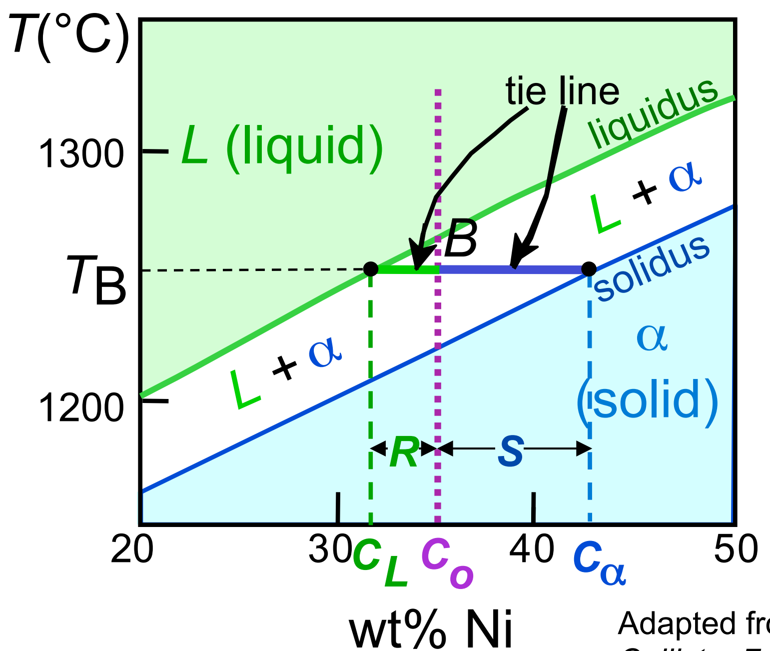
Chapter 9: Fe-C system

The Lever Rule

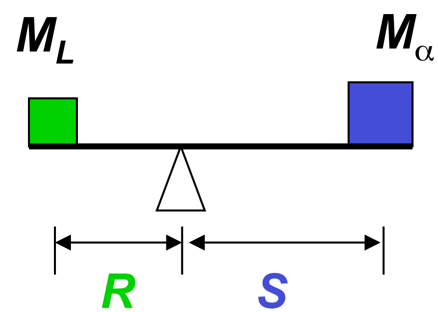
- Tie line – connects the phases in equilibrium with each other - essentially an isotherm



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

How much of each phase?

Think of it as a lever (teeter-totter)



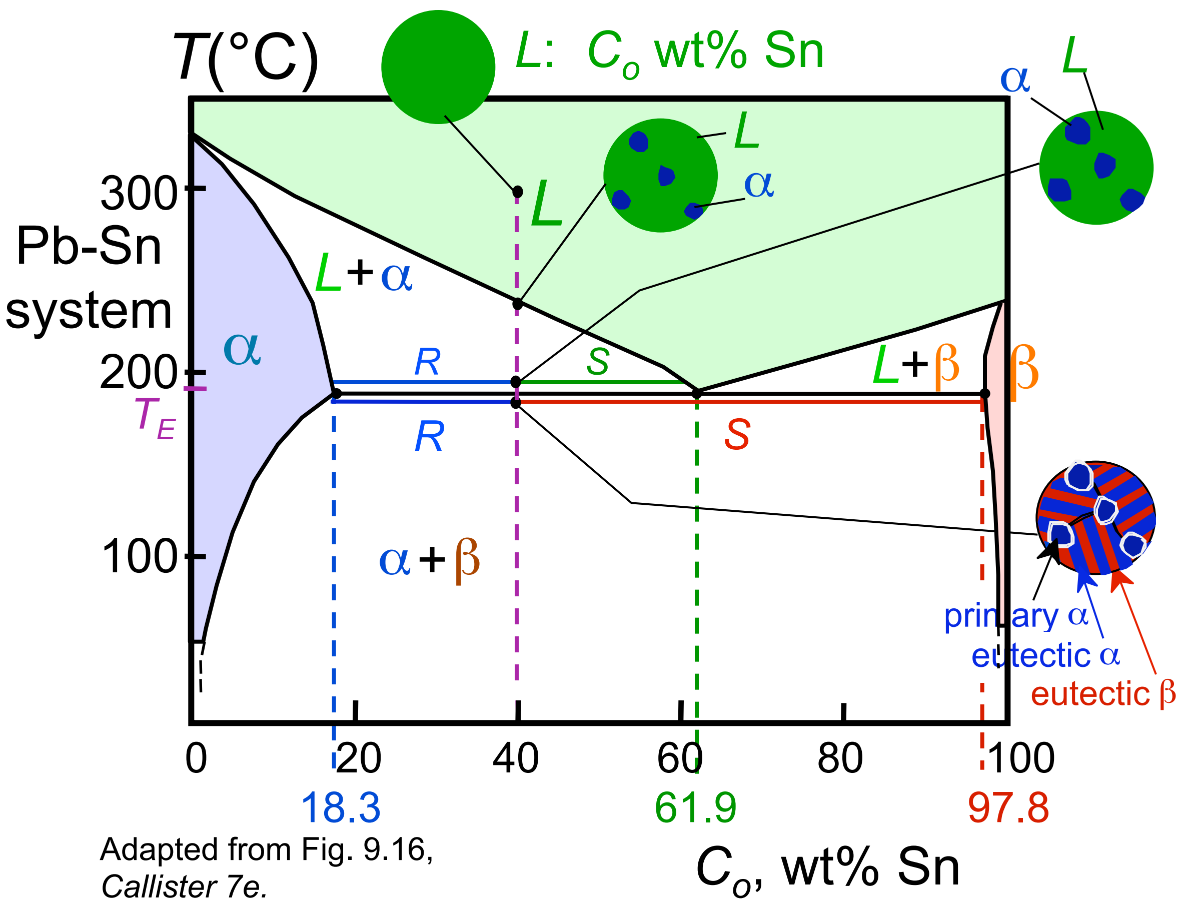
$$M_\alpha \cdot S = M_L \cdot R$$

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

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

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_α = 18.3 wt% Sn

C_L = 61.9 wt% Sn

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

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

- Just below T_E :

C_α = 18.3 wt% Sn

C_β = 97.8 wt% Sn

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

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

Eutectoid & Peritectic

- Eutectic - liquid in equilibrium with two solids

$$L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + \beta$$

- Eutectoid - solid phase in equation with two solid phases

$$S_2 \rightleftharpoons S_1 + S_3$$

intermetallic compound - cementite

$$\gamma \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \alpha + Fe_3C$$

(727ºC)

- Peritectic - liquid + solid 1 → solid 2 (Fig 9.21)

$$S_1 + L \rightleftharpoons S_2$$

$$\delta + L \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} \gamma$$

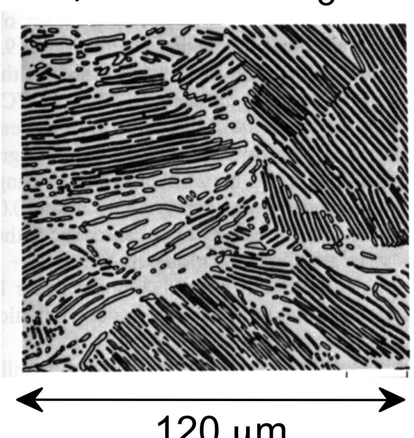
(1493ºC)

Iron-Carbon (Fe-C) Phase Diagram

- 2 important points

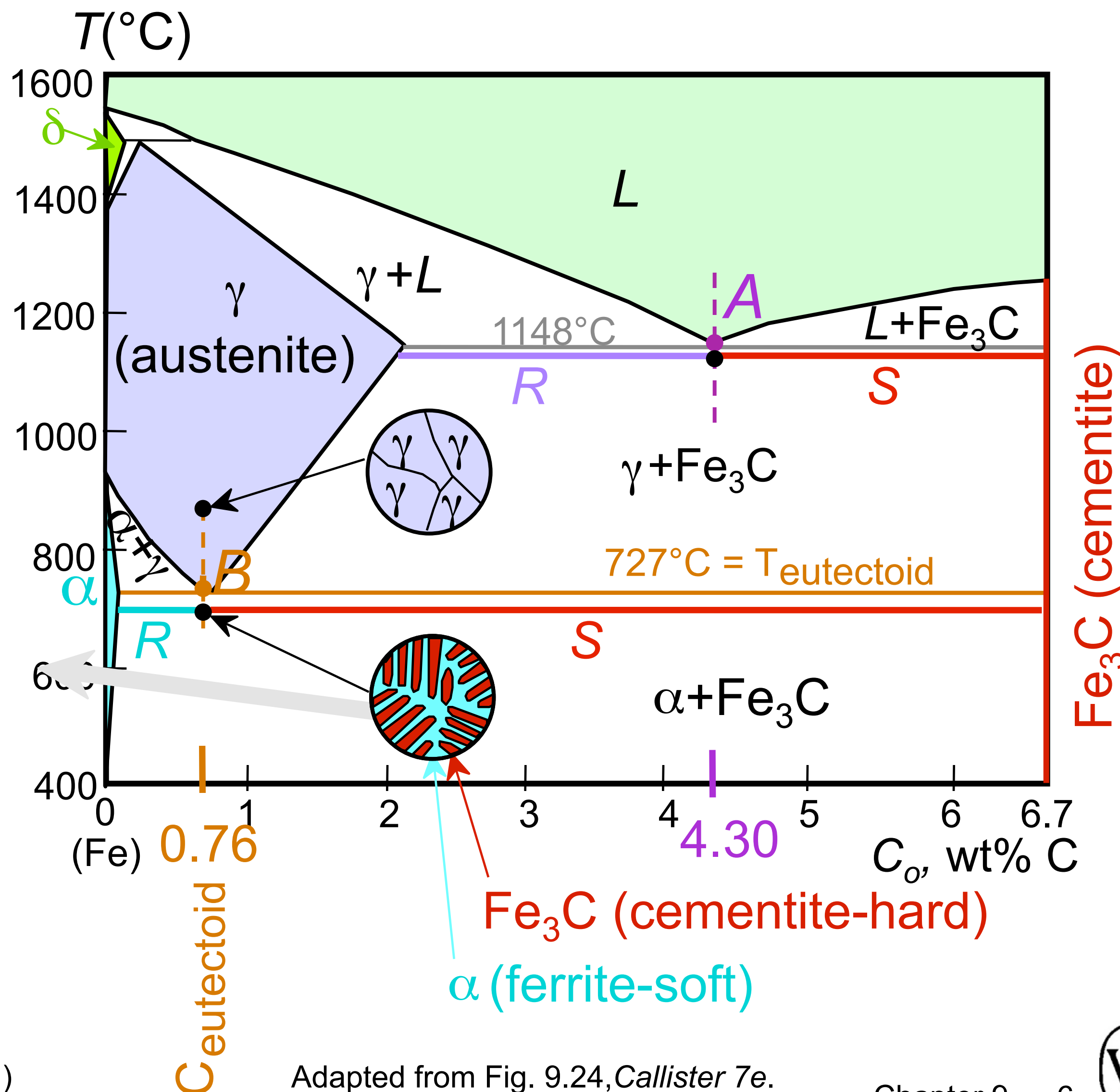
-Eutectic (*A*): $L \Rightarrow \gamma + Fe_3C$

-Eutectoid (*B*): $\gamma \Rightarrow \alpha + Fe_3C$



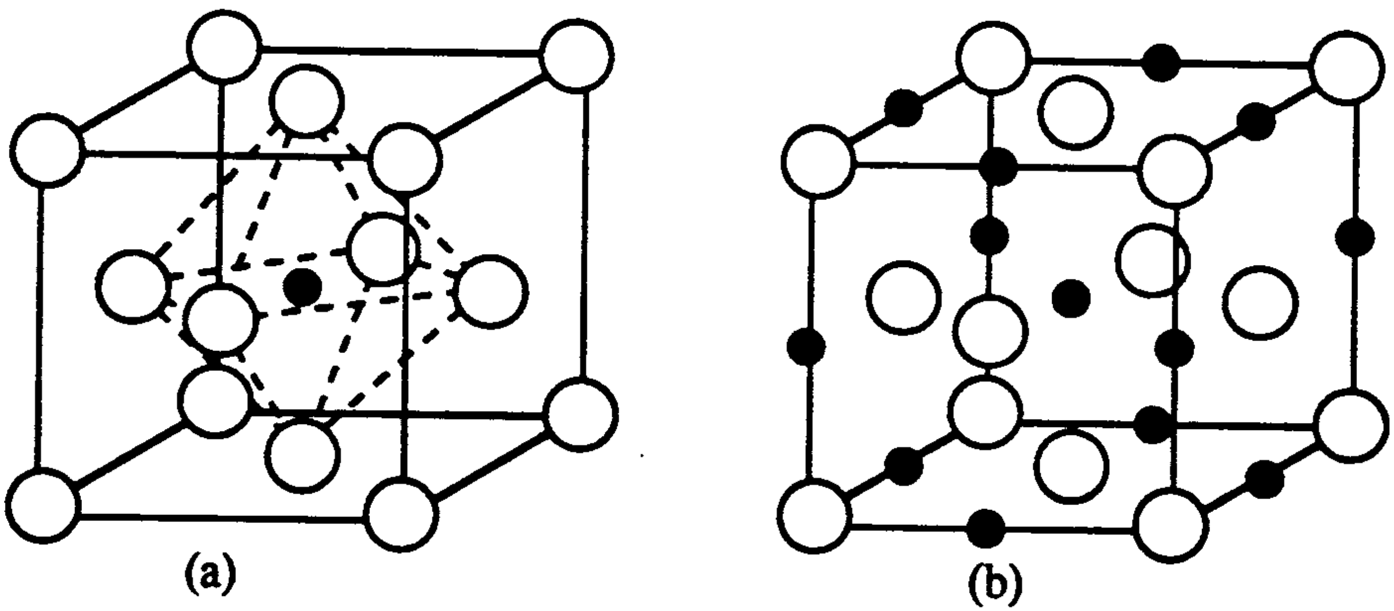
Result: Pearlite = alternating layers of α and Fe_3C phases

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

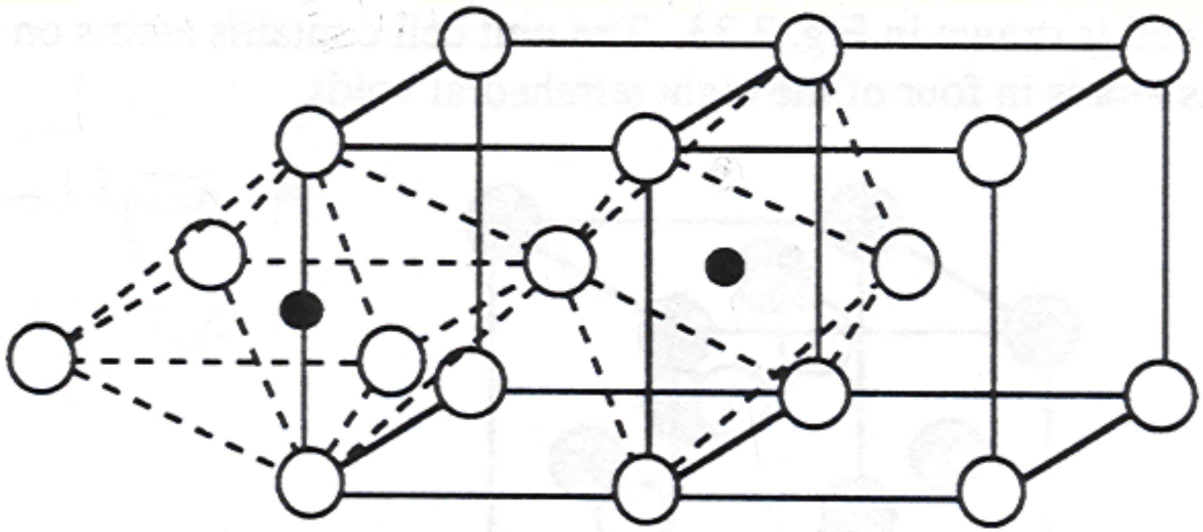


Adapted from Fig. 9.24, *Callister 7e*.

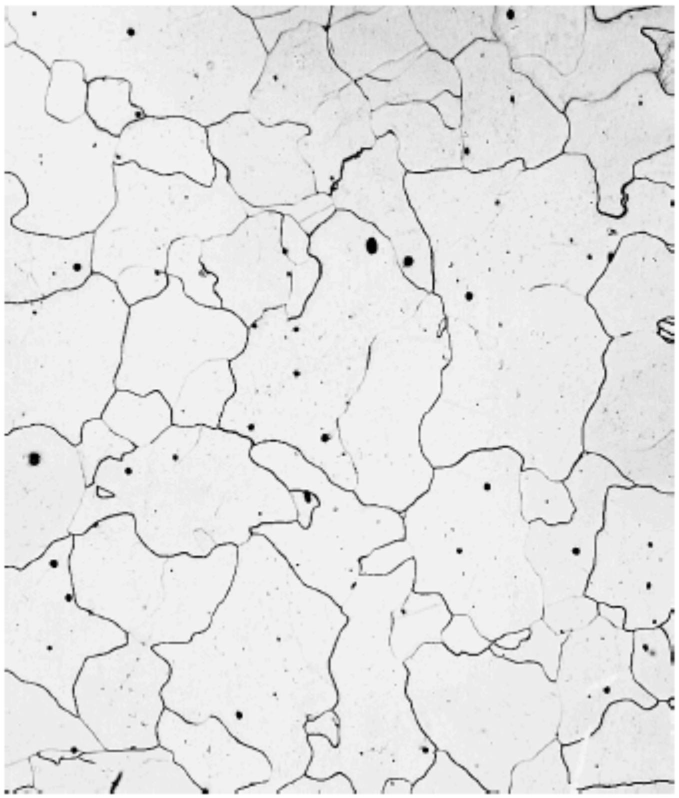
Interstitial sites of FCC



Interstitial sites of BCC

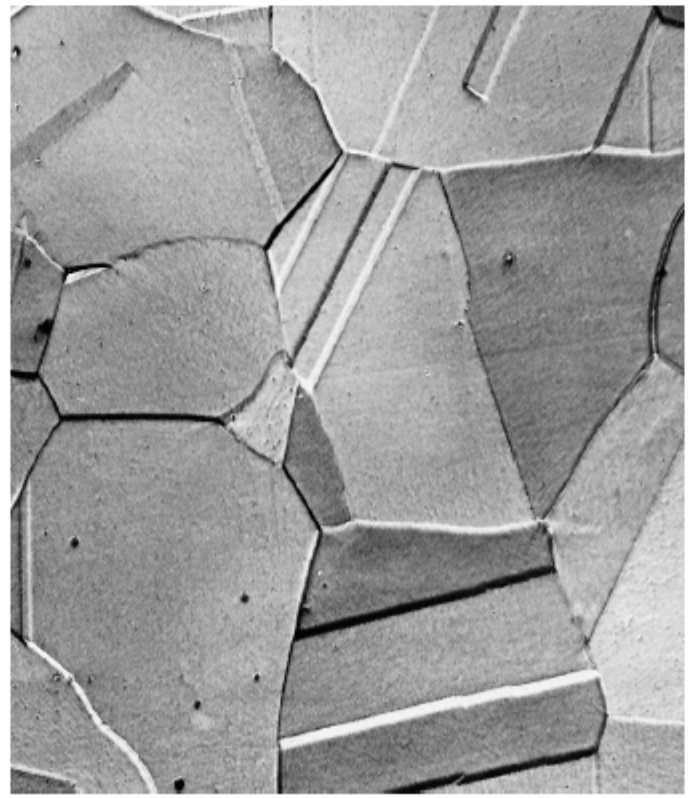


Microstructures of iron



(a)

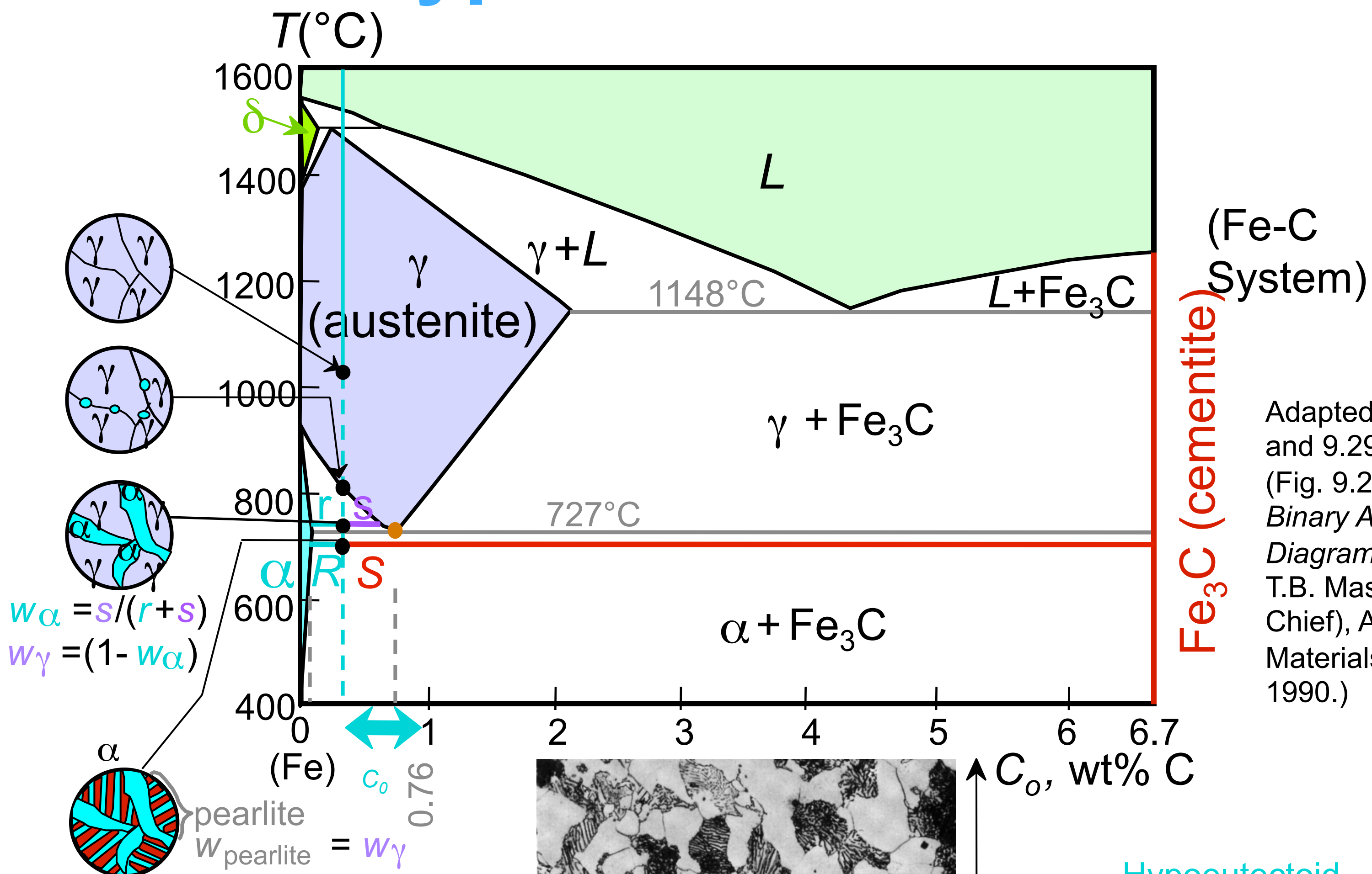
α- ferrite



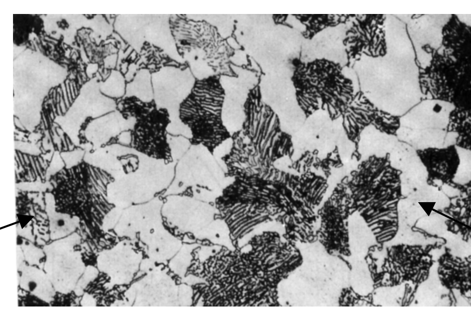
(b)

austenite

Hypoeutectoid Steel

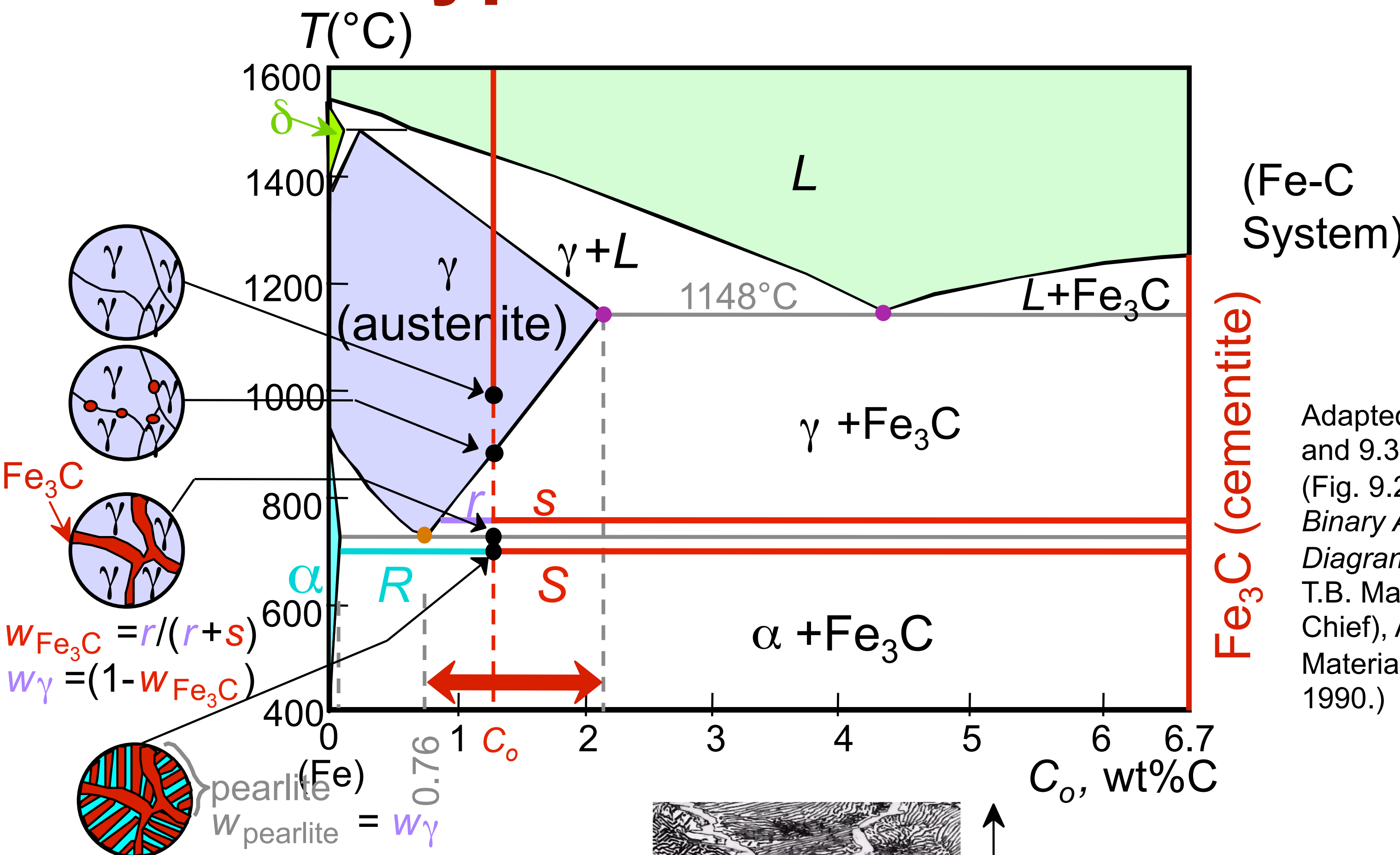


Adapted from Figs. 9.24 and 9.29, *Callister 7e*. (Fig. 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd ed., Vol. 1, T.B. Massalski (Ed.-in-Chief), ASM International, Materials Park, OH, 1990.)



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

Hypereutectoid Steel



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*.

Example: Phase Equilibria

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

a) composition of Fe_3C and ferrite (α)

b) the amount of carbide (cementite) in grams that forms per 100 g of steel

c) the amount of pearlite and proeutectoid ferrite (α)

Chapter 9 – Phase Equilibria

Solution: a) composition of Fe_3C and ferrite (α)

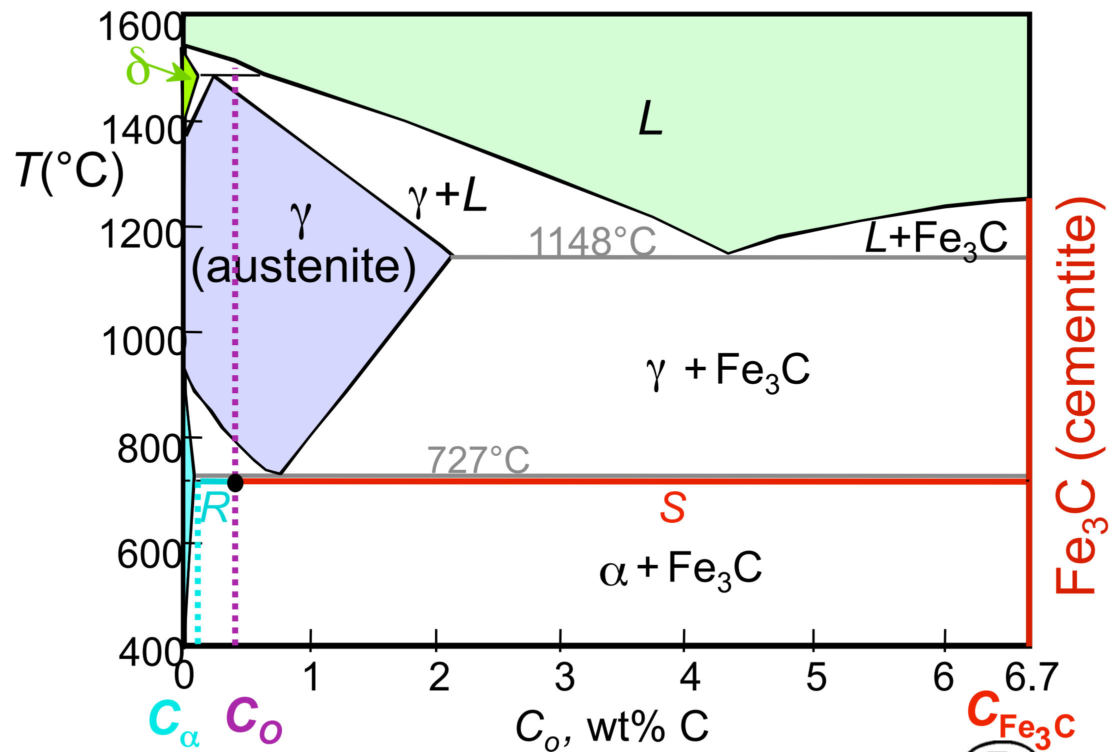
b) the amount of carbide (cementite) in grams that forms per 100 g of steel

C_O = 0.40 wt% C
C_α = 0.022 wt% C
C_{Fe_3C} = 6.70 wt% C

$$\frac{Fe_3C}{Fe_3C+\alpha} = \frac{C_o - C_\alpha}{C_{Fe_3C} - C_\alpha} x100$$

$$= \frac{0.4-0.022}{6.7-0.022} x\,100 = 5.7g$$

$Fe_3C = 5.7$ g
$\alpha = 94.3$ g



Chapter 9 – Phase Equilibria

c. the amount of pearlite and proeutectoid ferrite (α)

note: amount of pearlite = amount of γ just above T_E

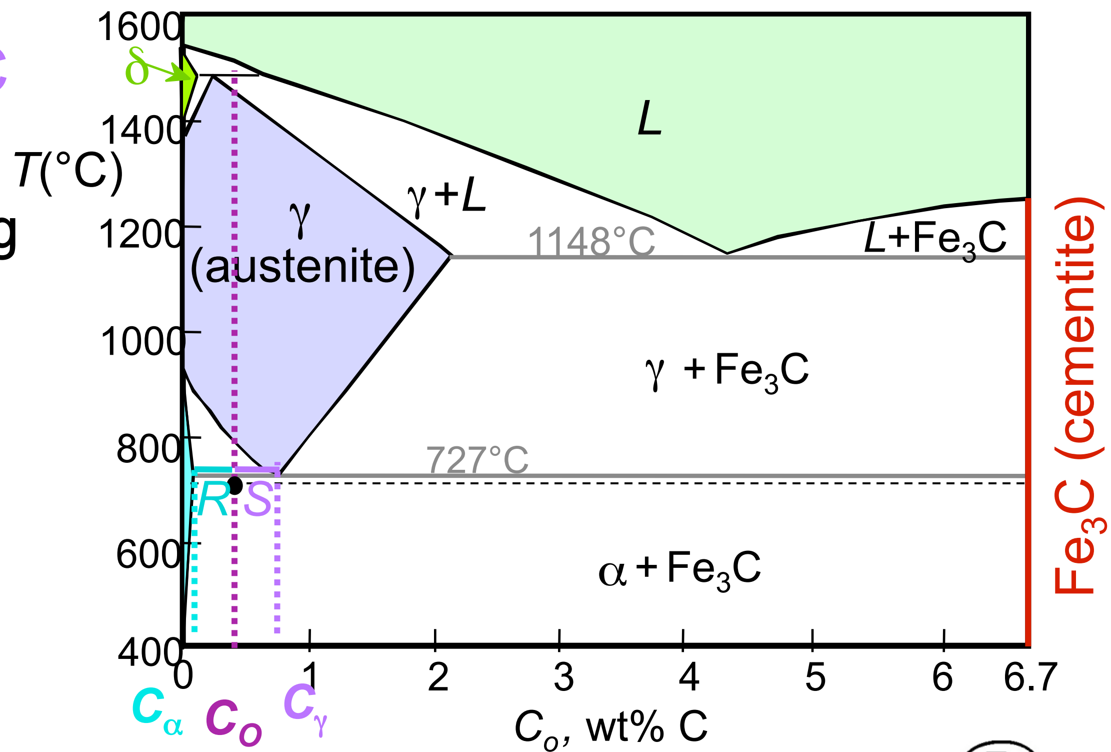
C_o = 0.40 wt% C

C_α = 0.022 wt% C

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

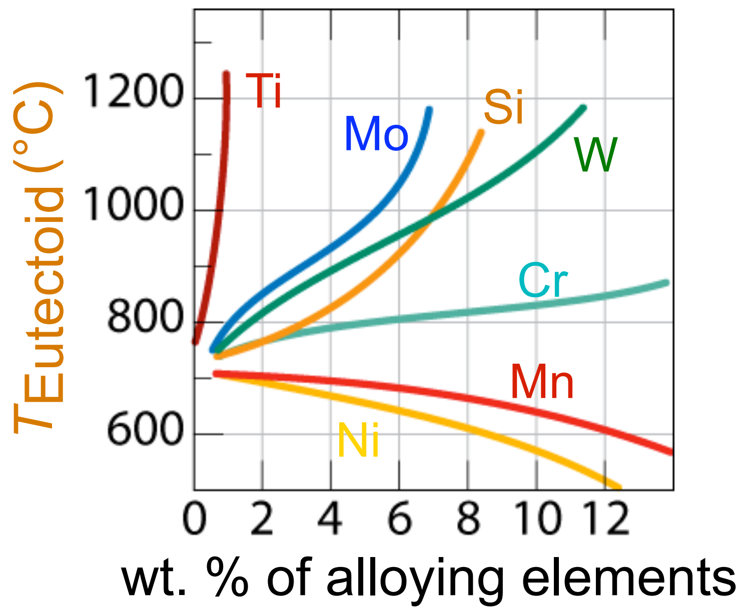
$$\frac{\gamma}{\gamma + \alpha} = \frac{C_o - C_\alpha}{C_\gamma - C_\alpha} \times 100 = 51.2 \text{ g}$$

pearlite = 51.2 g
proeutectoid α = 48.8 g



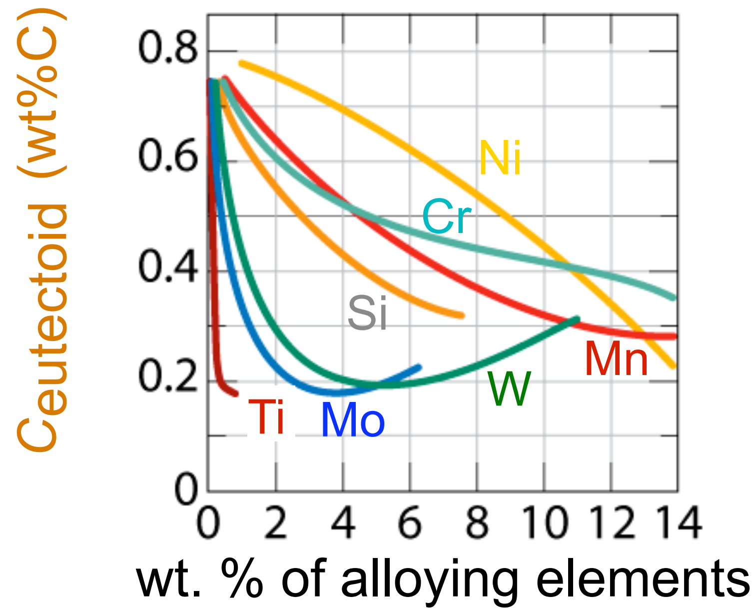
Alloying Steel with More Elements

- $T_{eutectoid}$ changes:



Adapted from Fig. 9.34,*Callister 7e*. (Fig. 9.34 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

- $C_{eutectoid}$ changes:



Adapted from Fig. 9.35,*Callister 7e*. (Fig. 9.35 from Edgar C. Bain, *Functions of the Alloying Elements in Steel*, American Society for Metals, 1939, p. 127.)

Summary

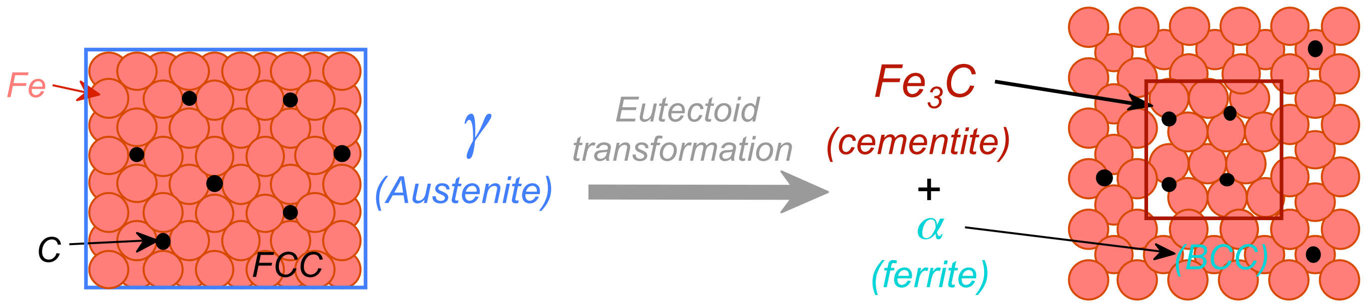
- Phase diagrams are useful tools to determine:
  - --the number and types of phases,
  - --the wt% of each phase,
  - --and the composition of each phase

  for a given *T* and composition of the system.

- Alloying to produce a solid solution usually
  - --increases the tensile strength (*TS*)
  - --decreases the ductility.
- Binary eutectics and binary eutectoids allow for a range of microstructures.

Chapter 10: Phase Transformations

- *Transforming one phase into another takes time.*



- *How does the rate of transformation depend on time and T?*
- *How can we slow down the transformation so that we can engineer non-equilibrium structures?*
- *Are the mechanical properties of non-equilibrium structures better?*

t=time!

T=temperature!

ΔT= temperature difference from phase transition temperature

Phase Transformations

Nucleation

– nuclei (seeds) act as template to grow crystals

Driving force to nucleate increases as we increase ΔT

In ΔT range close to T_m, rate of nucleation higher with higher ΔT

– *supercooling* (eutectic, eutectoid)

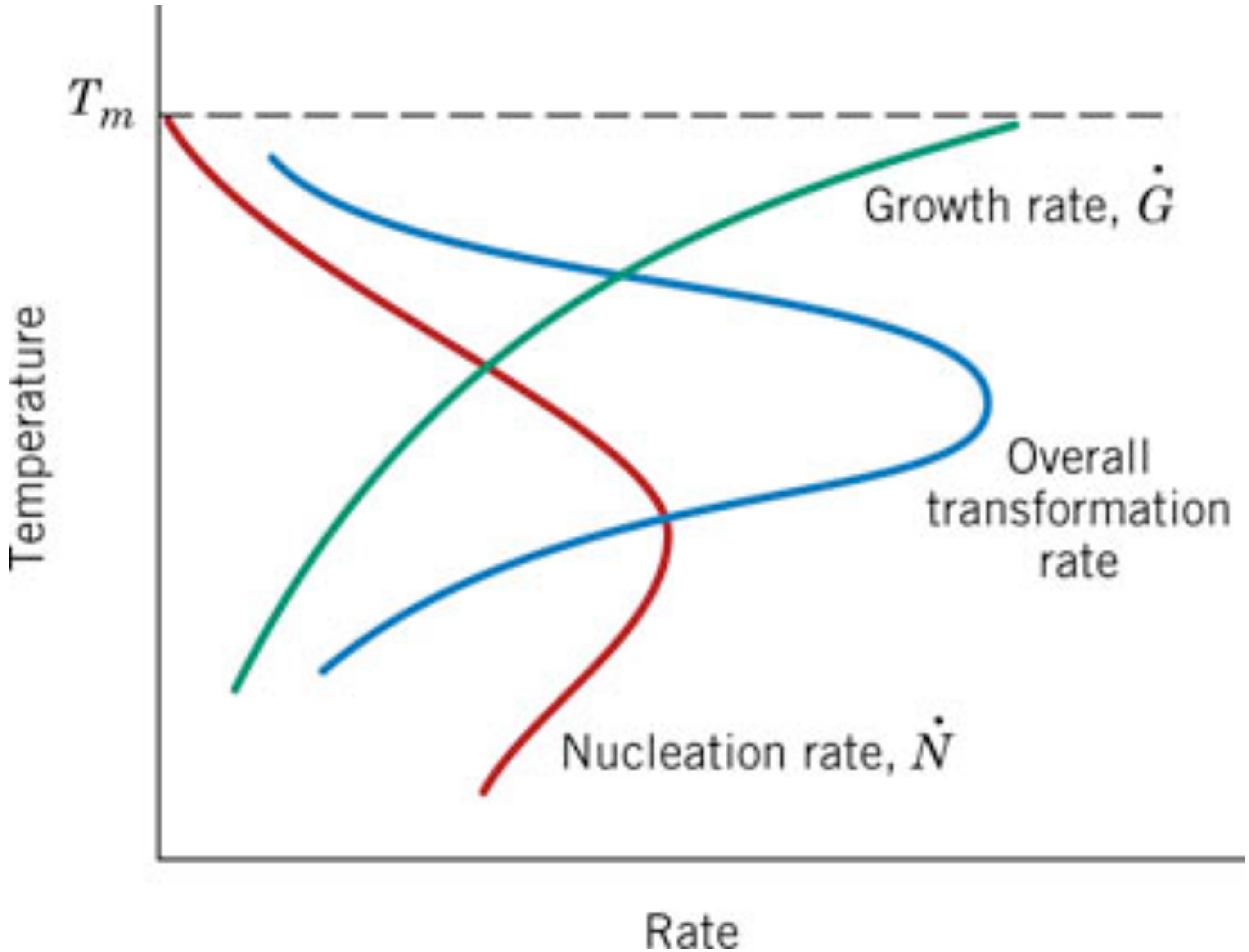
Growth

Growth rate increases with T (thermally activated)

$$dG/dt = C \exp(-Q/kT)$$

Small supercooling → few nuclei - large crystals

Large supercooling → rapid nucleation - many nuclei, small crystals

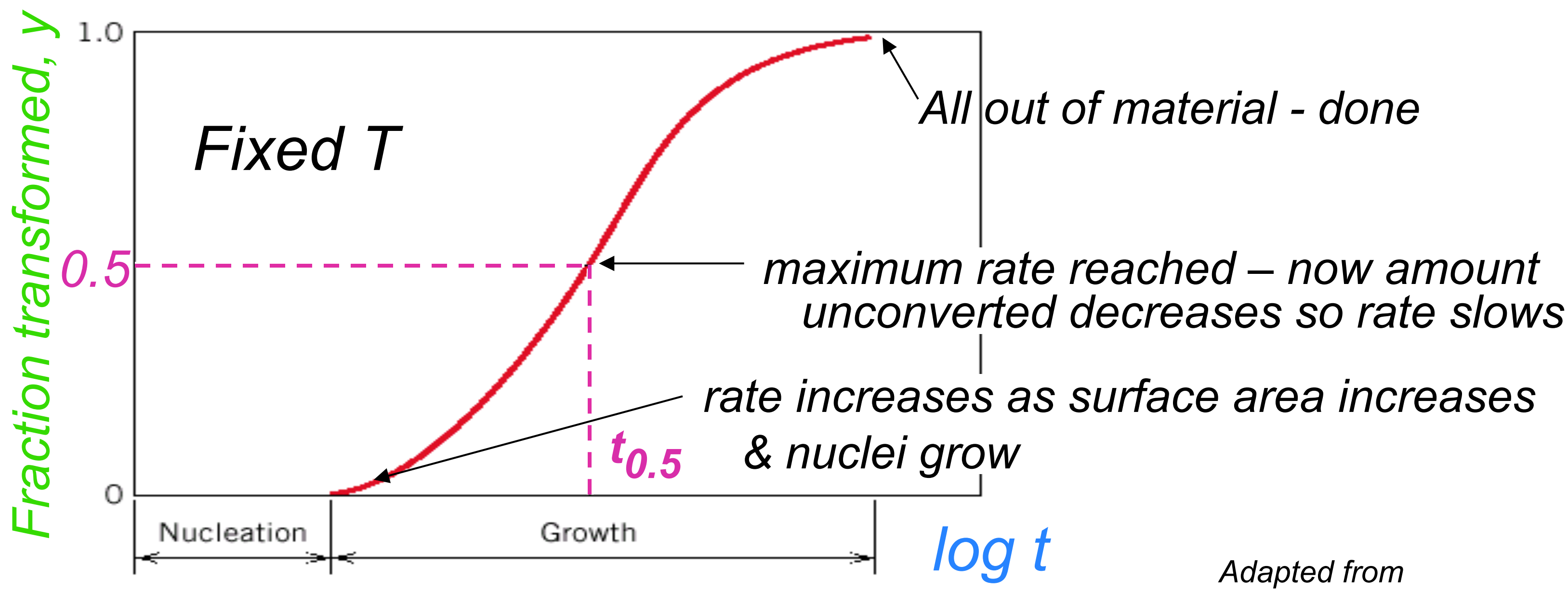

T_m
Growth rate, $\dot{G}$
Overall transformation rate
Nucleation rate, $\dot{N}$
Temperature
Rate

Rate of Phase Transformations

Kinetics - measure approach to equilibrium vs. time

- *Hold temperature constant & measure conversion vs. time*
  - *How is conversion measured?*
    - *X-ray diffraction – have to do many samples*
    - *electrical conductivity – follow one sample*
    - *sound waves – one sample*

Rate of Phase Transformation



Adapted from Fig. 10.10, Callister 7e.

Avrami rate equation => $y = 1 - \exp(-kt^n)$

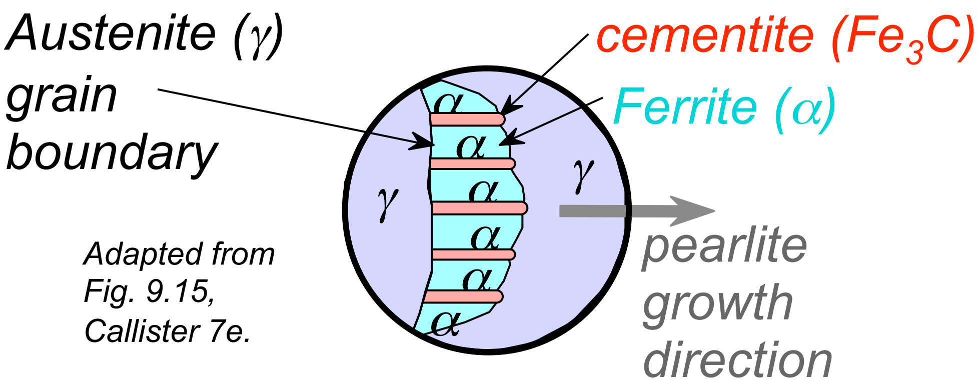
fraction transformed (y) **time** (t)

– *k* & *n* fit for specific sample

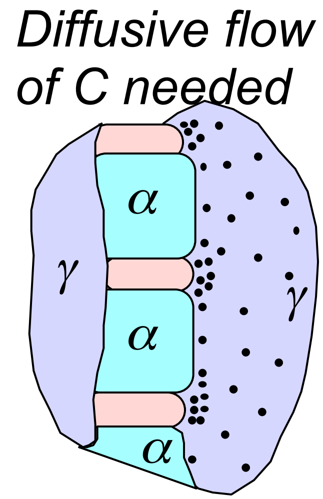
By convention $r = 1 / t_{0.5}$

Eutectoid Transformation Rate

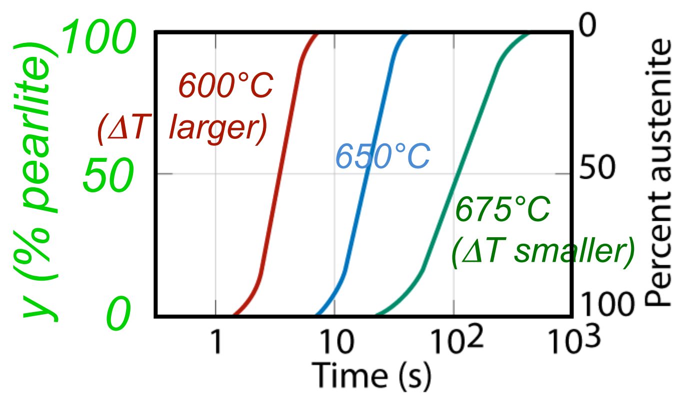
- *Growth of pearlite from austenite:*



Adapted from Fig. 9.15, Callister 7e.



- *Recrystallization rate increases with ΔT.*



Adapted from Fig. 10.12, Callister 7e.

Course pearlite → formed at higher T - softer

Fine pearlite → formed at low T - harder