1. (15%) It is determined that the Kirkendall markers placed at the interface of a diffusion couple, formed by welding a thin metal A to a similar plate of metal B, move with a velocity of \(4.5 \times 10^{-12}\) m/s toward the A component when the concentration \(N_A=0.38\) and the concentration gradient, \(dN_A/dx\), is \(2.5 \times 10^{-2}\) per m. The chemical diffusion coefficient under these conditions is \(3.25 \times 10^{-14}\) m/s. Determine the values of the intrinsic diffusivities of the two components.

2. (10%) (1) A ternary alloy may have a ternary eutectic point at which four phases may coexist. How many degrees of freedom are there when four phases coexist in a ternary? (Please explain the meaning of this freedom) (5%)
(2) A ternary alloy may have a three-phase field. How many degrees of freedom will there be in the three-phase field? (Please explain the meaning of this number of degrees of freedom) (5%)

3. (10%) Compute the free energy decrease associated with forming one mole of an ideal solution of A and B components at 1000K, if \(N_A=0.3\), \(G_A^0=50000\) J/mole and \(G_B^0=70000\) J/mole.

4. (10%) The total line length of the dislocation visible in a 4 cm by 4 cm TEM photograph of a metal foil, taken at a magnification of 20,000X is measured as 400 cm. The foil specimen imaged by this picture had a thickness of 300 nm. Determine the dislocation density in the specimen.

5. (5%) Define the slip plane of an edge dislocation and the slip plane of a screw dislocation in terms of the directions of Burgers vector and the dislocation.

6. (10%) (a) In alloys of two phases, describe the two types of boundaries separating the crystals. (b) When two grains of one phase meet a grain of the other phase at a common intersection, draw a simple figure to describe the relationship of surface tensions in the boundaries.

7. (10%) Compute the equilibrium concentration of vacancies in pure copper at 700 degree Celsius. The activation enthalpy, \(H_r\), is 83,700 J/mol, \(R\) is 8.314 J/mole-degree Kelvin.
8. (5%) Show that the passage of a Shockley partial dislocation over every one of a given set of close-packed planes in fcc crystals produces a twin of the original crystal.

9. (5%) Explain why grain boundaries move towards their centre of curvature during grain growth but away from their centre of curvature during recrystallization.

10. (8%) In many alloys, heterogeneous nucleation can preferably occur at grain boundaries during the aging treatment. Describe the effects of heterogeneous nucleation at the grain boundaries on the microstructural development. Discuss the following two cases of cooling rates (1) moderate rate of cooling and (2) very slow cooling, respectively.

11. (12%) Consider a solid embryo forming in contact with a perfectly flat mould wall. The embryo has the shape of a spherical cap with a wetting angle $\theta$. The formation of such an embryo will be associated with an excess free energy given by $\Delta G_{\text{het}} = -V_s \Delta G_v + A_{\text{SL}} \gamma_{\text{SL}} + A_{\text{SM}} \gamma_{\text{SM}} - A_{\text{ML}} \gamma_{\text{ML}}$, where $V_s$ is the volume of the spherical cap, $A_{\text{SL}}$ and $A_{\text{SM}}$ are the areas of the solid/liquid and solid/mould interfaces, and $\gamma_{\text{ML}}, \gamma_{\text{SM}}$ and $\gamma_{\text{SL}}$ are the free energies of the solid/liquid, solid/mould and mould/liquid interfaces.

   (a) Given the following relationships for a spherical cap:
   
   $A_{\text{SL}} = 2\pi r^2 (1 - \cos \theta)$
   
   $A_{\text{SM}} = \pi r^2 \sin^2 \theta$
   
   $V_s = \pi r^3 (2 + \cos \theta)(1 - \cos \theta)^2 / 3$

   show that the $\Delta G_{\text{het}}$ can be written in terms of the wetting angle $(\theta)$ and the cap radius $(r)$ as

   $\Delta G_{\text{het}} = \left\{-\frac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2 \gamma_{\text{SL}}\right\} S(\theta)$

   where $S(\theta) = (2 + \cos \theta)(1 - \cos \theta)^2 / 4$ and is therefore referred to as a shape factor.

   (b) Prove that the activation energy barrier against heterogeneous nucleation ($\Delta G_{\text{het}}^*$) is smaller than $\Delta G_{\text{hom}}^*$ by the shape factor $S(\theta)$. Also show a condition that the energy barrier for heterogeneous nucleation can be very much smaller than for homogeneous nucleation.