Written Exam, Radiation damage in materials (SH2605)
09.00-13.00, Oct 26, 2009, KTH, Stockholm

Allowed aids: pocket calculator.

To pass the exam, you need at least 8 points.
Grading is determined by the total number of points (where home assignments can sum up to a maximum of 8 points):
A:15-16, B:13-14.5, C:11-12.5, D:9.5-10.5, E:8-9, F:0-7.5

Half-points (0.5 etc) can be rewarded for partially correct answers

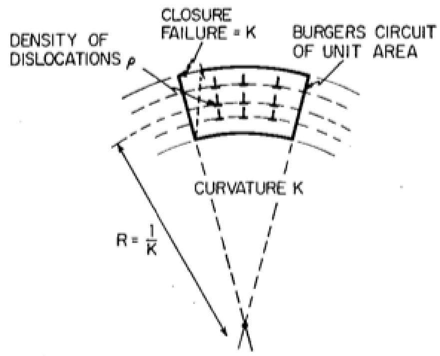
Motivate your answers by calculations and text (and pictures, if you want). Write clearly.

Make your own, reasonable assumptions, when necessary. It should be clear from your text what assumptions you make.

Good Luck!

Questions

1. Your exam has a paper clip attached to it. If you bend the material and it deforms plastically, it means that you introduce dislocations. Imagine a side-view of the clip as in the figure. The radius of curvature is R. Give an expression for the density ρ of dislocations introduced, in terms of R and the burgers vector b. Assuming that the material is iron, what is the density? Assume some reasonable values of R and b. [2 p]



2. Sheet steel is produced by rolling steel in a number of steps, thereby deforming the material, which introduces dislocations. If the starting product is a 1 m^3 block, and the final product has a dislocation density of $10^{16}/m^2$, what is the total length of dislocations in the material? Half an extra point if you use a convenient unit. [1+0.5 p]

3. From last year's exam: Consider a flux of 10^{15} neutrons $cm^{-2}s^{-1}$ in Fe. (This is what you would have in the core of a fast reactor.) The energy is 1 MeV. What will be the damage rate in units of dpa/s? You can assume a lattice constant of 2.85 Å, and a cross-section of 3×10^{-24} cm^2. You can ignore electron stopping. [2 p]

4. According to the Kinchin-Pease model, the number of displacements from a primary knock-on atom of energy T is

$$
\begin{aligned}
\nu(T) &= 0 \text{ for } T < E_\mathrm{d} \\
\nu(T) &= 1 \text{ for } E_\mathrm{d} < T < 2E_\mathrm{d} \\
\nu(T) &= \frac{T}{2E_\mathrm{d}} \text{ for } 2E_d < T < E_\mathrm{c} \\
\nu(T) &= \frac{E_\mathrm{c}}{2E_\mathrm{d}} \text{ for } T > E_\mathrm{c}
\end{aligned}
\tag{1}
$$

One assumption behind the derivation of the KP model is that the atoms interact by hard-sphere scattering. Now, assume instead that the interaction is of the exponential Born-Meyer type, i.e., the cross section is given by

$$\sigma(E_i, T) = \frac{\pi B^2}{\gamma E_i} \left[\frac{A}{\mu E_i} \right]^2. \tag{2}$$

where A and B are parameters specific for the type of atoms in question.

i) How does the predicted number of displacements change compared to the original KP model? [1 p]

ii) How does the cross section vary as the energy decreases? [1 p]

iii) How does the mean-free path λ vary as the energy decreases? [1 p]

5. For Rutherford scattering, the differential cross section is given by

$$\sigma(E_i, T) = \frac{\pi b_0}{4} \frac{E_i \gamma}{T^2}. \tag{3}$$

with

$$b_0 = \frac{q_1' q_2'}{\eta E_i} \tag{4}$$

where the particle charges Ze were rewritten using

$$q' = \frac{Ze}{\sqrt{4\pi\epsilon_0}}. \tag{5}$$

Derive expressions for

- The average energy transfer

$$\bar{T} = \frac{\int_{\check{T}}^{\hat{T}} T\sigma(E_i, T)dT}{\int_{\check{T}}^{\hat{T}} \sigma(E_i, T)dT}. \tag{6}$$

- The total cross section

$$\sigma(E_i) = \int_{\check{T}}^{\hat{T}} \sigma(E_i, T)dT. \tag{7}$$

Use $\check{T} = E_D$.

[1+0.5 p]

6. Proton or ion irradiation is sometimes used as a replacement for neutrons in the study of radiation effects in materials. For a 2 MeV proton incident on a sheet of Al, calculate

i) the energy transfer in a head-on collision, $\hat{T}$. [1 p]

ii) The mean energy transfer $\bar{T}$. [1 p]

iii) The mean free path λ. How does it compare with that for neutrons? [2 p]

Assume Rutherford scattering, and use $\epsilon_0 = 8.85 \times 10^{-12}$ As/Vm, $e = 1.602 \times 10^{-19}$ J, the atomic number of Al $Z = 13$, the atomic mass $A = 26.98$ and finally, recall that $\eta = M_2/(M_1 + M_2)$ and $\gamma = 4M_1M_2/(M_1 + M_2)^2$. Oh, and the lattice constant, it's $a_0 = 4.05$ Å.

7. Defects produced by radiation increase the strength of a material by pinning dislocations. Assume that a defect cluster (interstitial or vacancy) is impenetrable, i.e., a dislocation can only pass the obstacle by climbing or by forming a loop (Orowan mechanism).

   i) Derive an expression for the critical stress F_{c} required to pass the obstacle by the Orowan mechanism. Assume a mean distance l between obstacles, and a line tension $T = \frac{Gb^2}{2}$. [2 p]

   ii) For Fe we have $G = 84$ GPa, and $b = 2.5$ Å. What is the increase in critical shear stress if the mean distance between obstacles is 0.1 μ? [2 p]