

Phase equilibria: solubility limit

Introduction

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

Adapted from Fig. 9.1,
Callister 7e.

- **Solubility Limit:**

Max concentration for which only a single phase solution occurs.

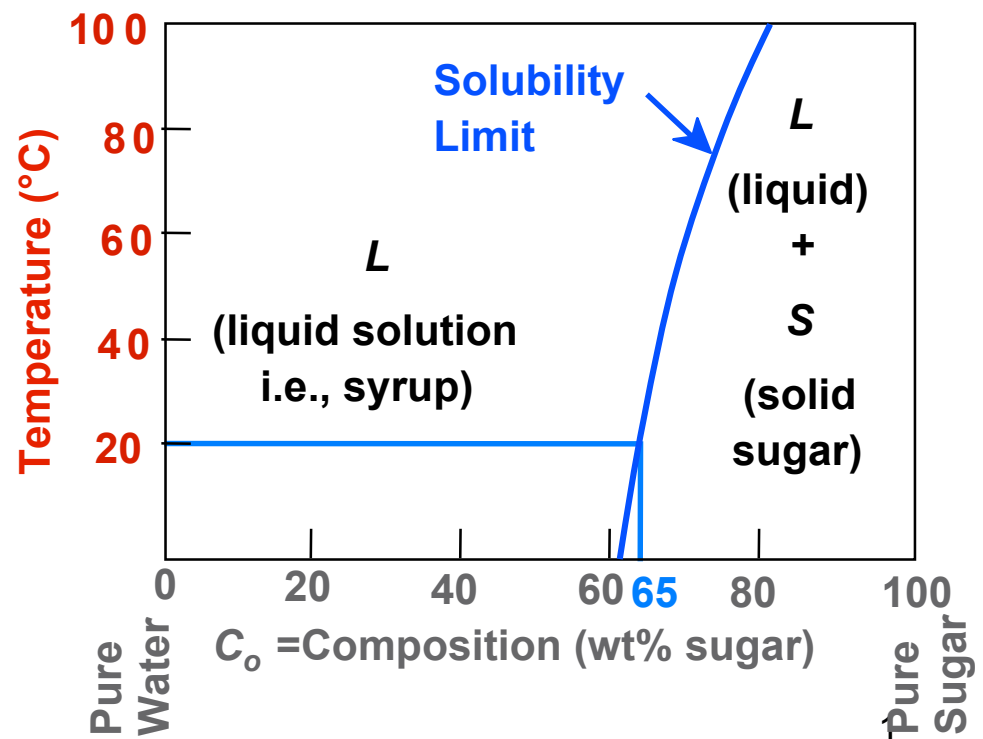
Question: What is the solubility limit at 20°C?

Answer: 65 wt% sugar.

If $C_o < 65$ wt% sugar: syrup

If $C_o > 65$ wt% sugar: syrup + sugar.

Sucrose/Water Phase Diagram

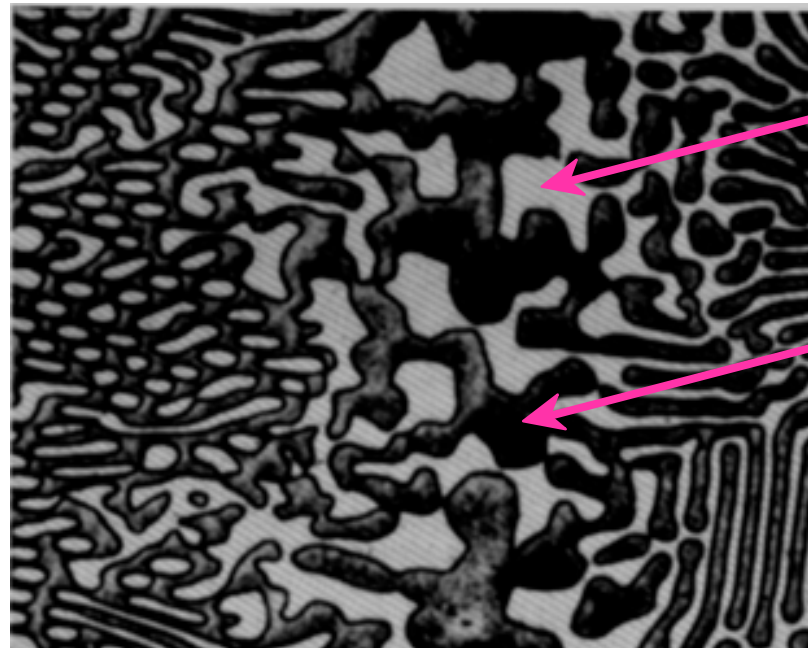


Components and phases

- **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.



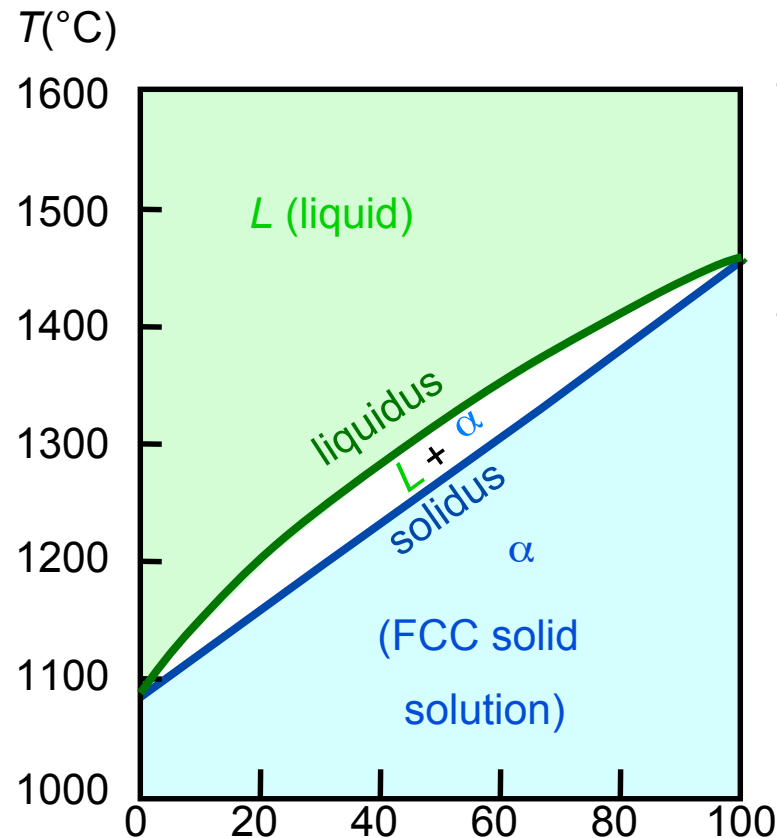
β (lighter
phase)

α (darker
phase)

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

$L + \alpha$

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:

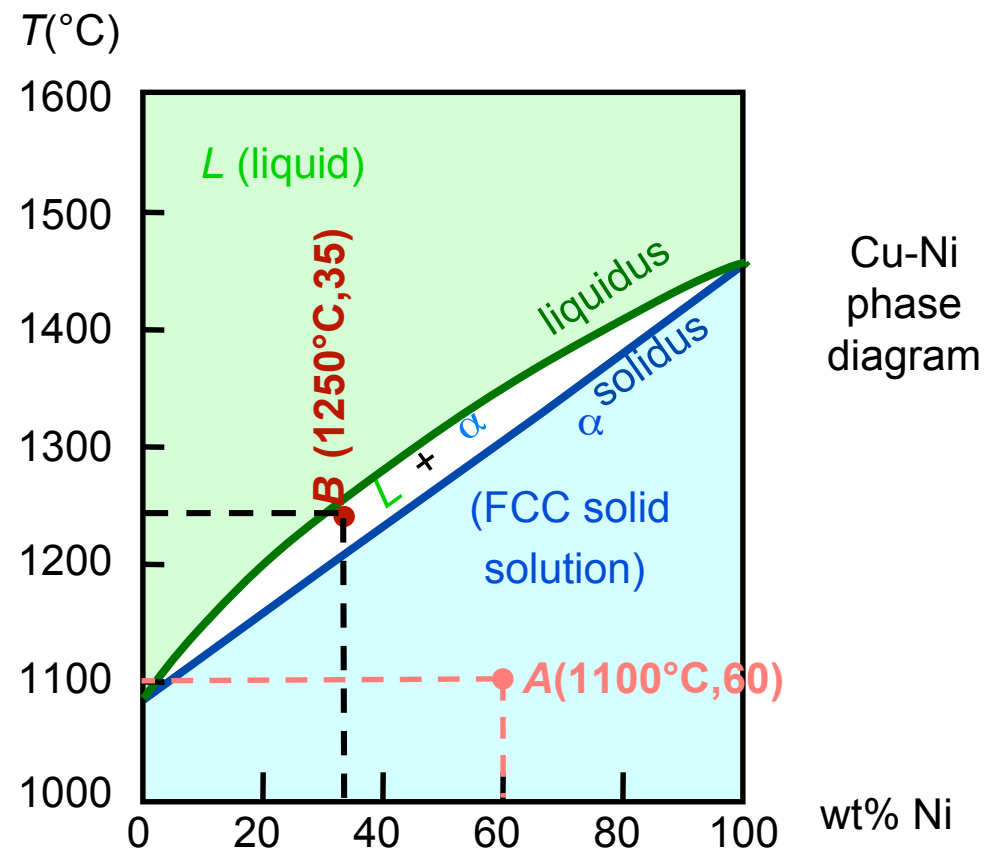
$A(1100^{\circ}\text{C}, 60)$:

1 phase: α

$B(1250^{\circ}\text{C}, 35)$:

2 phases: $L + \alpha$

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:

$C_o = 35 \text{ wt\% Ni}$

At $T_A = 1320^\circ\text{C}$:

Only Liquid (L)

$C_L = C_o (= 35 \text{ wt\% Ni})$

At $T_D = 1190^\circ\text{C}$:

Only Solid (α)

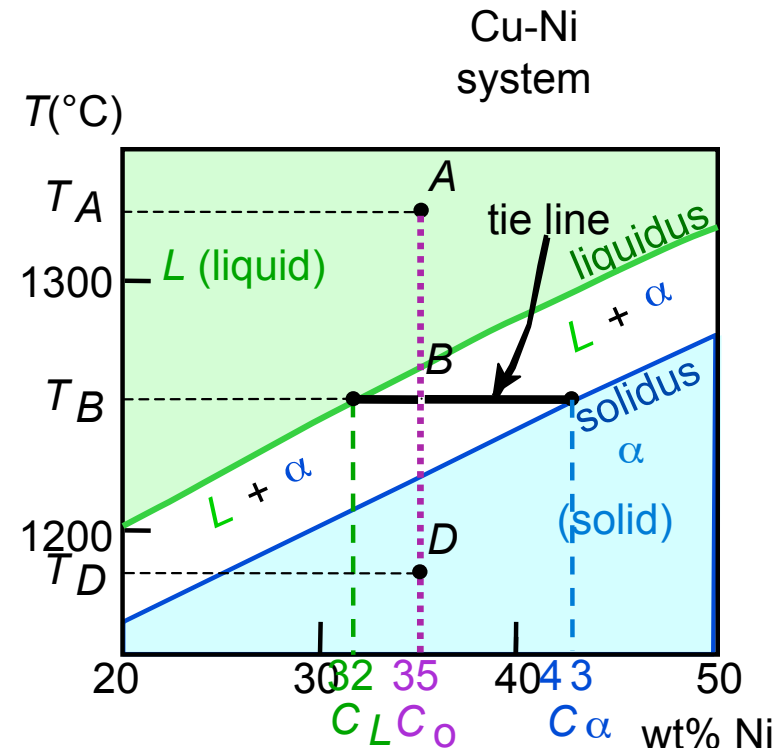
$C_\alpha = C_o (= 35 \text{ wt\% Ni})$

At $T_B = 1250^\circ\text{C}$:

Both α and L

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

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



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

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

- Examples:

$C_o = 35 \text{ wt\% Ni}$

At T_A : Only Liquid (L)

$$W_L = 100 \text{ wt\%}, W_\alpha = 0$$

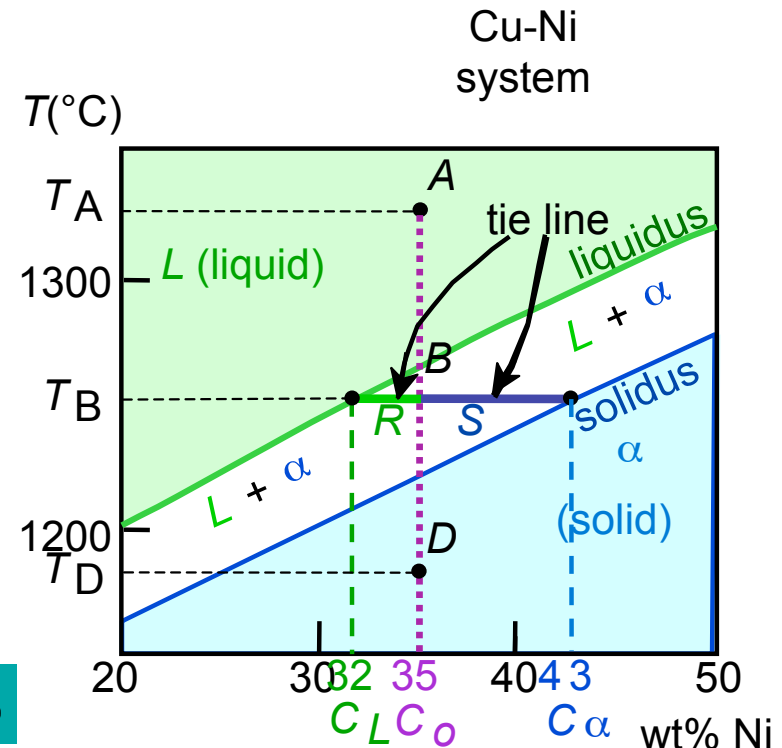
At T_D : Only Solid (α)

$$W_L = 0, W_\alpha = 100 \text{ wt\%}$$

At T_B : Both α and L

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

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

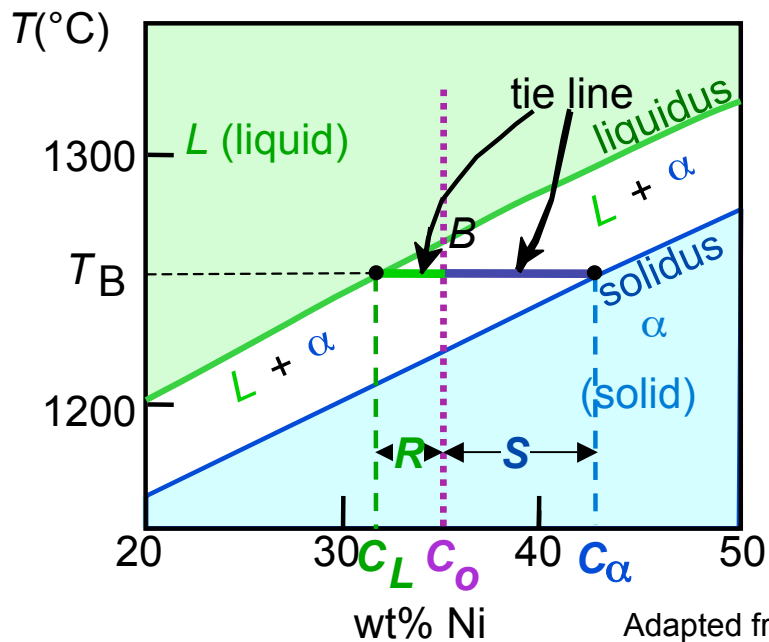


Adapted from Fig. 9.3(b), Callister 7e.

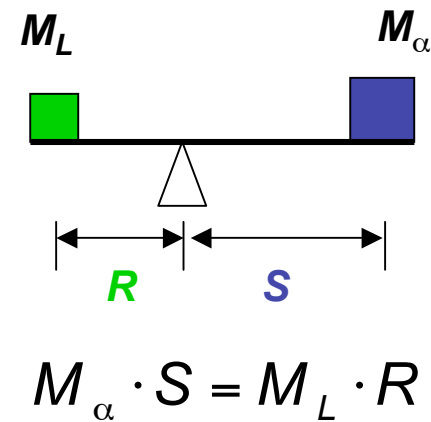
(Fig. 9.3(b) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH, 1991.)

The lever rule

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



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

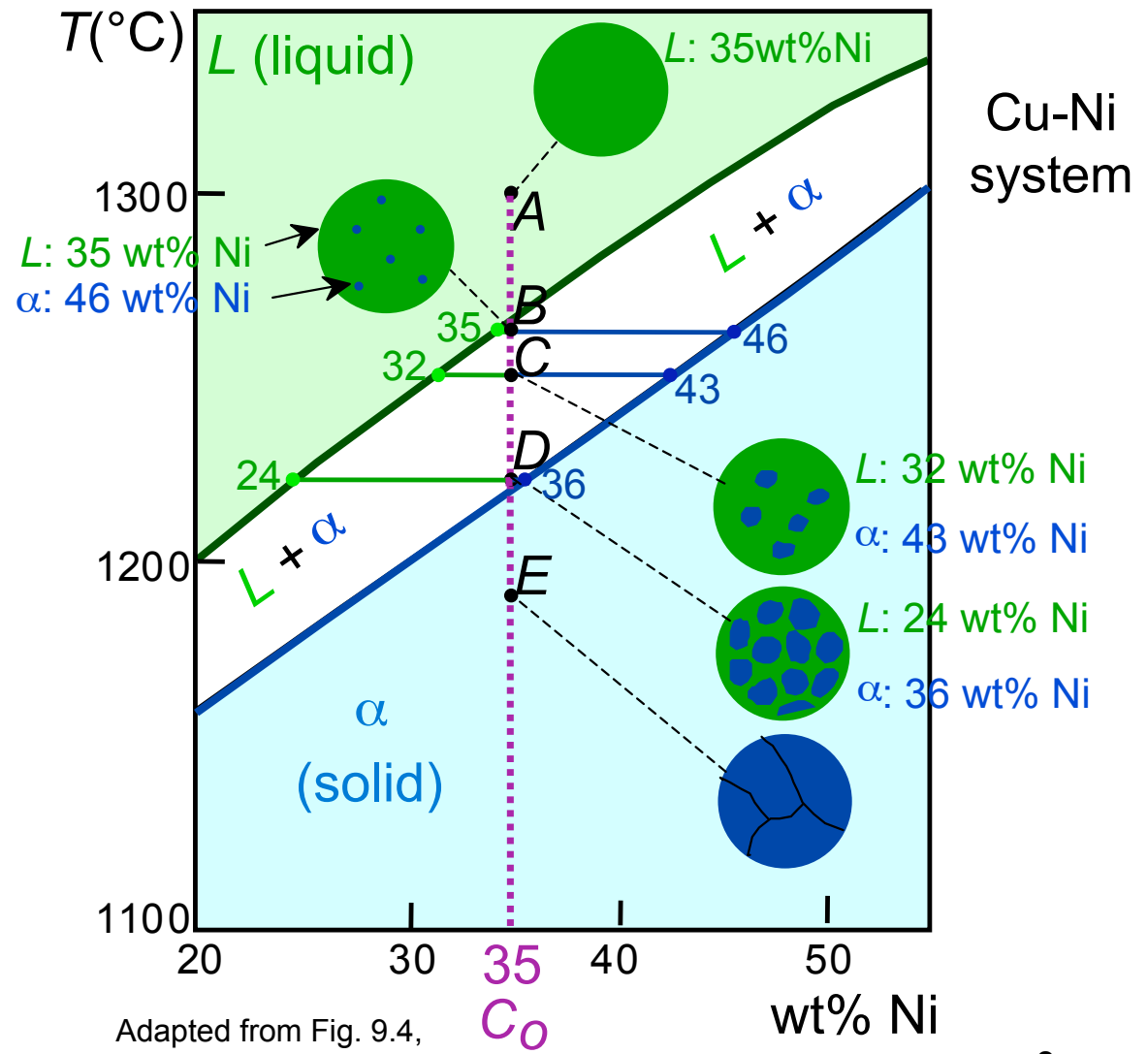


$$W_L = \frac{M_L}{M_L + M_{\alpha}} = \frac{S}{R + S} = \frac{C_{\alpha} - C_0}{C_{\alpha} - C_L}$$

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

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
 $C_o = 35 \text{ wt\% Ni}$.



Binary eutectic systems

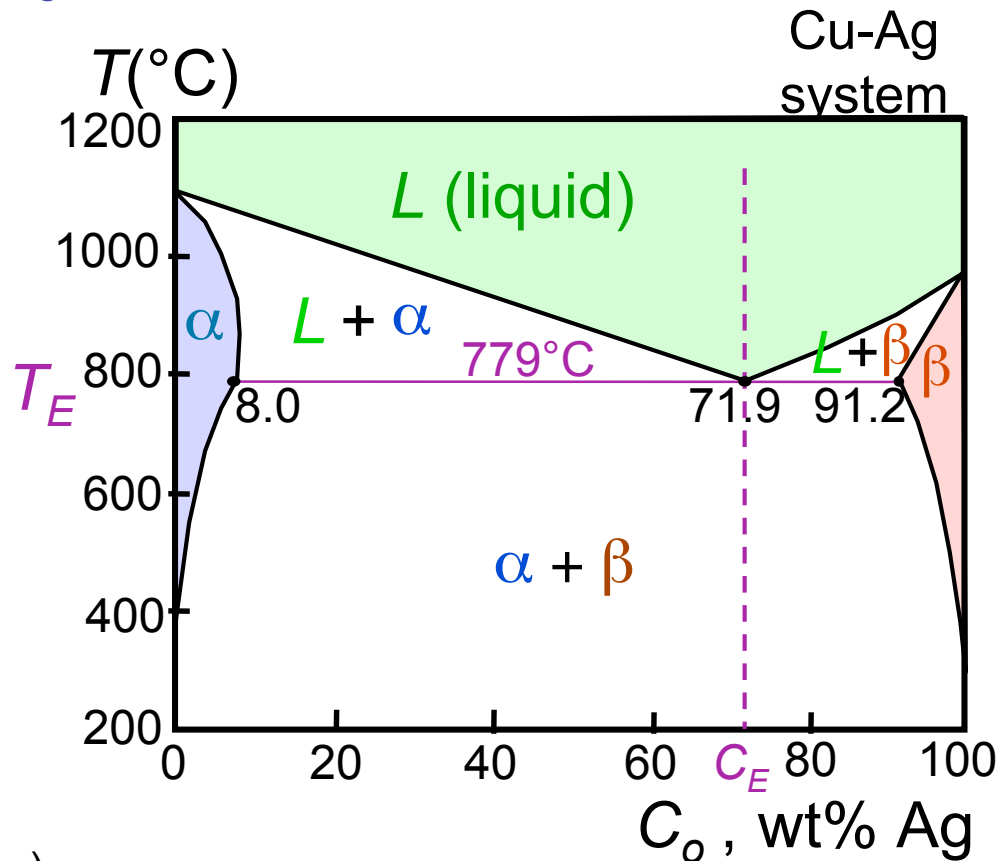
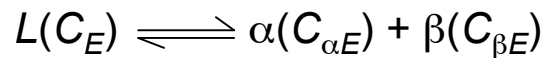
↑
2 components

↖ 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



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: $\alpha + \beta$

--compositions of phases:

$$C_0 = 40 \text{ wt\% Sn}$$

$$C_\alpha = 11 \text{ wt\% Sn}$$

$$C_\beta = 99 \text{ wt\% Sn}$$

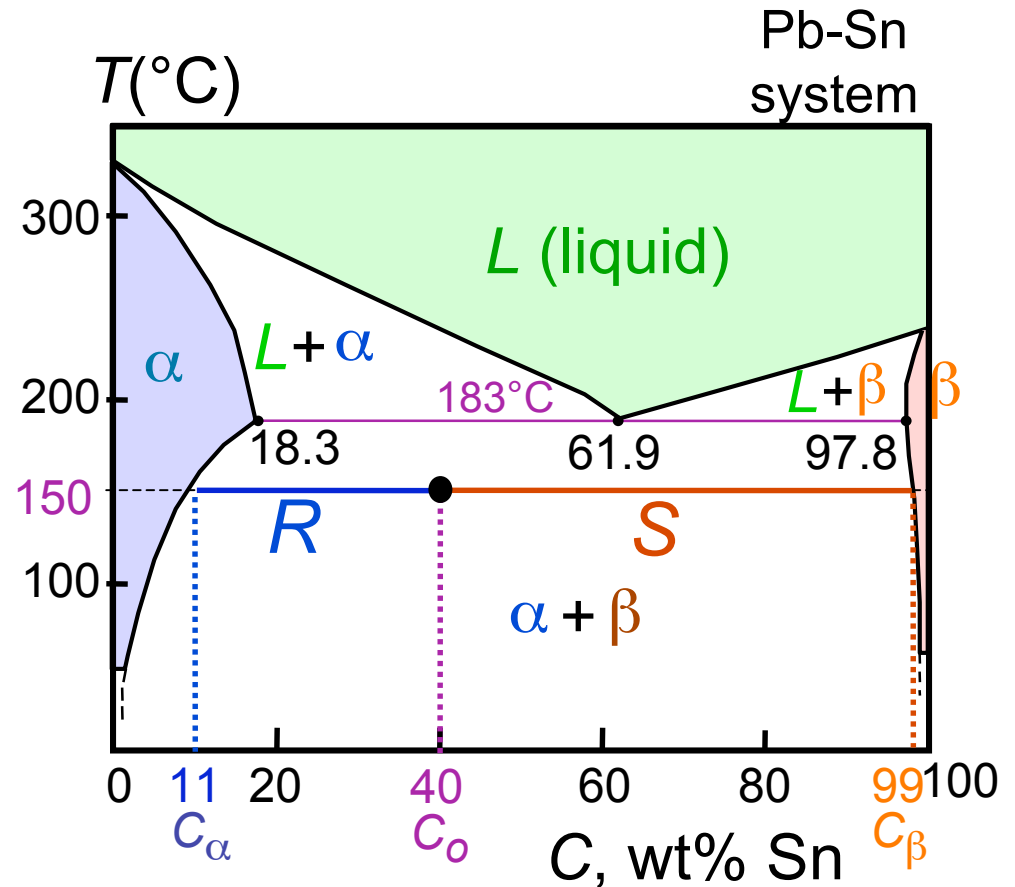
--the relative amount of each phase:

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

$$= \frac{99 - 40}{99 - 11} = \frac{59}{88} = 67 \text{ wt\%}$$

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

$$= \frac{40 - 11}{99 - 11} = \frac{29}{88} = 33 \text{ wt\%}$$



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: $\alpha + L$

--compositions of phases:

$$C_O = 40 \text{ wt\% Sn}$$

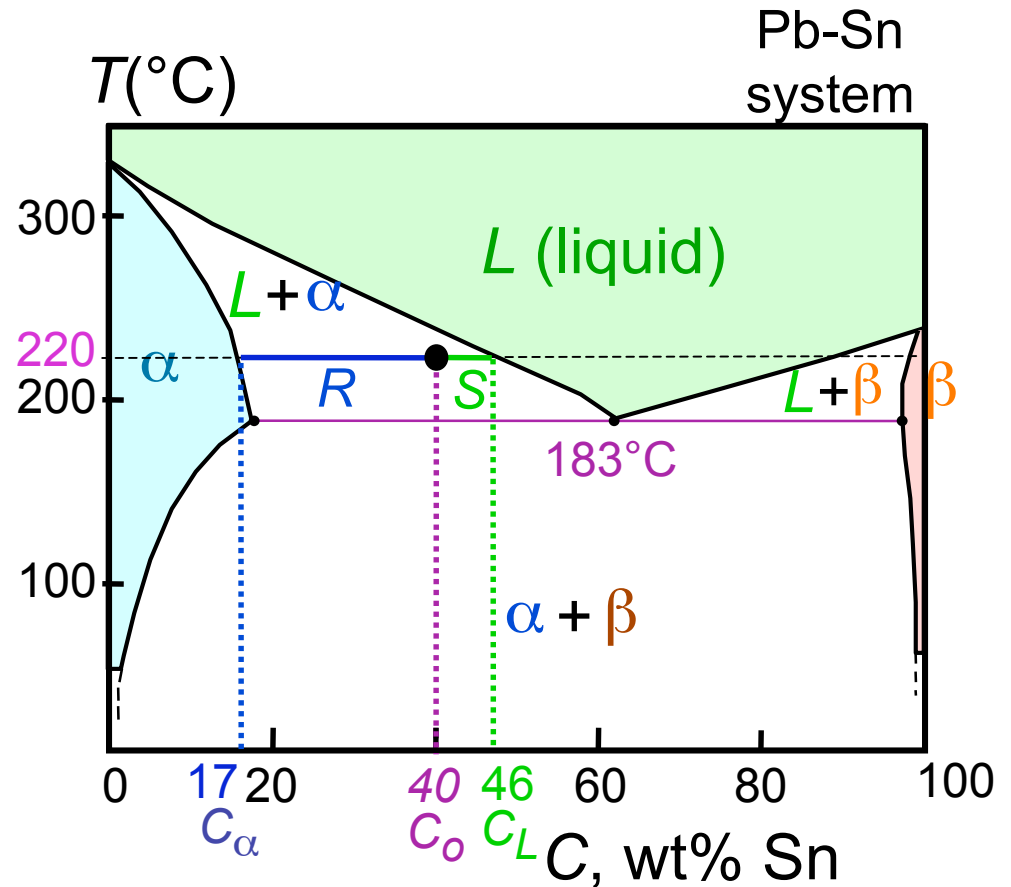
$$C_\alpha = 17 \text{ wt\% Sn}$$

$$C_L = 46 \text{ wt\% Sn}$$

--the relative amount of each phase:

$$W_\alpha = \frac{C_L - C_O}{C_L - C_\alpha} = \frac{46 - 40}{46 - 17} = \frac{6}{29} = 21 \text{ wt\%}$$

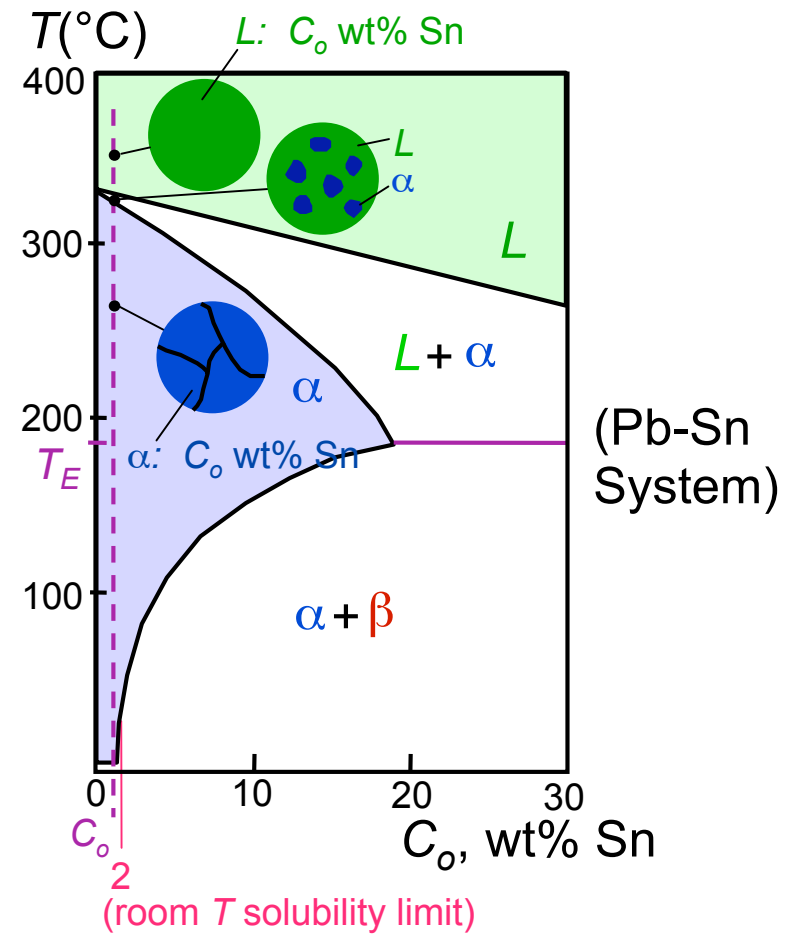
$$W_L = \frac{C_O - C_\alpha}{C_L - C_\alpha} = \frac{40 - 17}{46 - 17} = \frac{23}{29} = 79 \text{ wt\%}$$



Adapted from Fig. 9.8,
Callister 7e.

Microstructures in eutectic systems

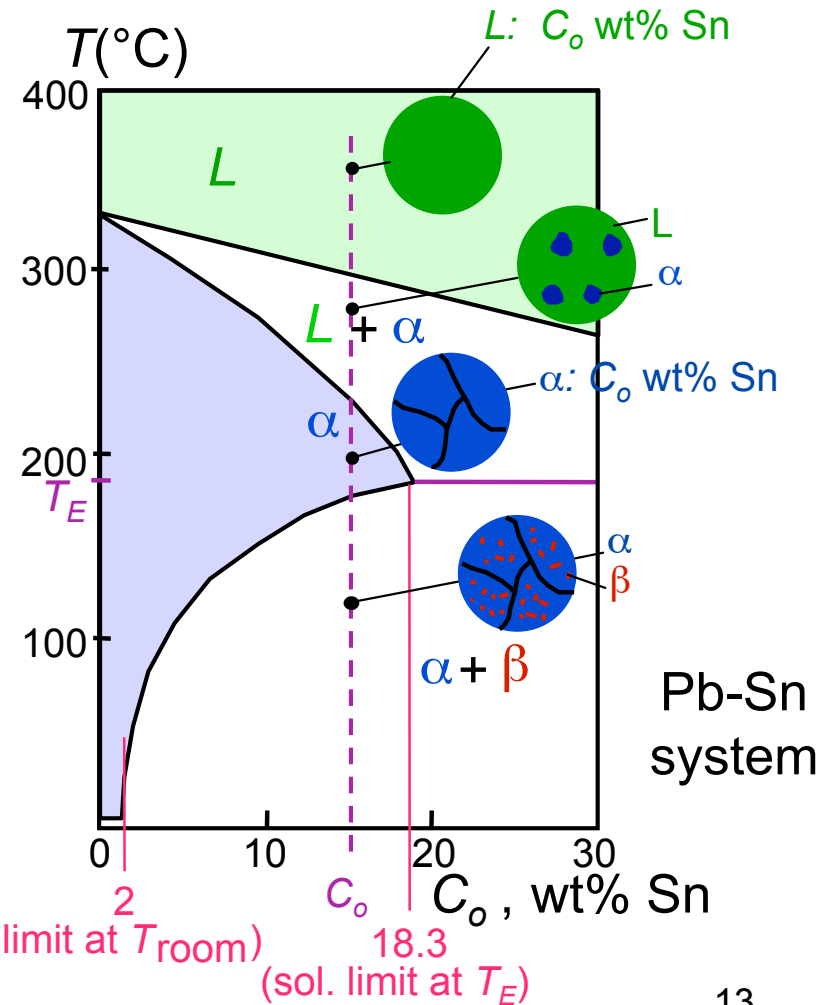
- $C_o < 2 \text{ wt\% Sn}$
- Result:
 - at extreme ends
 - polycrystal of α grains
i.e., only one solid phase.



Adapted from Fig. 9.11,
Callister 7e.

Microstructures in eutectic systems

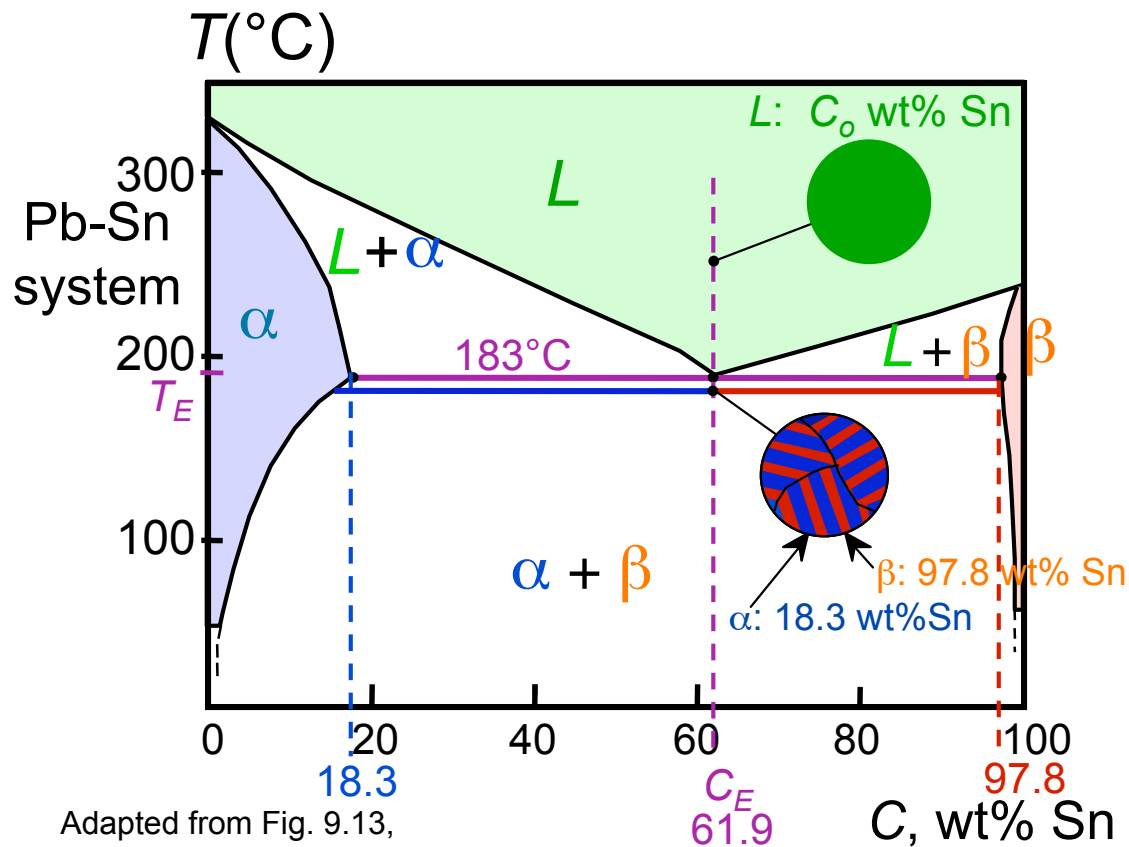
- 2 wt% Sn < C_o < 18.3 wt% Sn
- Result:
 - Initially liquid + α
 - then α alone
 - finally two phases
 - α polycrystal
 - fine β -phase inclusions



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.

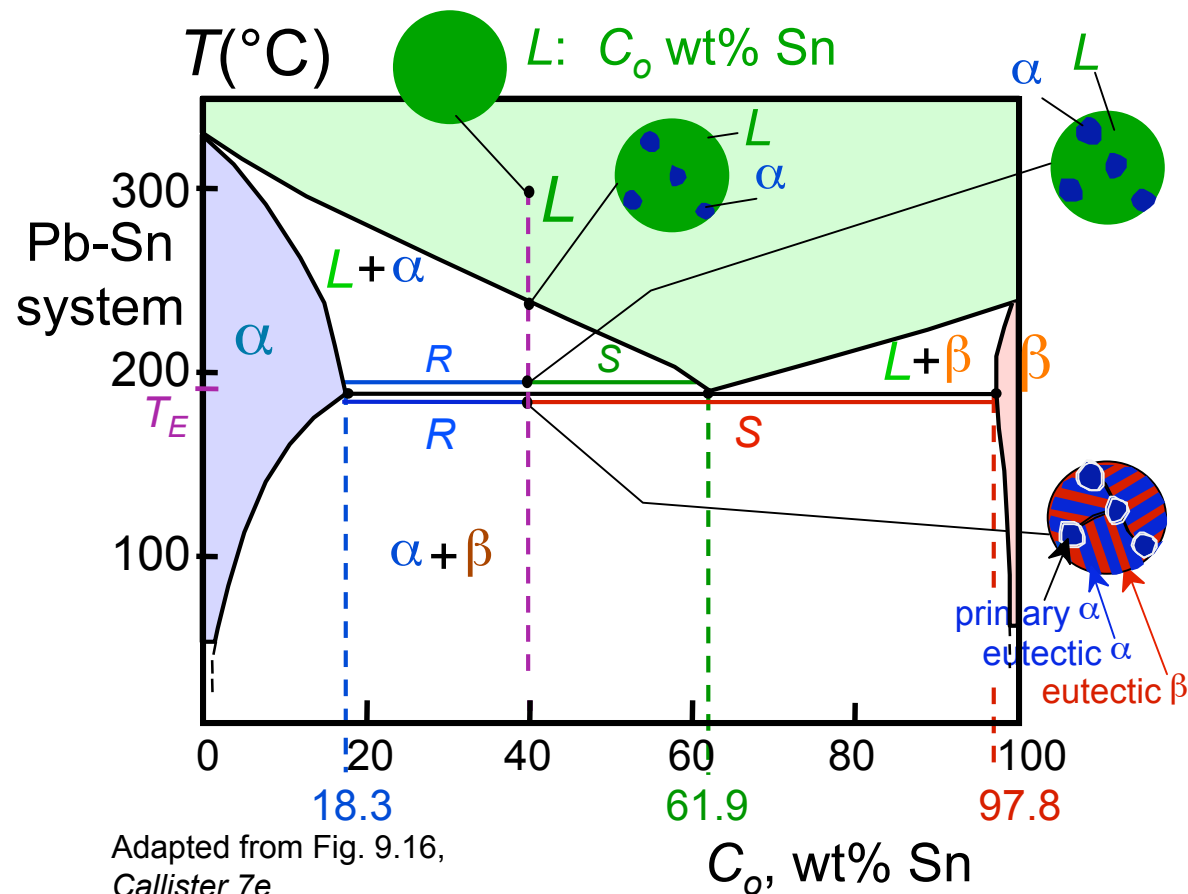
Micrograph of Pb-Sn
eutectic
microstructure



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.

- Just above T_E :

$$C_{\alpha} = 18.3 \text{ wt\% Sn}$$

$$C_L = 61.9 \text{ wt\% Sn}$$

$$W_{\alpha} = \frac{S}{R + S} = 50 \text{ wt\%}$$

$$W_L = (1 - W_{\alpha}) = 50 \text{ wt\%}$$

- Just below T_E :

$$C_{\alpha} = 18.3 \text{ wt\% Sn}$$

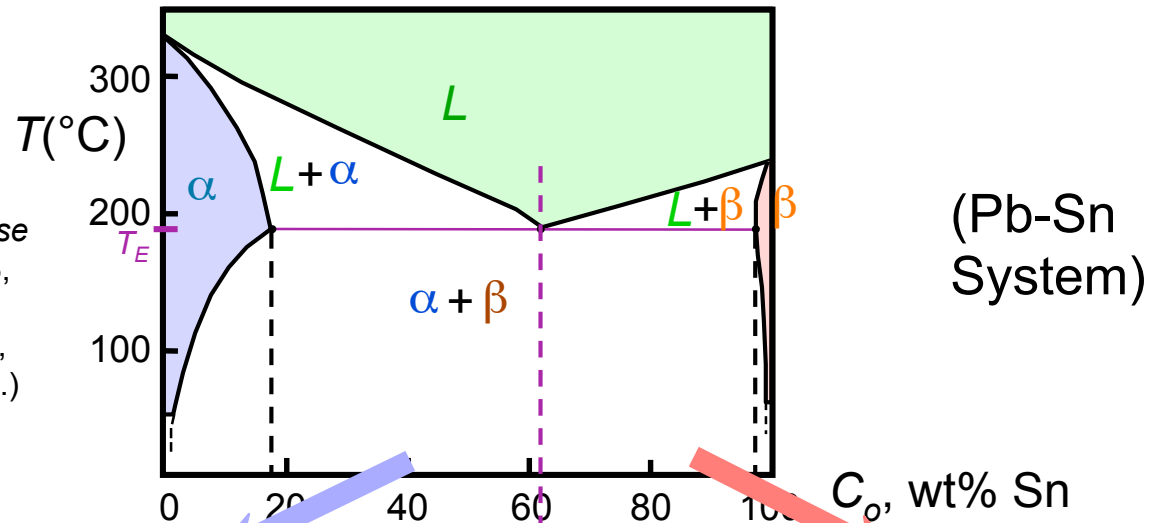
$$C_{\beta} = 97.8 \text{ wt\% Sn}$$

$$W_{\alpha} = \frac{S}{R + S} = 73 \text{ wt\%}$$

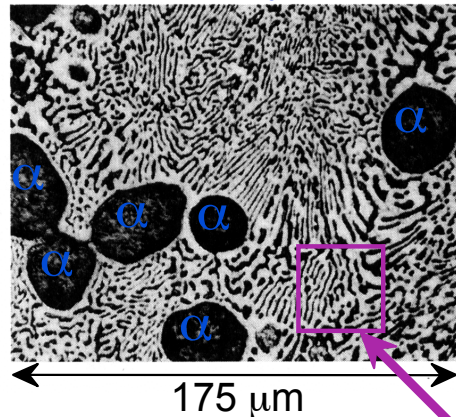
$$W_{\beta} = 27 \text{ wt\%}$$

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.)



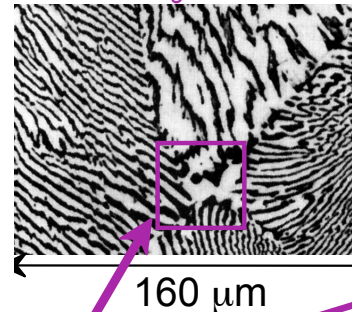
hypoeutectic: $C_0 = 50 \text{ wt\% Sn}$



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

eutectic
61.9

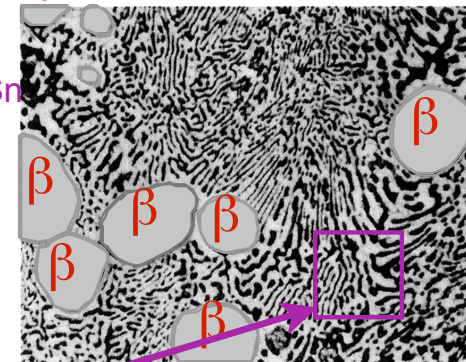
eutectic: $C_0 = 61.9 \text{ wt\% Sn}$



eutectic micro-constituent

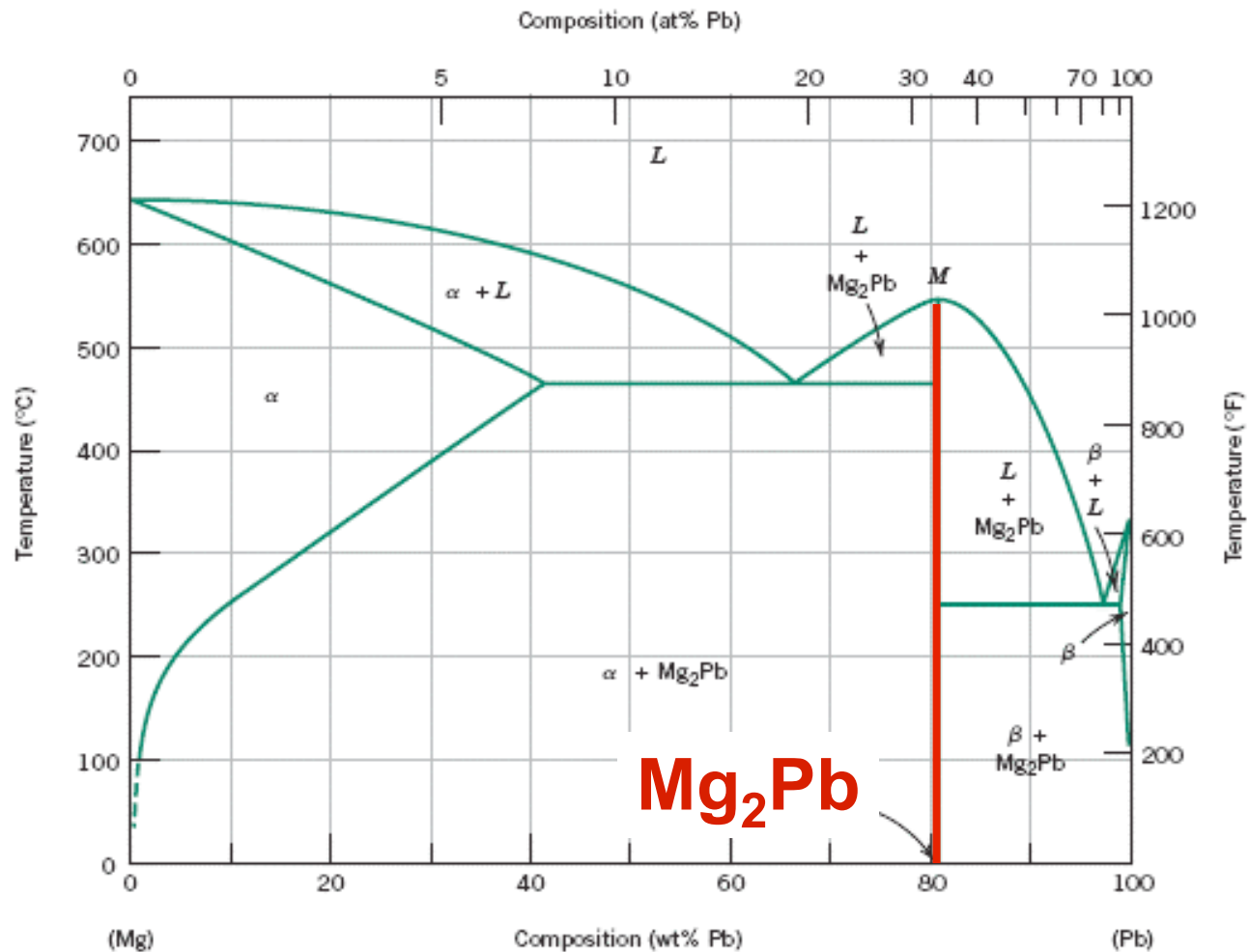
Adapted from Fig. 9.14, *Callister 7e*.

hypereutectic: (illustration only)



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

Intermetallic compounds



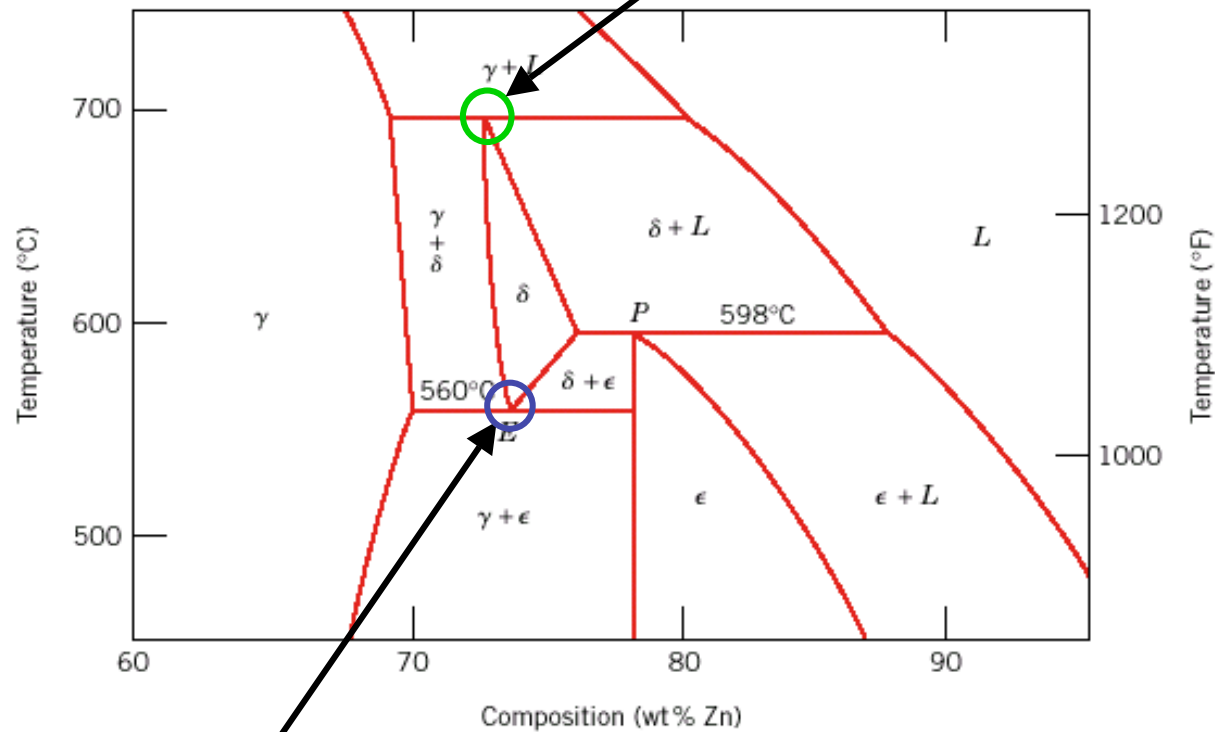
Adapted from
Fig. 9.20, Callister 7e.

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

Peritectic & eutectoid

- Cu-Zn Phase diagram

Peritectic transition $\gamma + L \rightleftharpoons \delta$



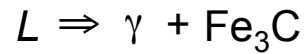
Eutectoid transition $\delta \rightleftharpoons \gamma + \epsilon$

Adapted from
Fig. 9.21, Callister 7e.

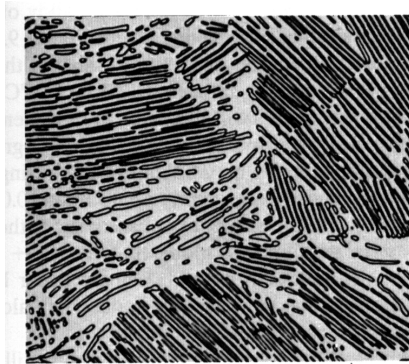
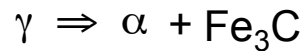
Fe-C phase diagram

- 2 important points

-Eutectic (A):

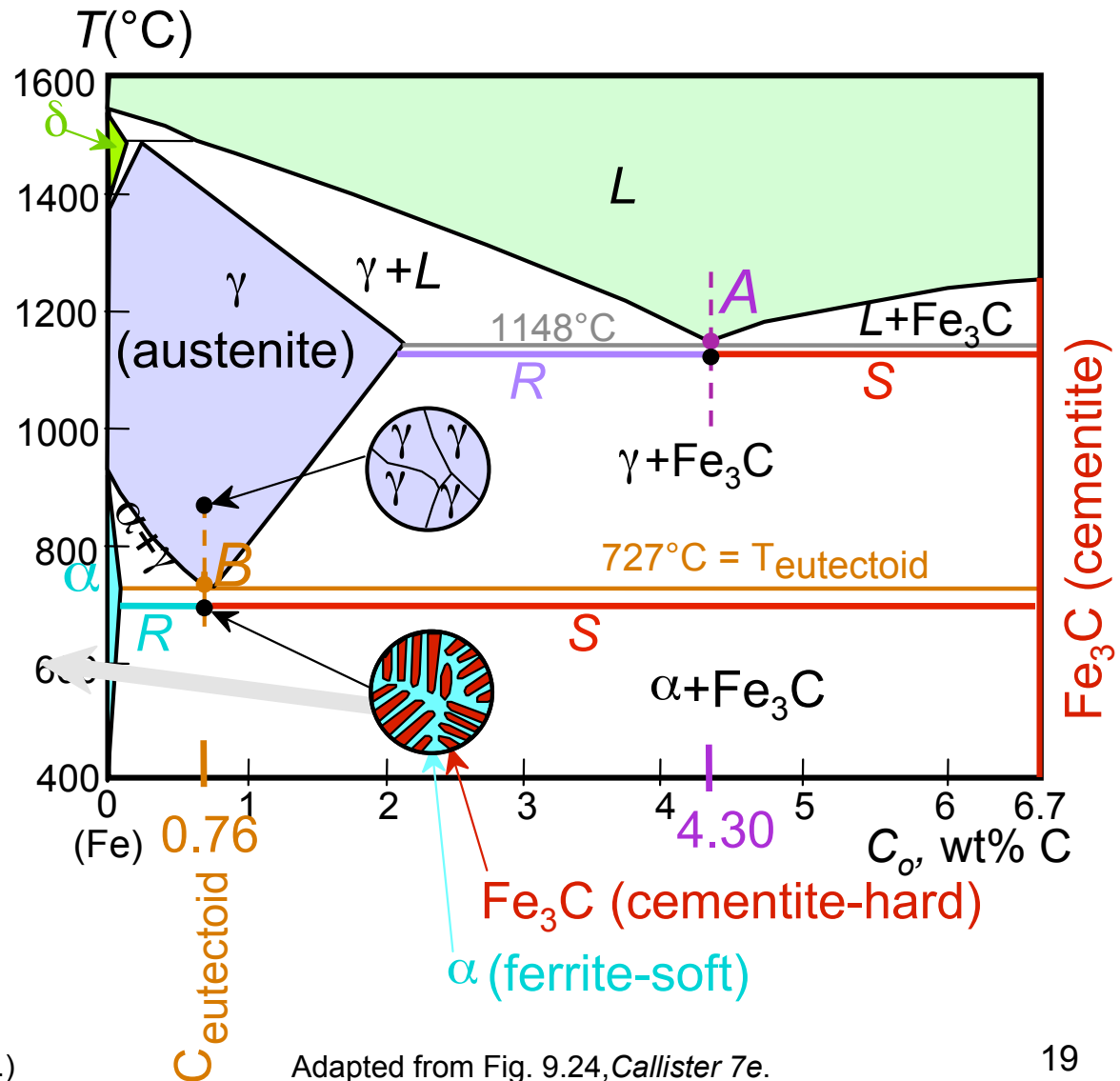


-Eutectoid (B):

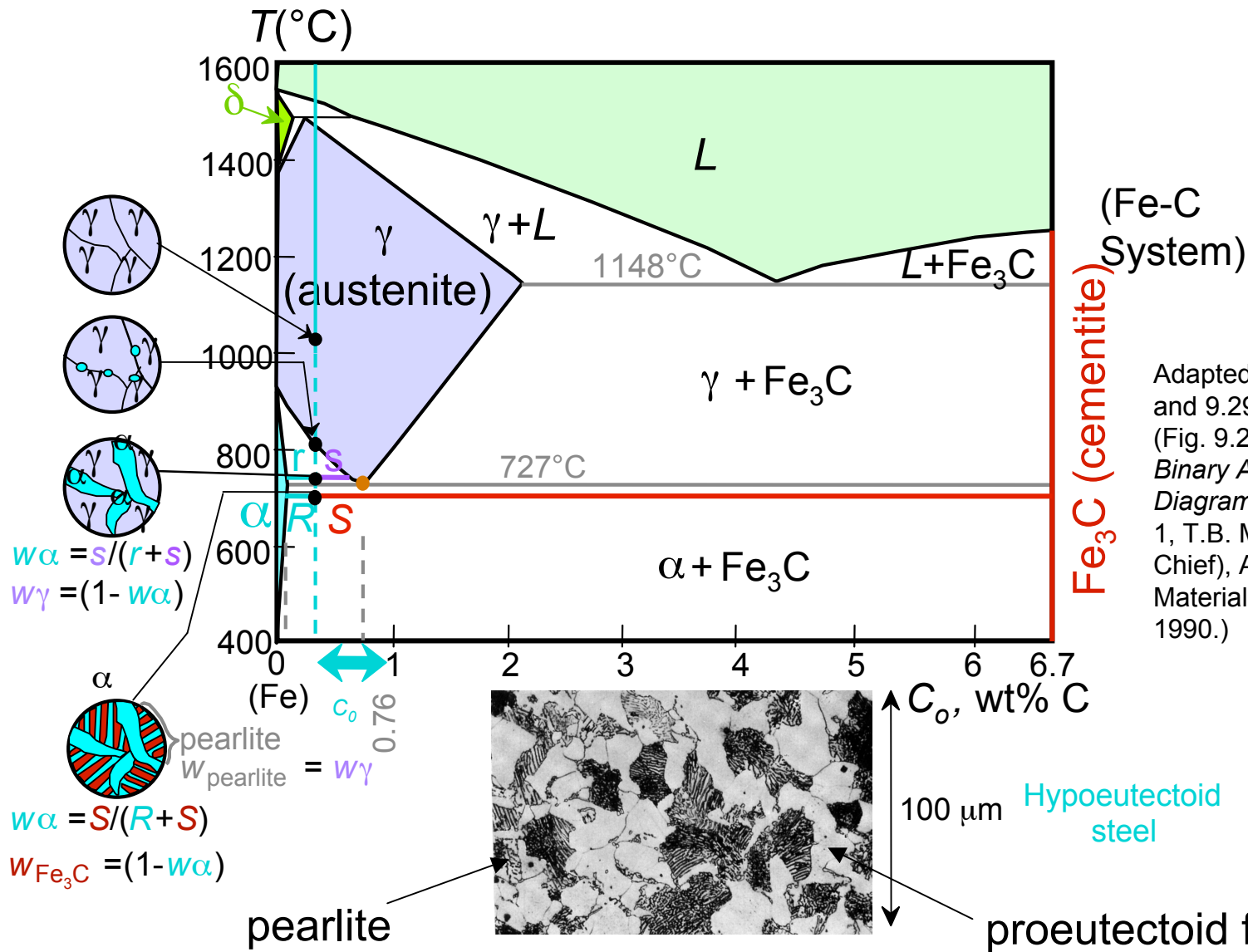


Result: Pearlite = alternating layers of α and Fe_3C phases

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

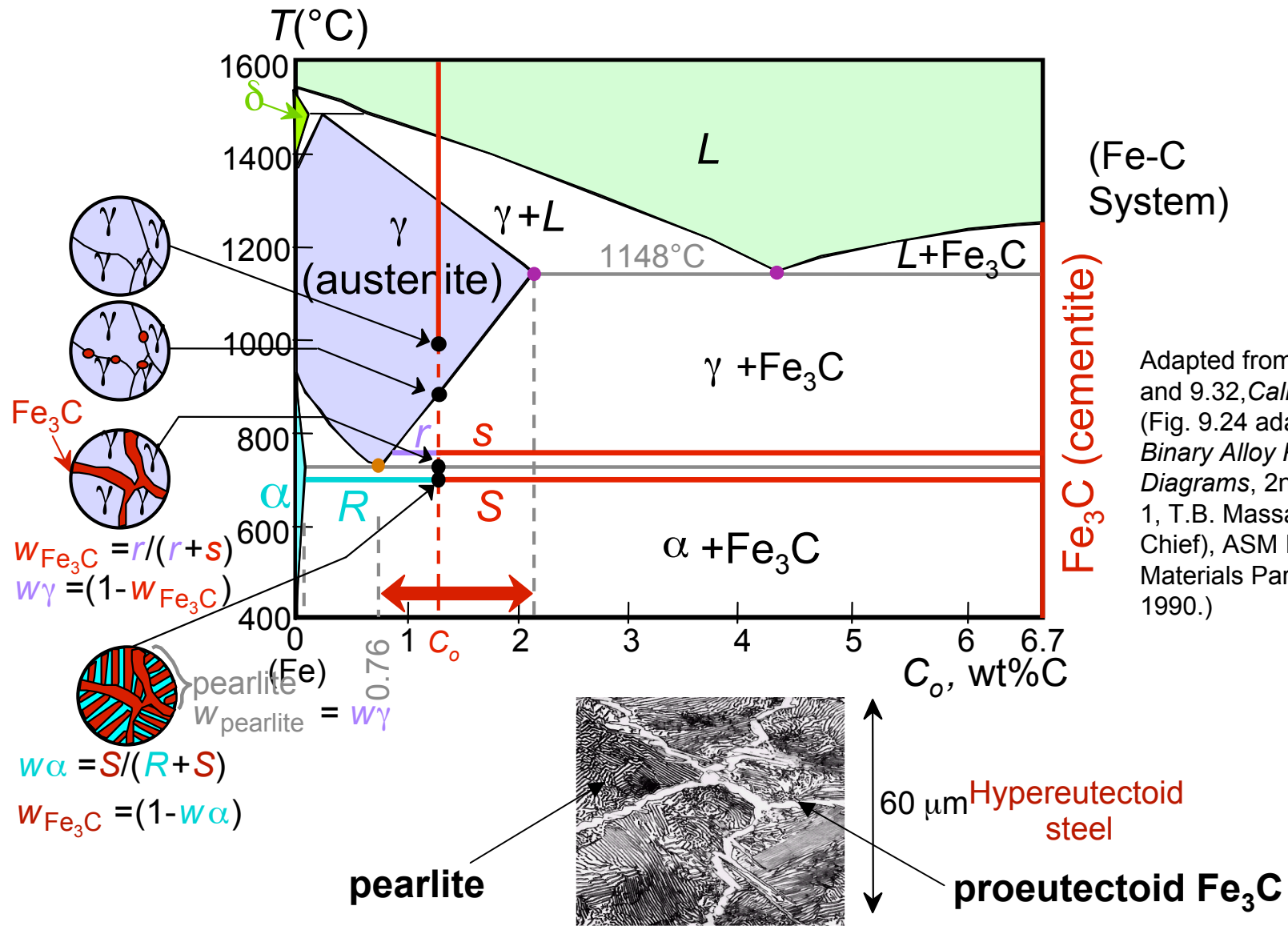


Hypoeutectoid steel



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

Hypereutectoid steel



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