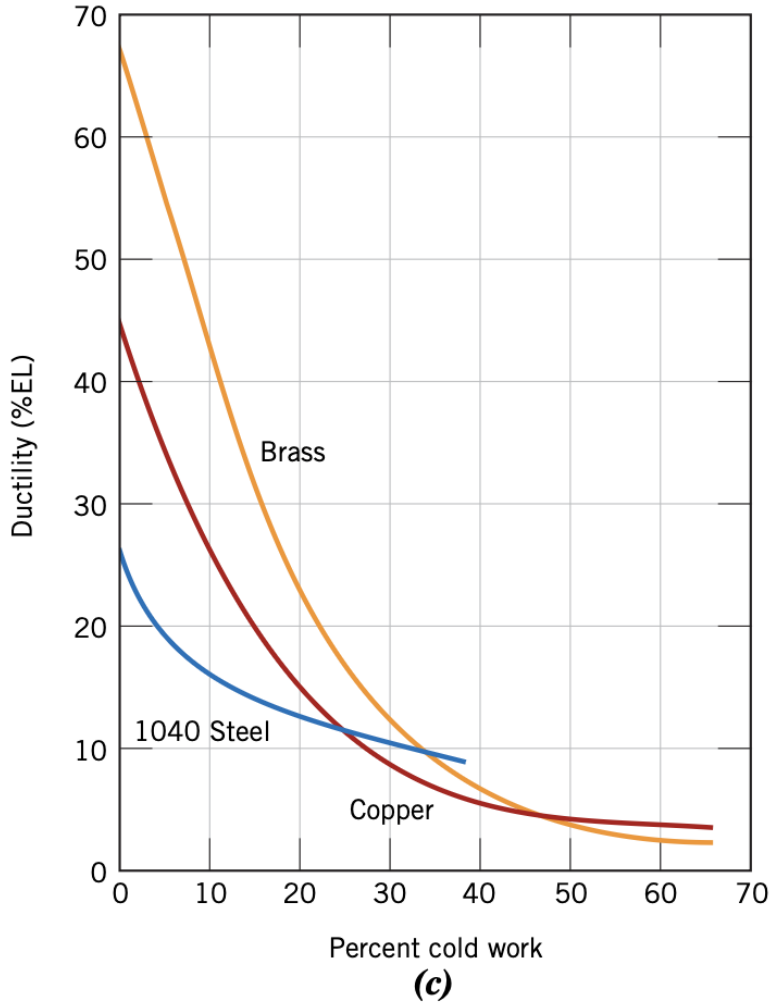
- Number of dislocations increases significantly.
- Distance between dislocations decreases.
- Majority of the dislocation interactions are repulsive, and so dislocation movement is restricted.

Image: Callister

Strain-Hardening of Metals







first. further. forward.

Image: Callister

Grain Refinement

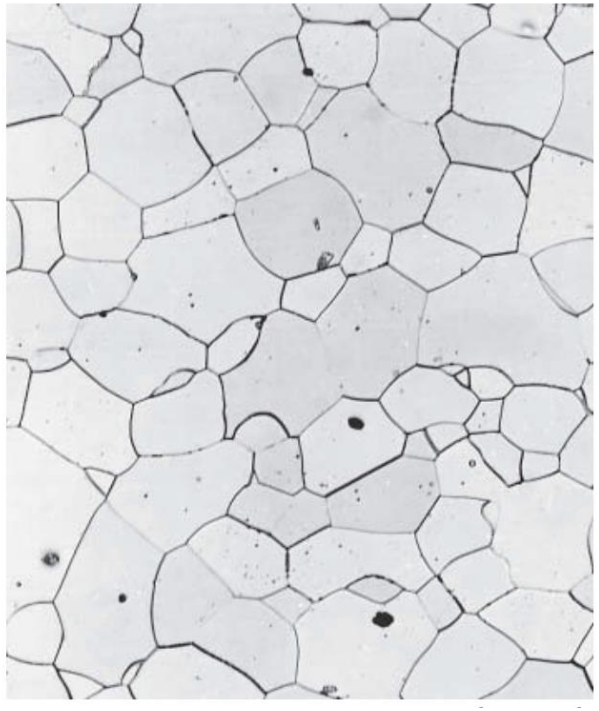
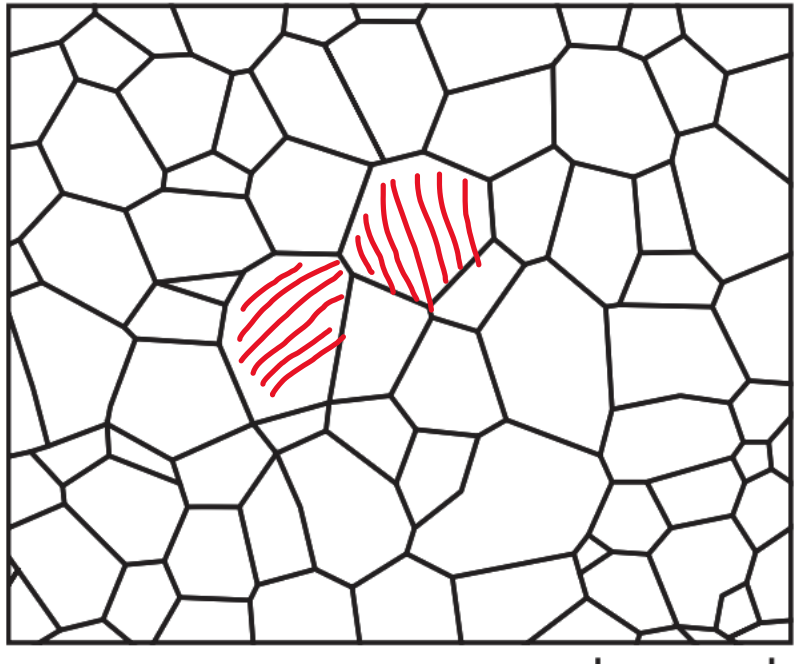


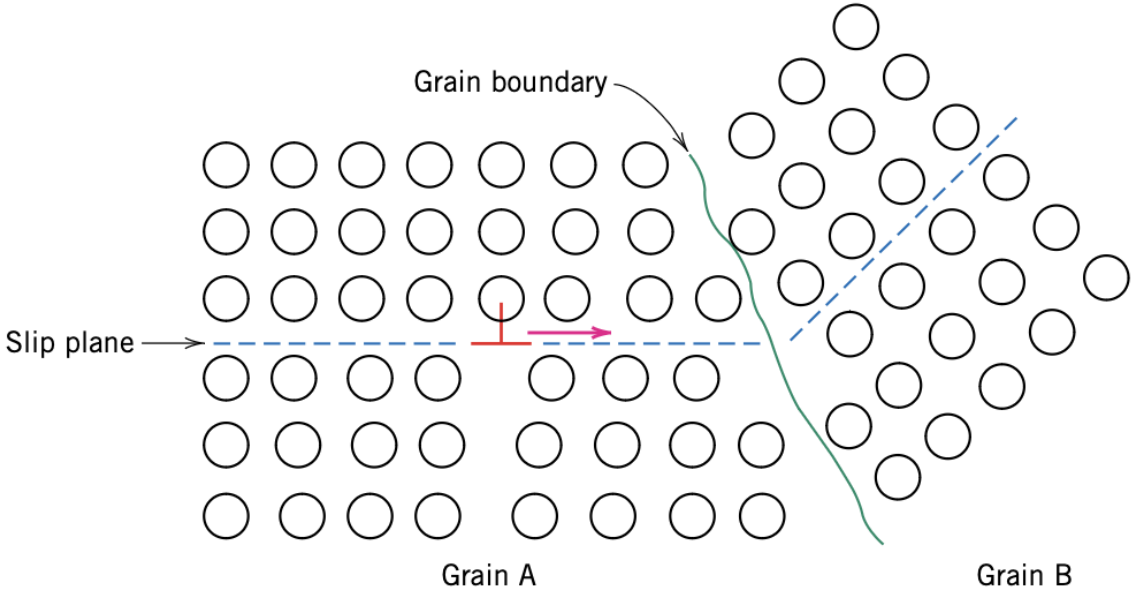
Image: Polished iron-chromium alloy sample at 100x magnification



Adjacent grains will have different crystal orientations

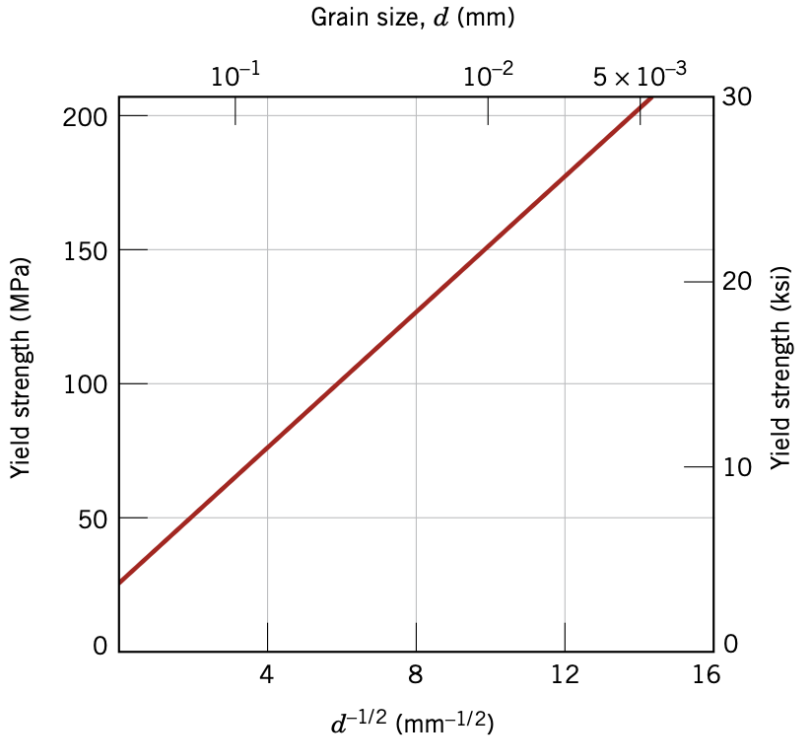
Image: Callister

Effect of grain size on strengthening of materials



Hall-Petch equation

$$\sigma_y = \sigma_0 + k_y d^{-1/2}$$

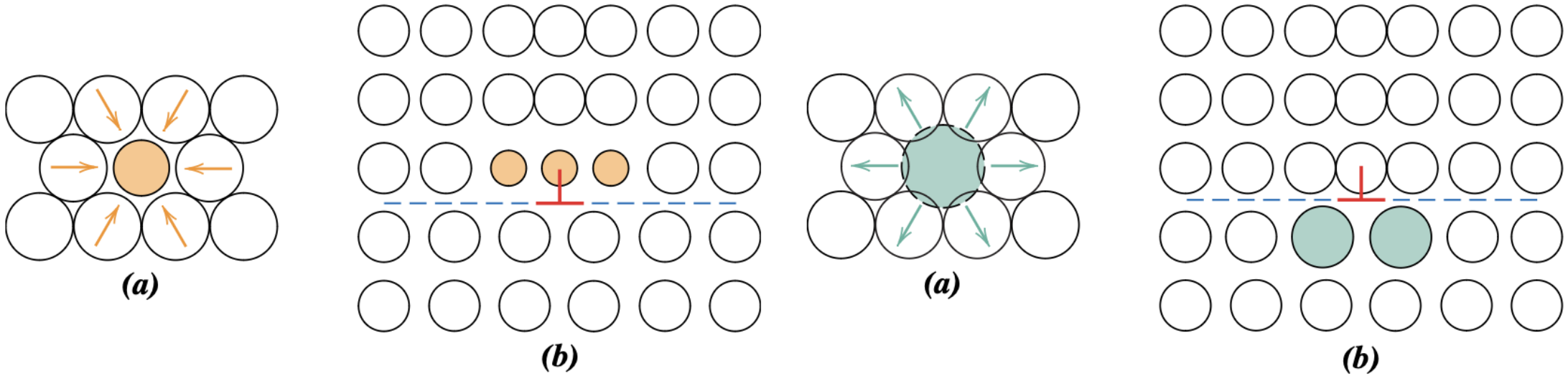


The influence of grain size on the yield strength of a 70 Cu–30 Zn brass alloy.

first. further. forward.

Image: Callister

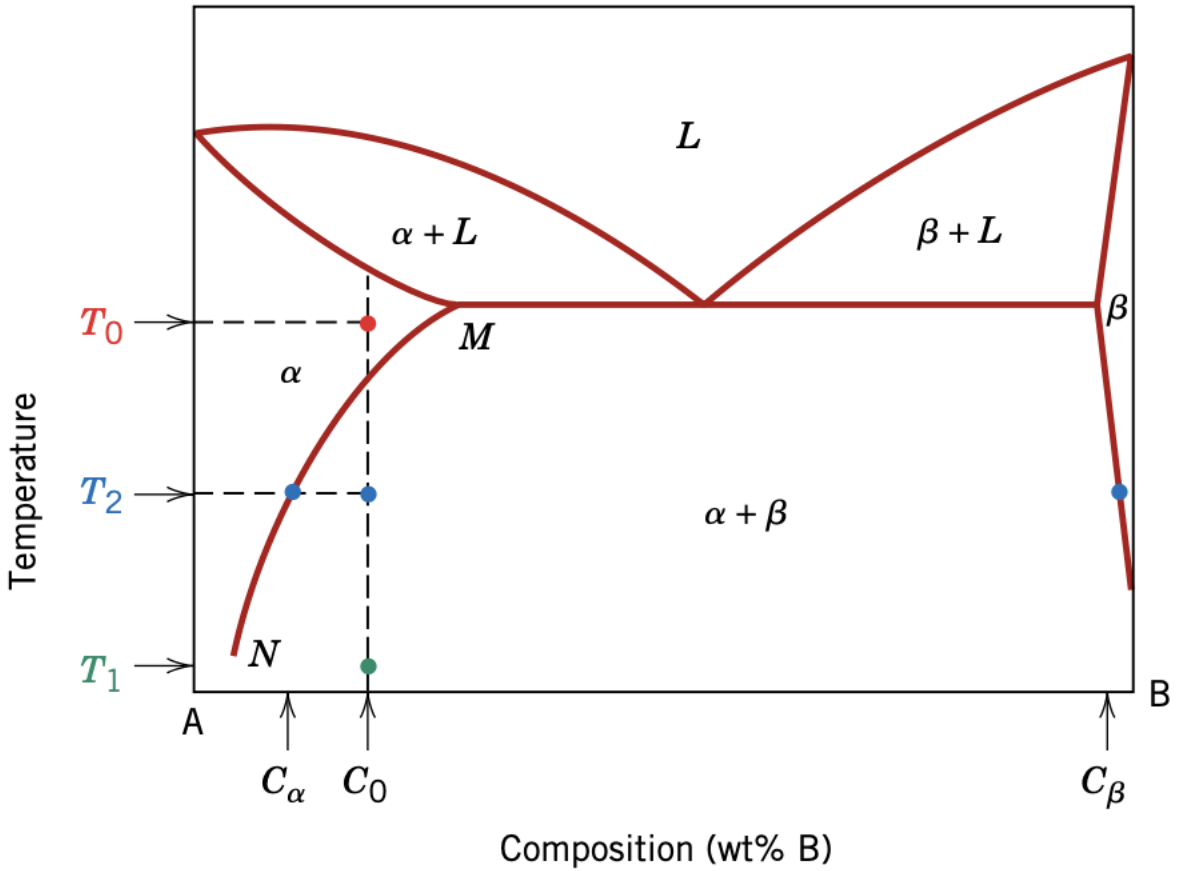
Alloying: Solid Solution Strengthening

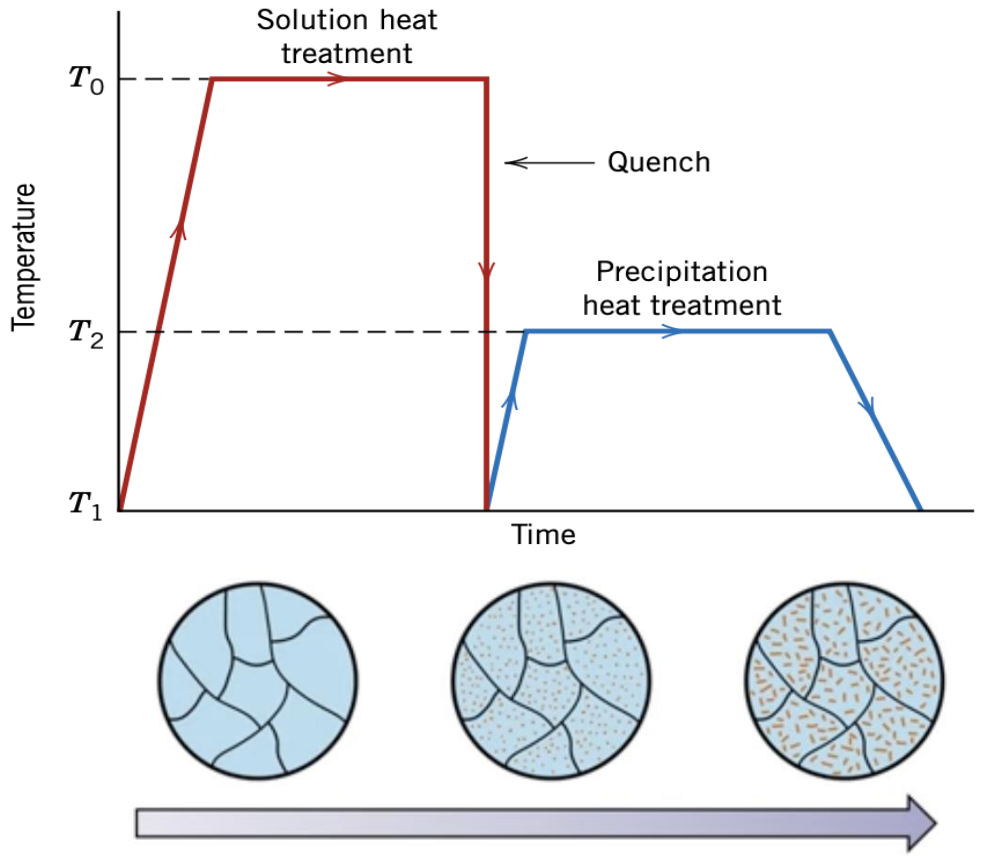


Reduce the overall strain energy surrounding dislocations

Image: Callister

Alloying: Precipitation hardening





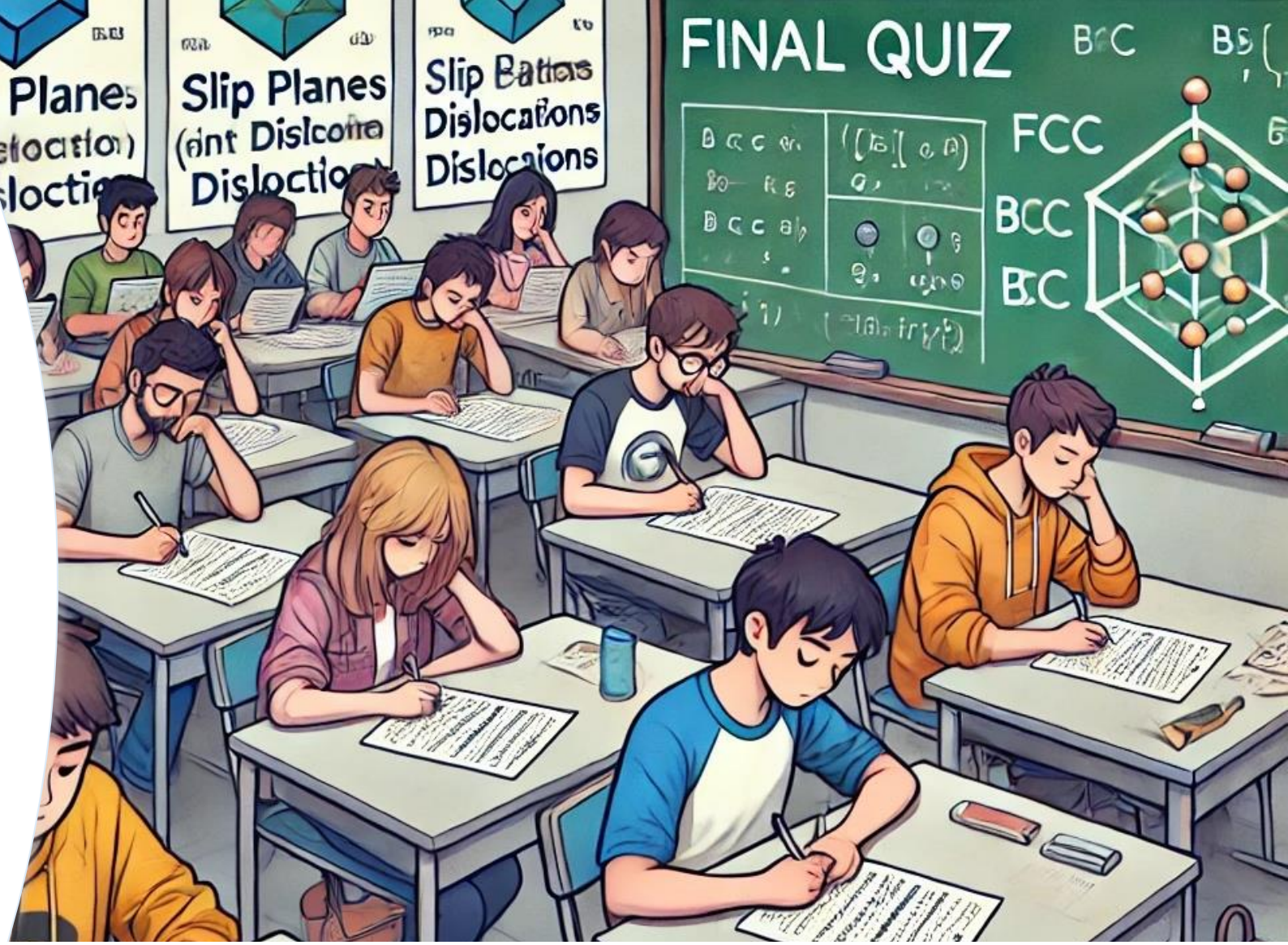
first. further. forward.

Image: Callister

Summary

- ✓ We **explored** edge, screw, and mixed dislocations.
- ✓ We **learned** how dislocation motion leads to plastic deformation.
- ✓ We **studied** strain fields around dislocations and their interaction with the lattice.
- ✓ We **covered** slip systems and critical resolved shear stress in slip processes.
- ✓ We **discussed** how grain boundaries block dislocation movement.
- ✓ We **learned** about various strengthening mechanisms in materials.

Final Quiz



Thank You !!!

Class Assessment Survey



UCMERCED
first.
further.
forward.