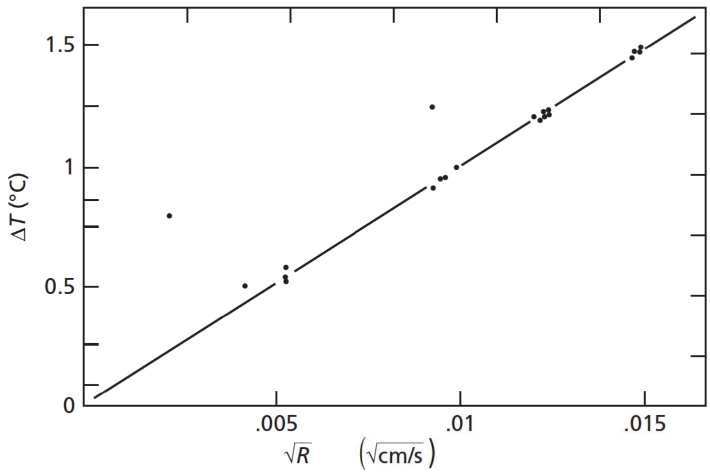

FIG. 14.47 Interface undercooling for tin-lead eutectic. [From Hunt, J. D., and Chilton, J. R., *J. Inst. Metals*, **92** 21 (1963–64).]

Flemings[46] shows a plot in which λ plots linearly against $R^{-1/2}$ and uses experimental lead-tin data taken from several sources. On the other hand, Fig. 14.47, from Hunt and Chilton[49] is also based on lead-tin data and shows an example where ΔT_o varies directly as $R^{1/2}$.

PROBLEMS

14.1 (a) Suppose that 0.100 kg of liquid copper is supercooled 250 K, where it is allowed to nucleate and solidify adiabatically (no heat is lost to the surroundings). Calculate how much copper will solidify until the temperature recalesces to its melting point of 1356 K. The specific heats of solid and liquid copper in the temperature range of interest are, respectively:

$$C_{ps} = 22.64 + 5.86 \times 10^{-3}T, \text{ J/K} \cdot \text{mol}$$

$$C_{pl} = 31.4, \text{ J/K} \cdot \text{mol}$$

where T is the temperature in degrees Kelvin. The heat of fusion of copper is 13.20 kJ/mol and its molar weight is 0.0635 kg/mol.

(b) How much supercooling would be necessary in order to solidify the entire sample adiabatically?

14.2 (a) Consider the face-centered cubic crystal structure and the planes (100), (110), and (111). On the basis of the degree of close-packing associated with each plane, rank these planes in order of their growth velocity during freezing.

(b) Also rank the (100), (110), and (111) planes for the body-centered cubic lattice.

14.3 The dendrite arm spacing (DAS) is dependent on the cooling rate, ε, by an equation of the form $DAS = k\varepsilon^{-n}$. Suppose for Al-4.9% Cu, DAS was measured as 100 and 10 μm at the cooling rates 0.1 and 60 K/s, respectively.

(a) Determine k and n for the alloy.

(b) What cooling rate is necessary to reduce the arm spacing to 1.0 μm?

(c) Melt spinning and powder atomization are two techniques which are commonly used to achieve rapid cooling rates. Briefly describe what these techniques are.

14.4 An Al-5% Cu ingot is unidirectionally solidified under the conditions of no diffusion in the solid, complete diffusion in the liquid, and local equilibrium at the interface, so that the Scheil equation applies.

(a) Calculate the composition of the liquid when the ingot is 50 percent solid. What is the average composition of the solid?

(b) What is the interface temperature at this point?

(c) How much eutectic and second phase θ will have formed when the ingot is completely solidified?

(d) Plot the composition profile in the solidified ingot.

14.5 Some eutectics grow as rod eutectics while others grow as lamellar eutectics, as shown in the accompanying figure. Suppose that for an eutectic, the weight fraction of the α phase is f_α and for the β phase it is f_β and the densities of α and β are the same.

(a) Calculate f_α for the rod eutectic as a function of λ and r_α, where λ is the rod spacing and r_α is the radius of the α rods.

(b) Calculate f_α for the lamellar eutectic as a function of λ and S_α, where λ is the lamellar spacing and S_α is the thickness of the α plates.

(c) Calculate the α/β interface energy per unit volume of each eutectic, using $\gamma_{\alpha/\beta}$ for the interface energy per unit area.

(d) At what f_α would both eutectics have the same interfacial energy?

(e) What type of eutectic structure do you expect for an alloy in which the volume fraction of α is less than that calculated in part (d)? Justify your answer.

14.6 Assume that an alloy of nickel with 2 wt. percent aluminum is cast and, by metallographic examination, a dendrite arm spacing of 50 μ is observed. It is also determined that the composition difference between the center of an arm and the midpoint between two arms is 1 percent. Estimate the time required for homogenization if the annealing temperature is to be 1400°C and the composition difference is to be reduced to one-tenth of its original value. *Note*: see Table 12.5.

14.7 In a precipitation hardening alloy, coring usually results in the precipitation of an eutectic between the dendrite arms. With regard to aluminum-copper alloys, Singh and Flemings[50] have assumed that this eutectic is divorced (consists only of the θ phase) and have derived an equation to describe the kinetics of homogenization that is similar to that discussed in the text for homogenization of a cored solid solution alloy. This equation, which applies to a solution treatment close to the solvus, is

$$g = g_0 e^{-\pi^2 Dt/4l_0^2}$$

where g is the volume fraction of the θ phase at time t, g_0 is the volume fraction of θ when t is zero, D is the diffusion coefficient, and l_0 is equal to half the dendrite arm spacing, as shown in the schematic figure on the next page. (Note that the concentration inside the precipitate is constant since it equals that of the θ phase. In the alpha phase, the concentration of copper is assumed to vary sinusoidally with distance and to be a minimum at the midpoint corresponding to the centers of the dendrites.)

(a) Assuming that at the annealing temperature D is 10^{-14} m^2/s and that the original volume fraction of the θ phase is 1.0 percent, what solution time would be required to obtain a volume fraction of 0.01 percent if the dendrite arm spacing is 100 μ?

(b) What would be the corresponding time if the dendrite arm spacing was 10 μ?

14.8 Care must be taken in melting certain copper alloys to prevent absorption of hydrogen from the furnace gases or as a result of reaction with water

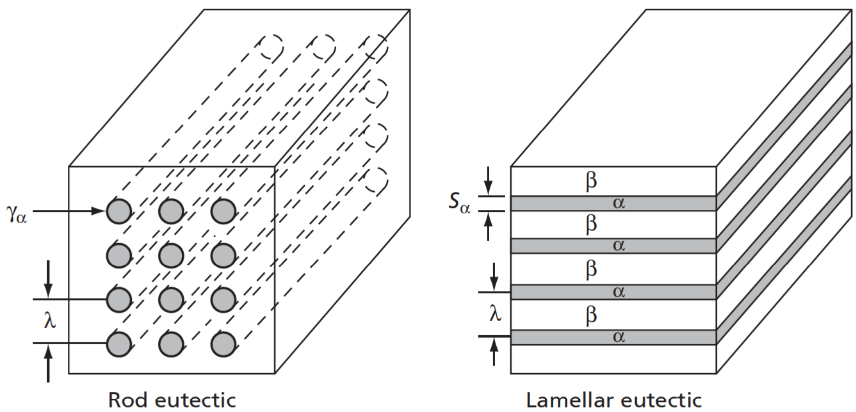

FIG. FOR PROB. 14.5

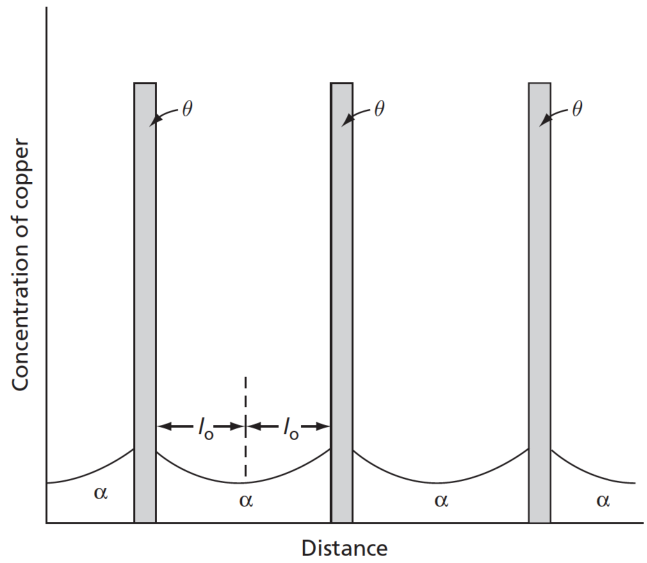

FIG. FOR PROB. 14.7

vapor. The release of this gas on freezing can result in an open, porous structure of little value. As an exercise, compute the volume of hydrogen that should be released in 10 cc of copper melted in a hydrogen atmosphere at a pressure of one atmosphere when the metal is frozen. The atomic volume of copper is 7.09 cm^3 per gm atom. Assume the ideal gas law and refer to Fig. 14.41.

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