MSE-483 ADVANCED PHASE TRANSFORMATIONS

FALL 2025

QUESTION 1

A material is found to undergo a first-order phase transformation from α to β. The crystal structures of both phases are such that the β phase may be formed by either coherent or incoherent homogeneous nucleation from the α phase. No strain energy penalties are incurred during the incoherent nucleation of β. Experiments have also revealed that the critical free energy barrier for nucleation must be smaller than $76k_BT$ for an appreciable nucleation rate.

1. Below what temperature does incoherent nucleation become thermodynamically feasible?
2. Below what temperature does coherent nucleation become thermodynamically possible?
3. What type of nucleation do you expect to occur at 510K? Justify your answer.

Material constants that you might find useful:

- $\gamma^c = 160$ mJ/m^2 : coherent interfacial energy
- $\gamma^i = 800$ mJ/m^2 : incoherent interfacial energy
- $\Delta g_{strain} = 2.6 \times 10^9$ J/m^3
- $\Delta g_{\alpha \to \beta} = 8 \times 10^6 (T - 900)$ J/m^3/K : free energy change upon transforming from α to β

QUESTION 2

Consider the formation of a solid nucleus of phase α within a liquid phase at a temperature T. At this temperature, the liquid phase is metastable and the solid phase is stable. The free energy change per unit volume for the formation of α from the liquid is $\Delta g^{l \to \alpha}$. The interfacial energy for a cuboidal and spherical nucleus are given by γ_c and γ_s respectively.

1. Write down the free energy change for an entirely liquid system to form a cuboidal nucleus of the α phase with dimensions of $a \times a \times b$
2. What is the critical nucleation size for a cuboidal nucleus? Express your answers in terms of $\gamma_c, \Delta g^{l \to \alpha}, \gamma_s$
3. How does the free energy barrier to form a cuboidal nucleus compare to the free energy of a spherical nucleus containing the same quantity of matter?

QUESTION 3

Martensitic transformations often involve a shape change, such that the nuclei of the martensitic phase are formed as thin plates. Such a morphology can be approximated by an oblate spheroid with semiaxes (r, r, c) with $r \gg c$. The volume (V) and surface area (S) of the oblate spheroid are given by:

$$V = \frac{4\pi}{3} r^2 c$$

$$S = 2\pi r^2$$

The strain energy per unit volume of the nucleus is:

$$\Delta g_\epsilon = \frac{Ac}{r}$$

The chemical driving force for the formation of the martensitic phase per unit volume and surface energy of the nucleus are denoted as Δg_β and γ respectively.

1. Write down an expression for the free energy to form a oblate spheroid nucleus with semiaxes (r, r, c).
2. Compute an expression for the shape parameters of the critical nucleus.
3. Compute an expression for the nucleation barrier.