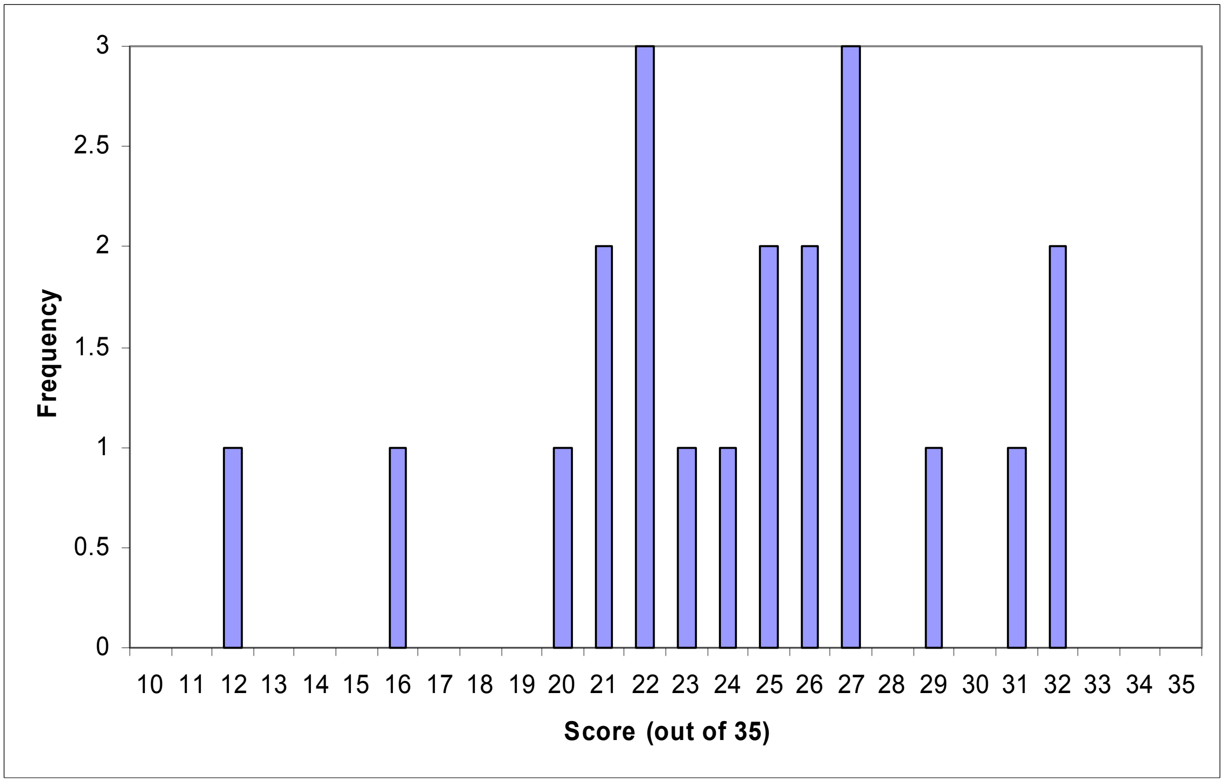
Department of Materials Science and Engineering
Massachusetts Institute of Technology
3.14 Physical Metallurgy – Fall 2003

Solutions to Exam I

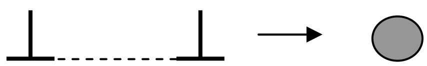


Class average: 24.0

Problem #1: Partial Dislocations and Cross-Slip

In an FCC metal, a screw dislocation approaches an obstacle and is momentarily stuck. After the stress is increased, the screw dislocation can bypass the obstacle by cross slipping:

Part A If the same screw dislocation were initially dissociated into two partials:



Can cross slip happen in this scenario? Why or why not?

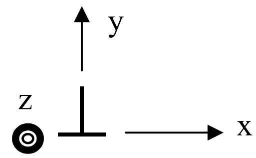
Cross slip can only happen in this situation if the applied stress is high enough to force recombination of the partial dislocations. As partials, no cross slip can occur.

Part B Would this obstacle be more effective in copper (low stacking fault energy) or aluminum (high stacking fault energy)?

This obstacle would be more effective in copper. Aluminum would have a small stacking fault that would happily recombine (at lower applied stress) and cross-slip over the particle. On the other hand, copper would have a large stacking fault (requiring a large applied stress for recombination) that would prohibit cross-slip, thus blocking the motion of the dislocation.

Problem #2: Stress/Strain Field of a Dislocation

In class we discussed the strain and stress fields of edge and screw dislocations separately. In this problem you will draw a picture of the stress field around a mixed dislocation, which is *equally composed of edge and screw character*.



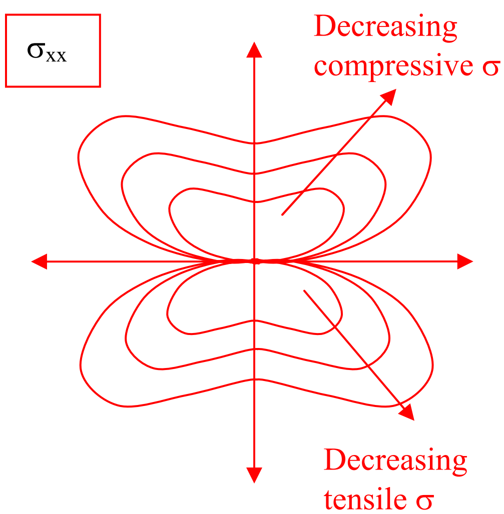
Please Note:
(i) at any point in space, the total stress is just the sum of the two contributions (edge and screw)
(ii) the equations for the edge and screw dislocations are given at the back, but you don't necessarily need them to answer this question; physical intuition will suffice.

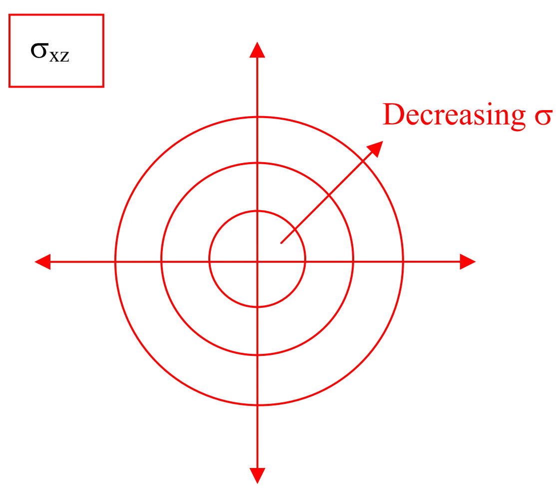
Part A: Draw contours of the σ_{xx} stress component in the above coordinate system

Part B: Draw contours of the σ_{xz} stress component in the above coordinate system

For edge component: σ_{xx} = $\sigma_{xz} = 0$

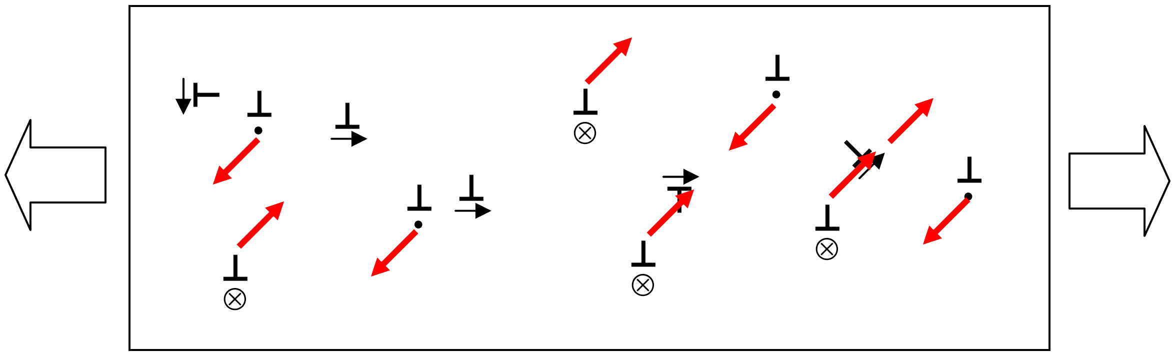
For screw component: $\sigma_{xx} = 0$ $\sigma_{xz} \sim 1/r$





Problem #3: Dislocation Dynamics

Here is a wee little specimen that has only a handful of dislocations in it, all of which have their line vectors pointing into the page:

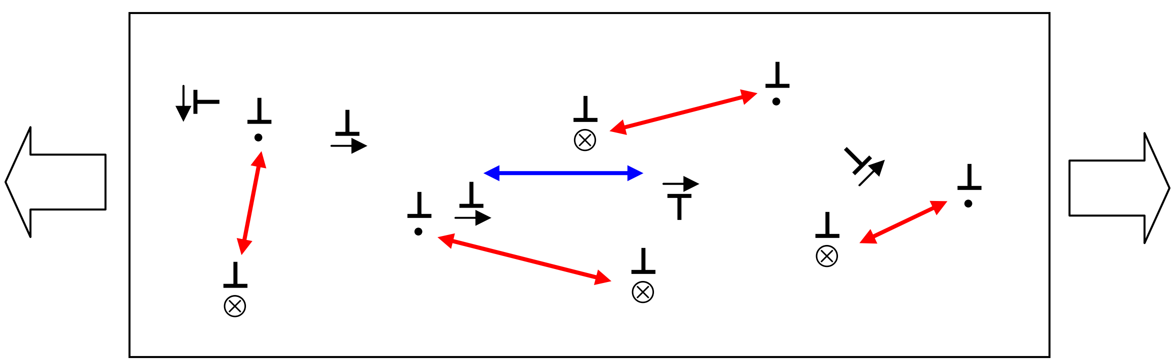


The Burger's vector is shown next to each dislocation; • is out of the page and ⊗ is into the page.

Screw dislocations will move at 45º to the stress axis, and positive and negative screws will move in opposite directions from each other. Only the edge dislocation with its burgers vector not perpendicular or parallel to the stress will move.

Part A: If a tensile stress is applied as shown, indicate on the above picture how each dislocation would move.

Part B: If the specimen were NOT deformed, but put directly into a furnace and annealed, draw how the configuration would change. Add some labels or description to note what mechanisms are occurring.



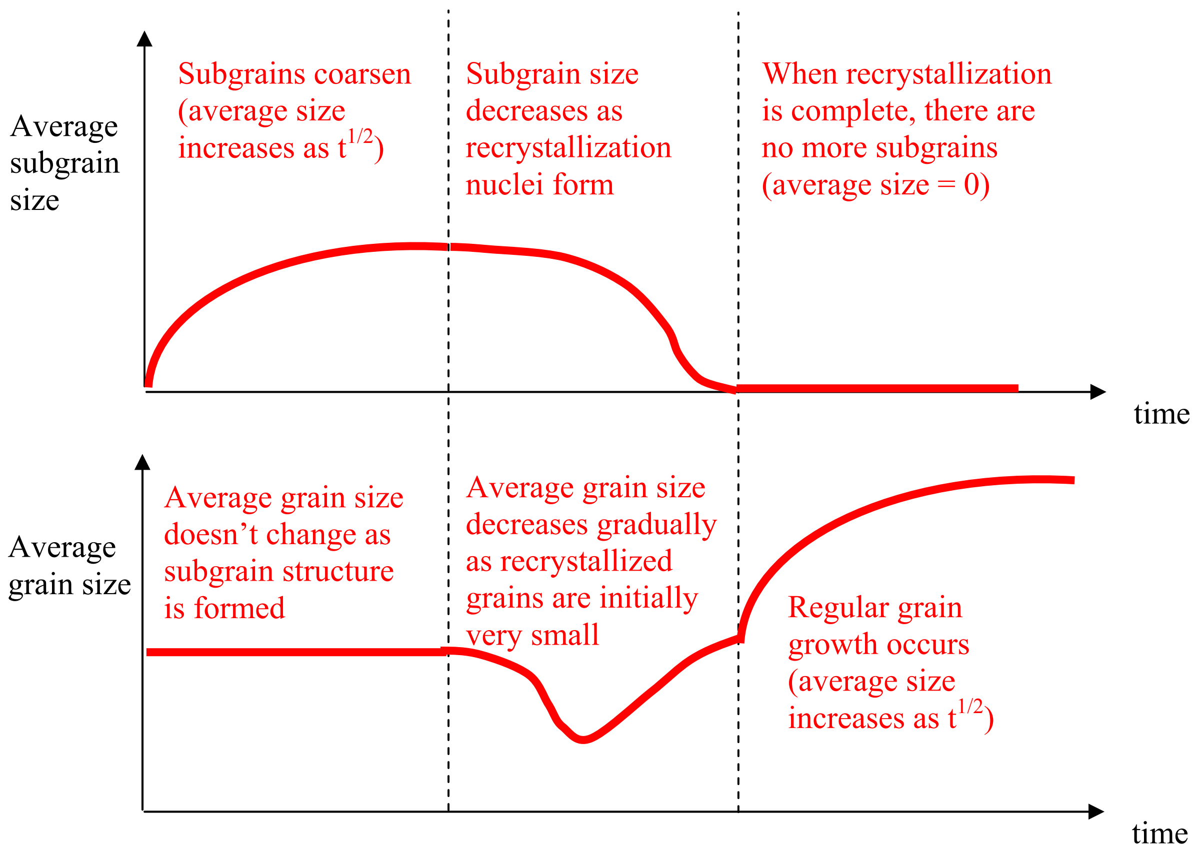
The pairs of screw dislocation with red arrows between them will cross-slip and annihilate. The edge dislocations may climb to appropriate slip planes and glide together to annihilate each other as indicated by blue arrows. Other dislocations may migrate to form a lower-energy structure.

Problem #4: Microstructural Evolution During Annealing

A polycrystalline metal specimen is deformed and annealed, during which the following events occur in sequence:

(i) recovery processes build a subgrain structure, which coarsens for some time
(ii) recrystallization commences
(iii) recrystallization runs to completion and structural coarsening continues

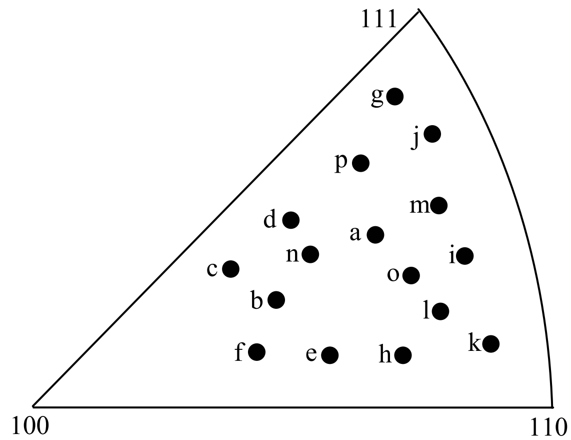
Draw two plots that depict (a) the average size of subgrains as a function of time and (b) the average size of legitimate grains, separated by high-angle boundaries, as a function of time. Synchronize the plots in time, and label each part of the curve with the events taking place.



Problem #5: Recrystallization Nuclei

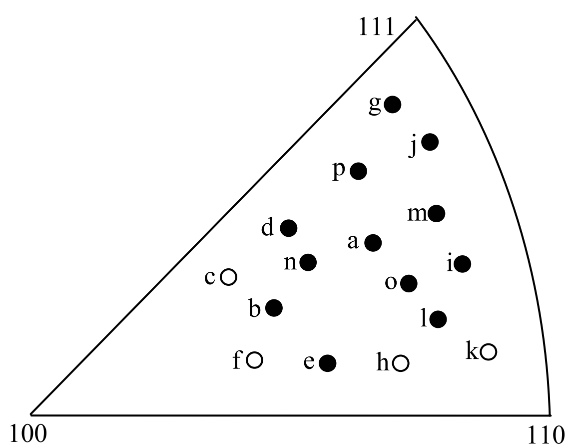
Consider the assemblage of square subgrains shown below. There are sixteen unique grain orientations (labeled a-p). These orientations are all indicated on the stereographic triangle at the right.

p	m	n	o	p	m
d	**a**	**b**	**c**	**d**	a
h	**e**	**f**	**g**	**h**	e
l	**i**	**j**	**k**	**l**	i
p	**m**	**n**	**o**	**p**	m
d	a	b	c	d	a



Five of the subgrains have been shaded. *From among these five*, which subgrain will most likely be a nucleus for recrystallization? Why?

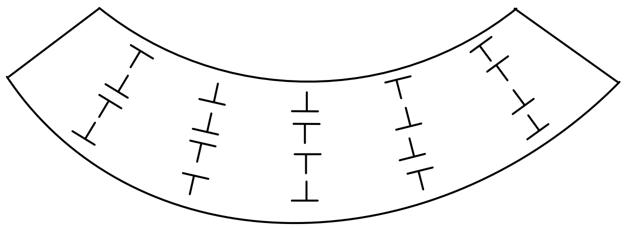
The subgrain with the most high-angle boundaries will be the most like nucleus for recrystallization. If adjacent grains are to have a high-angle boundary between them, their orientations should be far apart on the stereographic triangle. By comparing each grain with its 4 nearest neighbors, its clear that grain *g* has an orientation VERY different from all of its neighbors, resulting in 4 high-angle boundaries. Its neighbors are shown on the projection below.



Problem #6: Unphysics

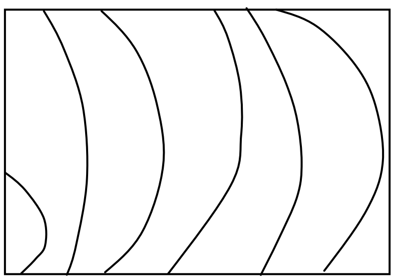
The four situations described below are all unphysical. For each, please identify with a short description the reason that it is unphysical.

a. The picture below is of a specimen with large lattice curvature and the dislocation array that is present to accommodate the deformation.



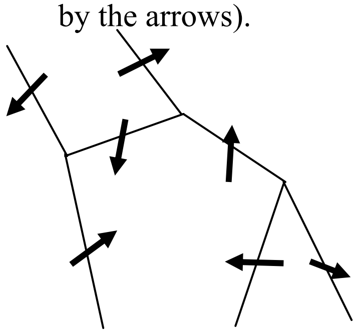
If the lattice is curved as shown, the dislocations should have their extra half-planes all pointing down to accommodate this deformation.

b. The microstructure below is the projection of the dislocations in an unstressed specimen.



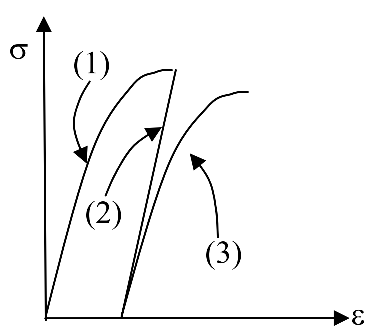
If there is no applied stress, the dislocation lines should be straight, in order to minimize their length and strain energy.

c. The diagram below shows several dislocation lines and their burger's vectors (indicated by the arrows).



The dislocation network does not obey Frank's rule. The burgers vector that meet at a junction of three dislocations do not sum to zero.

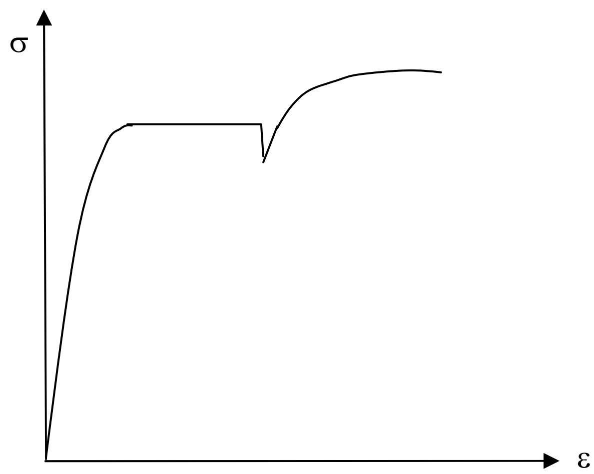
d. A uniaxial tensile stress is applied to a tungsten rod (body-centered cubic, density = 19.25 g/cm^3, coefficient of thermal expansion = 4.5 x 10^{-6} K^{-1}, melting temperature = 3695 K) and the stress-strain curve labeled (1) is recorded. The stress is then removed (2) and the W rod sits at room temperature for one day. The next day, a tensile stress is applied again (3) and the stress-strain behavior is shown on the same graph.



Tungsten's melting temperature is very high and recovery would not be able to occur at room temperature in 24 hours. When the stress is reapplied, the stress strain curve should have followed line (2) back to a higher yield point.

Problem 7: Deformation Mechanistics and Stress-Strain Behavior

A single crystal of an HCP metal is loaded in uniaxial tension, and the following stress-strain curve is recorded:

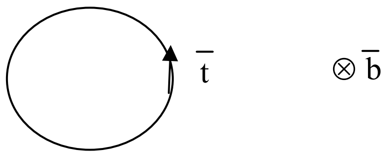


Using your vast knowledge of deformation physics in HCP metals, identify the likely mechanisms operating in this specimen over the course of the test. Be sure that your answer explains each detail of the above curve.

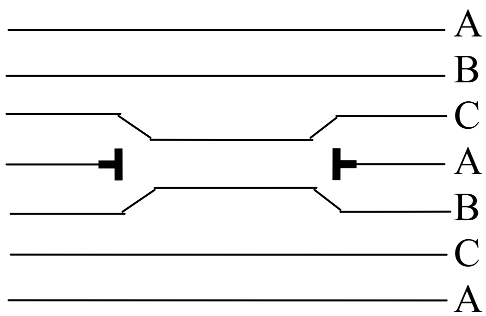
The HCP single crystal initially demonstrates elastic deformation until yielding occurs. The shear stress will be high enough to activate slip on the primary slip system. The horizontal part of the curve corresponds to deformation by "easy glide" – where dislocations are gliding on parallel planes and not intersecting. As the deformation progresses, the crystal is rotating so that the slip direction lines up with the stress axis. The dip in the curve happens as the HCP single crystal twins in response to the rotation. After it has twinned, it's essentially polycrystalline. Slip now occurs on multiple slip systems in the different grains and normal work hardening occurs.

Problem #8: The Frank Loop Dislocation

The 'Frank Loop' dislocation is nothing more than a disk of vacancies that lies in a {111} plane of *an FCC crystal*. Looking down on the {111} plane it looks like a loop, with its Burger's vector pointing out of the page:



Looking at a cross section of the loop (i.e., looking edge-on to the {111} planes), it looks like this:



Where the stacking sequence of {111} planes is noted at the right.

Part A: Can Dr. Frank's dislocation move at low temperatures? Why or why not?

No, the dislocation can not move at low temperatures. Since b and t are not co-linear, no slip is possible. Also, the temperature is too low for dislocation climb to occur.

Part B: Can it move at high temperatures? Why or why not?

Yes, the loop can move at high temperatures. Diffusion will be possible and the dislocation loop can grow or shrink through climb.