

MSE-483 ADVANCED PHASE TRANSFORMATIONS  
FALL 2025

**QUESTION 1**

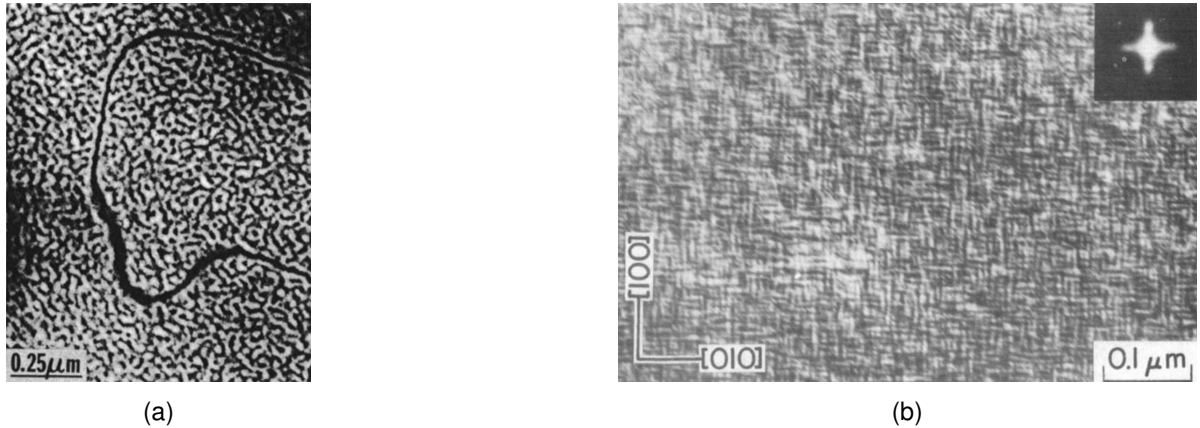


Figure 1: TEM of (a) Fe-Al<sup>1</sup> and (b) Fe-Mo<sup>2</sup> alloy specimens after spinodal decomposition

Both Fe-Al and Fe-Mo alloys undergo spinodal decomposition, yet the resulting microstructures are different. The transmission electron micrographs in fig. 1 depict a typical spinodal microstructure for both alloys.

1. What characteristic feature common to both microstructures is suggestive of spinodal decomposition? What is the theoretical reason for this characteristic feature?
2. What is a significant morphological difference between the spinodal microstructures in the two alloys? Can you identify *two* physical properties of the alloy systems, that could explain the difference in microstructures?

**QUESTION 2**

Explain why the chemical free energy cannot depend linearly on the magnitude of the composition gradient, i.e.,  $|\nabla c|$

**QUESTION 3**

1. What are the units of the gradient energy coefficient,  $K$ ?
2. Calculate an approximate value of  $K$  for an equiatomic alloy that undergoes spinodal unmixing. The dominant wavelength observed in an experiment conducted at 500K is 10 nm. The temperature above which the alloy is completely miscible is 1000 K. You can assume that the thermodynamics of this alloy follow the regular solution model.

**QUESTION 4**

An A-B alloy has the following free energy function:

$$G_m = x_A G_m^A + x_B G_m^B + RT (x_A \log(x_A) + x_B \log(x_B)) + x_A x_B \Omega \quad (1)$$

1. Use your favorite tool to compute the  $T - x$  phase diagram for a system with a free energy function given by eq. (1). Mark the chemical spinodals on the  $T - x$  phase diagram.
2. Plot the amplification factor at  $T = 600\text{K}$  that appeared in the time dependent concentration profile obtained by solving the Cahn-Hilliard equation for spinodal decomposition at  $x_B = 0.5$
3. What is the dominant periodicity that will emerge at 600K within the microstructure during the early stages of spinodal decomposition at  $x_B = 0.5$
4. How does the dominant periodicity compare to typical atomic distances?

The physical constants for this alloy are found to be:

- $G_A$  (Gibbs free energy of pure A) = -3500 J/mol
- $G_B$  (Gibbs free energy of pure B) = -2000 J/mol
- $\Omega = 16000$  J/mol
- R (universal gas constant)
- $L = 7.3 \times 10^{-18} x_B(1 - x_B)$  mol<sup>2</sup>/(cm J s)
- $V_m = 13.7$ cm<sup>3</sup>/mole
- K (gradient energy coefficient) =  $56 \times 10^{-10}$ J cm<sup>2</sup>/mol

### QUESTION 5

The time taken to reach a given degree of decomposition can be measured and plotted at several temperatures. Such a plot is typically called a time-temperature-transformation (TTT) diagram. For spinodal decomposition, the TTT diagram has a “C” shape. It is often desirable to find the temperature at which we are able to achieve a given amount of decomposition in the shortest possible time. Derive an expression for the temperature at which the rate of spinodal decomposition is maximum. The material is found to have a free energy identical to that of the previous problem. Material constants such as  $\Omega$ ,  $V_m$ ,  $K$  are also identical. The transport coefficient is found to be,  $L = x(1 - x)A \exp(-\frac{Q}{RT})$ , where  $A$  and  $Q$  are positive constants.

### REFERENCES

- [1] Samuel M. Allen. Phase separation of Fe-Al alloys with Fe<sub>3</sub>Al order. *Philosophical Magazine*, 36(1):181–192, 1977.
- [2] T. Miyazaki, S. Takagishi, H. Mori, and T. Kozakai. The phase decomposition of iron-molybdenum binary alloys by spinodal mechanism. *Acta Metallurgica*, 28(8):1143–1153, 1980.