Chemical Engineering 378

Science of Materials Engineering

Lecture 20

Phase Equilibrium, Fe & C Systems

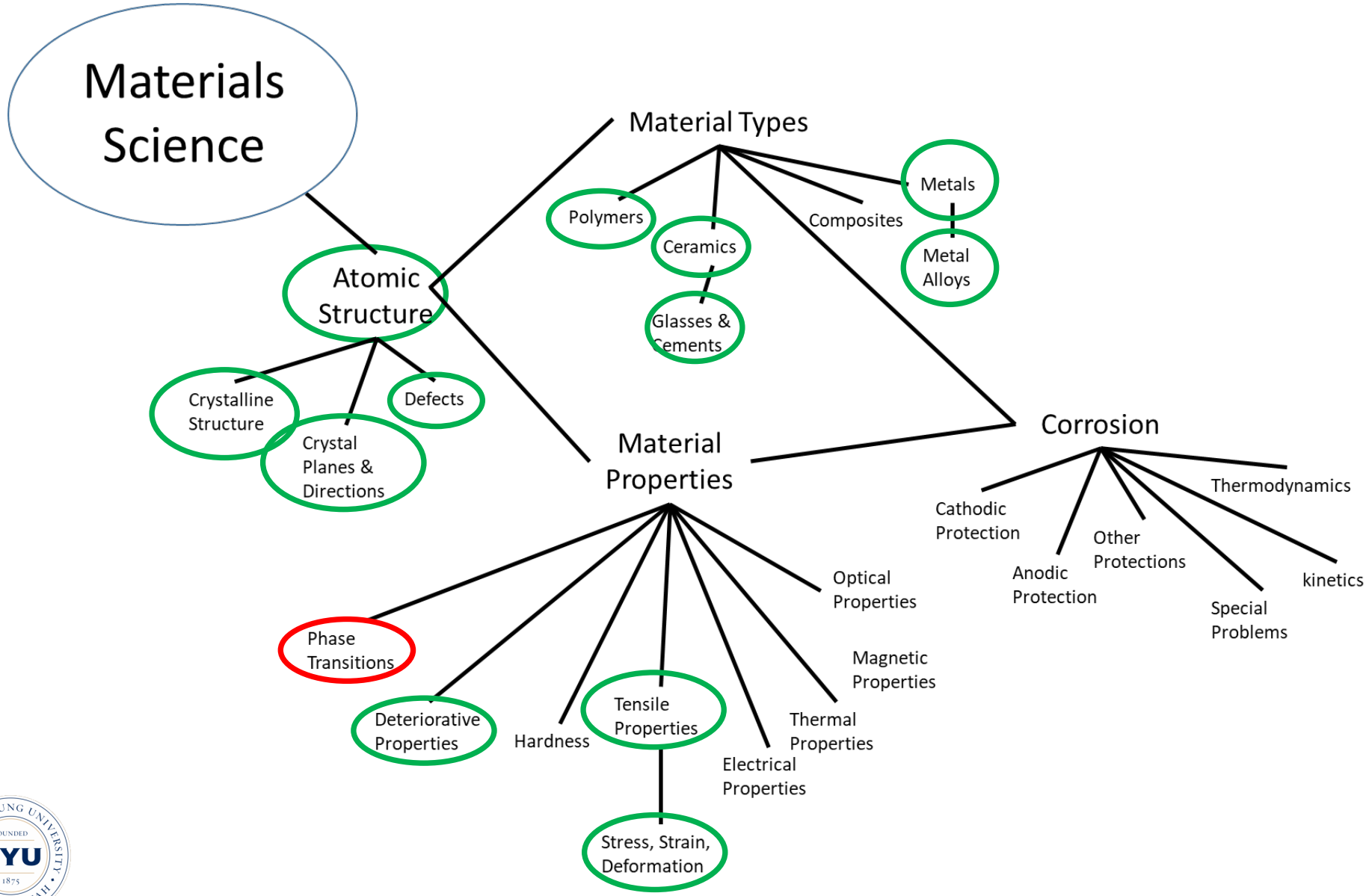
Spiritual Thought

D&C 89:18-19

18 And all saints who remember to keep and do these sayings, walking in obedience to the commandments, shall receive health in their navel and marrow to their bones;

19 And shall find wisdom and great treasures of knowledge, even hidden treasures;

Materials Roadmap



Microstructural Developments in Eutectic Systems IV

- For alloys for which 18.3 wt% Sn < C_0 < 61.9 wt% Sn
- Result: α phase particles and a eutectic microconstituent

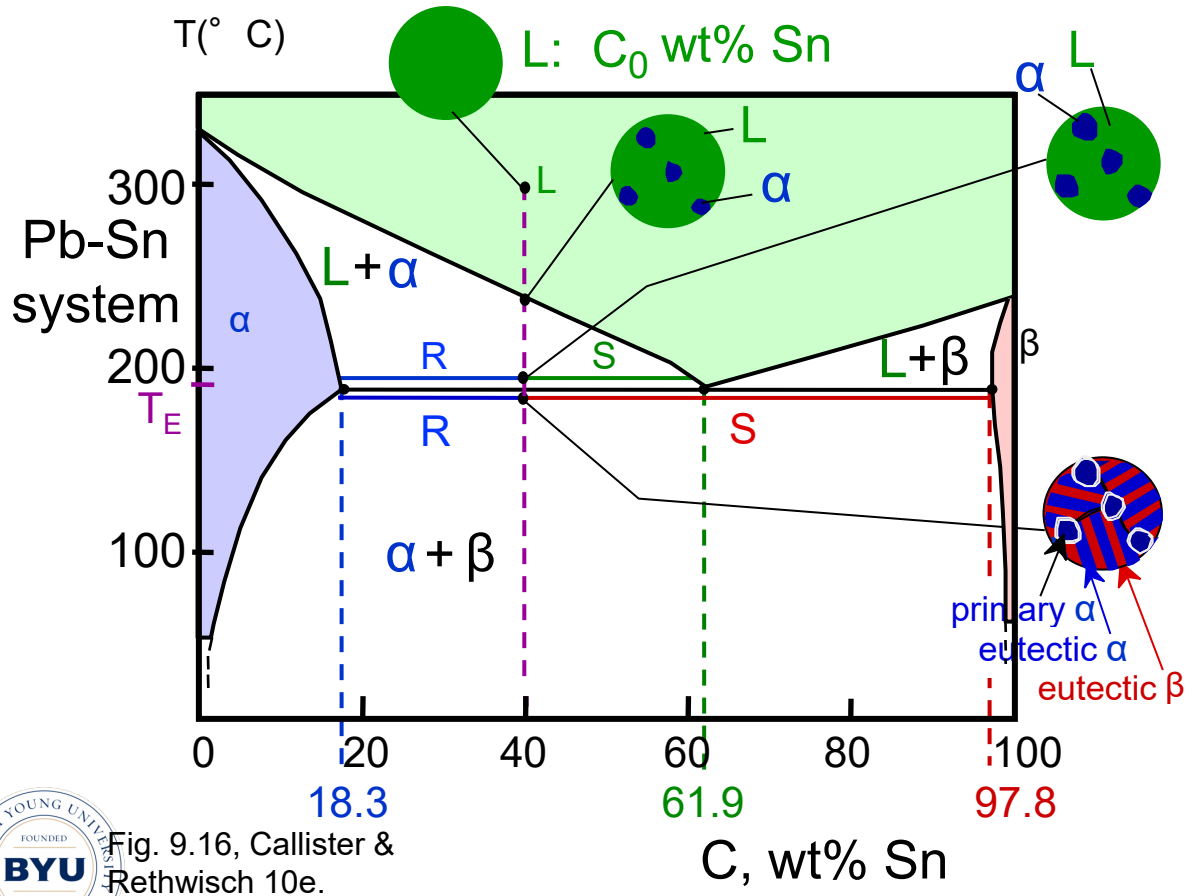


Fig. 9.16, Callister & Rethwisch 10e.

- Just above T_E :

C_α = 18.3 wt% Sn

C_L = 61.9 wt% Sn

$W_\alpha = \frac{S}{R+S} = 0.50$

$W_L = (1 - W\alpha) = 0.50$

- Just below T_E :

$C\alpha$ = 18.3 wt% Sn

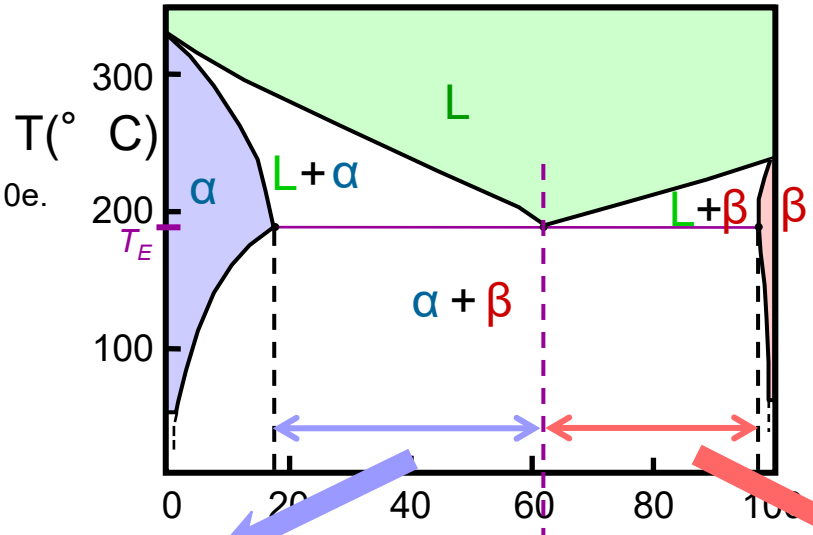
$C\beta$ = 97.8 wt% Sn

$W\alpha = \frac{S}{R+S} = 0.73$

$W\beta$ = 0.27

Hypoeutectic & Hypereutectic

Fig. 9.8, Callister & Rethwisch 10e.
[Adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 3, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



(Pb-Sn System)

(Figs. 9.14 and 9.17 from Metals Handbook, 9th ed., Vol. 9, Metallography and Microstructures, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

hypoeutectic: C_0 = 50 wt% Sn

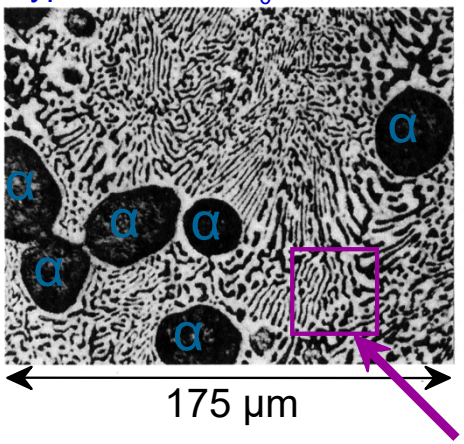
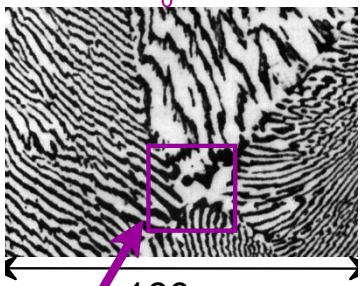


Fig. 9.17, Callister & Rethwisch 10e.

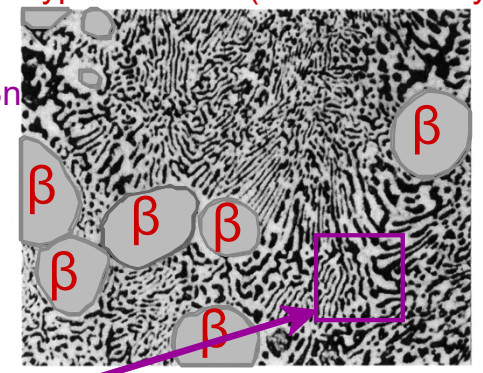
eutectic: C_0 = 61.9 wt% Sn



eutectic micro-constituent

Fig. 9.14, Callister & Rethwisch 10e.

hypereutectic: (illustration only)



Adapted from Fig. 9.17, Callister & Rethwisch 10e. (Illustration only)

Intermetallic Compounds

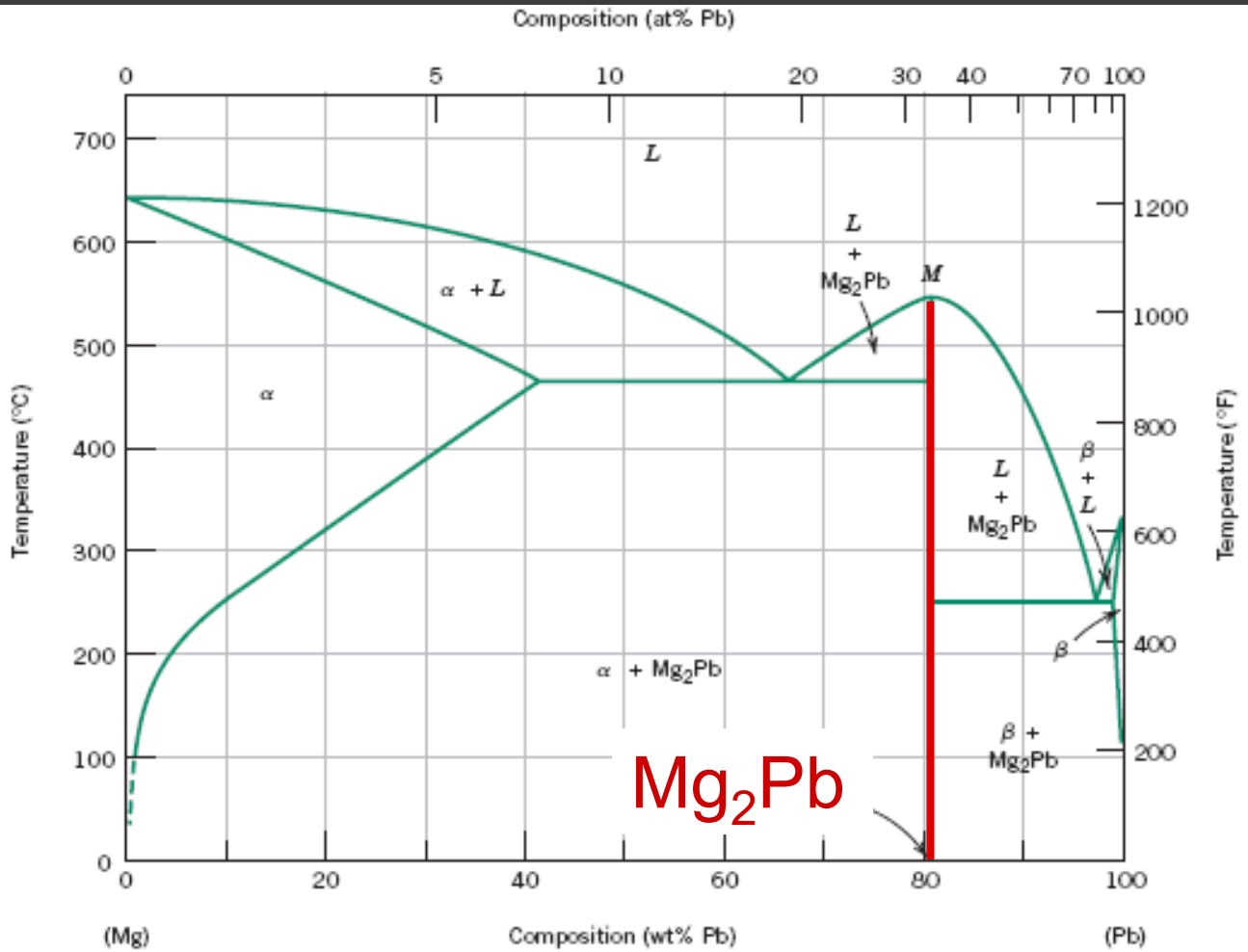


Fig. 9.20, Callister & Rethwisch 10e. [Adapted from Phase Diagrams of Binary Magnesium Alloys, A. A. Nayeb-Hashemi and J. B. Clark (Editors), 1988. Reprinted by permission of ASM International, Materials Park, OH.]

Note: intermetallic compound exists as a line on the diagram - not an area - because of stoichiometry (i.e. composition of a compound is a fixed value).

Eutectic, Eutectoid, & Peritectic

- Eutectic - liquid transforms to two solid phases

$$L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$ (For Pb-Sn, 183° C, 61.9 wt% Sn)

- Eutectoid – one solid phase transforms to two other solid phases

$$S_2 \rightleftharpoons S_1 + S_3$$

intermetallic compound - cementite

$$\gamma \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + Fe_3C$$ (For Fe-C, 727° C, 0.76 wt% C)

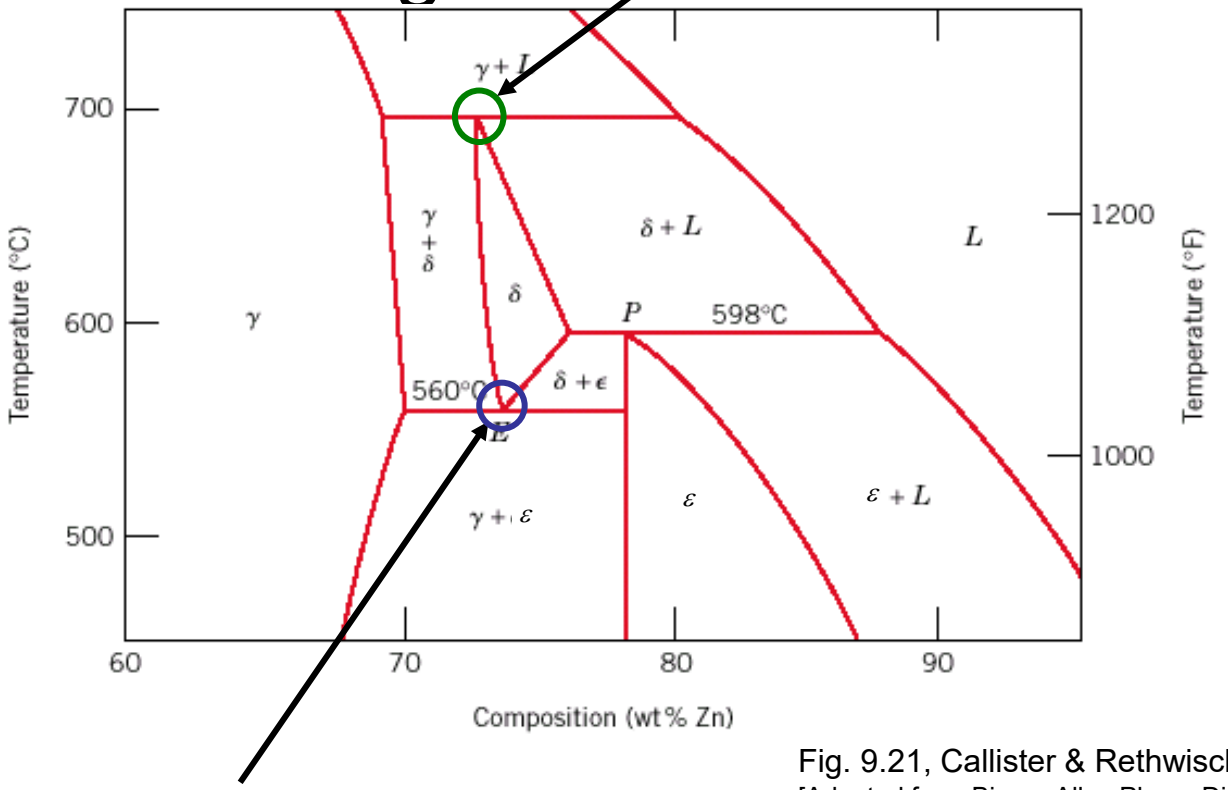
- Peritectic - liquid and one solid phase transform to a second solid phase
- $S_1 + L \rightleftharpoons S_2$

$$\delta + L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \gamma$$ (For Fe-C, 1493° C, 0.16 wt% C)

Eutectoid & Peritectic

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

Cu-Zn Phase diagram



Eutectoid transformation $\delta \rightleftharpoons \gamma + \varepsilon$

Fig. 9.21, Callister & Rethwisch 10e.
[Adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 2, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

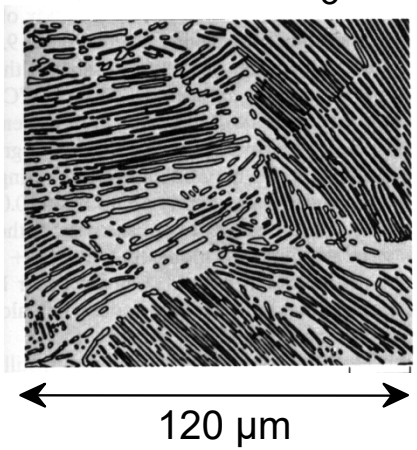
Iron-Carbon (Fe-C) Phase Diagram

- 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

Fig. 9.27, Callister & Rethwisch 10e. (From Metals Handbook, Vol. 9, 9th ed., Metallography and Microstructures, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

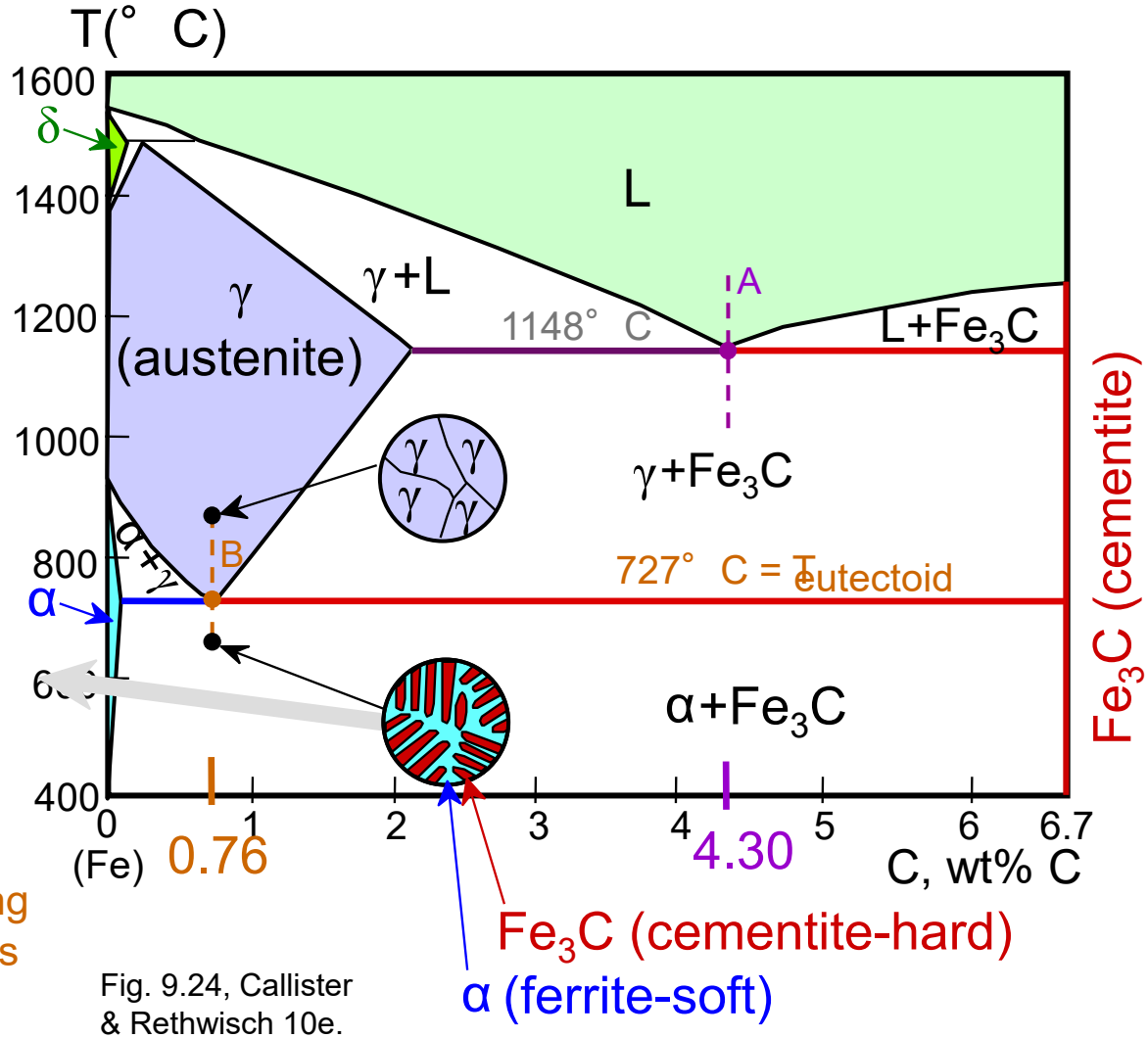
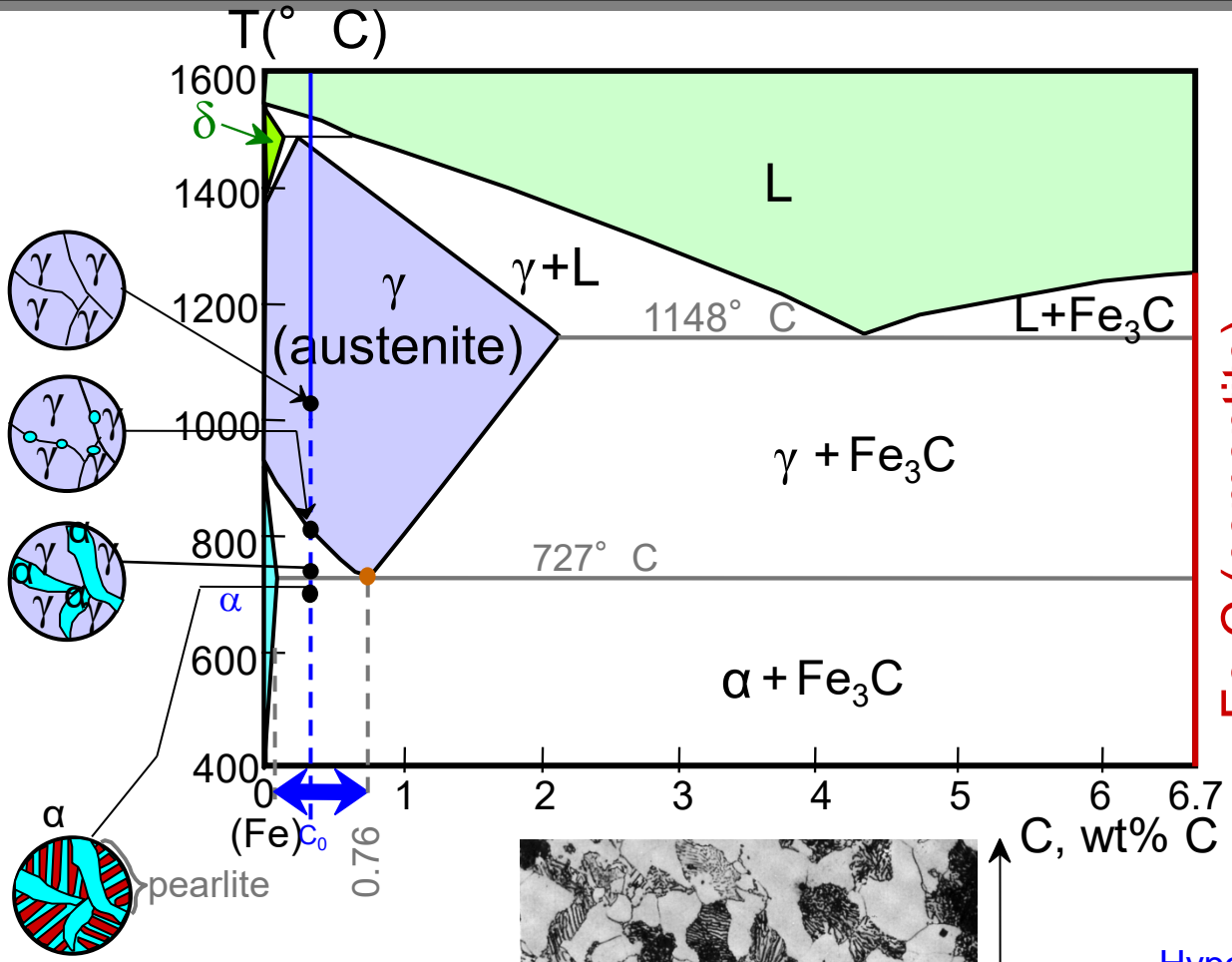
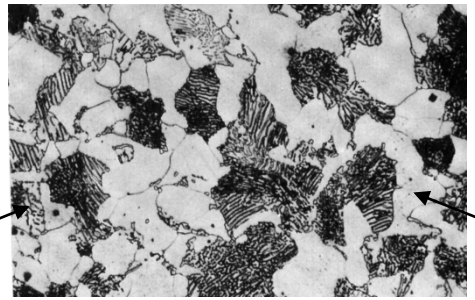


Fig. 9.24, Callister & Rethwisch 10e. [Adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

Hypoeutectoid Steel

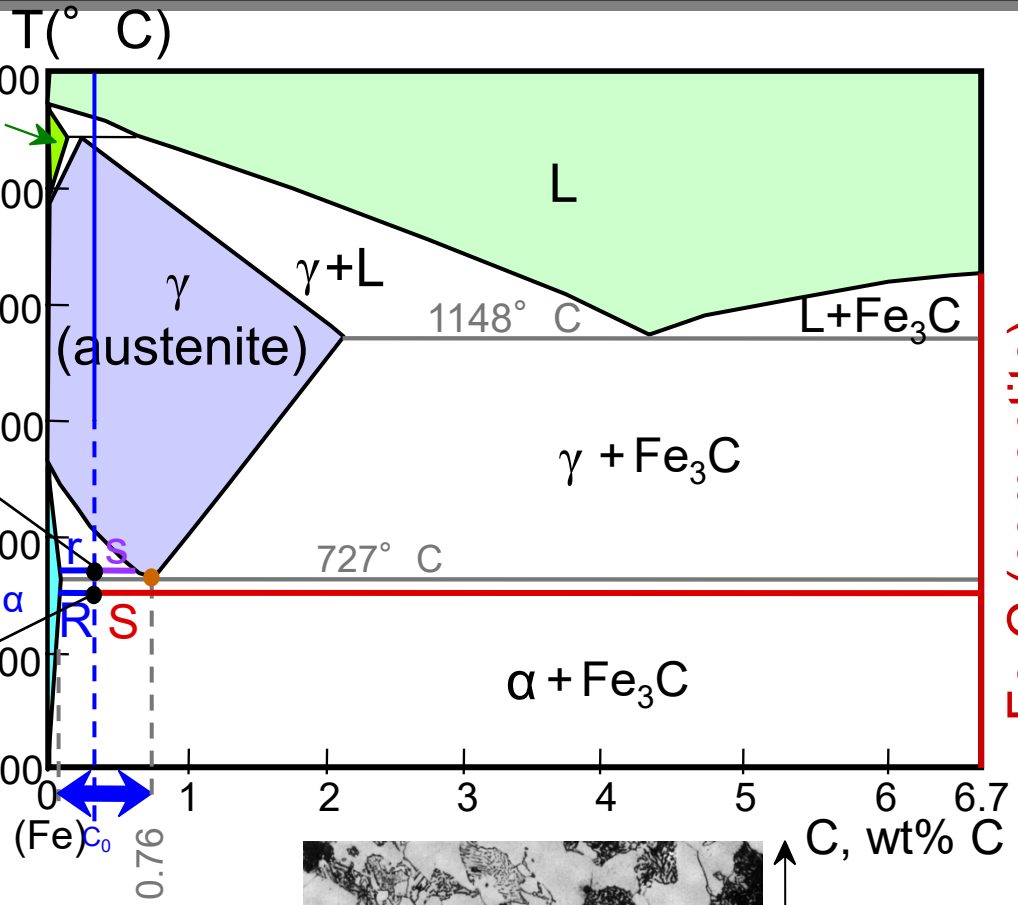


Adapted from Figs. 9.24 and 9.29, Callister & Rethwisch 10e.
[Figure 9.24 adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Adapted from Fig. 9.30, Callister & Rethwisch 10e.
(Photomicrograph courtesy of Republic Steel Corporation.)

Hypoeutectoid Steel



$W_\alpha = s/(r+s)$

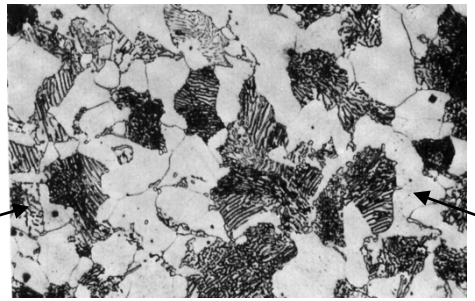
$W_\gamma = (1 - W_\alpha)$

$W_{pearlite} = W_\gamma$

$W_{\alpha'} = S/(R+S)$

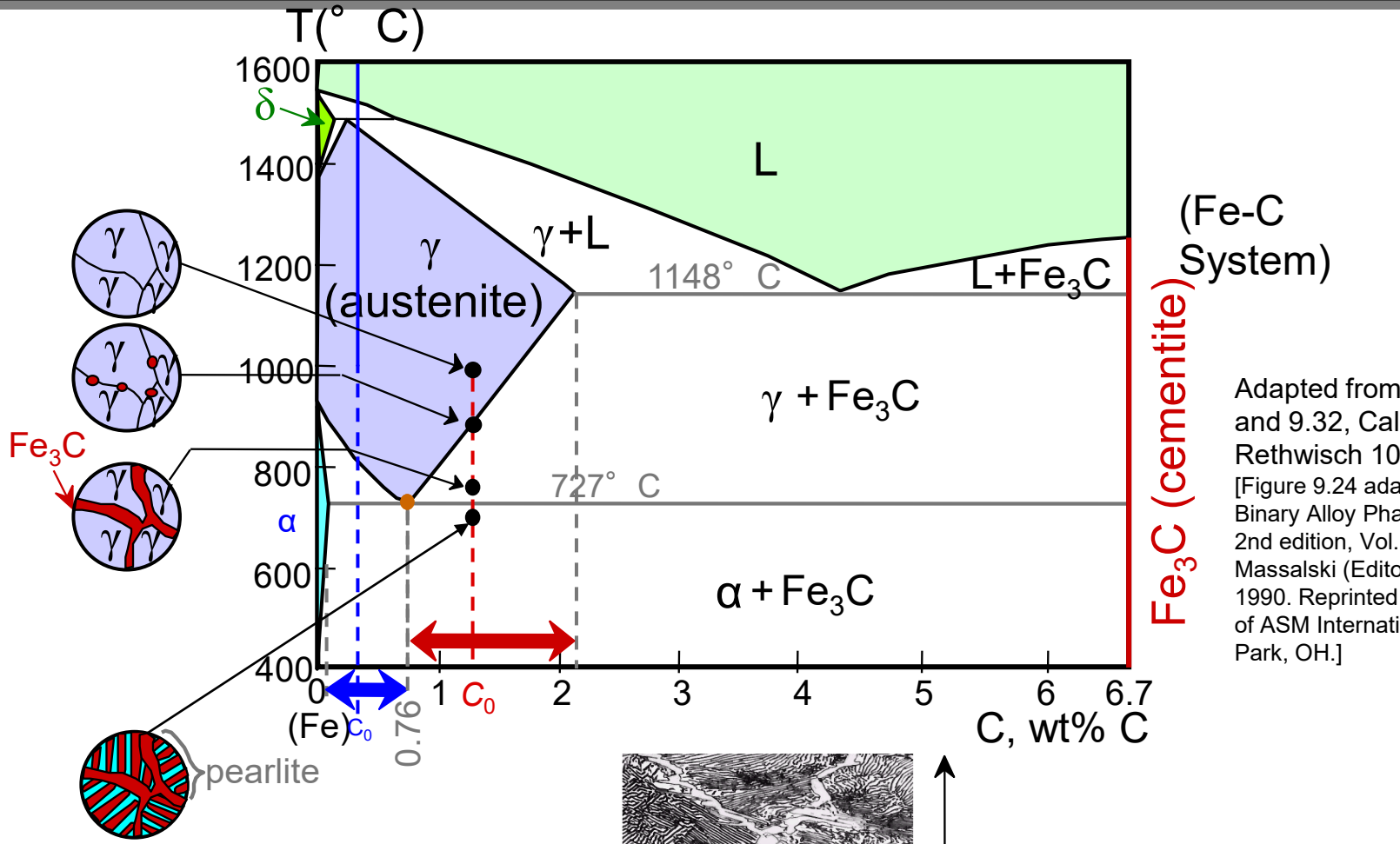
$W_{Fe_3C} = (1 - W_{\alpha'})$

Adapted from Figs. 9.24 and 9.29, Callister & Rethwisch 10e.
[Figure 9.24 adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Adapted from Fig. 9.30, Callister & Rethwisch 10e.
(Photomicrograph courtesy of Republic Steel Corporation.)

Hypereutectoid Steel



Adapted from Figs. 9.24 and 9.32, Callister & Rethwisch 10e.
[Figure 9.24 adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

60 μm

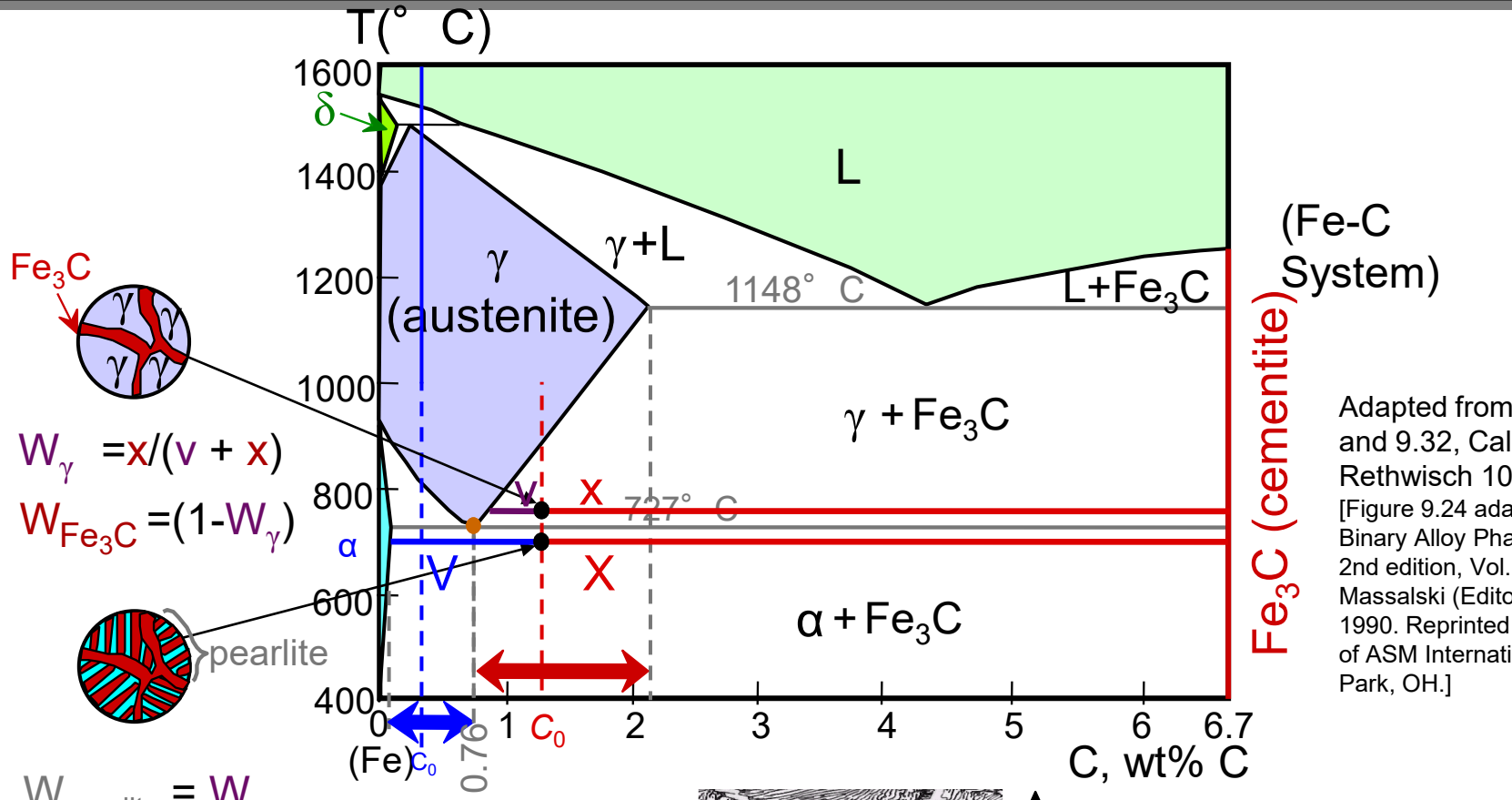
Hypereutectoid steel

pearlite

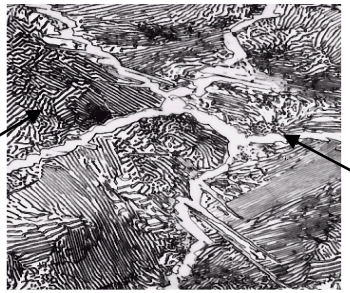
proeutectoid Fe_3C

Adapted from Fig. 9.33, Callister & Rethwisch 10e.
(Copyright 1971 by United States Steel Corporation.)

Hypereutectoid Steel



Adapted from Figs. 9.24 and 9.32, Callister & Rethwisch 10e.
[Figure 9.24 adapted from Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Adapted from Fig. 9.33, Callister & Rethwisch 10e.
(Copyright 1971 by United States Steel Corporation.)

Example Problem

For a 99.6 wt% Fe-0.40 wt% C steel at a temperature just below the eutectoid, determine the following:

a) The compositions of Fe_3C and ferrite (α).

b) The amount of cementite (in grams) that forms in 100 g of steel.

c) The amounts of pearlite and proeutectoid ferrite (α) in the 100 g.

Solution to Example Problem

a) Using the RS tie line just below the eutectoid

C_α = 0.022 wt% C

C_{Fe_3C} = 6.70 wt% C

b) Using the lever rule with the tie line shown

$$W_{Fe_3C} = \frac{R}{R+S} = \frac{C_0 - C_\alpha}{C_{Fe_3C} - C_\alpha}$$

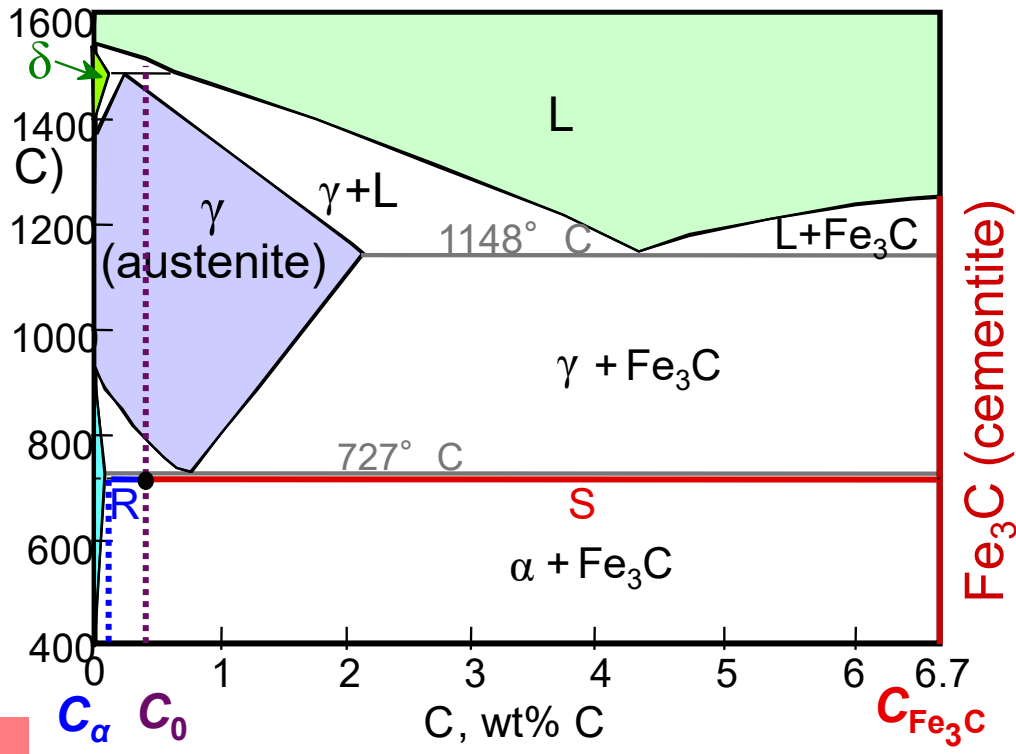
$$= \frac{0.40 - 0.022}{6.70 - 0.022} = 0.057$$

Amount of Fe_3C in 100 g

= (100 g)W_{Fe_3C}

= (100 g)(0.057) = 5.7 g

Fig. 9.24, Callister & Rethwisch 10e.
[From Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Solution to Example Problem (cont.)

c) Using the *VX* tie line just above the eutectoid and realizing that

C_0 = 0.40 wt% C

C_α = 0.022 wt% C

$C_{pearlite} = C_\gamma$ = 0.76 wt% C

$$W_{pearlite} = \frac{V}{V+X} = \frac{C_0 - C_\alpha}{C_\gamma - C_\alpha}$$

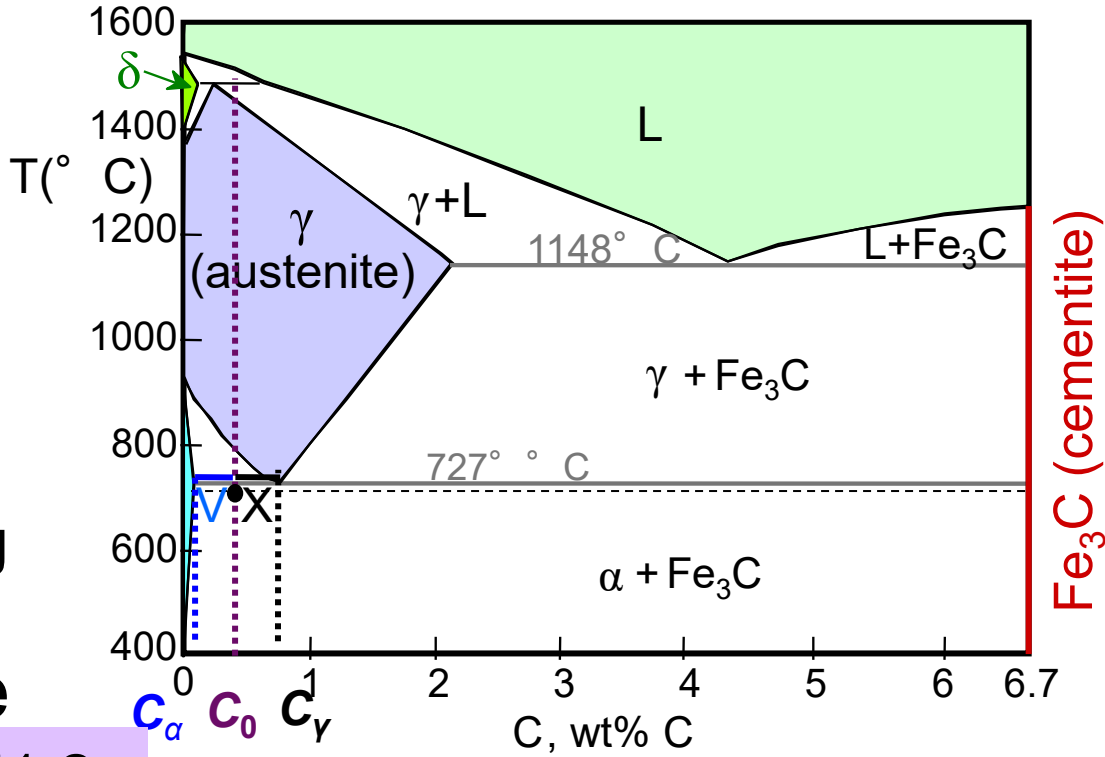
$$= \frac{0.40 - 0.022}{0.76 - 0.022} = 0.512$$

Amount of pearlite in 100 g

= (100 g)$W_{pearlite}$

= (100 g)(0.512) = 51.2 g

Fig. 9.24, Callister & Rethwisch 10e.
[From Binary Alloy Phase Diagrams, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Alloying with Other Elements

- $T_{eutectoid}$ changes:

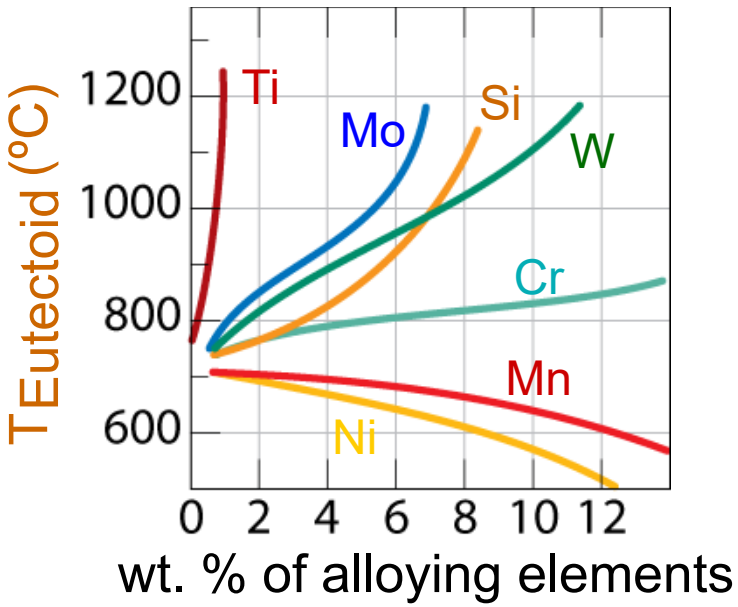


Fig. 9.34, Callister & Rethwisch 10e.
(From Edgar C. Bain, Functions of the Alloying Elements in Steel, 1939. Reproduced by permission of ASM International, Materials Park, OH.)

- $C_{eutectoid}$ changes:

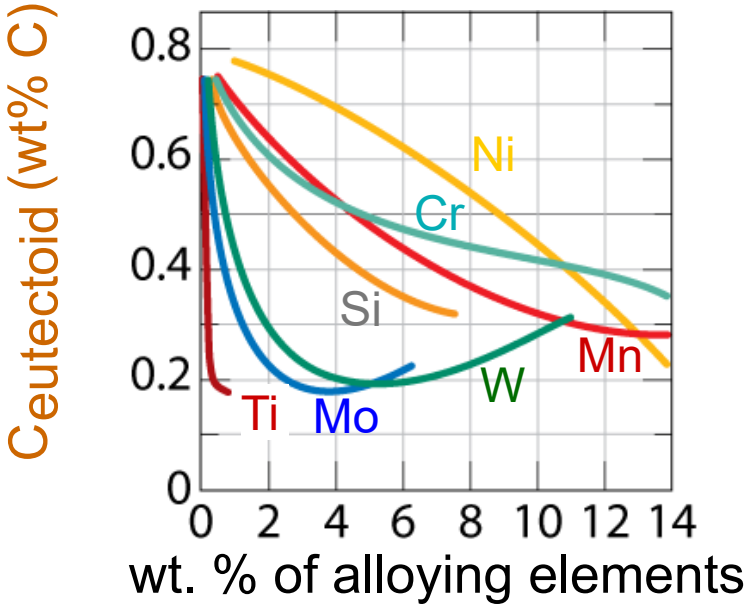
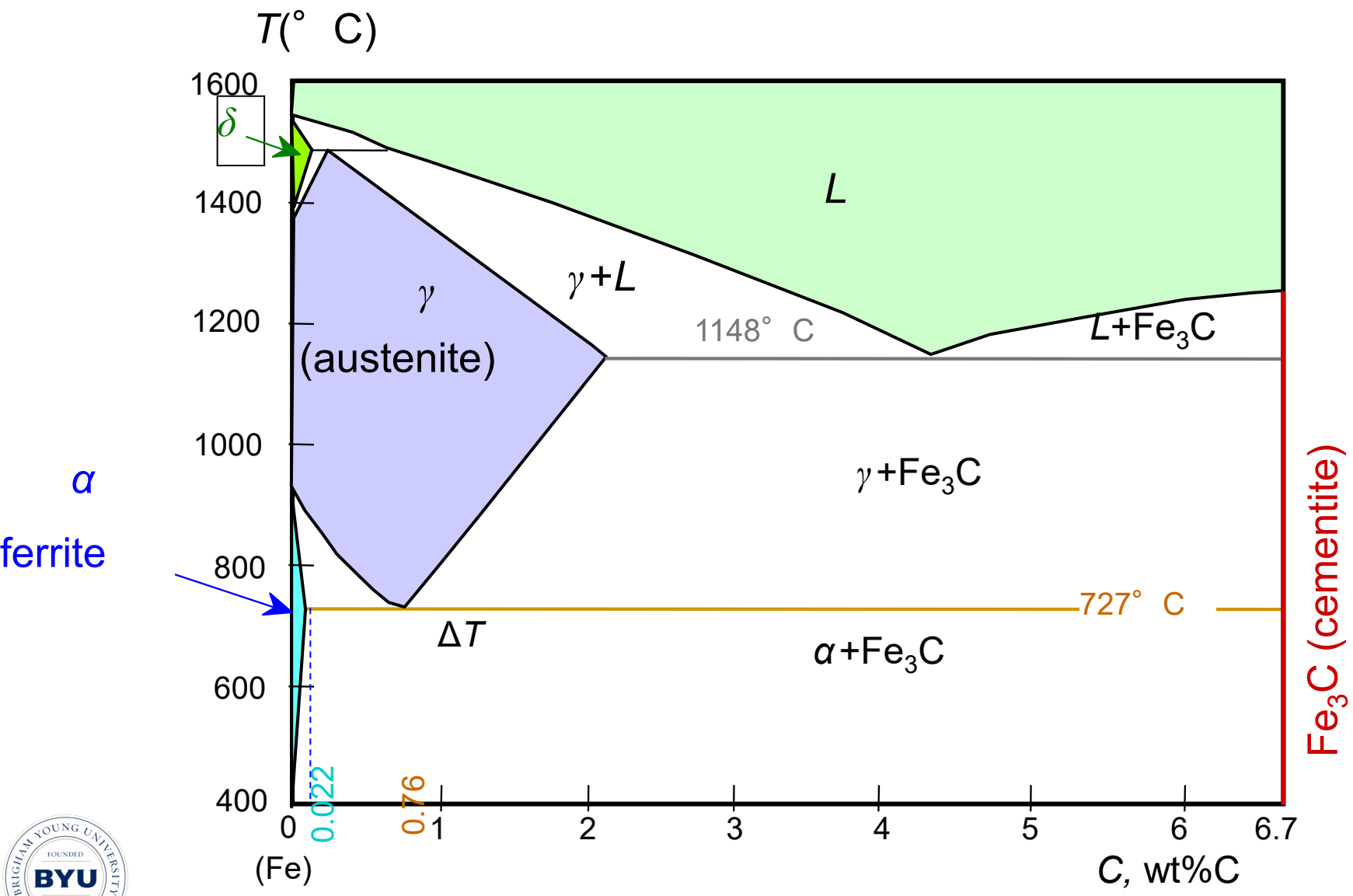
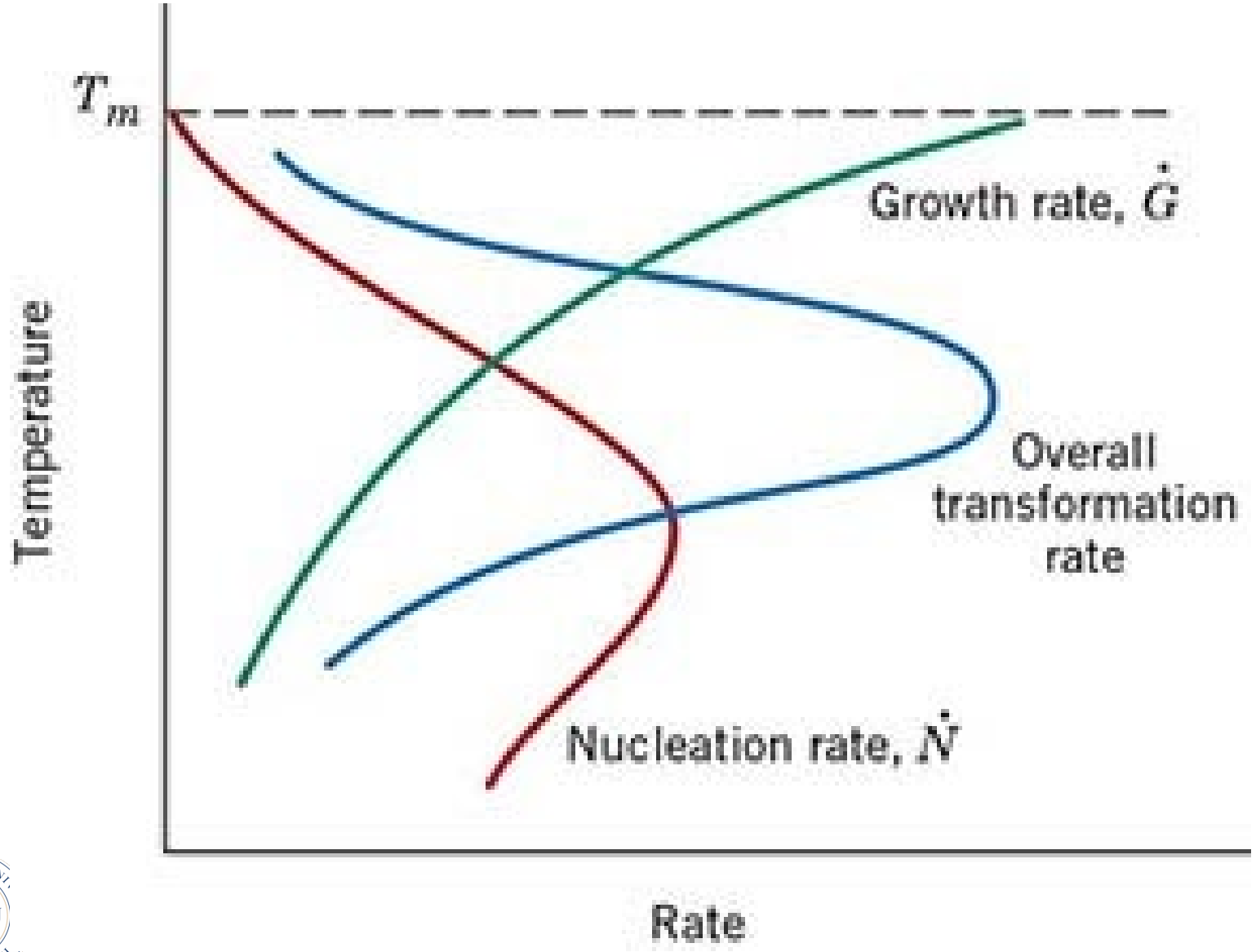


Fig. 9.35,Callister & Rethwisch 10e.
(From Edgar C. Bain, Functions of the Alloying Elements in Steel, 1939. Reproduced by permission of ASM International, Materials Park, OH.)

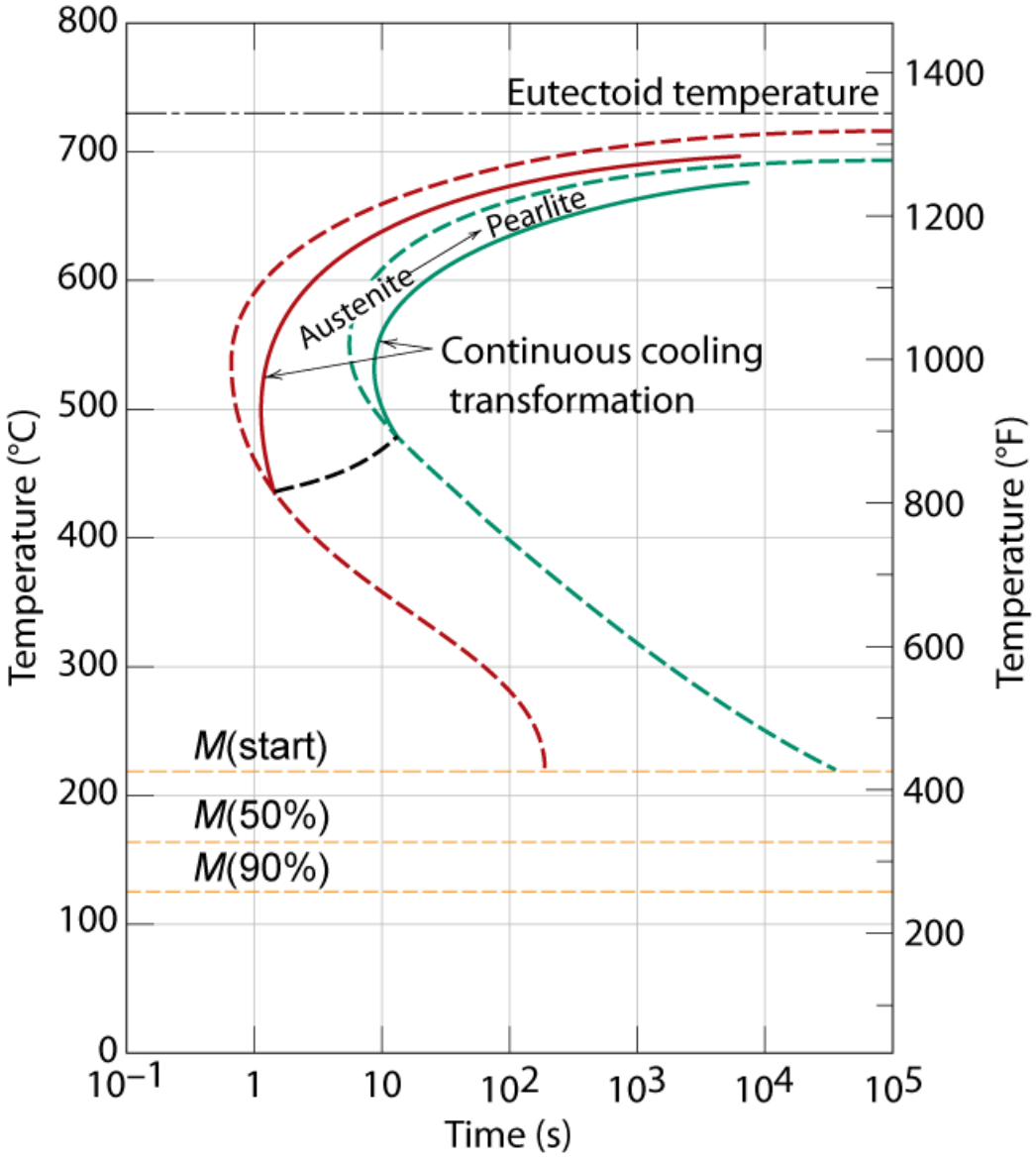
Transformations & Undercooling



Transformation Rate Mechanics



Transformation Diagram



Proeutectoid Transformations