Announcements

- About half of the quizzes (WebCT#2) are graded.
- Today, we have a ***DEMO!***

Phase Equilibria

Simple solution system (e.g., Ni-Cu solution)

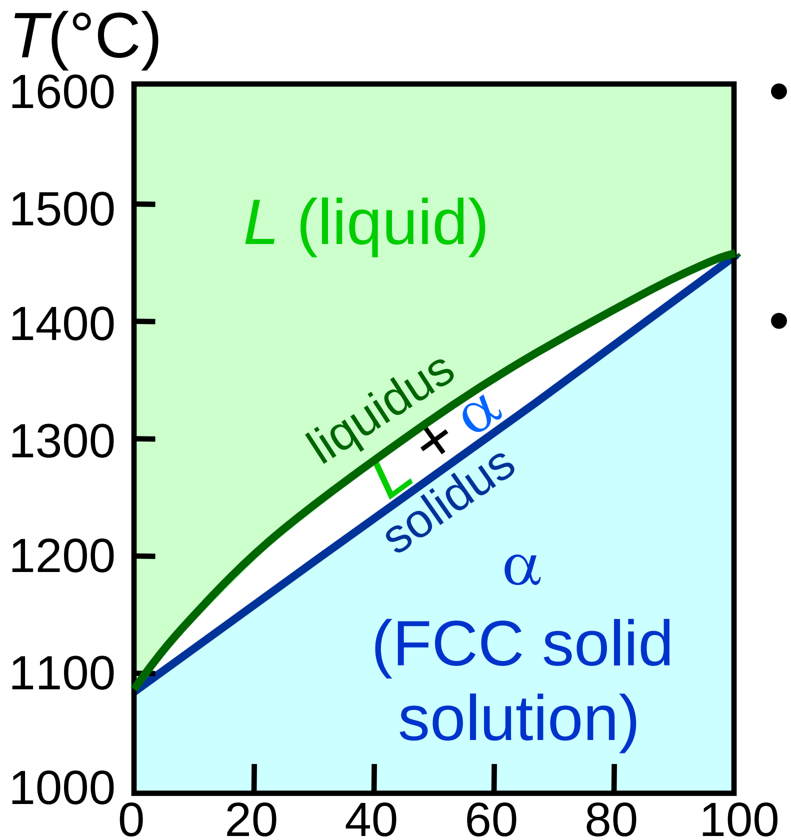
	Crystal Structure	electroneg	*r* (nm)	Valence
Ni	FCC	1.9	0.1246	2+
Cu	FCC	1.8	0.1278	1+

- Both have the same crystal structure (FCC) and have similar electronegativities and atomic radii (W. Hume – Rothery rules) suggesting high mutual solubility.
- Ni and Cu are totally miscible in all proportions.

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).

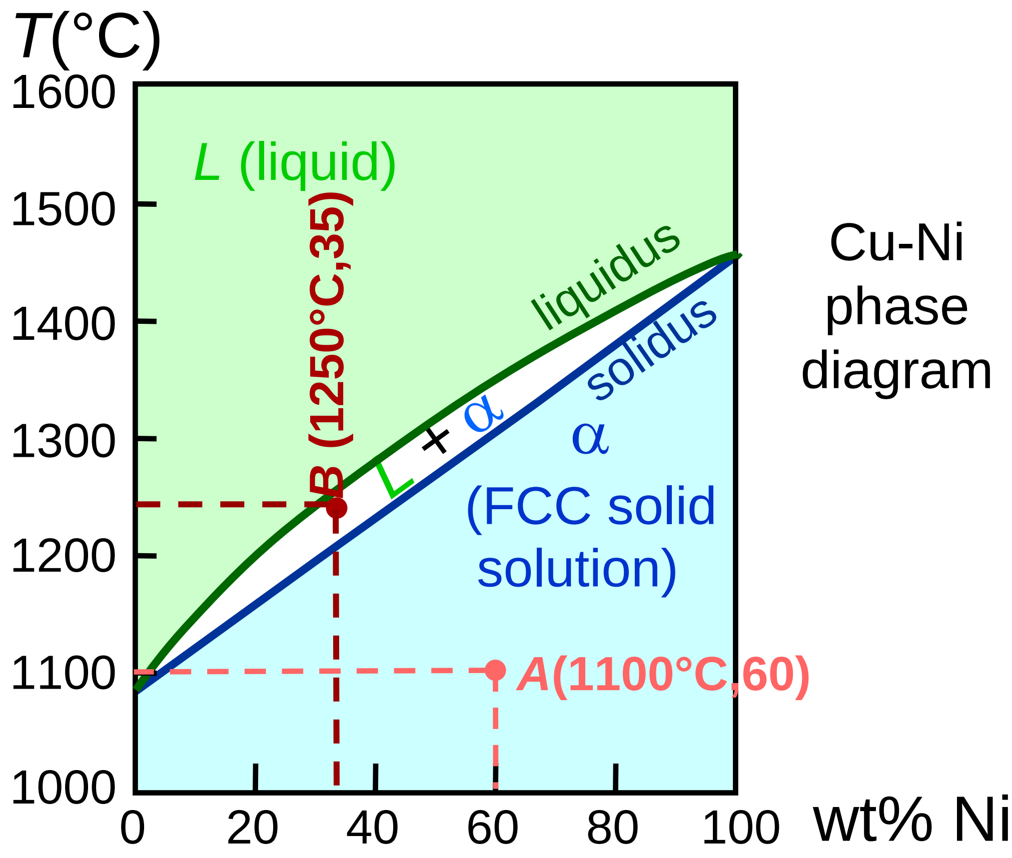
Phase Diagrams:
and types of phases

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

- Examples:

  A(1100°C, 60):
  1 phase: α

  B(1250°C, 35):
  2 phases: *L* + 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:
composition of phases

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

- Examples:

  C_o = 35 wt% Ni

  At T_A = 1320°C:

  Only Liquid (L)

  $C_L = C_o$ (= 35 wt% Ni)

  At T_D = 1190°C:

  Only Solid (α)

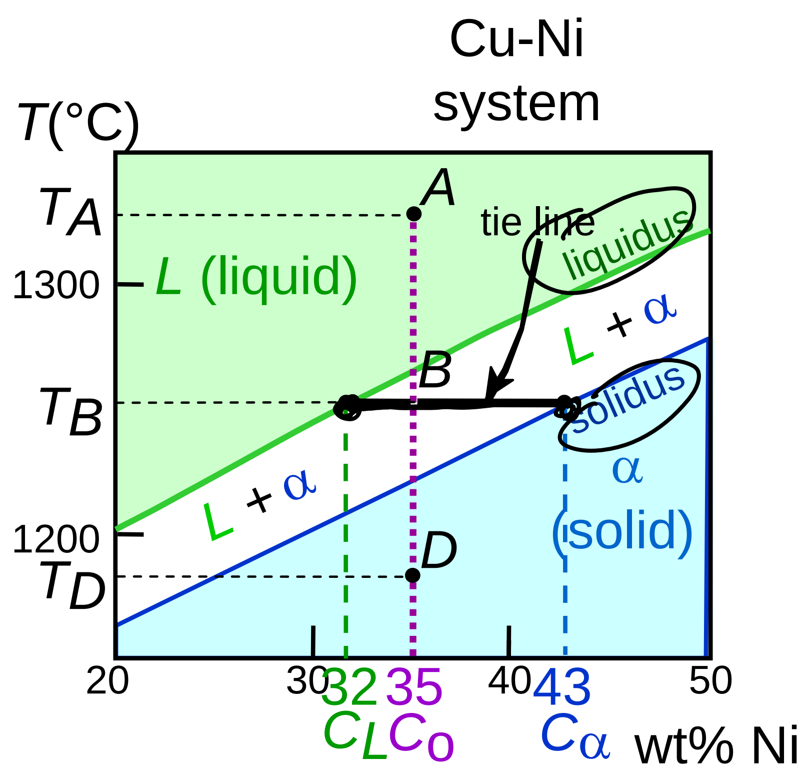
  $C_\alpha = C_o$ (= 35 wt% Ni)

  At T_B = 1250°C:

  Both α and L

  $C_L = C_{liquidus}$ (= 32 wt% Ni here)

  $C_\alpha = C_{solidus}$ (= 43 wt% Ni here)



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:
weight fractions of phases

Lever Rule

- 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

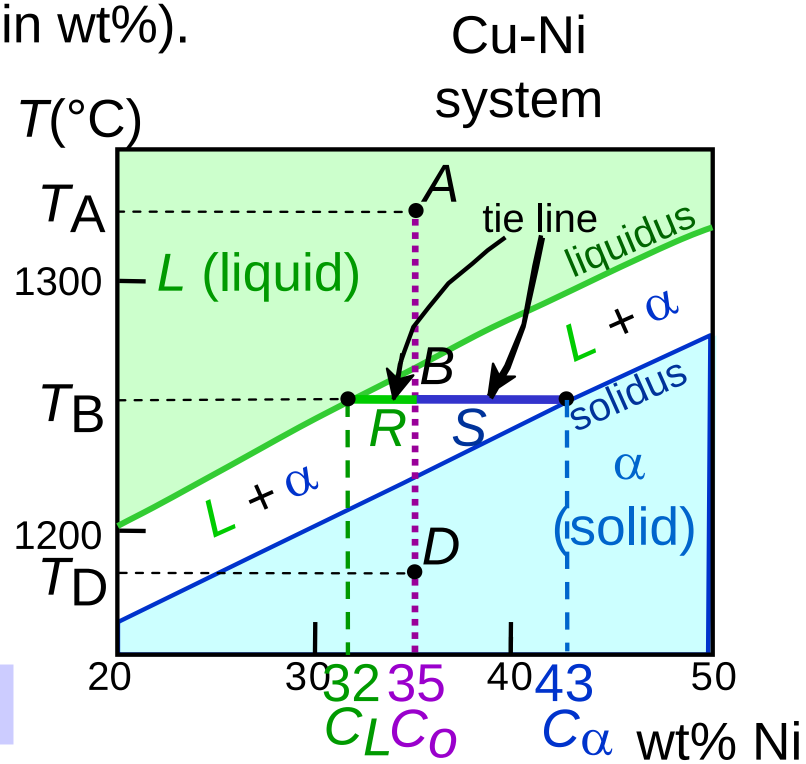
At T_D: Only Solid (α)

W_L = 0, W_α = 100 wt%

At T_B: Both α and L

$$W_L = \frac{S}{R+S} = \frac{43-35}{43-32} = 73\,wt\%$$

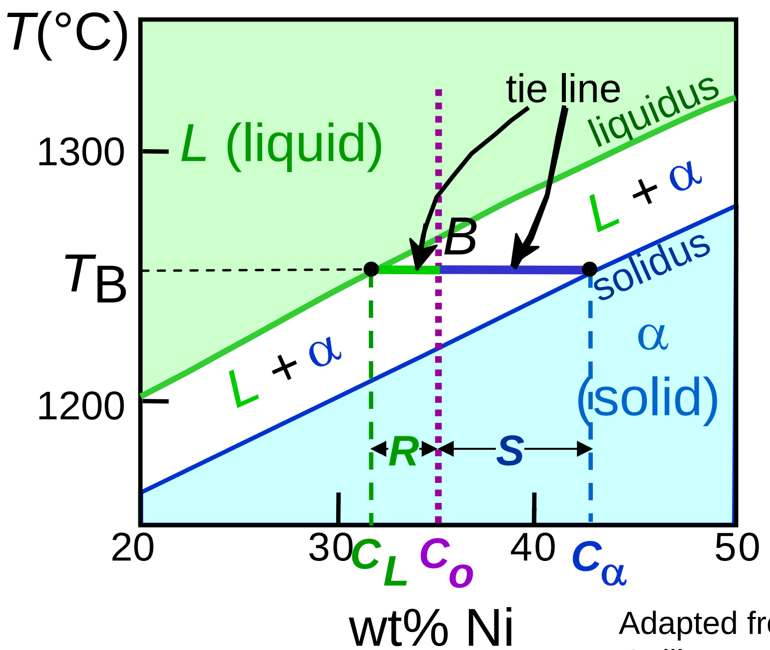
$$W_\alpha = \frac{R}{R+S} = 27\text{ wt\%}$$



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

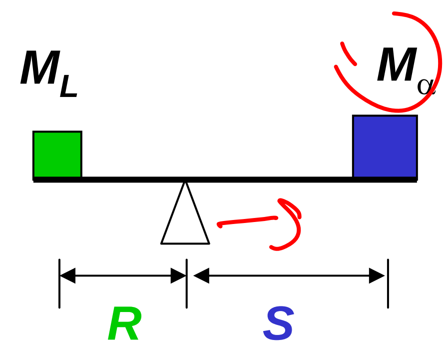
- Tie line – connects the phases in equilibrium with each other - essentially an isotherm



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

How much of each phase?

Think of it as a lever (teeter-totter)



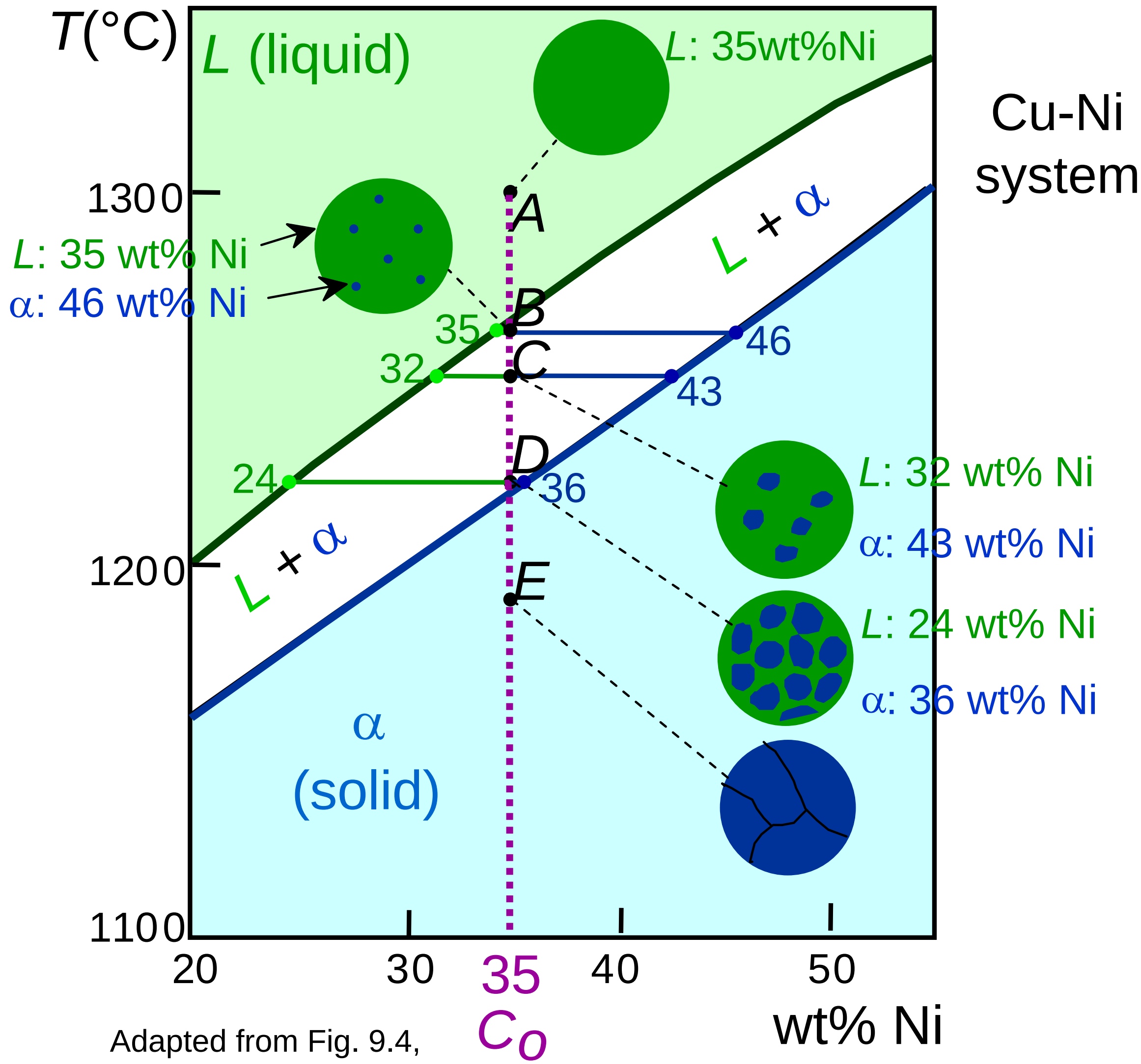
$$M_\alpha \cdot S = M_L \cdot R$$

$$W_L = \frac{M_L}{M_L + M_\alpha} = \frac{S}{R+S} = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

$$W_\alpha = \frac{R}{R+S} = \frac{C_0 - C_L}{C_\alpha - C_L}$$

Ex: Cooling in a Cu-Ni Binary

- 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

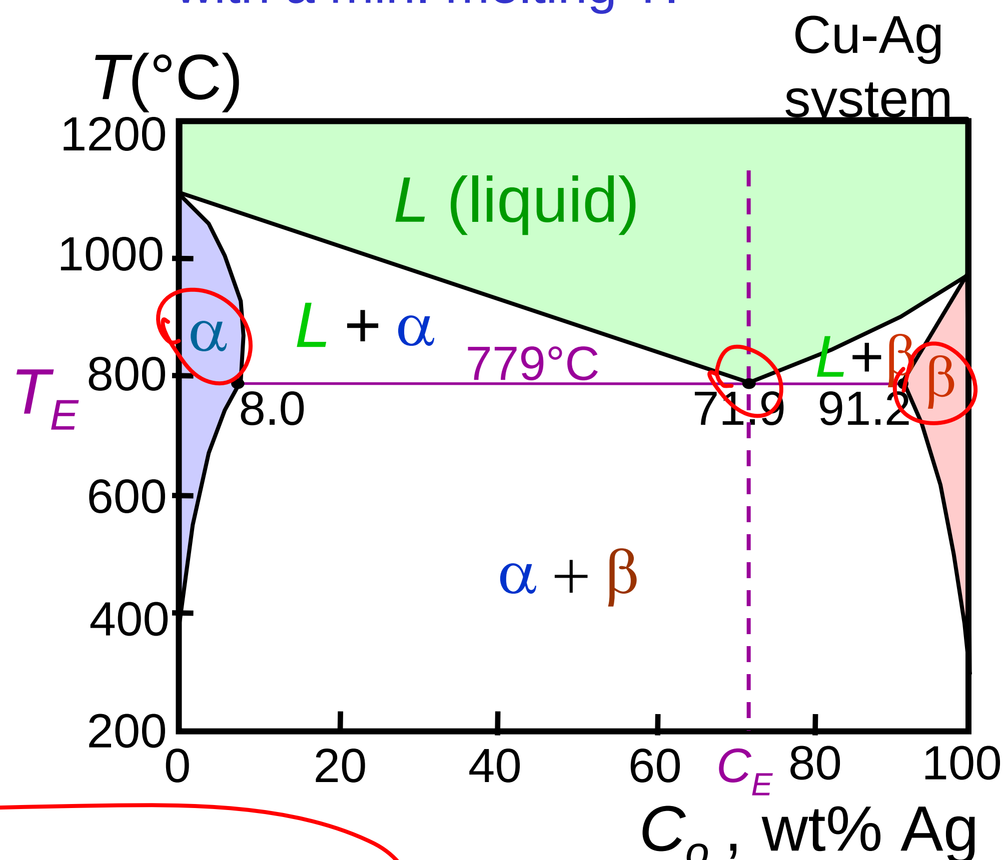
PbSn

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



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

- **Eutectic transition**

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

EX: Pb-Sn Eutectic System (1)

- For a 40 wt% Sn-60 wt% Pb alloy at 150°C, find...
  - --the phases present: $\alpha + \beta$
  - --compositions of phases:

    C_O = 40 wt% Sn

    C_α = 11 wt% Sn

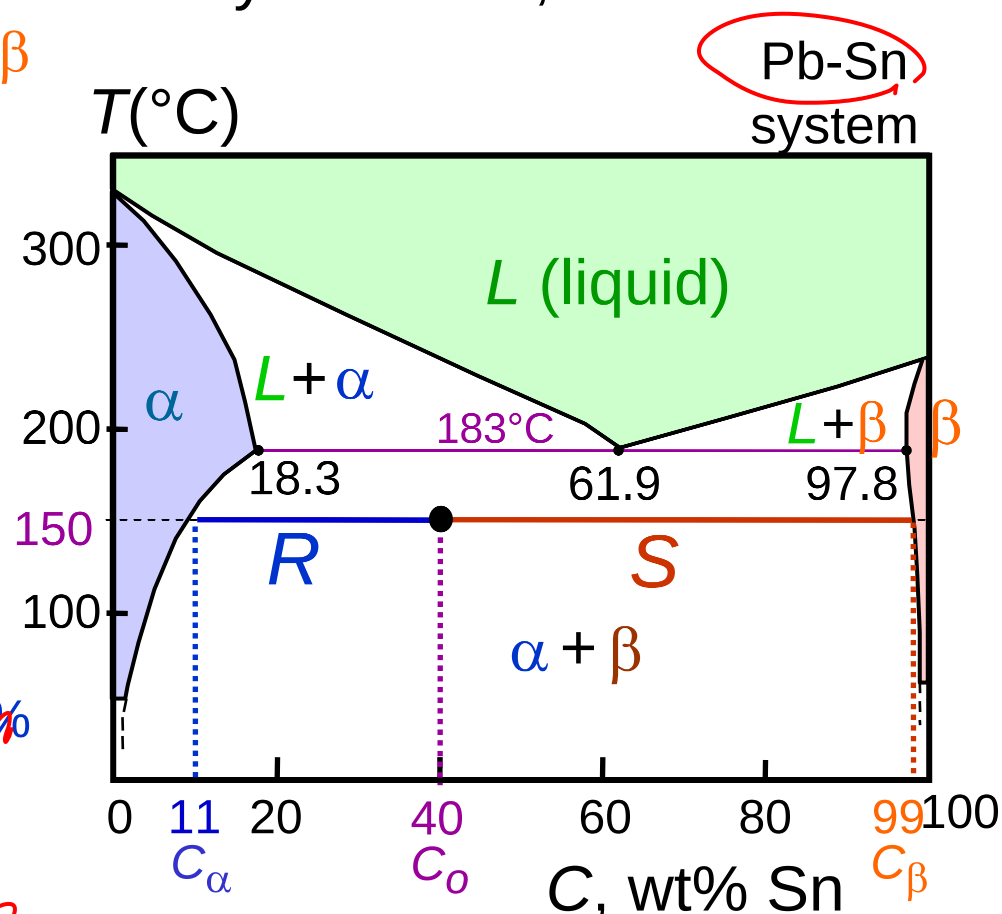
    C_β = 99 wt% Sn
  - --the relative amount of each phase:

$$W_\alpha = \frac{S}{R+S} = \frac{C_\beta - C_O}{C_\beta - C_\alpha} = \frac{99-40}{99-11} = \frac{59}{88} = 67 \text{ wt\%}$$

0.67

$$W_\beta = \frac{R}{R+S} = \frac{C_O - C_\alpha}{C_\beta - C_\alpha} = \frac{40-11}{99-11} = \frac{29}{88} = 33 \text{ wt\%}$$

0.33



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

0.67 × (11) + 0.33 (99)

EX: Pb-Sn Eutectic System (2)

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

  --the phases present: α + L

  --compositions of phases:

  C_O = 40 wt% Sn

  C_α = 17 wt% Sn

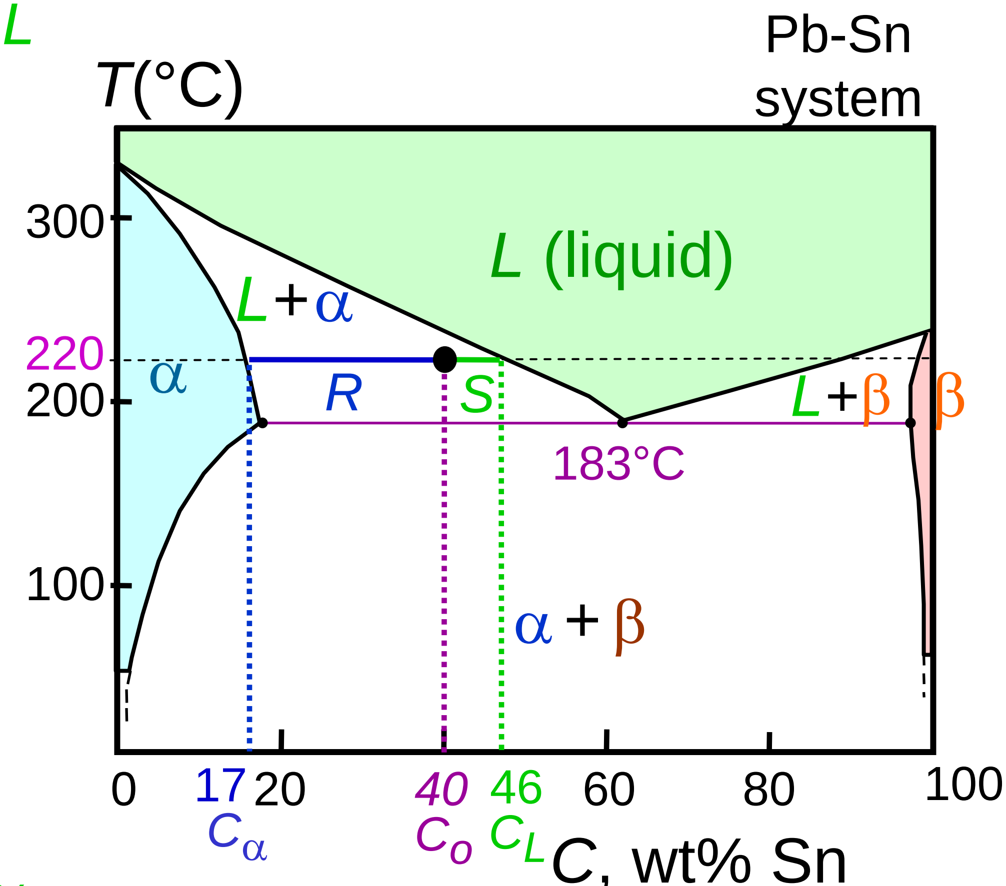
  C_L = 46 wt% Sn

  --the relative amount of each phase:

$$W_\alpha = \frac{C_L - C_O}{C_L - C_\alpha} = \frac{46 - 40}{46 - 17}$$

$$= \frac{6}{29} = 21 \text{ wt\%}$$

$$W_L = \frac{C_O - C_\alpha}{C_L - C_\alpha} = \frac{23}{29} = 79 \text{ wt\%}$$



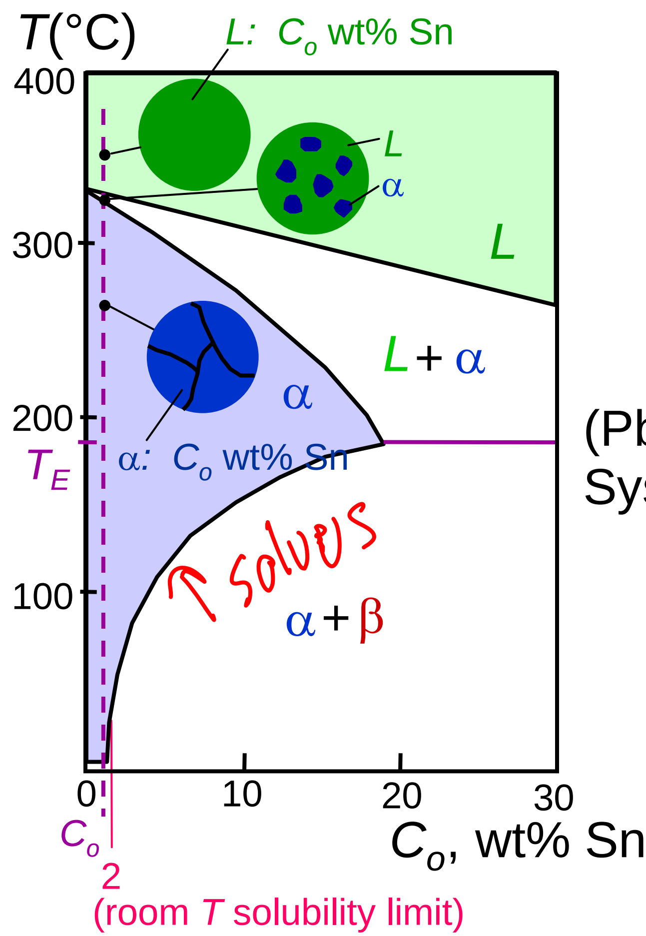
Adapted from Fig. 9.8, *Callister 7e.*

Microstructures in Eutectic Systems: I

- C_o < 2 wt% Sn
- Result:

  --at extreme ends

  --polycrystal of α grains
  i.e., only one solid phase.

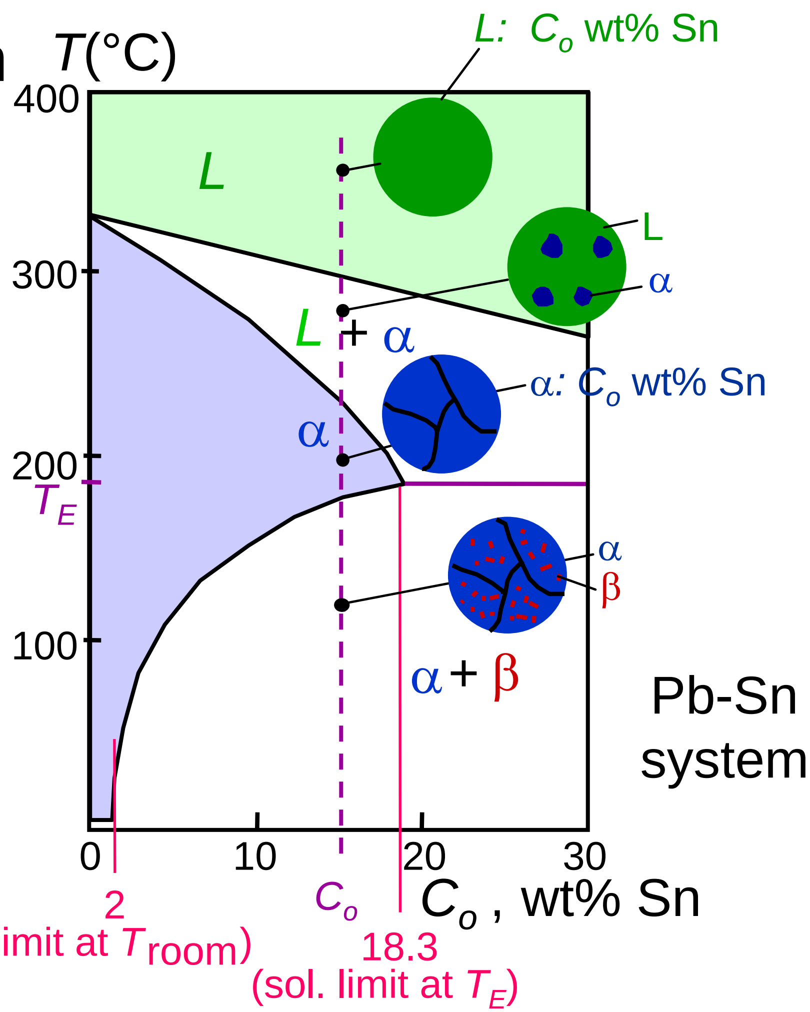


(Pb-Sn System)

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

Microstructures in Eutectic Systems: II

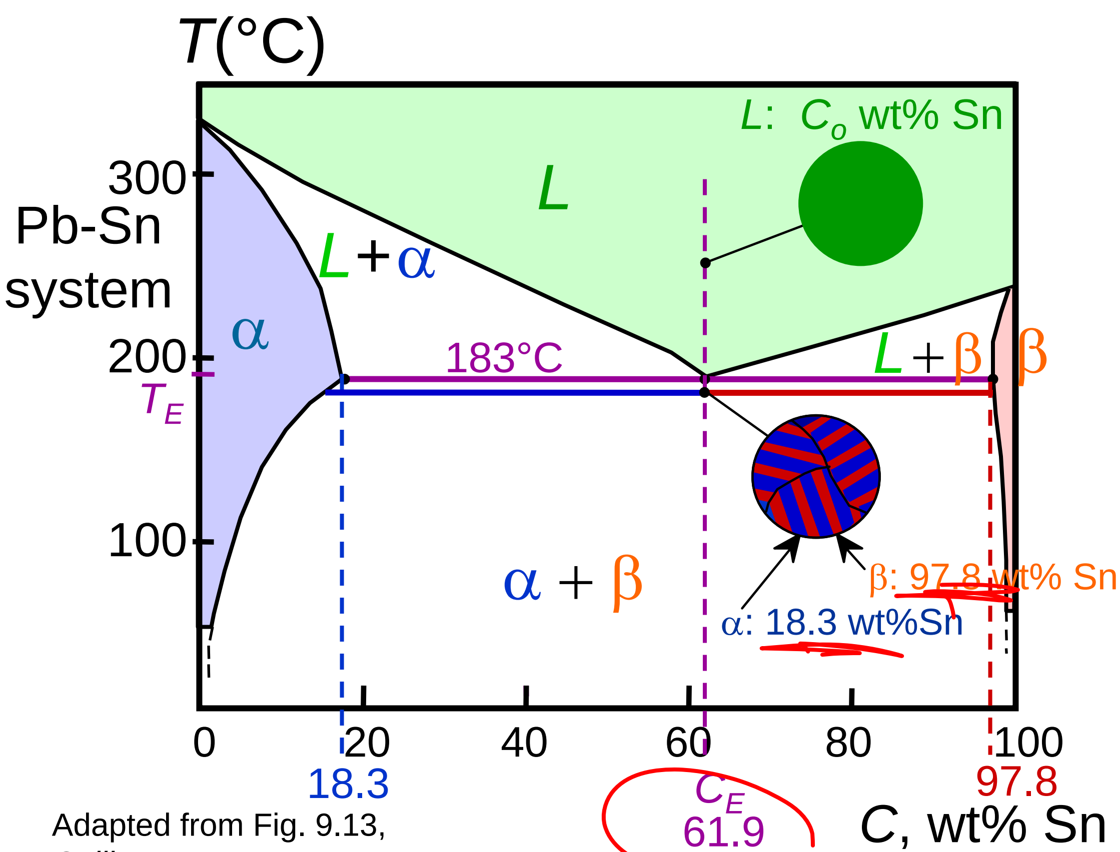
- 2 wt% Sn < C_o < 18.3 wt% Sn
- Result:
  - Initially liquid + α
  - then α alone
  - finally two phases
    - α polycrystal
    - fine β-phase inclusions



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

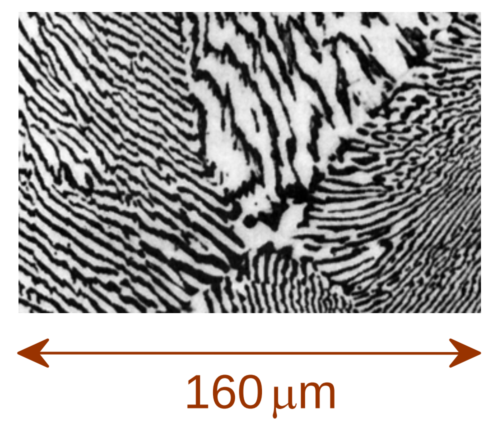
Microstructures in Eutectic Systems: III

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



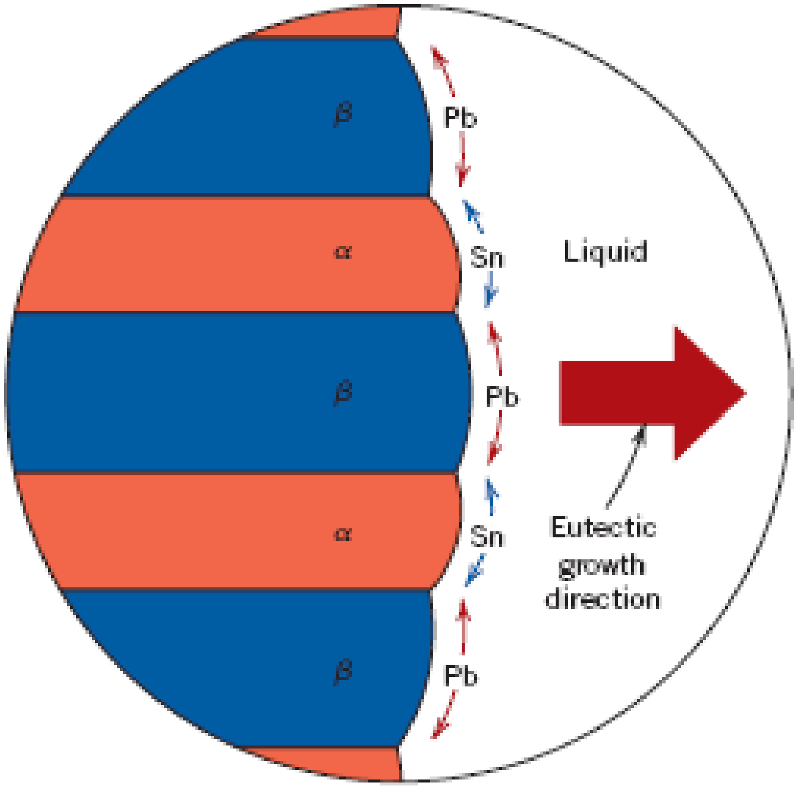
Adapted from Fig. 9.13, *Callister 7e.*

Micrograph of Pb-Sn eutectic microstructure

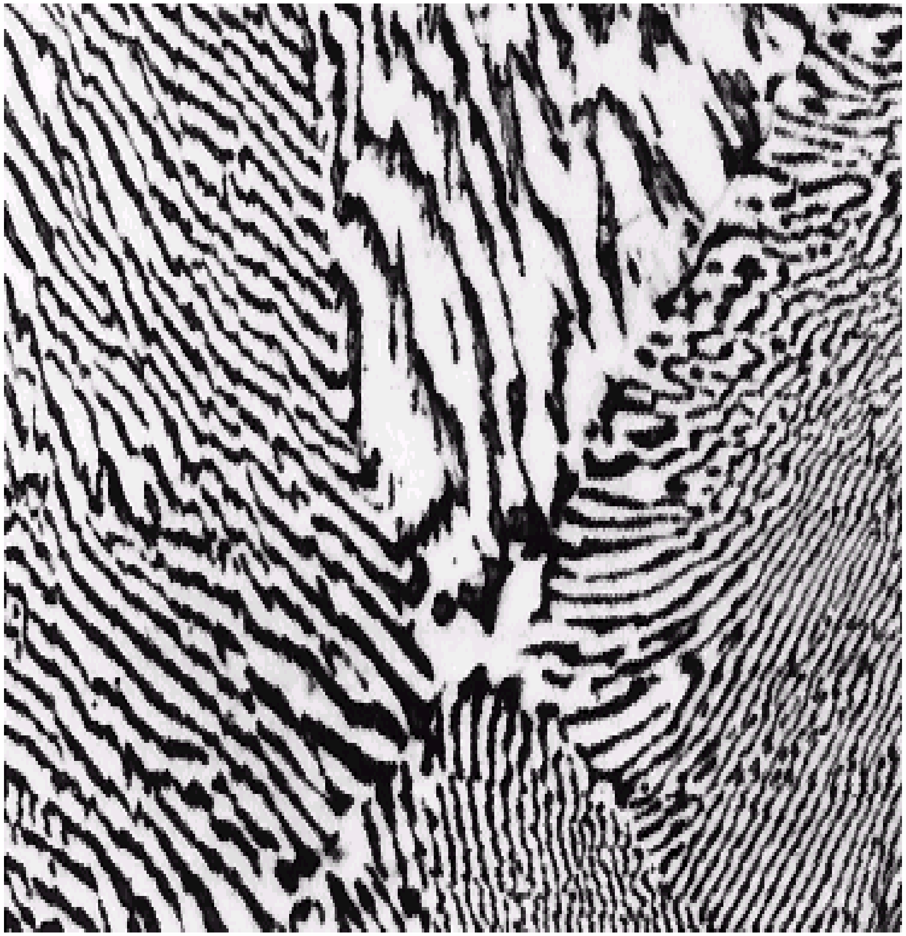


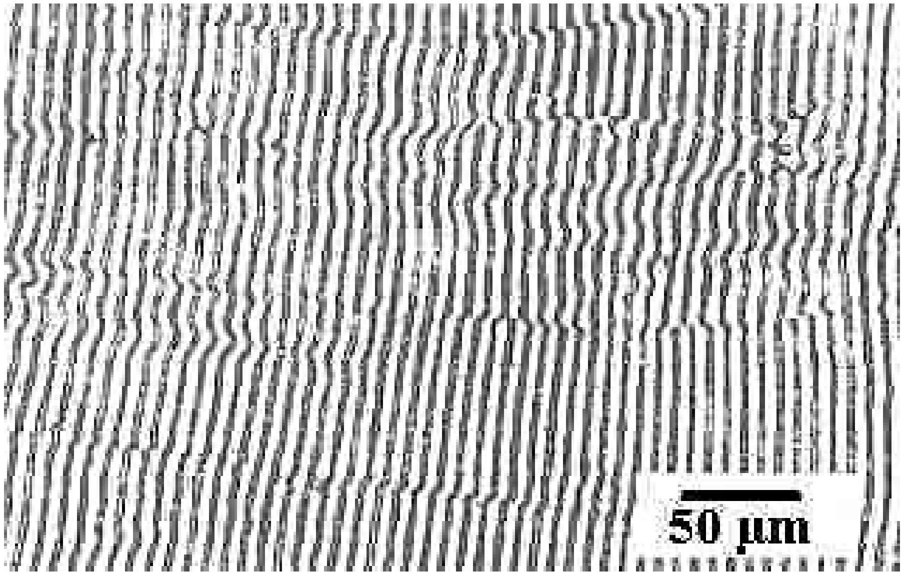
Adapted from Fig. 9.14, *Callister 7e.*

Lamellar Eutectic Structure

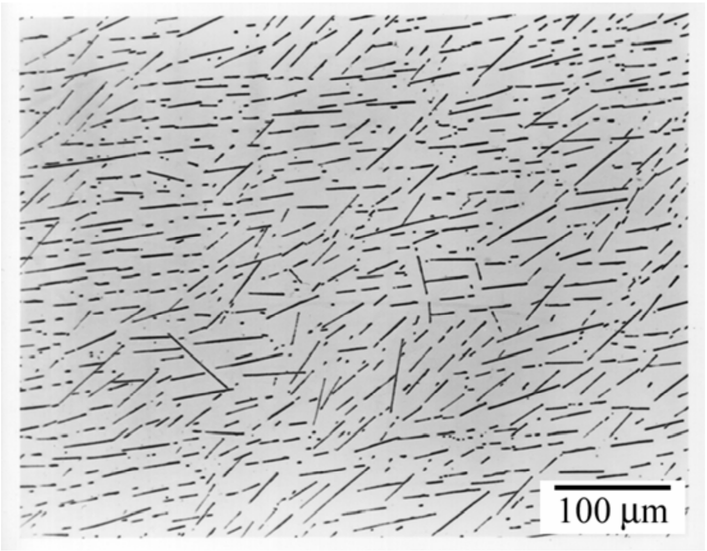


Adapted from Figs. 9.14 & 9.15, *Callister 7e.*

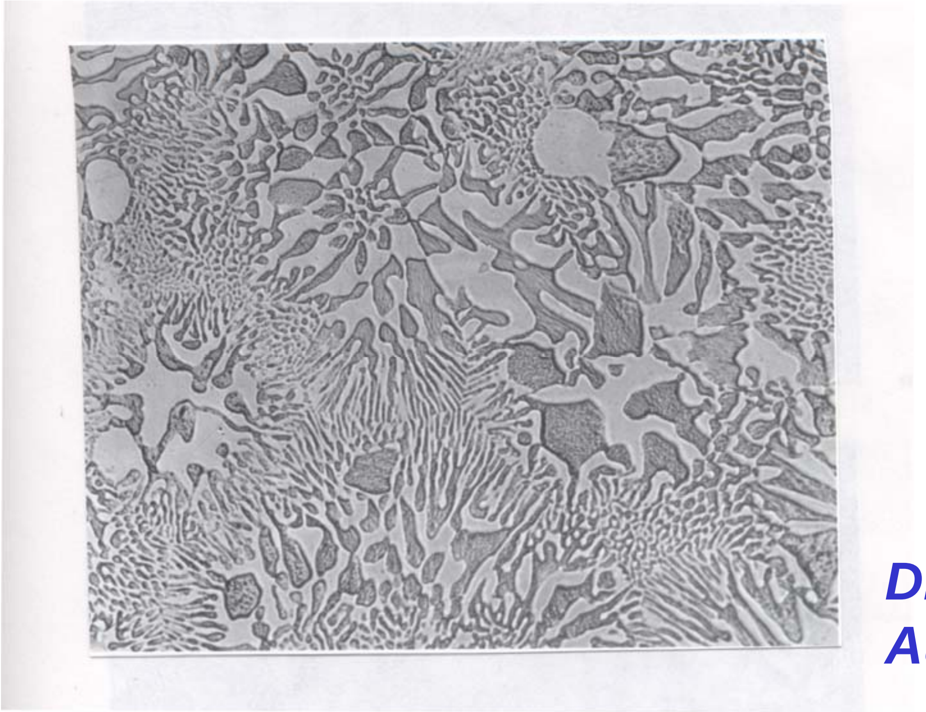




Lamellar, Pb-Sn



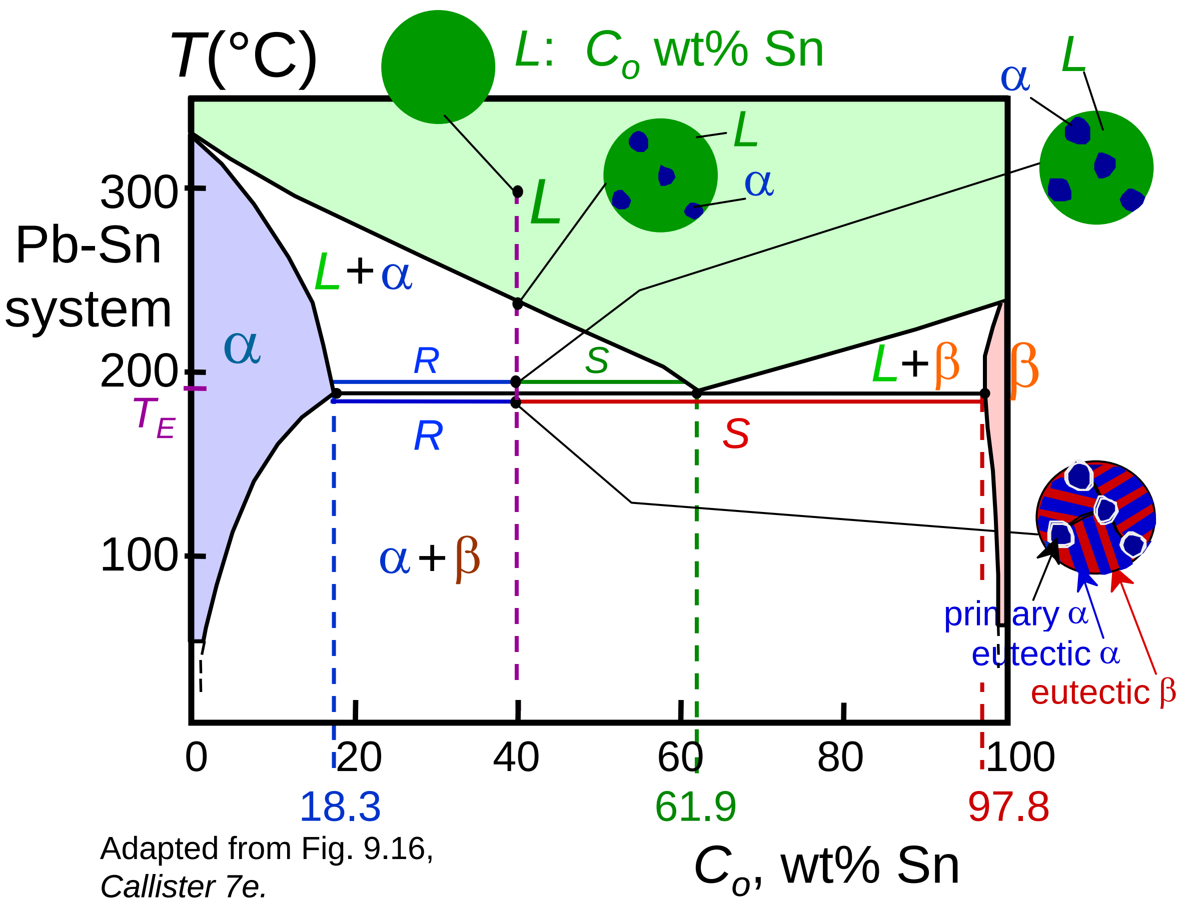
Rod-Like, Ag-Sn



Disordered,
Au-Sn

Microstructures in Eutectic Systems: IV

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

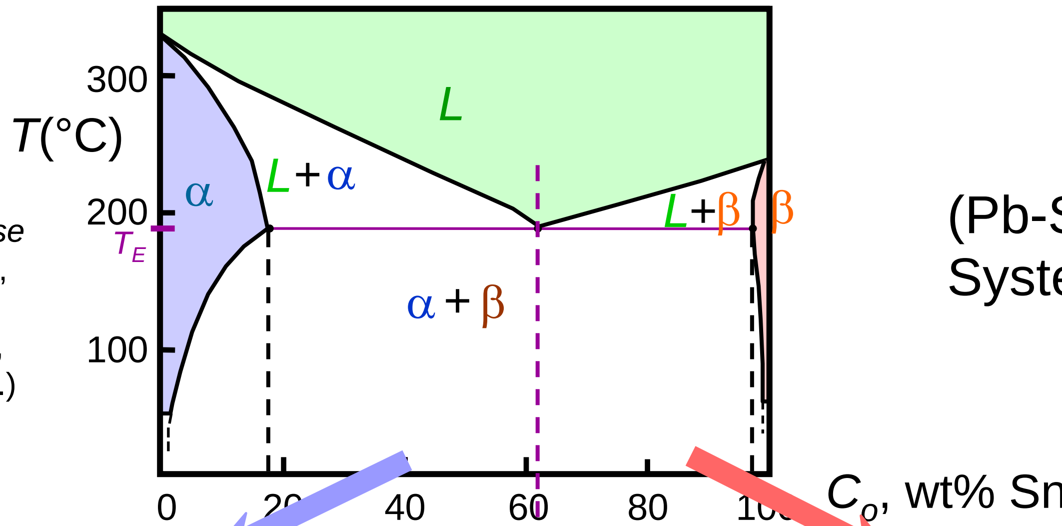


Adapted from Fig. 9.16, *Callister 7e.*

- Just above T_E :
  - C_α = 18.3 wt% Sn
  - C_L = 61.9 wt% Sn
  - $W_\alpha = \dfrac{S}{R+S}$ = 50 wt%
  - W_L = (1- W_α) = 50 wt%
- Just below T_E :
  - C_α = 18.3 wt% Sn
  - C_β = 97.8 wt% Sn
  - $W_\alpha = \dfrac{S}{R+S}$ = 73 wt%
  - W_β = 27 wt%

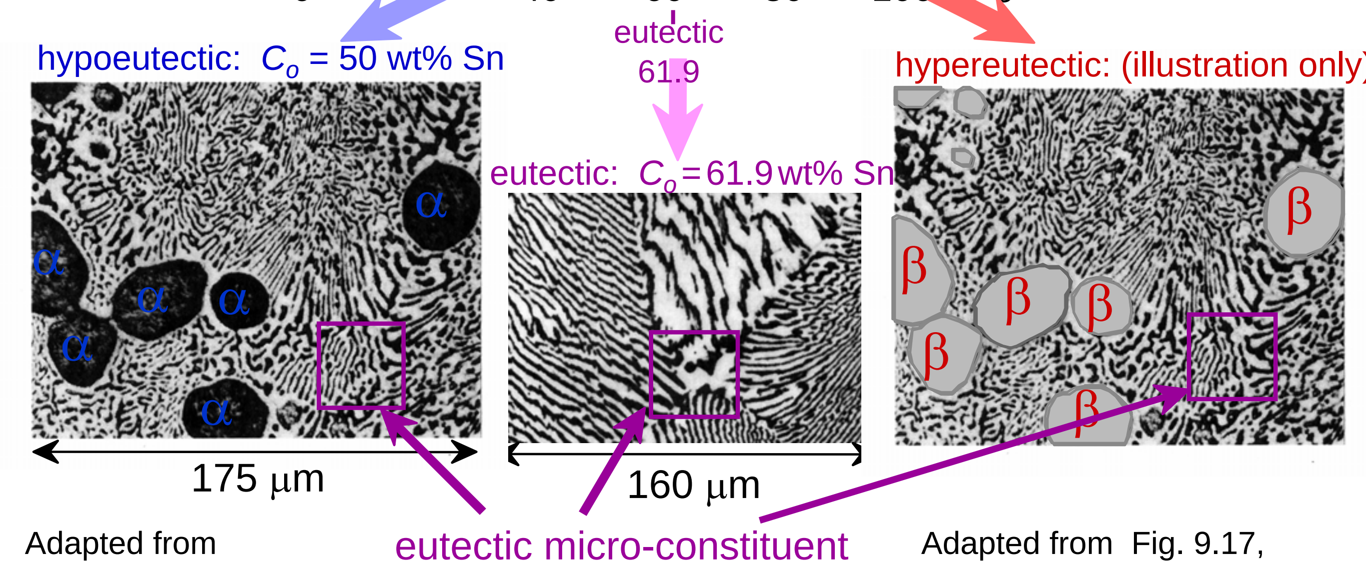
Hypoeutectic & Hypereutectic

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.)



(Pb-Sn System)

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

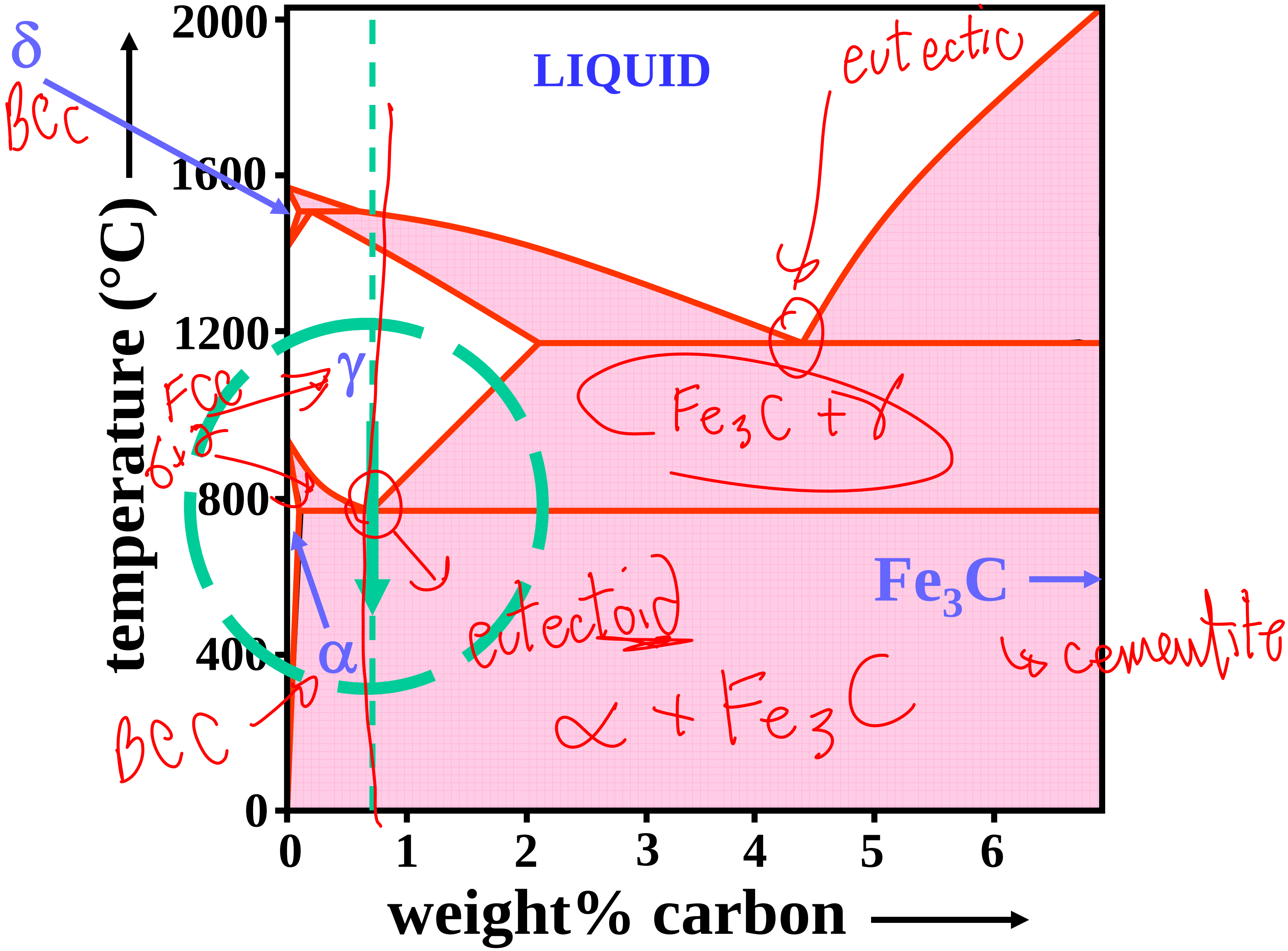


Adapted from Fig. 9.17, *Callister 7e.*

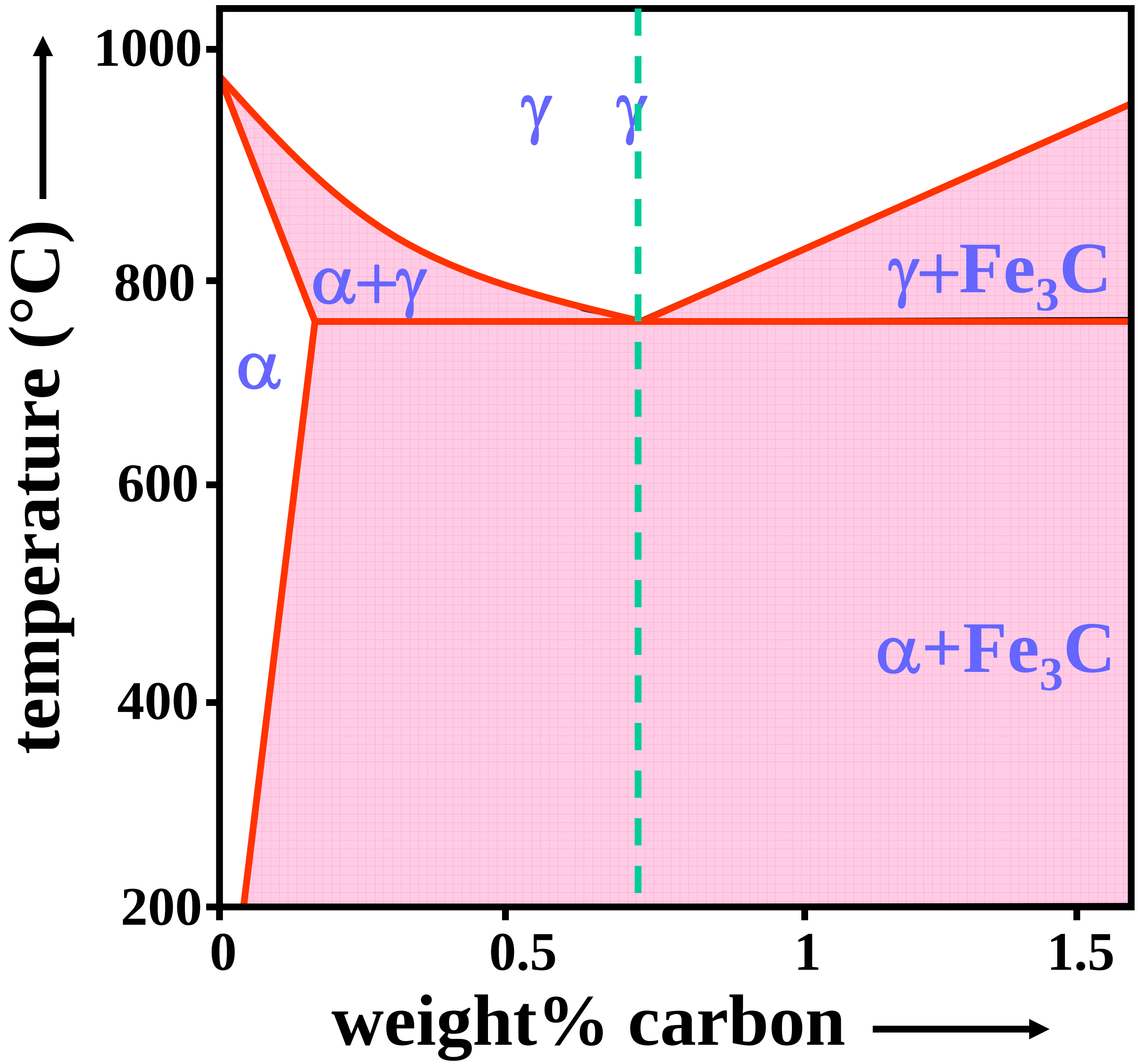
Adapted from Fig. 9.14, *Callister 7e.*

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

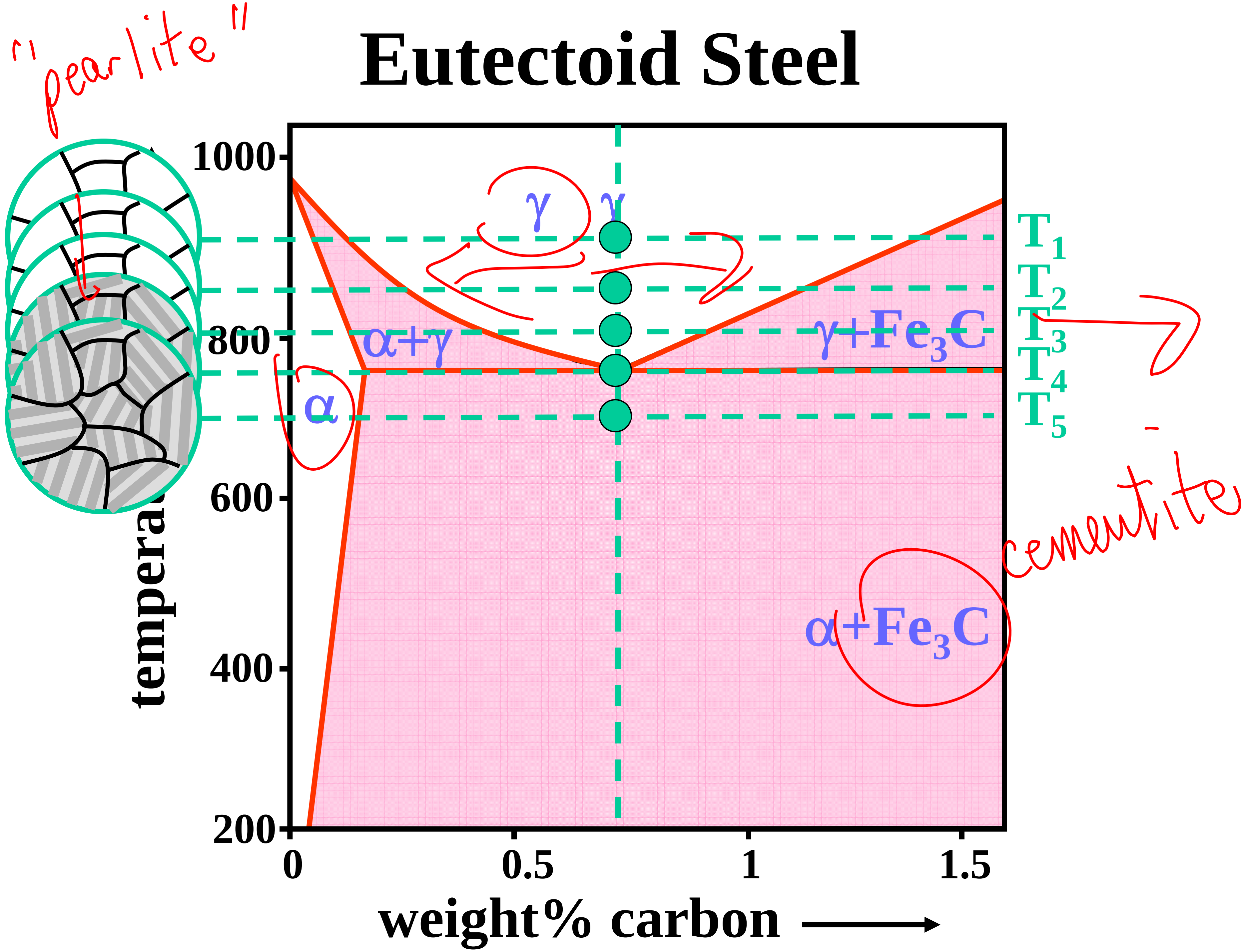
STEEL PHASE DIAG



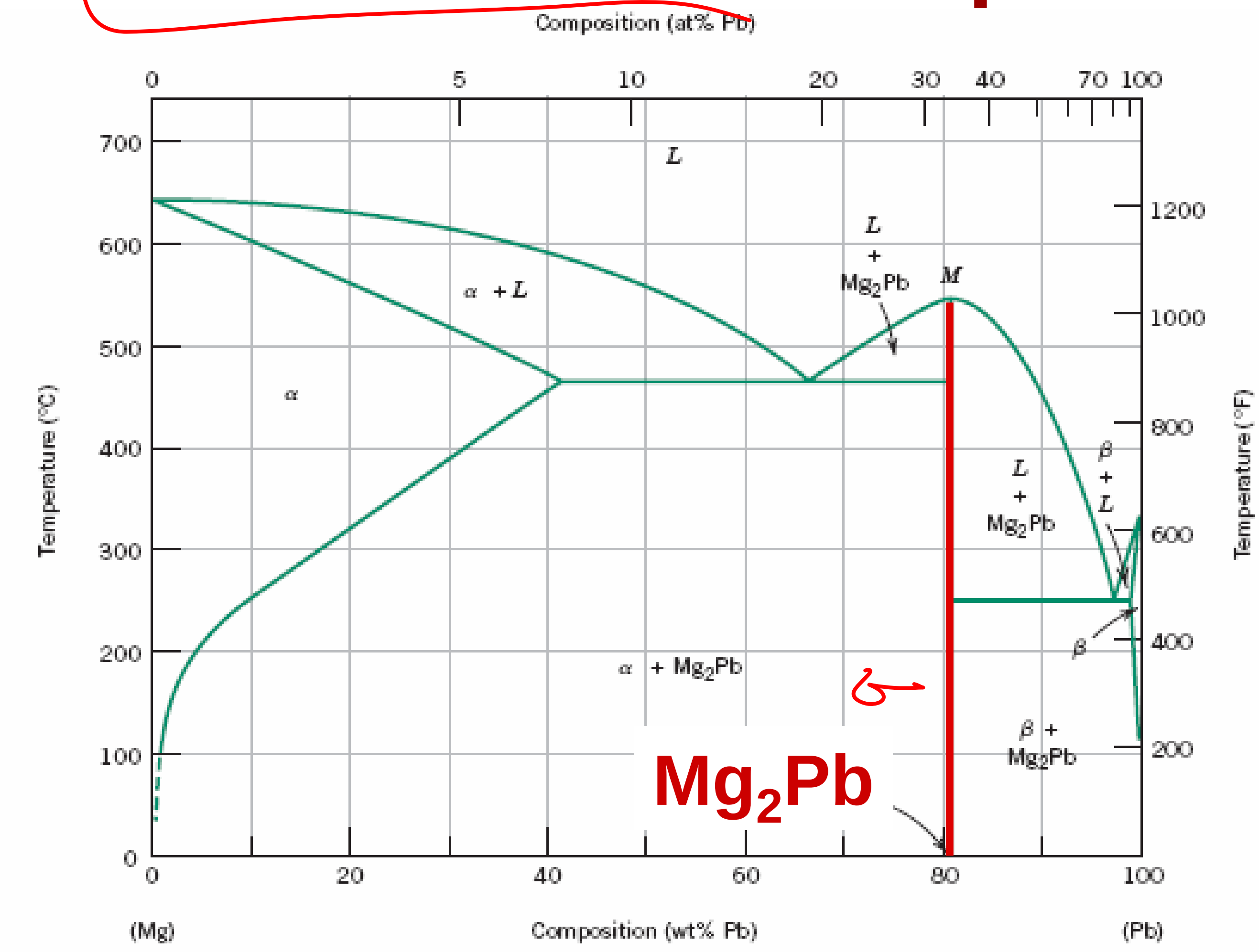
Eutectoid Steel



Eutectoid Steel



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.

Phase diagrams