6.5 A metal contains N voids/cm^3 of radius R and a dislocation density ρ. The metal is subject to a hydrostatic *tensile* stress σ which causes the dislocations and voids to exchange vacancies.

What is the swelling rate? Assume that the self-diffusion coefficient of the metal, D, is known.

- vacancy conservation equation in terms of the fluxes of vacancies to or from the voids and dislocations

$$J_V^d \rho = J_V^C N \qquad (1)$$

- driving forces for vacancy flows to and from the defects

$$\text{Voids:} \quad \pm\left[C_V - C_V^{eq}\exp\left(\frac{2\gamma}{R}\frac{\Omega}{kT}\right)\right] \qquad \text{disl.} \quad \pm\left[C_V^{eq}\exp\left(\frac{\sigma\Omega}{kT}\right) - C_V\right]$$

vacancy fluxes:

(per void)

$$J_V^C = 4\pi R D_V\left[C_V - C_V^{eq}\exp\left(\frac{2\gamma}{R}\frac{\Omega}{kT}\right)\right] \approx 4\pi R D_V\left[C_V - C_V^{eq}\left(1+\frac{2\gamma}{R}\frac{\Omega}{kT}\right)\right] \quad (2a)$$

(per unit length)

$$J_V^d = Z_V D_V\left[C_V^{eq}\exp\left(\frac{\sigma\Omega}{kT}\right) - C_V\right] \approx Z_V D_V\left[C_V^{eq}\left(1+\frac{\sigma\Omega}{kT}\right) - C_V\right] \quad (2b)$$

Substitute (2a) & (2b) into (1) & solve for C_V; insert in (2a)

Swelling rate: $d(\Delta V/V)/dt = J_V^C N\Omega$

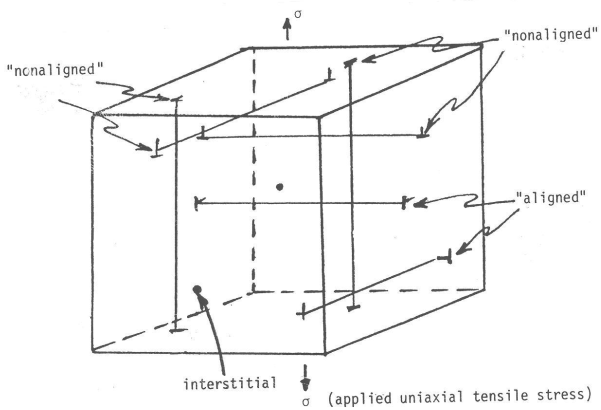
Insert sol'n for C_V into (2a):

$$\frac{d}{dt}\left(\frac{\Delta V}{V}\right) = D\left[\frac{(Z_V\rho)(4\pi RN)}{Z_V\rho + 4\pi RN}\right]\frac{\Omega}{kT}\left(\sigma - \frac{2\gamma}{R}\right)$$

$D = D_V C_V^{eq}\Omega$

- swelling largest if $Z_V\boldsymbol{\rho} >> 4\pi RN$
- if $\boldsymbol{\sigma} > 2\boldsymbol{\gamma}/R$, swelling; if $\boldsymbol{\sigma} < 2\boldsymbol{\gamma}/R$, shrinkage

7.4 SIPA creep with voids/recombination



$$Z_{I(a)} - Z_{I(na)} = \alpha(c_a - c_{na})\sigma$$

$$\dot{\varepsilon}_{SIPA} = \tfrac{2}{9}\rho\Omega D_I C_I (Z_{I(a)} - Z_{I(na)}) = \tfrac{2}{9}\rho\Omega D_I C_I \alpha(c_a - c_{na})\sigma$$

Point defect balances:

All $Z_I = 1$

1. <u>With voids</u>: $K/\Omega = \rho D_I C_I + 4\pi R N D_I C_I$

Solve for $D_I C_I$: $$D_I C_I = \frac{K/\Omega}{\rho + 4\pi R N}$$

Next step: $$\dot{\varepsilon}_{SIPA} = \frac{\tfrac{2}{9}\alpha \Delta c K}{1 + 4\pi R N/\rho}\sigma$$

If $4\pi RN << \rho$, original SIPA formula recovered

2. <u>With recombination</u>: $K/\Omega = \rho D_I C_I + k_R C_V C_I$

Vacancy balance: $K/\Omega = \rho D_V C_V + k_R C_V C_I$

Solution $D_I C_I = D_V C_V$

Use above eqn to eliminate C_V from I balance; solve for C_I

$$D_I C_I = \frac{\left[(\rho D_I D_V)^2 + 4k_R D_I D_V (K/\Omega)\right]^{1/2} - \rho D_I D_V}{2k_R}$$

Substitute into ε_{SIPA} formula:

$$\frac{\dot{\varepsilon}_{SIPA}\text{ (with recomb.)}}{\dot{\varepsilon}_{SIPA}\text{ (without recomb.)}} = \frac{\sqrt{1+2E}-1}{E}$$

$$E = \frac{2k_R (K/\Omega)}{\rho^2 D_I D_V}$$

T↓	E >> 1	no SIPA creep
T↑	E << 1	no effect of recomb.