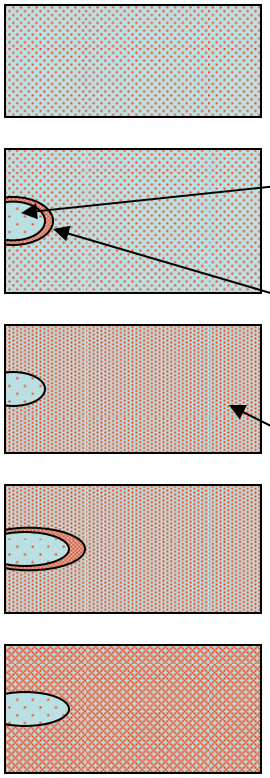
# Phase diagrams (cont.) and the Fe-C system

# Solidification: Pro-eutectic vs Eutectic

## Pro-eutectic solidification



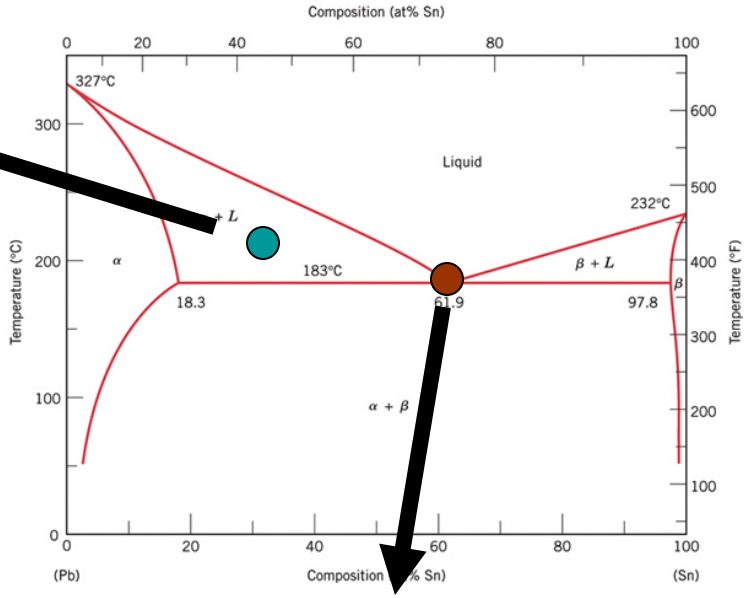
Ideal liquid,
uniform distribution

Solid Pb(Sn) (α) nucleates

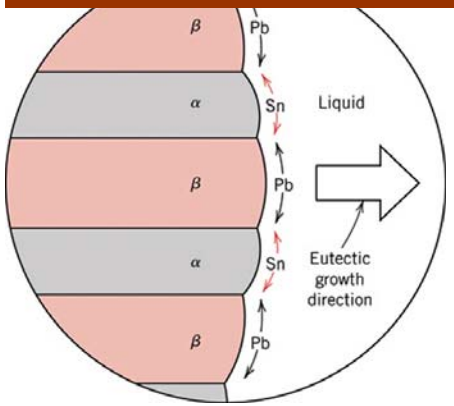
Solubility limit leads to
Sn rich area just outside α

Sn easily redistributes in L

Process continues until
eutectic temperature
is reached

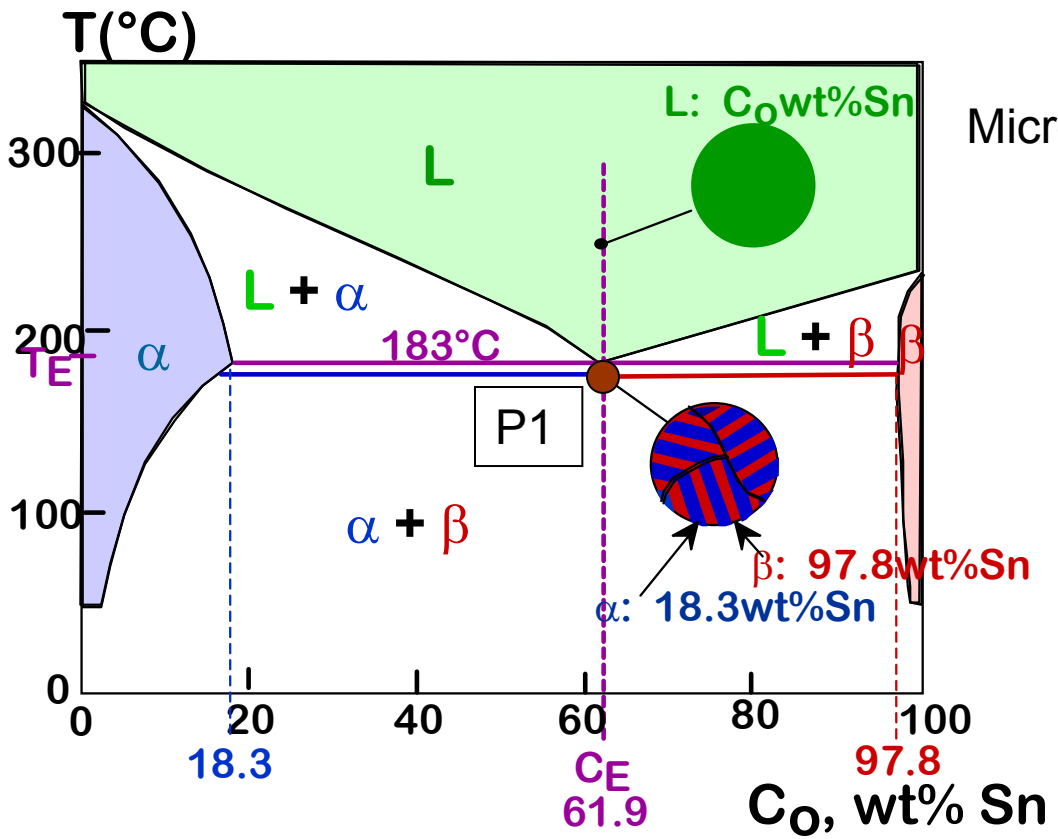



## Eutectic solidification



# MICROSTRUCTURES IN EUTECTIC SYSTEMS

- $C_o = C_E$
- Eutectic microstructure
  --alternating layers of $\alpha$ and $\beta$ crystals.




Phases at P1?

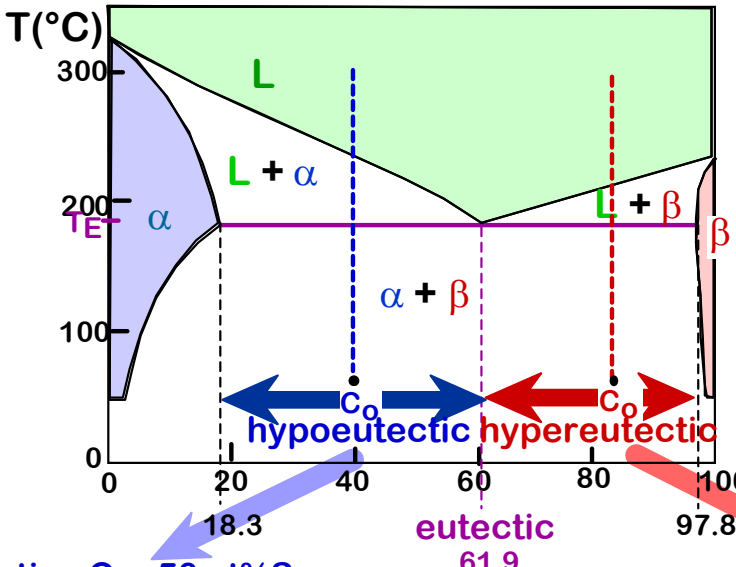
Microconstituents at P1?

How much of each phase?

Adapted from Fig. 9.12, *Callister 6e.* (Fig. 9.12 from *Metals Handbook*, Vol. 9, 9th ed., *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

# HYPOEUTECTIC & HYPEREUTECTIC

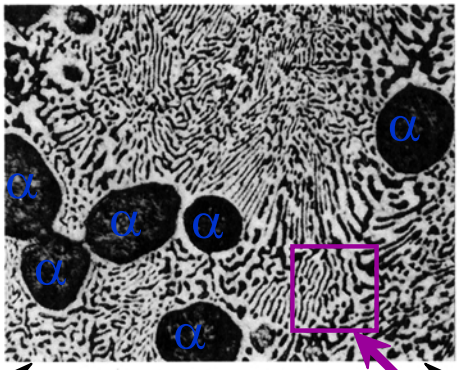
Adapted from Fig. 9.7, *Callister 6e.* (Fig. 9.7 adapted from *Binary Phase Diagrams*, 2nd ed., Vol. 3, T.B. Massalski (Editor-in-Chief), ASM International, Materials Park, OH, 1990.)




(Pb-Sn System)

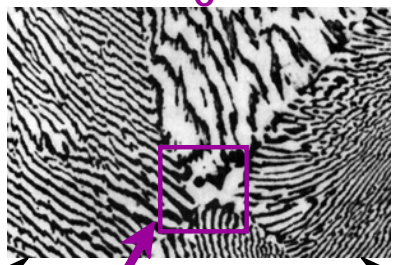
(Figs. 9.12 and 9.15 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

hypoeutectic: $C_O$=50wt%Sn



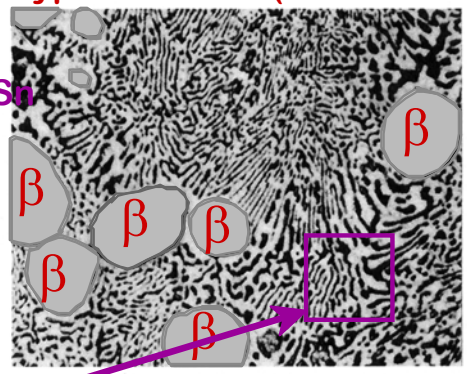

175μm

eutectic: $C_O$=61.9wt%Sn



160μm

hypereutectic: (illustration only)

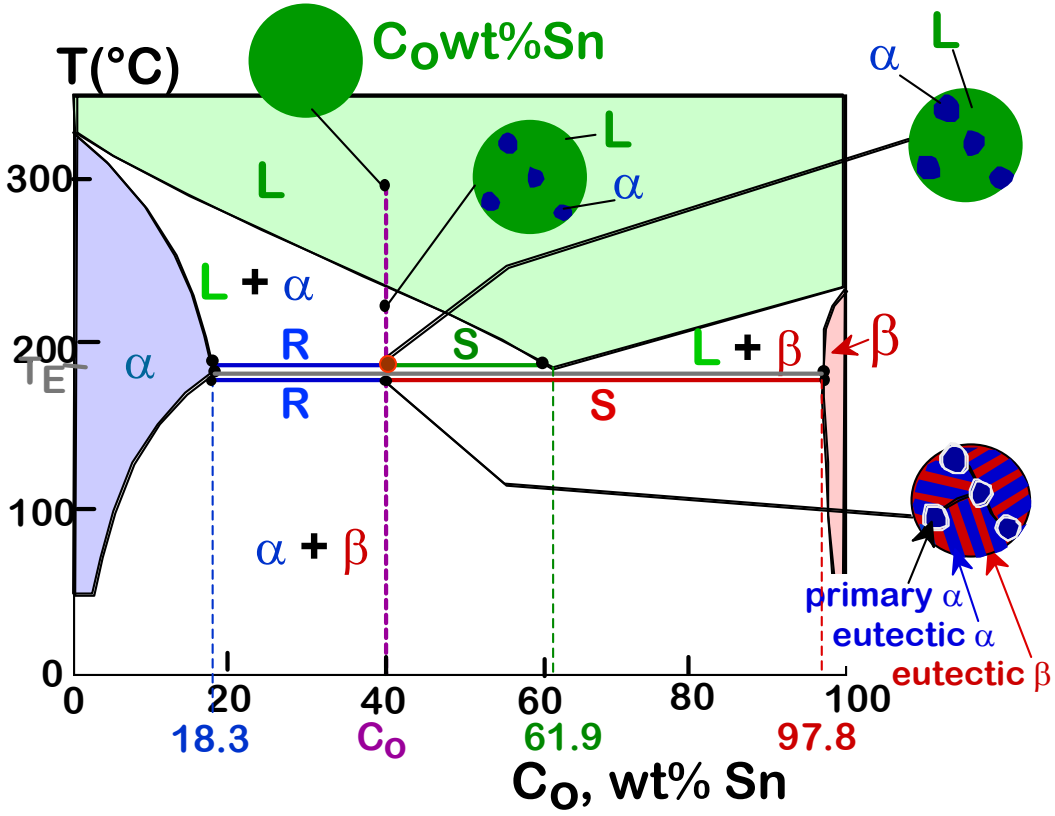



eutectic micro-constituent

# MICROSTRUCTURES IN EUTECTIC SYSTEMS

- 18.3wt%Sn < $C_o$ < 61.9wt%Sn

**Example: Pb-Sn system**




**Just Above $T_E$**

Phases?
Composition?
How much of each?

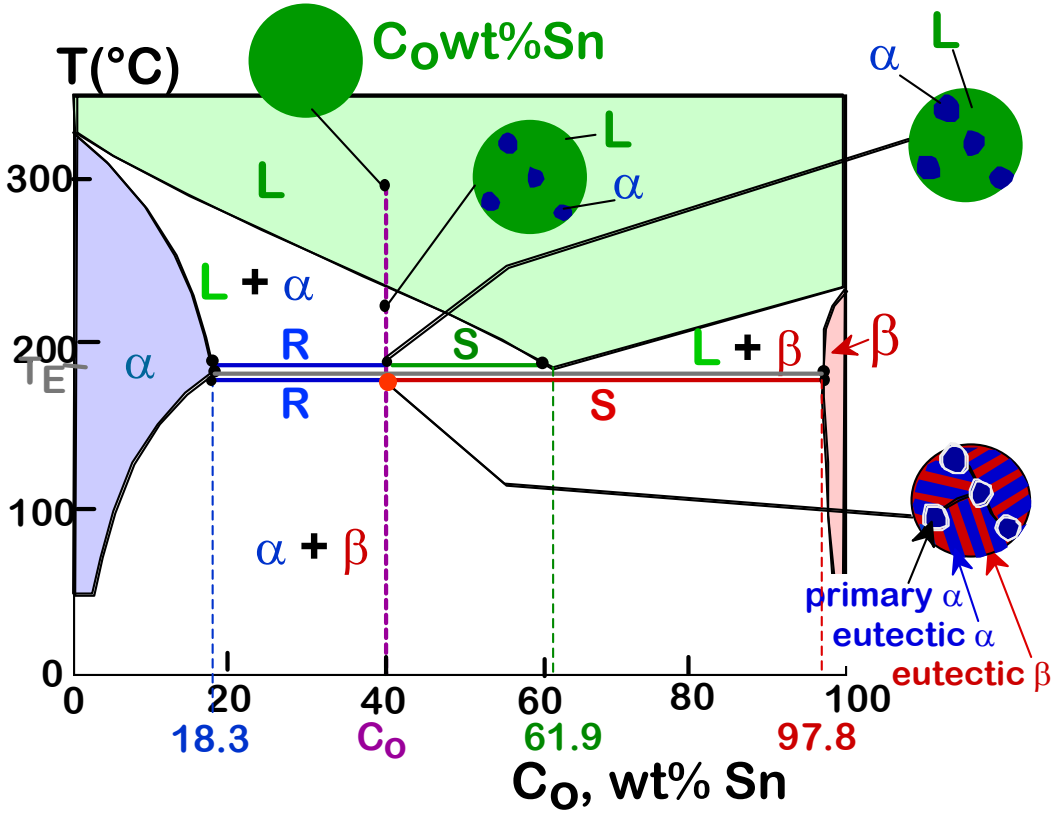
Microconstituents?
How much of each?

Adapted from Fig. 9.14, *Callister 6e.*

# MICROSTRUCTURES IN EUTECTIC SYSTEMS

- 18.3wt%Sn < $C_o$ < 61.9wt%Sn

**Example: Pb-Sn system**



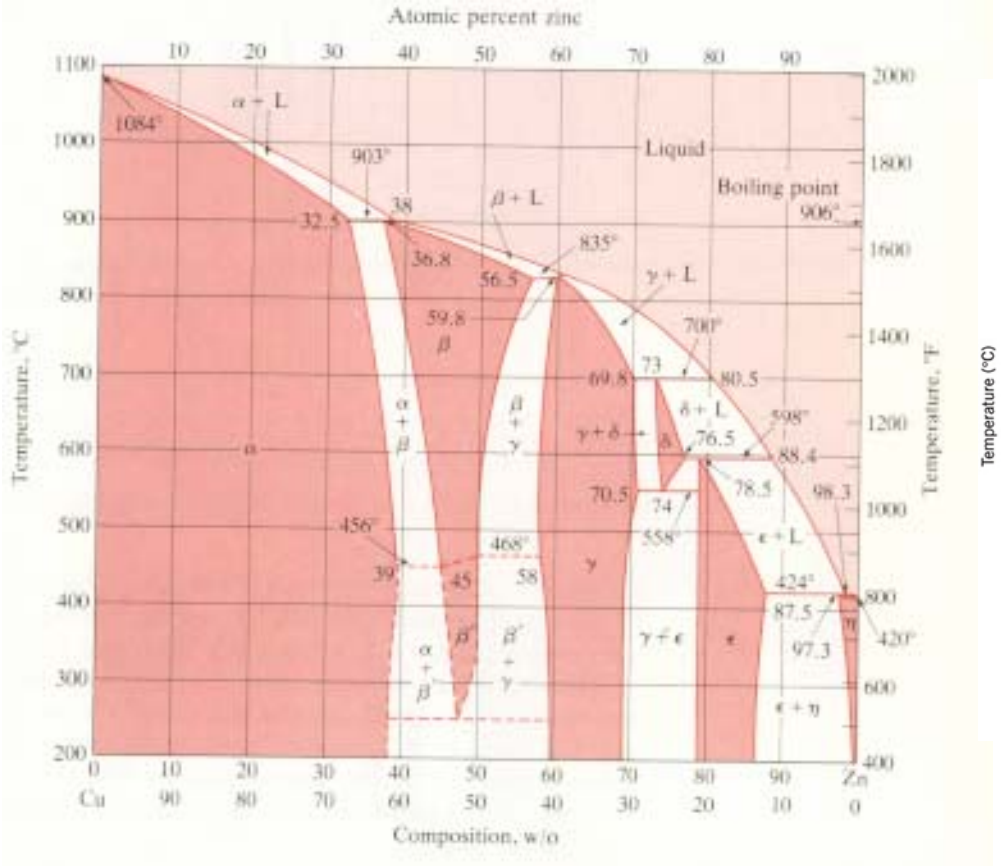

**Just Below $T_E$**

Phases?
Composition?
How much of each?

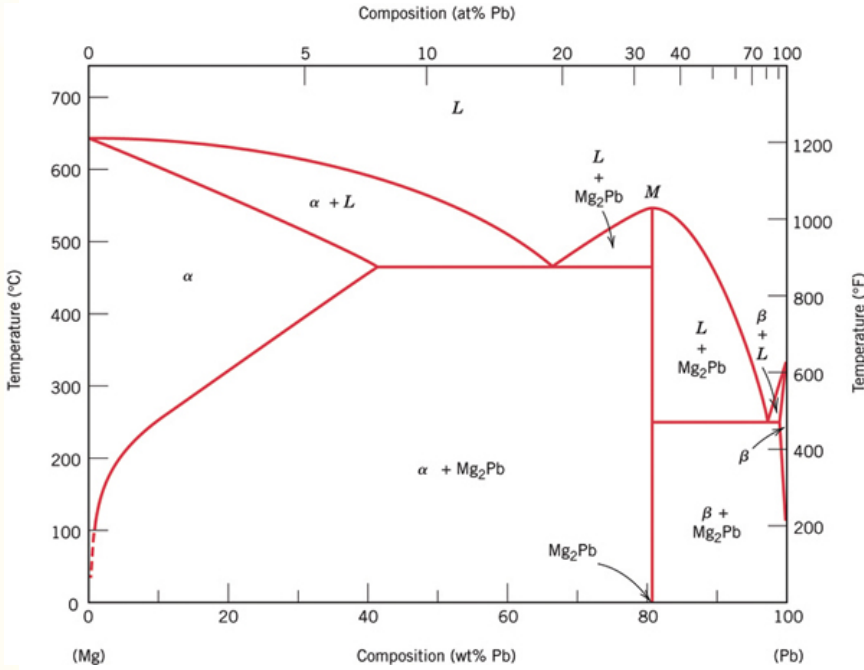
Microconstituents?
How much of each?

Adapted from Fig. 9.14, *Callister 6e.*

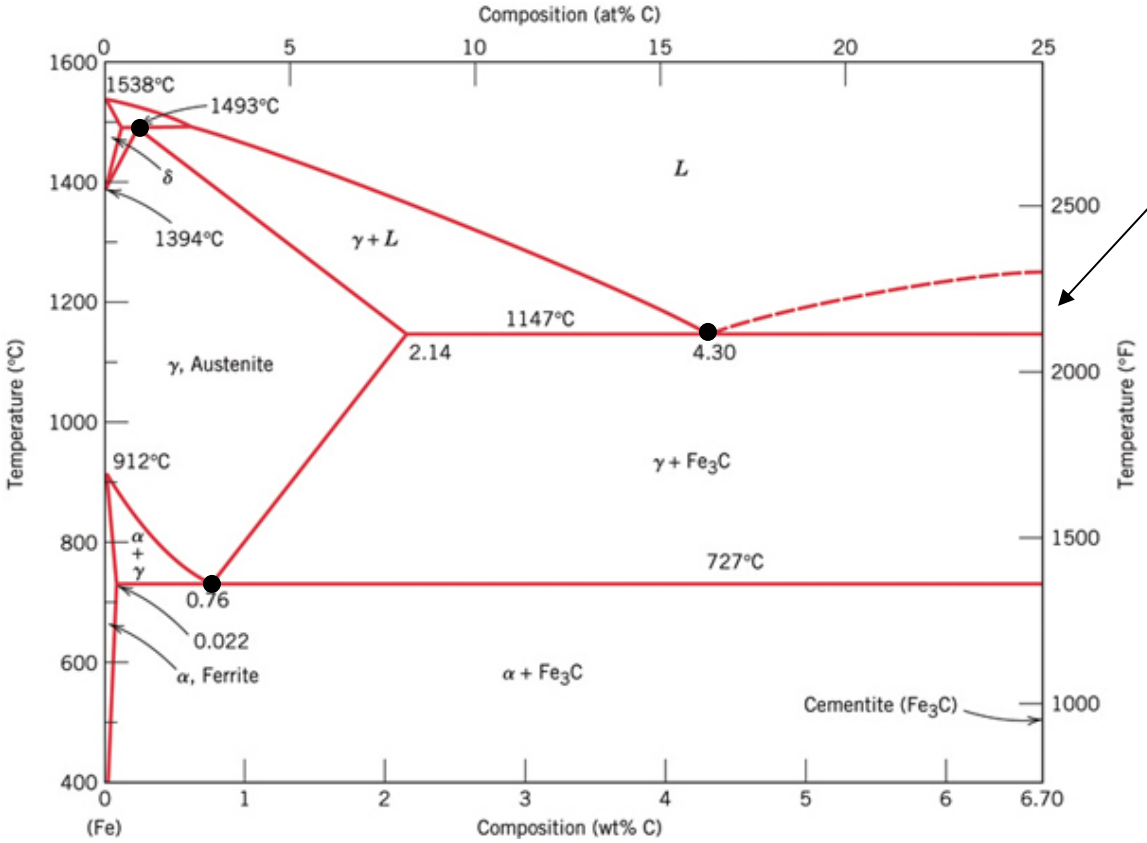
# Systems with intermediate compounds or solid solutions




Cu, Zn



# Iron - Carbon system: Consider only Fe to $Fe_3C$ portion



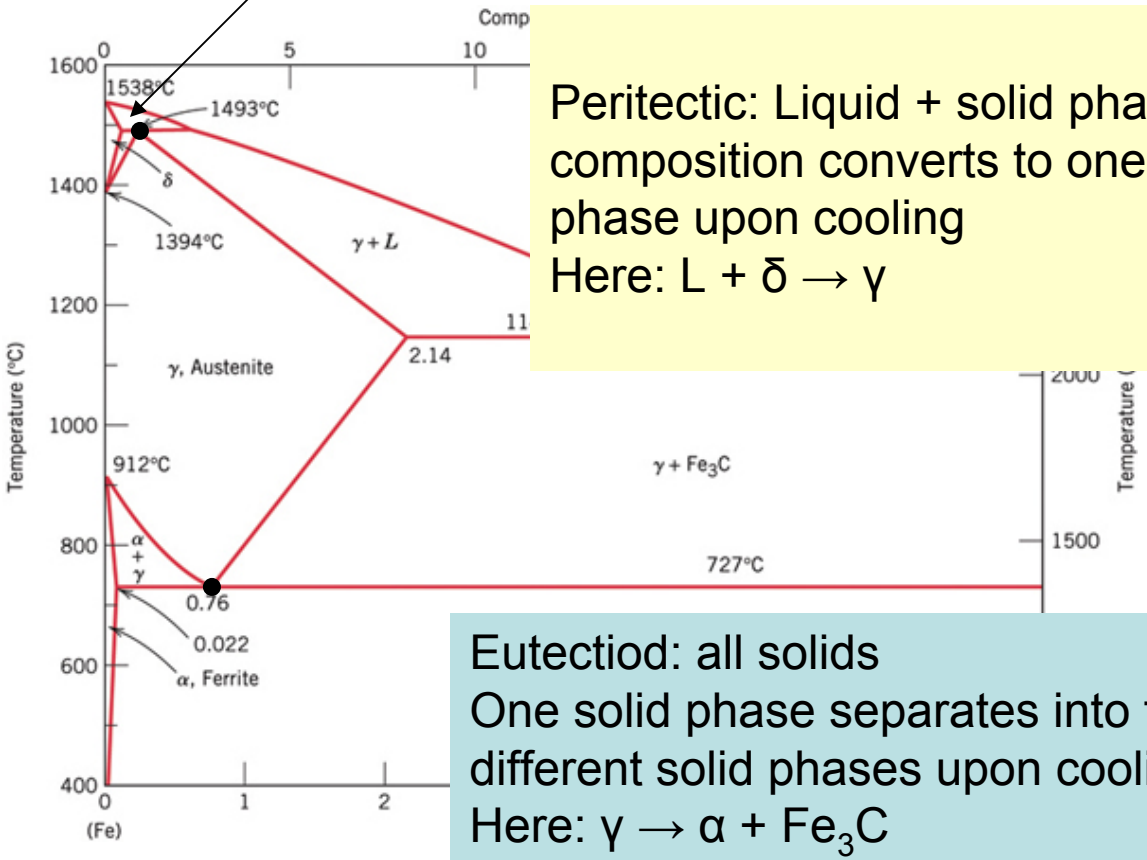

**AXES:**
**Cementite: $Fe_3C$ (Compound)**

**PURE Iron**
**Ferrite (α): BCC**
**Austenite(γ): FCC**
**Ferrite (δ): BCC**

**Solid solutions**
**α,δ,γ, interstitial C**
**Different solubilities**

# Peritectic and Eutectic Example: Iron - Carbon system

Phases?




Peritectic: Liquid + solid phase at given composition converts to one **different** solid phase upon cooling

Here: L + δ → γ

Eutectiod: all solids

One solid phase separates into two different solid phases upon cooling

Here: γ → α + $Fe_3C$

# Alloy Classifications in the Iron Carbon system

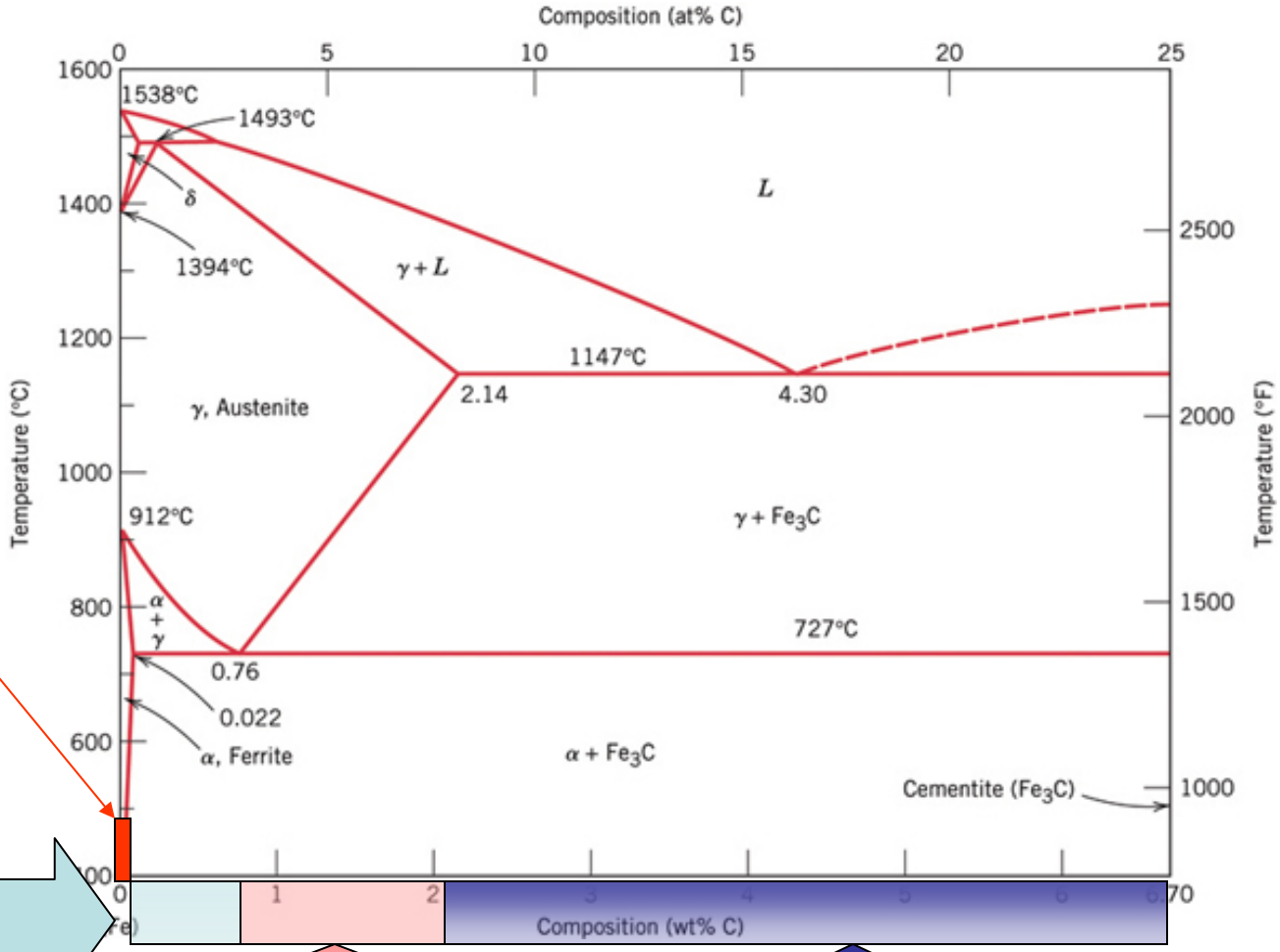
Numbers in %

Iron
0 – 0.008

Hypo Eutectoid **Steel**
0.008 – 0.76

Hyper Eutectoid **Steel**
0.76 – 2.14

**Cast Iron**
**2.14 – 6.7% C**



# IRON-CARBON (Fe-C) PHASE DIAGRAM

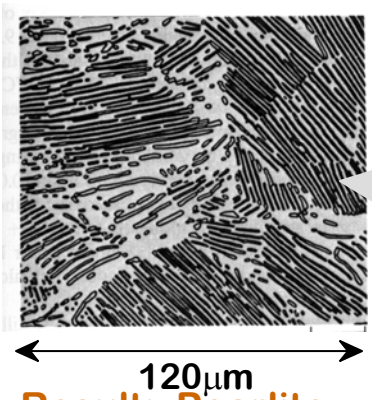
- 2 important points

**-Eutectic (A):**

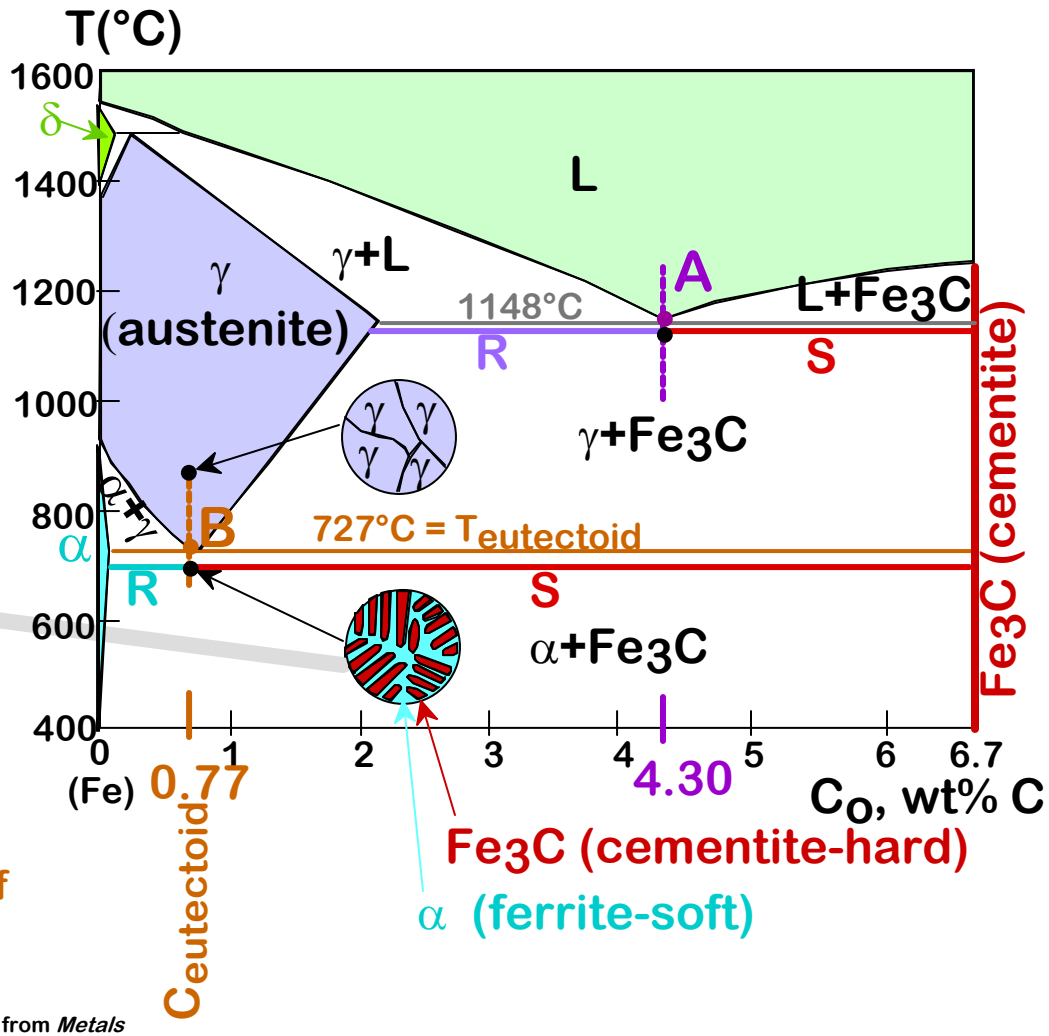
$L \Rightarrow \gamma + Fe_3C$

**-Eutectoid (B):**

$\gamma \Rightarrow \alpha + Fe_3C$

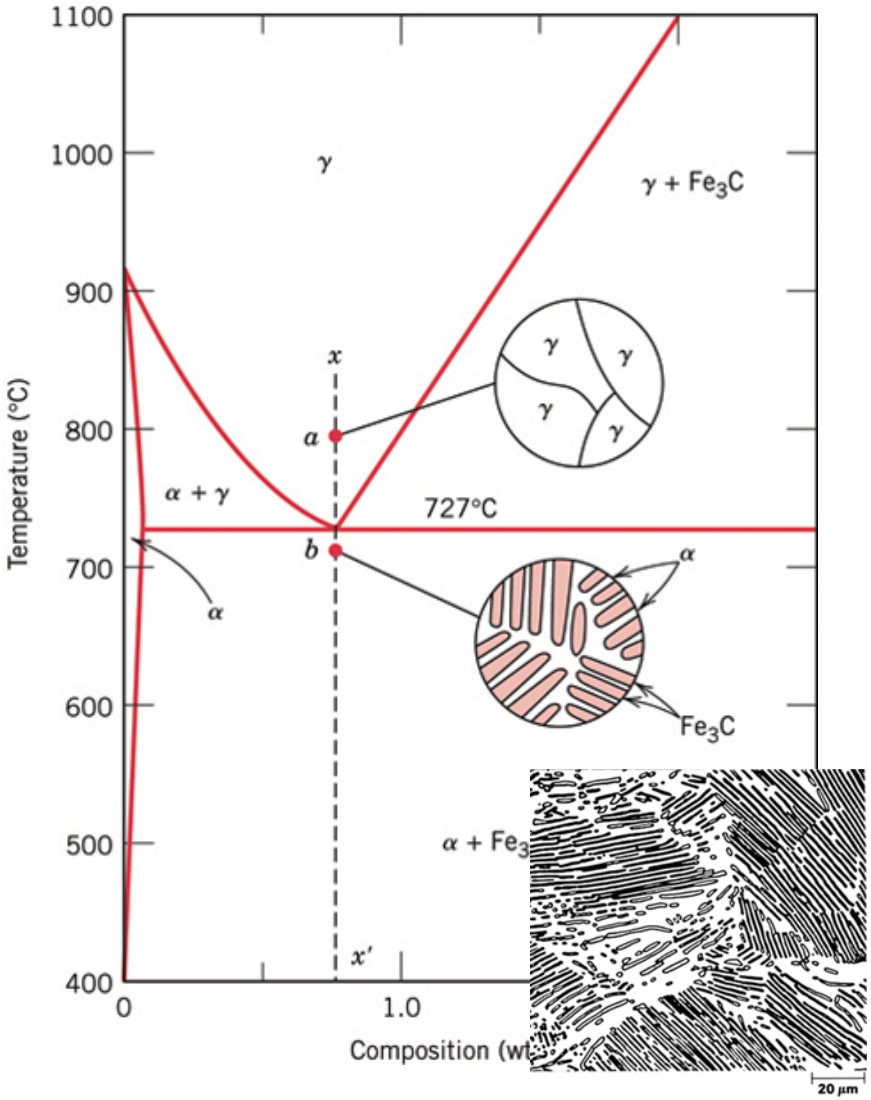



Result: Pearlite = alternating layers of α and $Fe_3C$ phases.



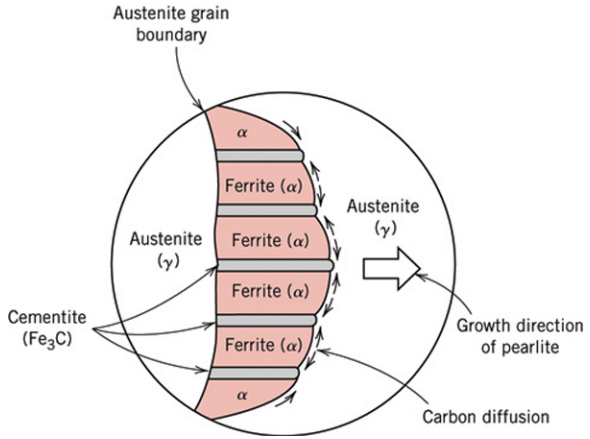

(Adapted from Fig. 9.24, *Callister 6e*. (Fig. 9.24 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, American Society for Metals, Materials Park, OH, 1985.)

# Eutectoid: 0.76% C
# Pearlite formation



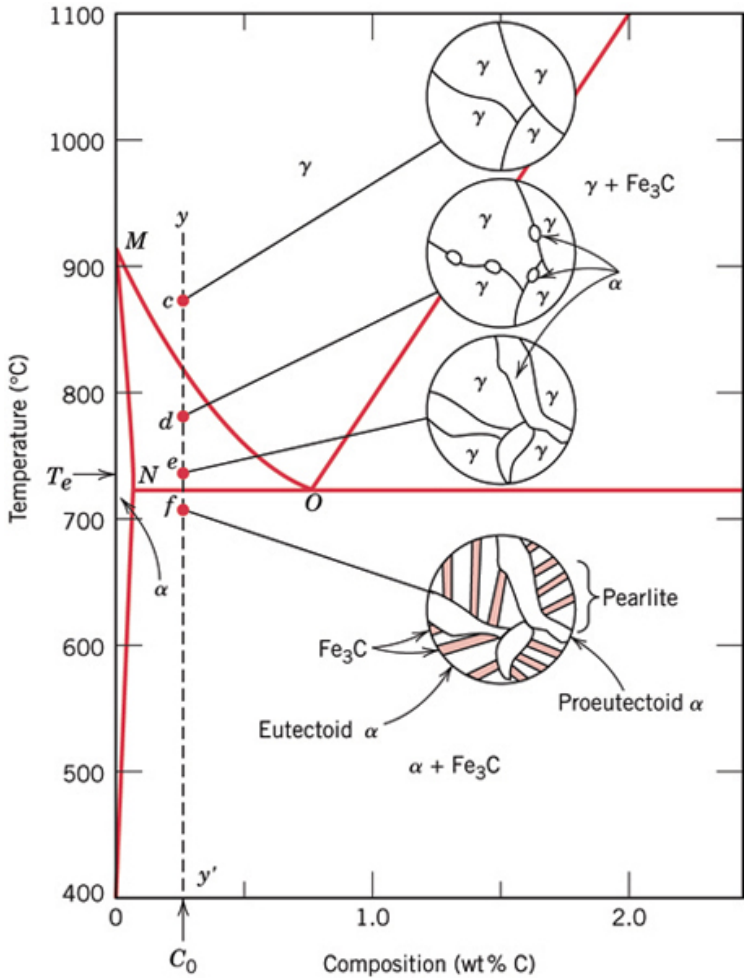

- Solid transformation
- γ → α + Fe3C

0.76% 0.02% 6.7%




Similar to Eutectic transformation - but now, diffusion occurs within solid

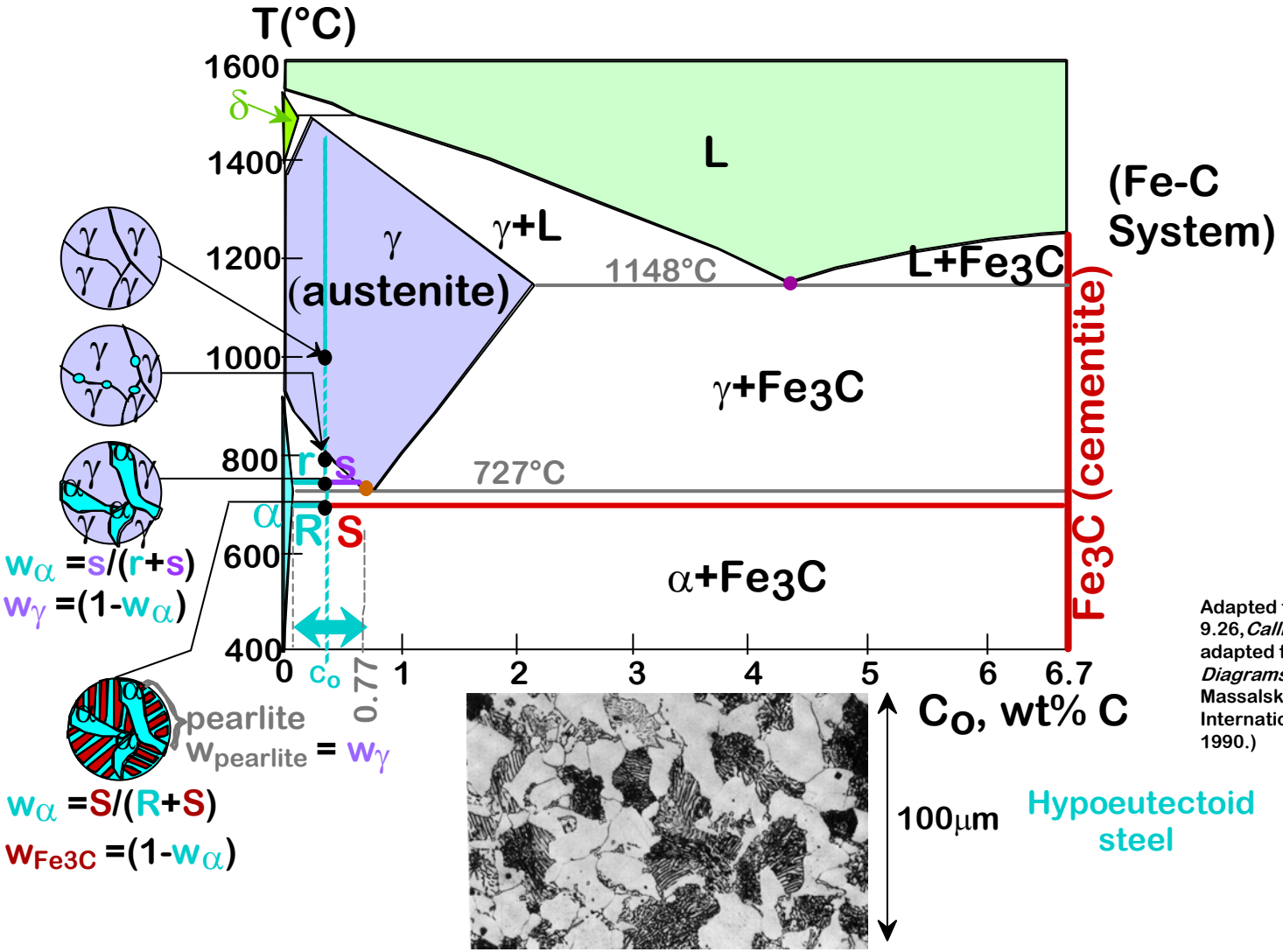
# Hypo eutectoid microstructure at Room T
# Proeutectoid Ferrite + Pearlite




- γ → α + γ
- Ferrite phase increases as T decreases
- At T(eutectoid)

  γ + α → Pearlite + α
  - Remaining austenite transforms to pearlite

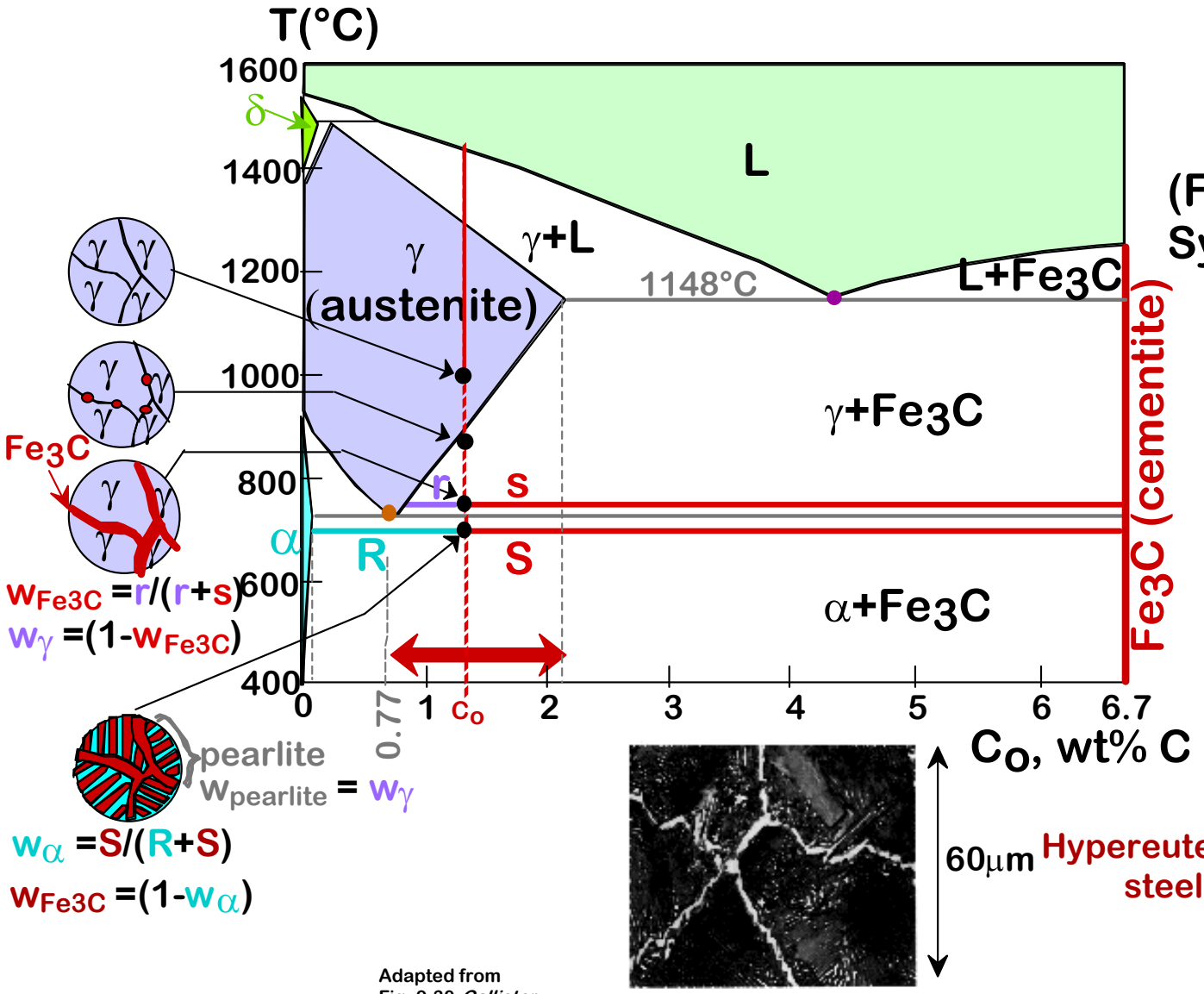
# HYPOEUTECTOID STEEL




Adapted from Figs. 9.21 and 9.26, *Callister 6e.* (Fig. 9.21 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. 9.27, *Callister 6e.* (Fig. 9.27 courtesy Republic Steel Corporation.)

# HYPEREUTECTOID STEEL





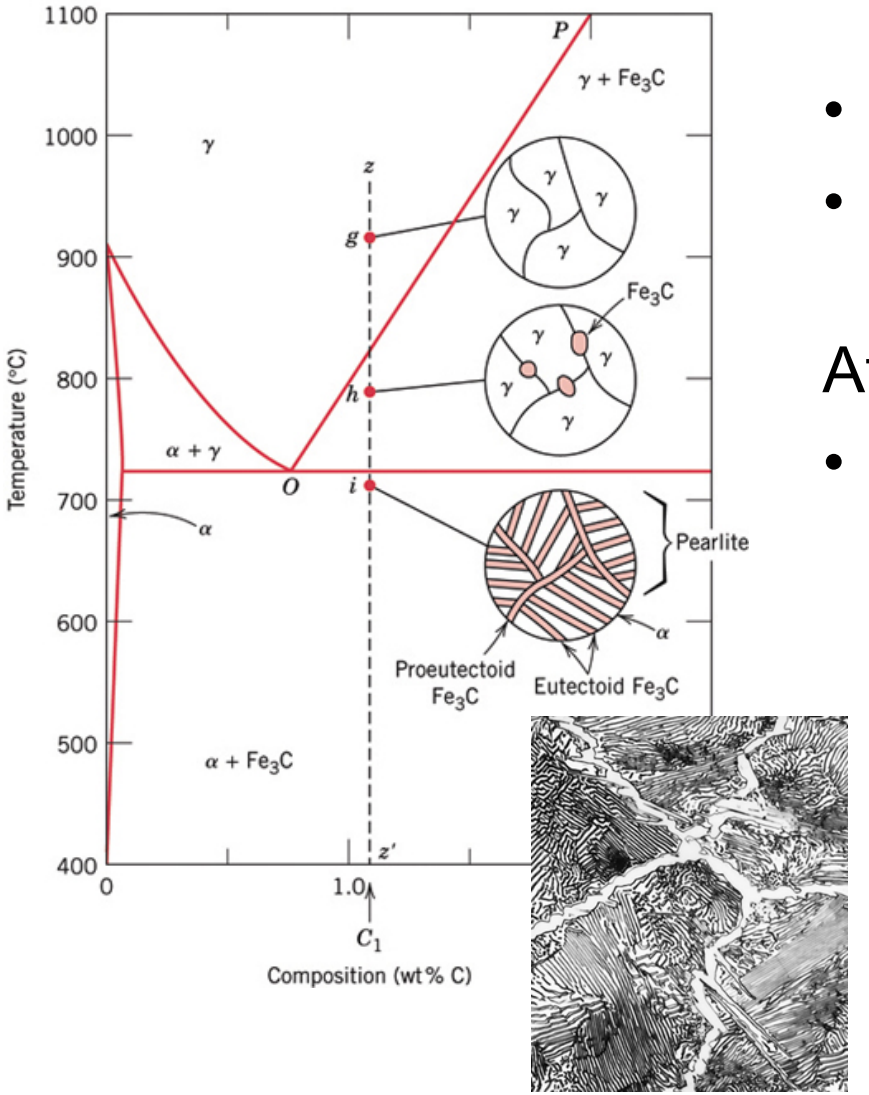


Hypereutectoid steel

Adapted from Figs. 9.21 and 9.29, *Callister 6e.* (Fig. 9.21 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 6e.* (Fig. 9.30 copyright 1971 by United States Steel Corporation.)

# Hyper eutectoid microstructure at Room T
# Proeutectoid Cementite + Pearlite



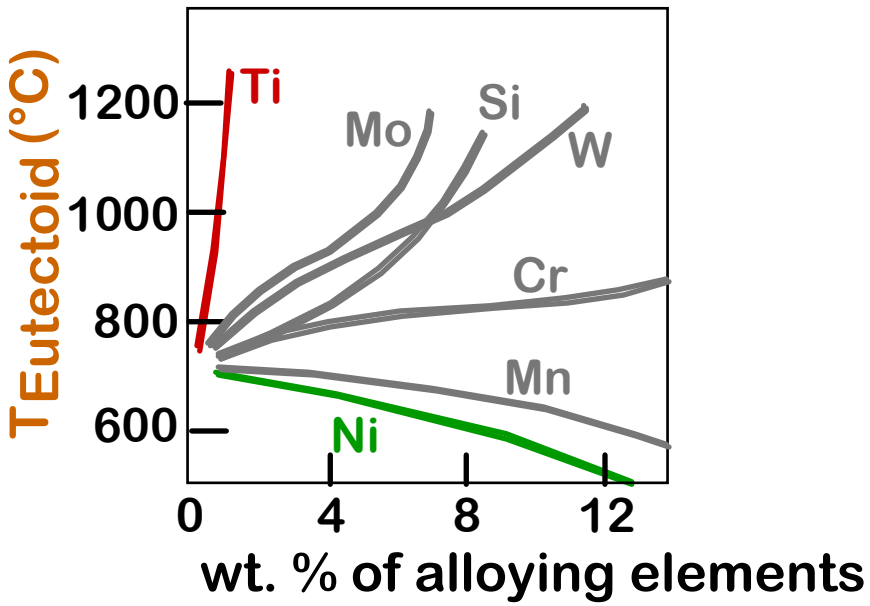

- γ → cementite + γ
- cementite phase increases

At T(eutectoid)

- γ + Fe3C → Fe3C + Pearlite
  - Remaining austenite transforms to pearlite

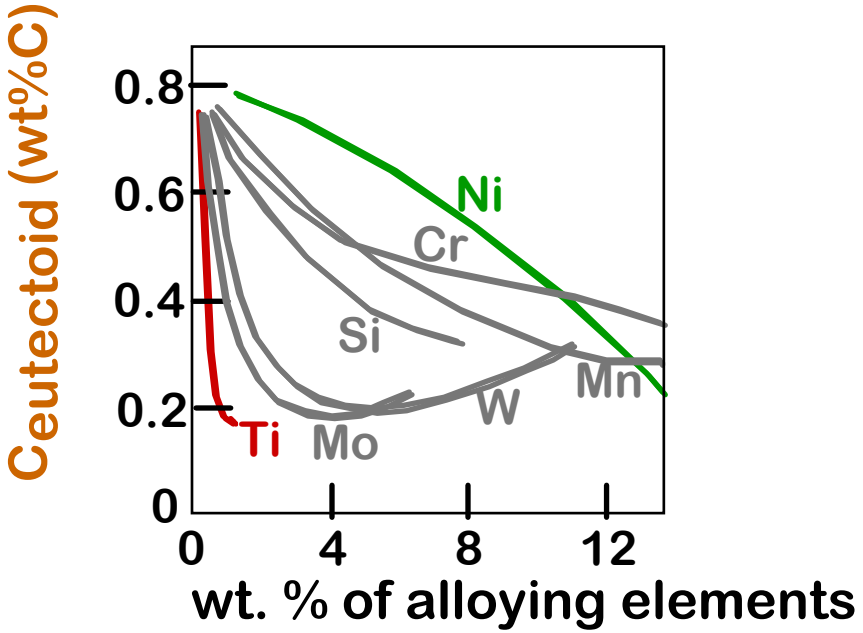
# ALLOYING STEEL WITH MORE ELEMENTS

- Change in $T_{eutectoid}$ (727 °C):




Adapted from Fig. 9.31, *Callister 6e*. (Fig. 9.31 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

- Change in $C_{eutectoid}$ (0.76% C):

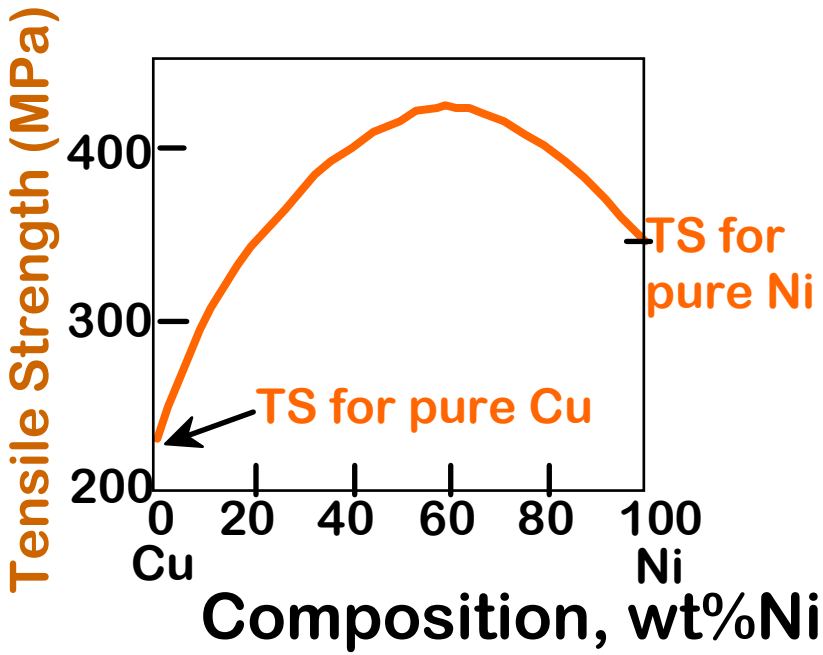



Adapted from Fig. 9.32, *Callister 6e*. (Fig. 9.32 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

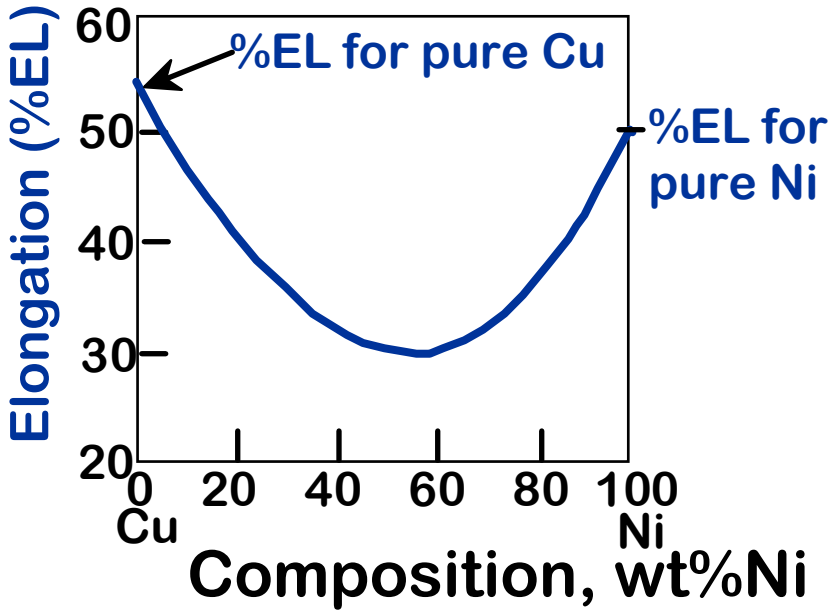
# MECHANICAL PROPERTIES: Cu-Ni System

- **Effect of solid solution strengthening on:**

--Tensile strength (TS)




--Ductility (%EL,%AR)




--Peak as a function of $C_o$

--Min. as a function of $C_o$