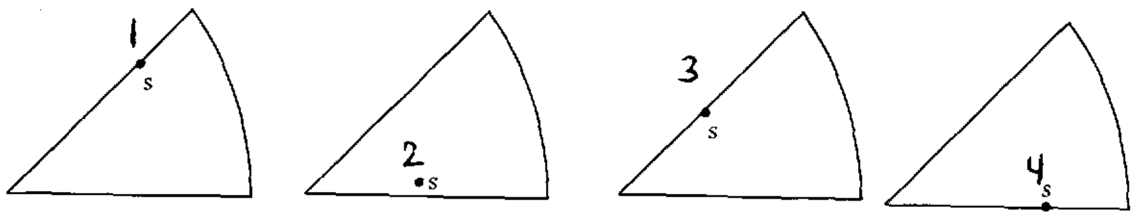
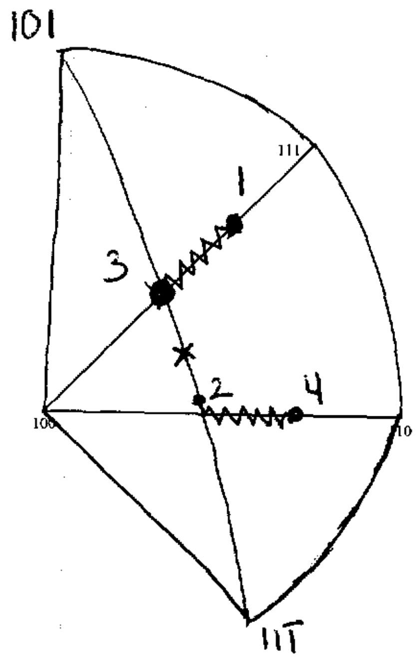
Problem #1: The Orientation of a Crystal is Inferred from Four Samples Processed Differently

A single crystal of an FCC metal is cut into four pieces and deformed uniaxially. The resulting four orientations are shown below, where the location of the stress axis is shown at the end of the test.



To complete this problem you need to do two things:

1. Identify the most likely original orientation of the testing (the original position of the stress axis—mark it in the blank stereographic triangle below)
2. Identify the four different deformations that must have been applied to these crystals in order to achieve the configurations shown at the end of the test.



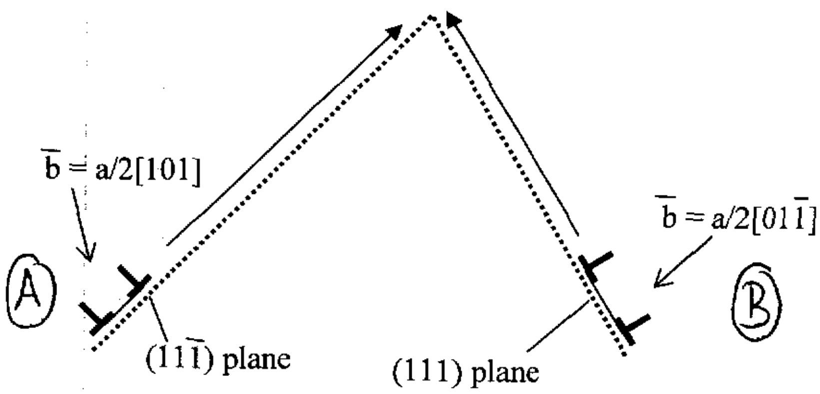
Uniaxial deformation rotates either toward $\langle 11\bar{1} \rangle$ (compression) or toward <101> (tension).
Requirement: One point in the triangle has to be on both trajectories.
#1 + #4 are on the symmetry line and are both on the stable configuration.
#2 + #3 are probably on the original trajectories

X is likely starting point ①

#3: small amount of tension ①
#1: large amount of tension ①
#2: small amount of compression ①
#4: large amount of compression ①

Problem #2: Lock, Stock, and a Barrel Full of Partials

Consider two dislocations moving on different $\{111\}$ planes in an FCC crystal, which are coming together at the same position as shown.



The two initial dislocations have Burgers vectors of a/2<110> type as shown; however, as the *picture implies, these dislocations are actually separated into partials of a/6<211> type.*

Part A:

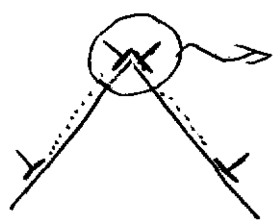
Write out the correct Burgers vectors for the four partials in this problem (not just families—make sure all the signs and order of the digits hkl are correct, and make sure that they lie in the slip plane).

1.5 A $\frac{a}{6}[2\bar{1}1] + \frac{a}{6}[112] = \frac{a}{2}[101]$ in $(1\overline{11})$ plane

1.5 B $\frac{a}{6}[11\bar{2}] + \frac{a}{6}[\bar{1}2\bar{1}] = \frac{a}{2}[01\bar{1}]$ in (111) plane

Part B:

Draw a picture showing the dislocation reaction that will occur when these dislocations meet. Will the reaction lead to a sessile or a glissile configuration?



$\frac{a}{6}[2\bar{1}1] + \frac{a}{6}[11\bar{2}] = \frac{a}{6}[361]$ 1

not a close packed direction not in $\{111\}$ planes → sessile 1

Problem 3: Twinning

In class we analyzed twinning in HCP metals quite thoroughly. We mentioned that twinning can happen in FCC metals, although it is not as common. In fact, we discussed the fact that in FCC crystals, the twinning plane is (111), and the twinning direction is $\langle 11\bar{2}\rangle$.

Part A:

Twinning involves two undistorted planes. The second undistorted plane is $(11\bar{1})$. What is the first undistorted plane?

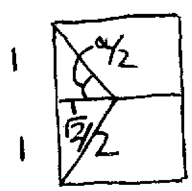
1

the twinning plane (111)

Part B:

Knowing the twinning planes and twinning direction, do a simple calculation to determine the amount of shear strain that would be produced by a twin. (Hint: you may want to draw some pictures of the unit cell in order to get a feeling for the orientation of these planes and directions with respect to one another)

2.5



$\rightsquigarrow \tan\left(\frac{\alpha}{2}\right) = \frac{2}{\sqrt{2}} \Rightarrow \alpha > 90^\circ$

$\alpha \approx 100 - 120^\circ \qquad \gamma \approx (\alpha - 90^\circ)\cdot 2$

$\approx (110^\circ - 90^\circ)\cdot 2 \approx 40^\circ$

Part C:

Do you think that twinning would have a sign dependence to it in an FCC crystal? In other words, will a positive stress cause twinning, but a negative stress not cause it (or vice versa)? Explain your thinking.

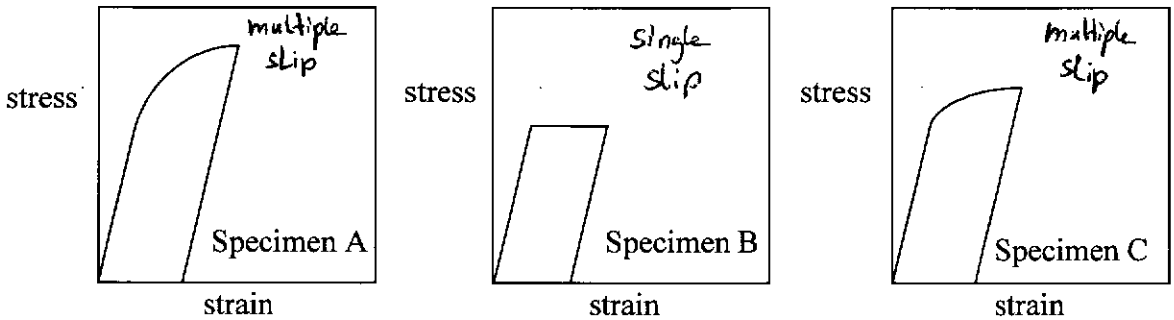
For a specific pair of planes and a single twinning direction, yes, there is a sign dependence.

$\alpha > 90^\circ$ twinning $\leftarrow \; \rightarrow$ no twinning $\rightarrow \; \leftarrow$

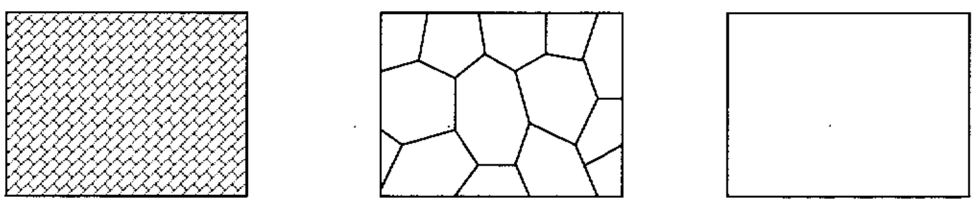
but, in FCC, there are so many planes/directions that some are always able to twin for a given stress state.

Problem #4: Post-UROP Forensics

Working in an MIT lab, you are studying deformation and annealing of **single crystals**. You have three identical specimens of the same metal, but which are cut with different crystal orientations. You carefully perform tensile tests to a fixed level of strain, and then unload them. You find:



Now you take the three specimens and give them to your UROP, with the request that they all be annealed at the same temperature for the same amount of time. Your UROP dutifully follows your orders, but manages to forget which sample is which! Looking for clues to sort out this mess, you perform metallography to look at the microstructure. Here is what you see:



Structure I Structure II Structure III

Sort out which post-annealing microstructure belongs to which sample, and write a short explanation for your choices.

B is single slip; stores few dislocations
C is multiple slipe; stores some dislocations
A is multiple slip; probably more slip systems ⇒ much more work hardening; stores many dislocations

3

$$\rho_\perp^A > \rho_\perp^C > \rho_\perp^B$$

$\rho_\perp^A$ ↓ ReX ↓ Structure II

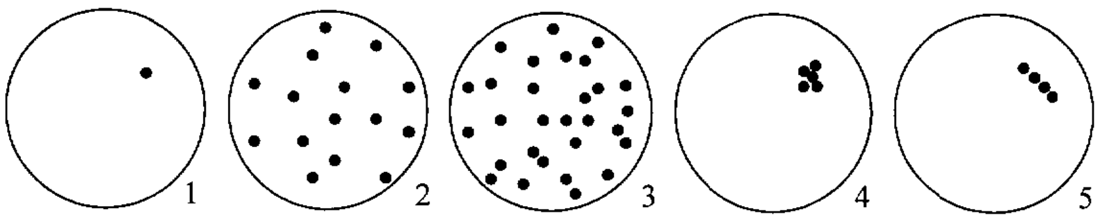
$\rho_\perp^C$ ↓ Polygonize ↓ I

$\rho_\perp^B$ ↓ Annealed/Recovered still SX ↓ III

2

Problem 5: Annealing in Stereo

Below are five stereographic projections presented in the external reference frame. These projections show the distribution of crystal orientations in different samples of an HCP metal. The points represent the orientations of the c-axis (0001) of the crystals.



Which of these projections corresponds to each of the following situations? Provide one sentence of explanation for each answer, please.

a. A single crystal is bent and then annealed lightly

$\Rightarrow$ many $\perp$ of same sign $\Rightarrow$ polygonize into straight boundaries of small misorientation but on many axis $\rightsquigarrow$ 5

1

b. A single crystal is deformed slightly in compression and annealed lightly

polygonization but with $\perp$ of many signs, orientations near original SX orientation but on many axes $\rightsquigarrow$ 4

1

c. A single crystal is deformed slightly in compression and annealed thoroughly

all $\perp$ annihilate $\rightsquigarrow$ SX $\rightsquigarrow$ 1

1

d. A single crystal is deformed heavily in compression and annealed

*ReX $\rightsquigarrow$ 2 "Random" orientations

1

e. The sample from 'd' above is again deformed heavily and annealed

1

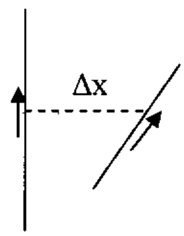
ReX + ReX $\Rightarrow$ smaller grains, more grains random orientations $\Rightarrow$ 3

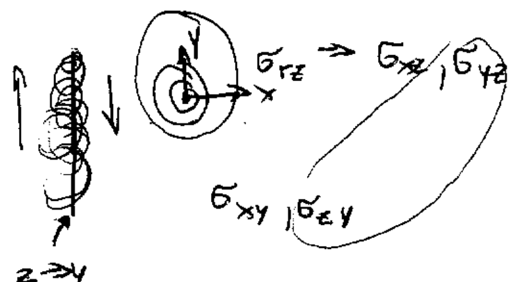
Problem 6: In Which We Consider the Interaction Among Non-Parallel Dislocations, Including Those That are Crossed and Those That Form Intriguing Loop Configurations

In class we dealt with the stress-field interactions between parallel dislocations only; we did not talk about whether dislocations feel each other in other configurations. Based on your understanding of dislocation stress fields, indicate whether the interaction in the following cases would be attractive, repulsive, or non-existent. In each picture below, the Burgers vectors are shown as arrows

Case A: Two screw dislocations separated by a distance Δx, at 90° from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)

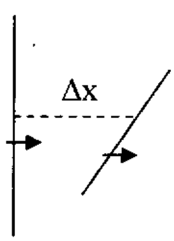
(1)

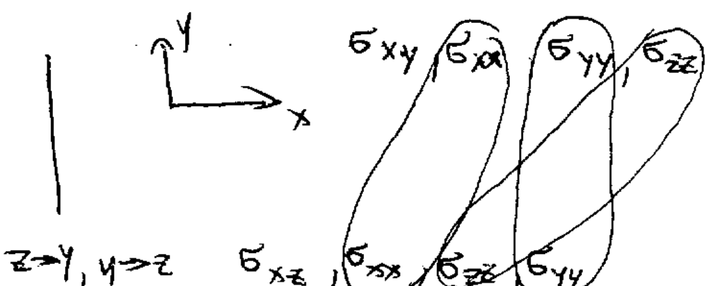




same overlap of stress fields can interact, both positive ⇝ repulsive

Case B: Two edge dislocations separated by a distance Δx, at 90° from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)

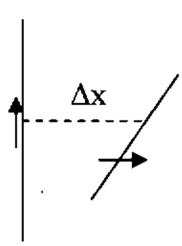


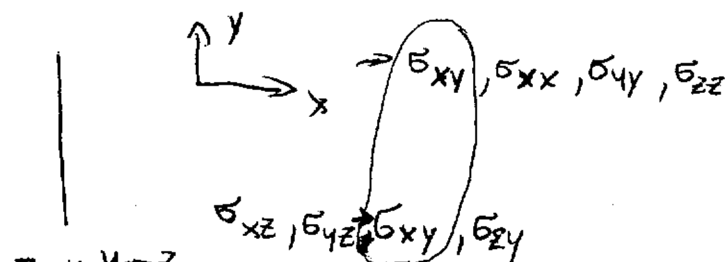


overlap is extensive, can interact
repulsive same dir. $\vec{b}$

Case C: An edge and a screw dislocation separated by a distance Δx, at 90° from one another. (The picture is drawn in perspective; the dislocations are parallel to the y and z axes)

(1)

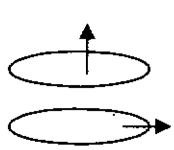


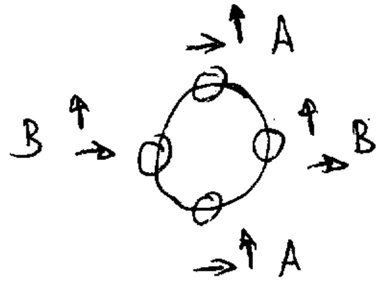


repulsive
Shear-interaction

Case D: Two loops atop one another, one with the Burger's vector in the plane of the loop, and one with it normal to the loop.

(2)





A: parallel screw and edge ⇝ no interaction
B: parallel edge of different kinds ⇝ can interact ⇝ repulsive

Helpful (?) Bonus Information

Stress field around an edge dislocation:

$$\sigma_{xx} \propto \frac{y(3x^2+y^2)}{(x^2+y^2)^2}$$

$$\sigma_{yy} \propto \frac{y(x^2-y^2)}{(x^2+y^2)^2}$$

$$\sigma_{xy} \propto \frac{x(x^2-y^2)}{(x^2+y^2)^2}$$

all other σ components are = 0.

Stress field around a screw dislocation:

$$\sigma_{rz} \propto \frac{1}{r}$$

all other σ components are = 0, and note that $r^2 = x^2+y^2$

Forces between dislocations:
Parallel edge:

$$F_y = \frac{\mu b^2}{2\pi(1-\nu)} \frac{y(3x^2+y^2)}{(x^2+y^2)^2}$$

$$F_x = \frac{\mu b^2}{2\pi(1-\nu)} \frac{x(x^2-y^2)}{(x^2+y^2)^2}$$

Parallel screw:

$$F_r = \frac{\mu b^2}{2\pi r}$$

JMAK Equation:

$f = 1\text{-}\exp(-kv^d t^{d+1})$

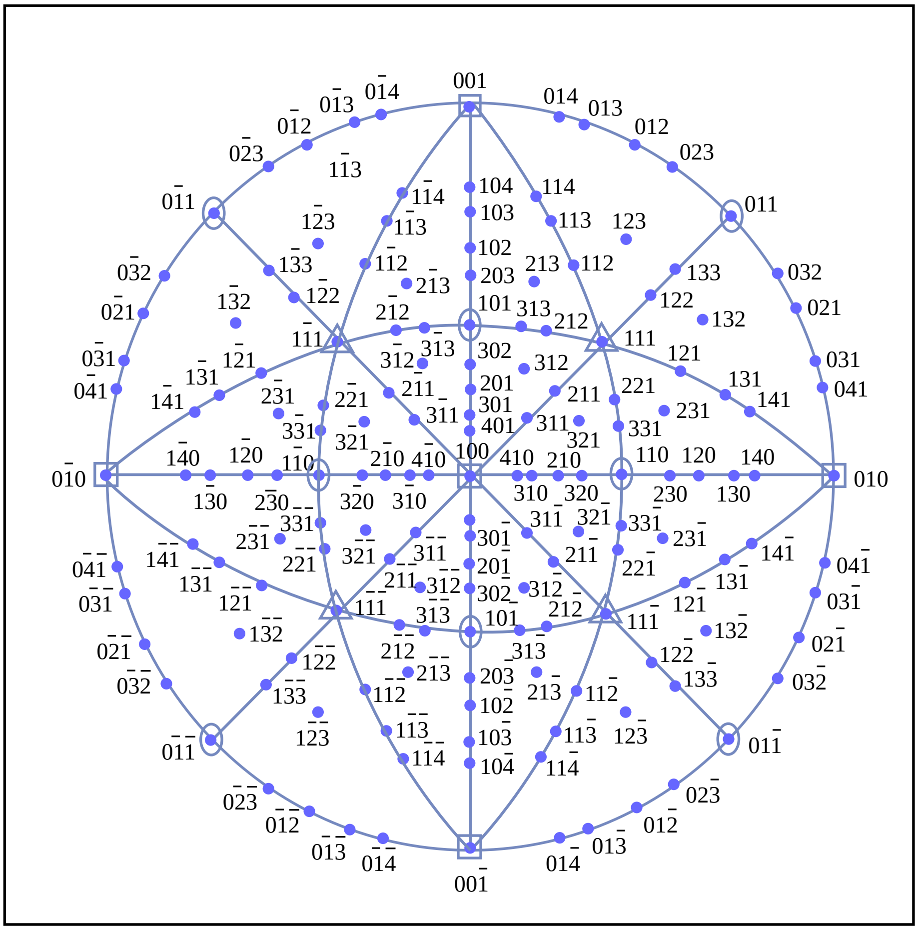


Figure by MIT OpenCourseWare.

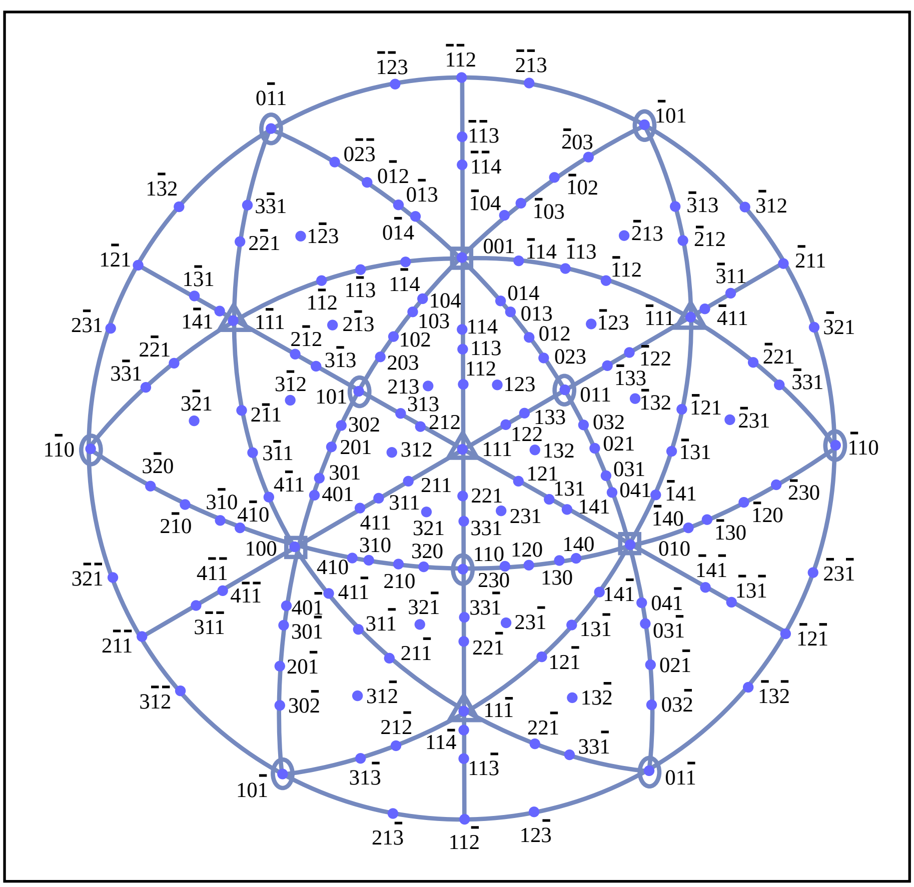


Figure by MIT OpenCourseWare.