9.2 (a) From Figure 9.8, the maximum solubility of Pb in Sn at 100°C corresponds to the position of the β–(α + β) phase boundary at this temperature, or to about 2 wt% Pb.

(b) From this same figure, the maximum solubility of Sn in Pb corresponds to the position of the α–(α + β) phase boundary at this temperature, or about 5 wt% Sn.

9.12 Upon cooling a 50 wt% Ni-50 wt% Cu alloy from 1400°C and utilizing Figure 9.3a:

(a) The first solid phase forms at the temperature at which a vertical line at this composition intersects the *L*–(α + *L*) phase boundary--i.e., at about 1320°C.

(b) The composition of this solid phase corresponds to the intersection with the *L*–(α + *L*) phase boundary, of a tie line constructed across the α + *L* phase region at 1320°C--i.e., $C_\alpha$ = 62 wt% Ni-38 wt% Cu.

(c) Complete solidification of the alloy occurs at the intersection of this same vertical line at 50 wt% Ni with the (α + *L*)–α phase boundary--i.e., at about 1270°C.

(d) The composition of the last liquid phase remaining prior to complete solidification corresponds to the intersection with the *L*–(α + *L*) boundary, of the tie line constructed across the α + *L* phase region at 1270°C--i.e., $C_L$ is about 37 wt% Ni-63 wt% Cu.

9.13 This problem asks us to determine the phases present and their concentrations at several temperatures, as an alloy of composition 52 wt% Zn-48 wt% Cu is cooled. From Figure 9.19:

At 1000°C, a liquid phase is present; $W_L = 1.0$

At 800°C, the β phase is present, and $W_\beta = 1.0$

At 500°C, β and γ phases are present, and

$$W_\gamma = \frac{C_0 - C_\beta}{C_\gamma - C_\beta} = \frac{52 - 49}{58 - 49} = 0.33$$

$$W_\beta = 1.00 - 0.33 = 0.67$$

At 300°C, the β' and γ phases are present, and

$$W_{\beta'} = \frac{C_\gamma - C_0}{C_\gamma - C_{\beta'}} = \frac{59 - 52}{59 - 50} = 0.78$$

$$W_\gamma = 1.00 - 0.78 = 0.22$$

## Development of Microstructure in Isomorphous Alloys

9.25 (a) Coring is the phenomenon whereby concentration gradients exist across grains in polycrystalline alloys, with higher concentrations of the component having the lower melting temperature at the grain boundaries. It occurs, during solidification, as a consequence of cooling rates that are too rapid to allow for the maintenance of the equilibrium composition of the solid phase.

(b) One undesirable consequence of a cored structure is that, upon heating, the grain boundary regions will melt first and at a temperature below the equilibrium phase boundary from the phase diagram; this melting results in a loss in mechanical integrity of the alloy.

## Development of Microstructure in Eutectic Alloys

9.28 Upon solidification, an alloy of eutectic composition forms a microstructure consisting of alternating layers of the two solid phases because during the solidification atomic diffusion must occur, and with this layered configuration the diffusion path length for the atoms is a minimum.

9.29 A "phase" is a homogeneous portion of the system having uniform physical and chemical characteristics, whereas a "microconstituent" is an identifiable element of the microstructure (that may consist of more than one phase).

## The Iron-Iron Carbide ($Fe-Fe_3C$) Phase Diagram

## Development of Microstructure in Iron-Carbon Alloys

9.46 This problem asks that we compute the mass fractions of α ferrite and cementite in pearlite. The lever-rule expression for ferrite is

$$W_\alpha = \frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_\alpha}$$

and, since $C_{Fe_3C}$ = 6.70 wt% C, $C_0$ = 0.76 wt% C, and $C_\alpha$ = 0.022 wt% C

$$W_\alpha = \frac{6.70 - 0.76}{6.70 - 0.022} = 0.89$$

Similarly, for cementite

$$W_{Fe_3C} = \frac{C_0 - C_\alpha}{C_{Fe_3C} - C_\alpha} = \frac{0.76 - 0.022}{6.70 - 0.022} = 0.11$$

9.47 (a) A "hypoeutectoid" steel has a carbon concentration less than the eutectoid; on the other hand, a "hypereutectoid" steel has a carbon content greater than the eutectoid.

(b) For a hypoeutectoid steel, the proeutectoid ferrite is a microconstituent that formed above the eutectoid temperature. The eutectoid ferrite is one of the constituents of pearlite that formed at a temperature below the eutectoid. The carbon concentration for both ferrites is 0.022 wt% C.

9.49 In this problem we are given values of $W_\alpha$ and $W_{Fe_3C}$ (0.86 and 0.14, respectively) for an iron-carbon alloy and then are asked to specify the proeutectoid phase. Employment of the lever rule for total α leads to

$$W_\alpha = 0.86 = \frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_\alpha} = \frac{6.70 - C_0}{6.70 - 0.022}$$

Now, solving for $C_0$, the alloy composition, leads to $C_0$ = 0.96 wt% C. Therefore, the proeutectoid phase is $Fe_3C$ since $C_0$ is greater than 0.76 wt% C.

9.51 We are called upon to consider various aspects of 6.0 kg of austenite containing 0.45 wt% C, that is cooled to below the eutectoid.

(a) Ferrite is the proeutectoid phase since 0.45 wt% C is less than 0.76 wt% C.

(b) For this portion of the problem, we are asked to determine how much total ferrite and cementite form. For ferrite, application of the appropriate lever rule expression yields

$$W_{\alpha} = \frac{C_{Fe_3C} - C_0}{C_{Fe_3C} - C_{\alpha}} = \frac{6.70 - 0.45}{6.70 - 0.022} = 0.94$$

which corresponds to (0.94)(6.0 kg) = 5.64 kg of total ferrite.

Similarly, for total cementite,

$$W_{Fe_3C} = \frac{C_0 - C_{\alpha}}{C_{Fe_3C} - C_{\alpha}} = \frac{0.45 - 0.022}{6.70 - 0.022} = 0.06$$

Or (0.06)(6.0 kg) = 0.36 kg of total cementite form.

(c) Now consider the amounts of pearlite and proeutectoid ferrite. Using Equation 9.20

$$W_p = \frac{C_0' - 0.022}{0.74} = \frac{0.45 - 0.022}{0.74} = 0.58$$

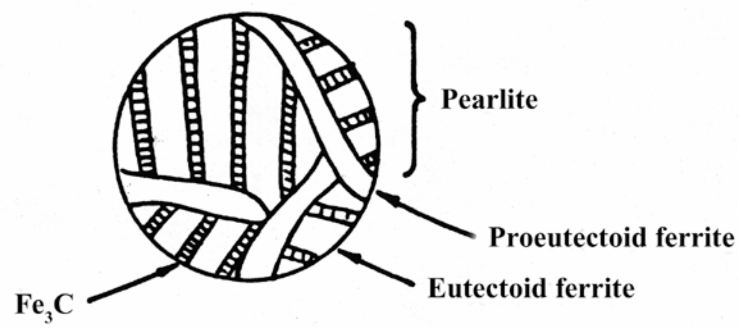
This corresponds to (0.58)(6.0 kg) = 3.48 kg of pearlite.

Also, from Equation 9.21,

$$W_{\alpha'} = \frac{0.76 - 0.45}{0.74} = 0.42$$

Or, there are (0.42)(6.0 kg) = 2.52 kg of proeutectoid ferrite.

(d) Schematically, the microstructure would appear as:


Pearlite
Proeutectoid ferrite
Eutectoid ferrite
$Fe_3C$

9.52 The mass fractions of proeutectoid ferrite and pearlite that form in a 0.35 wt% C iron-carbon alloy are considered in this problem. From Equation 9.20

$$W_{\text{p}} = \frac{C_0' - 0.022}{0.74} = \frac{0.35 - 0.022}{0.74} = 0.44$$

And, from Equation 9.21 (for proeutectoid ferrite)

$$W_{\alpha'} = \frac{0.76 - C_0'}{0.74} = \frac{0.76 - 0.35}{0.74} = 0.56$$

9.56 In this problem we are asked to consider 1.5 kg of a 99.7 wt% Fe-0.3 wt% C alloy that is cooled to a temperature below the eutectoid.

(a) Equation 9.21 must be used in computing the amount of proeutectoid ferrite that forms. Thus,

$$W_{\alpha'} = \frac{0.76 - C_0'}{0.74} = \frac{0.76 - 0.30}{0.74} = 0.622$$

Or, (0.622)(1.5 kg) = 0.933 kg of proeutectoid ferrite forms.

(b) In order to determine the amount of eutectoid ferrite, it first becomes necessary to compute the amount of total ferrite using the lever rule applied entirely across the $\alpha + Fe_3C$ phase field, as

$$W_{\alpha} = \frac{C_{Fe_3C} - C_0'}{C_{Fe_3C} - C_{\alpha}} = \frac{6.70 - 0.30}{6.70 - 0.022} = 0.958$$

which corresponds to (0.958)(1.5 kg) = 1.437 kg. Now, the amount of eutectoid ferrite is just the difference between total and proeutectoid ferrites, or

$$1.437 \text{ kg} - 0.933 \text{ kg} = 0.504 \text{ kg}$$

(c) With regard to the amount of cementite that forms, again application of the lever rule across the entirety of the $\alpha + Fe_3C$ phase field, leads to

$$W_{Fe_3C} = \frac{C_0' - C_{\alpha}}{C_{Fe_3C} - C_{\alpha}} = \frac{0.30 - 0.022}{6.70 - 0.022} = 0.042$$

which amounts to (0.042)(1.5 kg) = 0.063 kg cementite in the alloy.