Radiation damage in materials (SH2605) – VT 2018
Written Exam

8.00 – 13.00, March 12, 2018, B24, KTH, Stockholm

Allowed aids: pocket calculator, BETA (maths handbook) or similar, ruler, pencil/pen, eraser, snacks

To pass the exam you need at least **6 points out of 16.**

Grading is determined by the total number of points:
F: 0–5.0; Fx: 5.5; E: 6–8; D: 8.5–10.5; C: 11–12.5; B: 13–14; A: 14.5+

Half-points can be rewarded for partially correct answers.

Write clearly. Motivate your answers by calculations, text and figures if pertinent.

Make your own, reasonable assumptions, when necessary. Make sure to explicitly state what assumptions you make in the text.

Good luck and have fun!

Data sheet:

Various properties of selected metals:

	a_0	A	Z	E_d	H_f^v	S_f^v	H_m^v	E_f^i	S_f^i	H_m^i	γ	ν
bcc Fe	2.86 Å	56	26	40 eV	2.1 eV	2.4 k_B	0.7 eV	4.0 eV	0.7 k_B	0.3 eV	1.8 J/m²	15 THz
fcc Au	4.08 Å	197	79	40 eV	1.3 eV	1.9 k_B	0.8 eV	2.6 eV	0.6 k_B	0.2 eV	1.0 J/m²	49 THz

(The migration entropies of both vacancies and SIAs are very close to zero)

Models:

Compton scattering: $E_e = \frac{E_\gamma^2(1-\cos\theta)}{E_\gamma(1-\cos\theta)+m_e c^2}$ (θ = photon scattering angle)

Hard-sphere scattering cross section: $\sigma_s(E_i, T) = \frac{\sigma_s(E_i)}{\gamma E_i}$

Rutherford scattering cross section: $\sigma_s(E_i, T) = \frac{\pi b_0 \gamma E_i}{4T^2}$

The Kinchin-Pease model: $$n(T) = \begin{cases} 0, & T < E_d \\ 1, & E_d < T < 2E_d \\ \frac{T}{2E_d}, & 2E_d < T < E_c \\ \frac{E_c}{2E_d}, & T > E_c \end{cases}$$

Rate theory defect generation term: $K_0 = \xi n(T) \sigma_s N \varphi$

Neutral void-vacancy reaction rate: $K_{vV} = 4\pi R_V D_v$

Thermal atomic diffusion: $D_a^v = f \alpha a_0^2 \nu e^{G_a^v / k_B T}$

Constants:

Boltzmann's constant $k_B = 1.38 \cdot 10^{-23} J/K$
Elementary charge $e = 1.602 \cdot 10^{-19} C$
Electron rest mass $m_e = 9.11 \cdot 10^{-31} kg = 511\, keV/c^2$
Atomic mass unit $1u = 1.66 \cdot 10^{-27} kg = 931\, MeV/c^2$
Speed of light $c = 3 \cdot 10^8 m/s$

Problem 1 [2p]

a) Determine the *atomic* diffusion coefficients D_a^v (for the vacancy mechanism) and D_a^i (for the self-interstitial mechanism) for fcc Au at 600°C. [1p]

b) Determine the *defect* diffusion coefficients D^v and D^i for the same conditions and discuss eventual differences with respect to the atomic diffusion coefficients. [1p]

Problem 2 [3p]

a) Derive the expression for the maximal energy transfer from an elastic collision, as a function of the kinetic energy of the incoming particle (E_i). [2p]

b) What is the maximal kinetic energy that an Fe atom in the structural materials of a fusion reactor receives from 14 MeV neutrons coming from the d+t reactions in the plasma? [1p]

Problem 3 [2p]

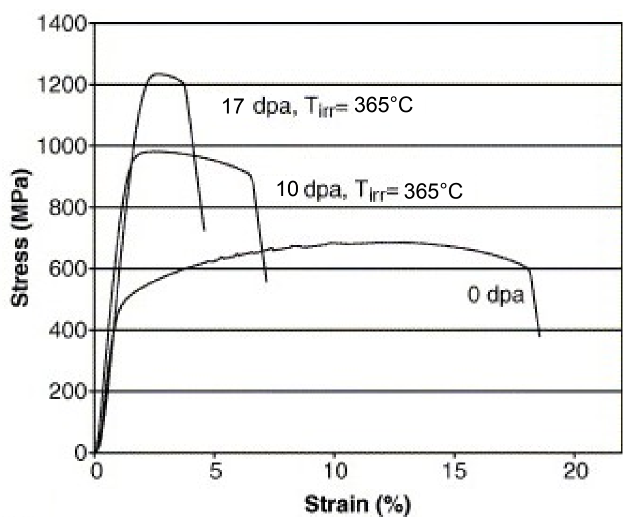
From the figures below, estimate, from this data on HT9-steel irradiated in FFTF:

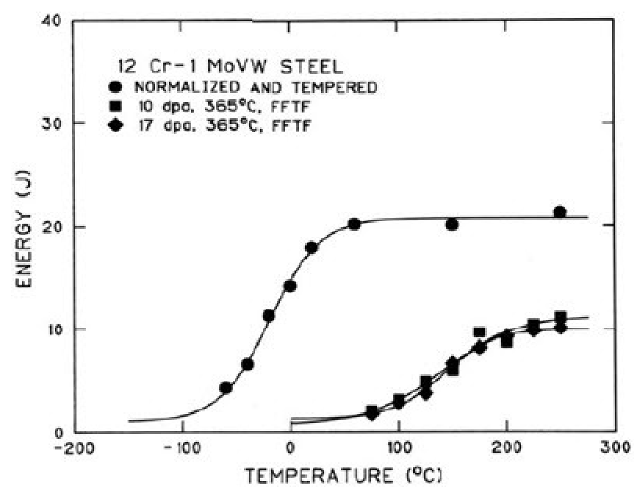
a) The loss of elongation for 10 dpa [0.5p]

b) The DBTT shift (at 7J) [0.5p]

c) The hardening for 17 dpa [0.5p]

d) The change in upper shelf energy [0.5p]





Problem 4 [4p]

a) For Rutherford scattering (Coulomb potential), determine an expression for the average transferred energy to a lattice atom, $\bar{T}$. Remember to replace the upper ($\hat{T}$) and lower limits ($\check{T}$) by more well-defined expressions or constants. [2p]

b) Derive an expression for the total cross section for Rutherford scattering $\sigma_s(E_i)$ [2p]

Problem 5 [2p]

Assume that the steady state concentration of vacancies in bcc iron, in a 2 MeV neutron flux of $5 \cdot 10^{14}$ cm^{-2}s^{-1} is given by $C_v = \frac{K_0}{K_{vV} C_V}$ and that the average void radius is 4 nm, the void density is 10^{17} m^{-3} and the total scattering cross section is 3 barns.

a) Determine the temperature at which the supersaturation factor of vacancies becomes unity, i.e. the temperature at which thermal effects start to dominate over irradiation ones. [2p]

Problem 6 [3p]

a) Order the {100},{110}, {111} planes in a bcc crystal according to their planar density. [1p]

b) Which and how many are the slip systems in a bcc crystal? [1p]

c) Which slip system will activate first during plastic deformation of the crystal in the direction $n_T = [1, 3, 7]$? [1p]