Phase equilibria: solubility limit

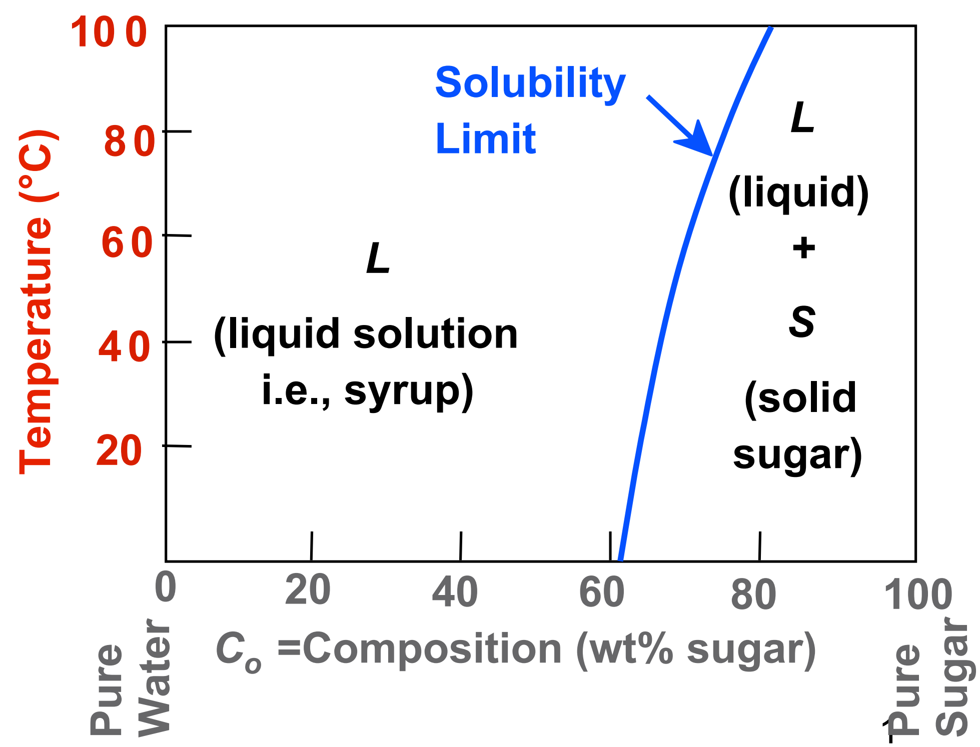
Introduction

- Solutions – solid solutions, single phase
- Mixtures – more than one phase

- Solubility Limit:
  Max concentration for which only a single phase solution occurs.

Adapted from Fig. 9.1, *Callister 7e.*

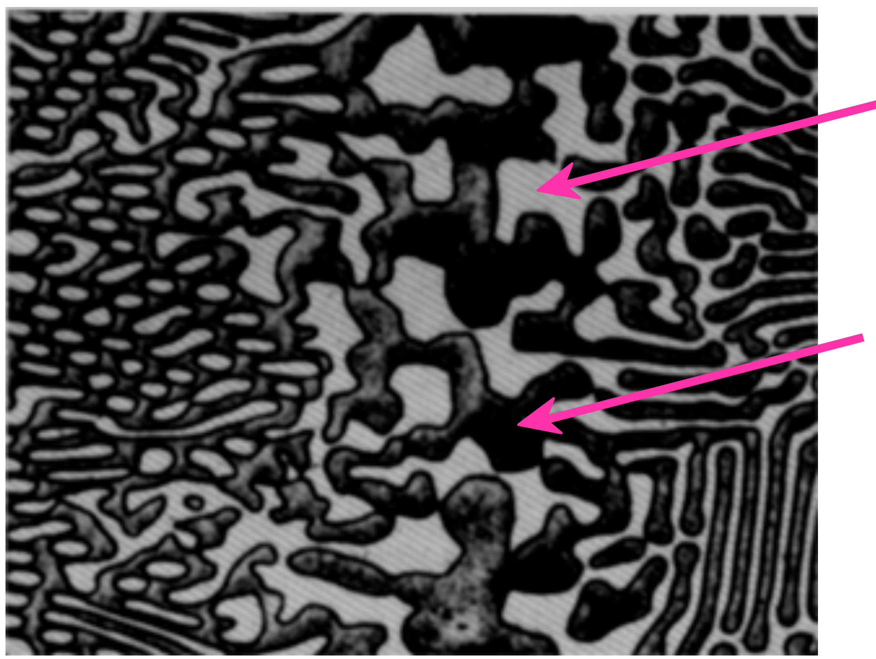
Sucrose/Water Phase Diagram



Components and phases

- Components:
  The elements or compounds which are present in the mixture (e.g., Al and Cu)
- Phases:
  The physically and chemically distinct material regions that result (e.g., α and β).

Aluminum-
Copper
Alloy

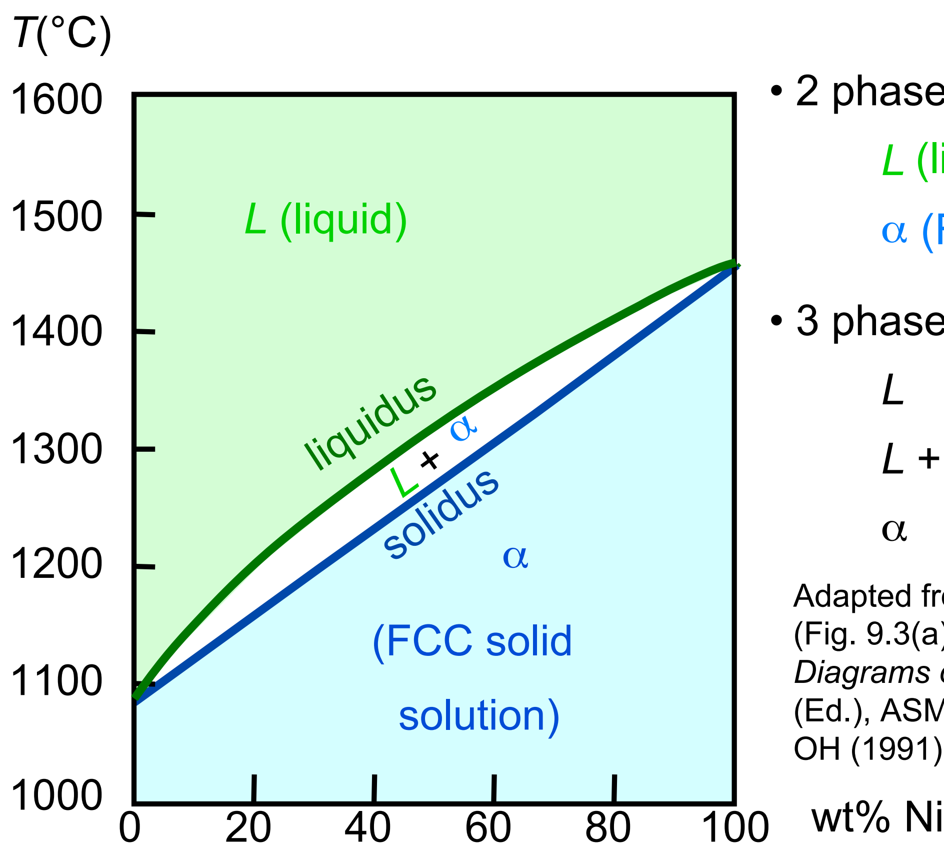


Adapted from chapter-opening photograph, Chapter 9, *Callister 3e.*

Phase diagrams

- Indicate phases as function of *T*, C_o, and *P*.
- For this course:
  - -binary systems: just 2 components.
  - -independent variables: *T* and C_o (*P* = 1 atm is almost always used).

- Phase Diagram for Cu-Ni system



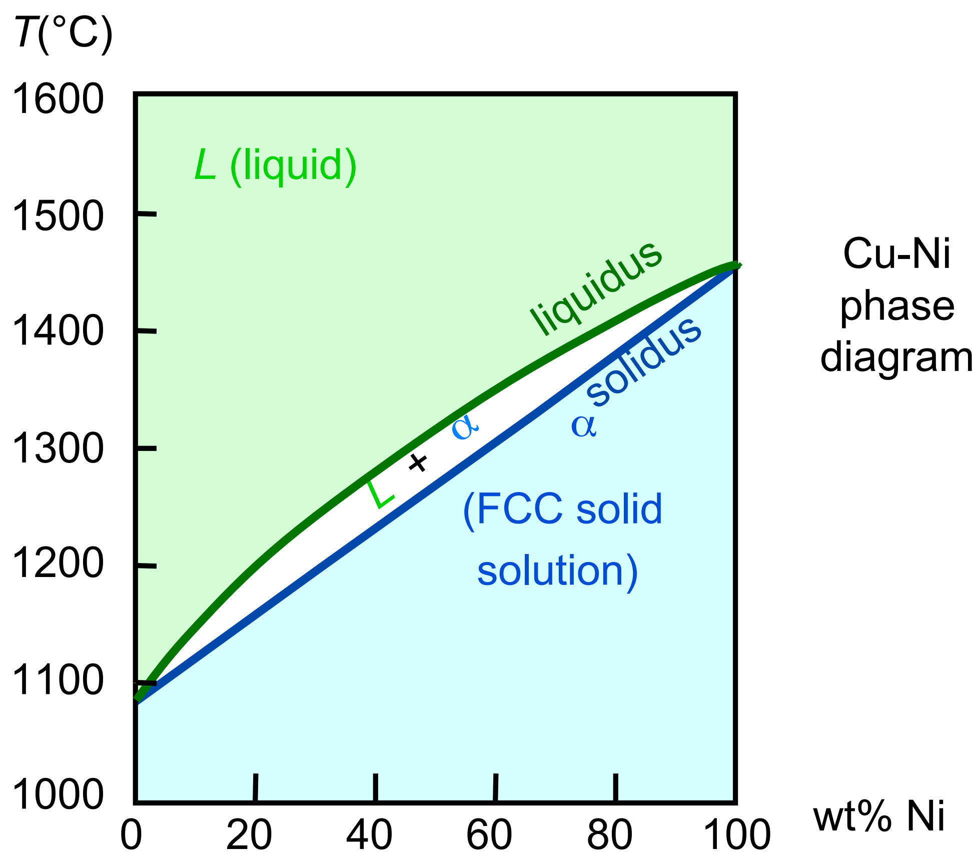
- 2 phases:
  - *L* (liquid)
  - α (FCC solid solution)
- 3 phase fields:
  - *L*
  - *L* + α
  - α

Adapted from Fig. 9.3(a), *Callister 7e.* (Fig. 9.3(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH (1991).

Phase diagrams

- Rule 1: If we know *T* and C_o, then we know:
  --the # and types of phases present.

- Examples:

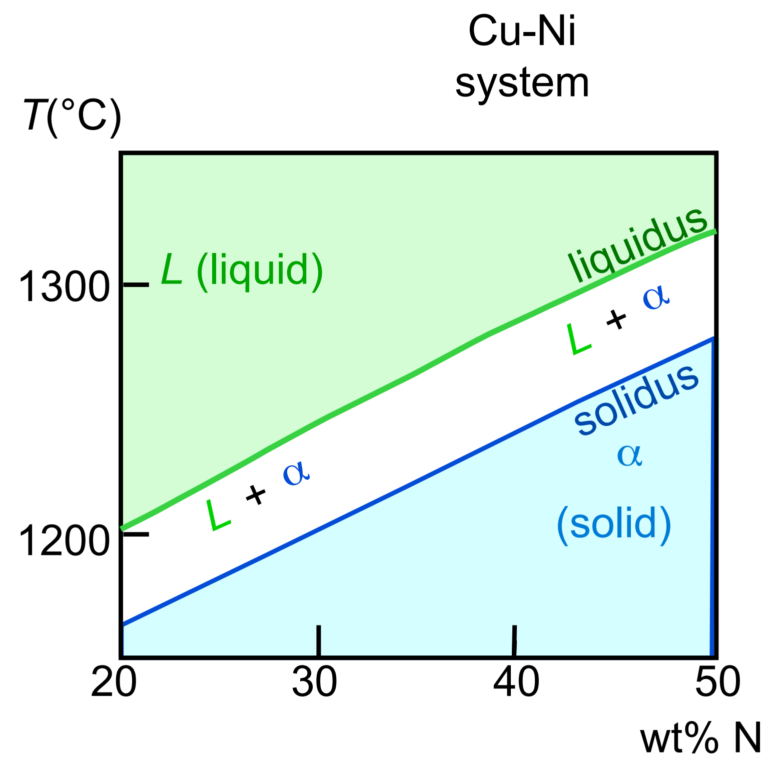


Adapted from Fig. 9.3(a), *Callister 7e.* (Fig. 9.3(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991).

Phase diagrams

- Rule 2: If we know *T* and C_o, then we know:
  --the composition of each phase.

- Examples:



Adapted from Fig. 9.3(b), *Callister 7e.*
(Fig. 9.3(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)

Phase diagrams

- Rule 3: If we know T and C_o, then we know:
  --the amount of each phase (given in wt%).

- Examples:

C_o = 35 wt% Ni

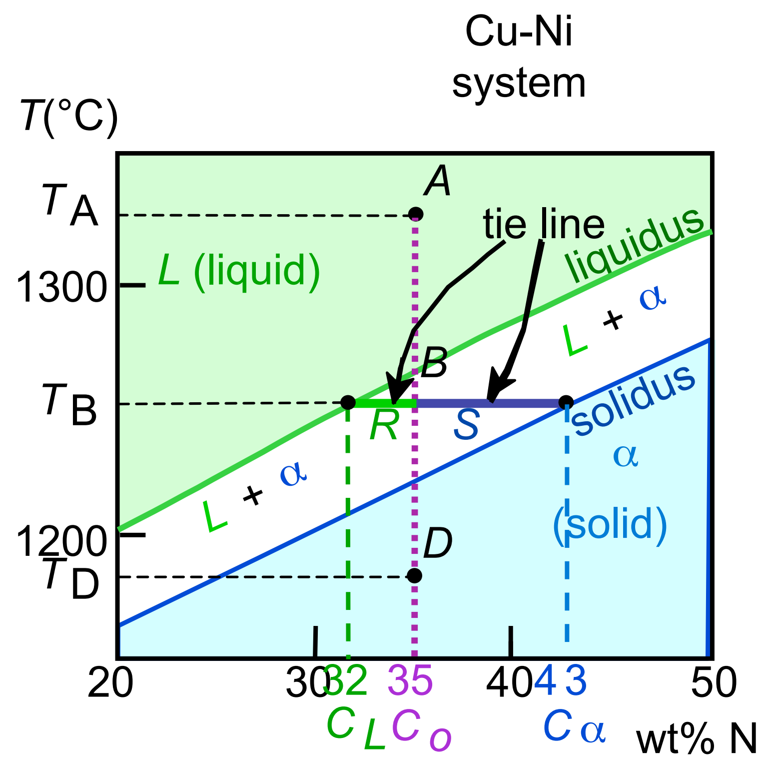
At T_A: Only Liquid (L)

W_L = 100 wt%, W_α = 0

At T_D: Only Solid (α)

W_L = 0, W_α = 100 wt%

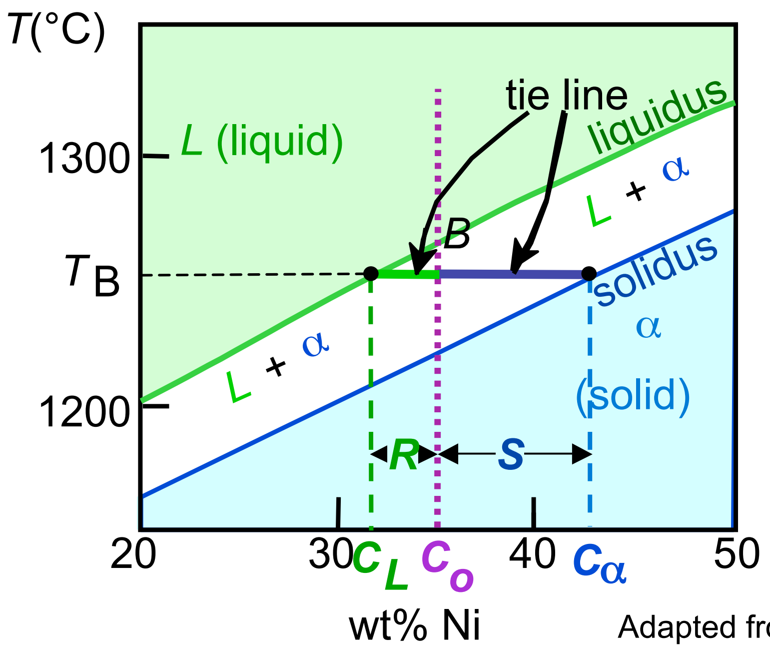
At T_B: Both α and L



Adapted from Fig. 9.3(b), *Callister 7e.*
(Fig. 9.3(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)

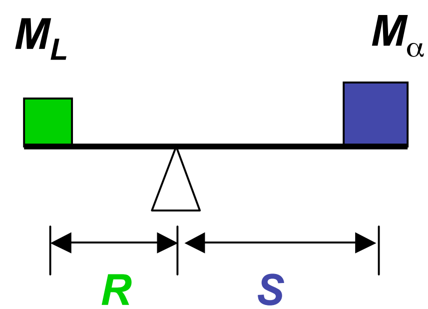
The lever rule

Tie line – connects the phases in equilibrium with each other - essentially an isotherm



Adapted from Fig. 9.3(b), *Callister 7e.*

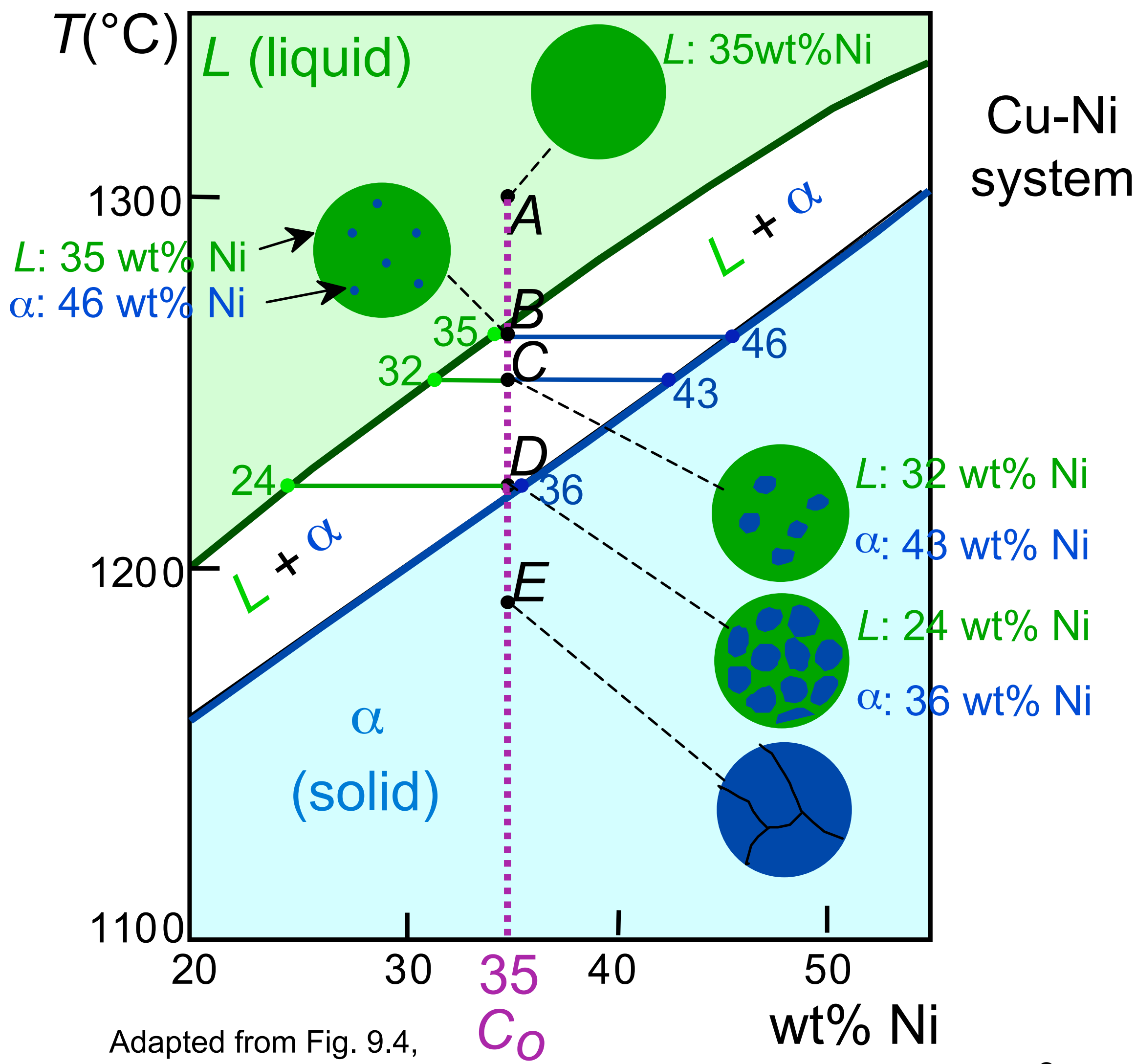
How much of each phase?
Think of it as a lever (teeter-totter)



$$M_\alpha \cdot S = M_L \cdot R$$

Cooling

- Phase diagram:
  Cu-Ni system.
- System is:
  --binary
  i.e., 2 components: Cu and Ni.
  --isomorphous
  i.e., complete solubility of one component in another; α phase field extends from 0 to 100 wt% Ni.
- Consider
  C_o = 35 wt%Ni.



Adapted from Fig. 9.4, *Callister 7e.*

Binary eutectic systems

2 components

has a special composition with a min. melting T.

Ex.: Cu-Ag system

- 3 single phase regions

  (L, α, β)

- Limited solubility:

  α : mostly Cu

  β : mostly Ag

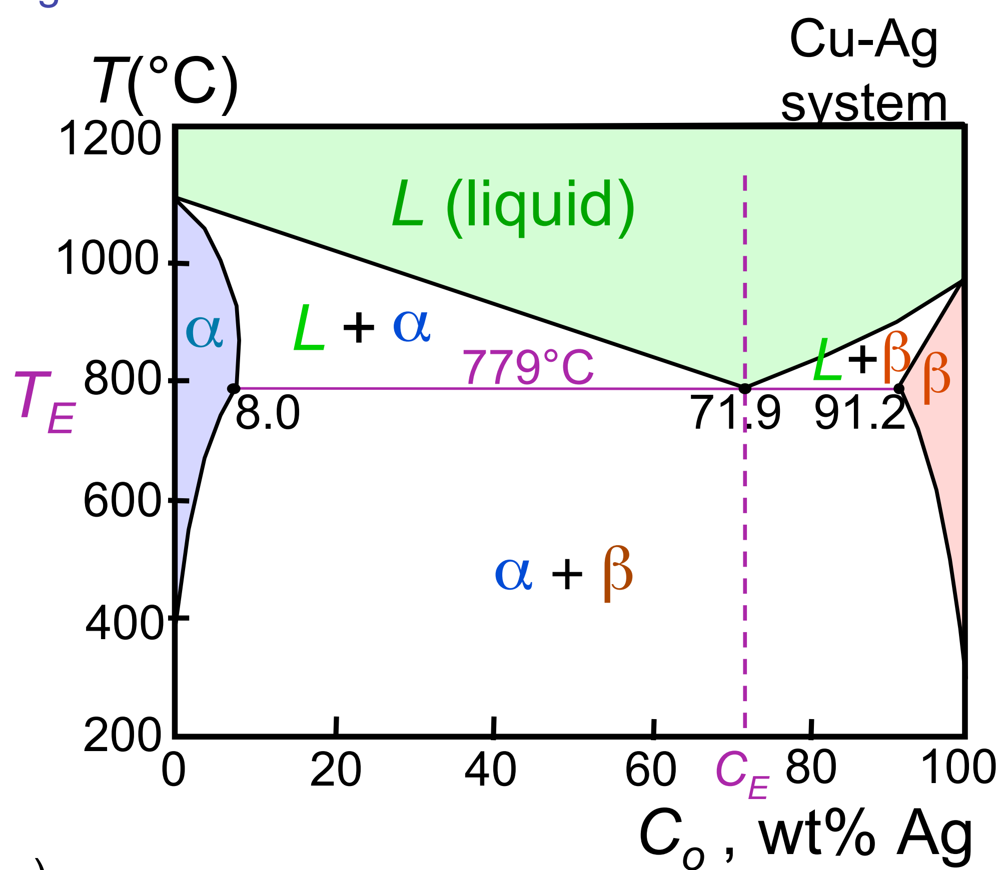
- T_E : No liquid below T_E

- C_E : Min. melting T_E

  composition

- **Eutectic transition**

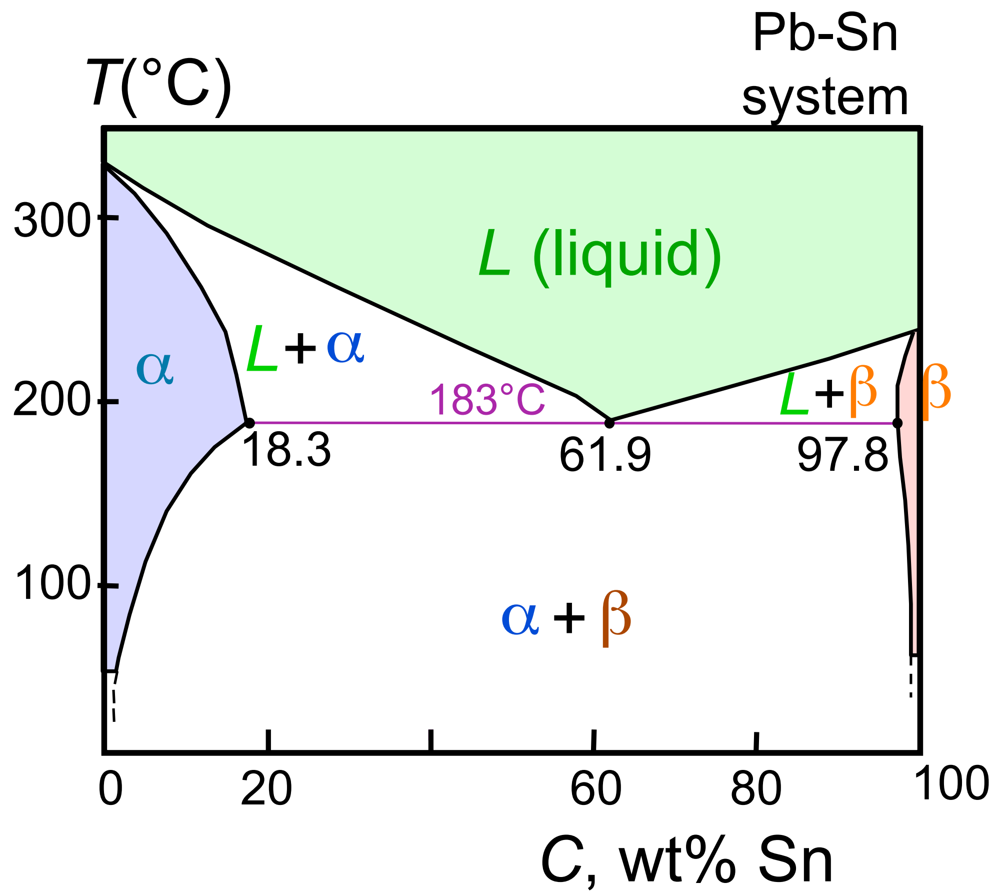
$$L(C_E) \rightleftharpoons \alpha(C_{\alpha E}) + \beta(C_{\beta E})$$



Adapted from Fig. 9.7, *Callister 7e.*

Binary eutectic systems

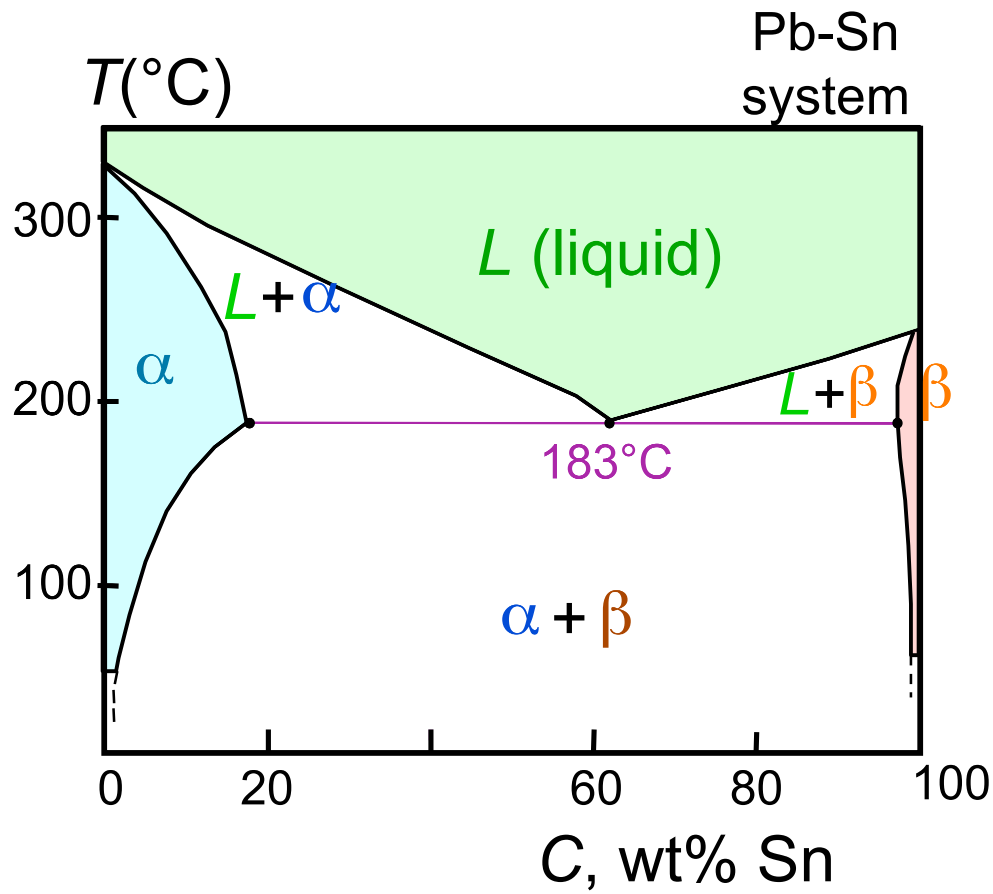
- For a 40 wt% Sn-60 wt% Pb alloy at 150°C, find...
  --the phases present:



Adapted from Fig. 9.8, *Callister 7e.*

Binary eutectic systems

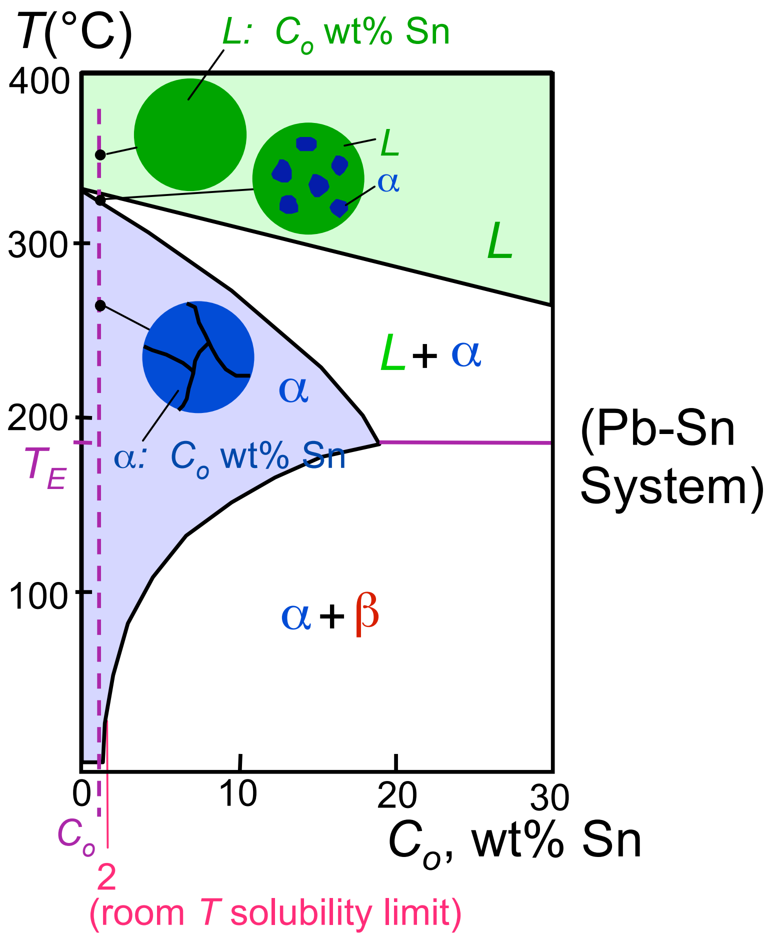
- For a 40 wt% Sn-60 wt% Pb alloy at 200°C, find...
  --the phases present:



Adapted from Fig. 9.8, *Callister 7e.*

Microstructures in eutectic systems

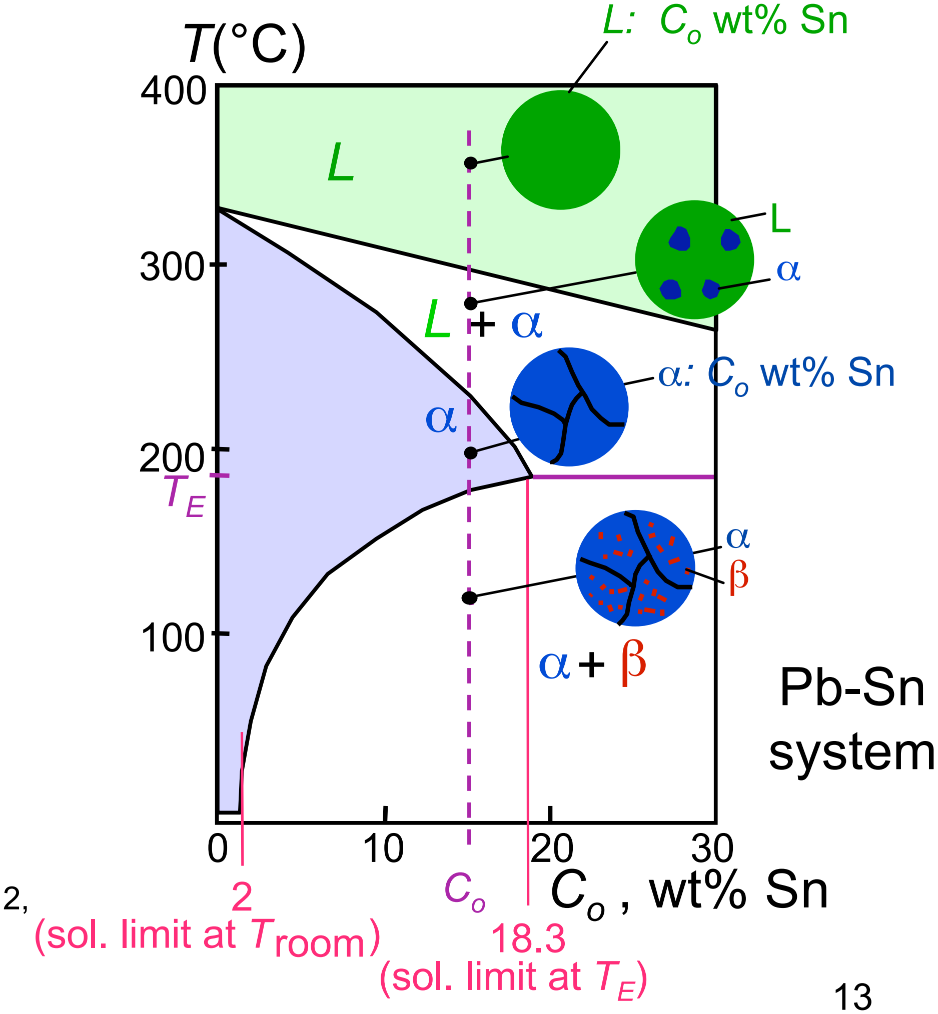
- C_o < 2 wt% Sn
- Result:
  --at extreme ends
  --polycrystal of α grains
  i.e., only one solid phase.



Adapted from Fig. 9.11, *Callister 7e.*

Microstructures in eutectic systems

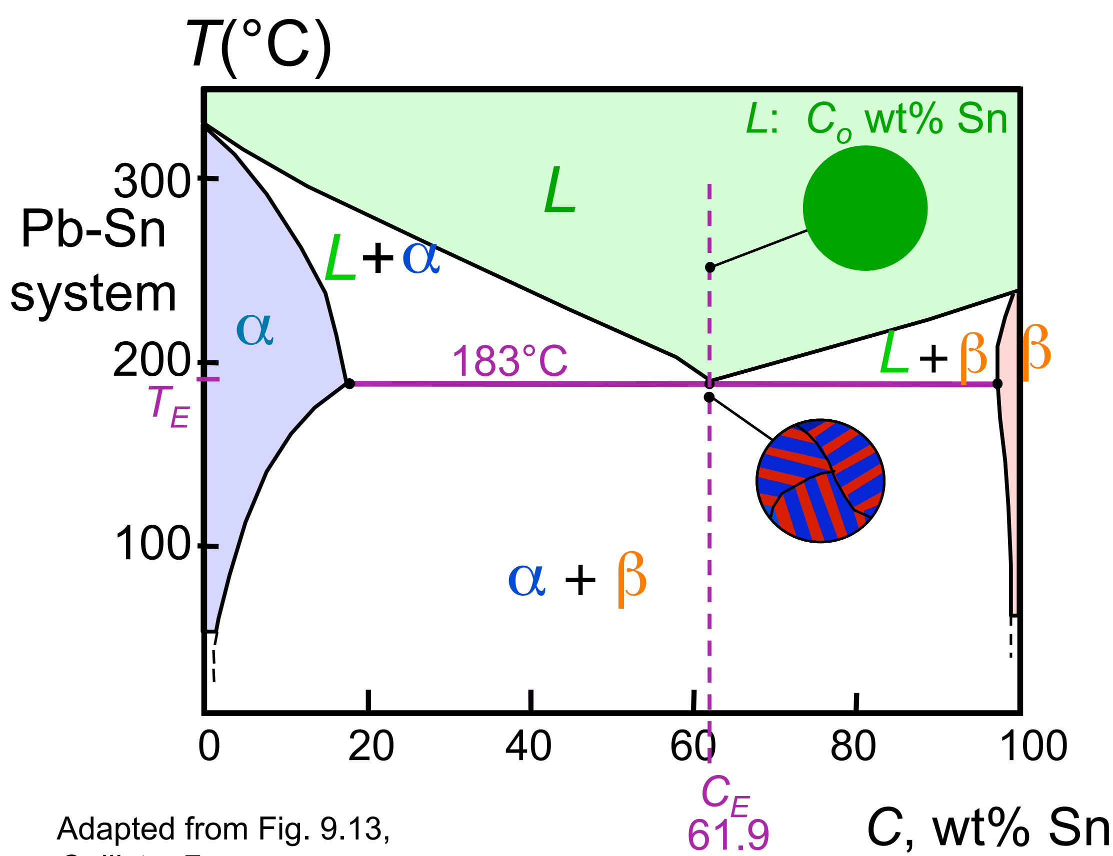
- 2 wt% Sn < C_o < 18.3 wt% Sn
- Result:
  - Initially liquid + α
  - then α alone
  - finally two phases
    - α polycrystal
    - fine β-phase inclusions



Adapted from Fig. 9.12, *Callister 7e.*

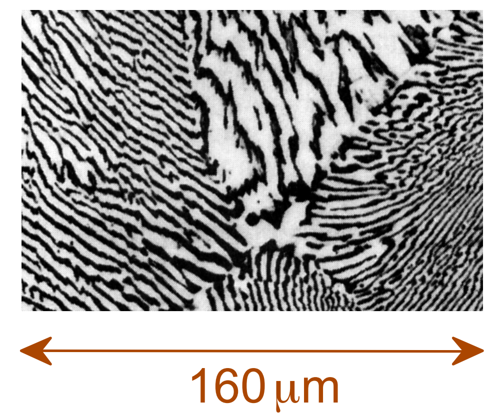
Microstructures in eutectic systems

- $C_o = C_E$
- Result: Eutectic microstructure (lamellar structure)
  --alternating layers (lamellae) of α and β crystals.



Adapted from Fig. 9.13, *Callister 7e.*

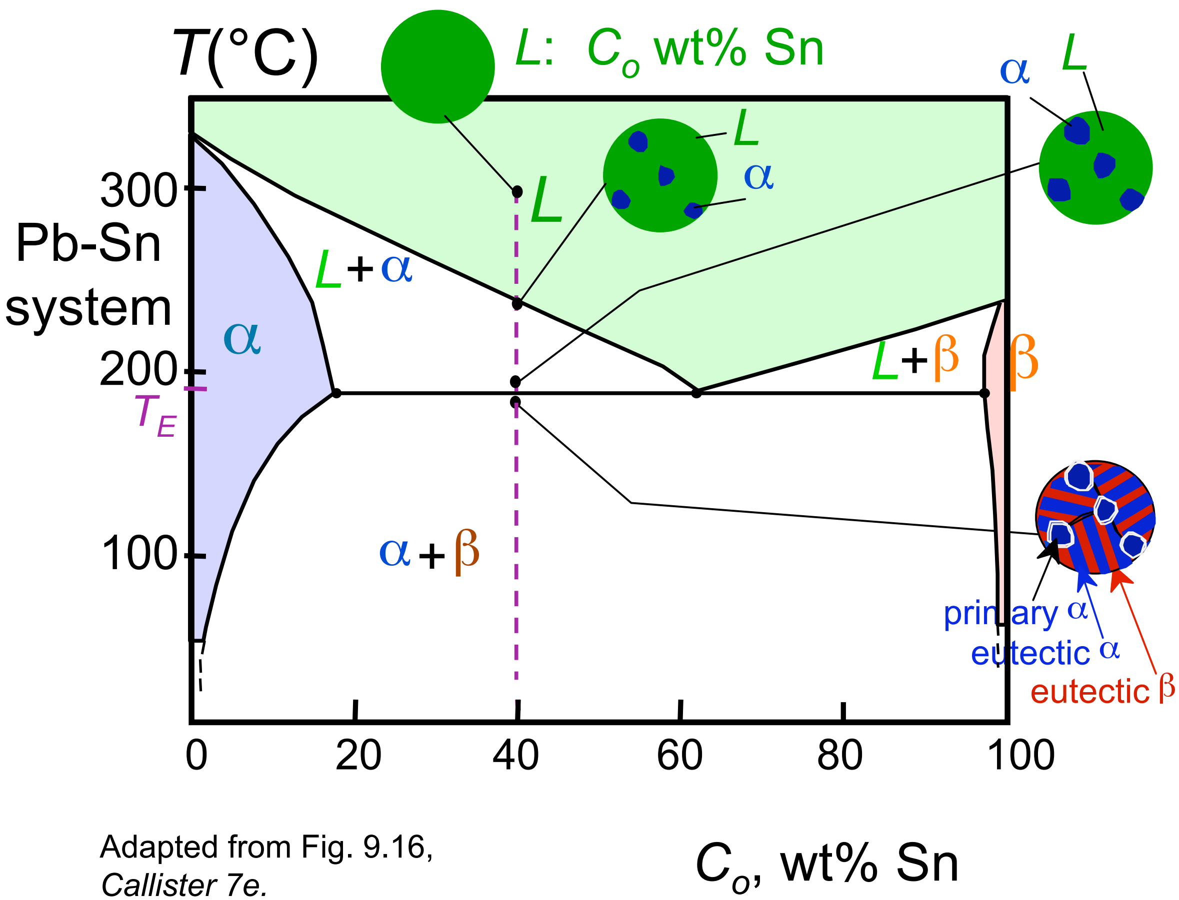
Micrograph of Pb-Sn eutectic microstructure



Adapted from Fig. 9.14, *Callister 7e.*

Microstructures in eutectic systems

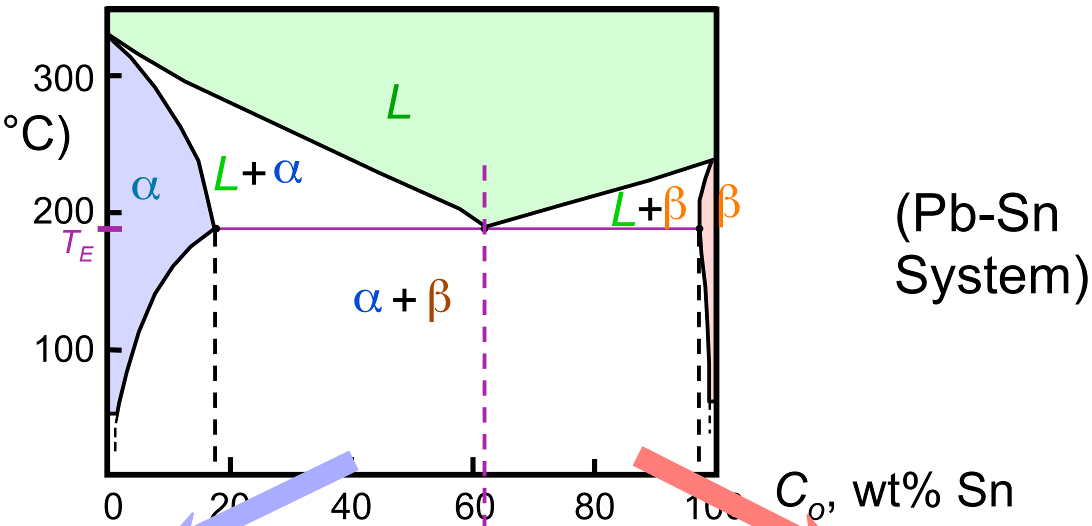
- 18.3 wt% Sn < C_o < 61.9 wt% Sn
- Result: α crystals and a eutectic microstructure



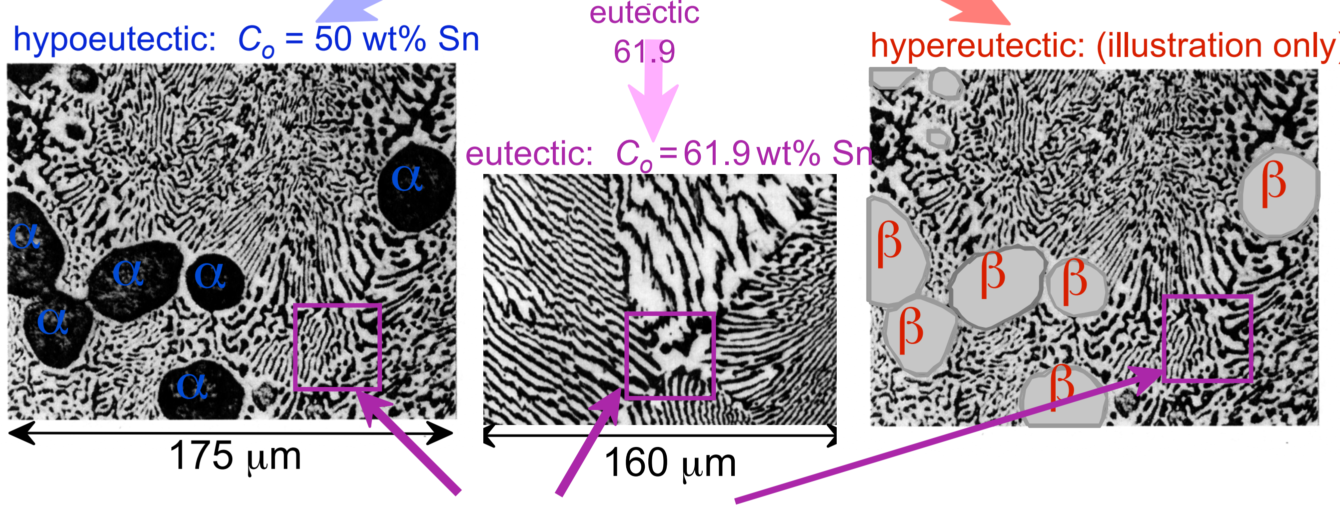
Adapted from Fig. 9.16, *Callister 7e.*

Hypoeutectic & hypereutectic

Adapted from Fig. 9.8, *Callister 7e.* (Fig. 9.8 adapted from *Binary Phase Diagrams*, 2nd ed., Vol. 3, T.B. Massalski (Editor-in-Chief), ASM International, Materials Park, OH, 1990.)



(Figs. 9.14 and 9.17 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

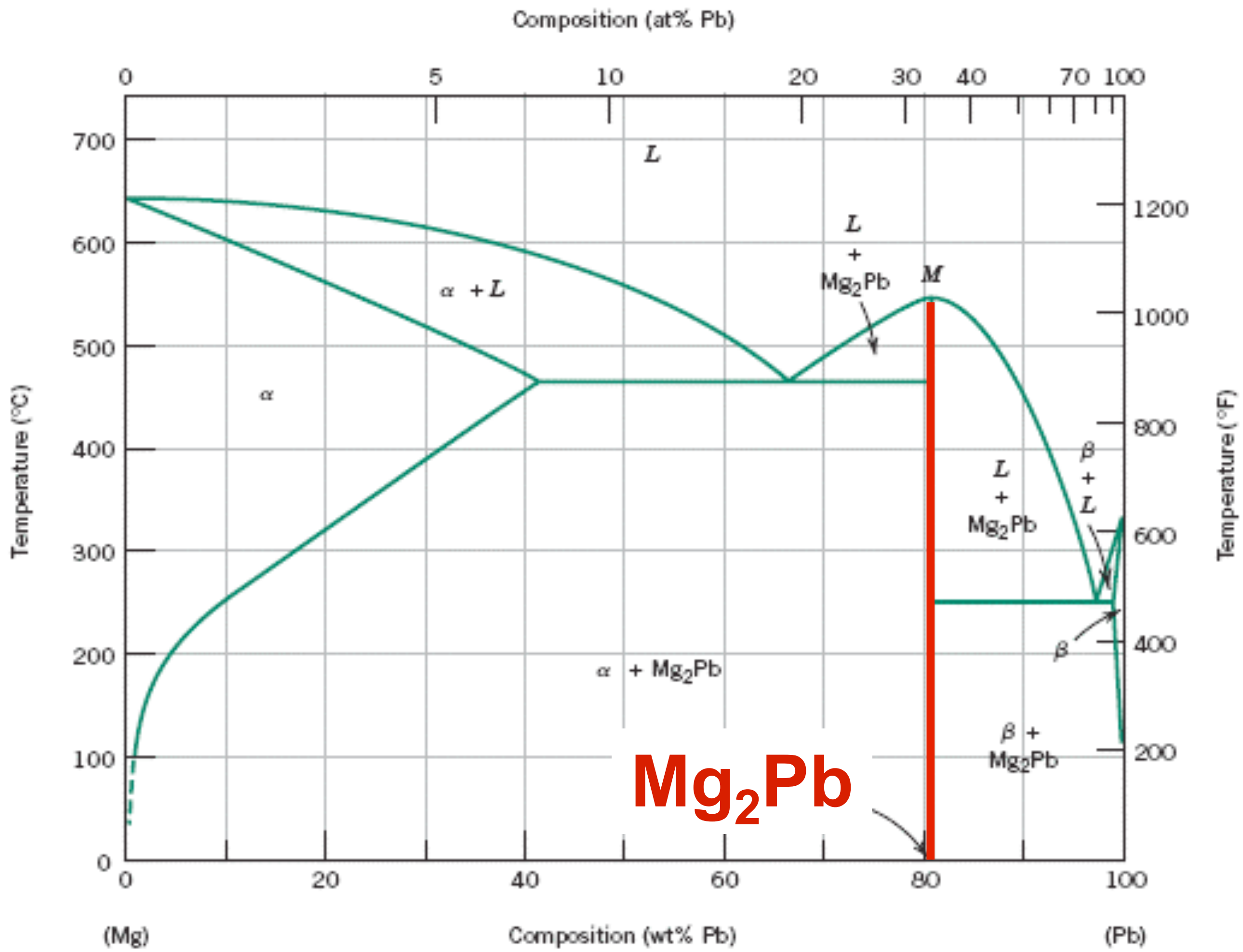


Adapted from Fig. 9.17, *Callister 7e.*

Adapted from Fig. 9.14, *Callister 7e.*

Adapted from Fig. 9.17, *Callister 7e.* (Illustration only)

Intermetallic compounds

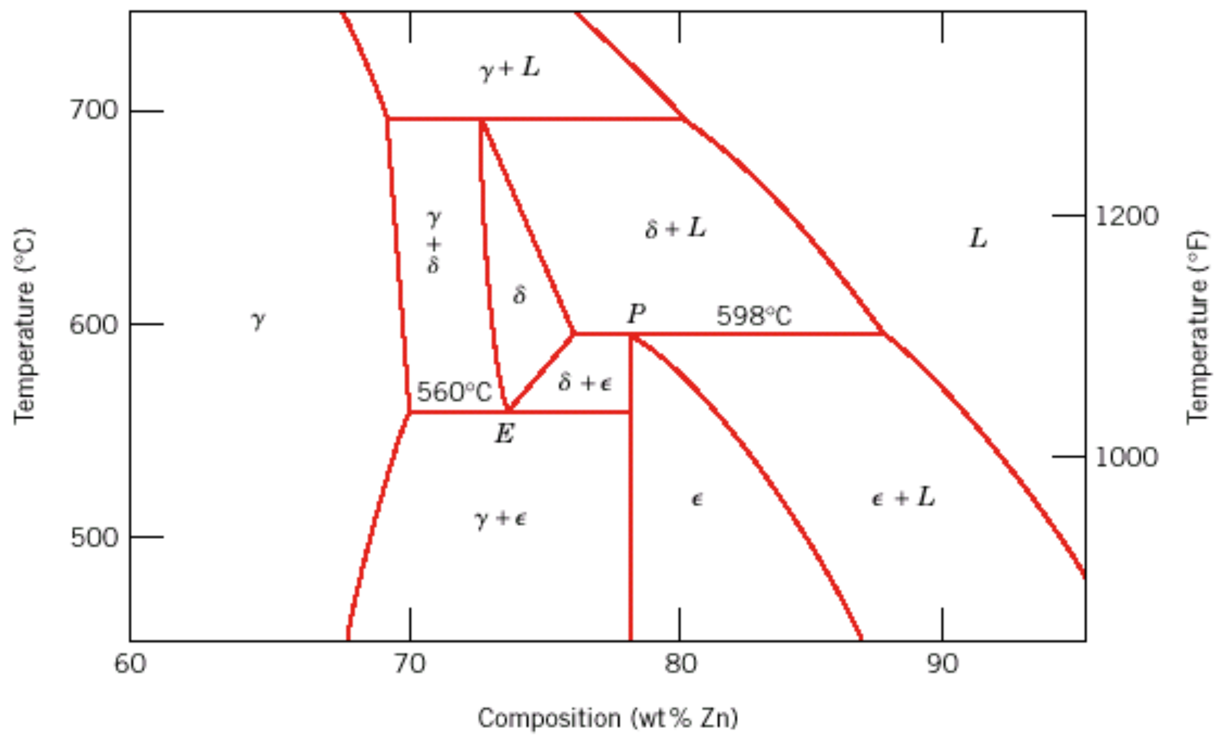


Adapted from Fig. 9.20, *Callister 7e.*

Note: intermetallic compound forms a line - not an area - because stoichiometry (i.e. composition) is exact.

Peritectic & eutectoid

- Cu-Zn Phase diagram



Adapted from
Fig. 9.21, *Callister 7e.*

Fe-C phase diagram

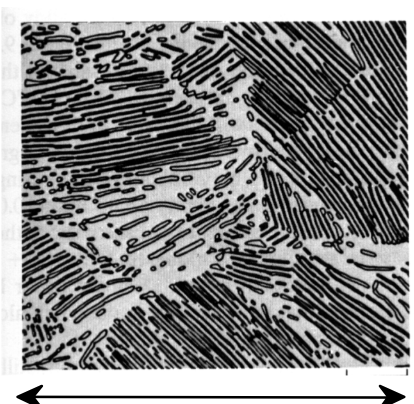
- 2 important points

-Eutectic (*A*):

$L \Rightarrow \gamma + Fe_3C$

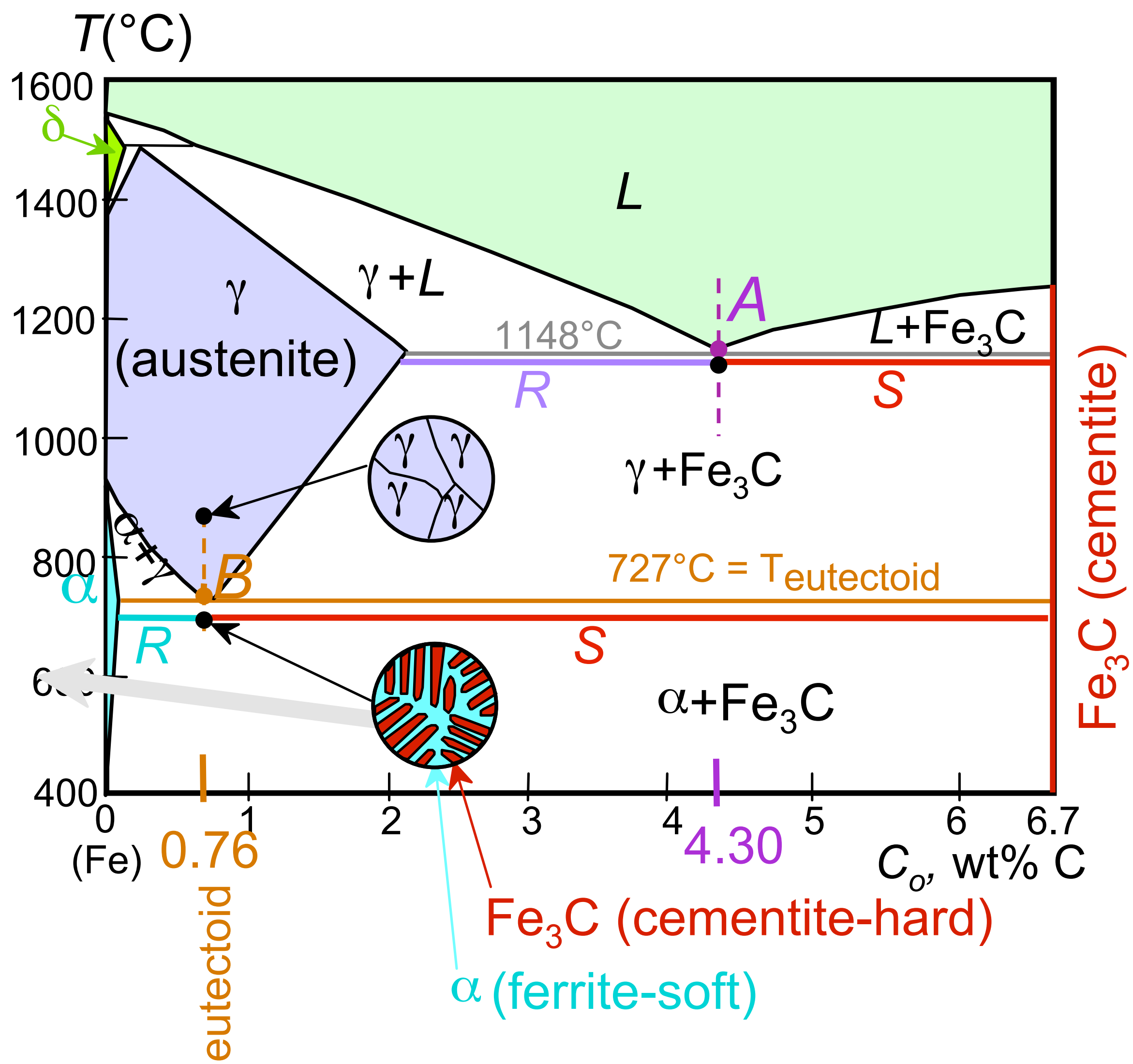
-Eutectoid (*B*):

$\gamma \Rightarrow \alpha + Fe_3C$



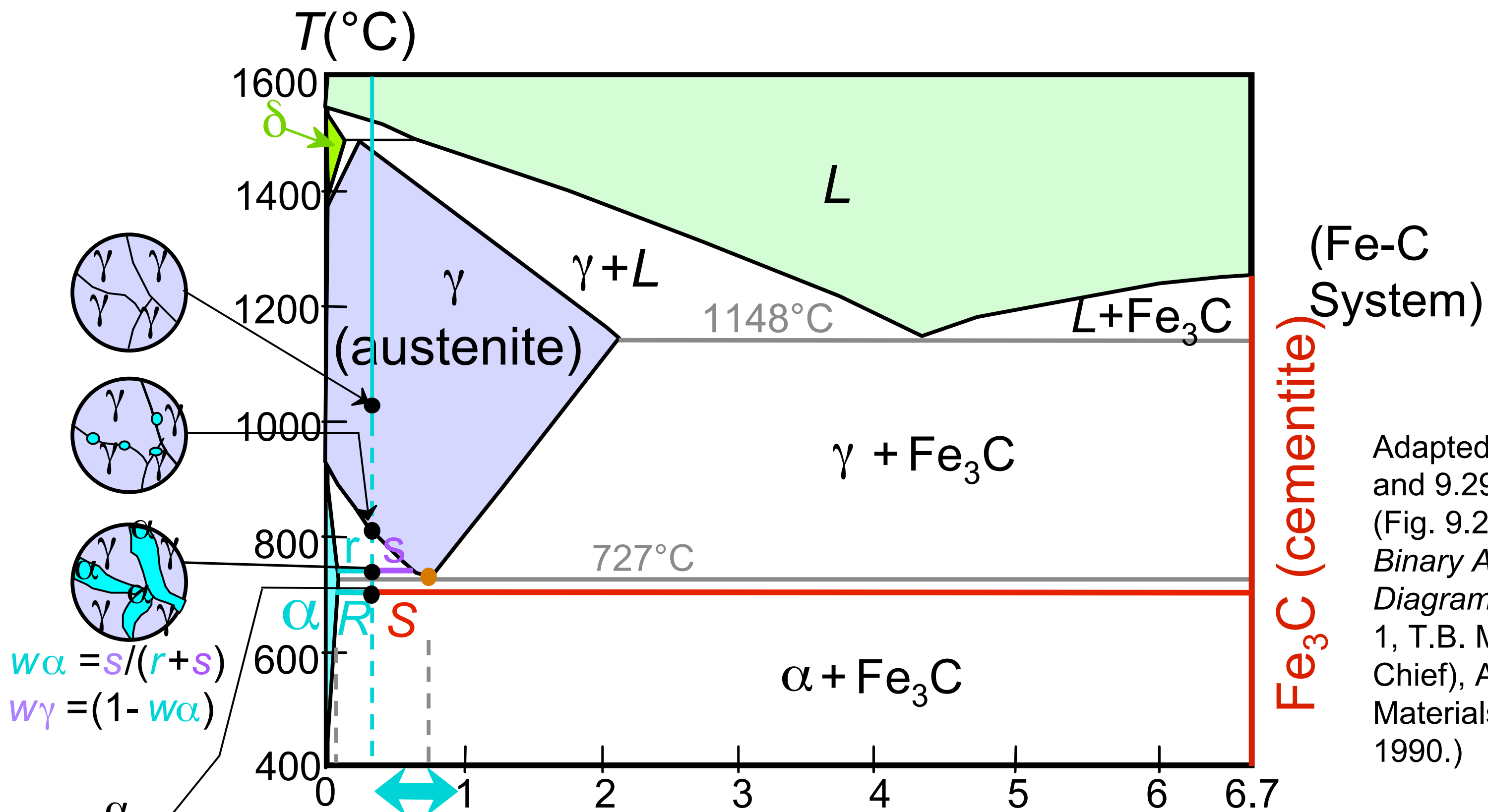
Result: Pearlite = alternating layers of α and Fe_3C phases

(Adapted from Fig. 9.27, *Callister 7e.*)

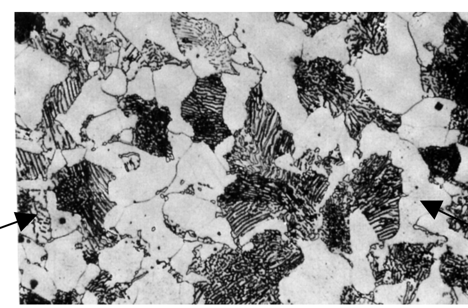


Adapted from Fig. 9.24, *Callister 7e*.

Hypoeutectoid steel

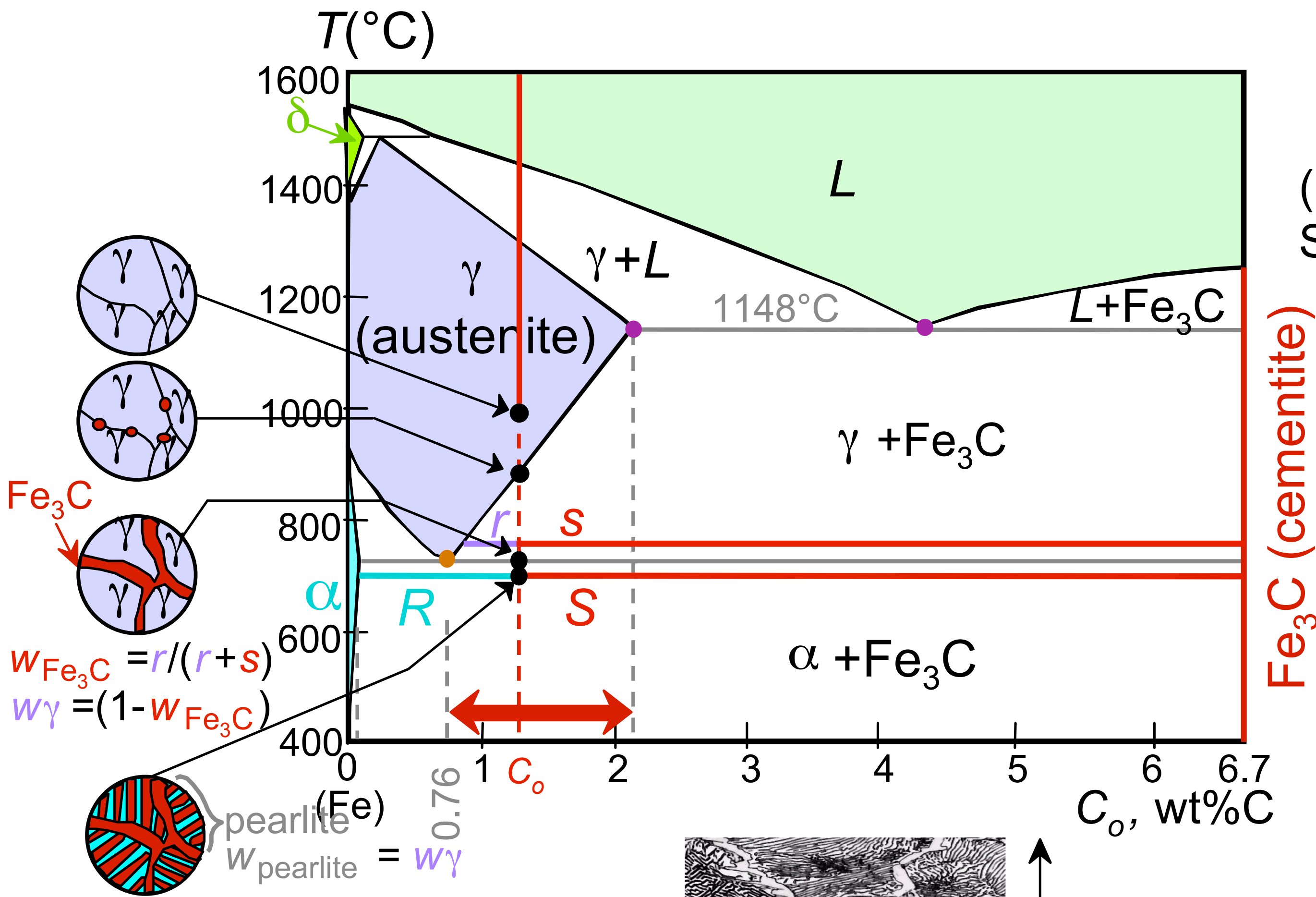


Adapted from Figs. 9.24 and 9.29, *Callister 7e*. (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)



Adapted from Fig. 9.30, *Callister 7e*.

Hypereutectoid steel



$w_{Fe_3C} = r/(r+s)$

$w_\gamma = (1 - w_{Fe_3C})$

$w_{pearlite} = w_\gamma$

$w_\alpha = S/(R+S)$

$w_{Fe_3C} = (1 - w_\alpha)$

Adapted from Figs. 9.24 and 9.32, *Callister 7e*. (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)

Adapted from Fig. 9.33, *Callister 7e*.