2019 Fall

Introduction to Materials Science and Engineering

11. 07. 2019

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Contents for previous class

Chapter 11 Phase Diagrams

- **Equilibrium_** $dG = 0$

  Lowest possible value of G
  No desire to change ad infinitum

- **Phase Transformation** $\Delta G = G_2 - G_1 < 0$

* **Single component system** **One element (Al, Fe), One type of molecule (H_2O)**

: **Equilibrium depends on pressure and temperature.**

* **Binary system (two components)** → A, B

: **Equilibrium depends on not only pressure and temperature but also composition.**

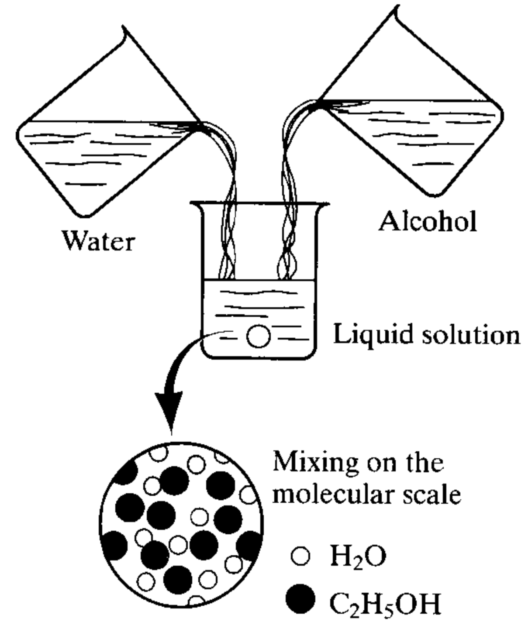
- **Binary System** mixture/ solution / compound

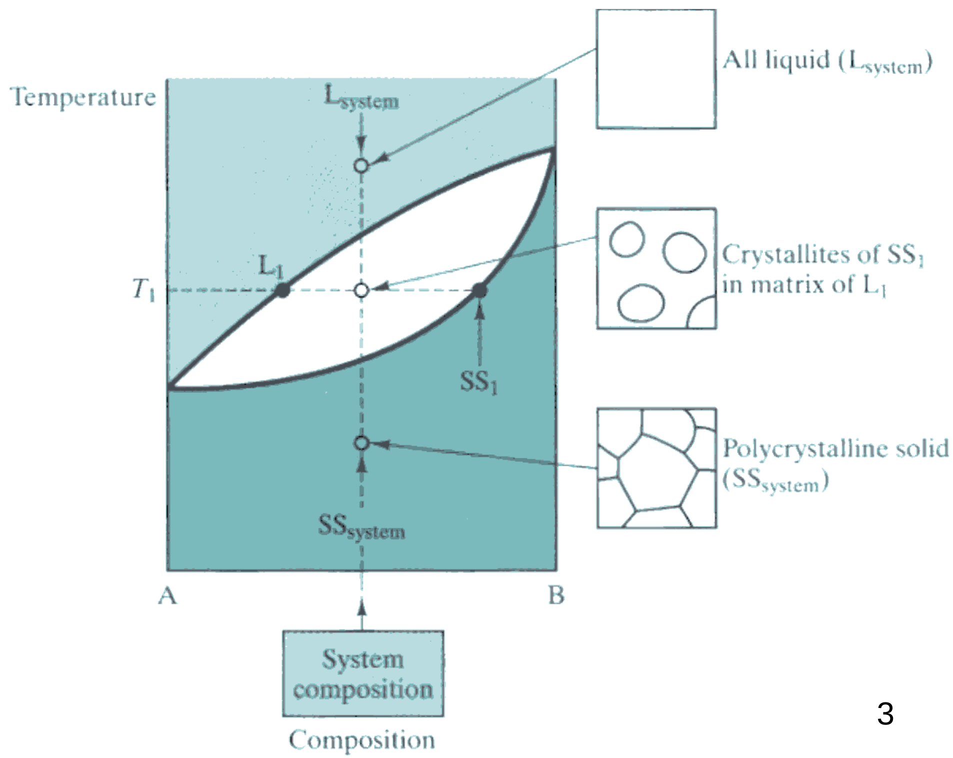
- Solubility

- Unlimited Solubility
  - Hume Rothery' Conditions
    - Similar Size
    - Same Crystal Structure
    - Same Valance
    - Similar Electronegativity
  - Implies single phase

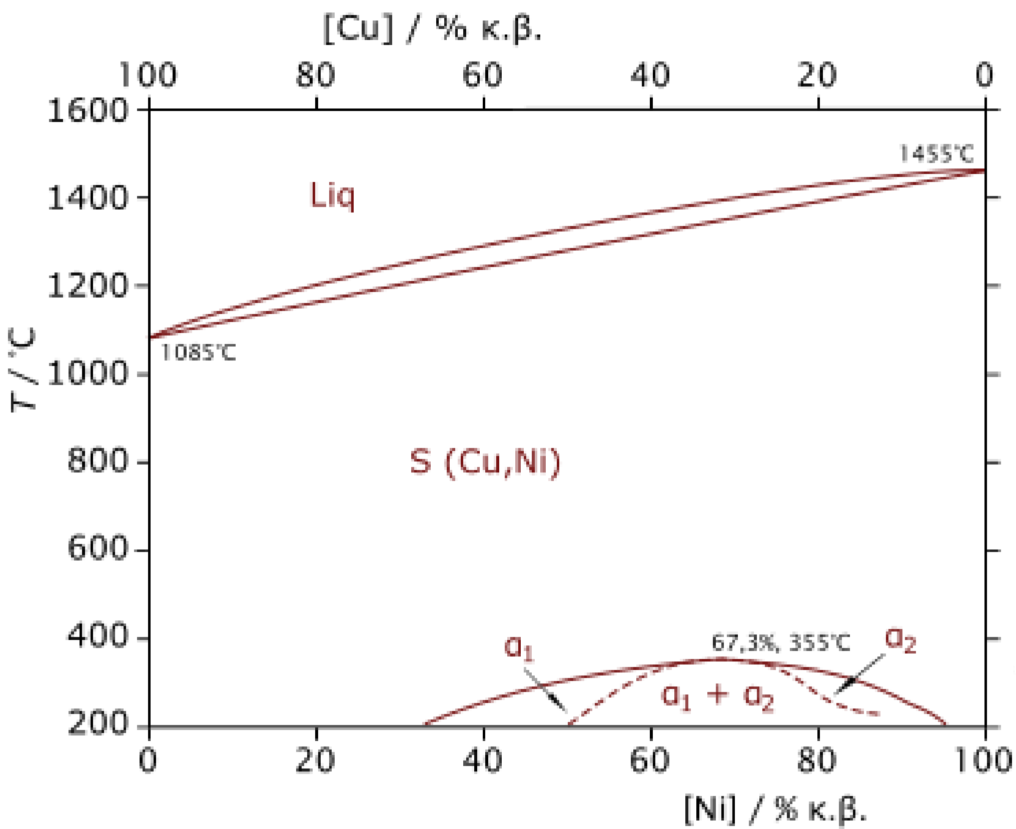
- Limited Solubility
  - Implies multiple phases

- No Solubility
  - oil and water region



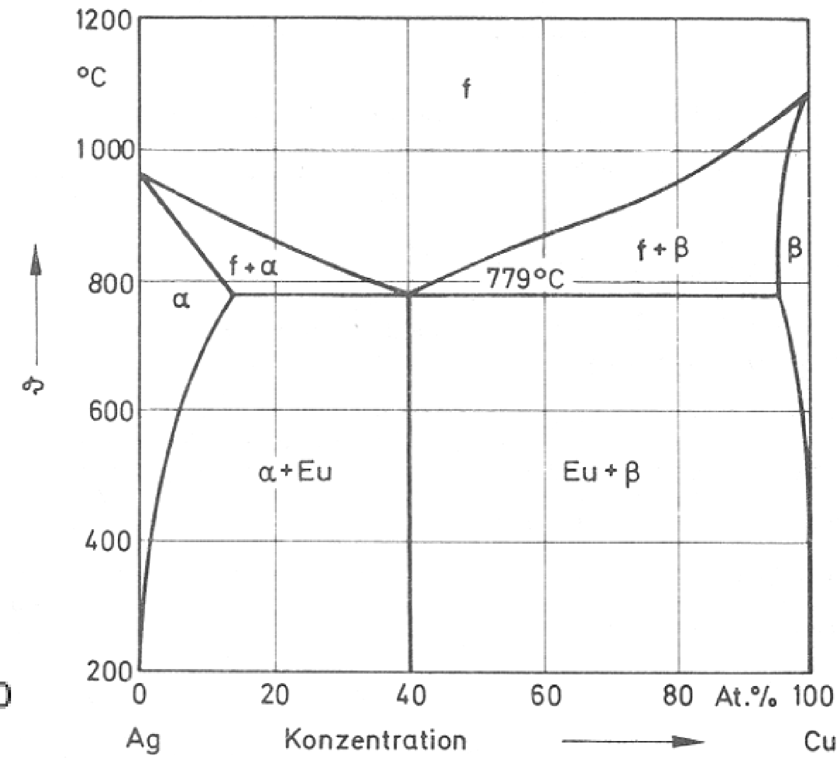


Cu-Ni Alloys



complete solid solution

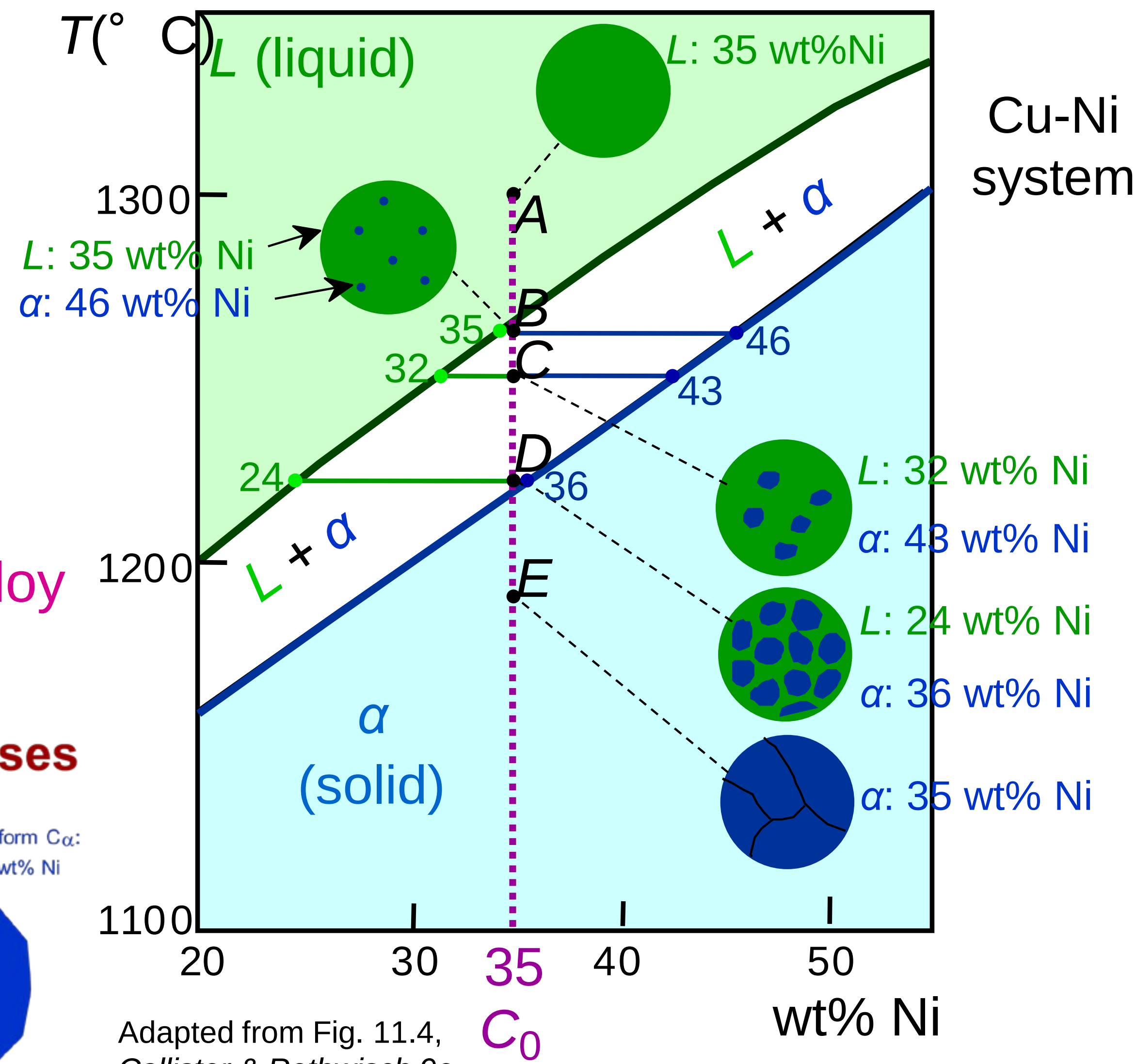
Cu-Ag Alloys



limited solid solution

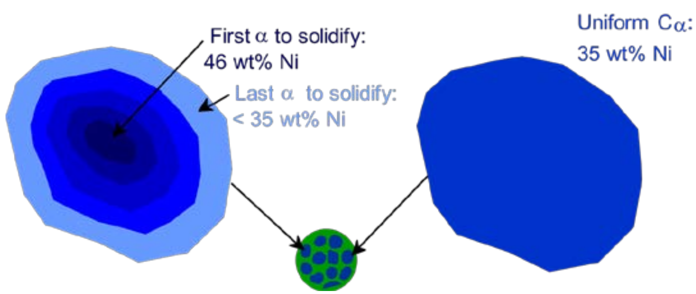
- Cooling of a Cu-Ni Alloy

- Phase diagram:
  Cu-Ni system.
- Consider microstuctural changes that accompany the cooling of a C_0 = 35 wt% Ni alloy



Adapted from Fig. 11.4, *Callister & Rethwisch 9e.*

- Cored vs Equilibrium Phases



Chapter 11: Phase Diagrams

What we will learn about

I. Component, Phase, Equilibrium

→ Phase diagram (Gibb's phase rule)

II. one component phase diagram

two component phase diagram

: solubility limit (Hume-Rothery Rule)

III. Isomorphous Binary Phase Diagram

: tie line, lever rule

IV. Binary-Eutectic Systems

V. Binary invariant reaction

: Eutectic, Eutectoid, & Peritectic

- Ternary, Quarternary phase diagram
- Phase transformation

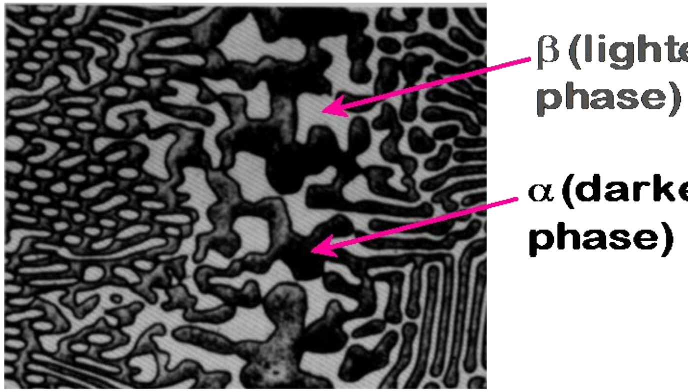
IV. Binary-Eutectic Systems

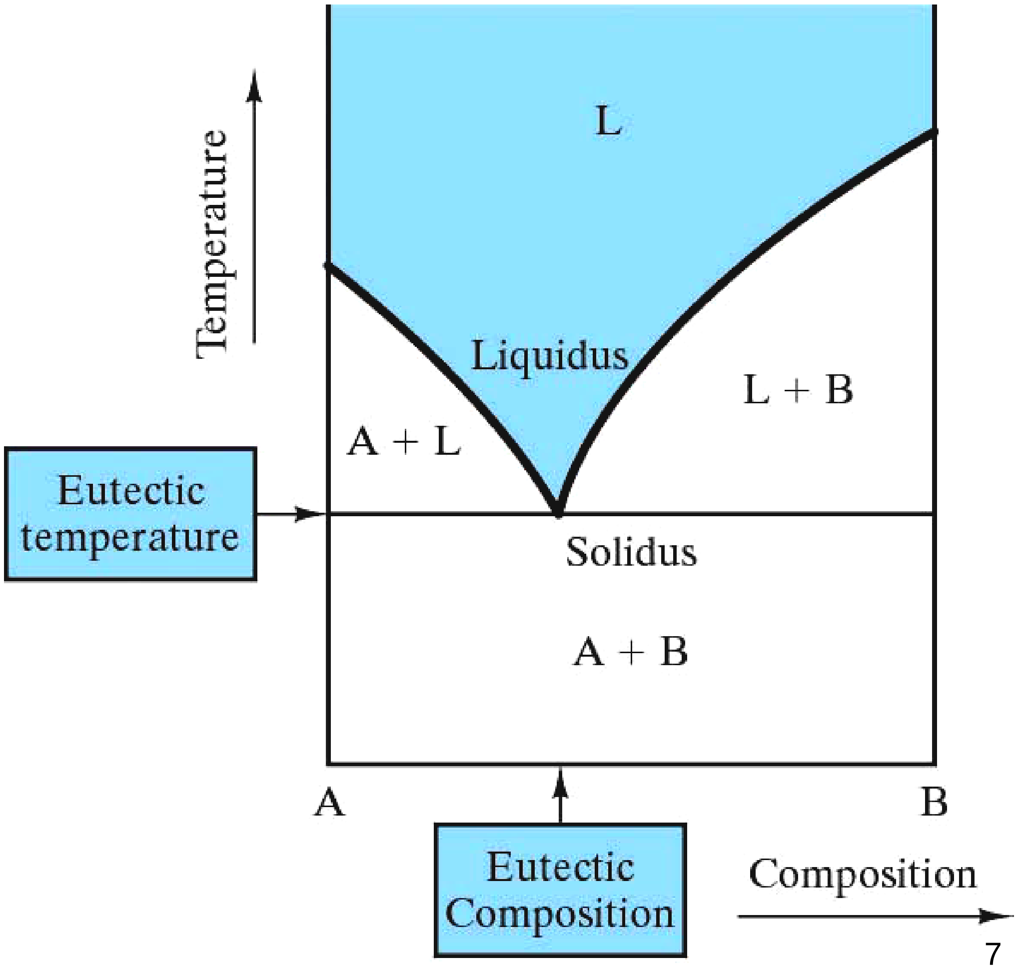
2 components

has a special composition with a min. melting *T*.

Eutectic reaction

L → $\alpha + \beta$

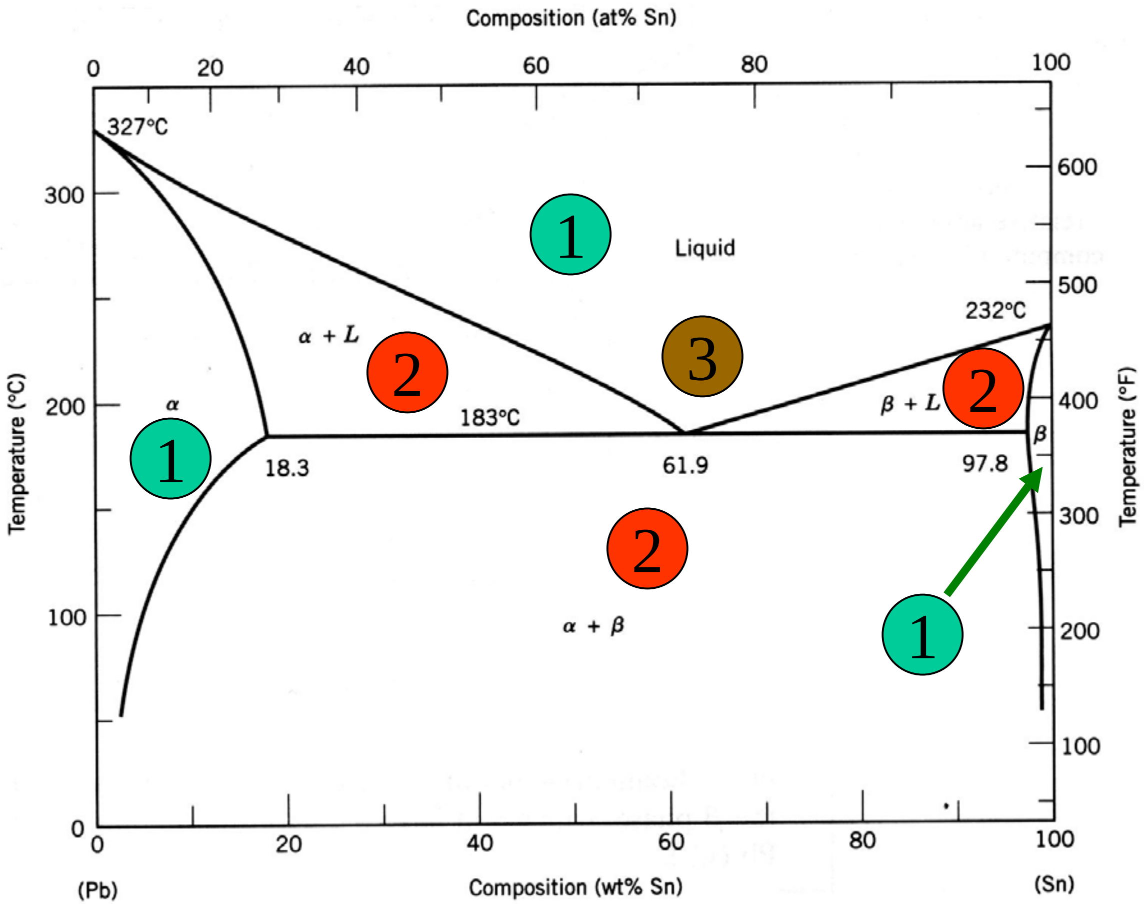




The Gibbs Phase Rule

For Constant Pressure,

P + F = C + 1



1 **single phase**
F = C - P + 1
= 2 - 1 + 1
= 2
can vary T and composition independently

2 **two phase**
***F = C - P* + 1**
= 2 - 2 + 1
= 1
can vary T *or* composition

3 **eutectic point**
F = C - P + 1
= 2 - 3 + 1
= 0
can't vary T or composition

EX 1: Cu-Ag Eutectic 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 : Composition at temperature T_E

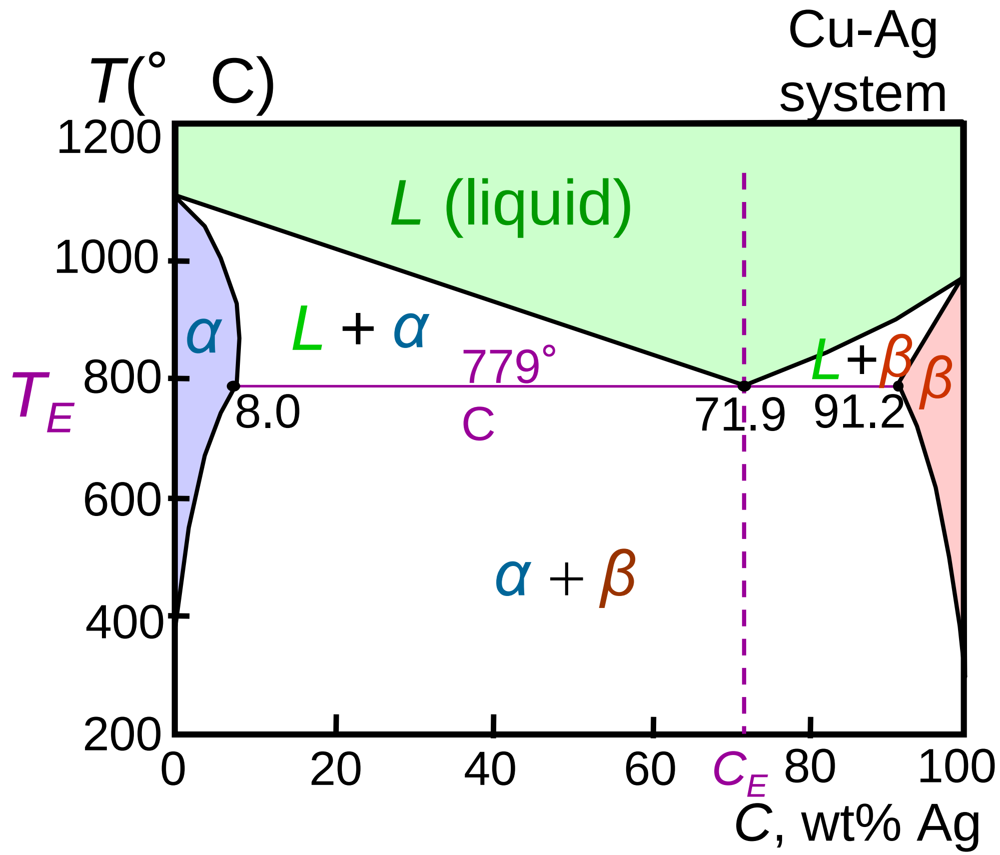


Fig. 11.6, *Callister & Rethwisch 9e*
[Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.].

- **Eutectic reaction**

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

$$L(71.9 \text{ wt\% Ag}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(8.0 \text{ wt\% Ag}) + \beta(91.2 \text{ wt\% Ag})$$

EX 2: Pb-Sn Eutectic System

- For a 40 wt% Sn-60 wt% Pb alloy at 150° C, determine:
  - -- the phases present

    Answer: $\alpha + \beta$
  - -- the phase compositions

    Answer: C_α = 11 wt% Sn

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

    Answer:

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

$$= \frac{99 - 40}{99 - 11} = \frac{59}{88} = 0.67$$

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

$$= \frac{40 - 11}{99 - 11} = \frac{29}{88} = 0.33$$

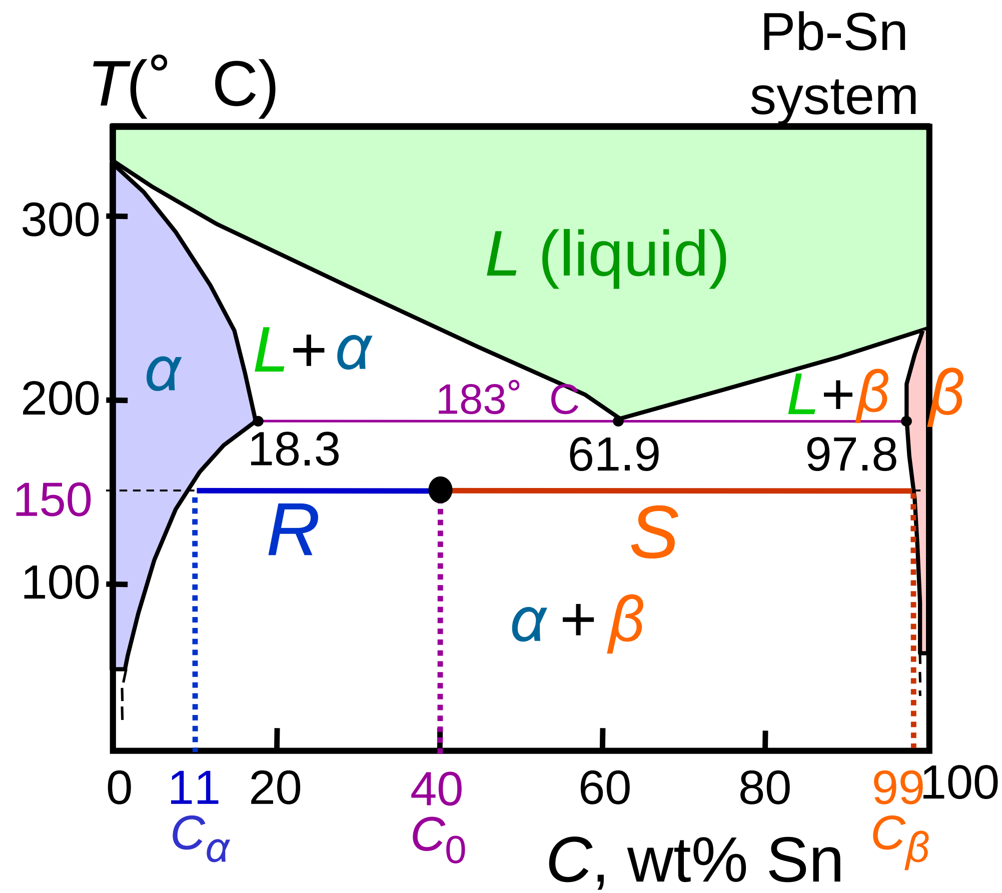


Fig. 11.7, *Callister & Rethwisch 9e.*
[Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 3, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

EX 2: Pb-Sn Eutectic System

- For a 40 wt% Sn-60 wt% Pb alloy at 220°C, determine:
  - -- the phases present:

Answer: $\alpha + L$

-- the phase compositions

Answer: C_α = 17 wt% Sn
C_L = 46 wt% Sn

-- the relative amount of each phase

Answer:

$$W_\alpha = \frac{C_L - C_0}{C_L - C_\alpha} = \frac{46 - 40}{46 - 17} = \frac{6}{29} = 0.21$$

$$W_L = \frac{C_0 - C_\alpha}{C_L - C_\alpha} = \frac{23}{29} = 0.79$$

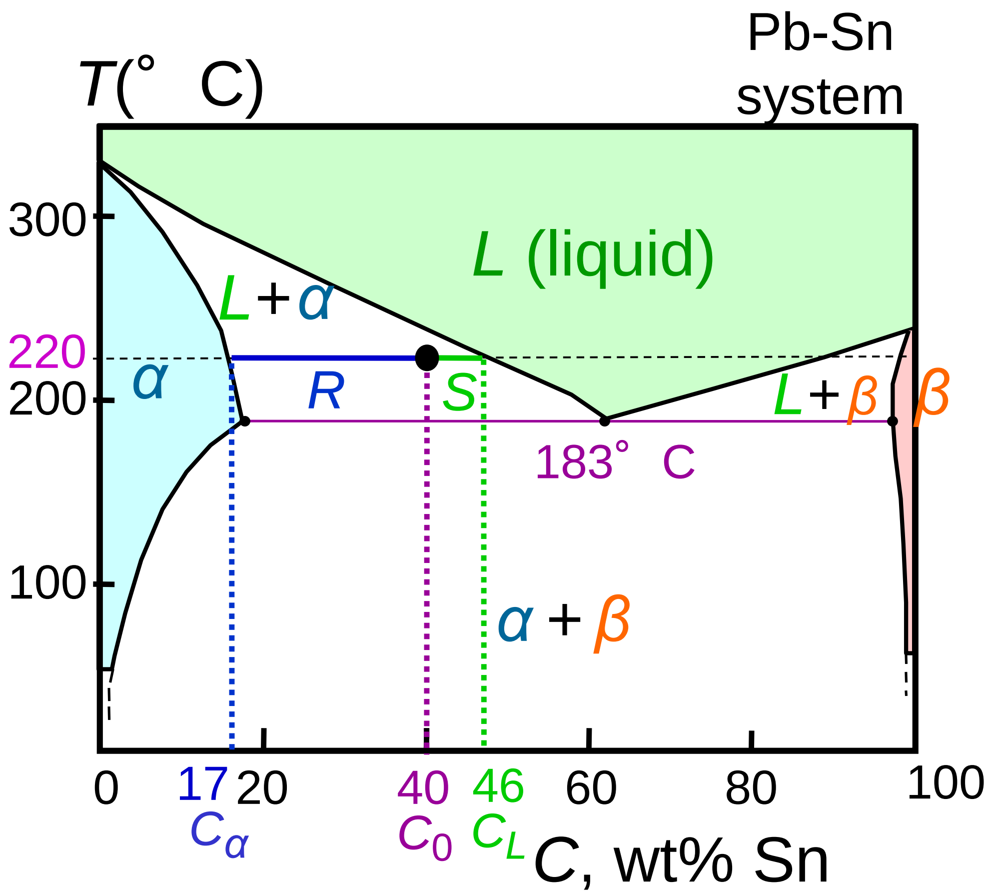


Fig. 11.7, *Callister & Rethwisch 9e.*
[Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 3, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

Microstructural Developments in Eutectic Systems I

- For alloys for which
  C_0 < 2 wt% Sn
- Result: at room temperature
  -- polycrystalline with grains of
  α phase having
  composition C_0

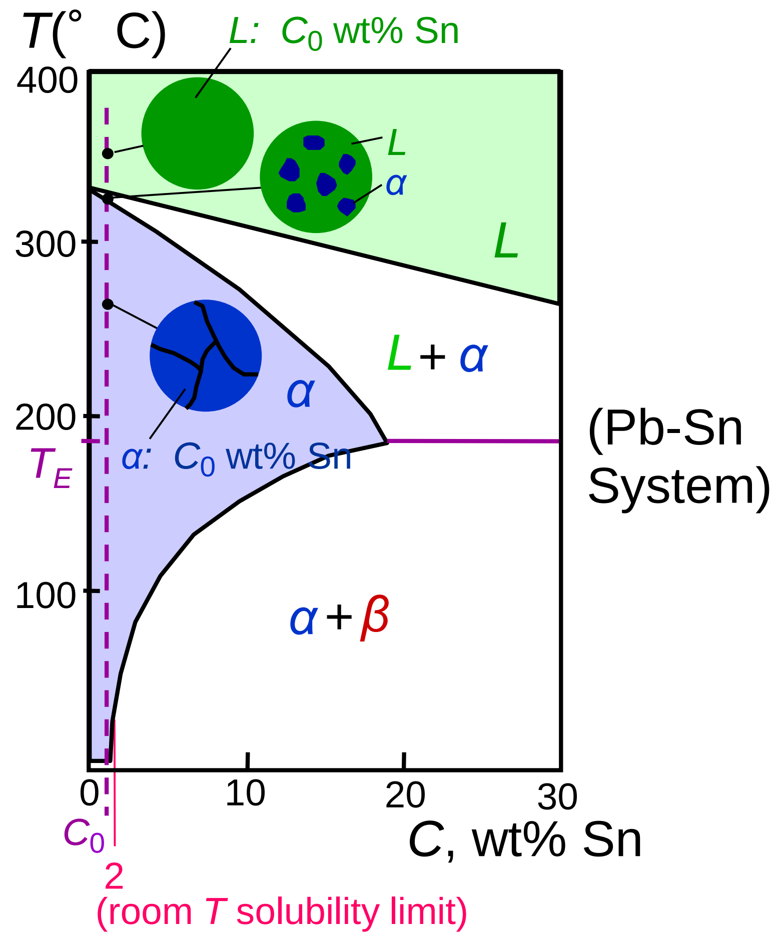


Fig. 11.10, *Callister & Rethwisch 9e.*

Microstructural Developments in Eutectic Systems II

- For alloys for which
  2 wt% Sn < C_0 < 18.3 wt% Sn
- Result:
  at temperatures in $\alpha + \beta$ range
  -- polycrystalline with α grains
  and small β-phase particles

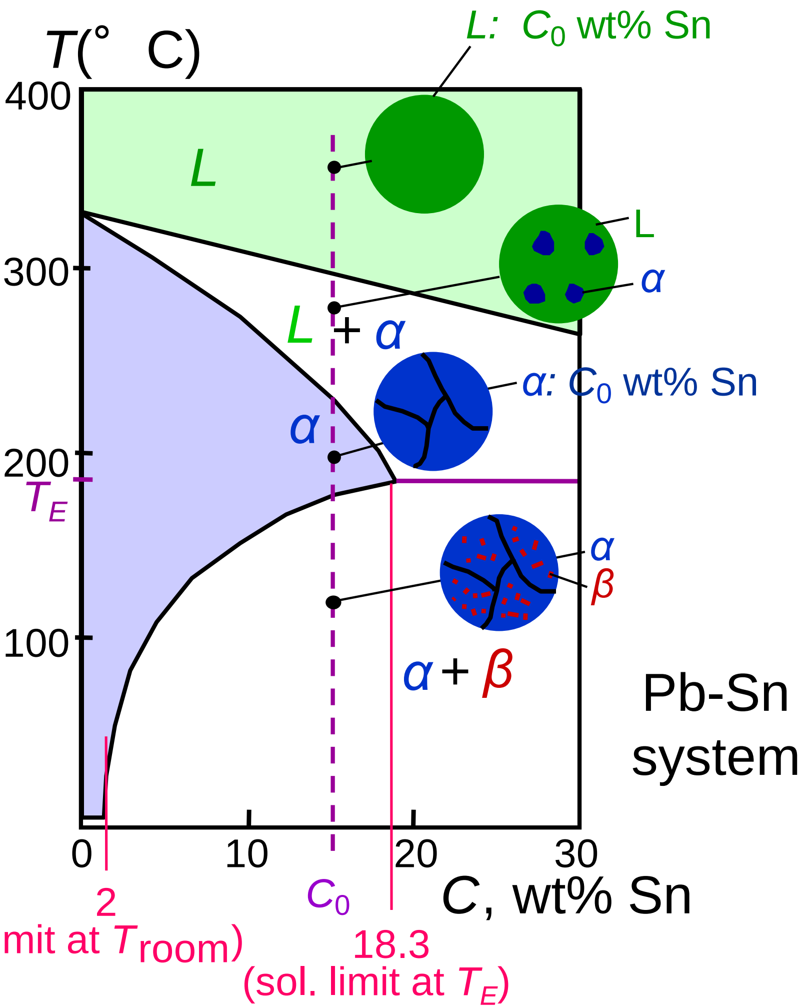


Fig. 11.11, *Callister & Rethwisch 9e.*

Microstructural Developments in Eutectic Systems III

- For alloy of composition $C_0 = C_E$
- Result: Eutectic microstructure (lamellar structure)
  -- alternating layers (lamellae) of α and β phases.

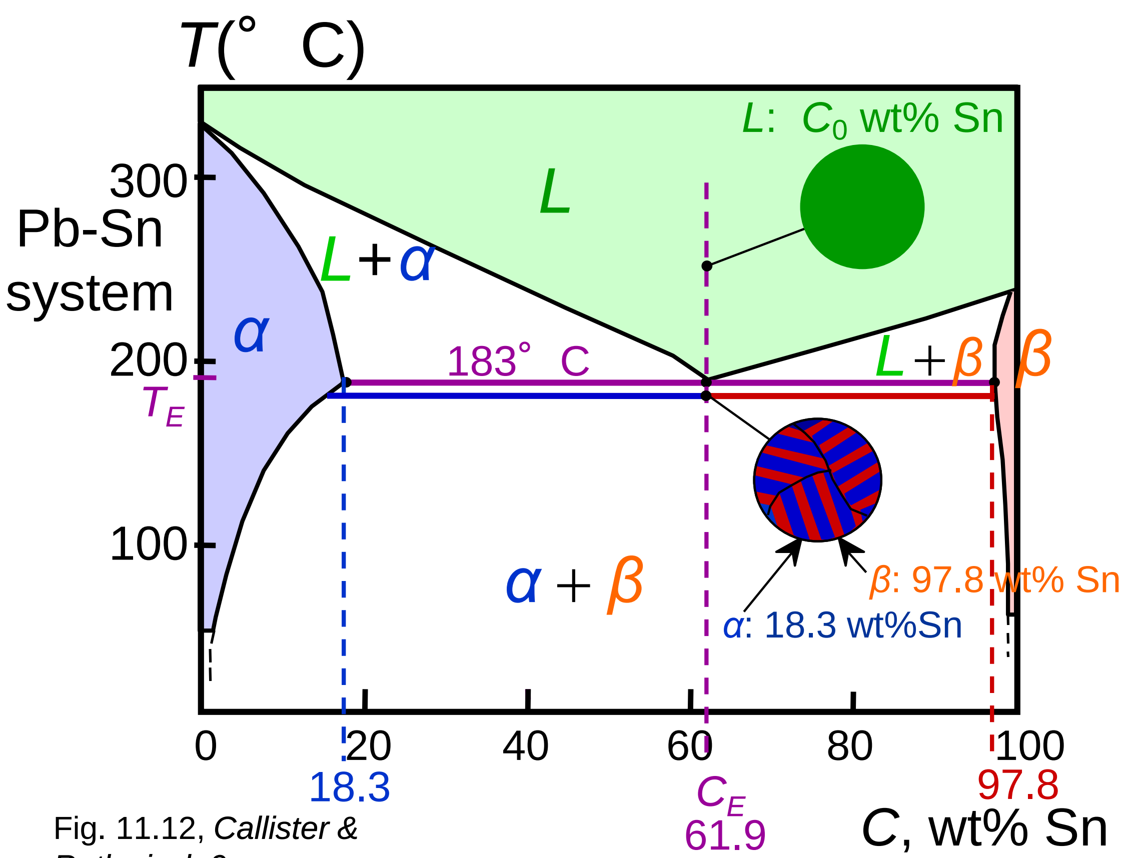


Fig. 11.12, *Callister & Rethwisch 9e.*

Micrograph of Pb-Sn eutectic microstructure

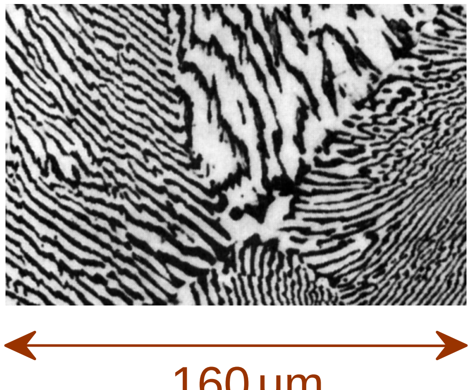
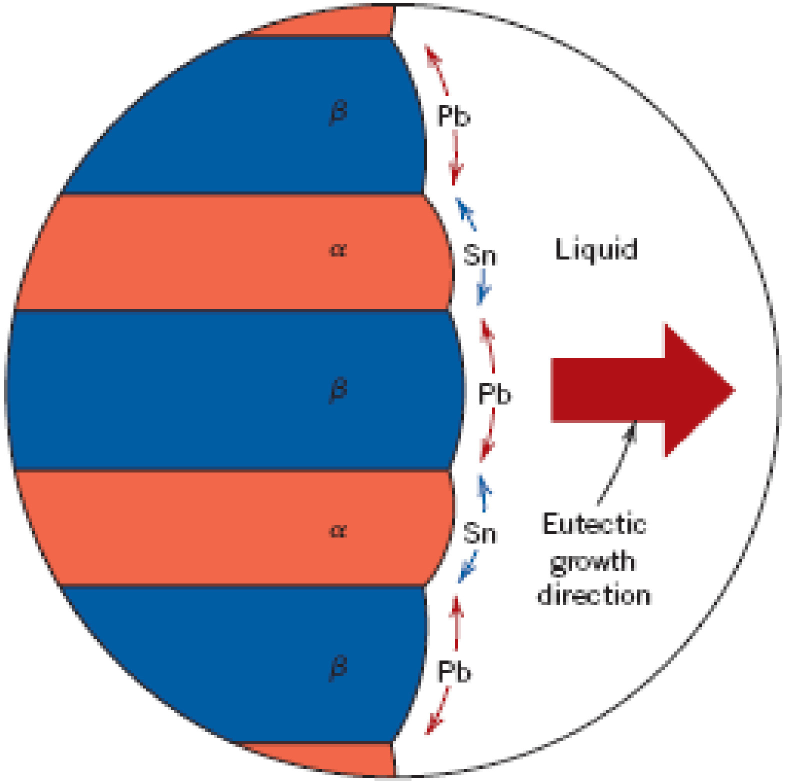
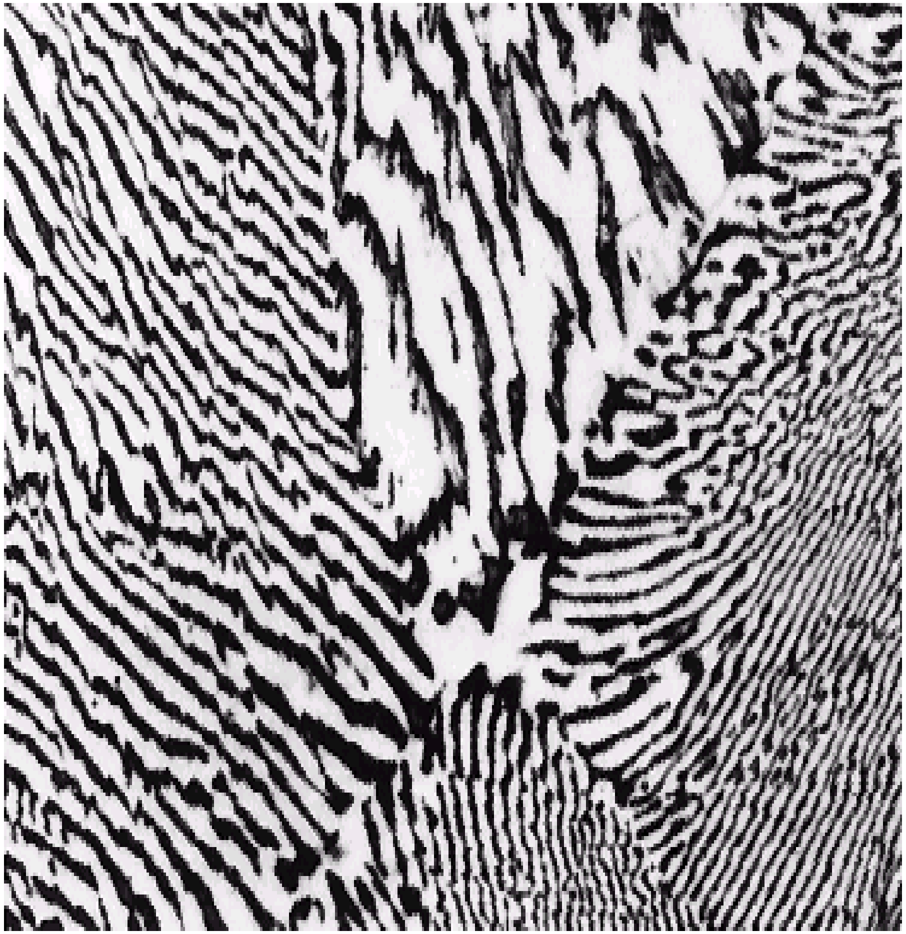


Fig. 11.13, *Callister & Rethwisch 9e.*
(From *Metals Handbook*, 9th edition, Vol. 9, *Metallography and Microstructures*, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

Lamellar Eutectic Structure





Figs. 11.13 & 11.14, *Callister & Rethwisch 9e.*
(Fig. 11.13 from *Metals Handbook*, 9th edition, Vol. 9, *Metallography and Microstructures*, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

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

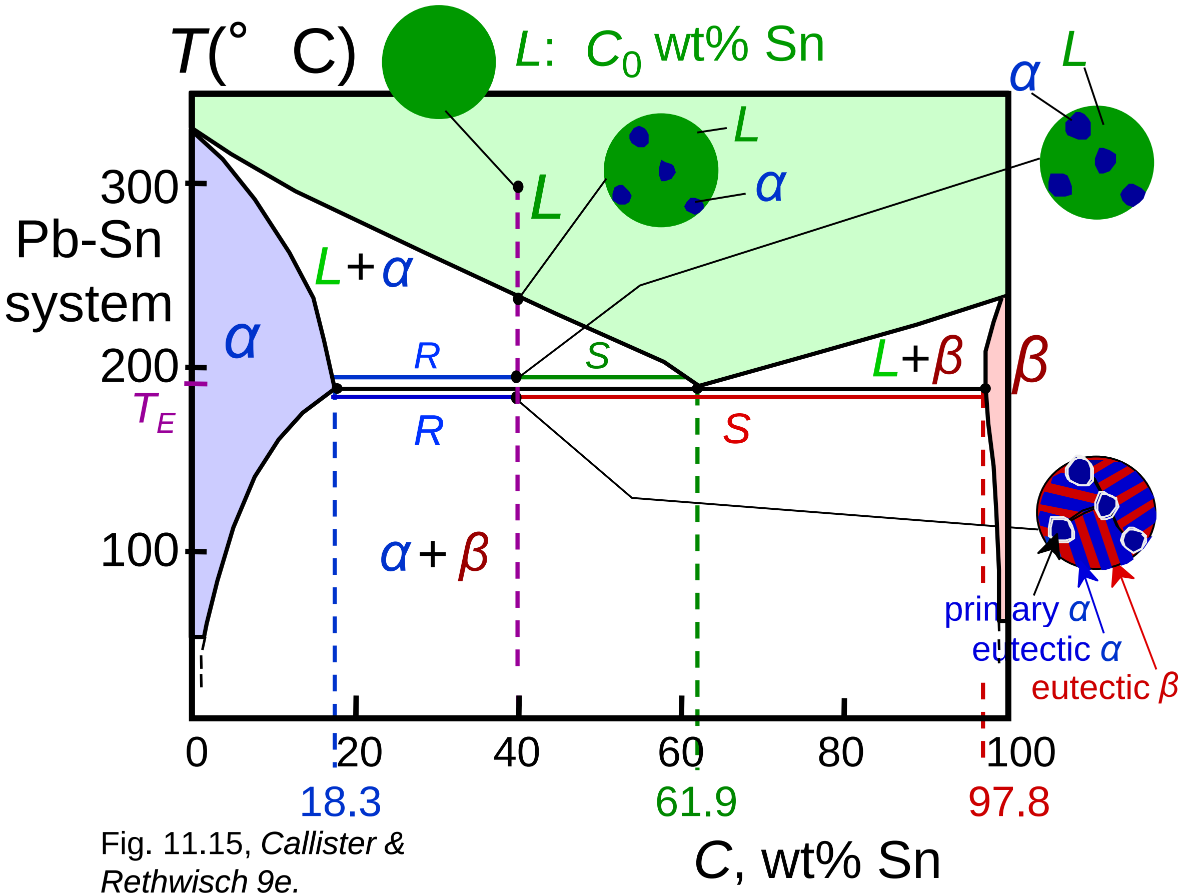


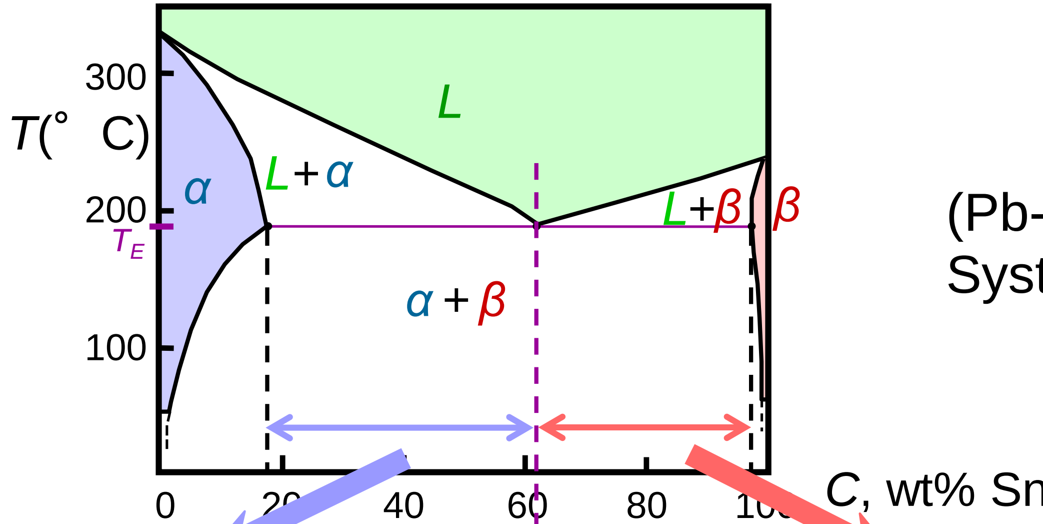
Fig. 11.15, *Callister & Rethwisch 9e.*

- 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_α = 18.3 wt% Sn
  - C_β = 97.8 wt% Sn
  - $W_\alpha = \frac{S}{R+S} = 0.73$
  - W_β = 0.27

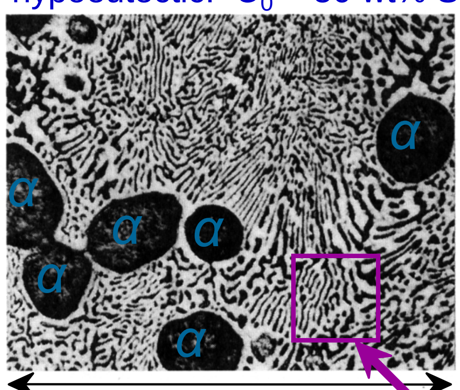
Hypoeutectic & Hypereutectic

Fig. 11.7, *Callister & Rethwisch 9e.* [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)

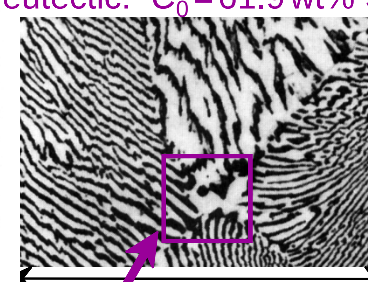
hypoeutectic: C_0 = 50 wt% Sn



175 μm

Fig. 11.16, *Callister & Rethwisch 9e.*

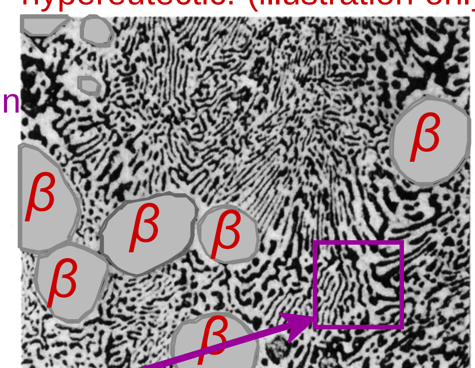
eutectic: C_0 = 61.9 wt% Sn



160 μm

Fig. 11.13, *Callister & Rethwisch 9e.*

hypereutectic: (illustration only)



Adapted from Fig. 11.16, *Callister & Rethwisch 9e.* (Illustration only)

eutectic micro-constituent

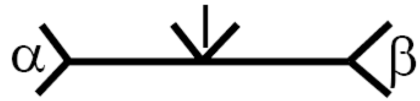
(Figs. 11.13 and 11.16 from *Metals Handbook*, 9th ed., Vol. 9, *Metallography and Microstructures*, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

Review of Invariant Binary Reactions

Eutectic Type

Eutectic

$l \rightleftarrows \alpha + \beta$



Al-Si, Fe-C

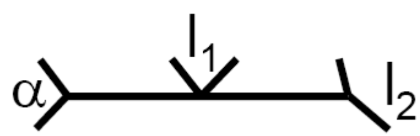
Eutectoid

$\gamma \rightleftarrows \alpha + \beta$

Fe-C

Monotectic

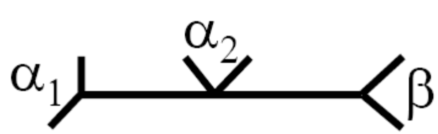
$l_1 \rightleftarrows \alpha + l_2$



Cu-Pb

Monotectoid

$\alpha_2 \rightleftarrows \alpha_1 + \beta$



Al-Zn, Ti-V

On cooling one phase going to two phases

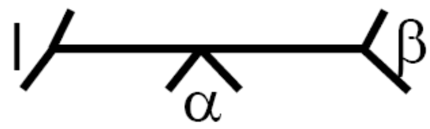
Metatectic reaction: $\beta \leftrightarrow L + \alpha$ **Ex. Co-Os, Co-Re, Co-Ru**

Review of Invariant Binary Reactions

Peritectic Type

Peritectic

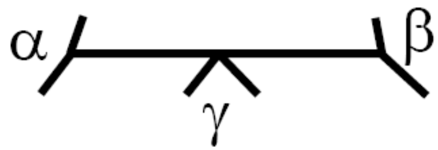
$l + \beta \rightleftarrows \alpha$



Fe-C

Peritectoid

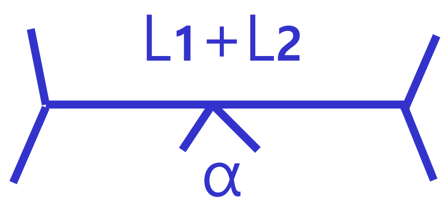
$\alpha + \beta \rightleftarrows \gamma$



Cu-Al

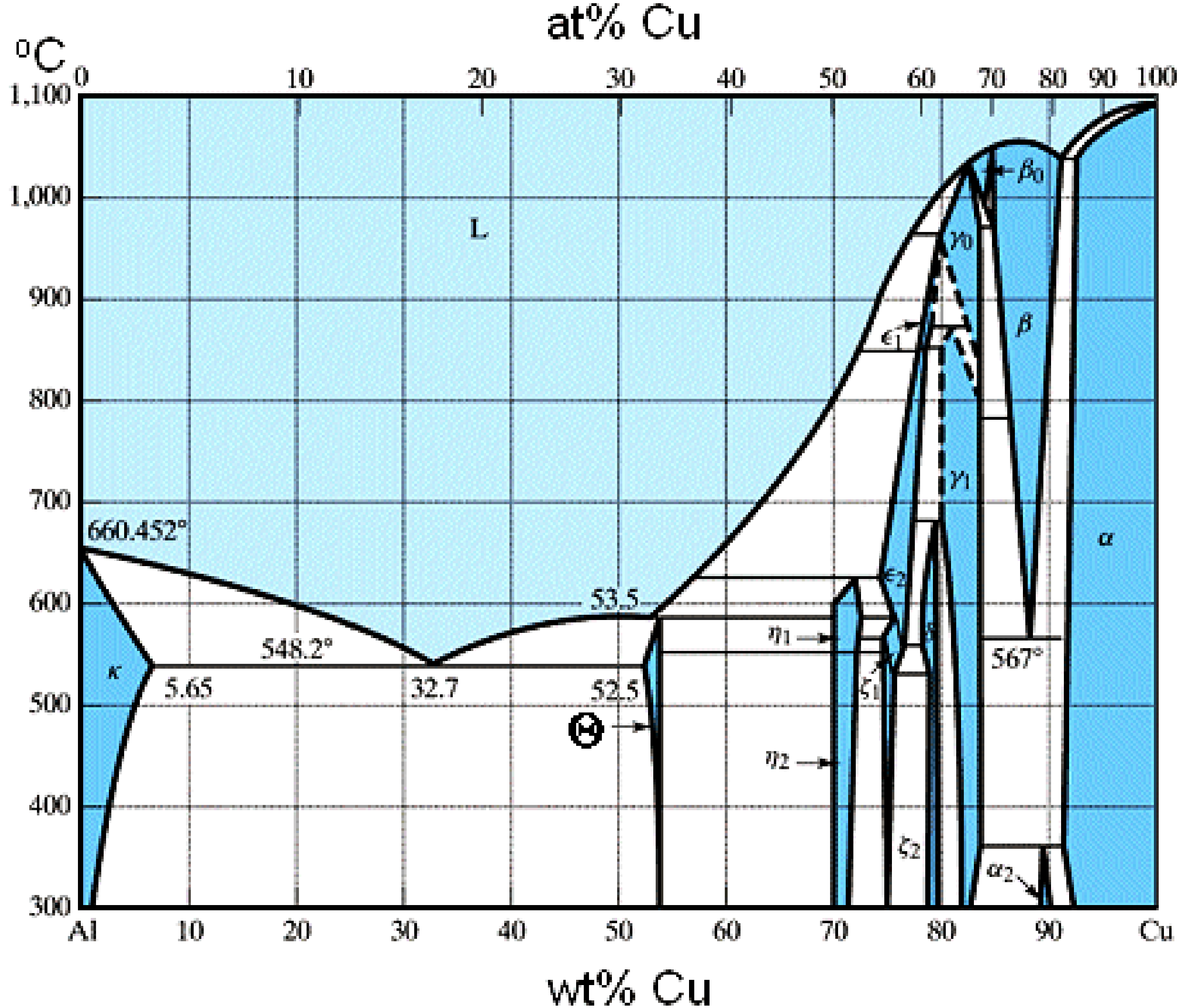
Syntectic reaction

$Liquid_1 + Liquid_2 \leftrightarrow \alpha$



K-Zn, Na-Zn,
K-Pb, Pb-U, Ca-Cd

On cooling two phases going to one phase


at% Cu
°C
0
10
20
30
40
50
60
70
80
90
100
1,100
1,000
900
800
700
600
500
400
300
L
660.452°
548.2°
53.5
5.65
32.7
52.5
κ
Θ
η_1
η_2
ζ_1
ζ_2
ϵ_1
ϵ_2
γ_0
γ_1
β_0
β
α
α_2
567°
Al
10
20
30
40
50
60
70
80
90
Cu
wt% Cu

V. 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

$$S_2 \rightleftharpoons S_1 + S_3$$

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

intermetallic compound - cementite

- Peritectic - liquid and one solid phase transform to a second solid phase

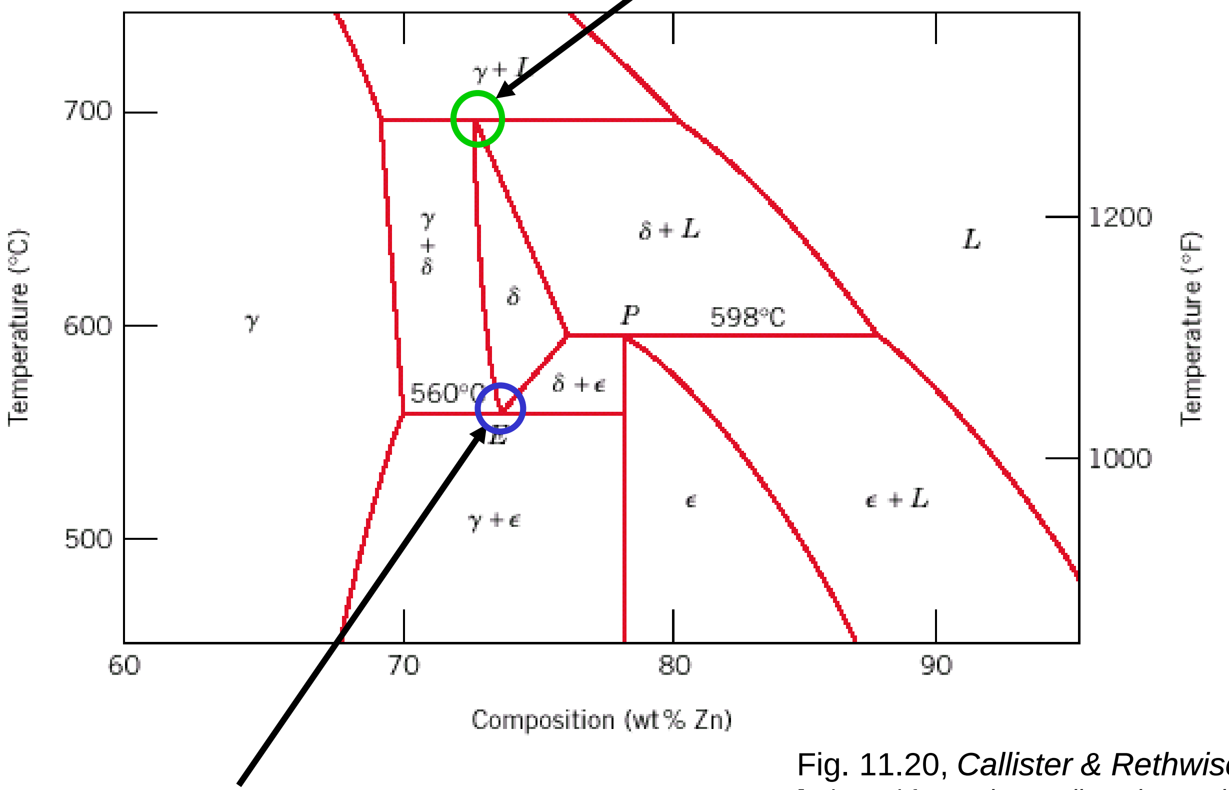
$$S_1 + L \rightleftharpoons S_2$$

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

a. Eutectoid & Peritectic

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

Cu-Zn Phase diagram



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

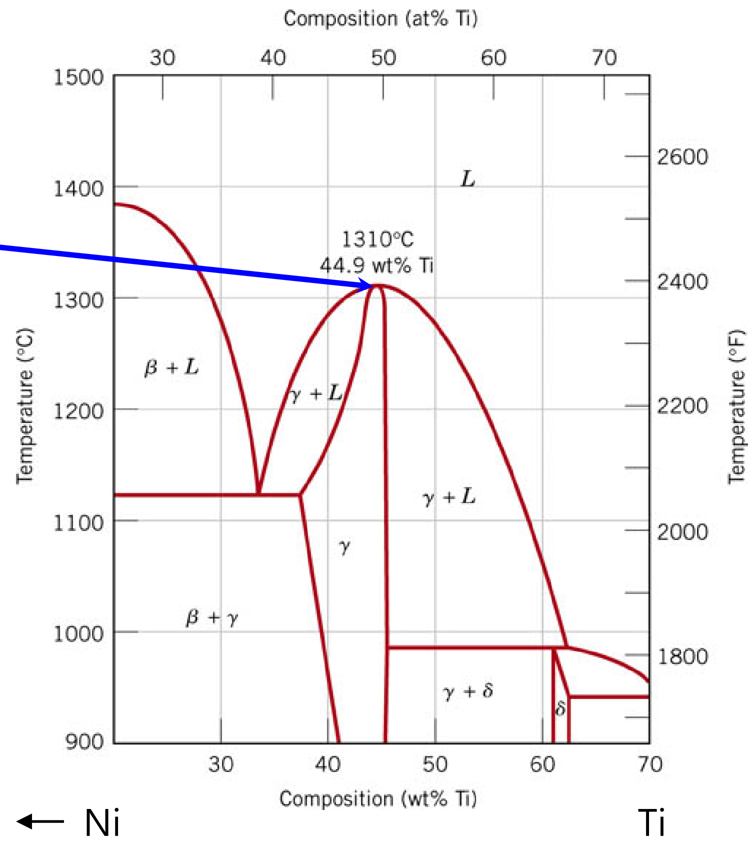
Fig. 11.20, *Callister & Rethwisch 9e.*
[Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 2, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

b. Congruent vs Incongruent

Congruent phase transformations: <u>no compositional change associated with transformation</u>

Examples:

- Allotropic phase transformations
- Melting points of pure metals
- Congruent Melting Point



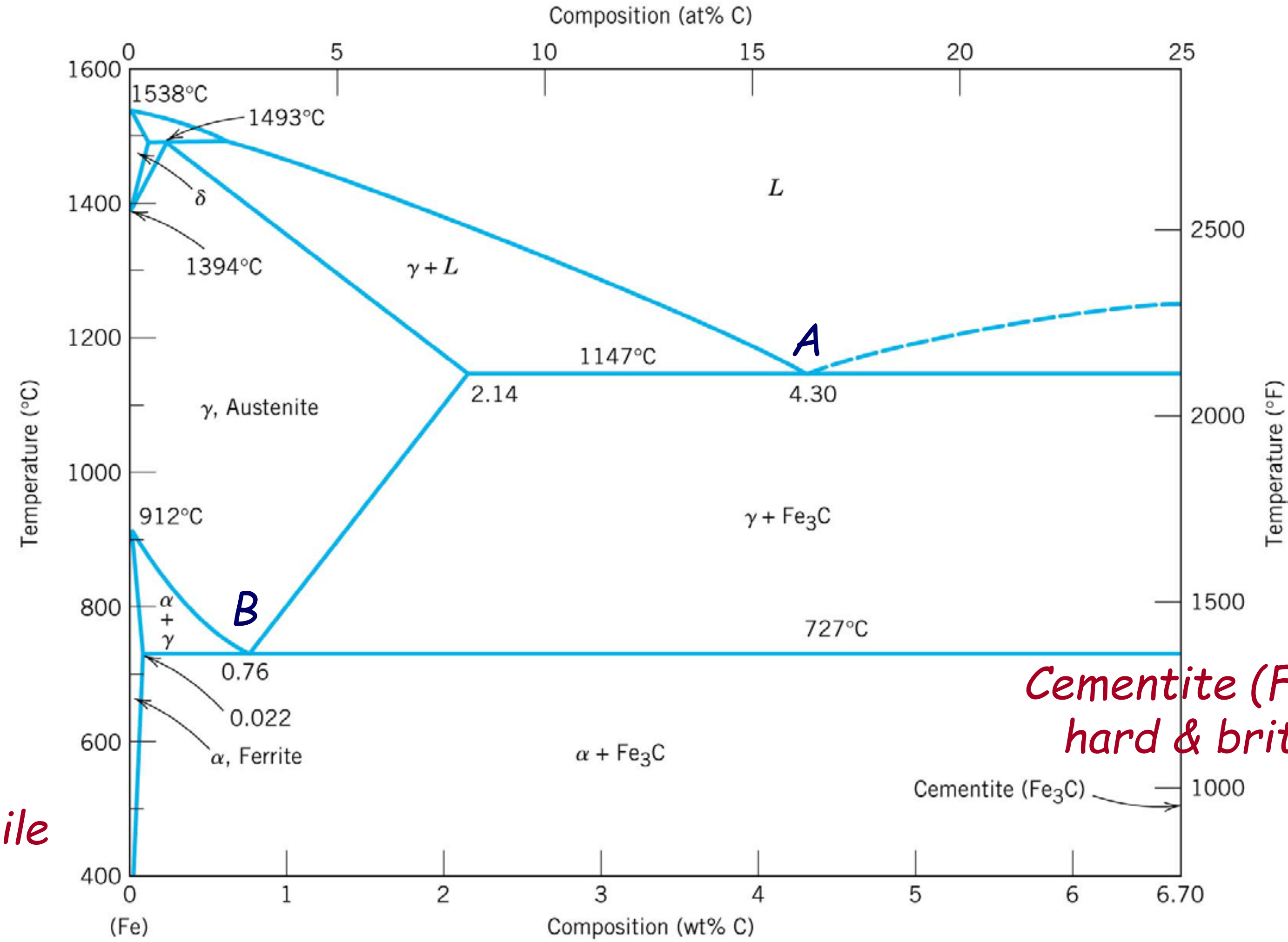
Incongruent phase transformation: <u>at least one phase will experience change in composition</u>

Examples:

- Melting in isomorphous alloys
- Eutectic reactions
- Pertectic Reactions
- Eutectoid reactions

c. Fe-C phase diagram

γ iron
austenite
(FCC)



α iron
Ferrite
(BCC)
soft & ductile

Cementite (Fe_3C)
hard & brittle

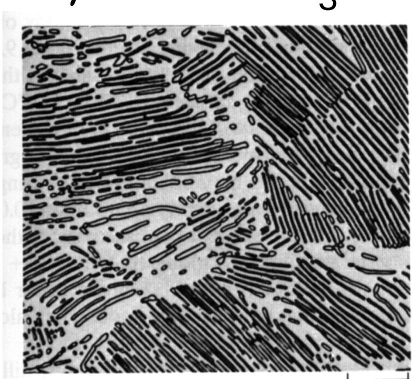
A; eutectic

B; eutectoid

C concentration	0.008w%	2.14w%	6.7w%
	iron	steel	cast iron

Iron-Carbon (Fe-C) Phase Diagram

- 2 important points
  - Eutectic (*A*): $L \Rightarrow \gamma + Fe_3C$
  - Eutectoid (*B*): $\gamma \Rightarrow \alpha + Fe_3C$



120 μm

Result: Pearlite = alternating layers of *α* and Fe_3C phases

Fig. 11.26, *Callister & Rethwisch 9e.*
(From *Metals Handbook*, Vol. 9, 9th ed., *Metallography and Microstructures*, 1985. Reproduced by permission of ASM International, Materials Park, OH.)

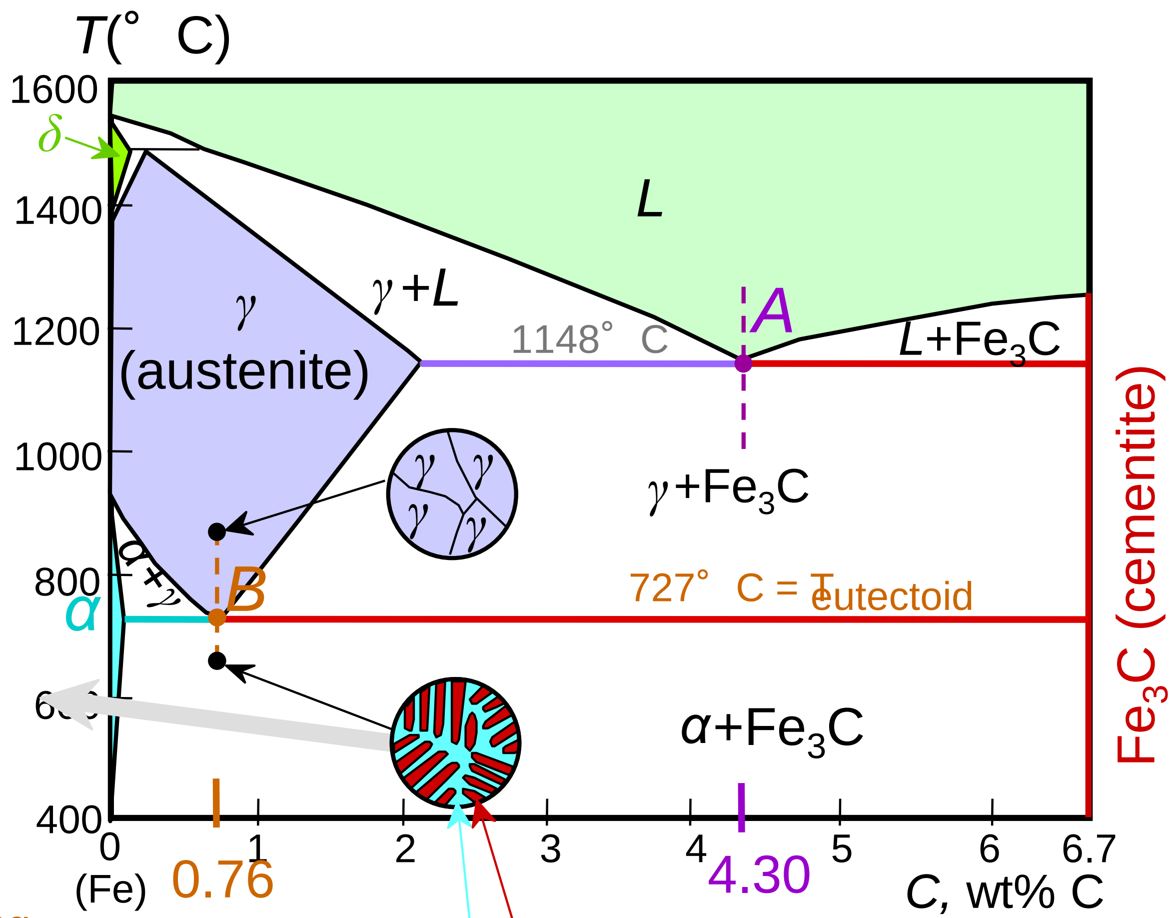
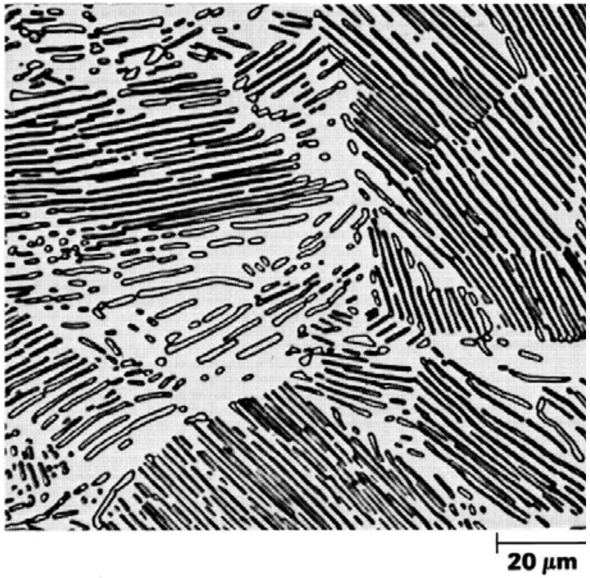
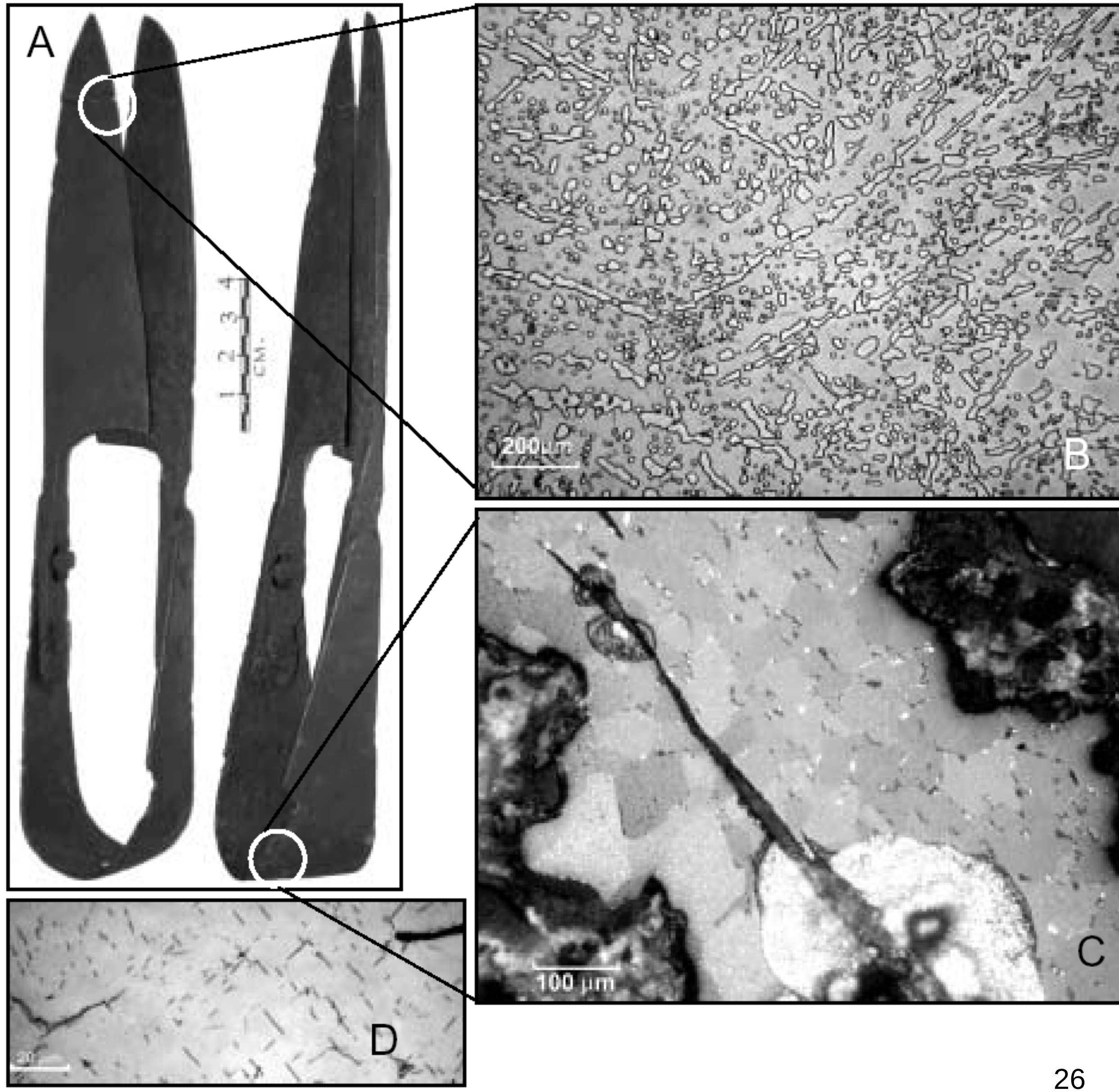


Fig. 11.23, *Callister & Rethwisch 9e.*
[Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

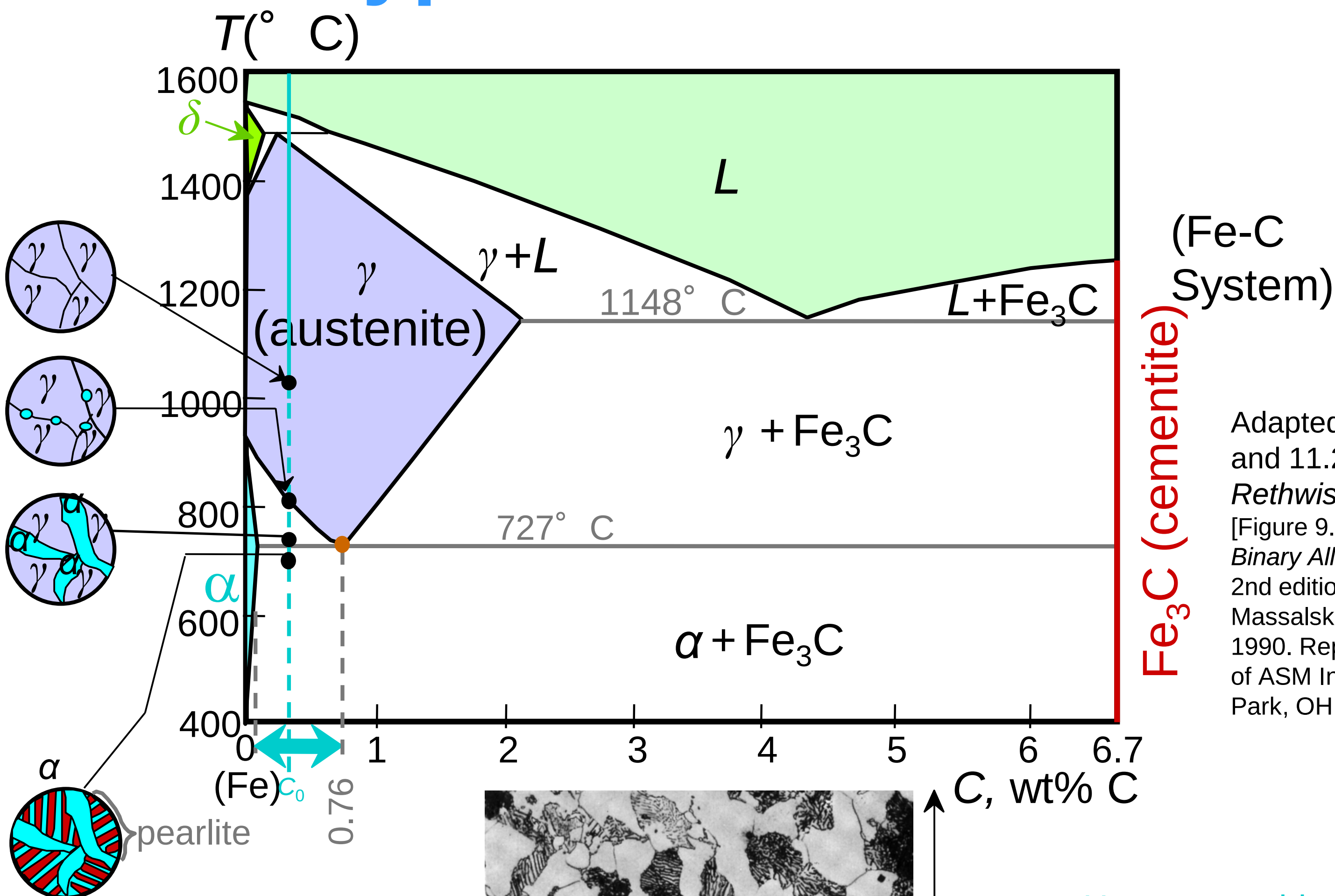
Pearlite microstructure



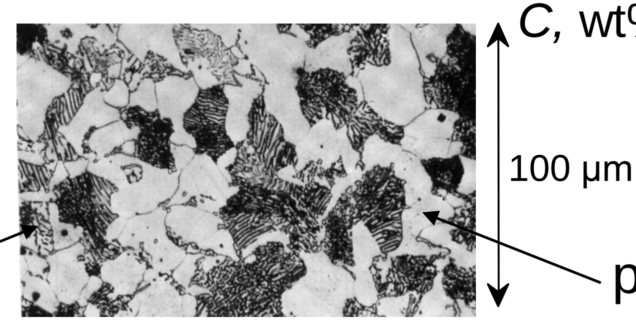


Cemen
(Fe_3(

Hypoeutectoid Steel

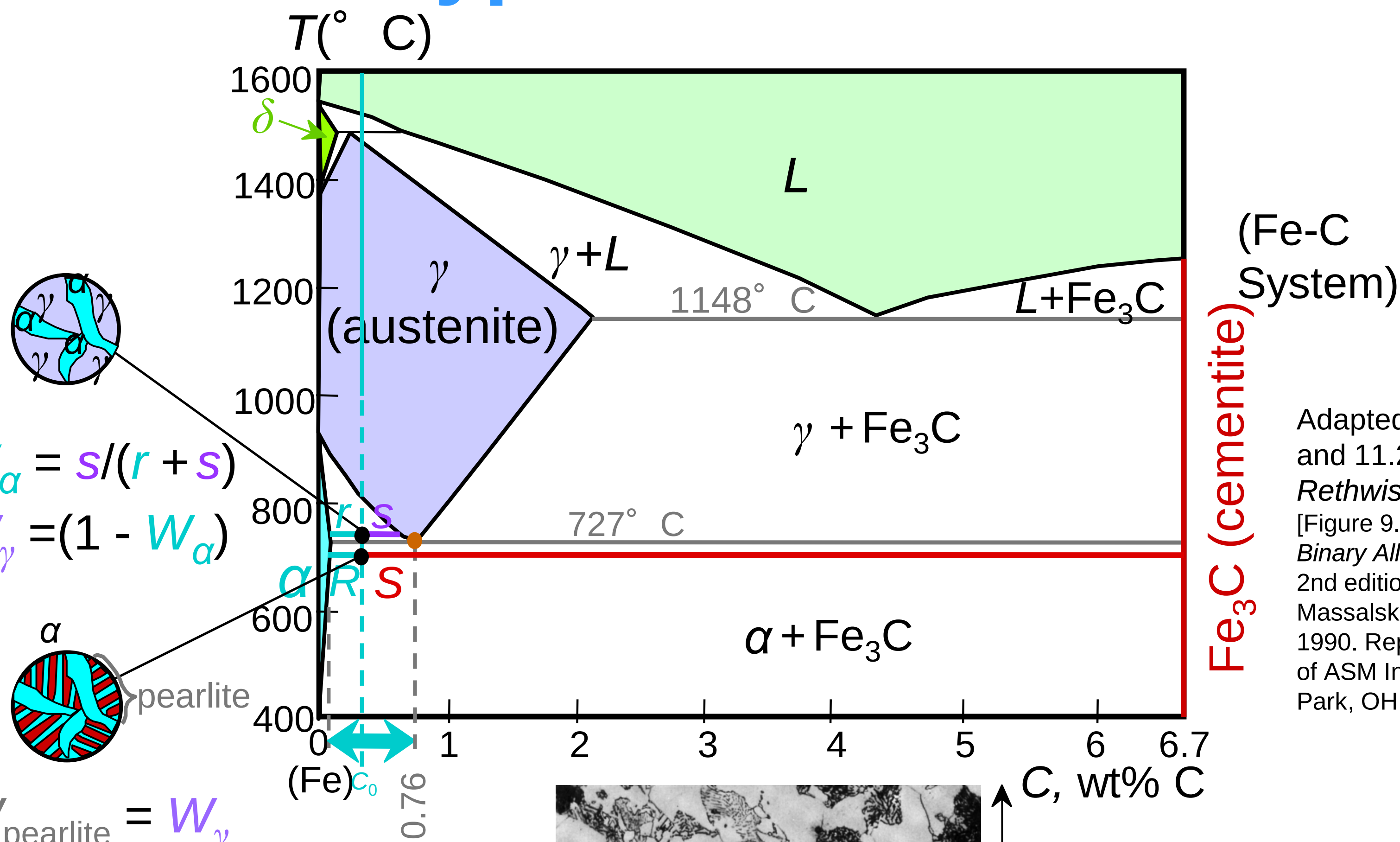


Adapted from Figs. 11.23 and 11.28, *Callister & Rethwisch 9e.*
[Figure 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Adapted from Fig. 11.29, *Callister & Rethwisch 9e.*
(Photomicrograph courtesy of Republic Steel Corporation.)

Hypoeutectoid Steel



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

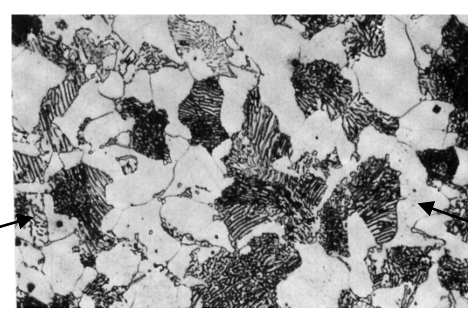
$W_\gamma = (1 - W_\alpha)$

$W_{pearlite} = W_\gamma$

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

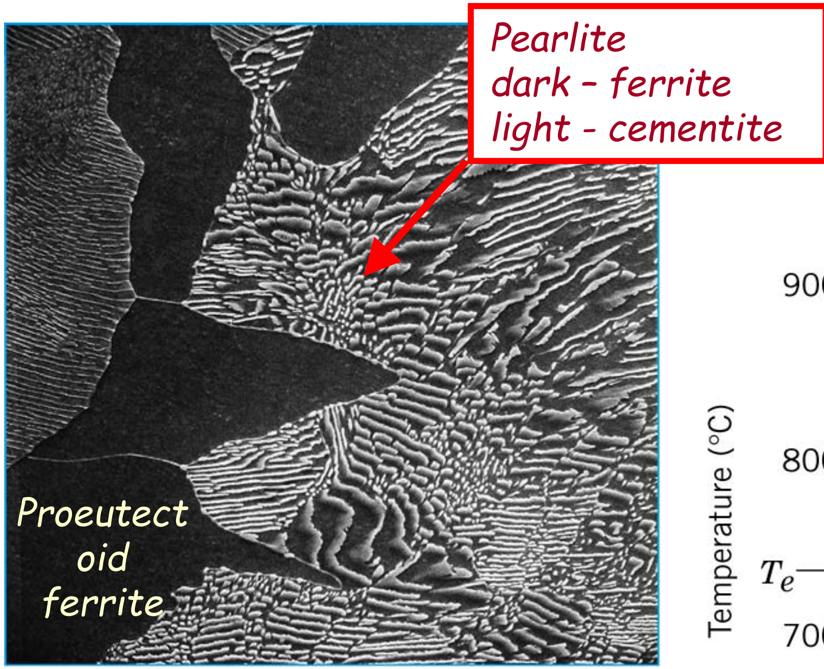
$W_{Fe_3C} = (1 - W_{\alpha'})$

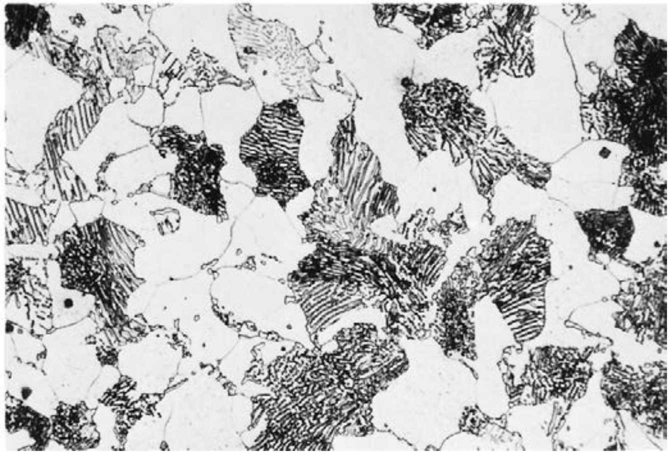
Adapted from Figs. 11.23 and 11.28, *Callister & Rethwisch 9e.*
[Figure 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]

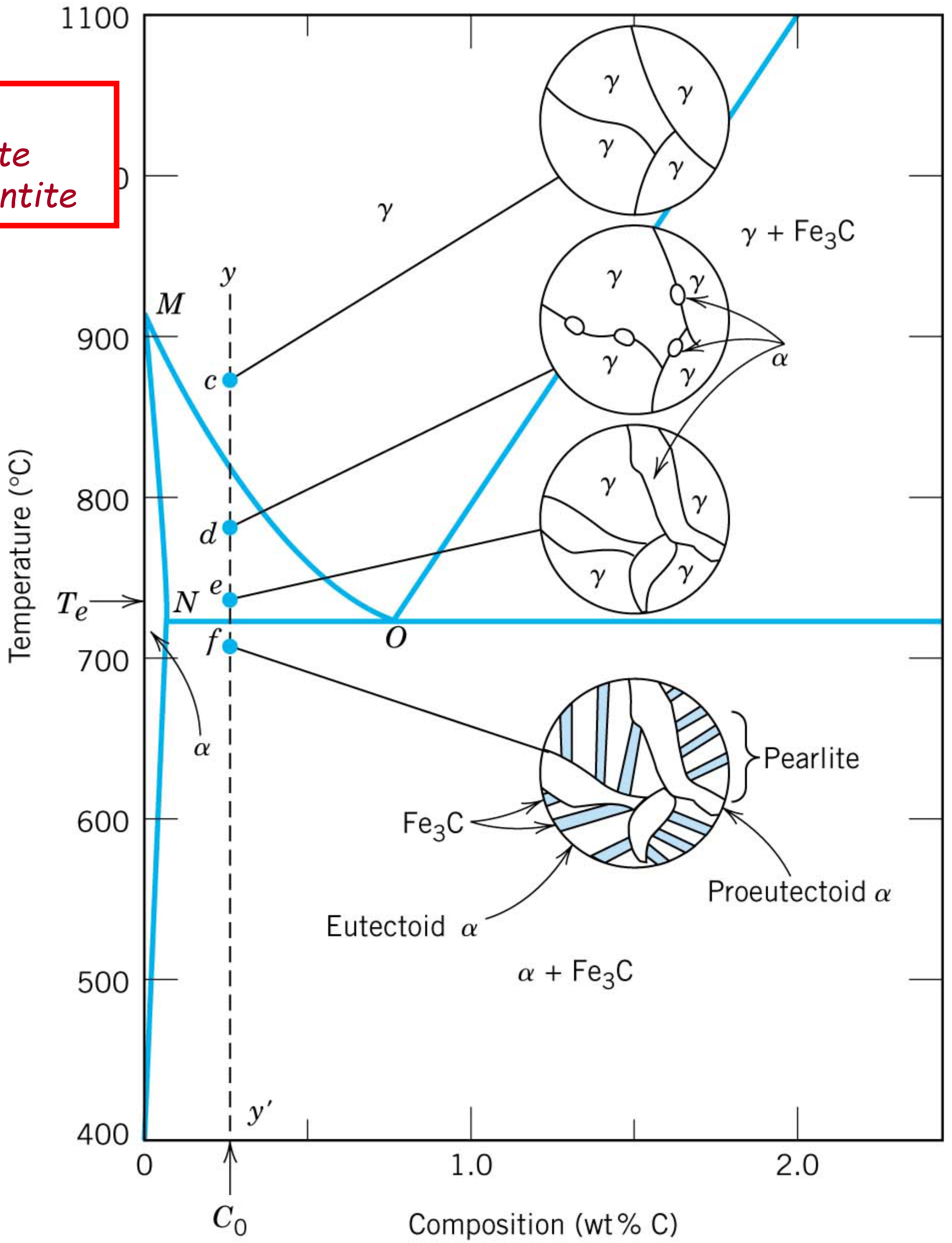


Adapted from Fig. 11.29, *Callister & Rethwisch 9e.*
(Photomicrograph courtesy of Republic Steel Corporation.)

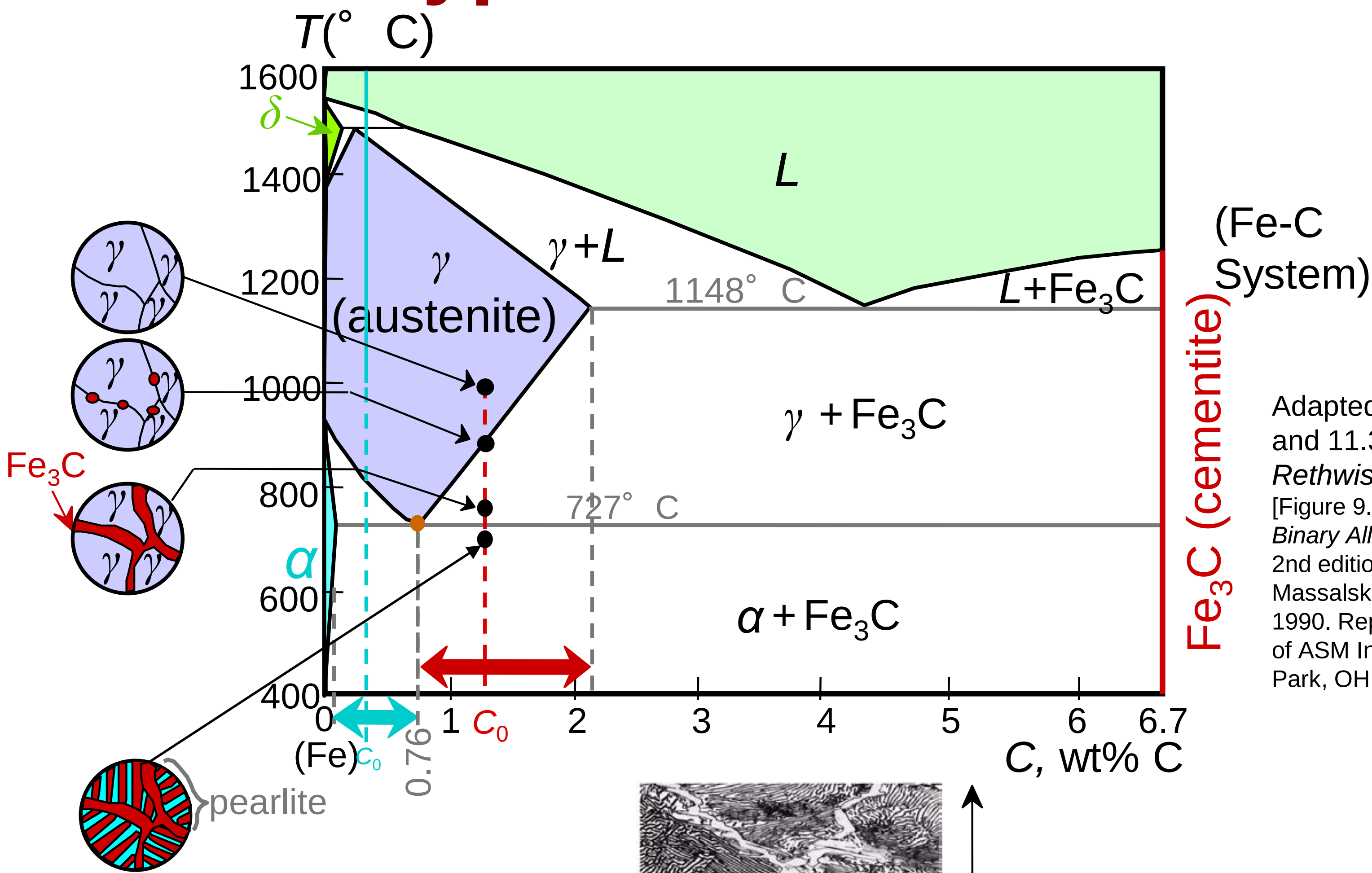
Hypoeutectoid Steel



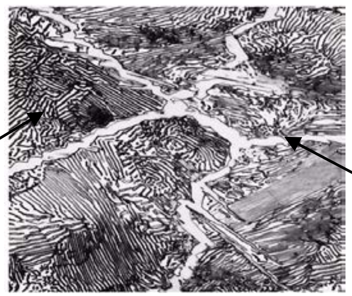




Hypereutectoid Steel

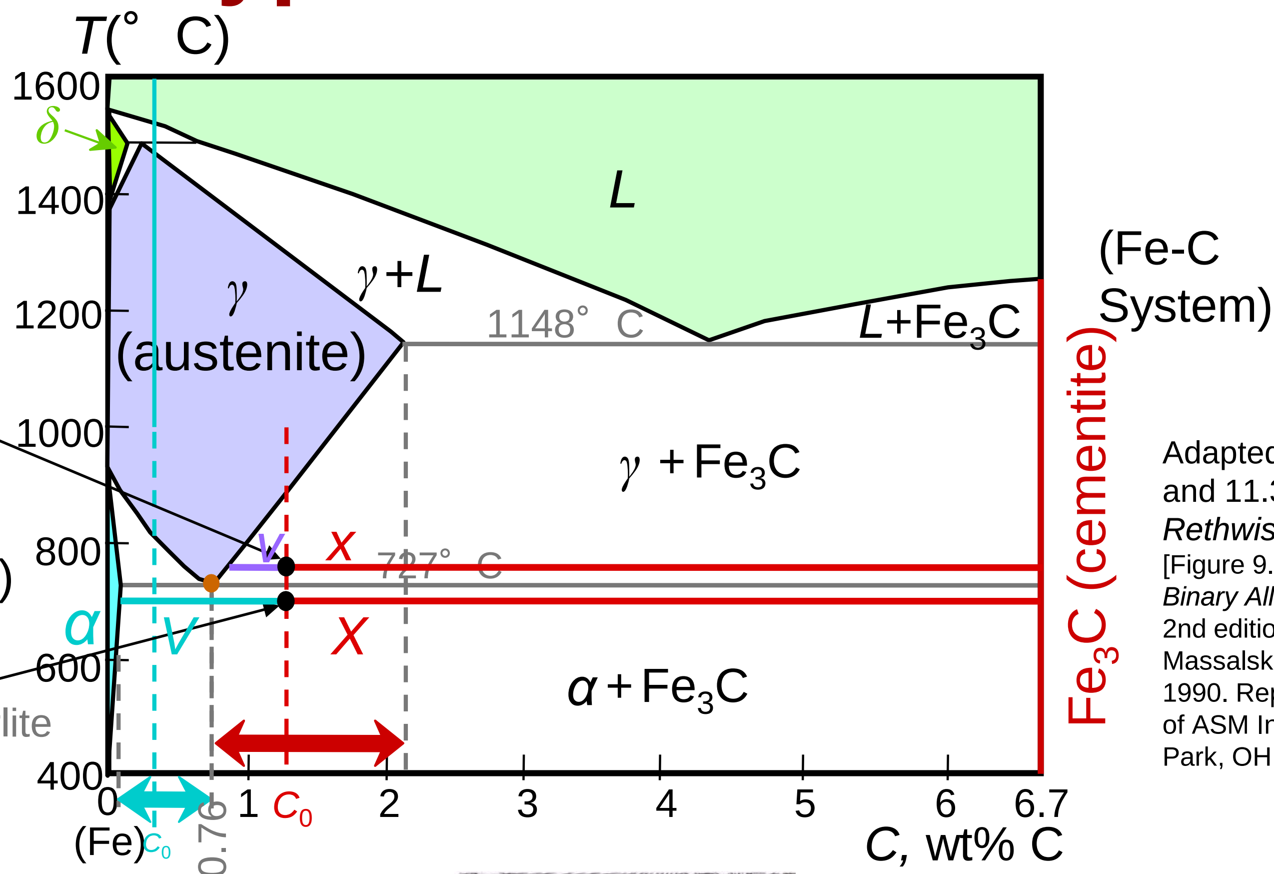


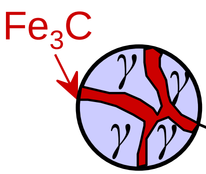
Adapted from Figs. 11.23 and 11.31, *Callister & Rethwisch 9e.*
[Figure 9.24 adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski (Editor-in-Chief), 1990. Reprinted by permission of ASM International, Materials Park, OH.]



Adapted from Fig. 11.32, *Callister & Rethwisch 9e*.
(Copyright 1971 by United States Steel Corporation.)

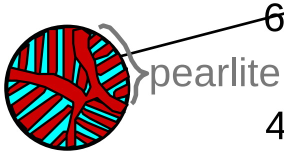
Hypereutectoid Steel





$W_{\gamma} = x/(v + x)$

$W_{Fe_3C} = (1 - W_{\gamma})$

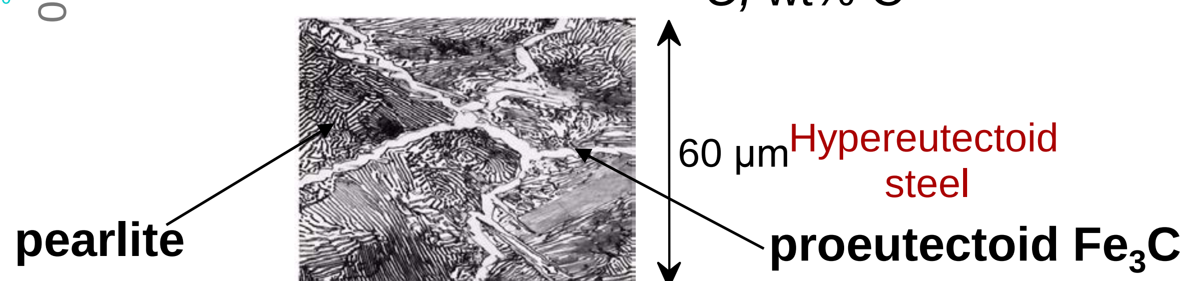


$W_{pearlite} = W_{\gamma}$

$W_{\alpha} = X/(V + X)$

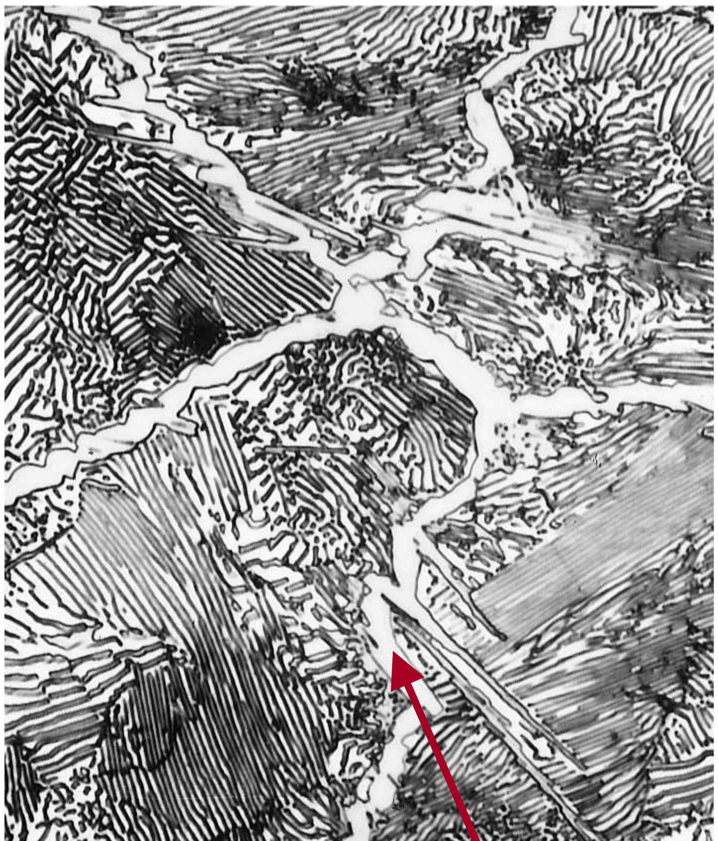
$W_{Fe_3C'} = (1 - W_{\alpha})$

Adapted from Figs. 11.23 and 11.31, *Callister & Rethwisch 9e.*
[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.]



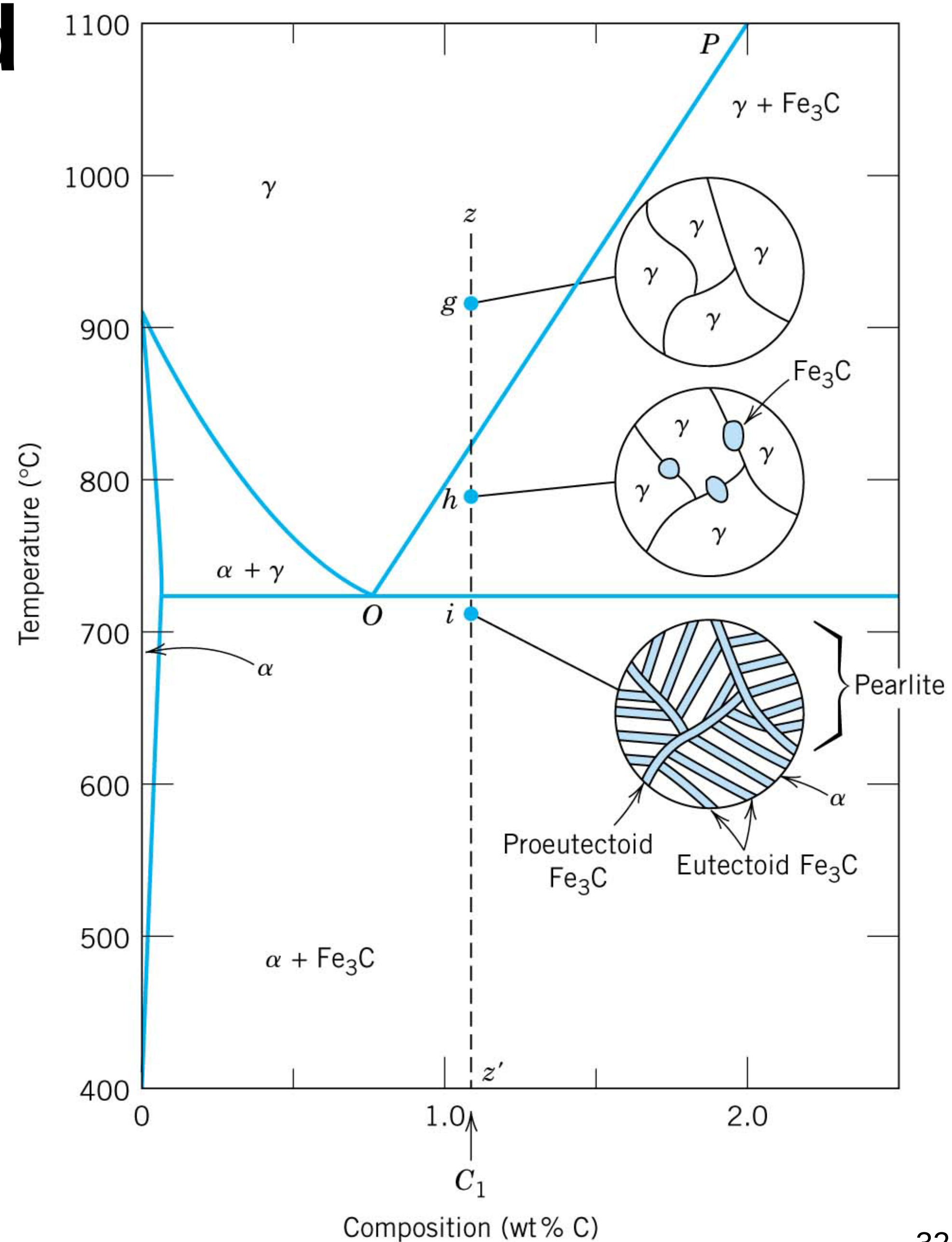
Adapted from Fig. 11.32, *Callister & Rethwisch 9e*.
(Copyright 1971 by United States Steel Corporation.)

Hypereutectoid Steel

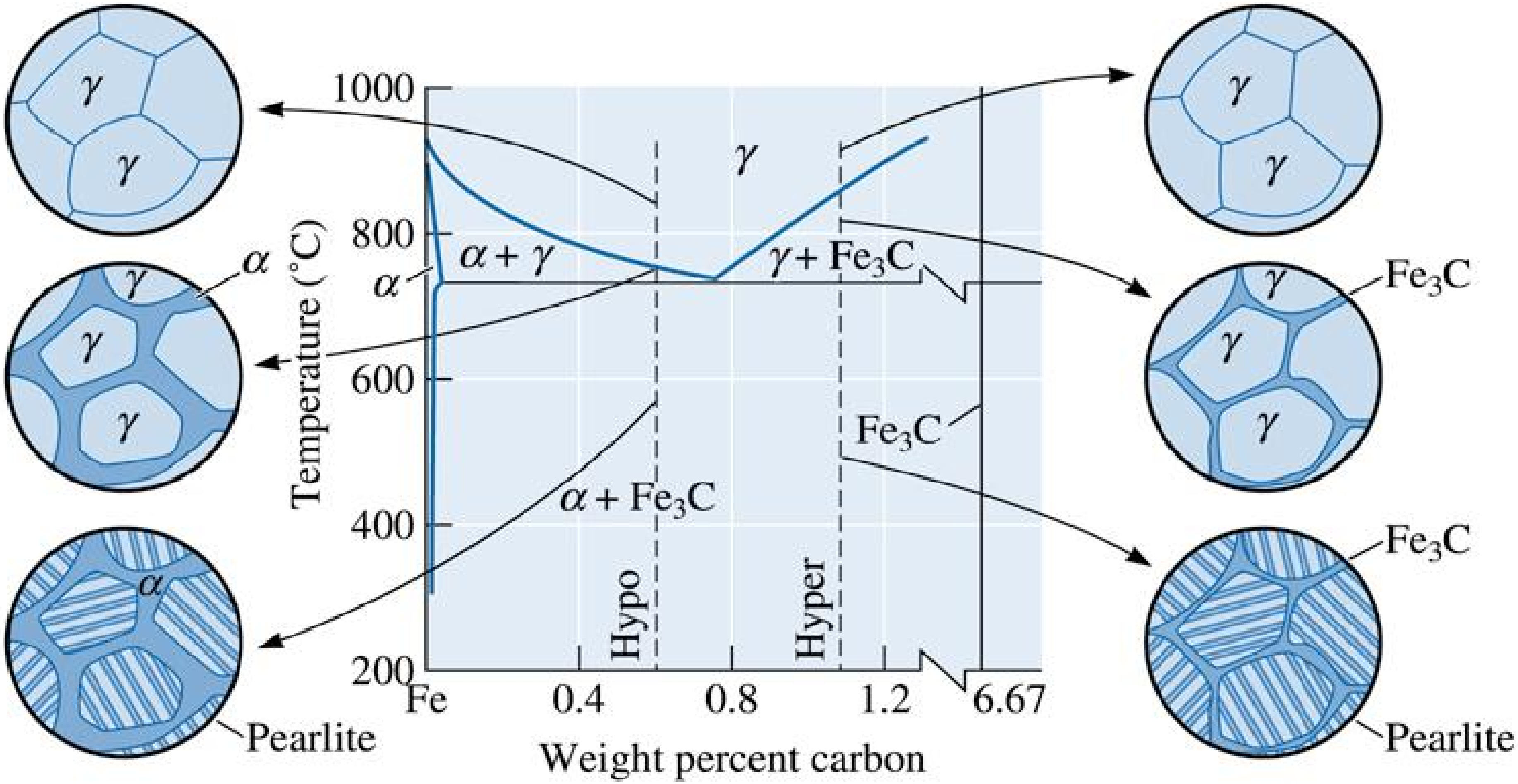


Pearlite

Proeutectoid cementite



Evolution of microstructure of hypoeutectoid and hypereutectoid steels during cooling



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

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

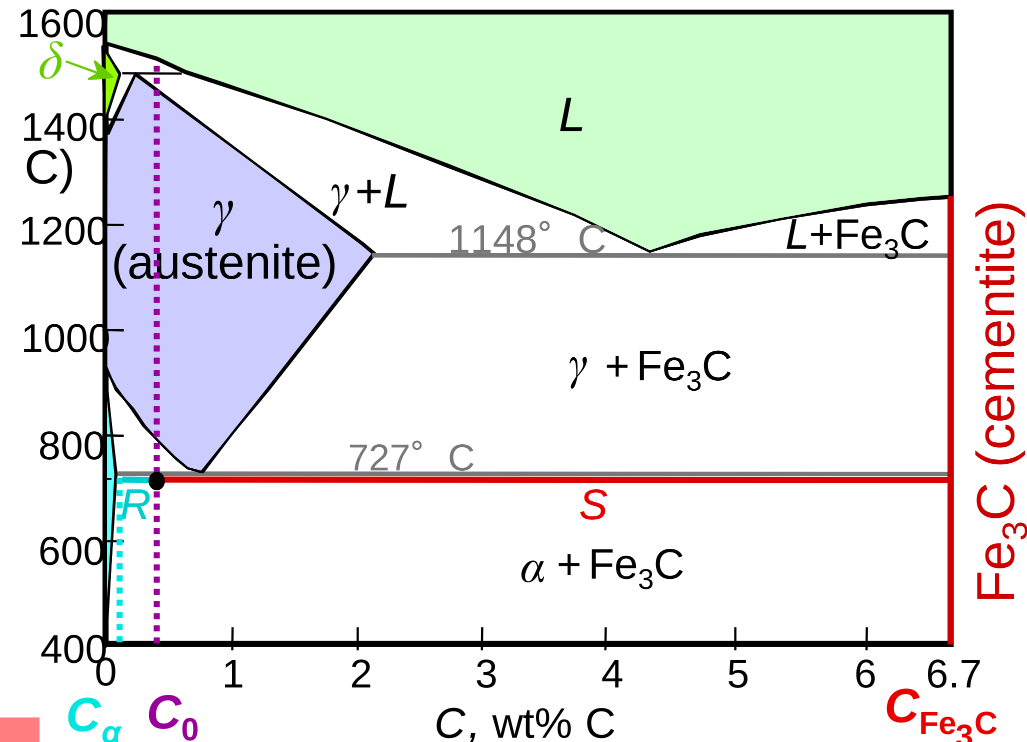
$$= \frac{0.40 - 0.022}{6.70 - 0.022} = 0.057$$

Amount of Fe_3C in 100 g

$= (100\text{ g})W_{Fe_3C}$

$= (100\text{ g})(0.057) =$ **5.7 g**

Fig. 11.23, *Callister & Rethwisch 9e.*
[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.)

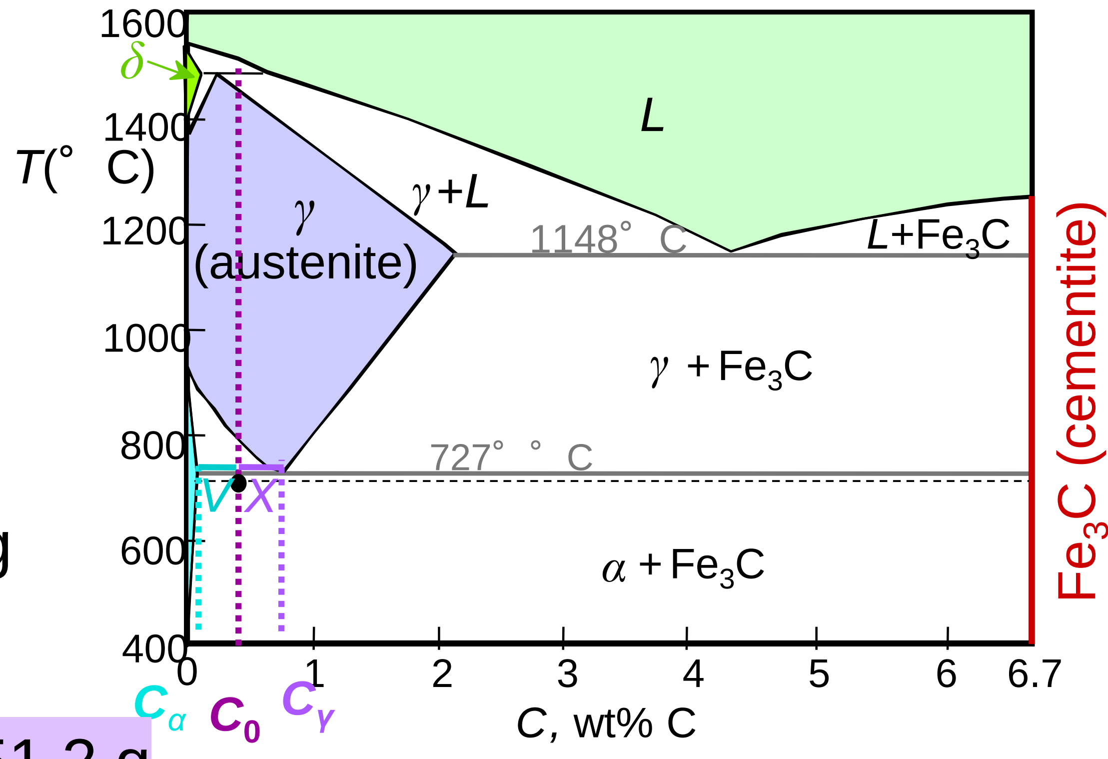
c) Using the *VX* tie line just above the eutectoid and realizing that

C_0 = 0.40 wt% C
C_α = 0.022 wt% C
$C_{pearlite}$ = C_γ = 0.76 wt% C

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

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

Fig. 11.23, *Callister & Rethwisch 9e.*
[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.]



Amount of pearlite in 100 g

= (100 g)$W_{pearlite}$

= (100 g)(0.512) = 51.2 g

Alloying with Other Elements

- $T_{eutectoid}$ changes:

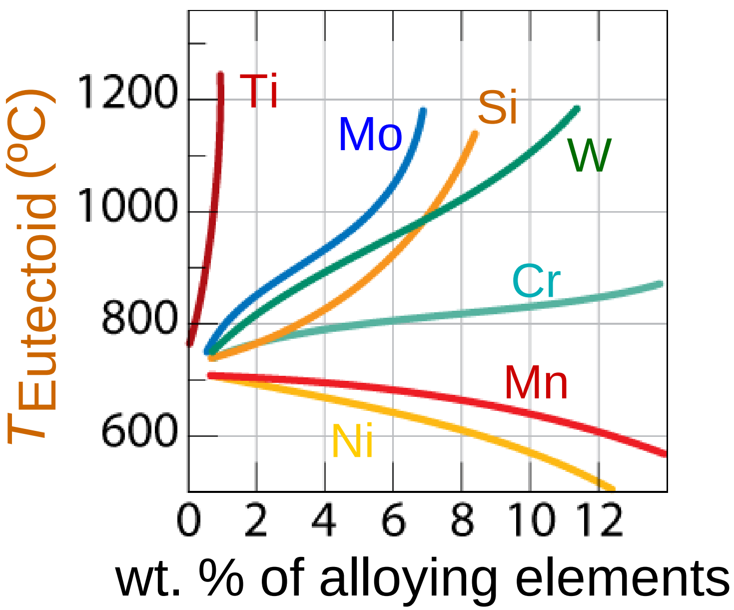


Fig. 11.33, *Callister & Rethwisch 9e*.
(From Edgar C. Bain, *Functions of the Alloying Elements in Steel,* 1939. Reproduced by permission of ASM International, Materials Park, OH.)

- $C_{eutectoid}$ changes:

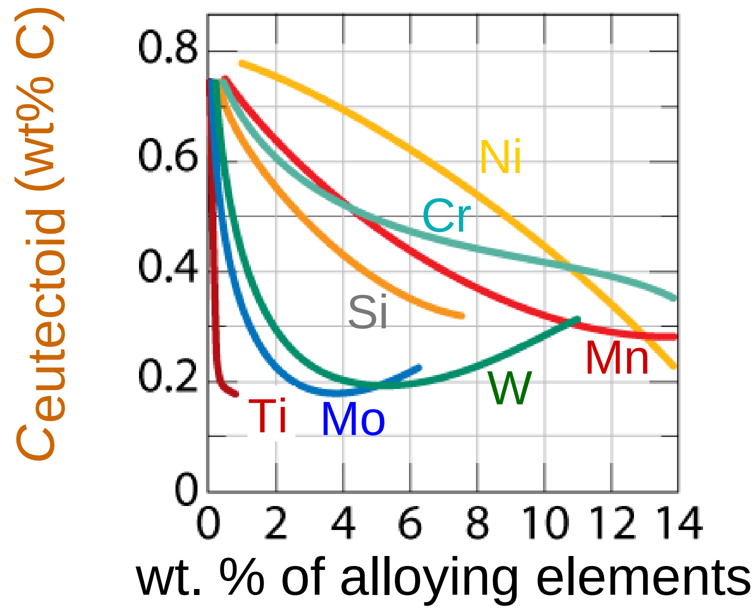
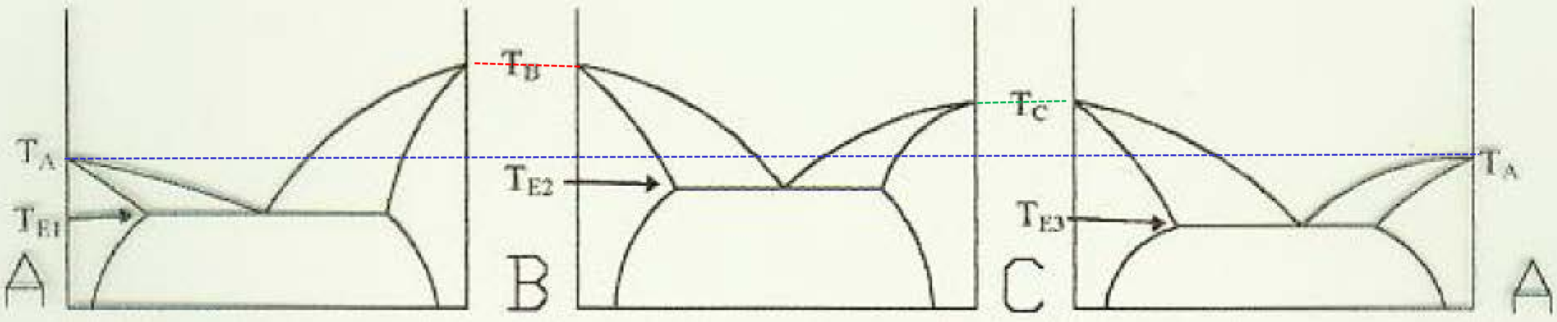


Fig. 11.34,*Callister & Rethwisch 9e*.
(From Edgar C. Bain, *Functions of the Alloying Elements in Steel,* 1939. Reproduced by permission of ASM International, Materials Park, OH.)

Ternary Eutectic System
(with Solid Solubility)

P1:



T_A: Melting Point Of Material A

T_B: Melting Point Of Material B

T_C: Melting Point Of Material C

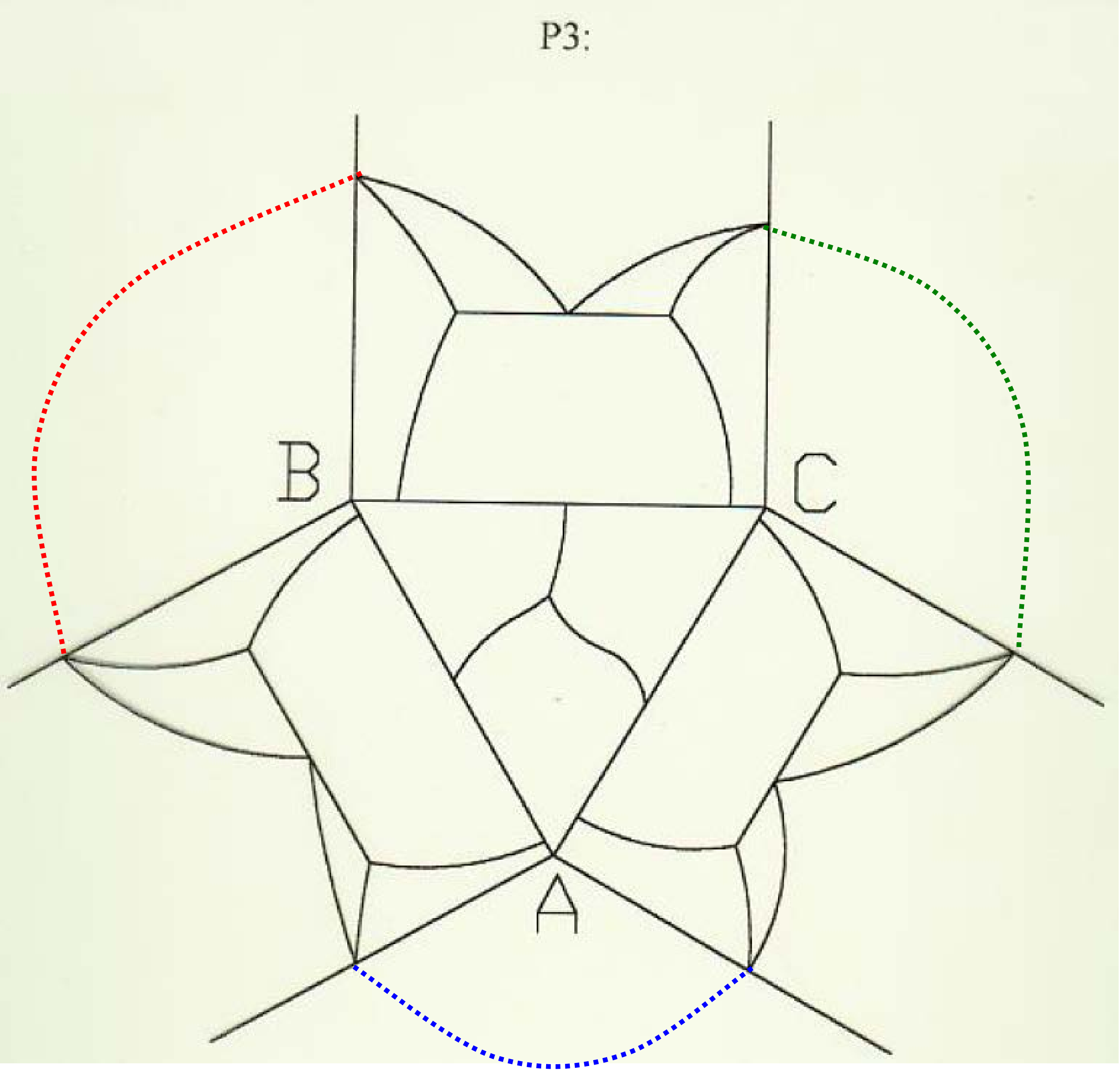
T_{E1}: Eutectic Temperature Of A-B

T_{E2}: Eutectic Temperature Of B-C

T_{E3}: Eutectic Temperature Of C-A

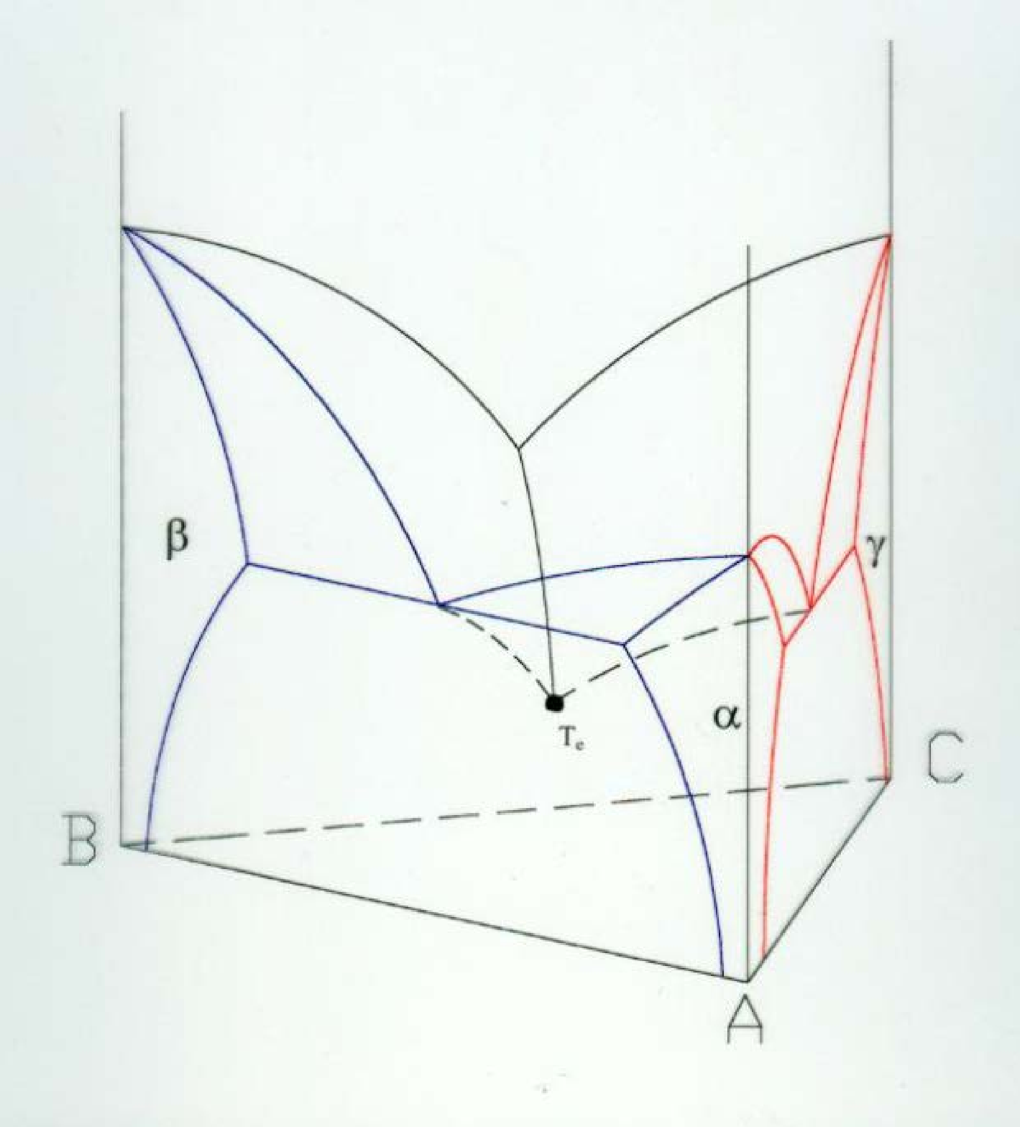
Ternary Eutectic System

(with Solid Solubility)

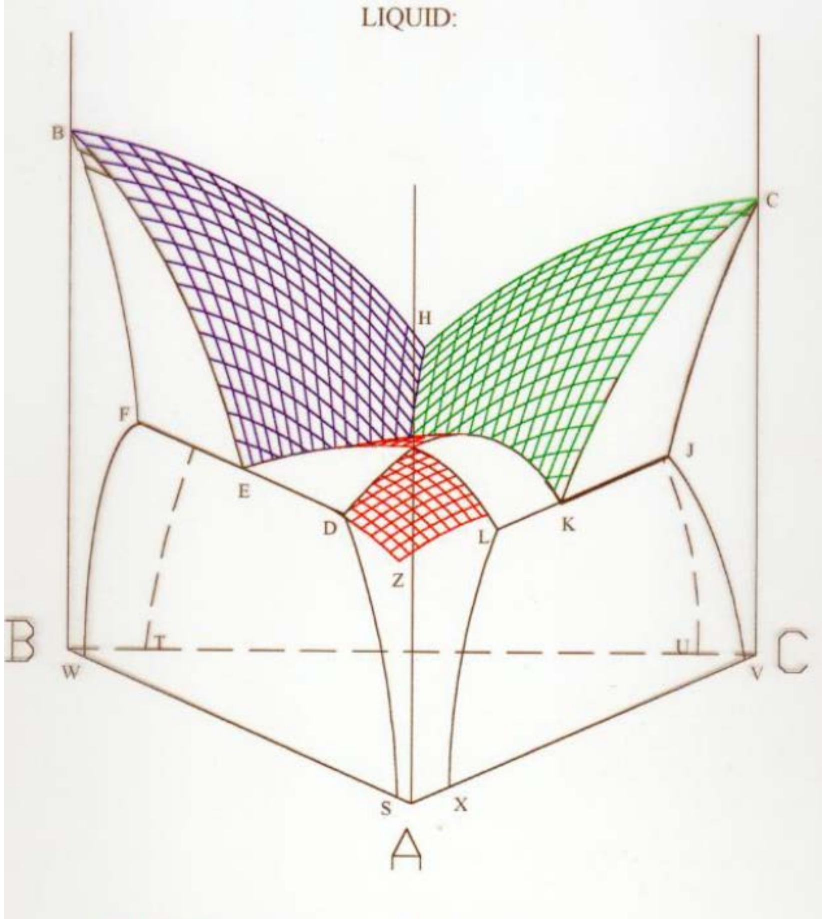


Ternary Eutectic System

(with Solid Solubility)

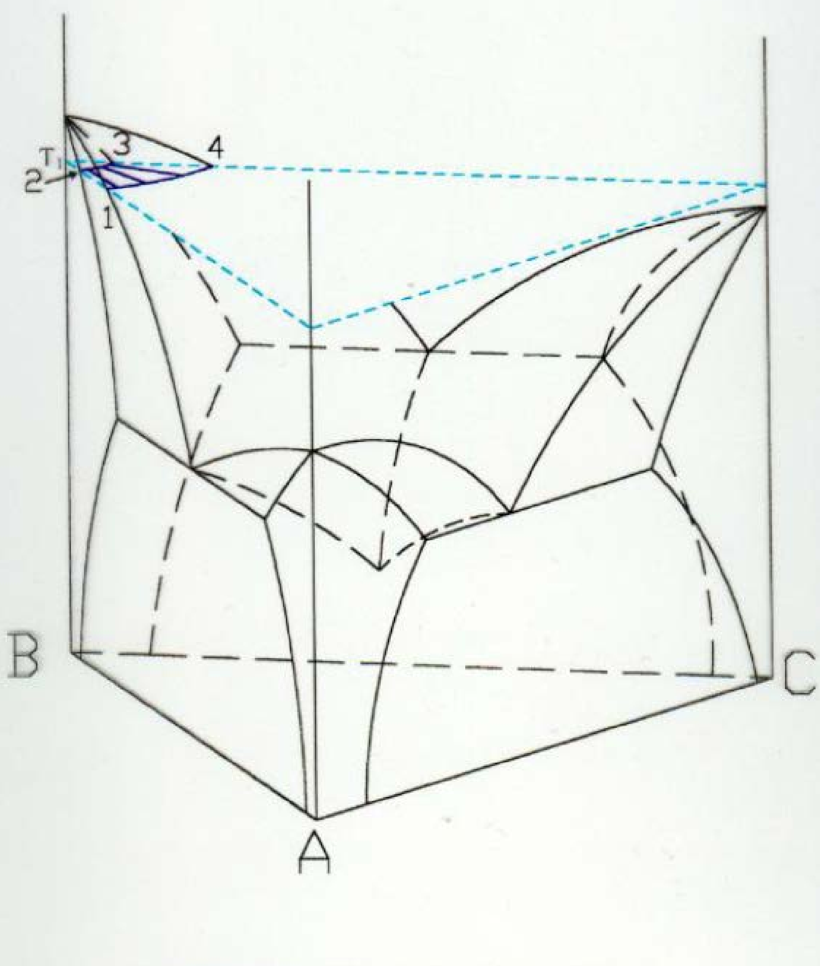


Main outline of Ternary Phase Diagram with Ternary Eutectic (T_e) and Solid Single Phase Regions Shown

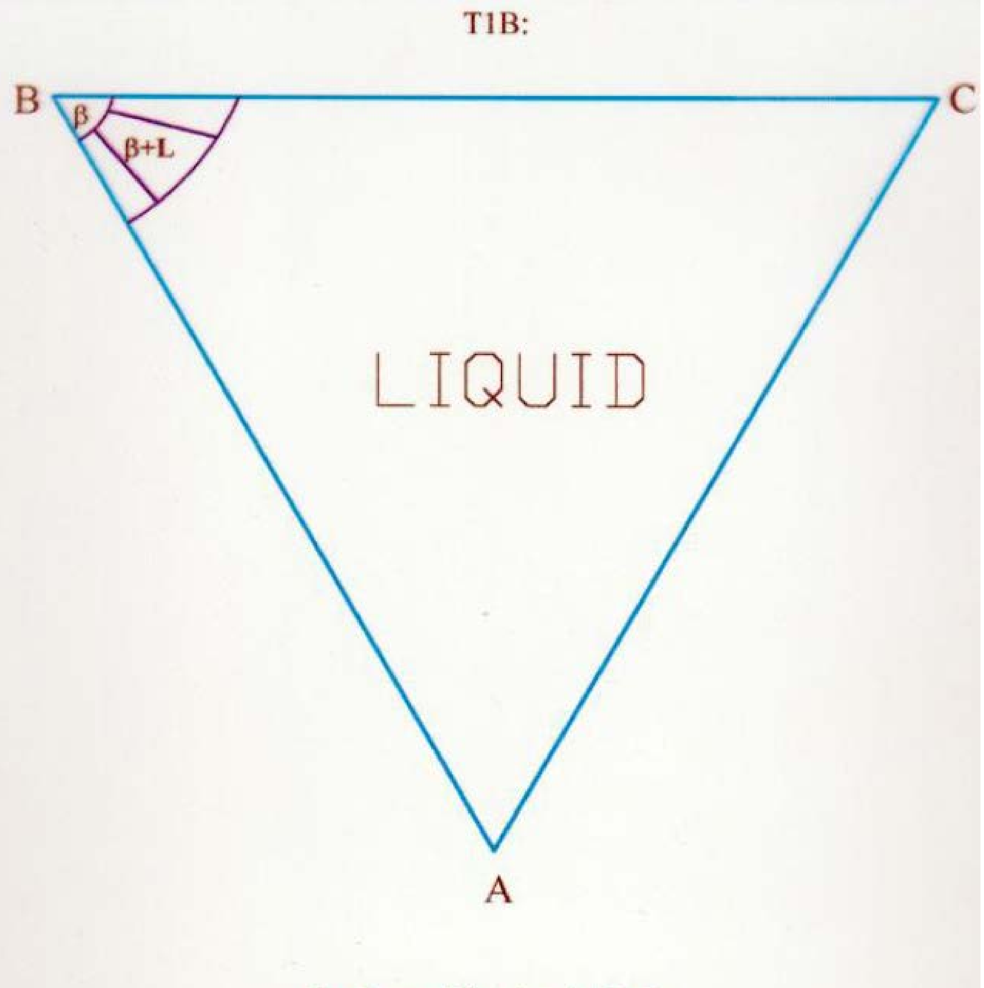


All Liquidus surfaces (α+L-Red, β+L-Purple, γ+L-Green)

Ternary Eutectic System
(with Solid Solubility)

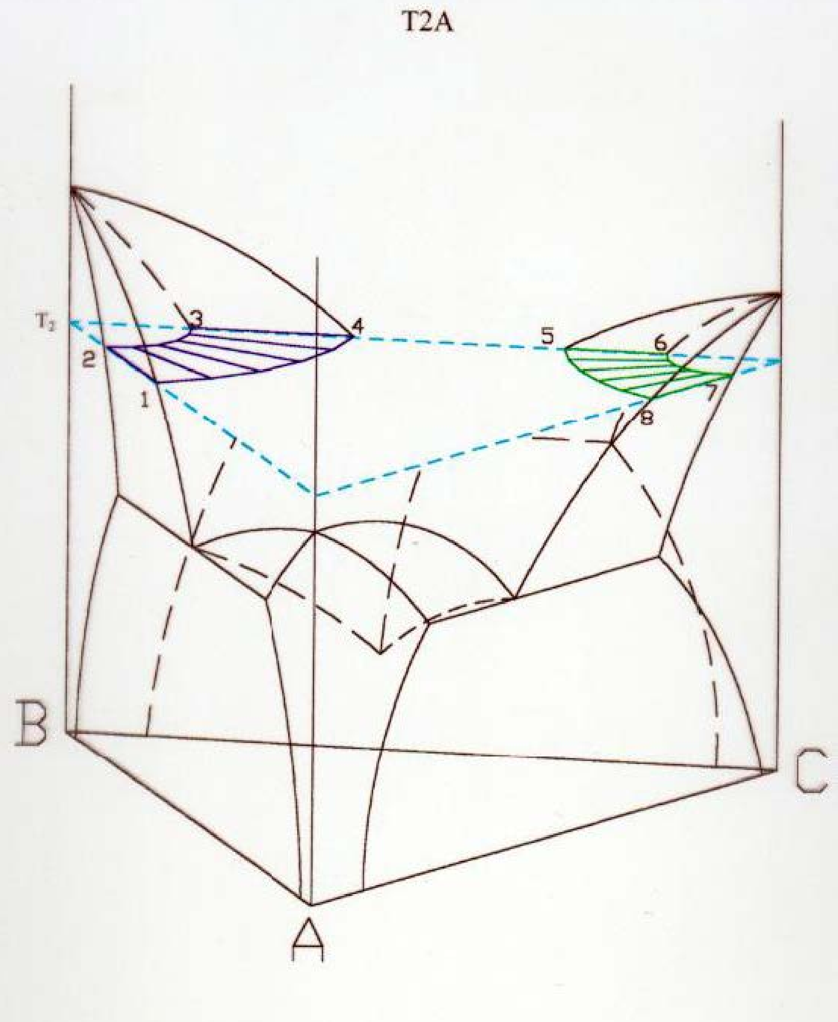


Temperature Slice At $T_1 < T_B$, But $>T_A$, T_C

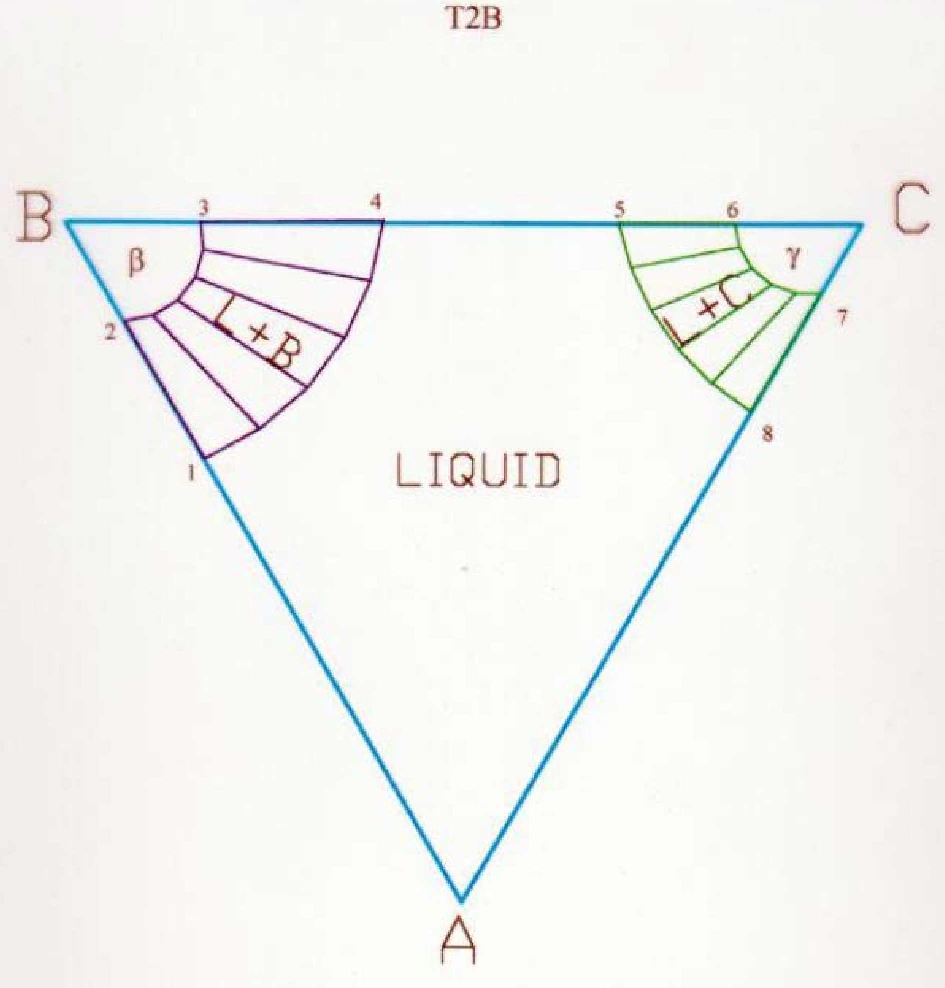


Isothermal Section At $T=T_1$

Ternary Eutectic System
(with Solid Solubility)



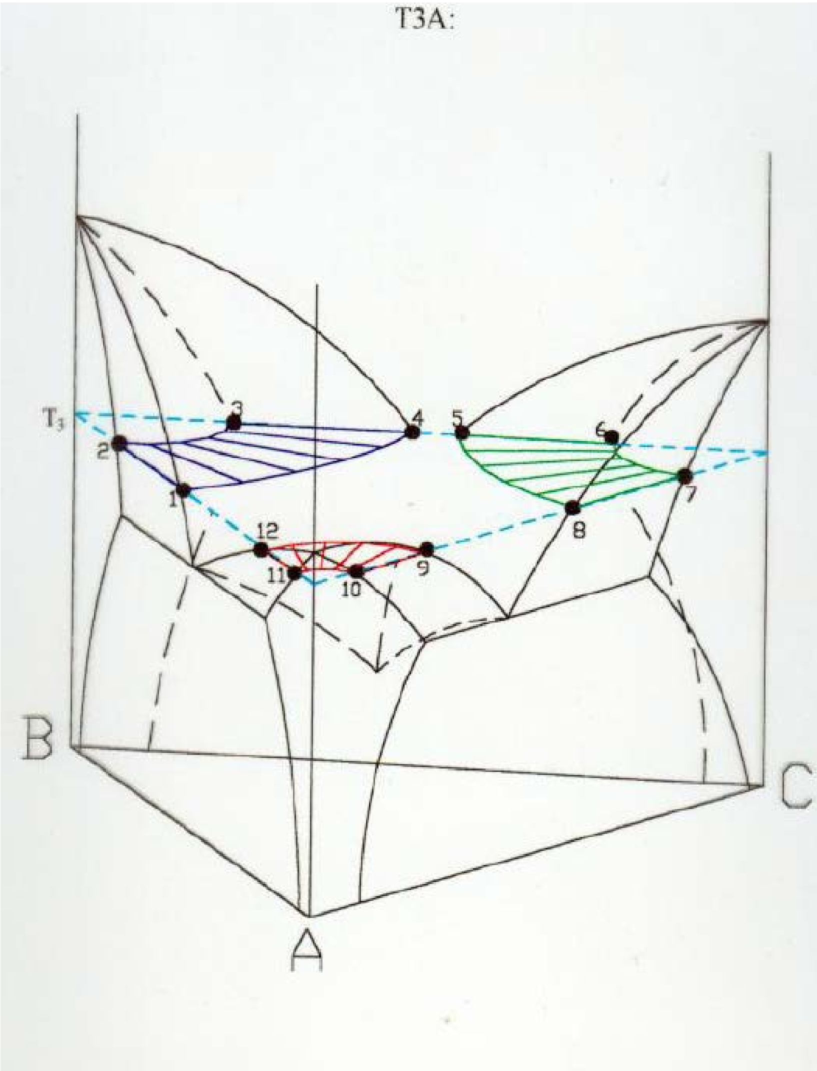
Temperature Slice At $T_2 > T_A$ But, $T_2 < T_B, T_C$



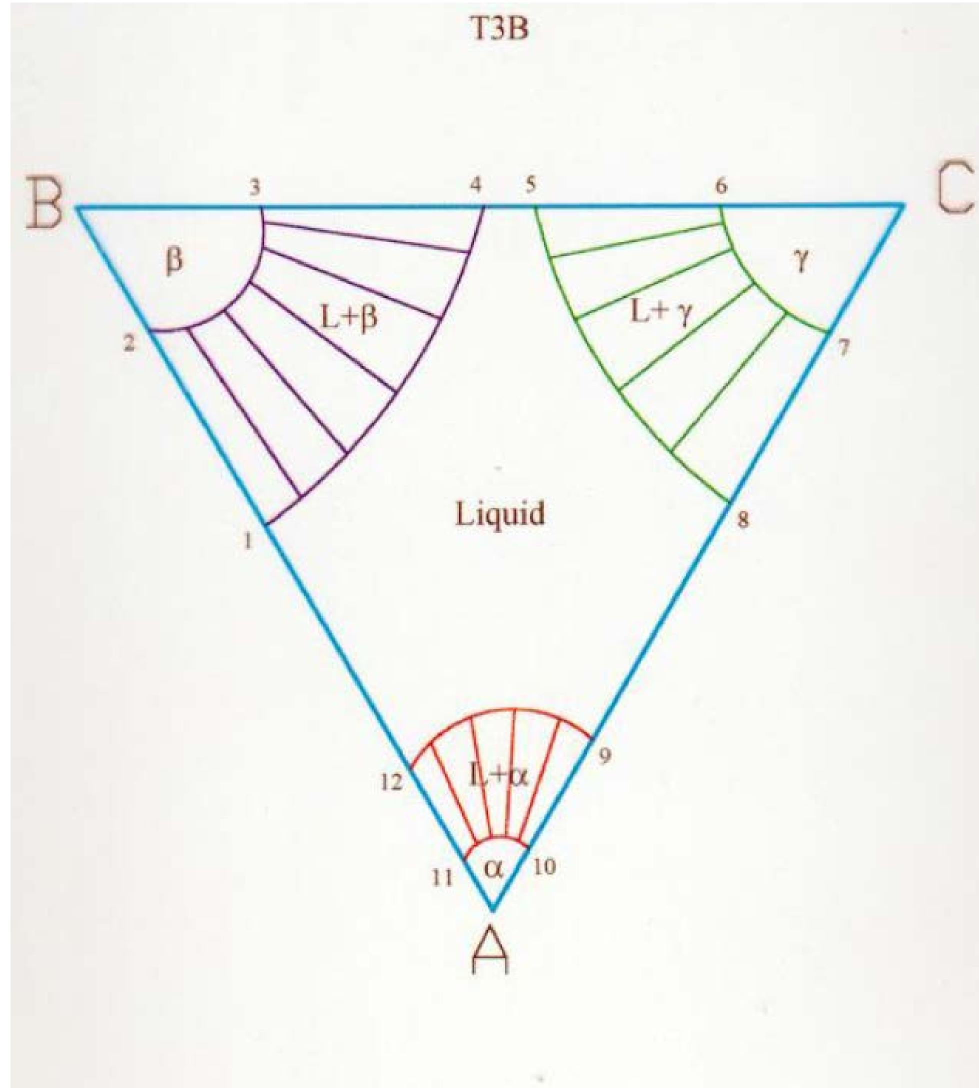
Isothermal Section At $T = T_2$

Ternary Eutectic System

(with Solid Solubility)

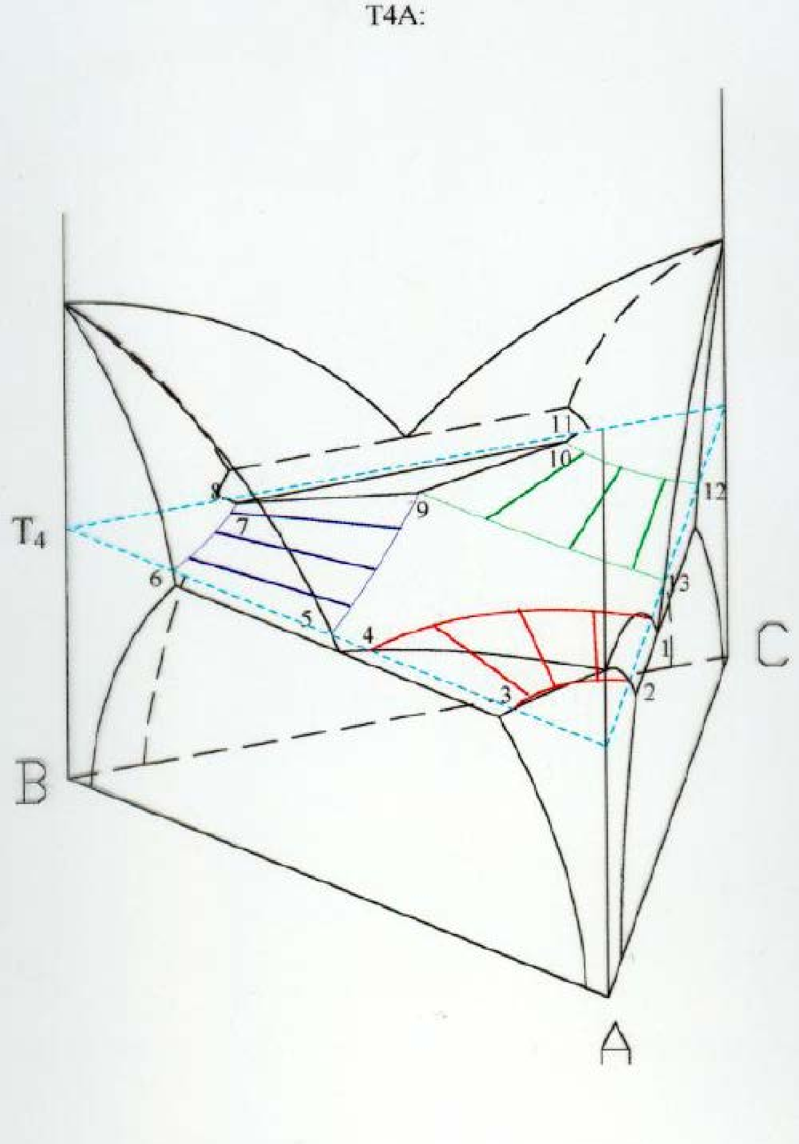


Temperature Slice At $T_3 < T_A, T_B, T_C$, But $T3 > T_{E1}, T_{E2}, T_{E3}$

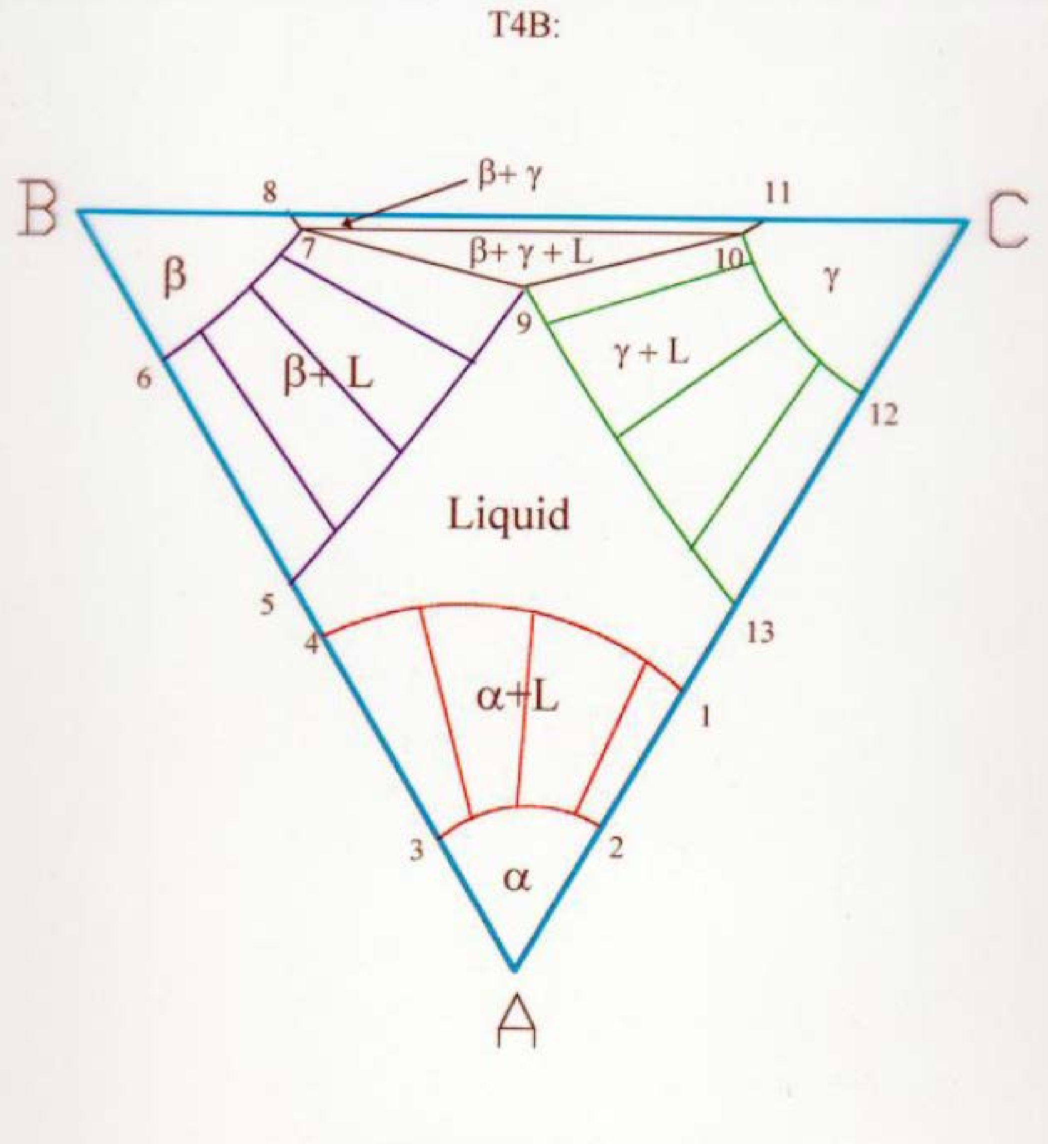


Isothermal Section At $T = T_3$

Ternary Eutectic System
(with Solid Solubility)

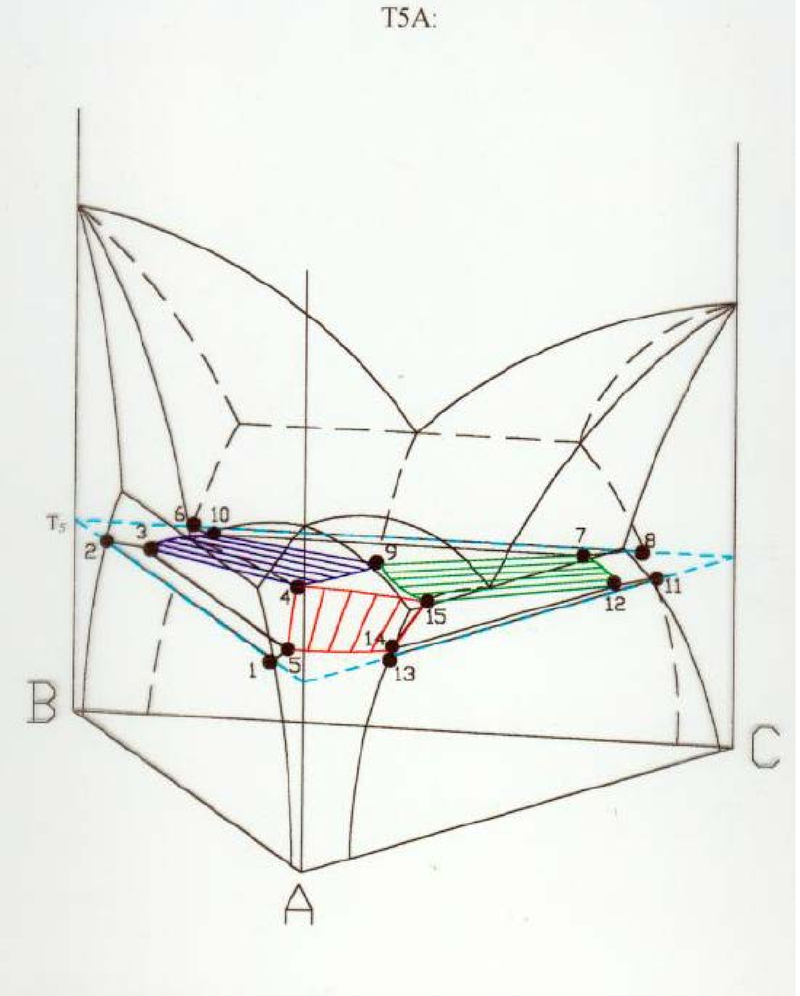


Temperature Slice At $T_4 < T_{E2}$ And $T_4 > T_{E1}, T_{E3}$

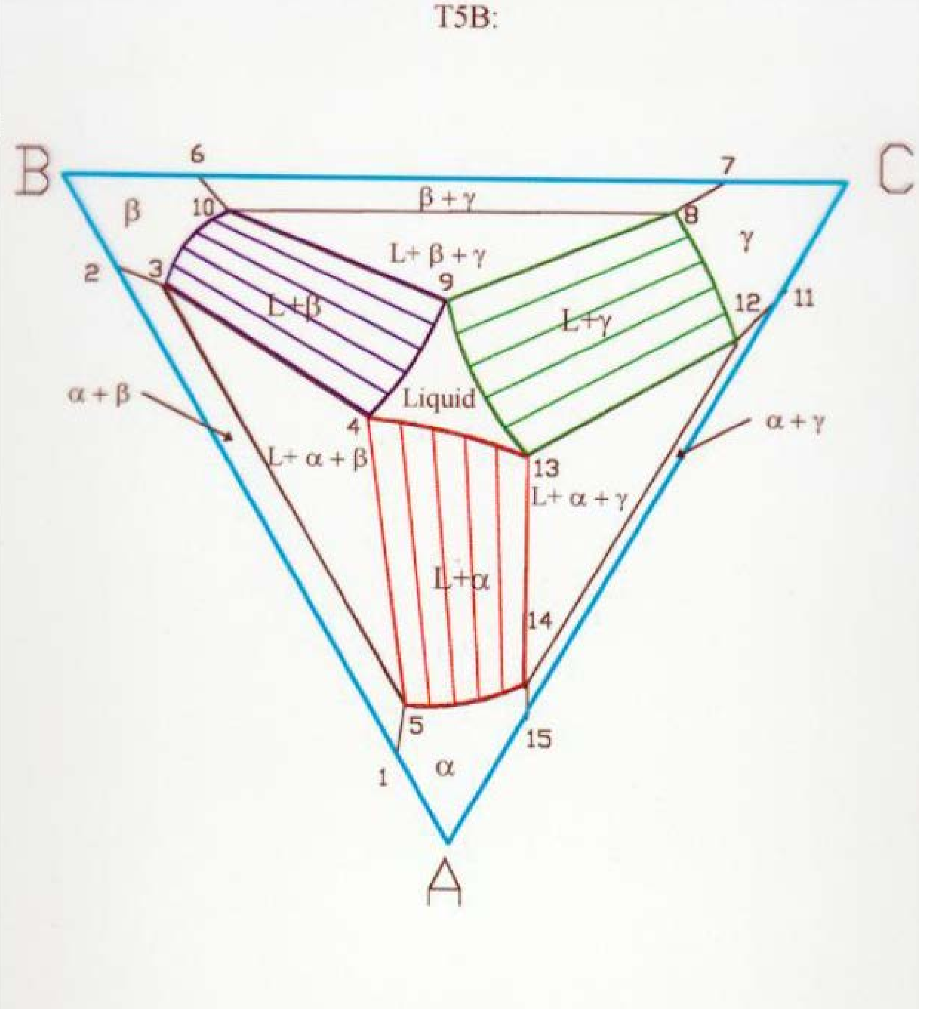


Isothermal Section At $T=T_4$

Ternary Eutectic System
(with Solid Solubility)



Temperature Slice Below All Binary Eutectics But, Above The Ternary Eutectic

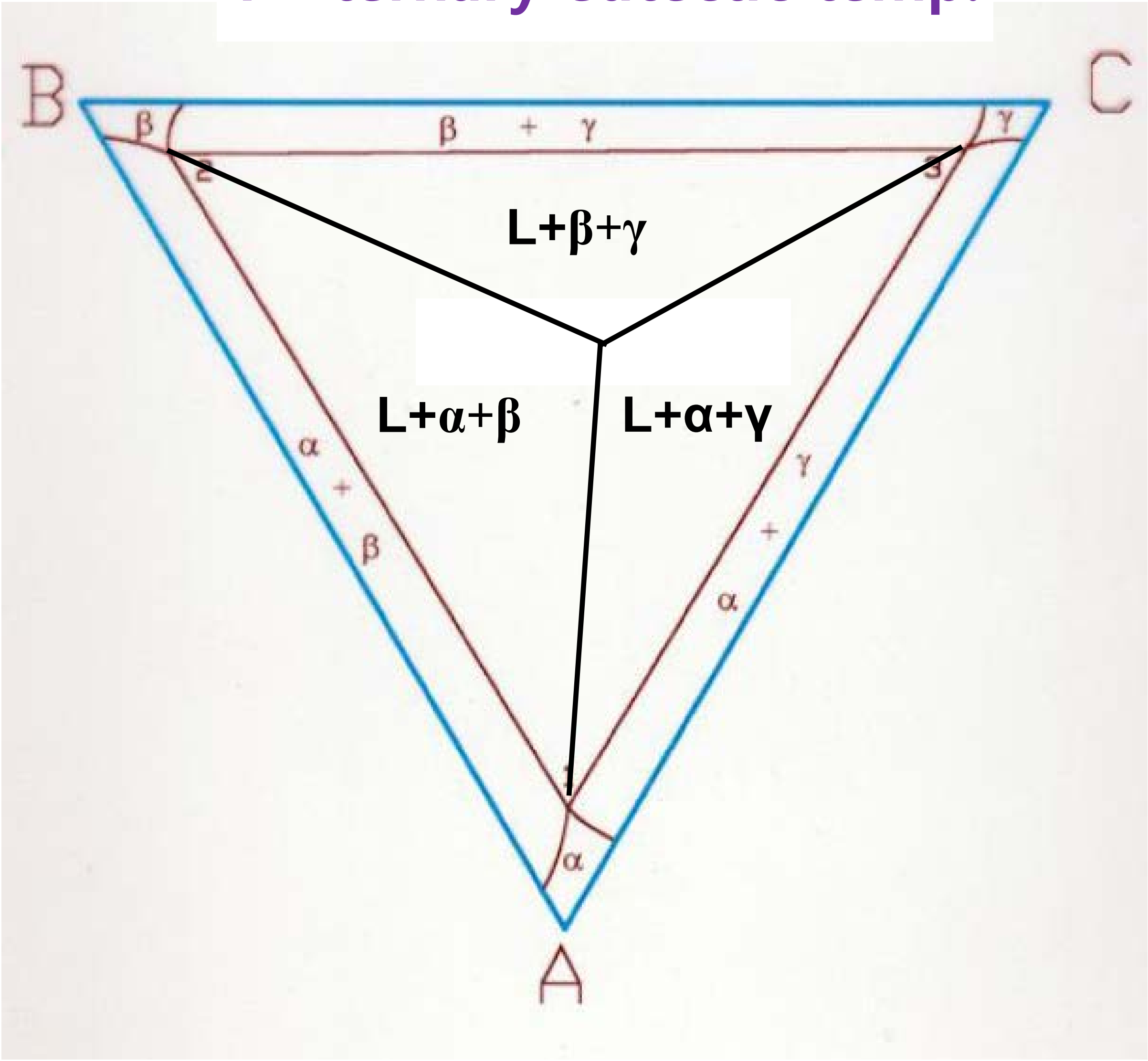


Isothermal Section At T=T_5

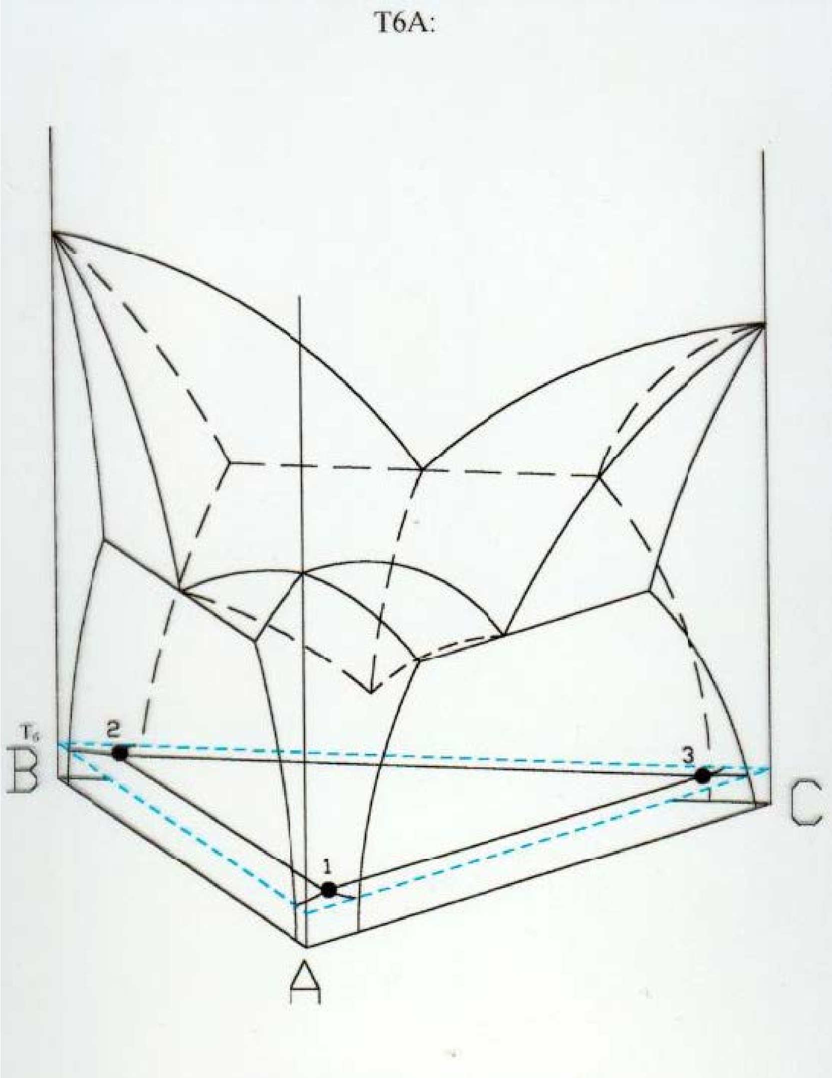
Ternary Eutectic System

(with Solid Solubility)

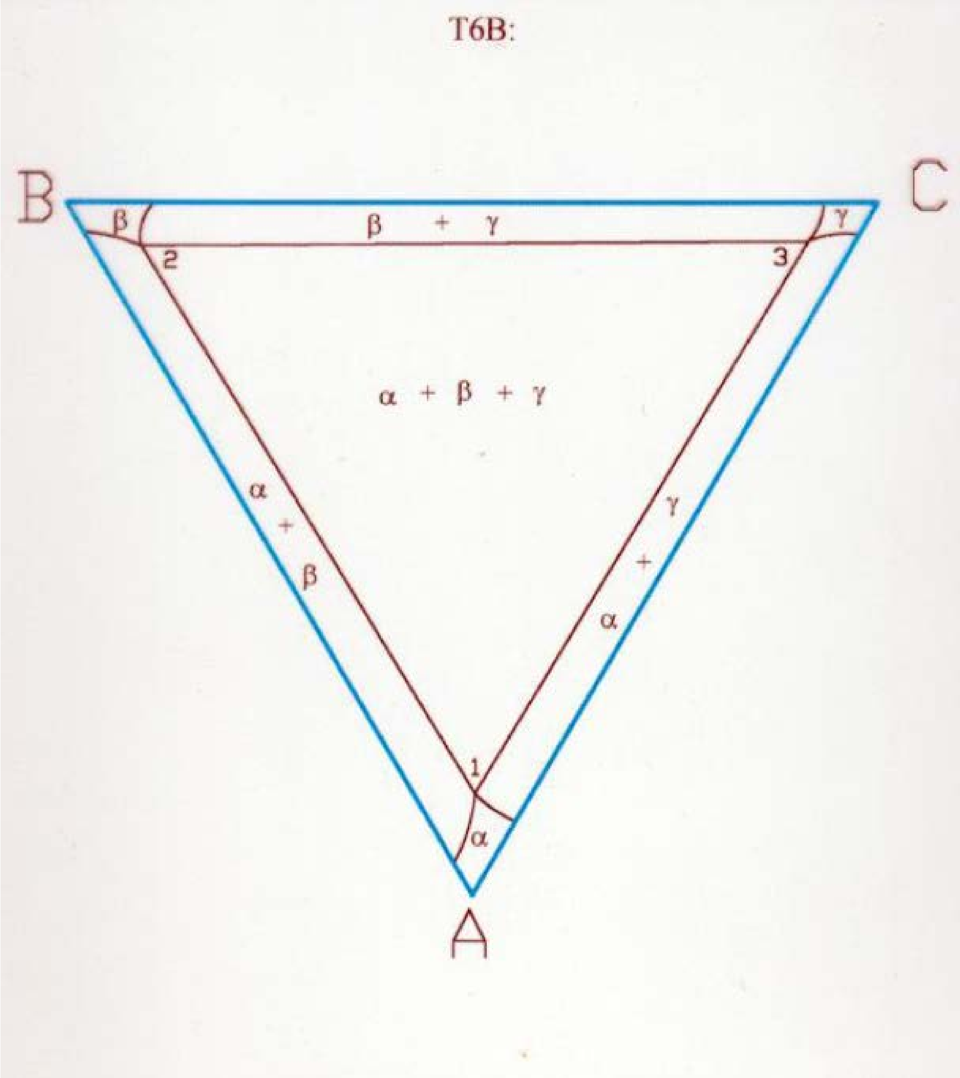
T= ternary eutectic temp.



Ternary Eutectic System
(with Solid Solubility)



Temperature Slice at $T_6 < T_E$

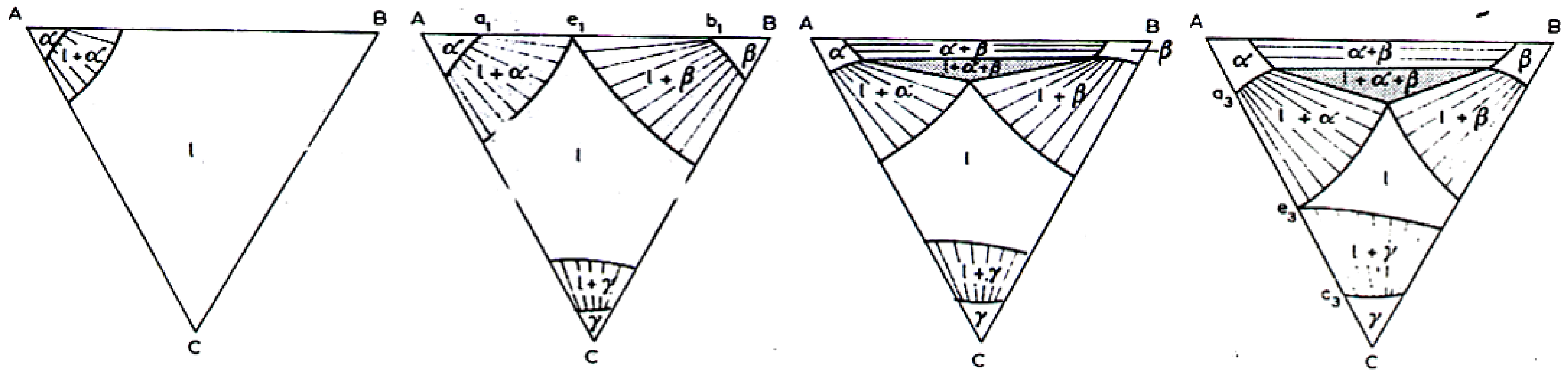


Isothermal Section At $T=T_6$

http://www.youtube.com/watch?v=yzhVomAdetM

THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

- **Isothermal section** ($T_A > T > T_B$)

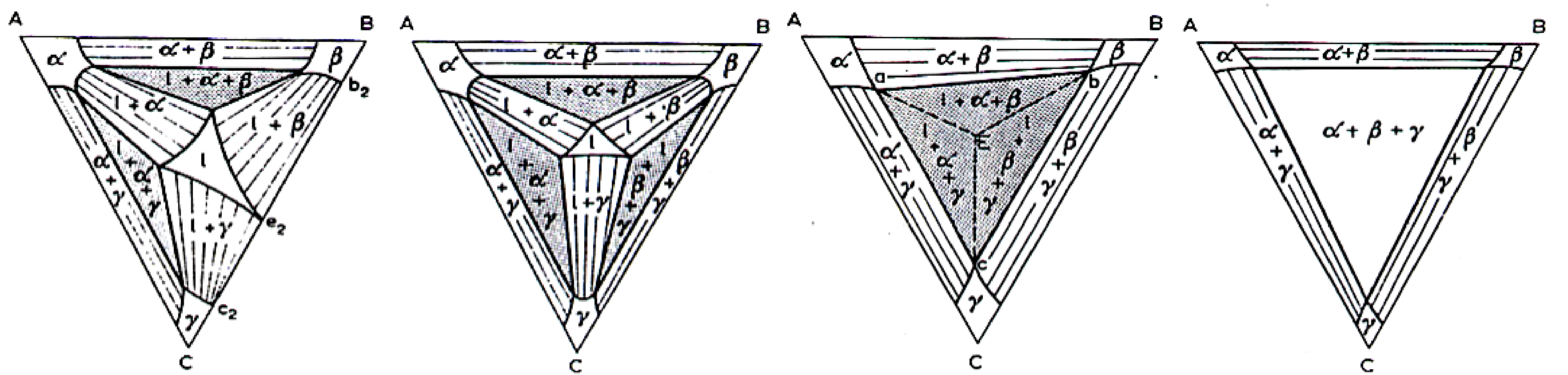


(a) $T_A > T > T_B$

(b) $T = e_1$

(c) $e_1 > T > e_3$

(d) $T = e_3$



(e) $T = e_2$

(f) $e_2 > T > E$

(g) $T_A = E$

(h) $E = T$

THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

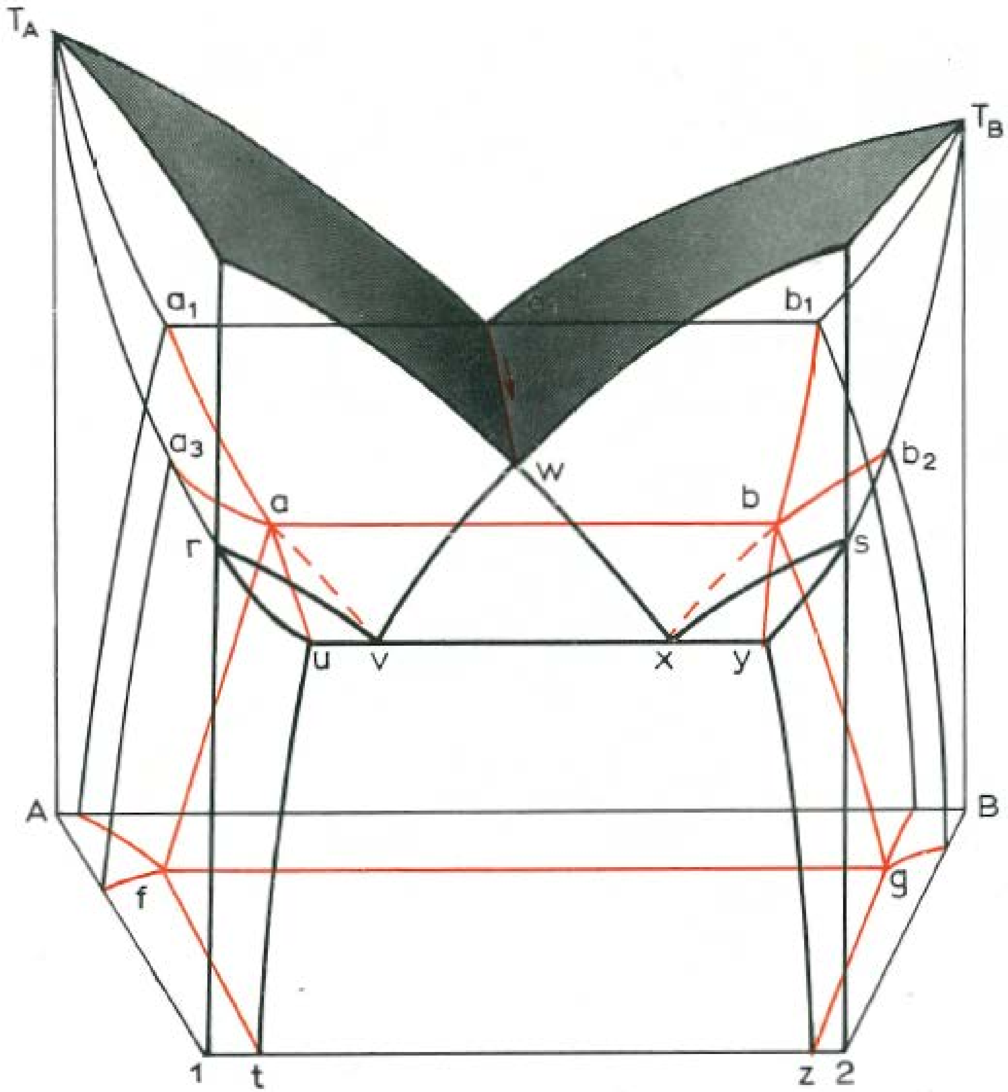
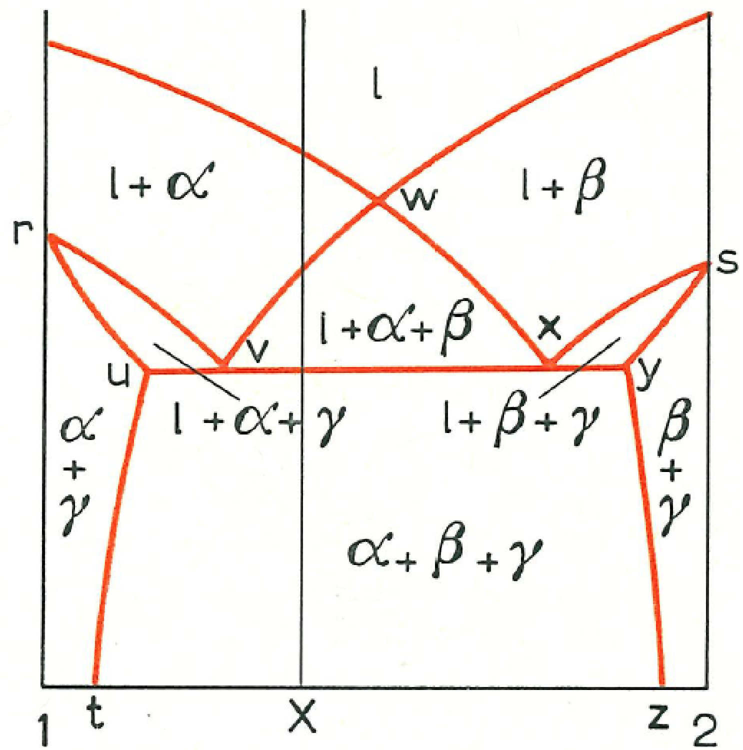
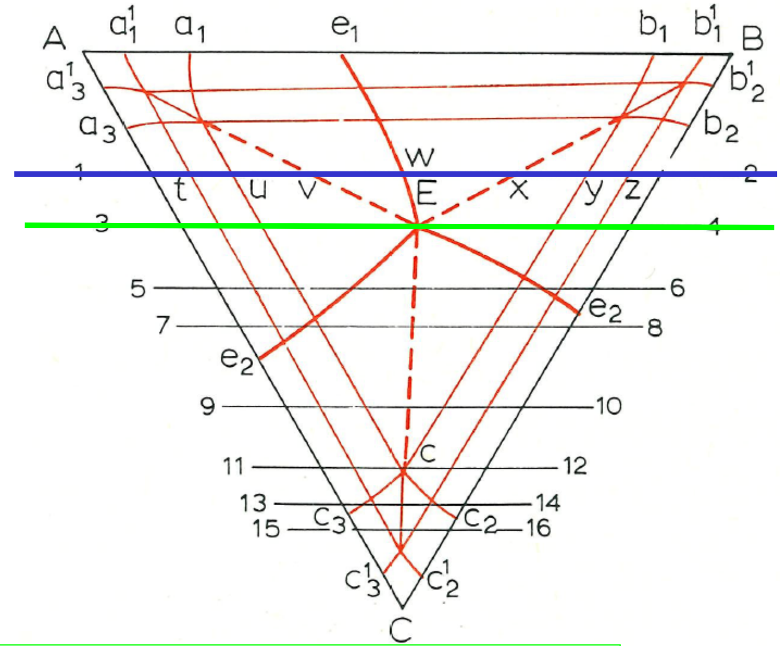


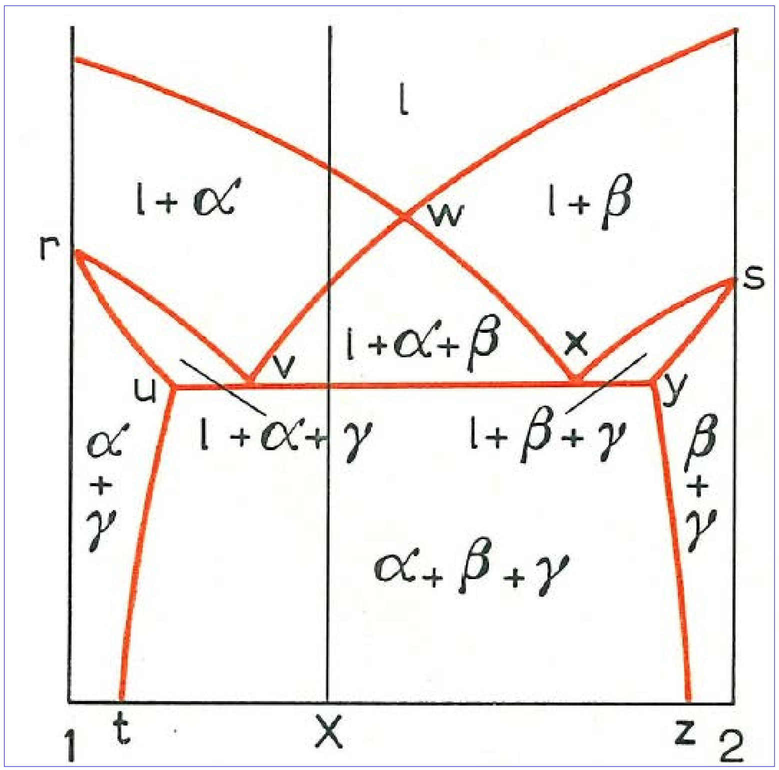
Fig. 179. Construction of vertical section 1–2.

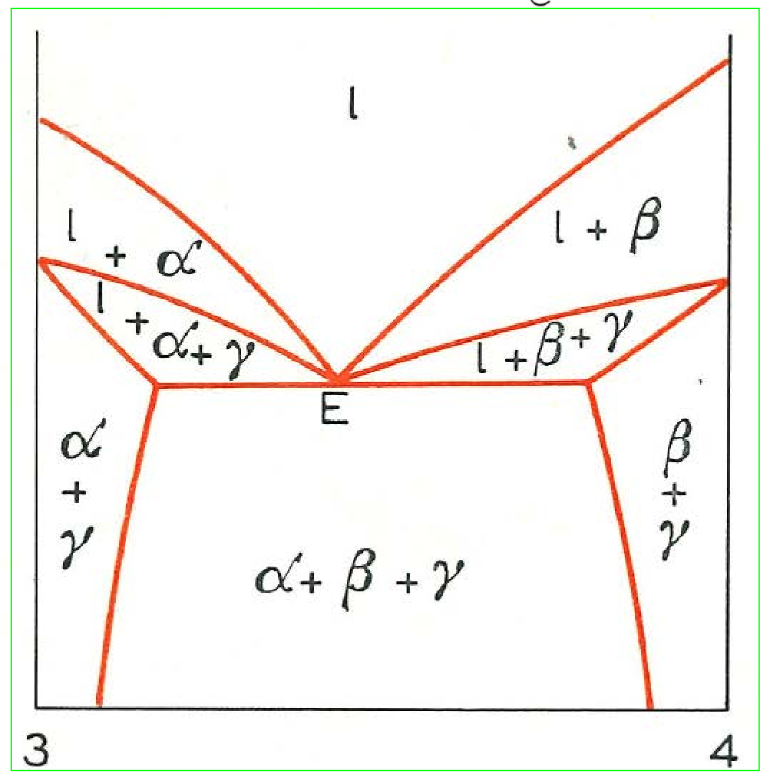


THE EUTECTIC EQUILIBRIUM
($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

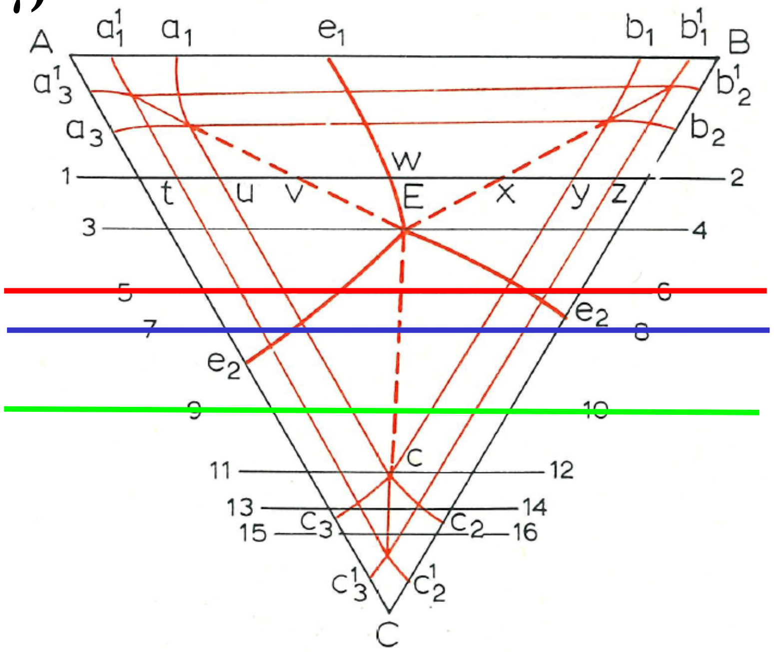


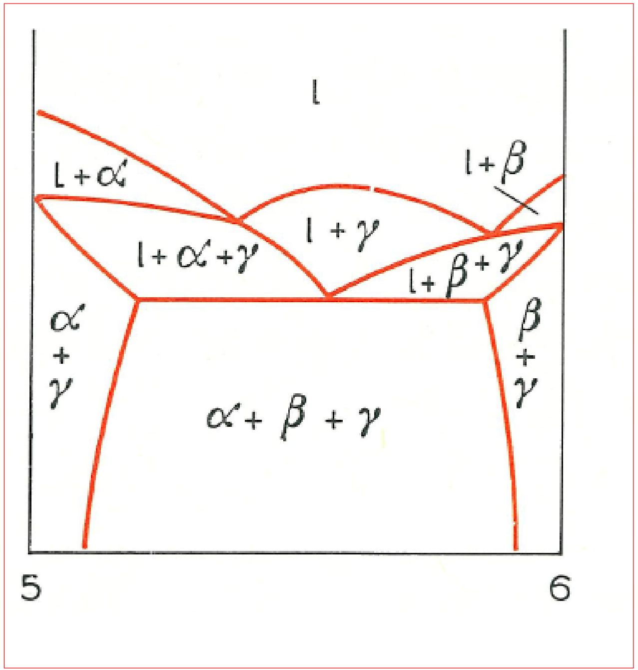


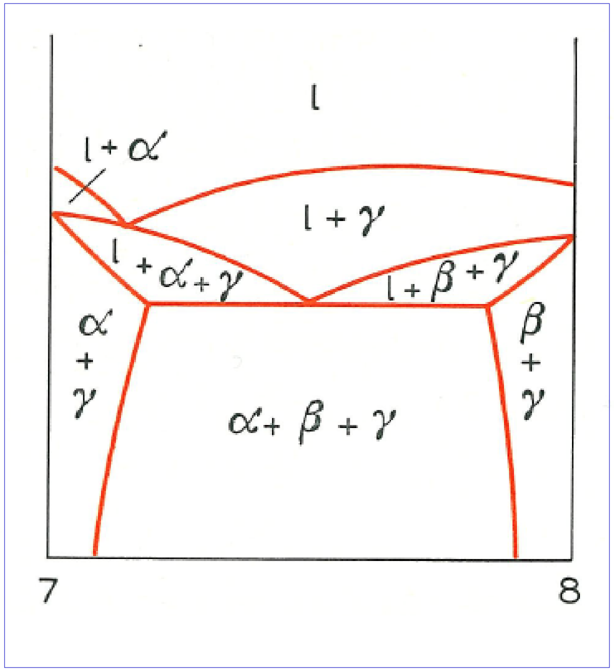


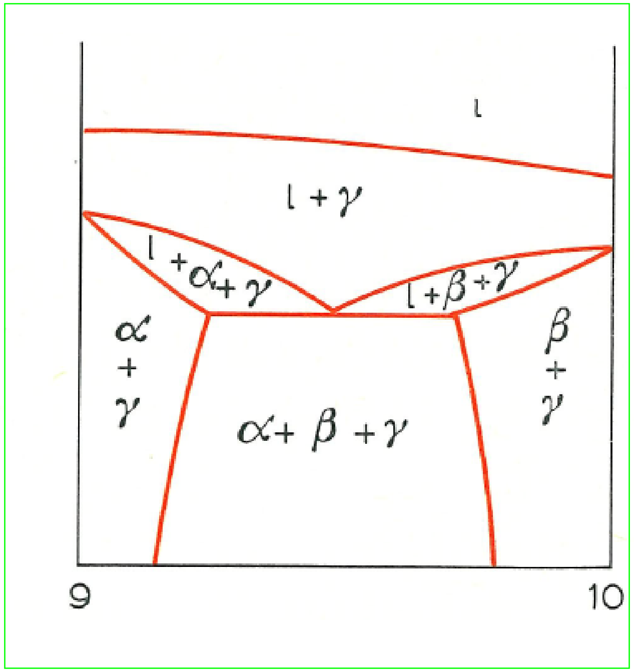
THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**



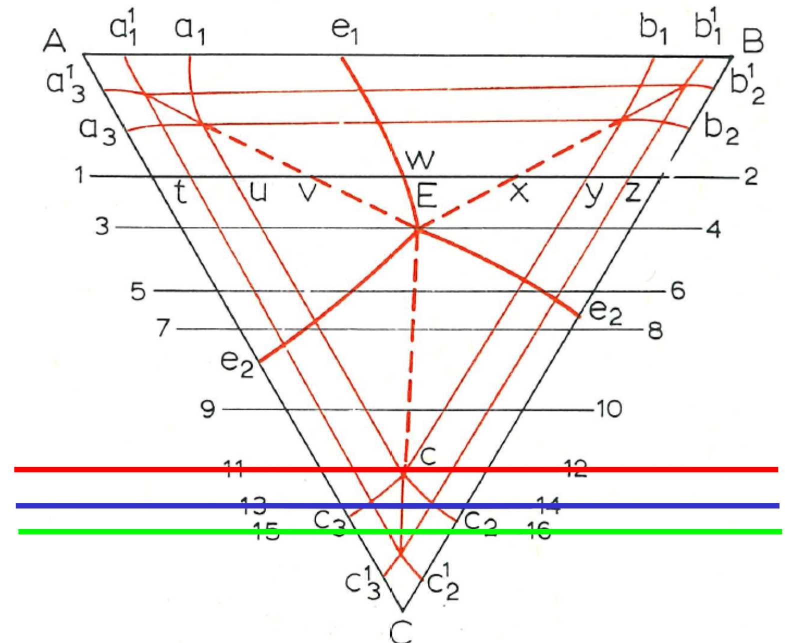


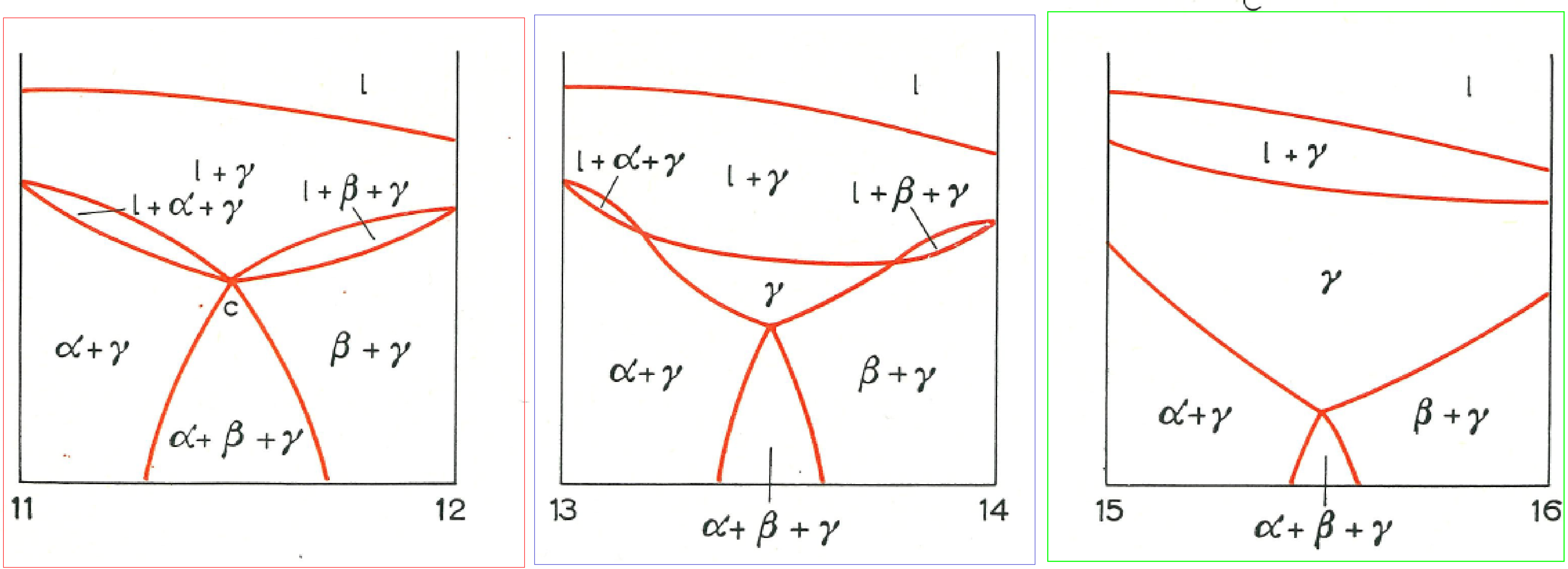




THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**





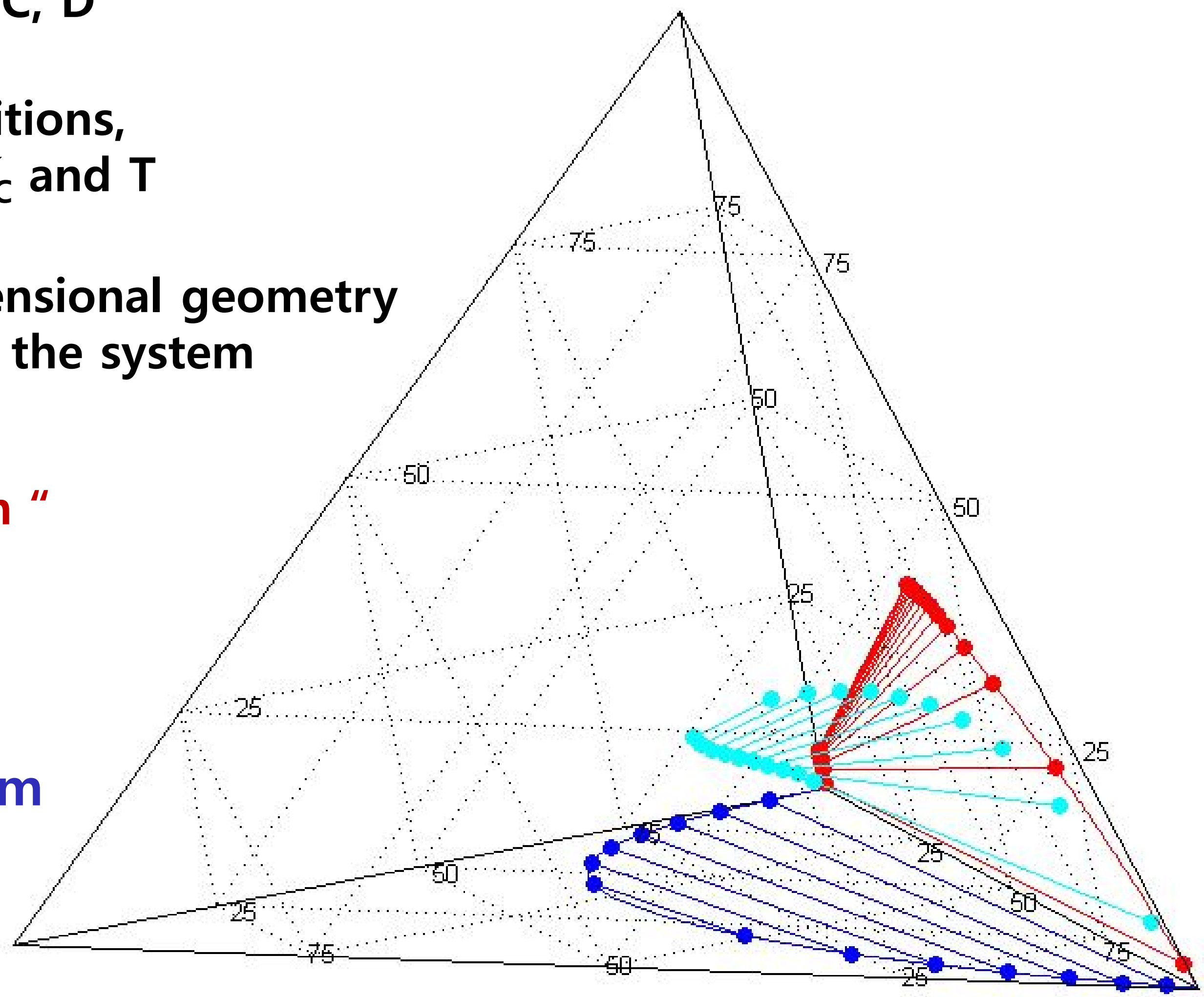
< Quaternary phase Diagrams >

Four components: A, B, C, D

Assuming isobaric conditions,
Four variables: X_A, X_B, X_C and T

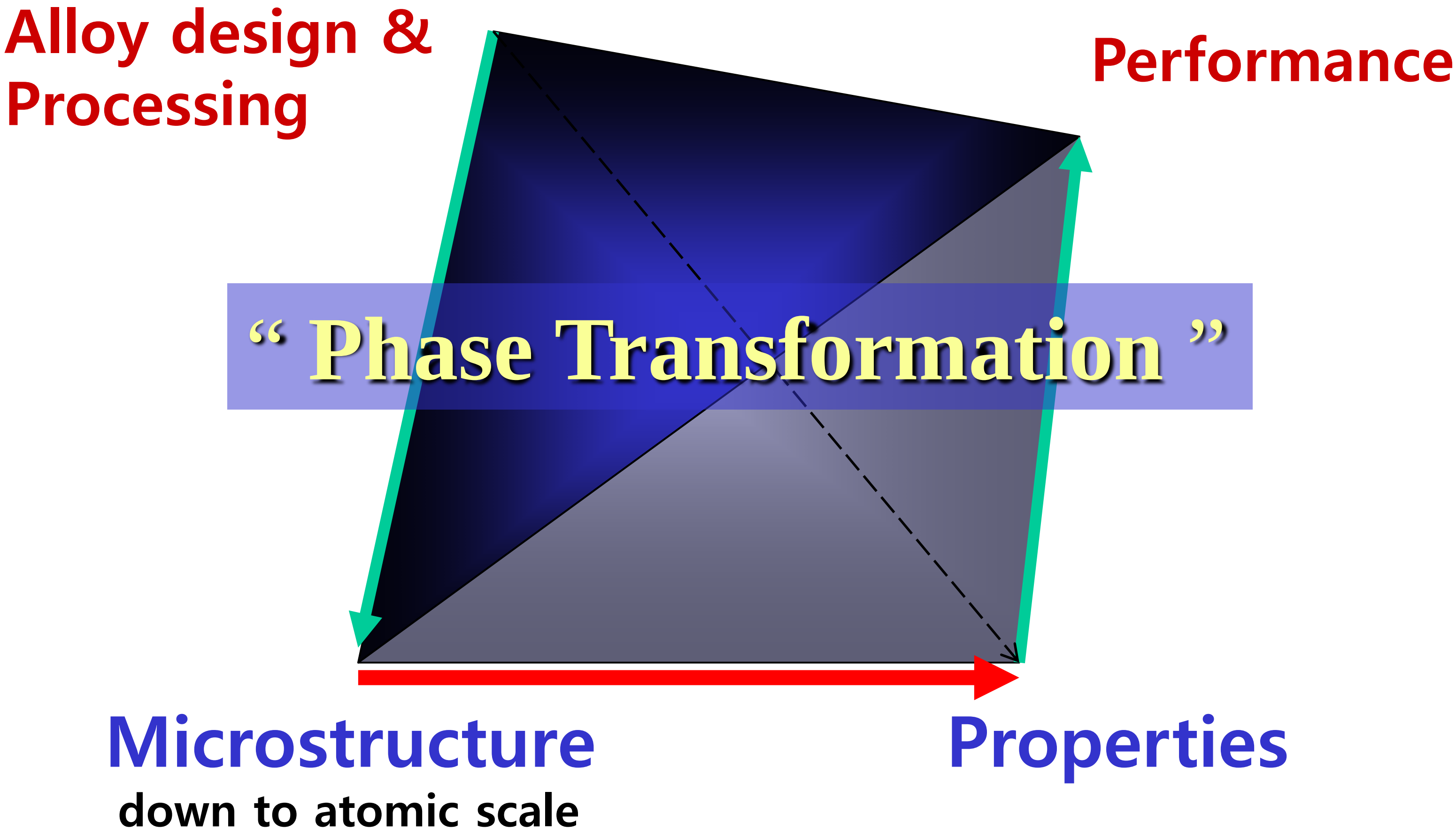
A difficulty of four-dimensional geometry
→ further restriction on the system

Most common figure:
“ equilateral tetrahedron “



- **4 pure components**
- **6 binary systems**
- **4 ternary systems**
- **A quarternary system**

Microstructure-Properties Relationships



“Tailor-made Materials Design”

Contents_Phase transformation course

Background to understand phase transformation

- (Ch1) Thermodynamics and Phase Diagrams
- (Ch2) Diffusion: Kinetics
- (Ch3) Crystal Interface and Microstructure

Representative Phase transformation

- (Ch4) Solidification: Liquid → Solid
- (Ch5) Diffusional Transformations in Solid: Solid → Solid
- (Ch6) Diffusionless Transformations: Solid → Solid

Summary

- Phase diagrams are useful tools to determine:
  -- the number and types of phases present,
  -- the composition of each phase,
  -- and the weight fraction of each phase
  given the temperature and composition of the system.

- The microstructure of an alloy depends on
  -- its composition, and
  -- whether or not cooling rate allows for maintenance of equilibrium.

- Important phase diagram phase transformations include eutectic, eutectoid, and peritectic.