



ENGINEERING MATERIALS

Proeutectic $\alpha = 24\%$

100% Liquid

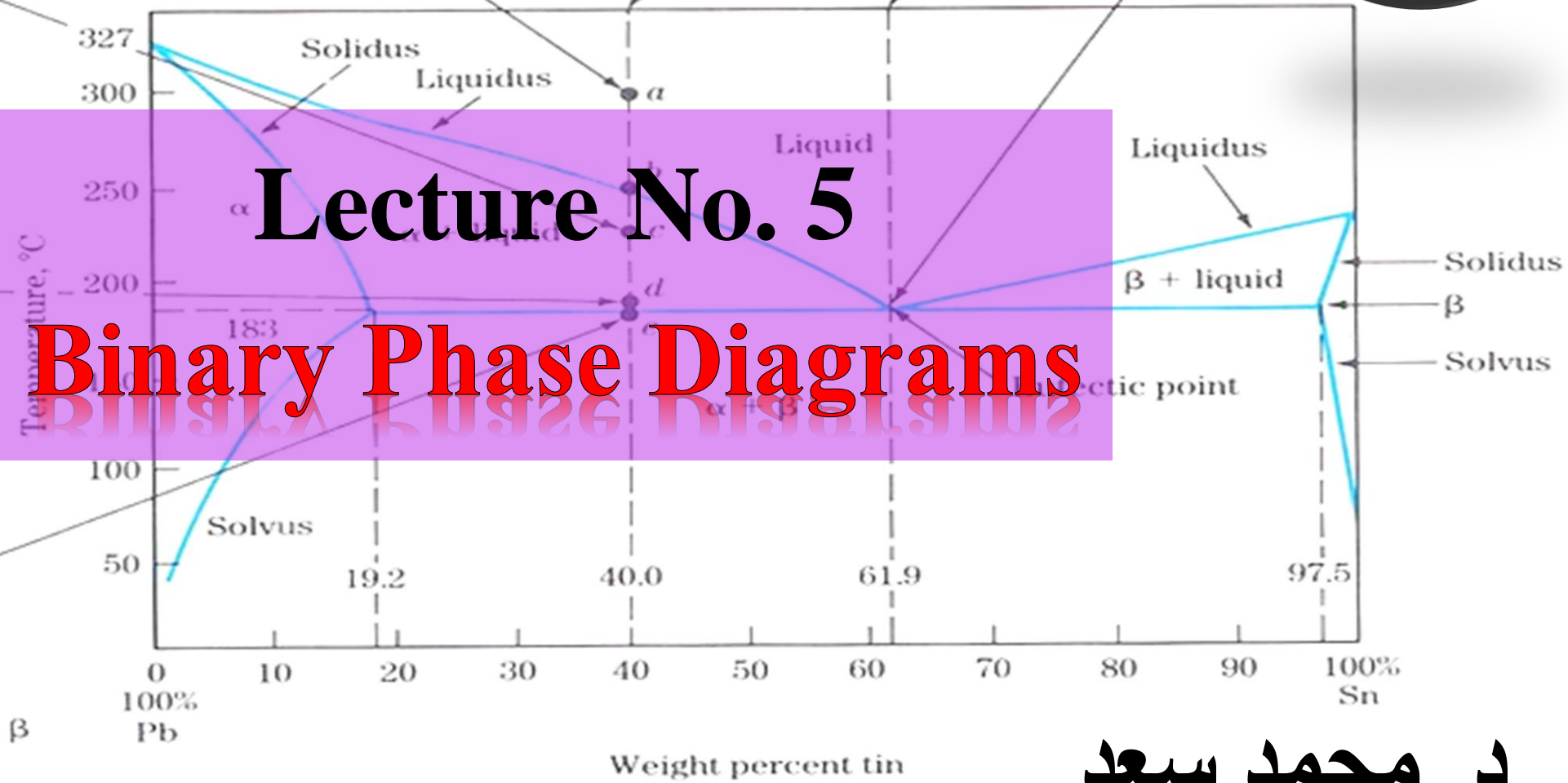
Proeutectic $\alpha = 51\%$

Liquid = 49%

Proeutectic α

Eutectic β

Eutectic α



Lecture No. 5

Binary Phase Diagrams

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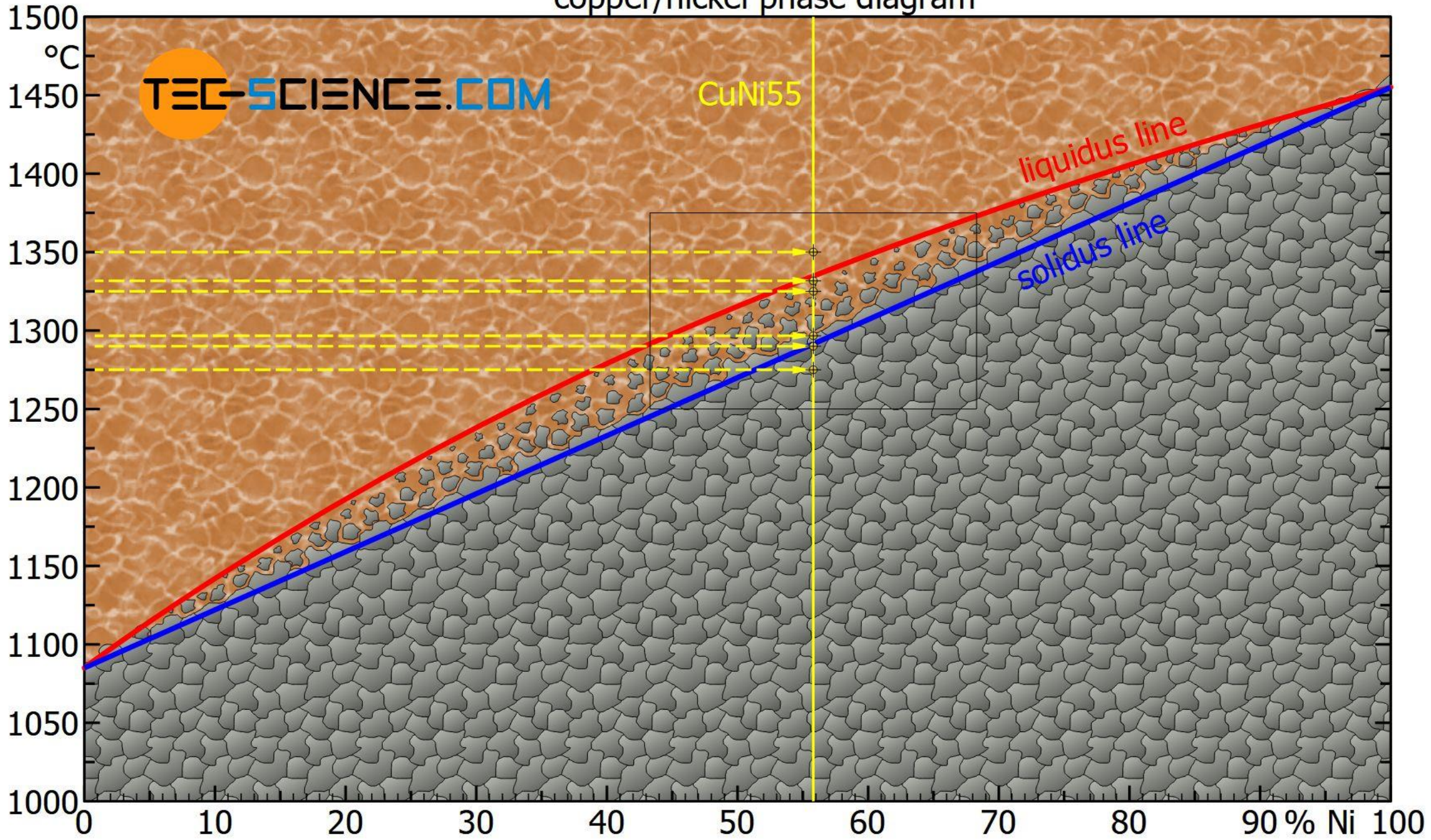
copper/nickel phase diagram



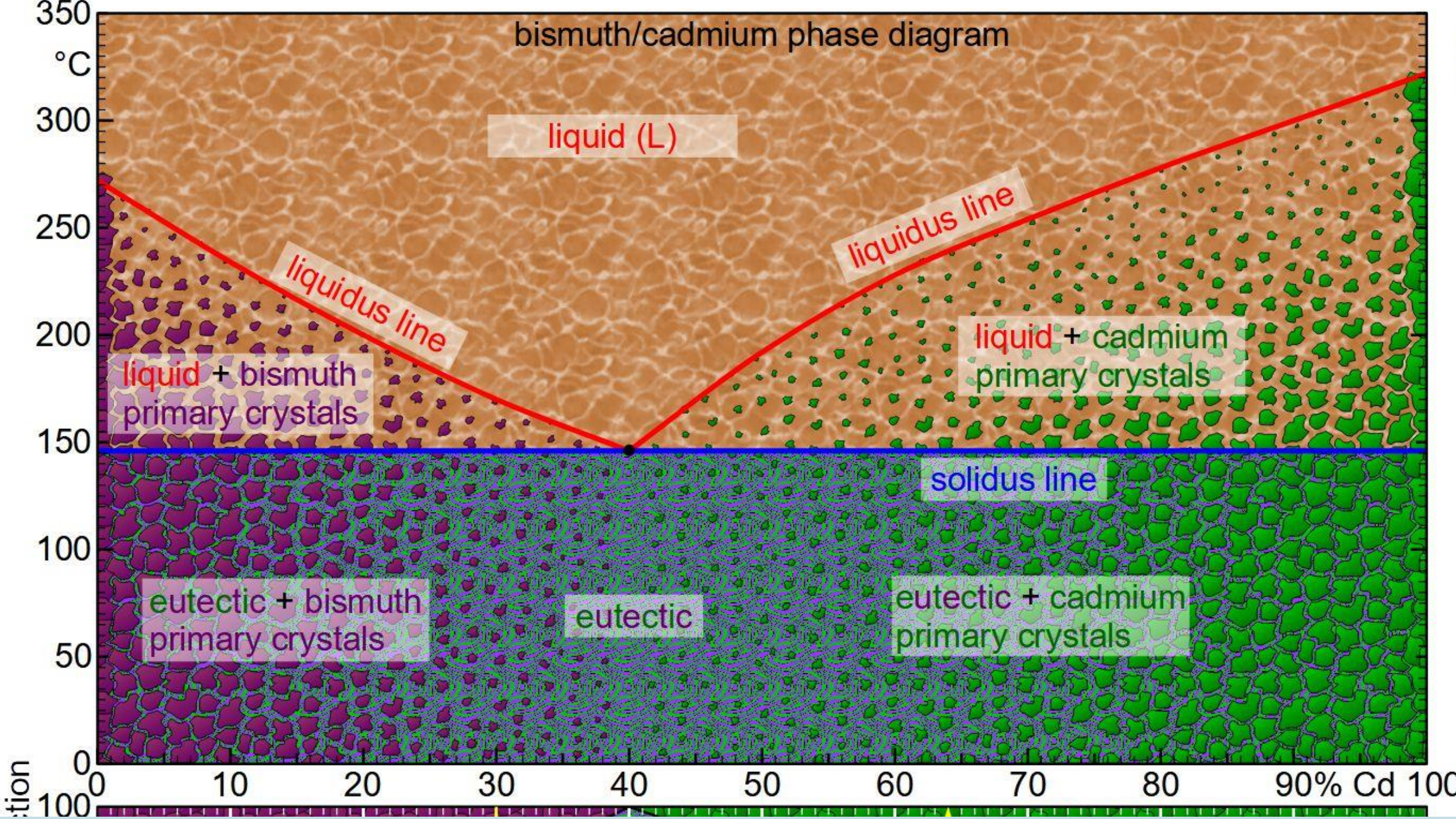
CuNi55

liquidus line

solidus line




bismuth/cadmium phase diagram



ation
100

0 10 20 30 40 50 60 70 80 90% Cd 100

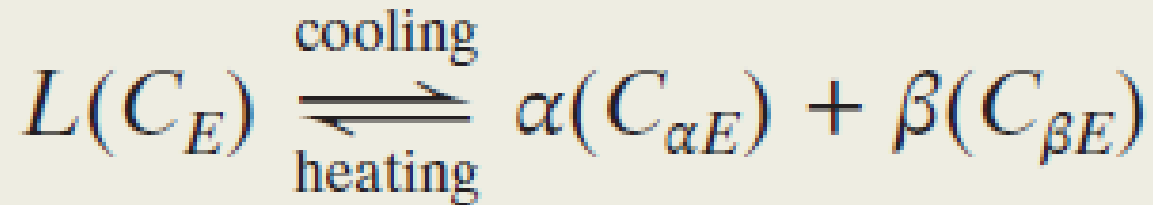


this type of equilibrium diagrams produced when the two alloy components are completely soluble in each other in the liquid state but completely insoluble in each other in the solid state.

The solid alloy shows a mixture of crystals of the two metals concerned. Each of the two metals in the solid alloy retains its independent identity. At one particular composition, called the *eutectic composition*, the temperature at which solidification starts to occur is a minimum.

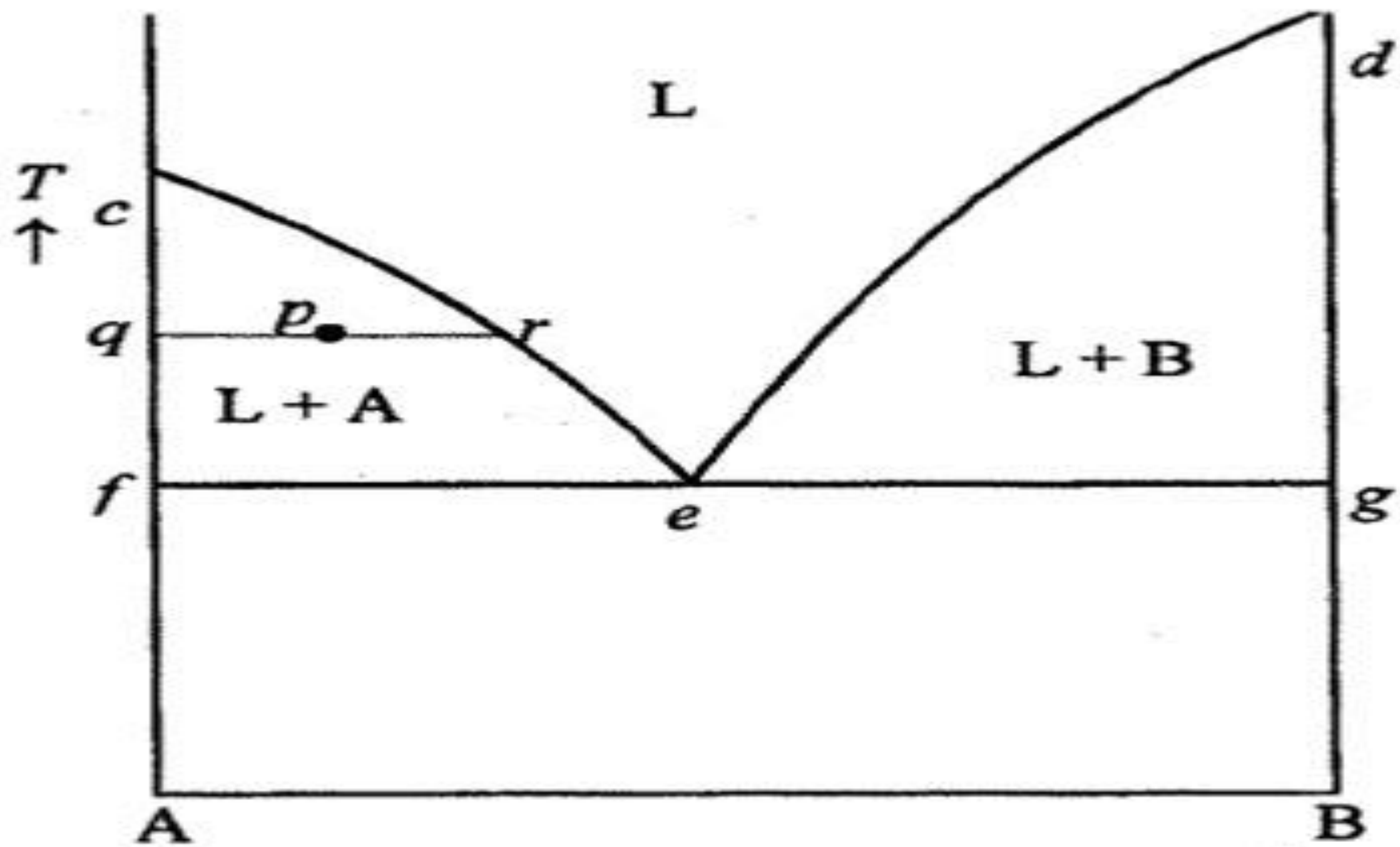
At this temperature, called the eutectic temperature, the liquid changes to the solid state without any change in temperature. The solidification at the eutectic temperature, for the eutectic composition, has both the metals simultaneously coming out of the liquid. Both metals crystallize together.

The resulting structure, known as the *eutectic structure*, is generally a laminar structure with layers of metal A alternating with layers of metal B.



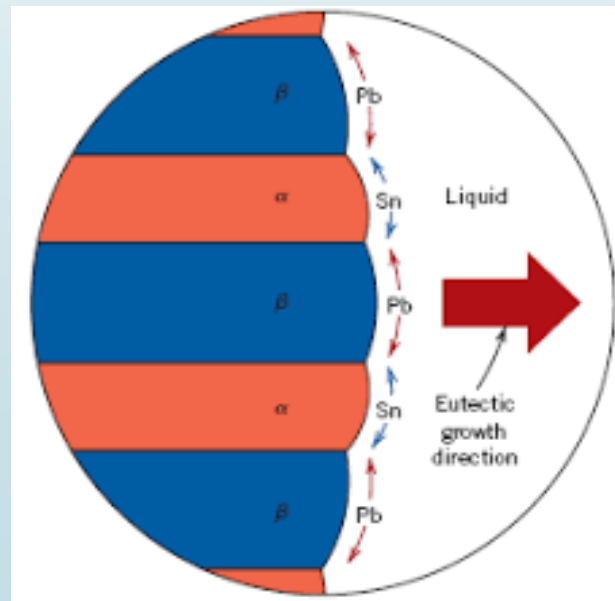
It is extremely doubtful whether such a situation as this really exists in practice since most solid metals appear to dissolve quantities, however small, of other metals.

However, in the case of bismuth and cadmium the mutual solid solubility is so small that we can neglect it for the sake of our argument and assume that the metals are completely insoluble in the solid state as shown in figure below.



The properties of the eutectic can be summarized as:

- 1 Solidification takes place at a single fixed temperature.
- 2 The solidification takes place at the lowest temperature in that group of alloys.
- 3 The composition of the eutectic composition is a constant for that group of alloys.
- 4 It is a mixture, for an alloy made up from just two metals, of the two phases.
- 5 The solidified eutectic structure is generally a lamellar structure.






The structure for two metals that are completely insoluble in each other in the solid state are:

- 1 The structure prior to the eutectic composition is of crystals of B(Bismuth) in material of eutectic composition and structure.
- 2 At the eutectic structure the material is entirely eutectic in composition and structure.
- 3 The structure after the eutectic composition is of crystals of A(Cadmium) in eutectic composition and structure material.

Two metals mutually soluble in all proportions in the liquid state but only partially soluble in the solid state



Lead-tin alloys are of this type. Figure (6.10a) shows the equilibrium diagram for lead-tin alloys. The solidus line is that line, started at 0 tin-100 percent lead, between the (liquid+ α) and the α areas, between the (liquid+ α) and the (α + β) areas, between the (liquid+ β) and the (α + β) areas, and between the (liquid+ β) and the β areas. The α , the β , and the (α + β) areas all represent solid forms of the alloy. The transition across the line between α and (α + β) is thus a transition from one solid form to another solid form. Such a line is called the *solvus*. Figure (6.10b) shows the early part of figure (6.10a) and the liquidus, solidus and solvus lines.

the α phase, having a low concentration of tin in lead, mixed with small solid solution crystals, the β phase, having a high concentration of tin in lead.

At the eutectic temperature the maximum amount of tin that can be dissolved in lead in the solid state is 19.2 percent see Figure (6.10b). Similarly the maximum amount of lead that can be dissolved in tin, at the eutectic temperature, is 2.5 percent.

The eutectic composition is 61.9 percent tin and 38.1 percent lead at room temperature having structure a mixture of α with high lead concentration and β with high tin concentration.

For alloys having a composition with between 19.2 percent and 61.9 percent tin at room temperature is a structure having the α solid solution crystals, some β precipitate, and the eutectic structure .

For alloys having a composition with between 61.9 percent and 97.5 percent tin at room temperature is a structure having the β solid solution crystals, some α precipitate, and the eutectic structure.

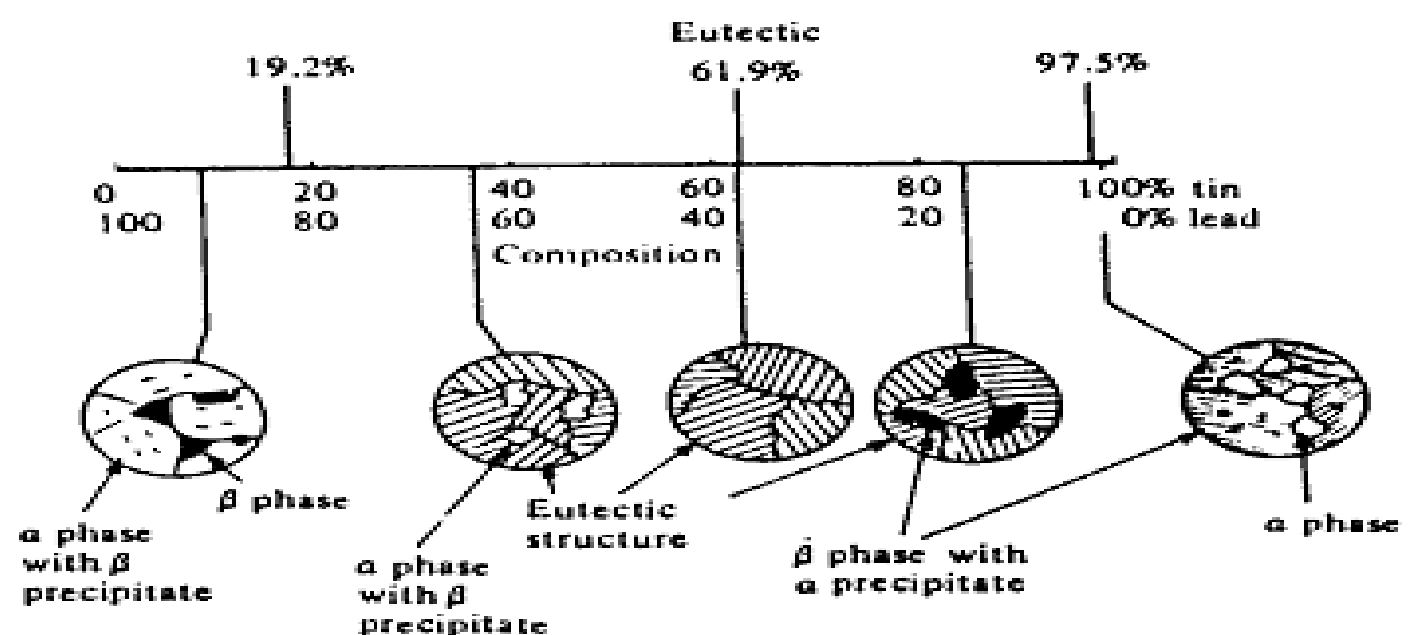
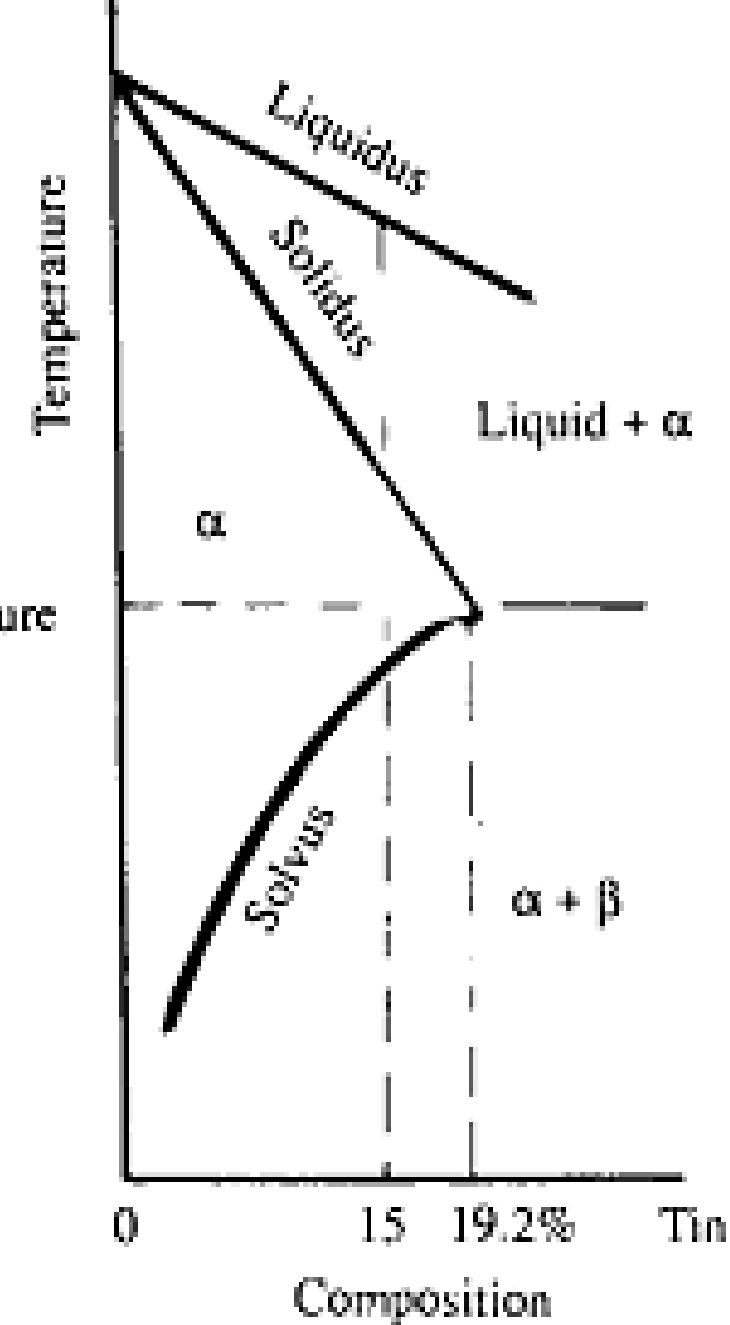
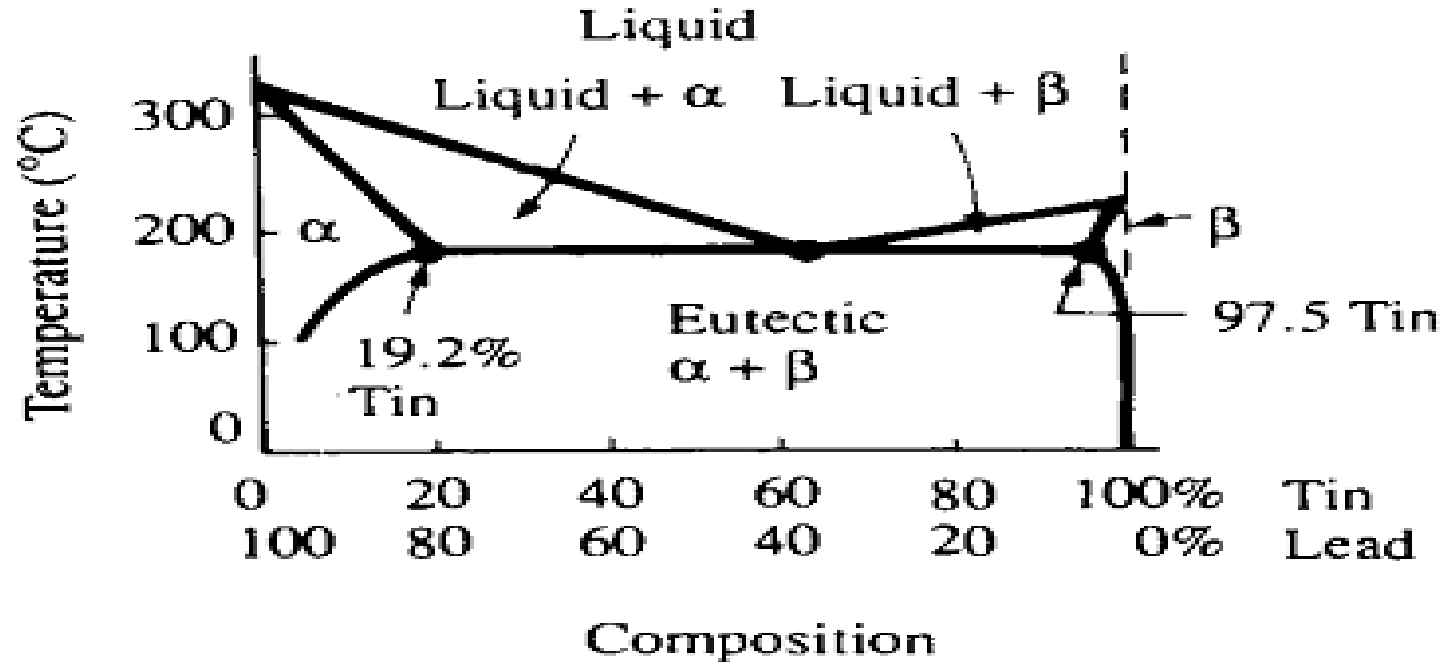
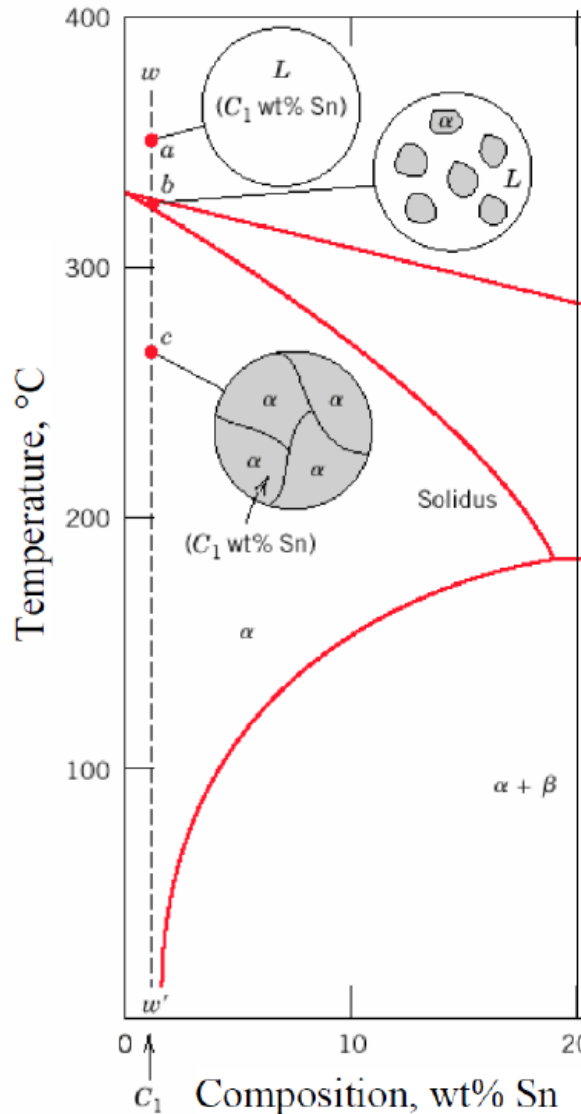


Figure 6.10: (a) Equilibrium diagram for lead-tin alloys, (b) The liquidus, solidus and solvus lines.

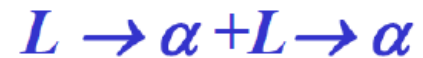
Development of microstructure in eutectic alloys (I)

Several different types of microstructure can be formed in slow cooling at different compositions. Let's consider cooling of liquid lead-tin system as an example.



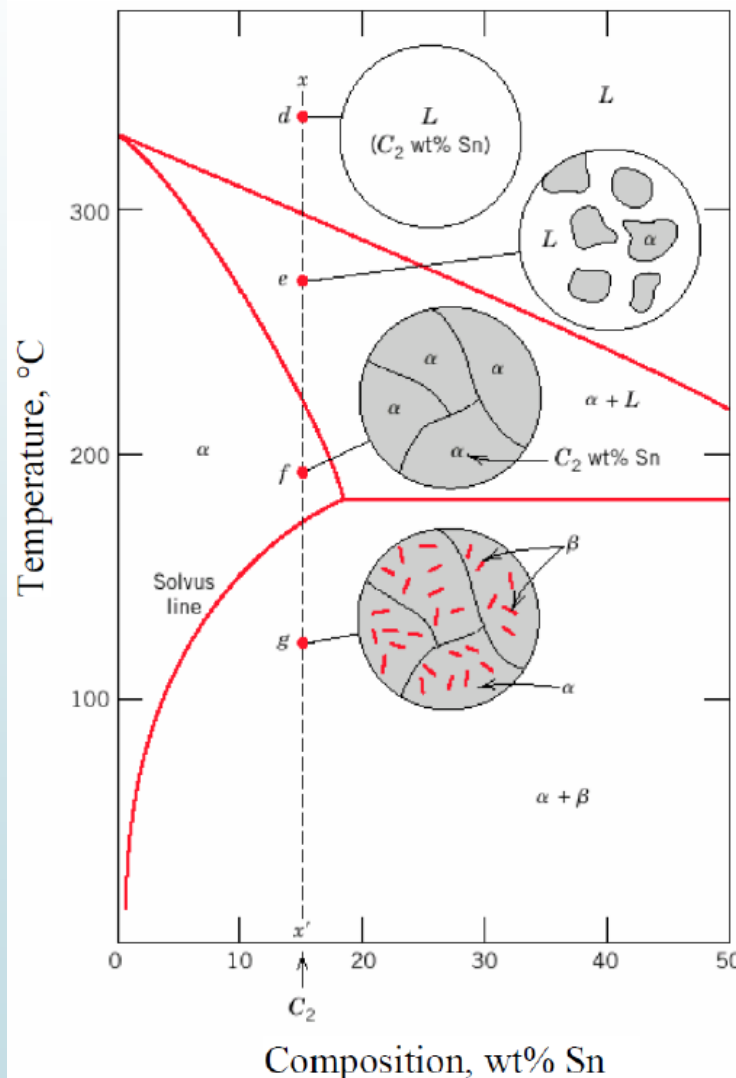
Pb-Sn

In the case of lead-rich alloy (0-2 wt. % of tin) solidification proceeds in the same manner as for isomorphous alloys (e.g. Cu-Ni) that we discussed earlier.

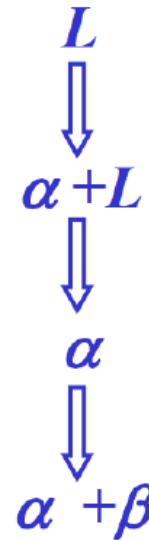


Development of microstructure in eutectic alloys (II)

At compositions between the room temperature solubility limit and the maximum solid solubility at the eutectic temperature, β phase nucleates as the α solid solubility is exceeded up on crossing the solvus line



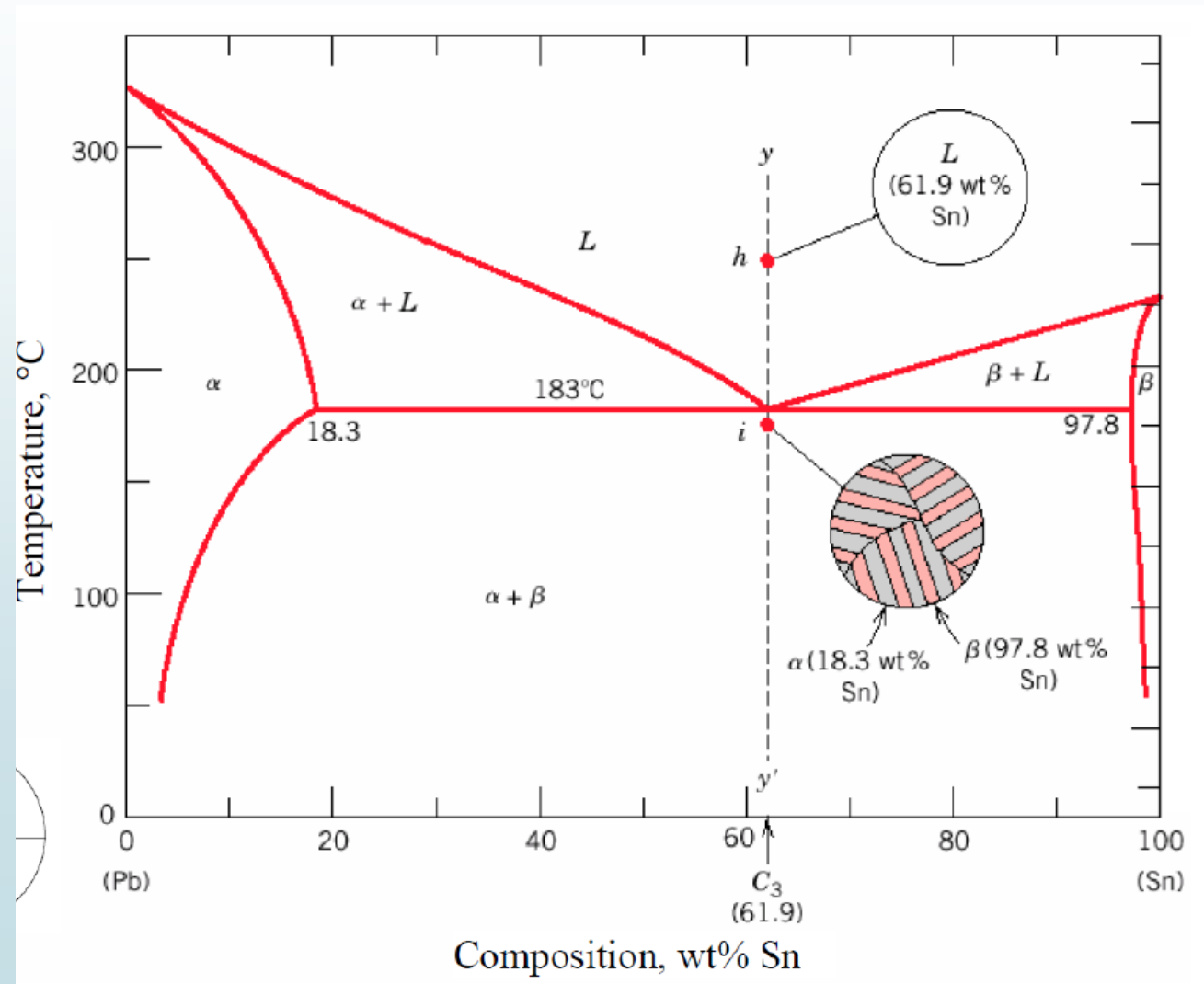
Pb-Sn



Development of microstructure in eutectic alloys (III)

Solidification at the eutectic composition

No changes above the eutectic temperature T_E . At T_E all the liquid transforms to α and β phases (*eutectic reaction*).



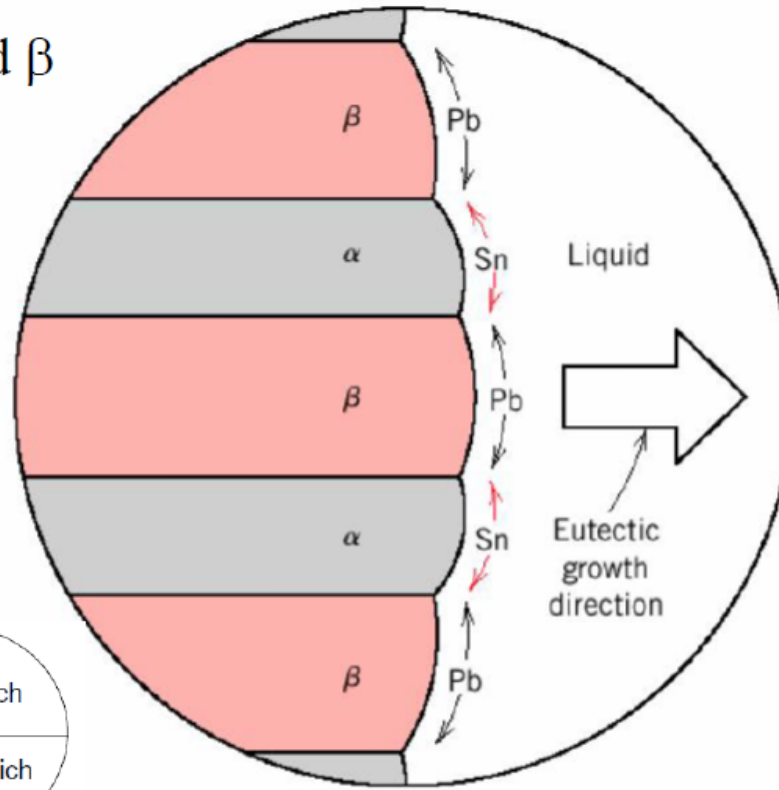
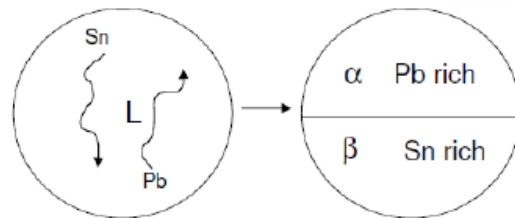
Development of microstructure in eutectic alloys (IV)

Pb-Sn

Solidification at the eutectic composition

Compositions of α and β phases are very different \rightarrow eutectic reaction involves redistribution of Pb and Sn atoms by atomic diffusion.

This simultaneous formation of α and β phases result in a layered (lamellar) microstructure that is called **eutectic structure**.



160 μ m



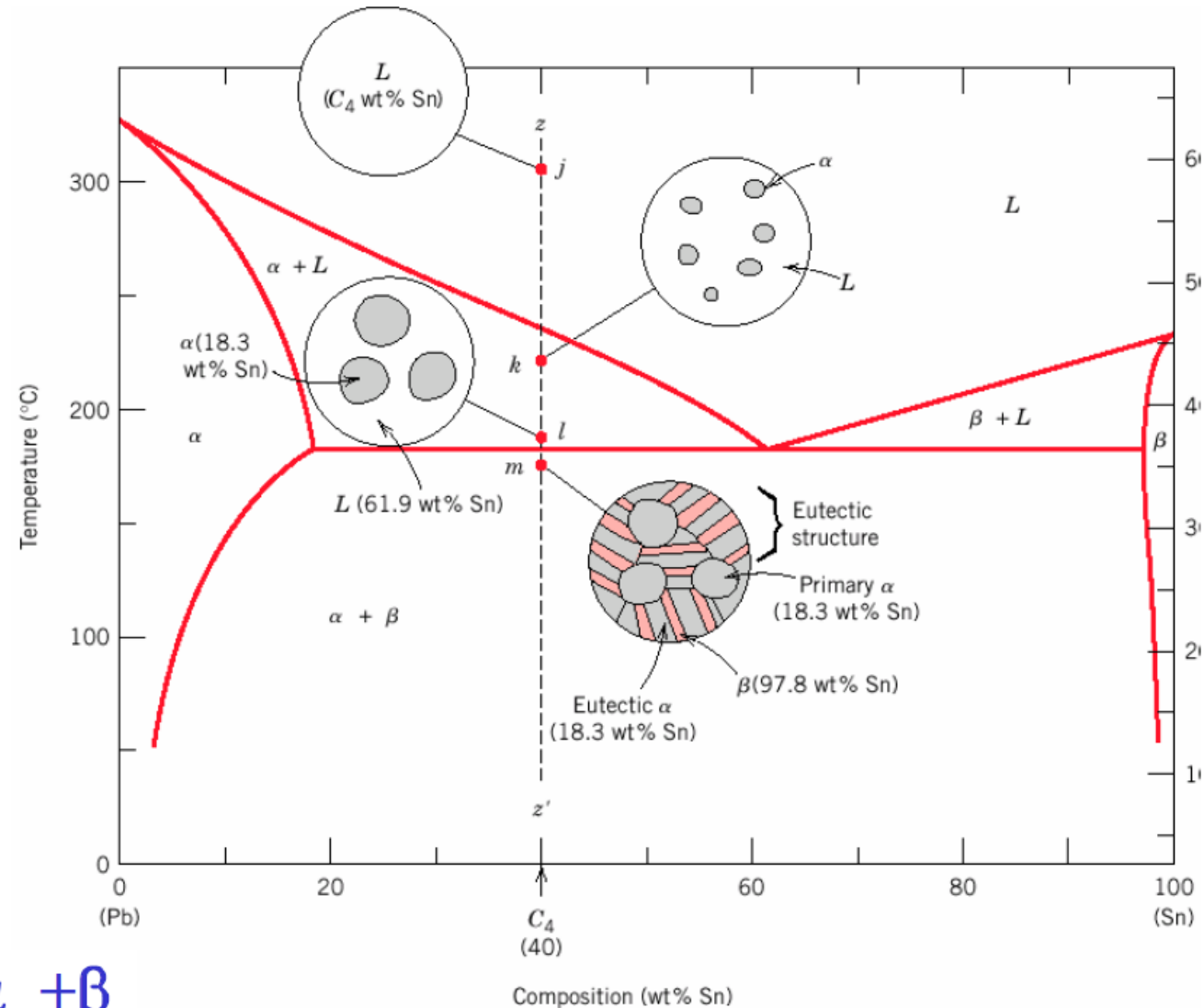
Formation of the eutectic structure in the lead-tin system. In the micrograph, the dark layers are lead-rich α phase, the light layers are the tin-rich β phase.

Development of microstructure in eutectic alloys (V)

Compositions other than eutectic but within the range of the eutectic isotherm

Primary α phase is formed in the $\alpha + L$ region, and the eutectic structure that includes layers of α and β phases (called **eutectic α** and **eutectic β** phases) is formed upon crossing the eutectic isotherm.

Pb-Sn




$L \rightarrow \alpha + L \rightarrow \alpha + \beta$

For multiphase alloys, it is often more convenient to specify relative phase amount in terms of volume fraction rather than mass fraction. Phase volume fractions are preferred because they (rather than mass fractions) may be determined from examination of the microstructure; furthermore, the properties of a multiphase alloy may be estimated on the basis of volume fractions.

For an alloy consisting of α and β phases, the volume fraction of the α phase, V_α , is defined as

$$V_\alpha = \frac{v_\alpha}{v_\alpha + v_\beta}$$



where v_α and v_β denote the volumes of the respective phases in the alloy. An analogous expression exists for V_β , and, for an alloy consisting of just two phases, it is the case that

$$V_\alpha + V_\beta = 1.$$

On occasion, conversion from mass fraction to volume fraction (or vice versa) is desired. Equations that facilitate these conversions are as follows:

$$V_{\alpha} = \frac{\frac{W_{\alpha}}{\rho_{\alpha}}}{\frac{W_{\alpha}}{\rho_{\alpha}} + \frac{W_{\beta}}{\rho_{\beta}}}$$

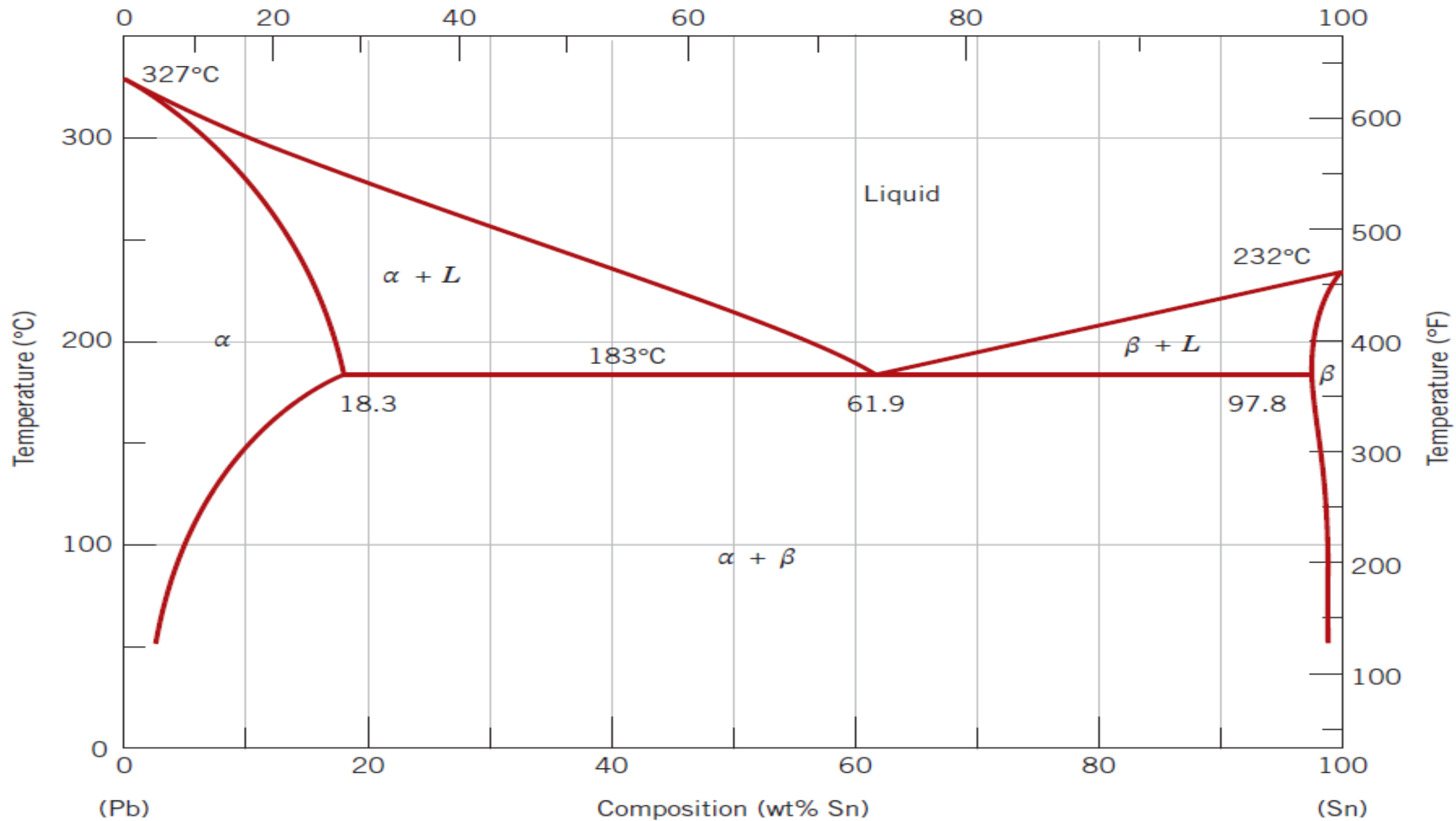
$$V_{\beta} = \frac{\frac{W_{\beta}}{\rho_{\beta}}}{\frac{W_{\alpha}}{\rho_{\alpha}} + \frac{W_{\beta}}{\rho_{\beta}}}$$

$$W_{\alpha} = \frac{V_{\alpha} \rho_{\alpha}}{V_{\alpha} \rho_{\alpha} + V_{\beta} \rho_{\beta}}$$

$$W_{\beta} = \frac{V_{\beta} \rho_{\beta}}{V_{\alpha} \rho_{\alpha} + V_{\beta} \rho_{\beta}}$$

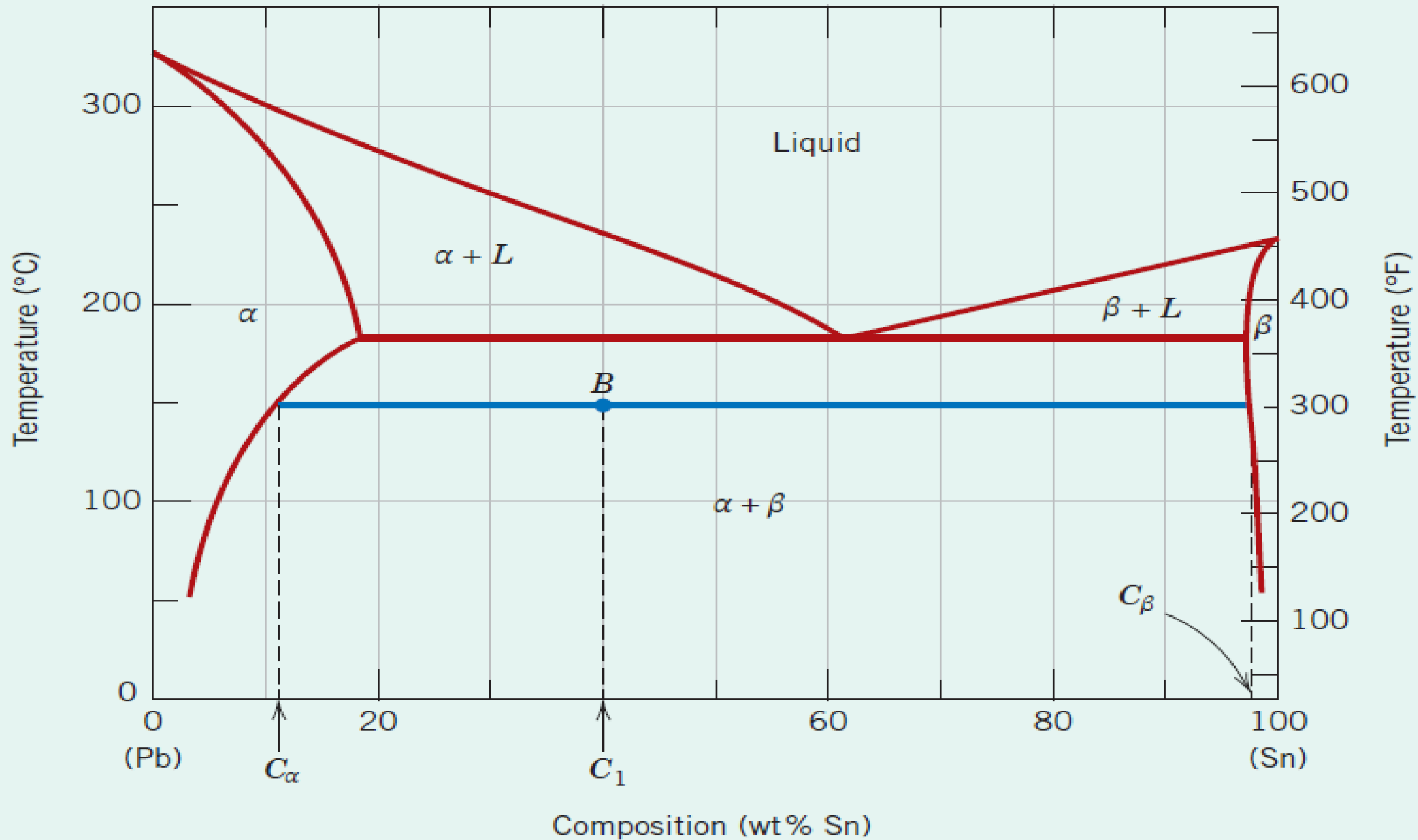
Determination of Phases Present and Computation of Phase Compositions

For a 40 wt% Sn–60 wt% Pb alloy at 150°C (300°F), **(a)** what phase(s) is (are) present?
(b) What is (are) the composition(s) of the phase(s)?



Locate this temperature–composition point on the phase diagram (point B in Figure). Inasmuch as it is within the $\alpha + \beta$ region, both α and β phases will coexist.

(b) Because two phases are present, it becomes necessary to construct a tie line across the $\alpha + \beta$ phase field at 150°C , as indicated in Figure 9.9. The composition of the α phase corresponds to the tie line intersection with the $\alpha/(\alpha + \beta)$ solvus phase boundary—about 11 wt% Sn–89 wt% Pb, denoted as C_α . This is similar for the β phase, which has a composition of approximately 98 wt% Sn–2 wt% Pb (C_β).



For the lead–tin alloy in Example Problem 1, calculate the relative amount of each phase present in terms of **(a)** mass fraction and **(b)** volume fraction. At 150°C, take the densities of Pb and Sn to be 11.35 and 7.29 g/cm³, respectively.

Because the alloy consists of two phases, it is necessary to employ the lever rule. If C_1 denotes the overall alloy composition, mass fractions may be computed by subtracting compositions, in terms of weight percent tin, as follows:

$$W_{\alpha} = \frac{C_{\beta} - C_1}{C_{\beta} - C_{\alpha}} = \frac{98 - 40}{98 - 11} = 0.67$$

$$W_{\beta} = \frac{C_1 - C_{\alpha}}{C_{\beta} - C_{\alpha}} = \frac{40 - 11}{98 - 11} = 0.33$$

$$\rho_{\alpha} = \frac{100}{\frac{C_{\text{Sn}(\alpha)}}{\rho_{\text{Sn}}} + \frac{C_{\text{Pb}(\alpha)}}{\rho_{\text{Pb}}}}$$

where $C_{\text{Sn}(\alpha)}$ and $C_{\text{Pb}(\alpha)}$ denote the concentrations in weight percent of tin and lead, respectively, in the α phase. From Example Problem 9.2, these values are 11 wt% and 89 wt%. Incorporation of these values along with the densities of the two components leads to

$$\rho_{\alpha} = \frac{100}{\frac{11}{7.29 \text{ g/cm}^3} + \frac{89}{11.35 \text{ g/cm}^3}} = 10.69 \text{ g/cm}^3$$

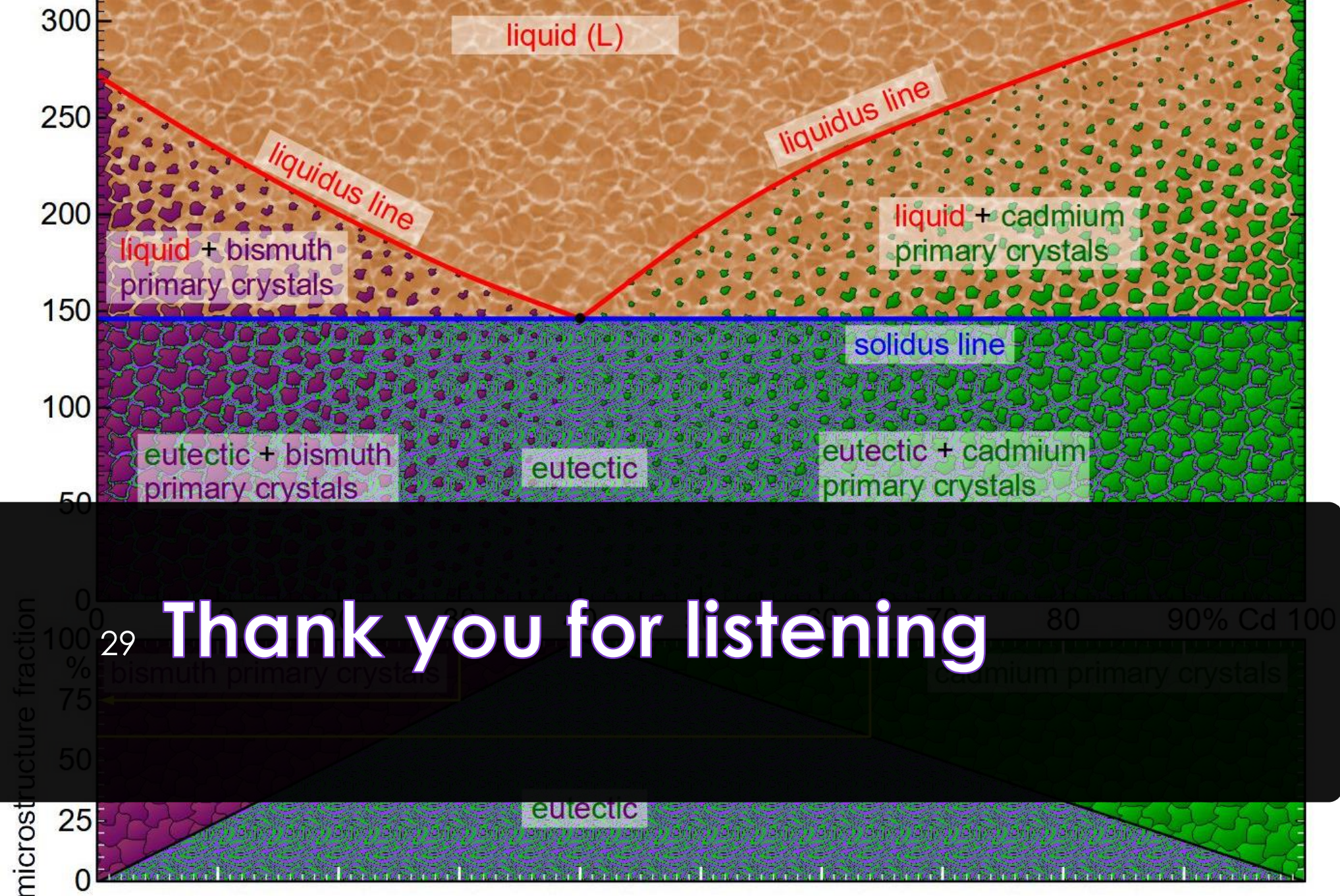
Similarly for the β phase:

$$\begin{aligned} \rho_{\beta} &= \frac{100}{\frac{C_{\text{Sn}(\beta)}}{\rho_{\text{Sn}}} + \frac{C_{\text{Pb}(\beta)}}{\rho_{\text{Pb}}}} \\ &= \frac{100}{\frac{98}{7.29 \text{ g/cm}^3} + \frac{2}{11.35 \text{ g/cm}^3}} = 7.34 \text{ g/cm}^3 \end{aligned}$$

Now it becomes necessary to employ Equations 9.6a and 9.6b to determine V_α and V_β as

$$\begin{aligned} V_\alpha &= \frac{\frac{W_\alpha}{\rho_\alpha}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}} \\ &= \frac{\frac{0.67}{10.69 \text{ g/cm}^3}}{\frac{0.67}{10.69 \text{ g/cm}^3} + \frac{0.33}{7.34 \text{ g/cm}^3}} = 0.58 \end{aligned}$$

$$\begin{aligned} V_\beta &= \frac{\frac{W_\beta}{\rho_\beta}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}} \\ &= \frac{\frac{0.33}{7.34 \text{ g/cm}^3}}{\frac{0.67}{10.69 \text{ g/cm}^3} + \frac{0.33}{7.34 \text{ g/cm}^3}} = 0.42 \end{aligned}$$



29 Thank you for listening