

2019 Spring

“Phase Equilibria *in* Materials”

05.01.2019

Eun Soo Park

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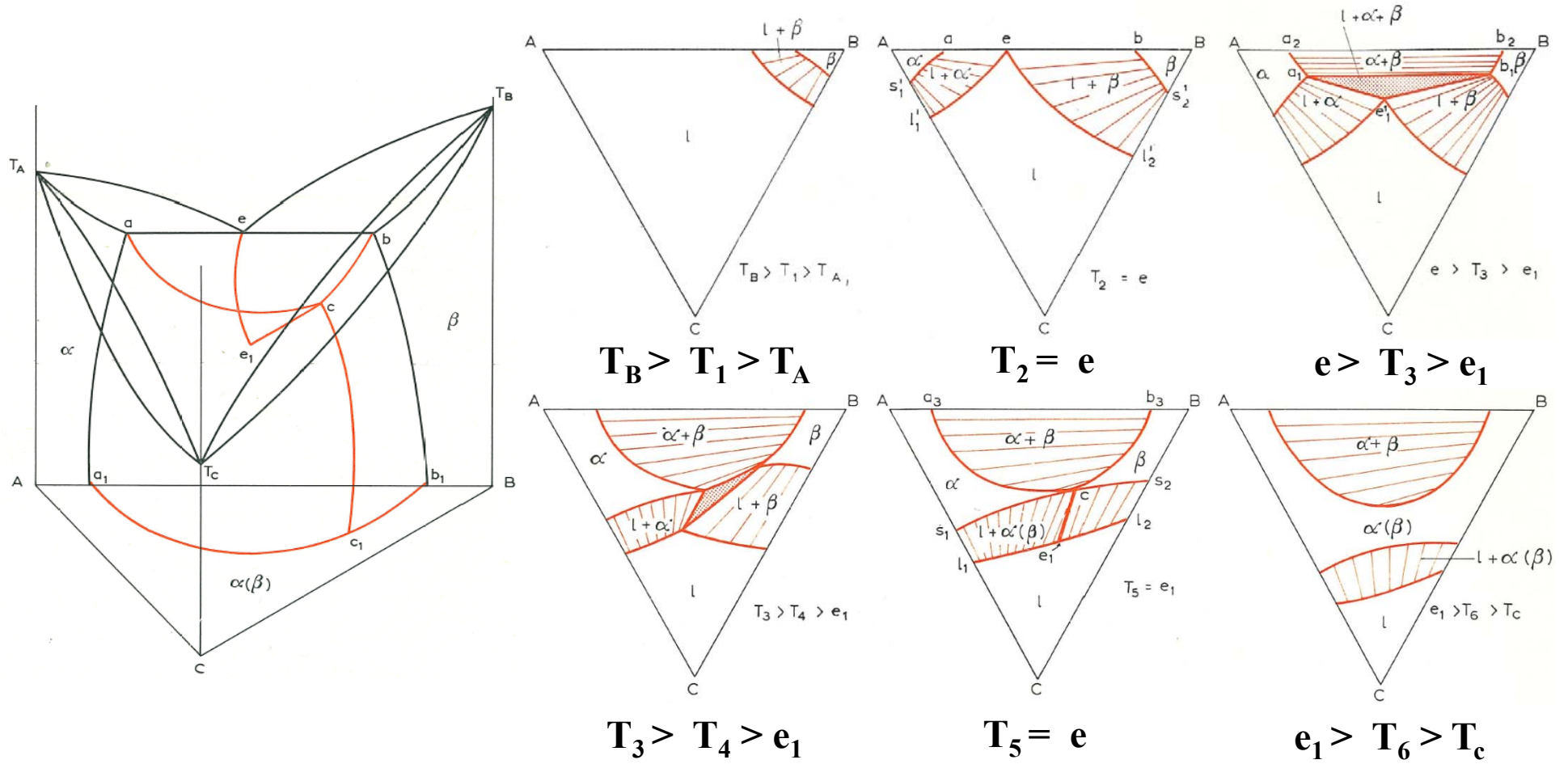
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9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

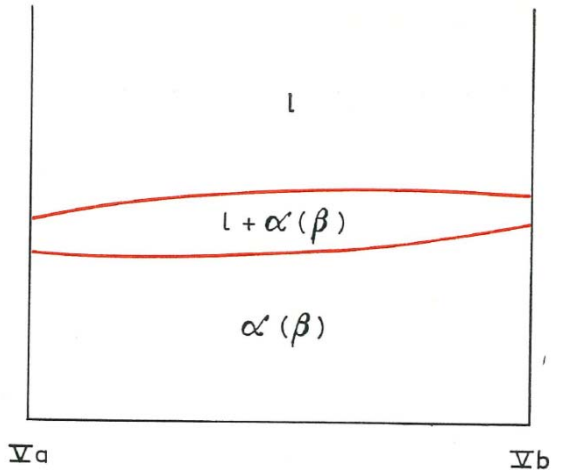
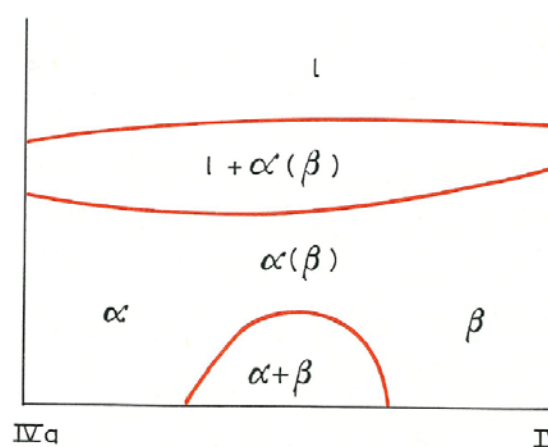
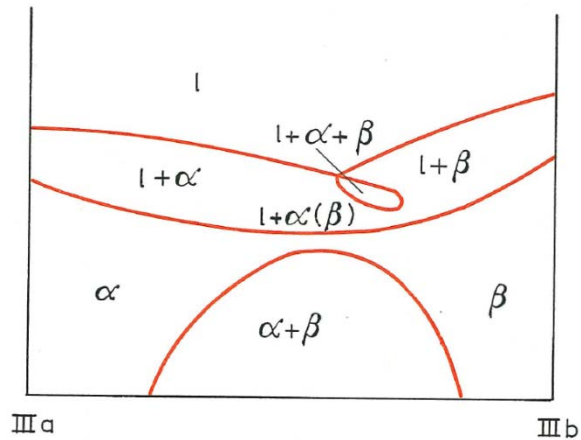
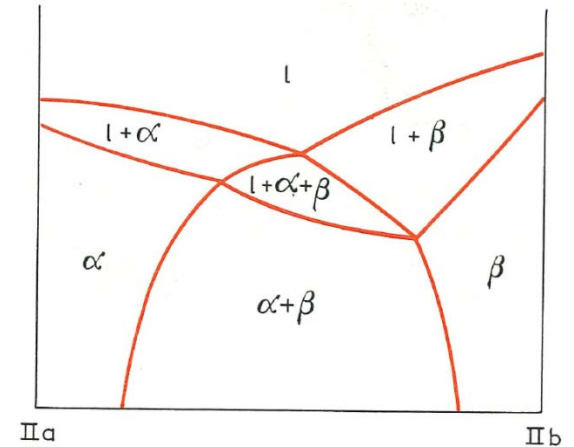
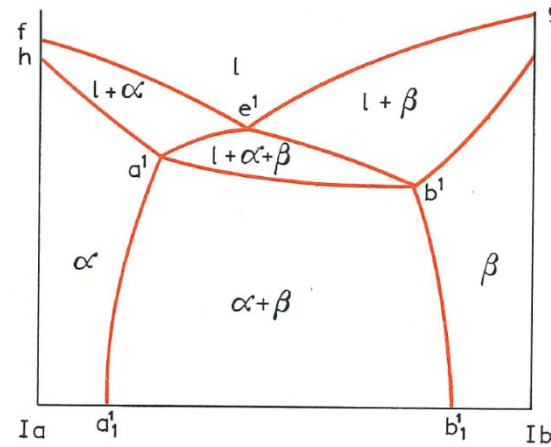
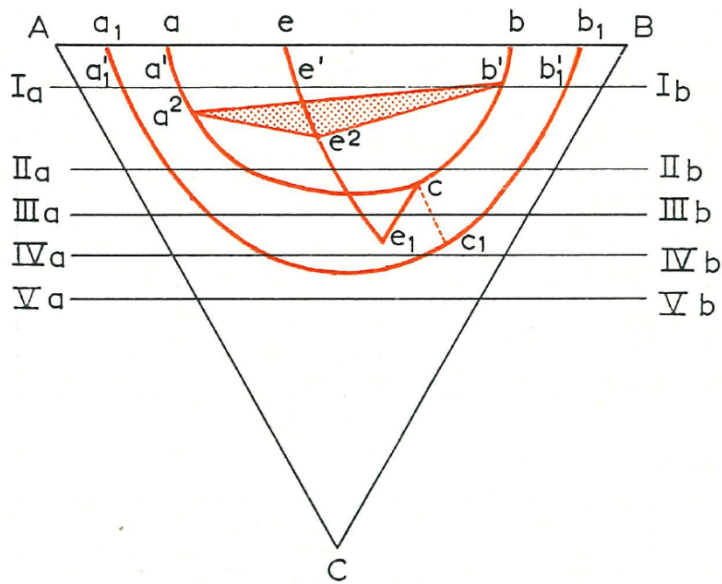
- Isothermal section



cf) Movie

9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- Vertical section



> Point 1: 4 on the α solidus surface

> Point 1- Point 2

* 4→6 on the α solidus surface

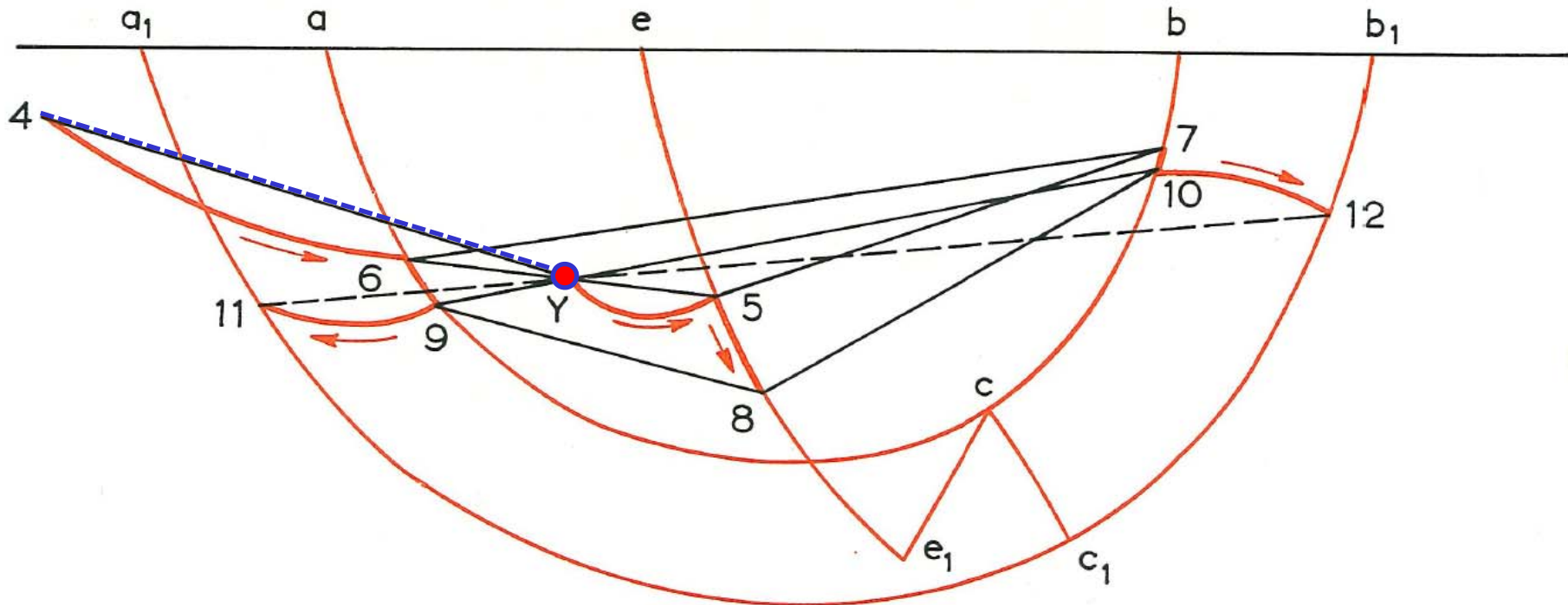
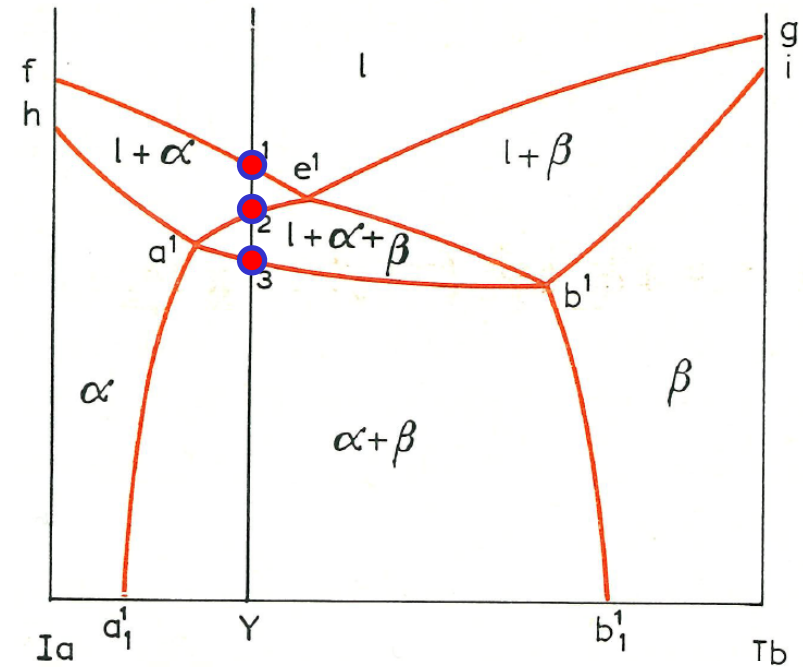
* 1→5 on the α liquidus surface

Three phase equilibrium l5, α 6, β 7

* α : 6→9, β : 7→10, l: 5→8

> Point 3: on the tie line 9-10

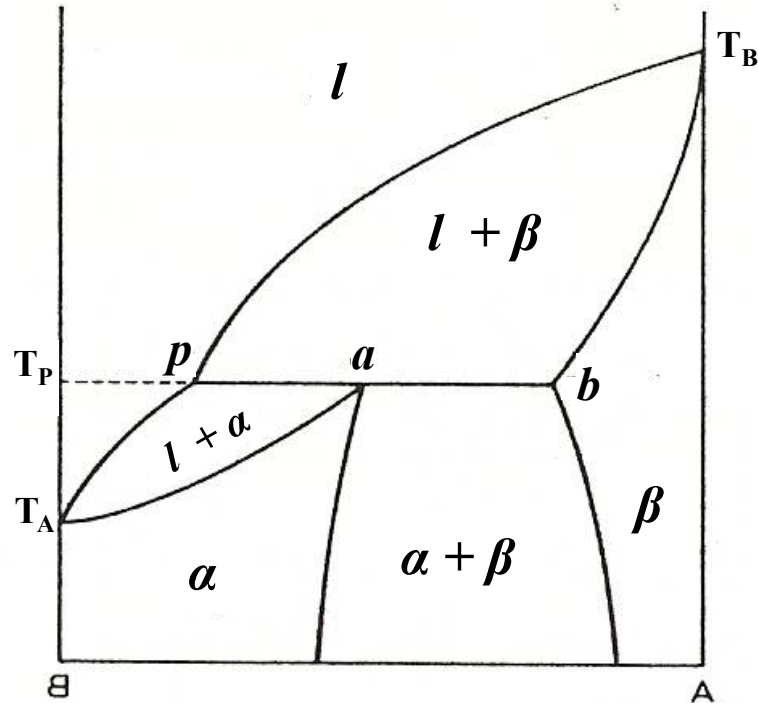
> Point 3-Y: α : 9→11, β : 10→12



Projection of the solidification sequence for alloy Y on the concentration triangle

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

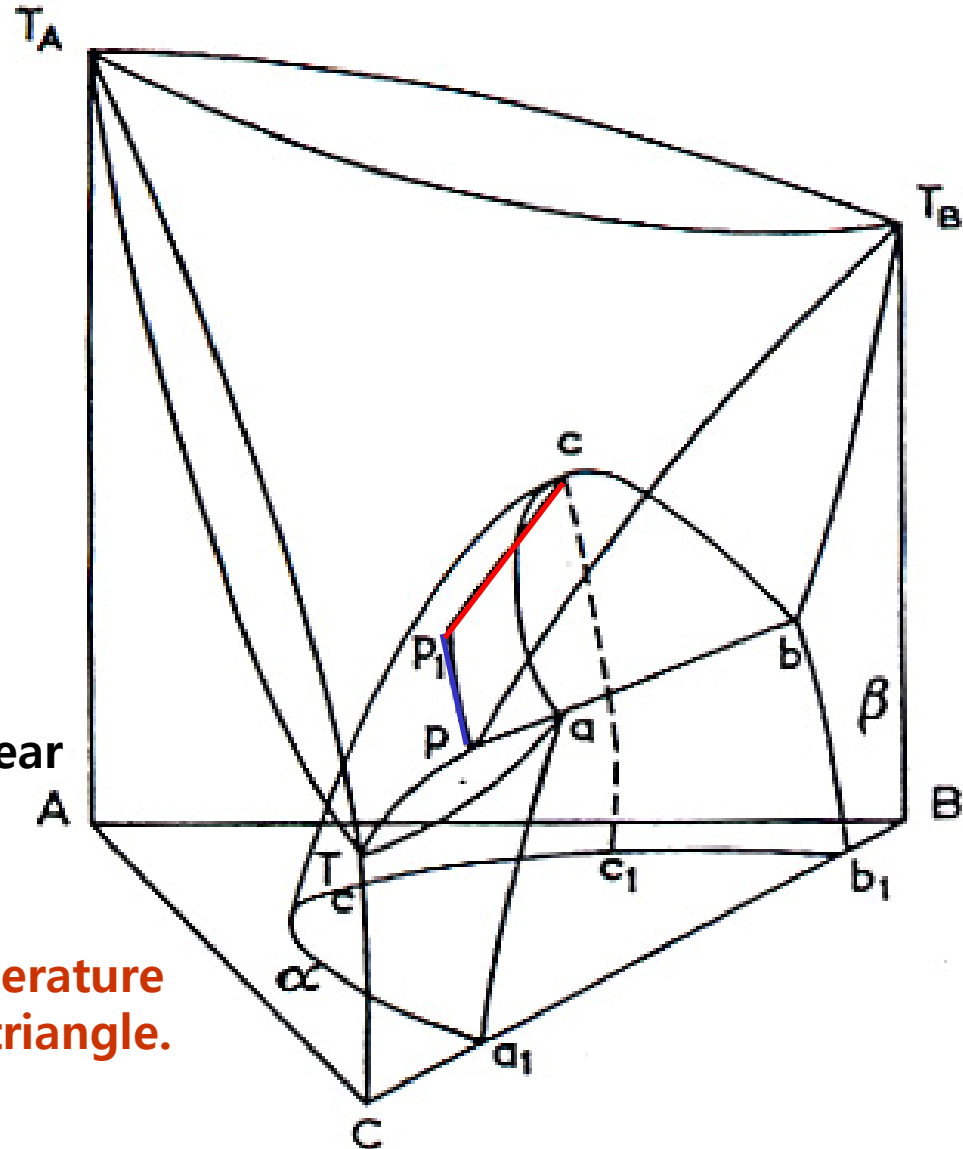
- A peritectic solubility gap in one binary system



: A minimum or a maximum may appear in the monovariant liquid curve.

PP_1 : monovariant curve for liquid

Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.

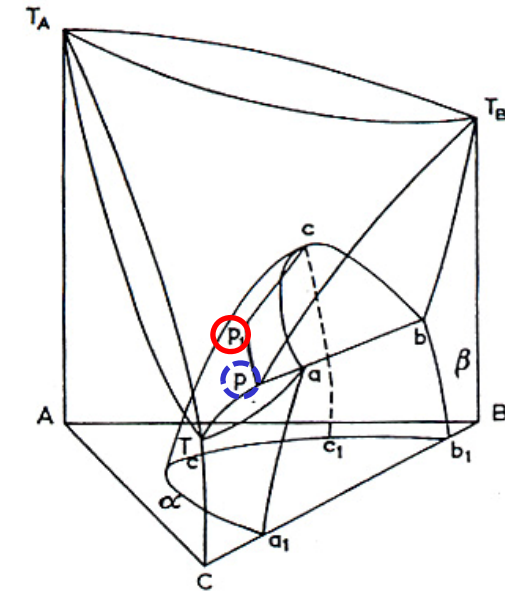


9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

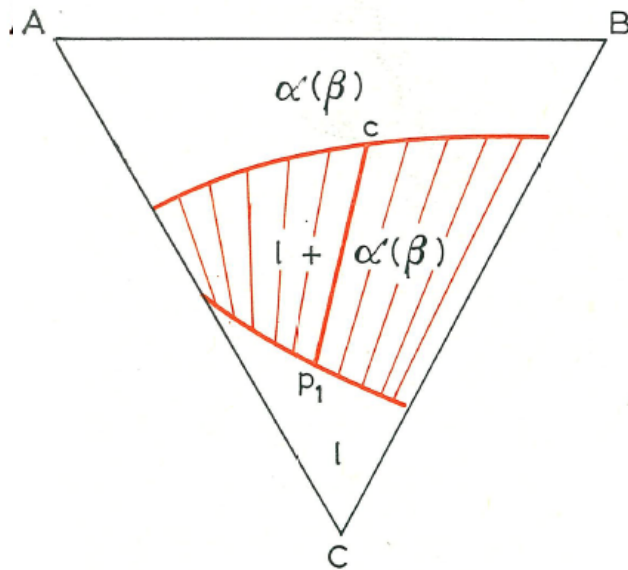
- A peritectic solubility gap in one binary system

PP_1 : monovariant curve for liquid

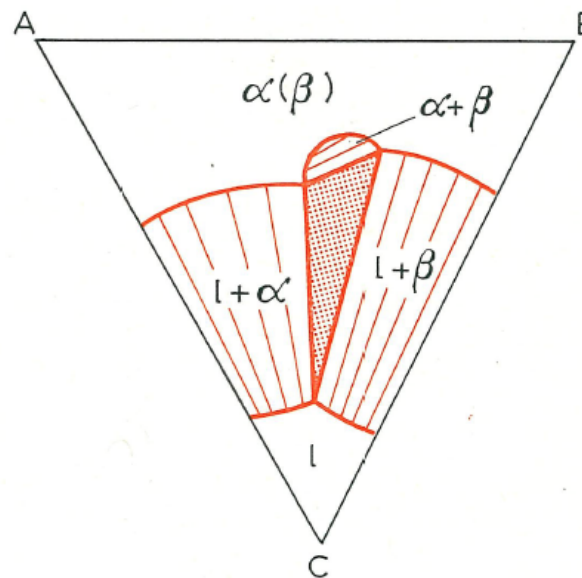
Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.



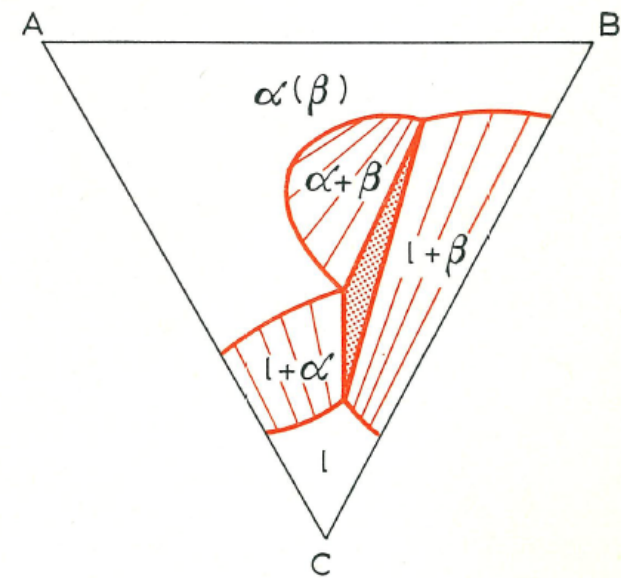
isothermal section



$$T = P_1$$



$$P_1 > T_1 > P$$



$$T_1 > T_2 > P$$

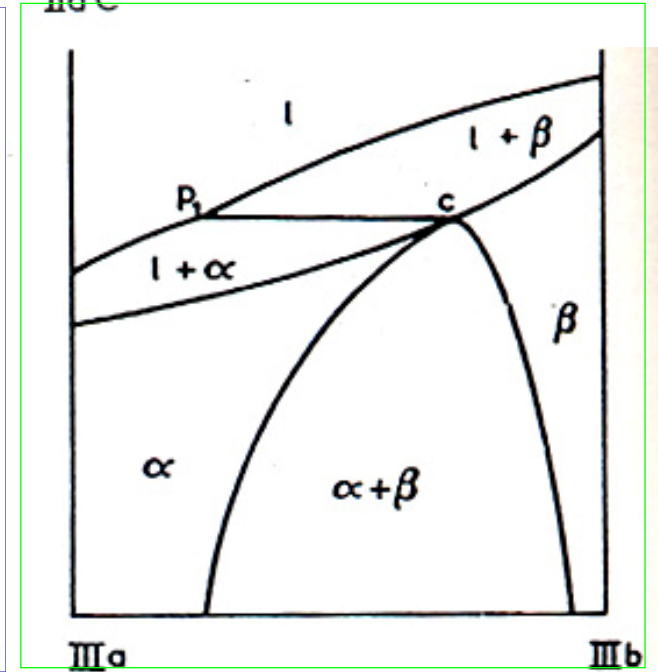
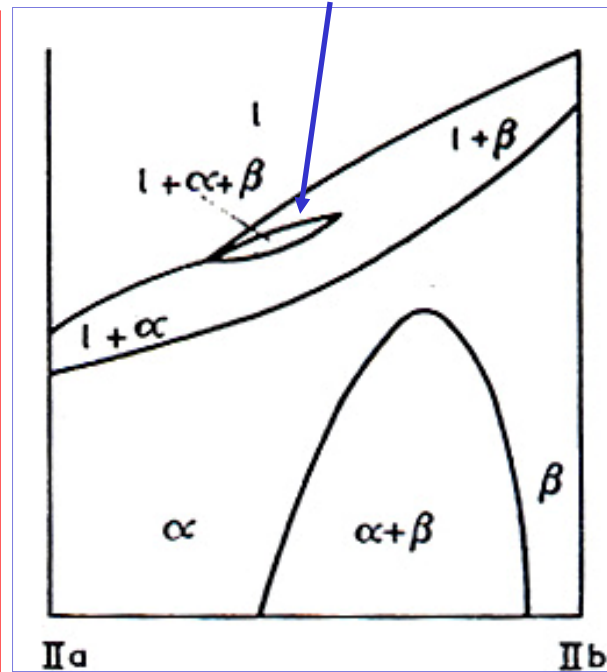
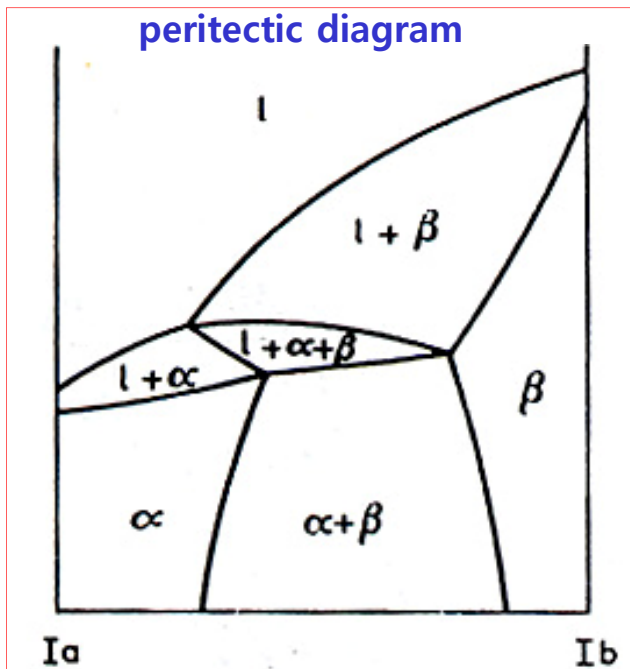
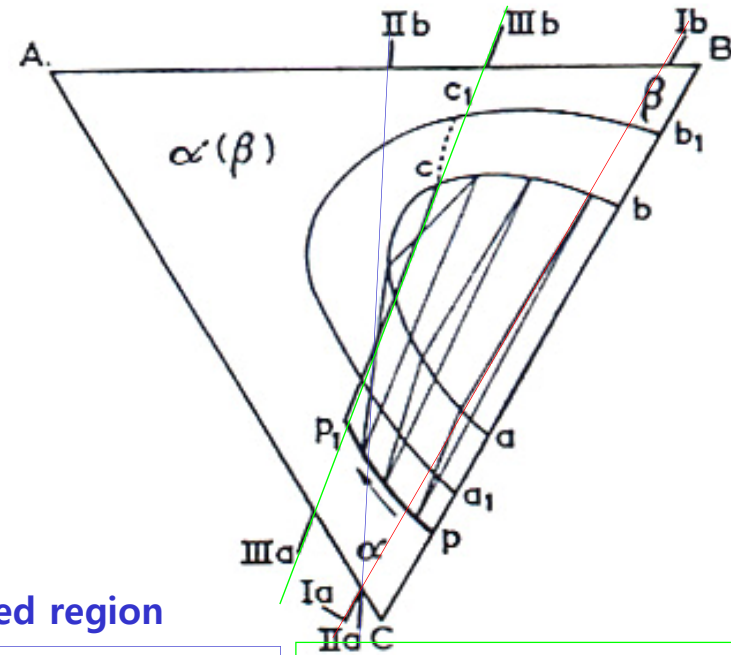
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A peritectic solubility gap in one binary system

<vertical section>

Similar to the binary peritectic diagram

loop shaped region



9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

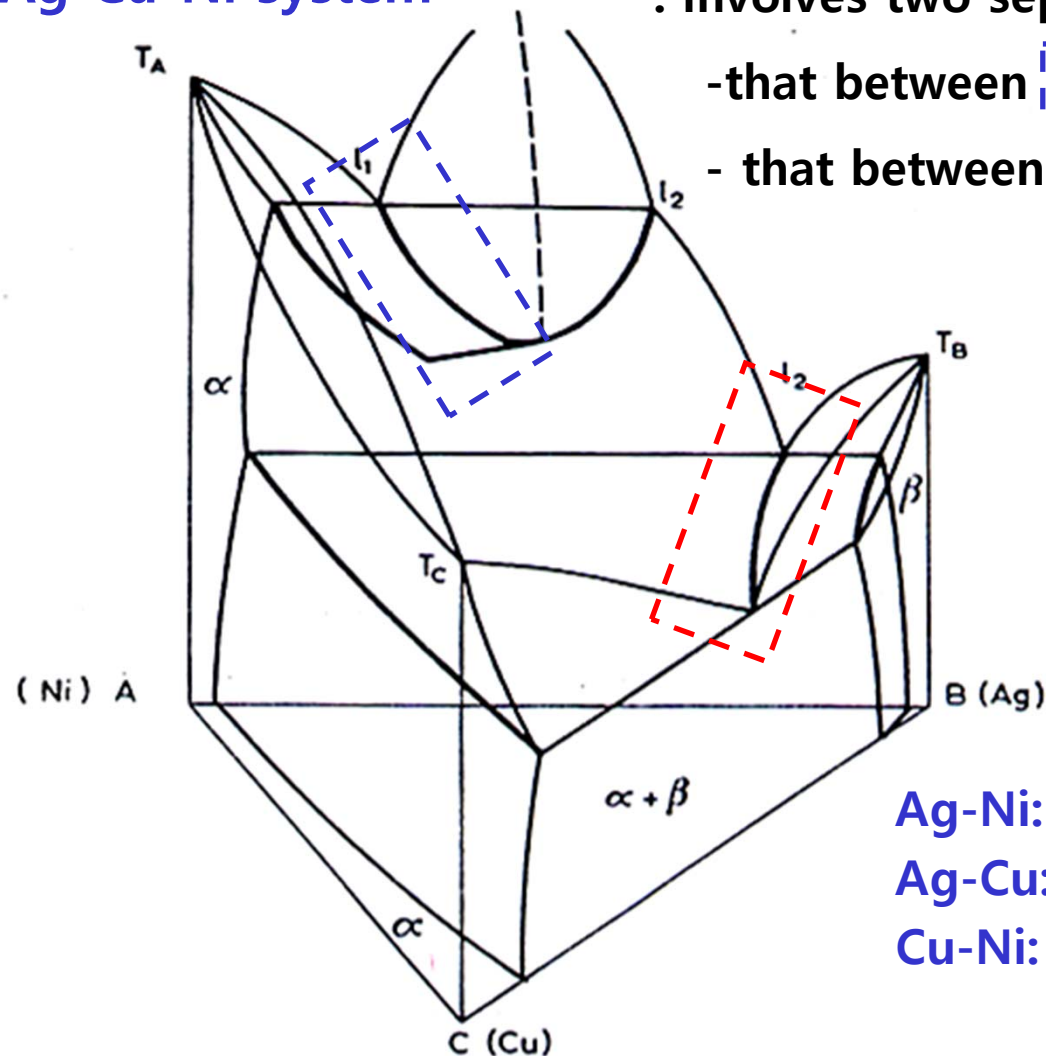
- Binary Monotectic, syntectic and metatectic reactions in combination with each other as well as with binary eutectic and peritectic reactions.

- **Ag-Cu-Ni system**

: involves two separate three phase equilibria

- that between α , l_1 and l_2 , and

- that between α , β and l_2



Ag-Ni: monotectic

Ag-Cu: eutectic

Cu-Ni: continuous series of solid soln

Chapter 10. Ternary phase Diagrams

Four-Phase Equilibrium

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

b. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

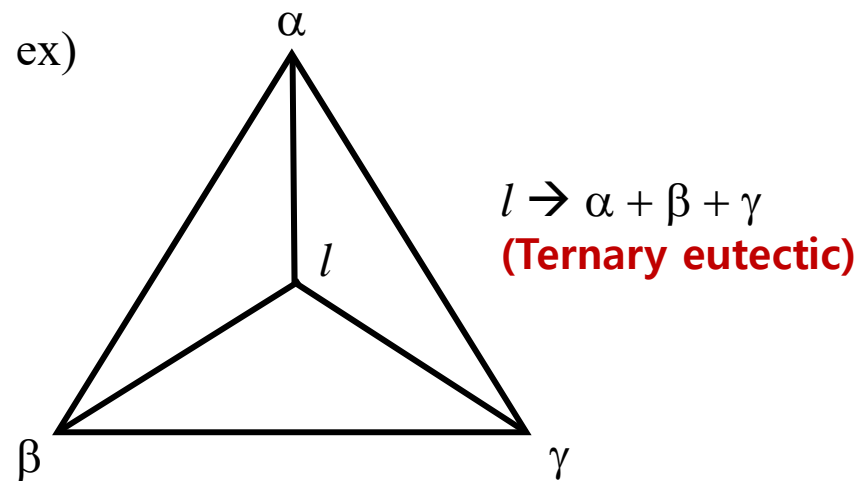
c. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

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

Three phase equil. ($f = 1$) - eutectic, peritectic

Now we consider of four-phase equilibrium

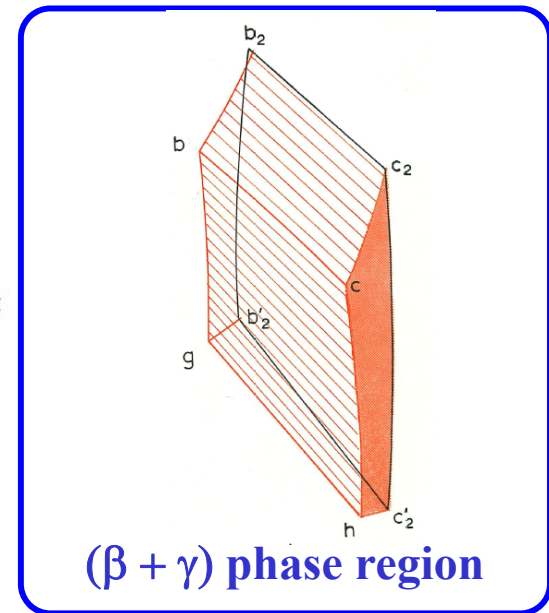
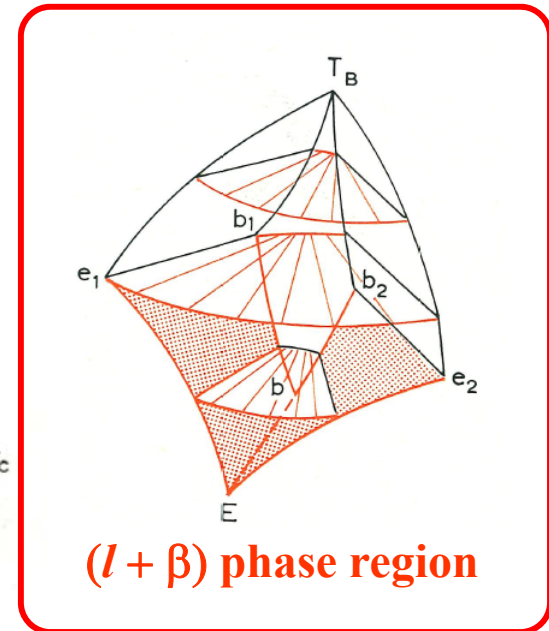
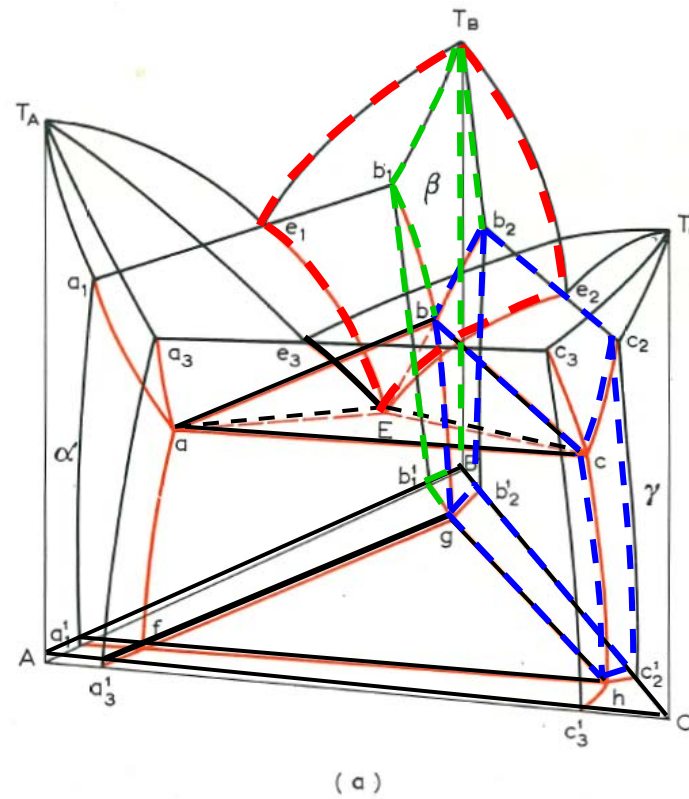
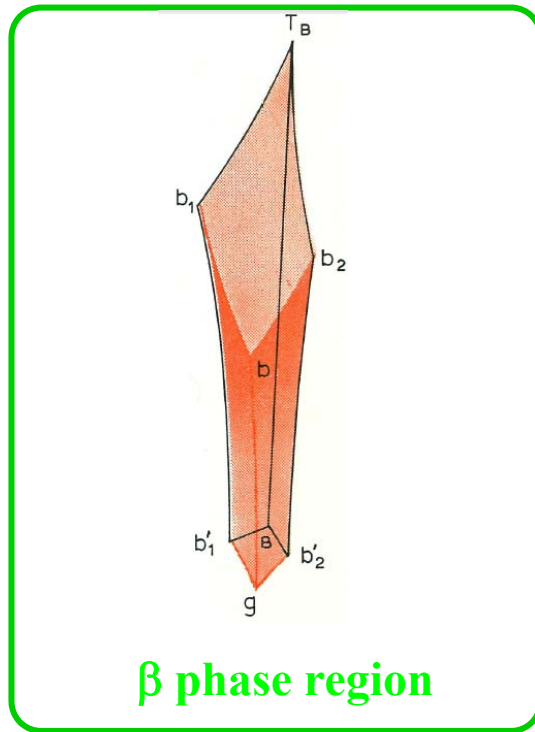
- max N of phase
- $f = 0$: composition of four phases at temp. \rightarrow fixed
- isothermal four phase regions



cf) $l + \alpha \rightarrow \beta + \gamma$: **ternary quasi-peritectic**
 $l + \alpha + \beta \rightarrow \gamma$: **ternary peritectic**

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

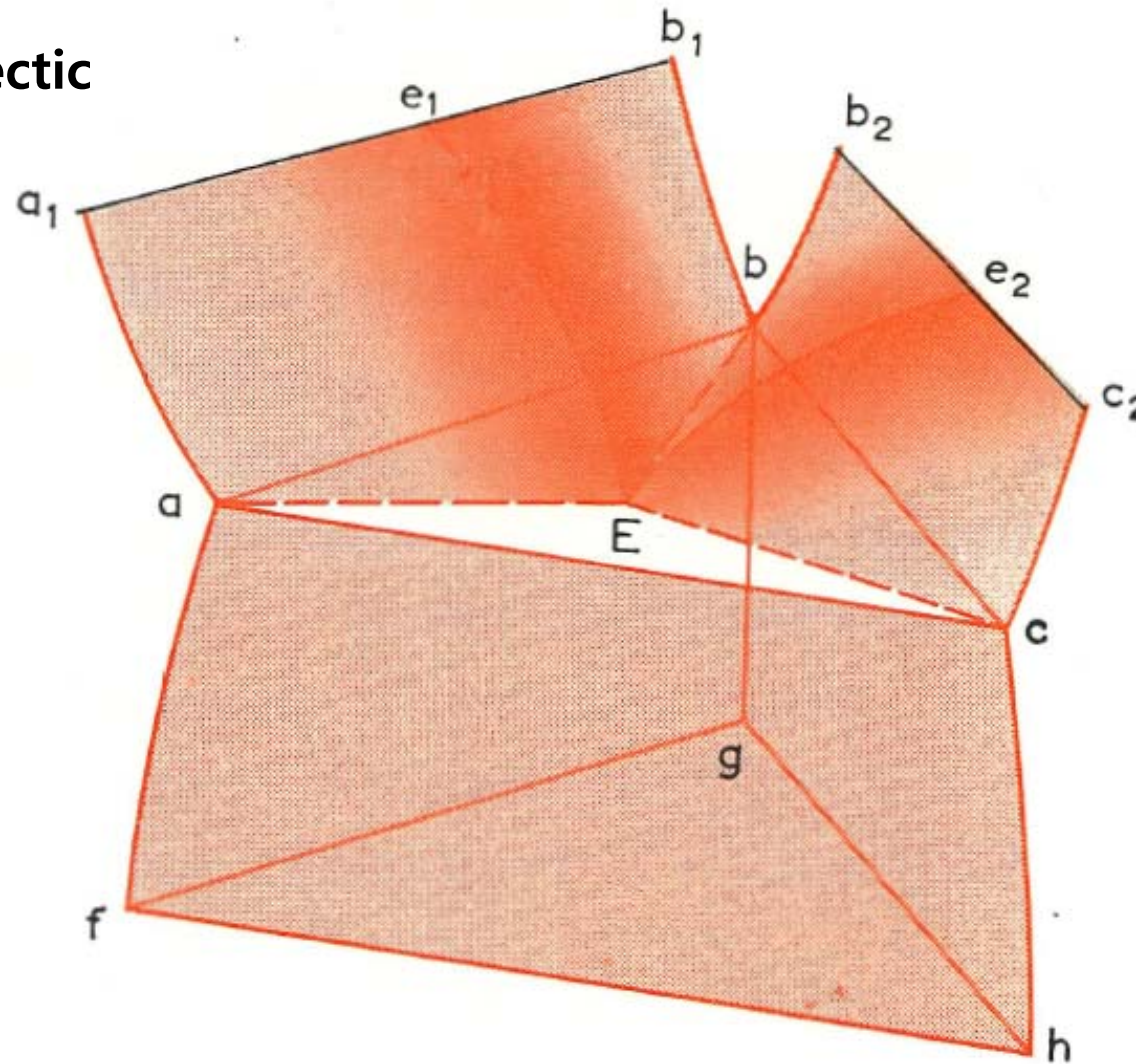
Ternary eutectic



$$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$$

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

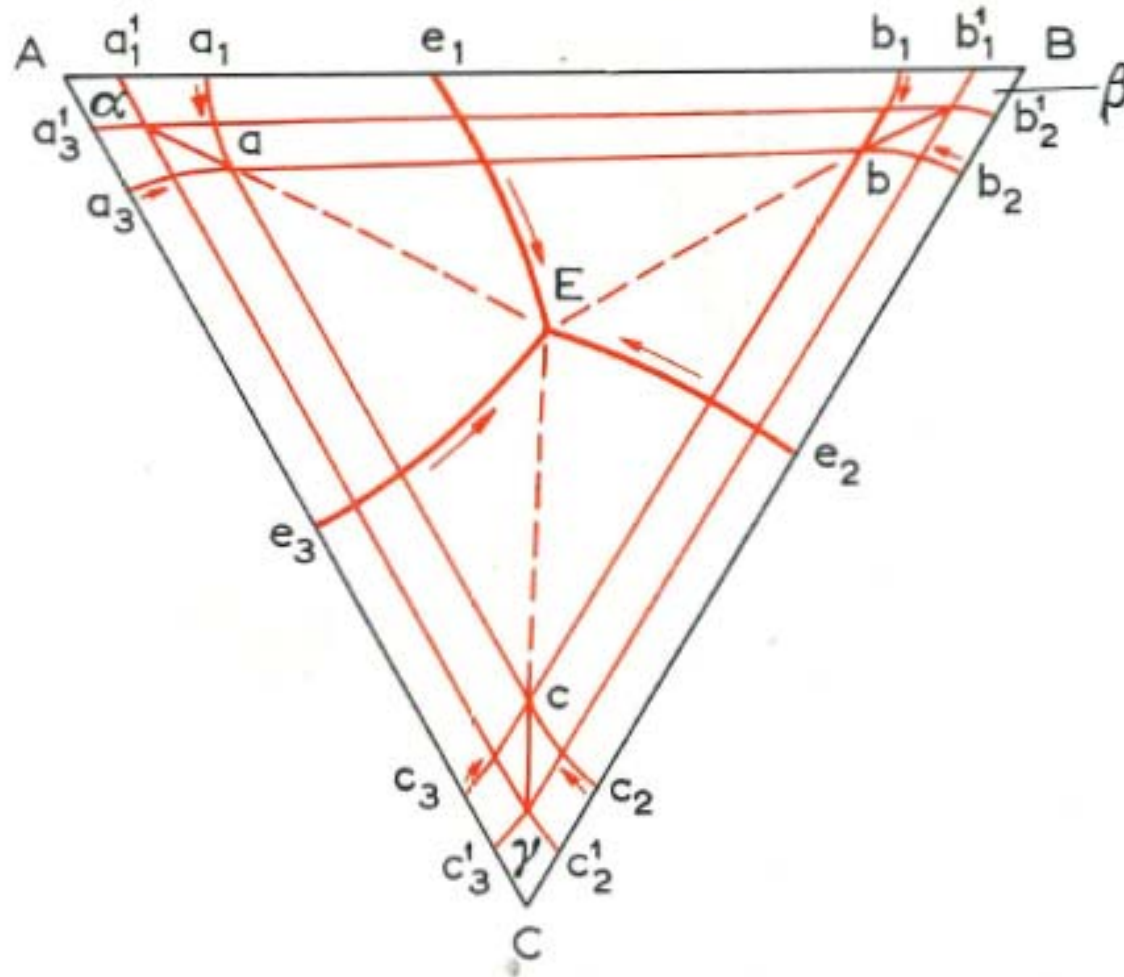
Ternary eutectic



The eutectic four-phase plane as the junction of four tie triangles

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

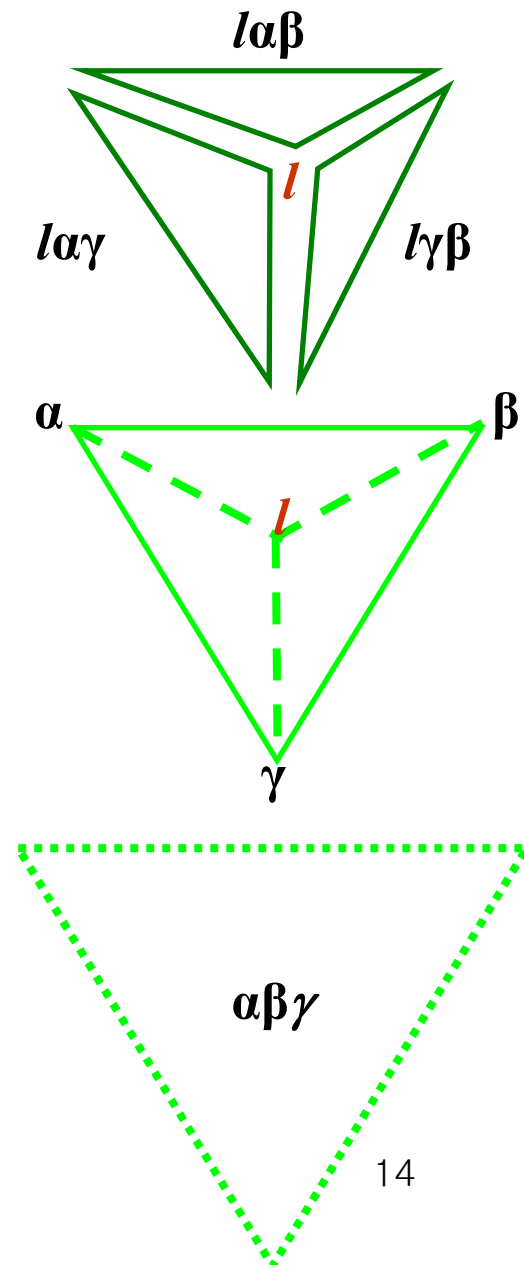
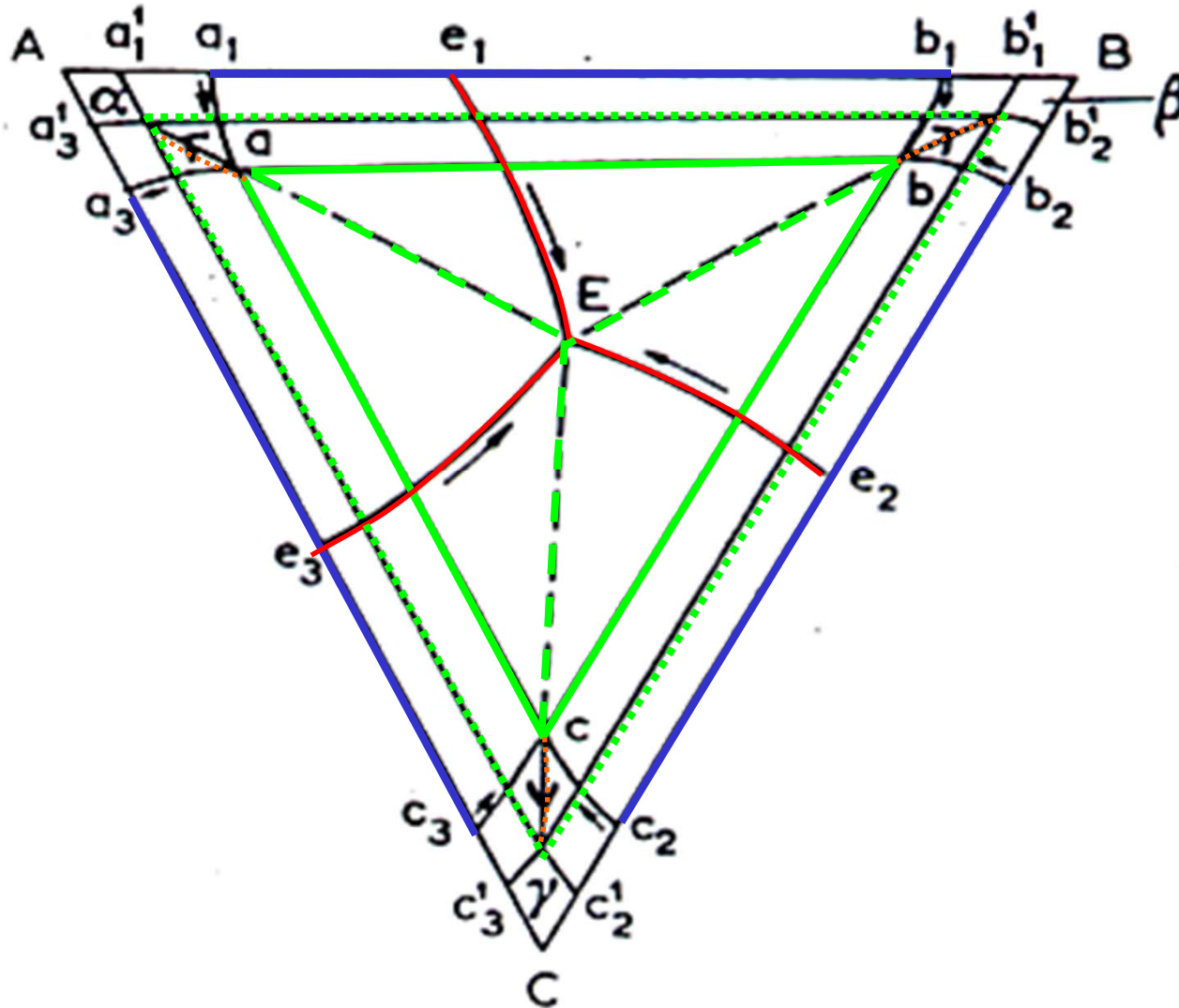
Ternary eutectic • Projection : solid solubility limit surface
: monovariant liquidus curve



$$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$$

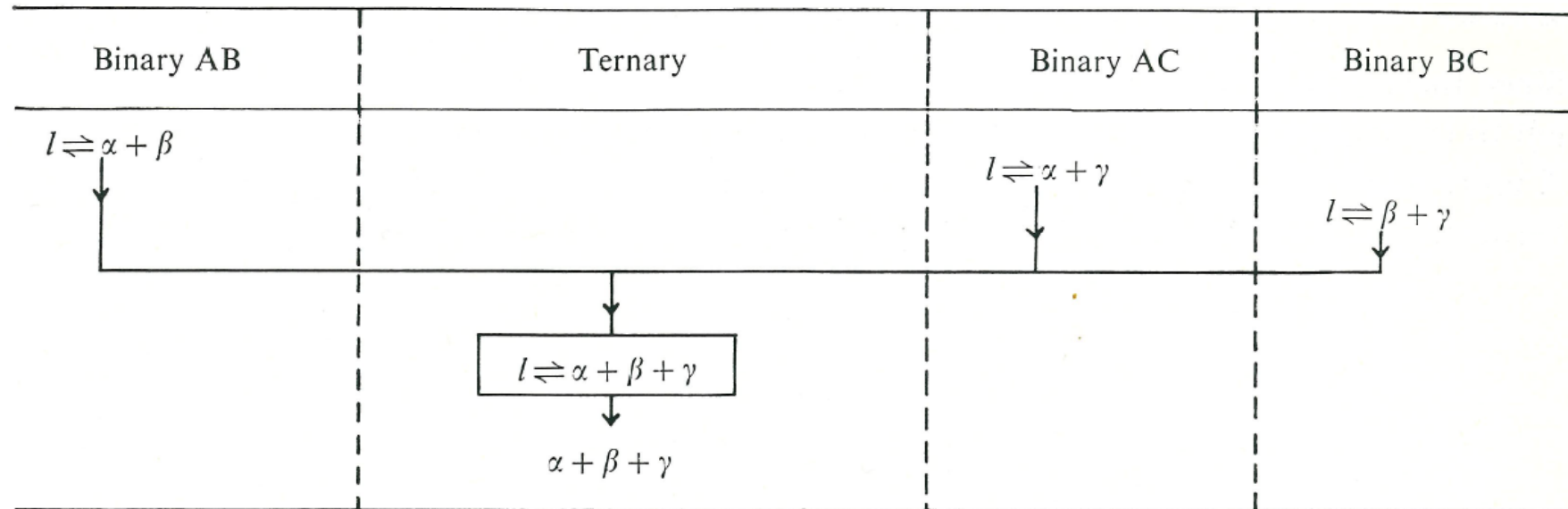
THE TERNARY EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

- **Projection** : solid solubility limit surface
: monovariant liquidus curve

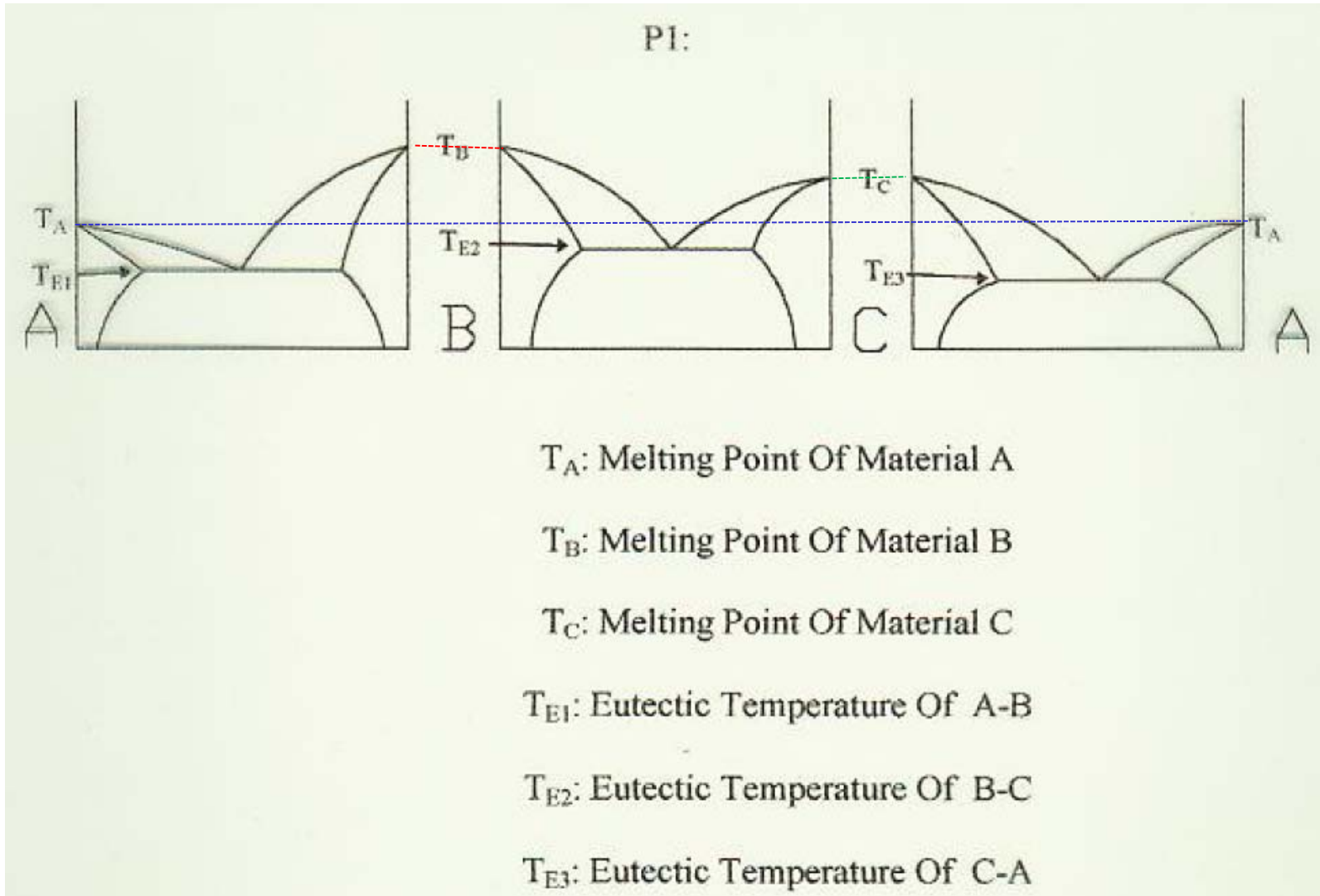


**Tabular representation of ternary equilibria:
interlinks the binary and ternary reactions in tabular form**

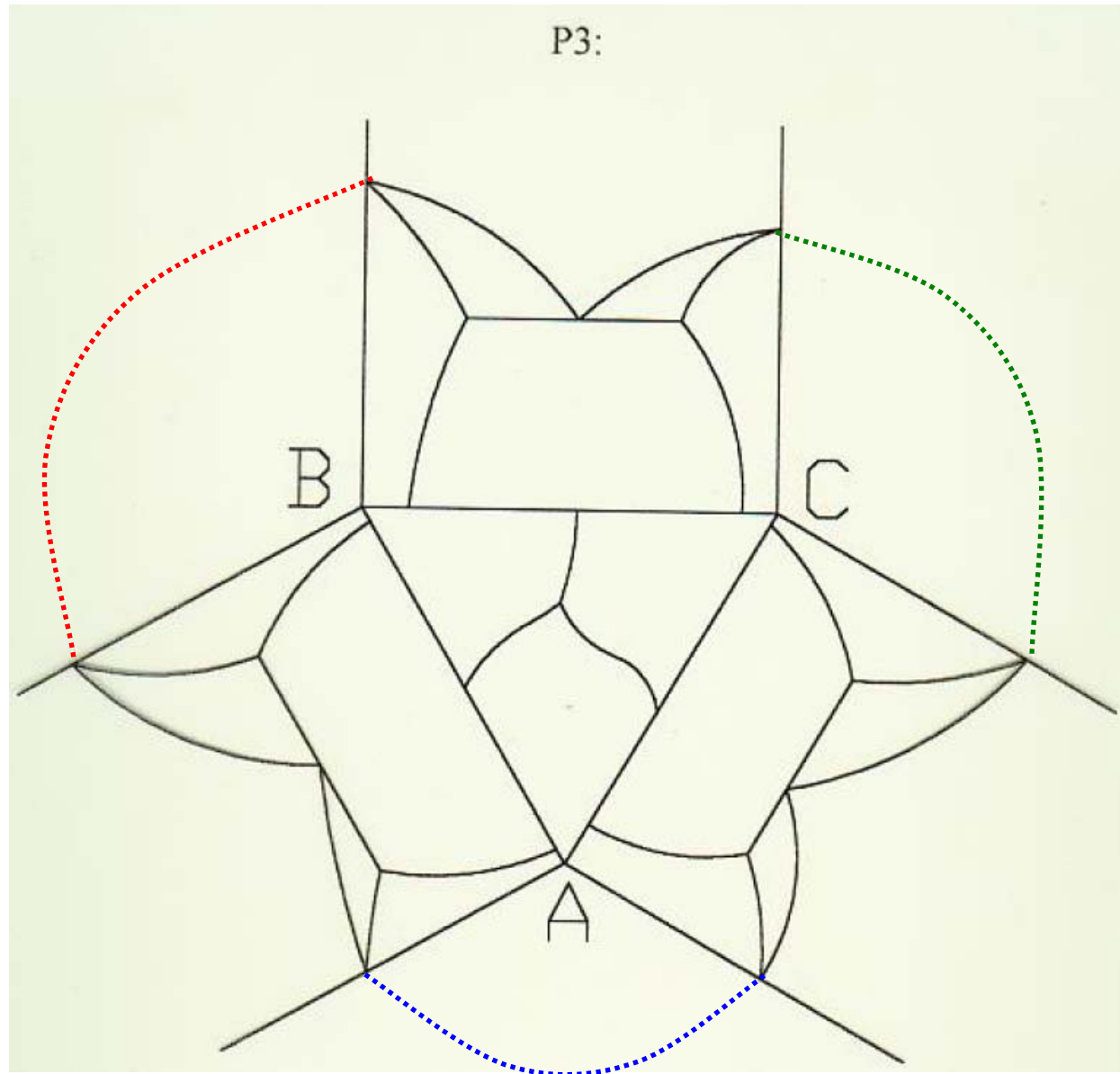
EUTECTIC EQUILIBRIUM $l \rightleftharpoons \alpha + \beta + \gamma$



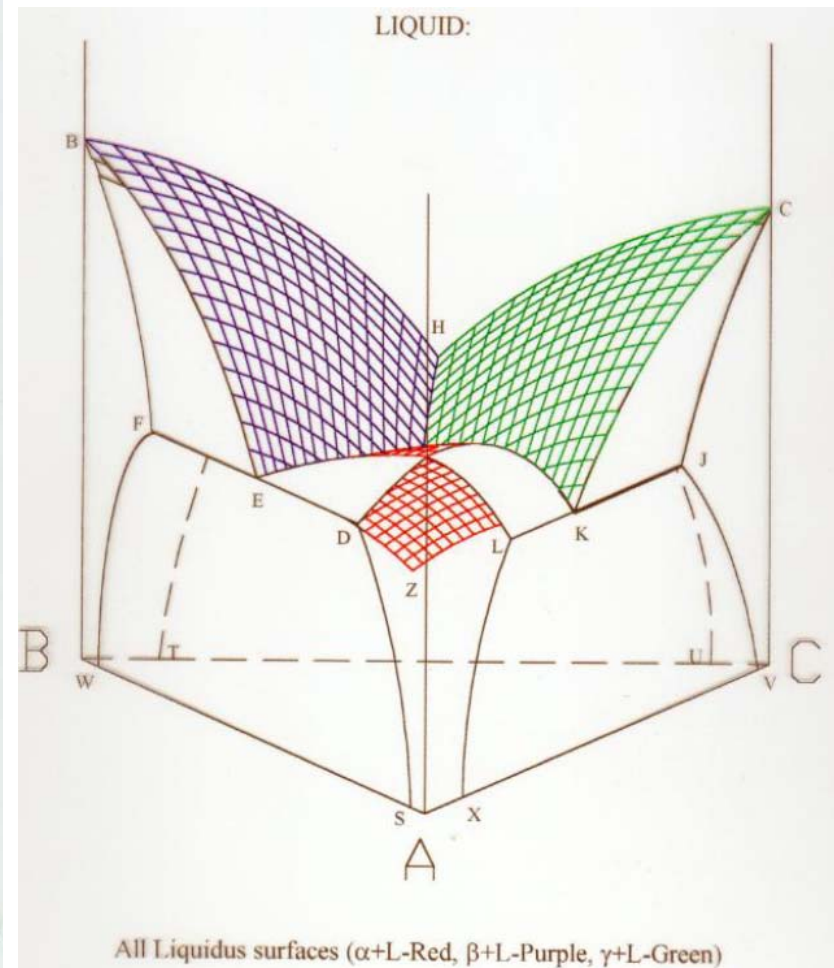
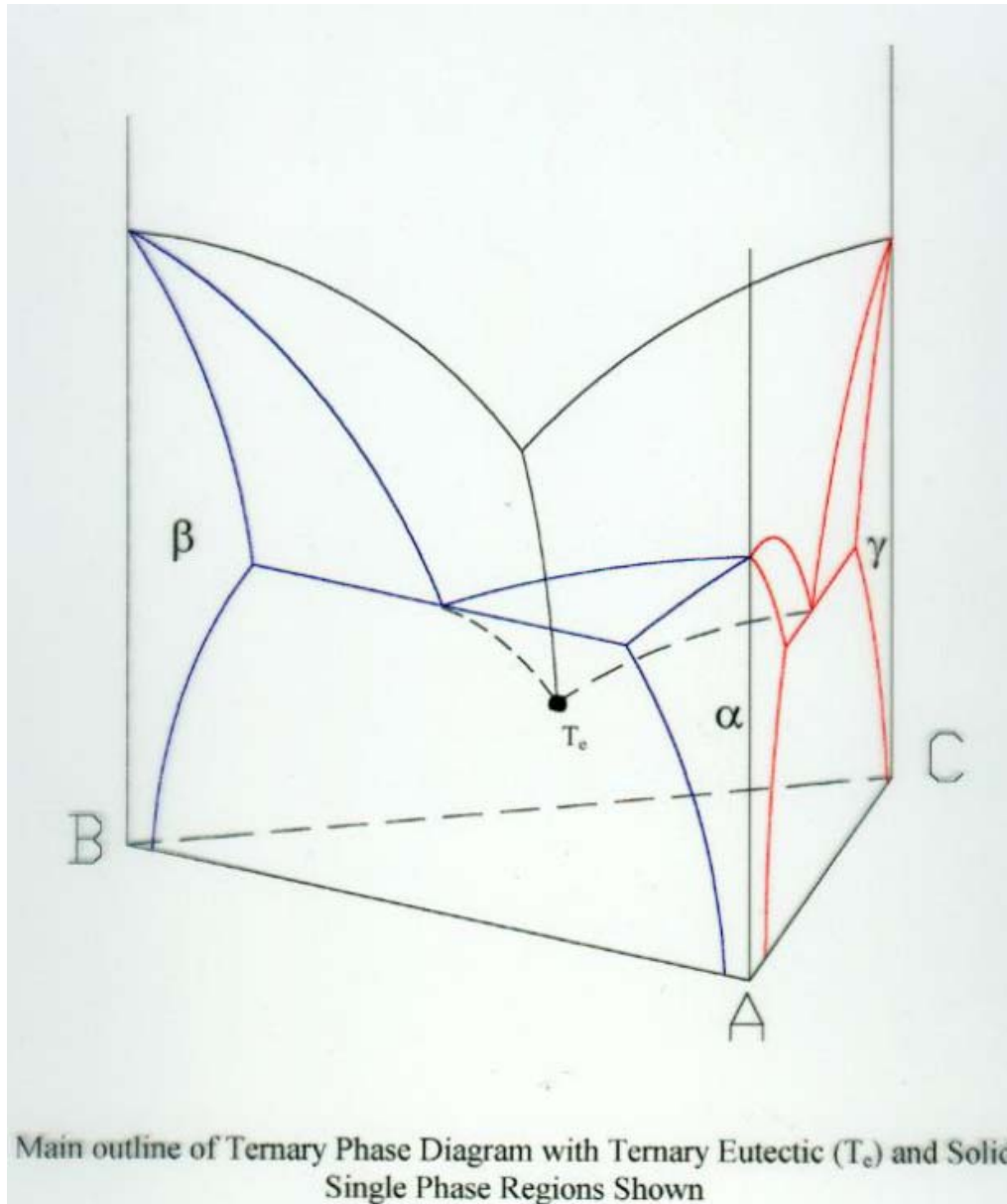
Ternary Eutectic System (with Solid Solubility)



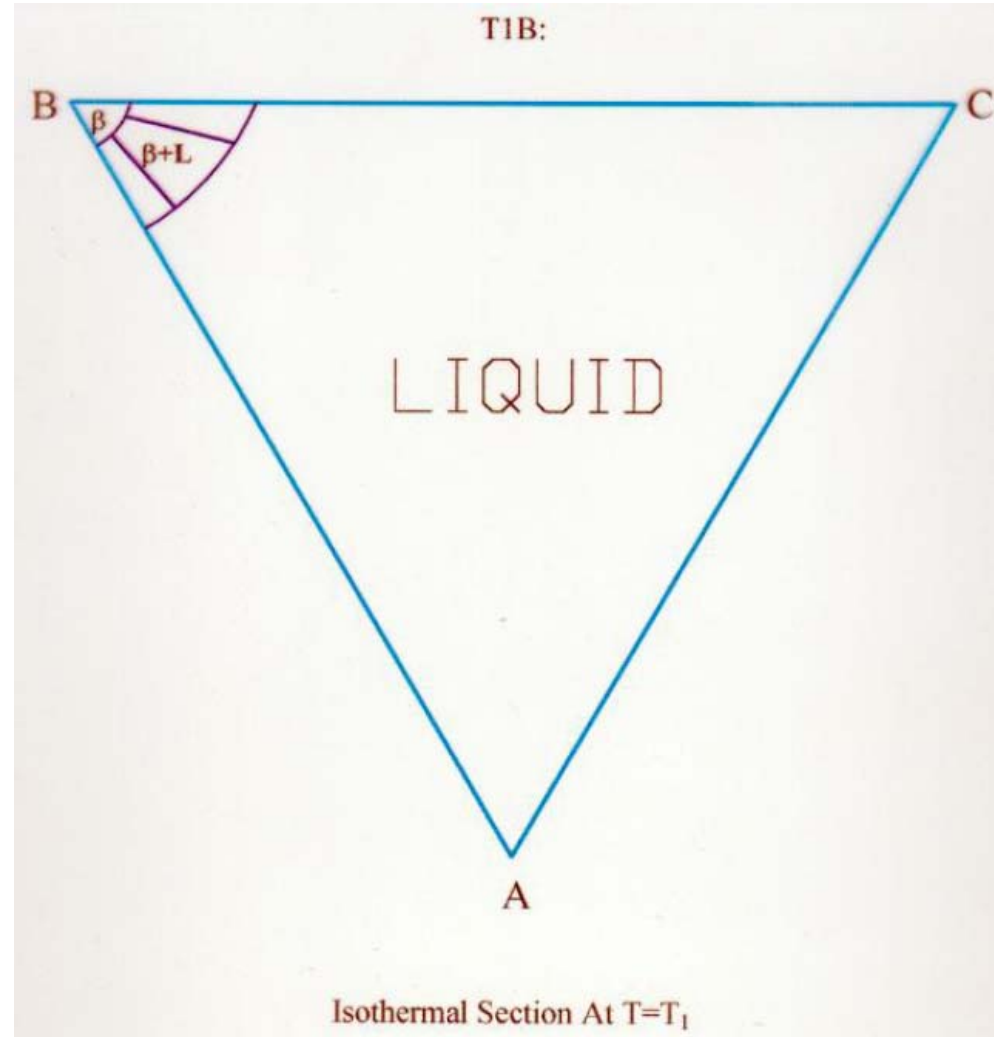
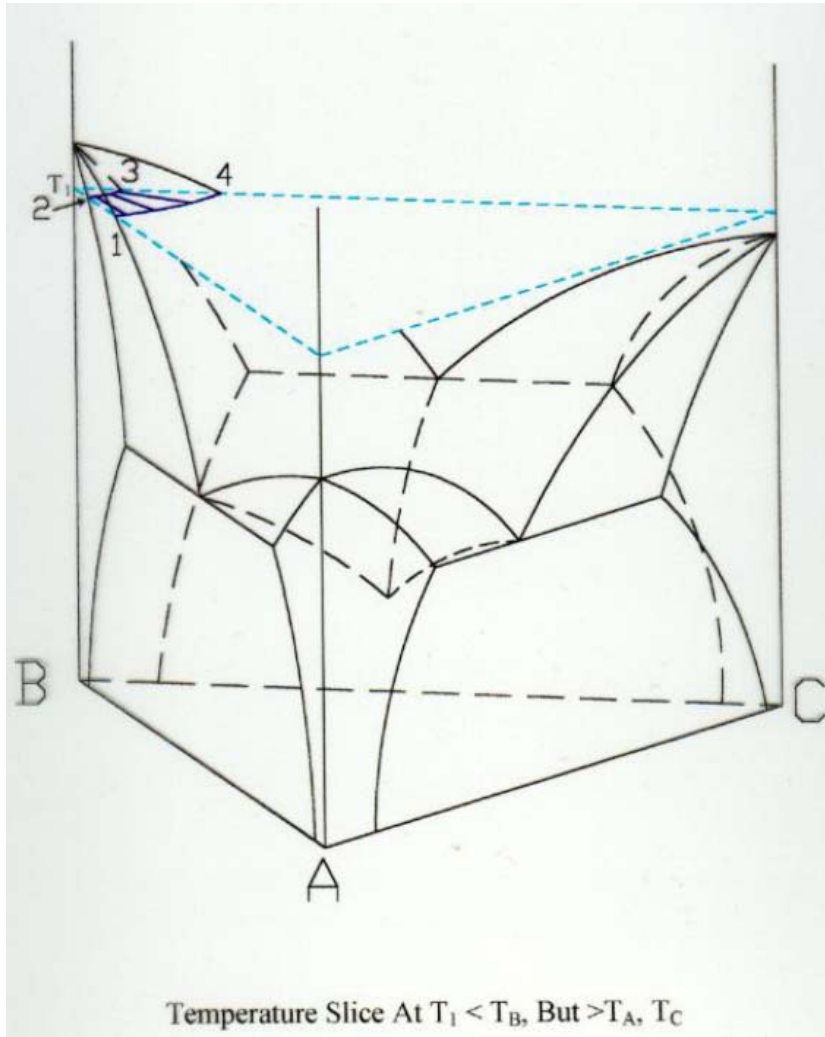
Ternary Eutectic System (with Solid Solubility)



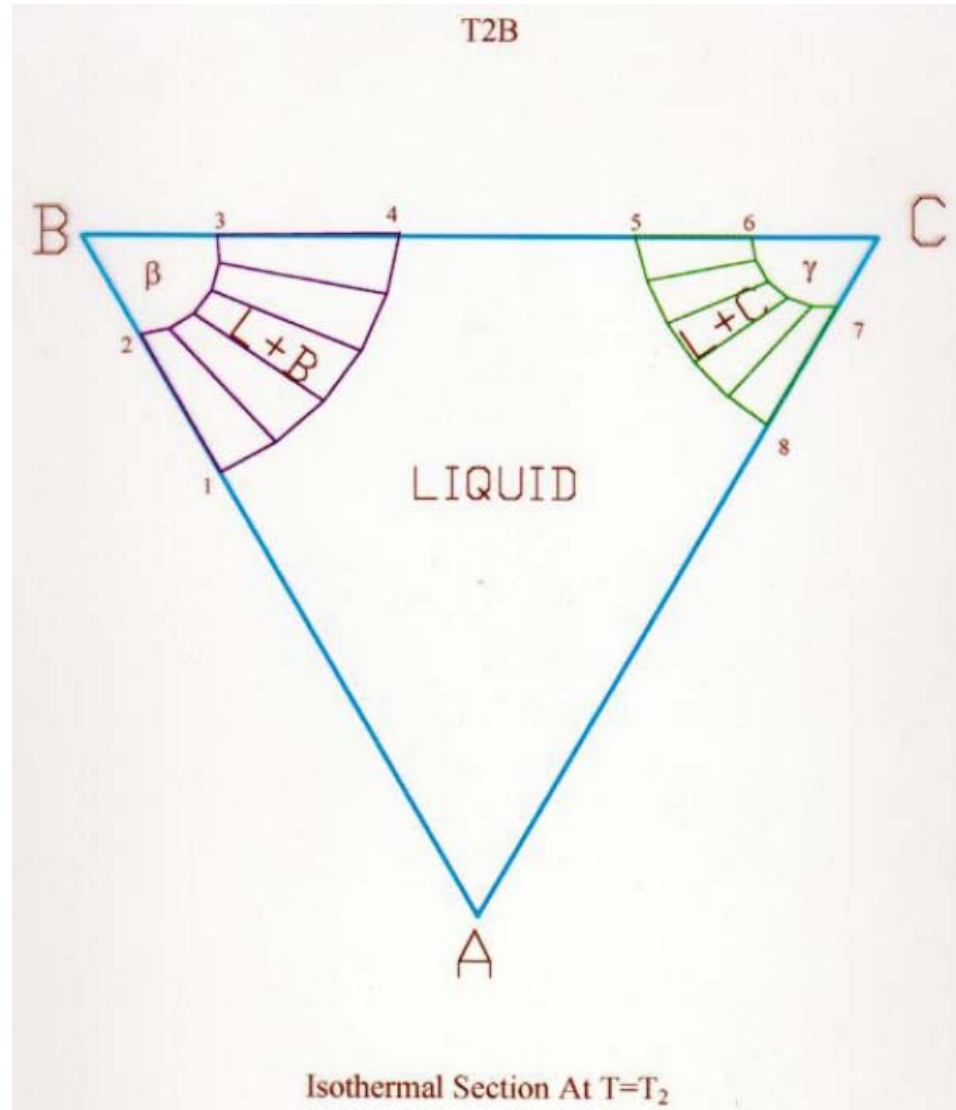
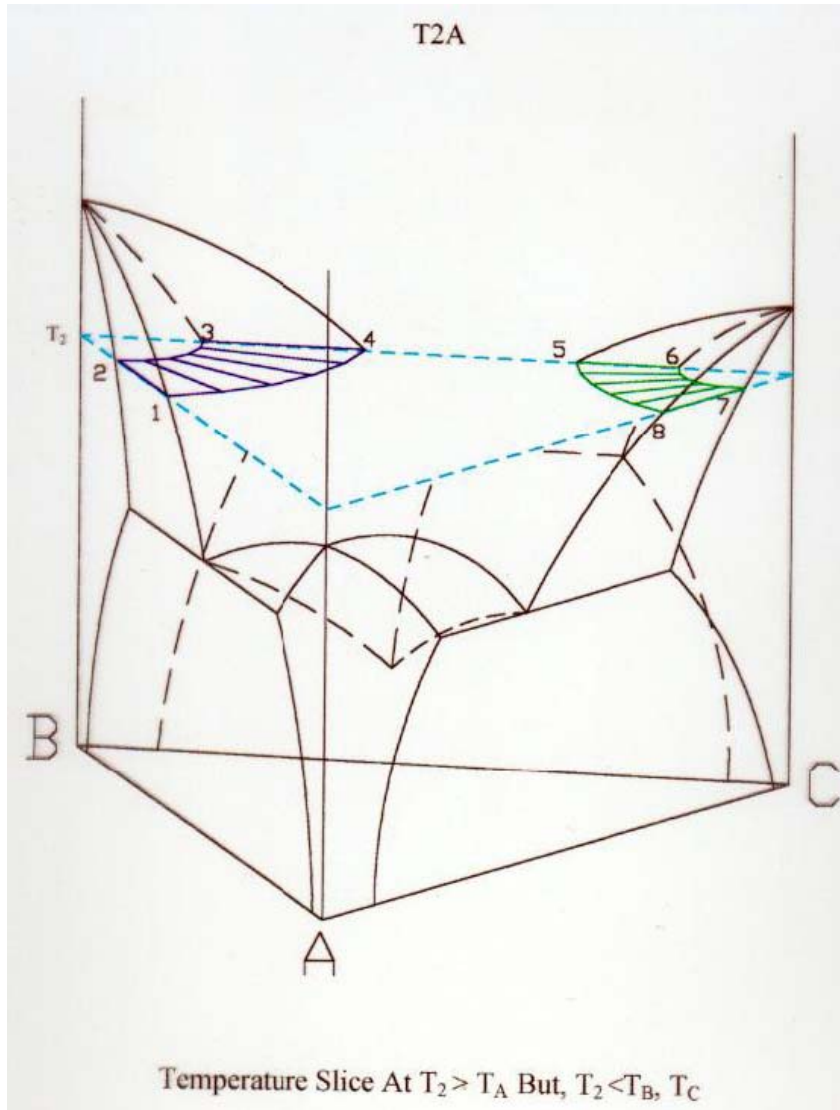
Ternary Eutectic System (with Solid Solubility)



Ternary Eutectic System (with Solid Solubility)

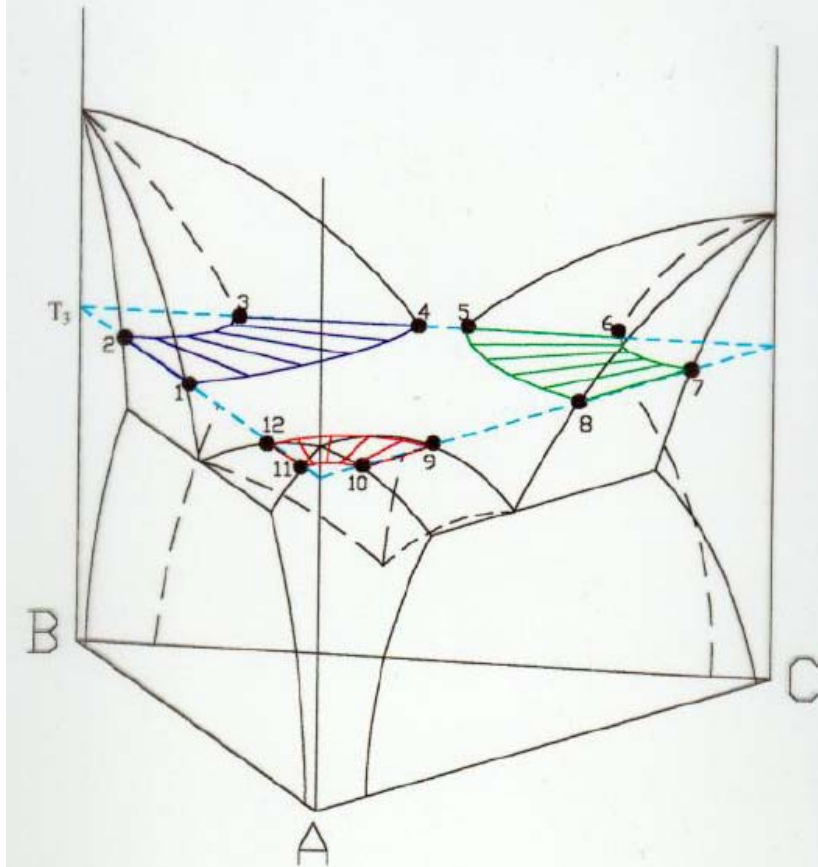


Ternary Eutectic System (with Solid Solubility)



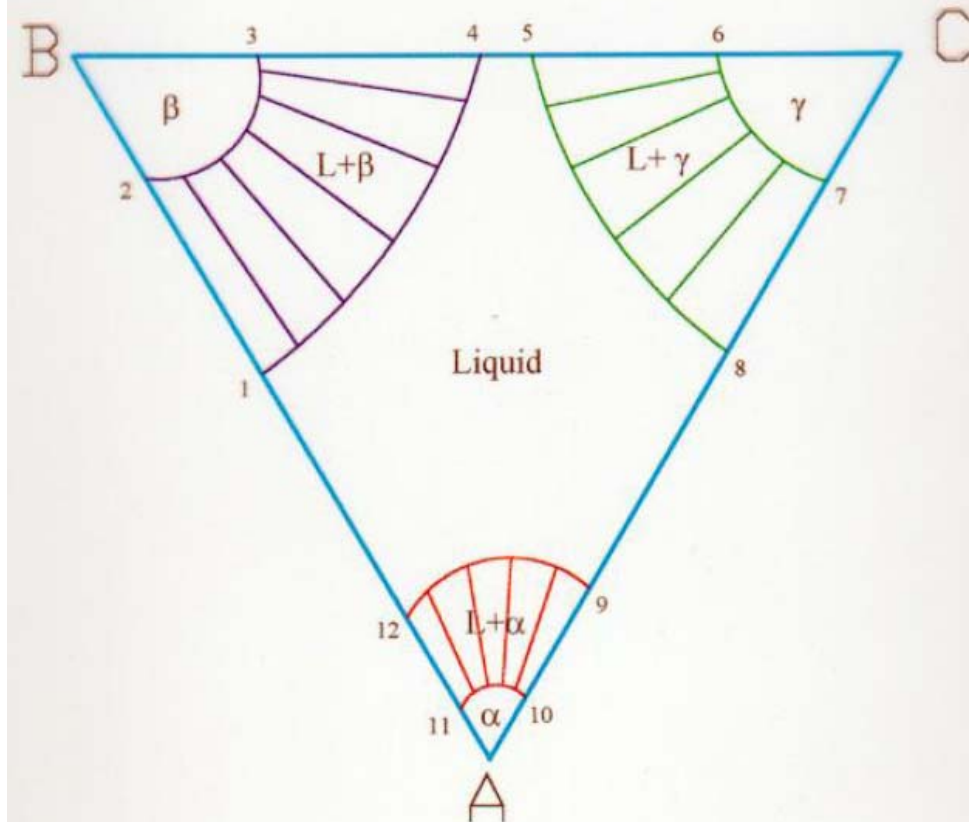
Ternary Eutectic System (with Solid Solubility)

T3A:



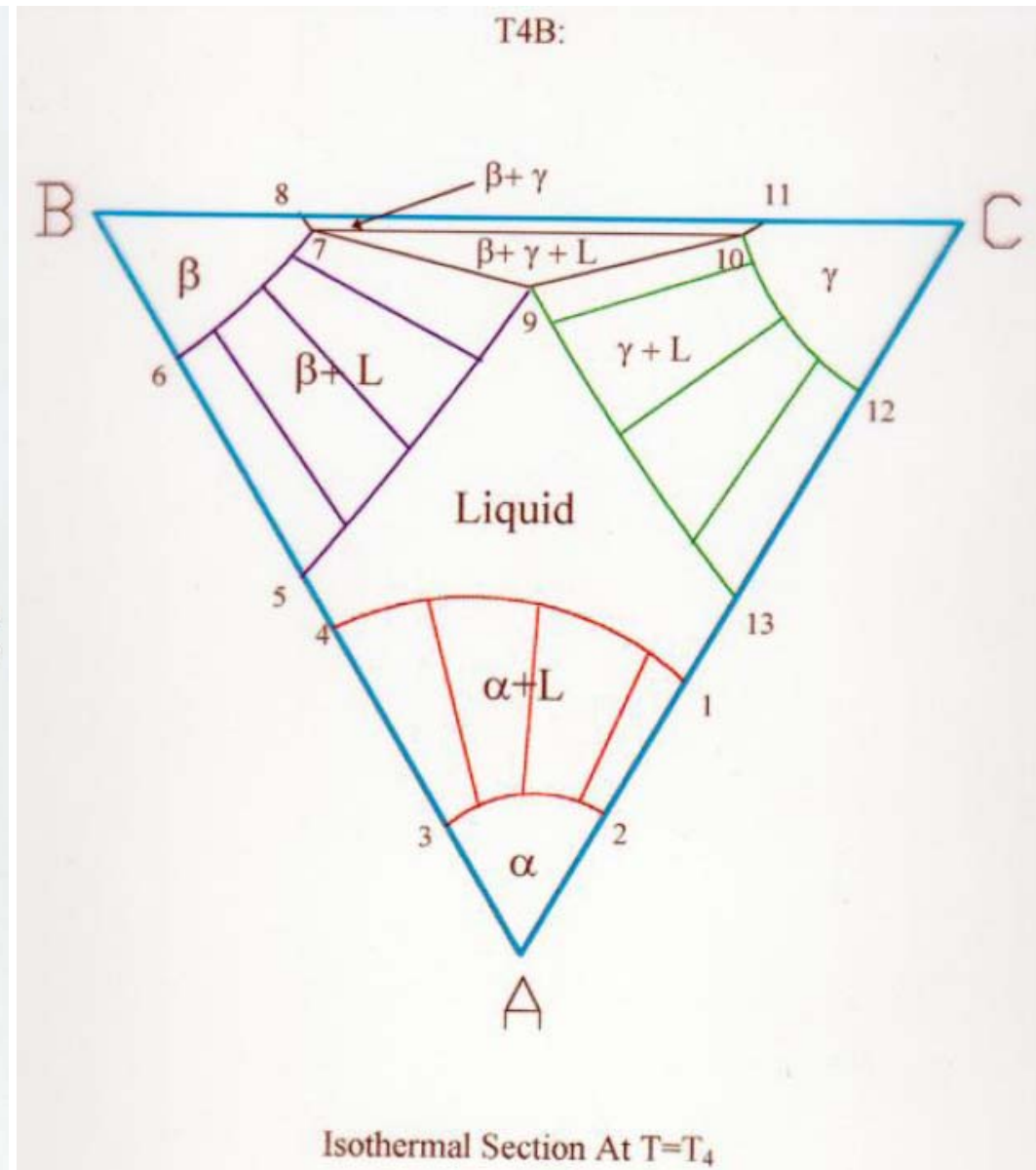
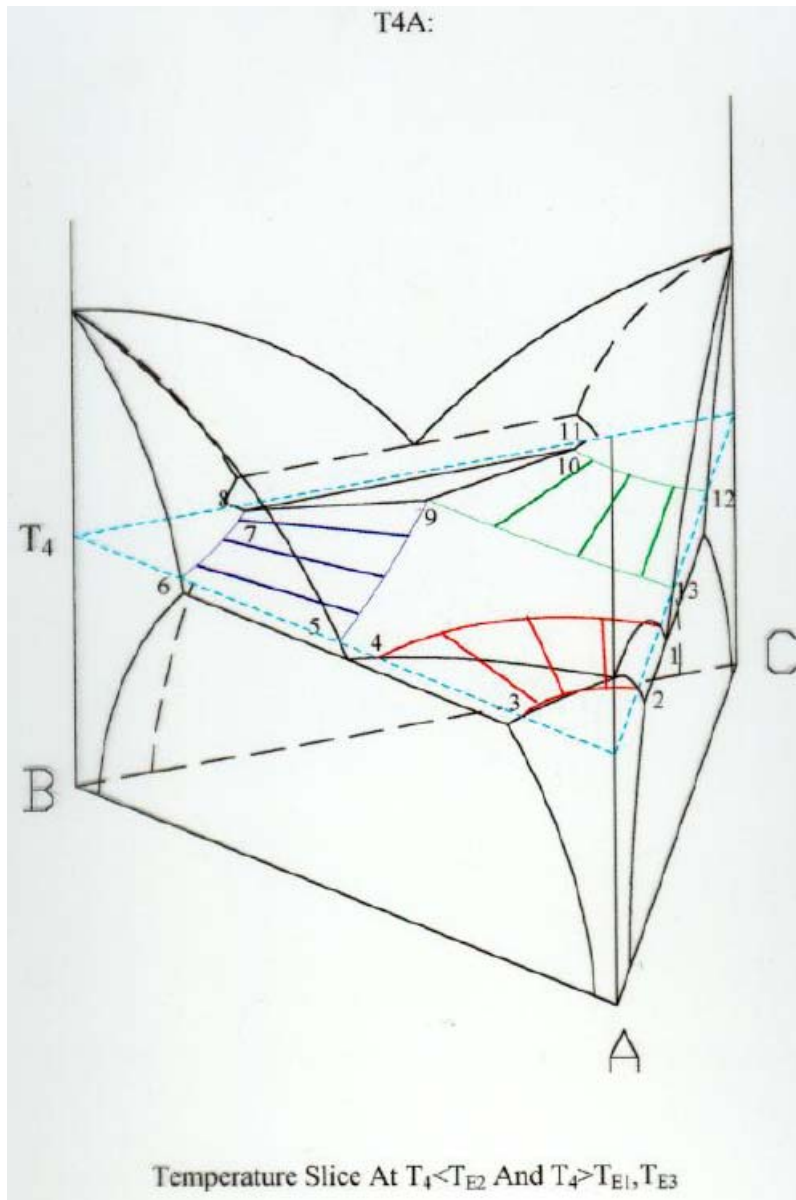
Temperature Slice At $T_3 < T_A, T_B, T_C$, But $T_3 > T_{E1}, T_{E2}, T_{E3}$

T3B

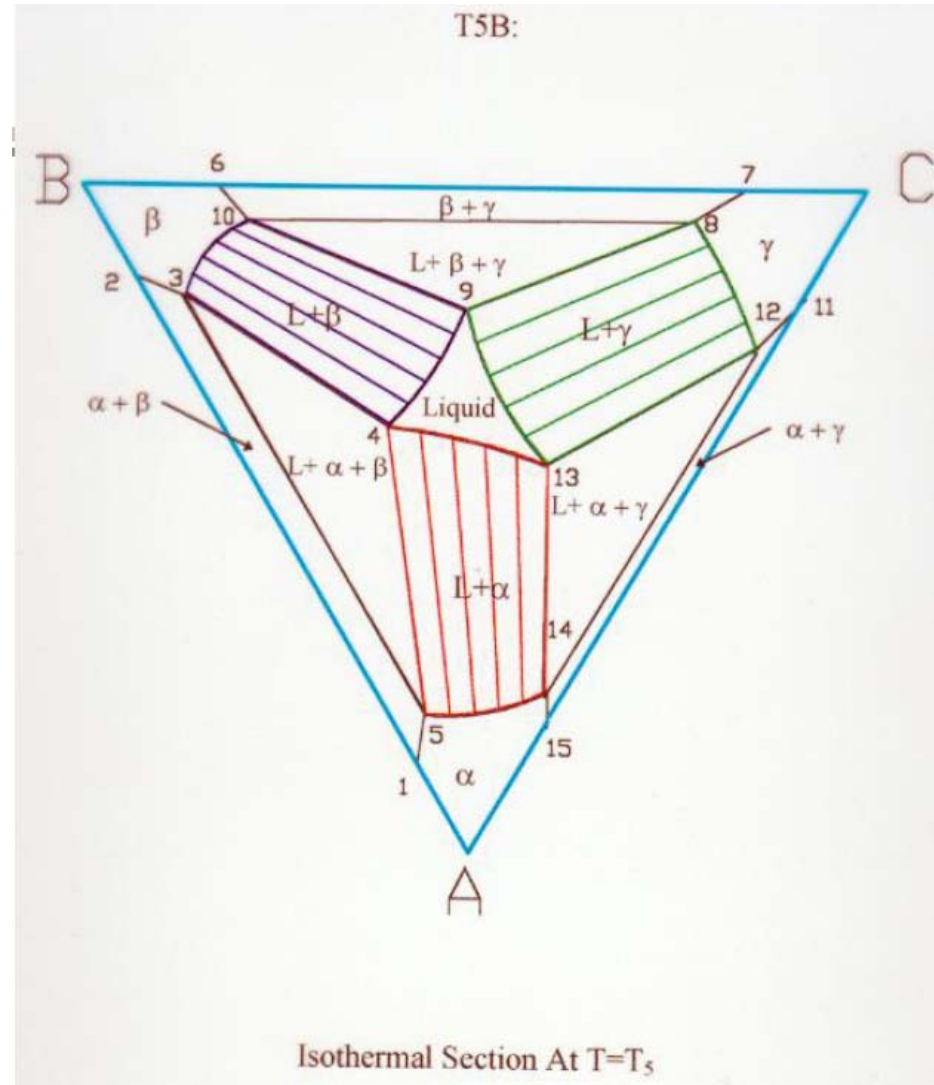
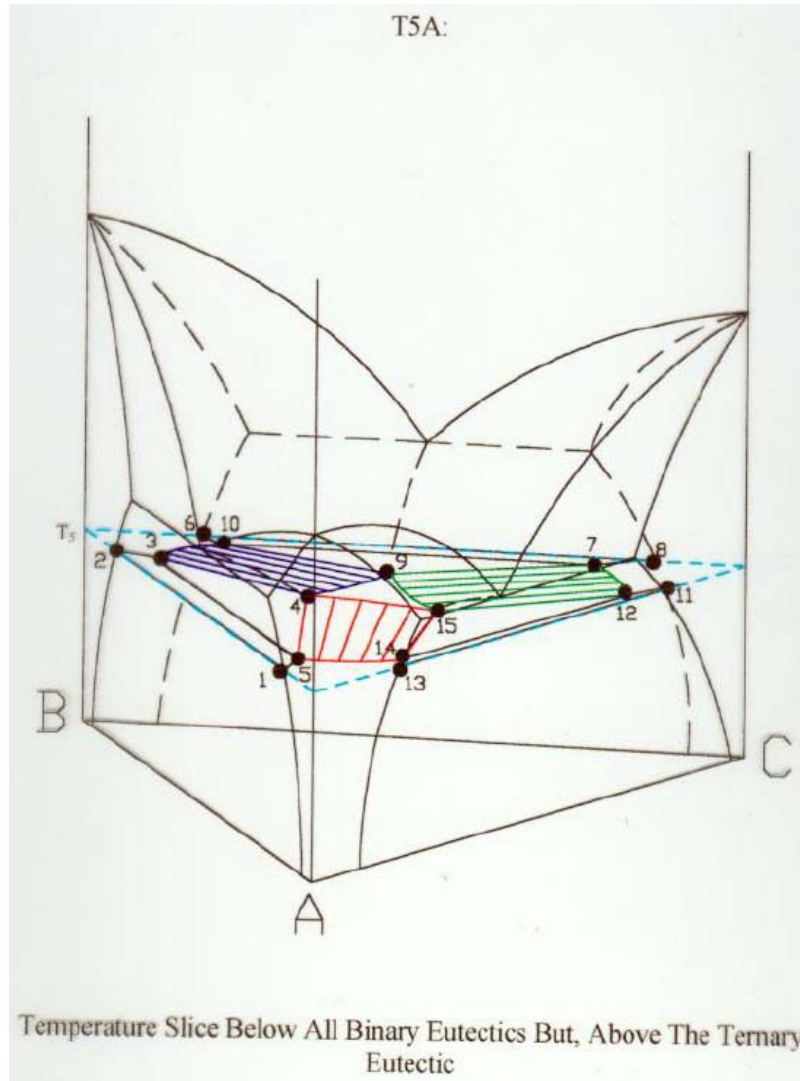


Isothermal Section At $T = T_3$

Ternary Eutectic System (with Solid Solubility)

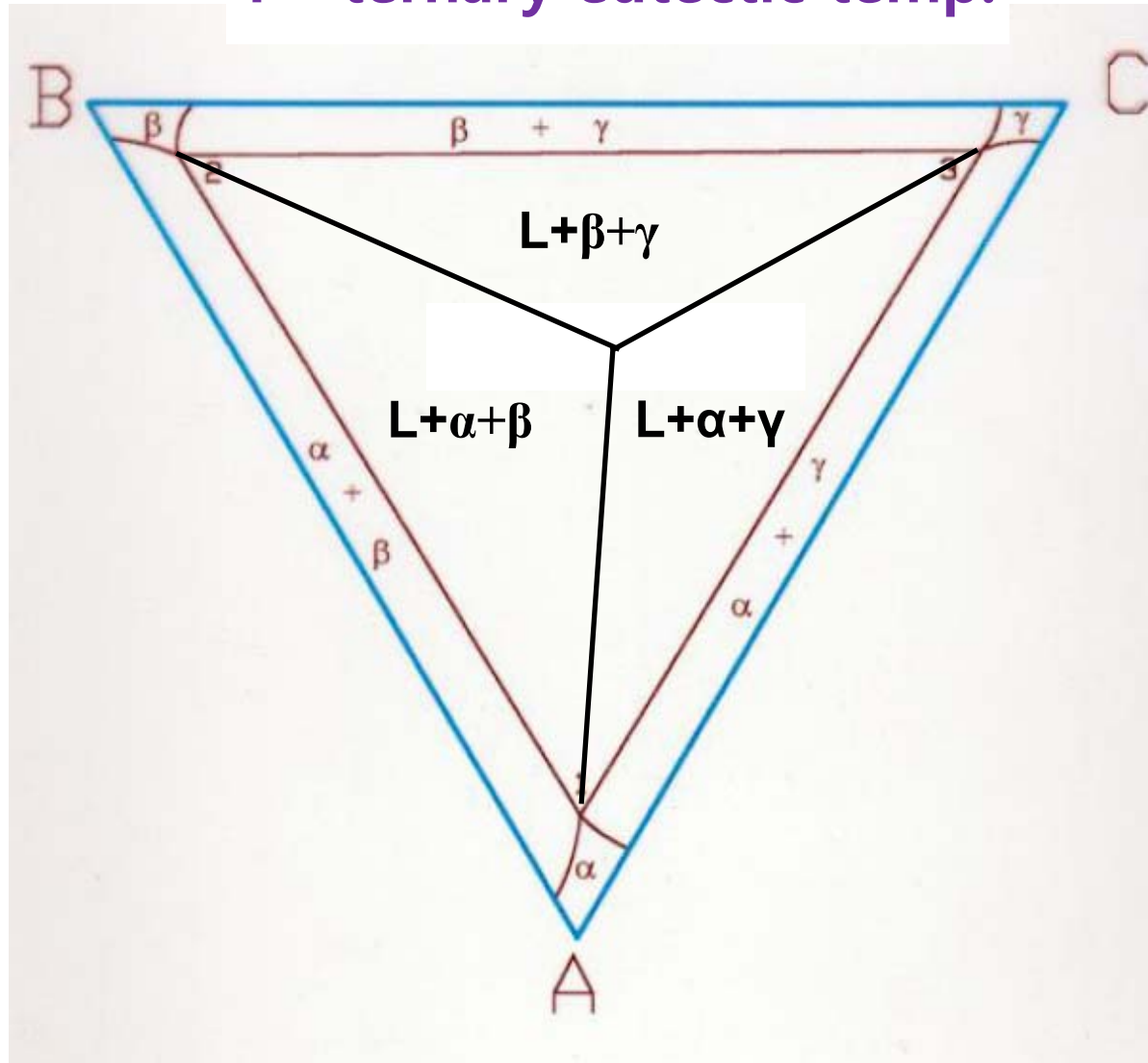


Ternary Eutectic System (with Solid Solubility)

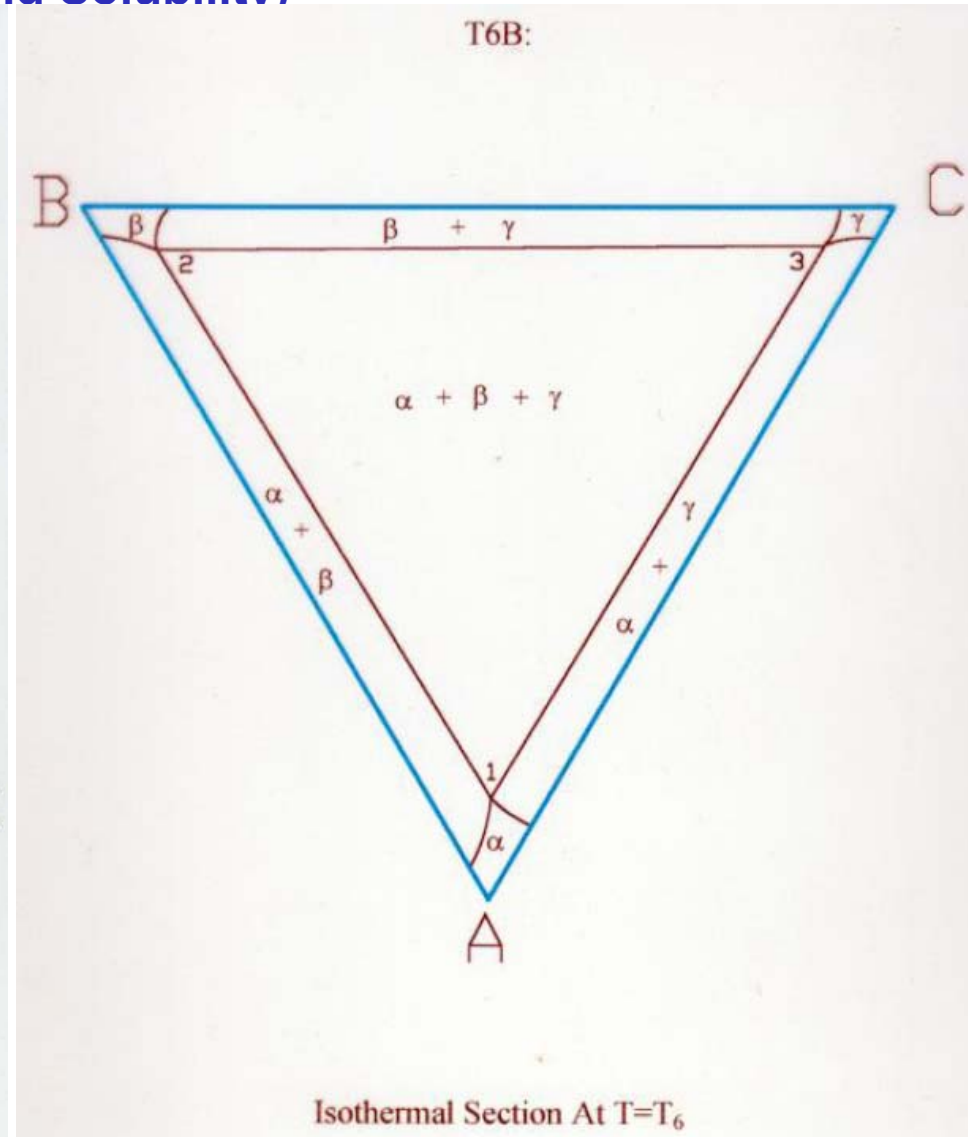
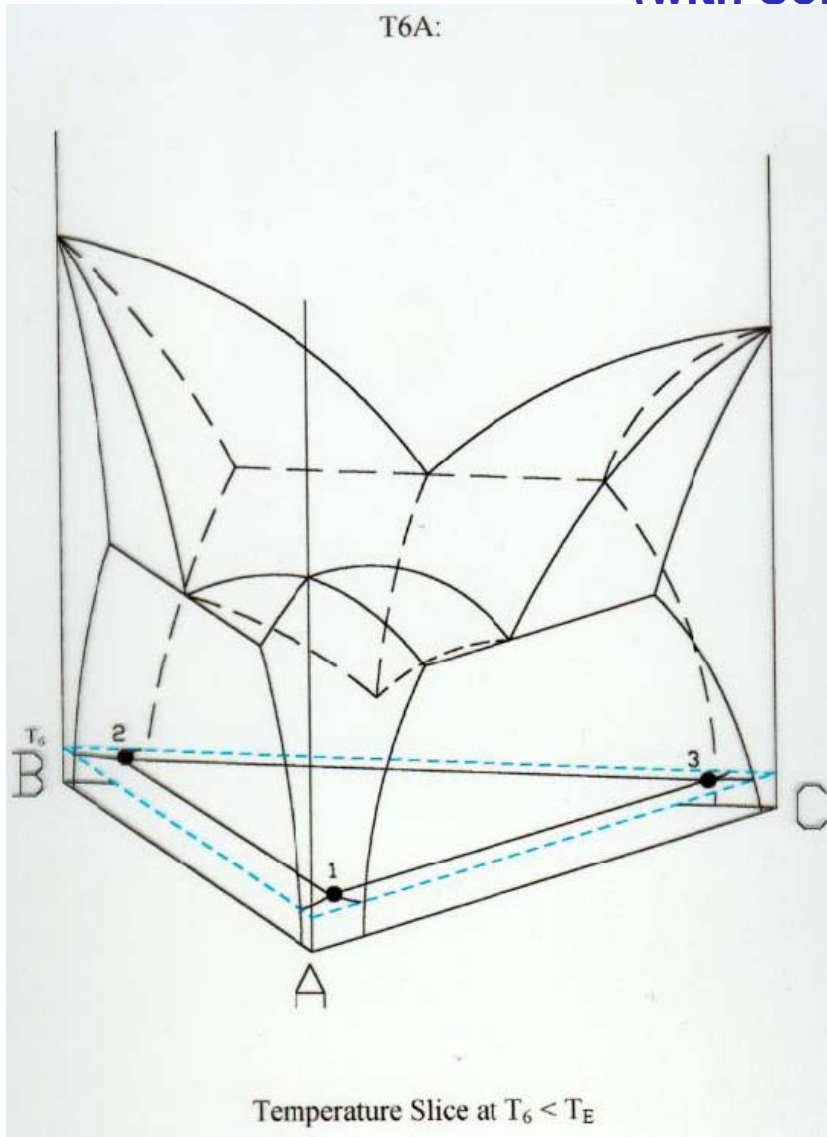


Ternary Eutectic System (with Solid Solubility)

T = ternary eutectic temp.

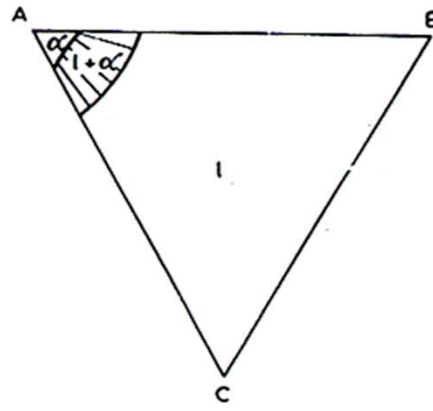


Ternary Eutectic System (with Solid Solubility)

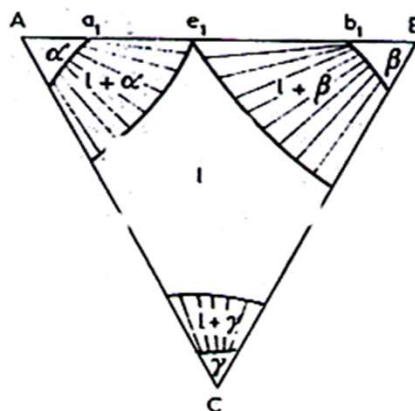


10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

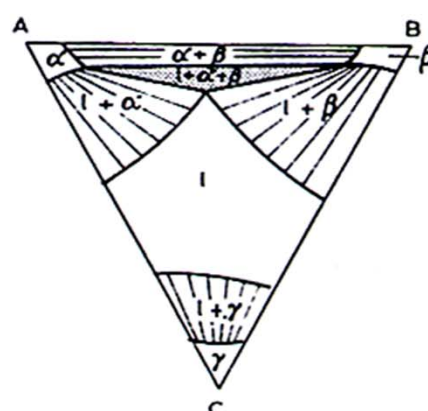
- Isothermal section ($T_A > T > T_B$)



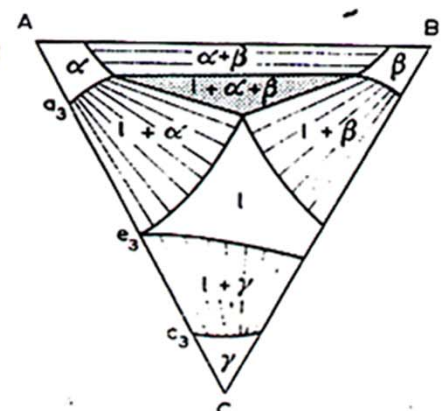
(a) $T_A > T > T_B$



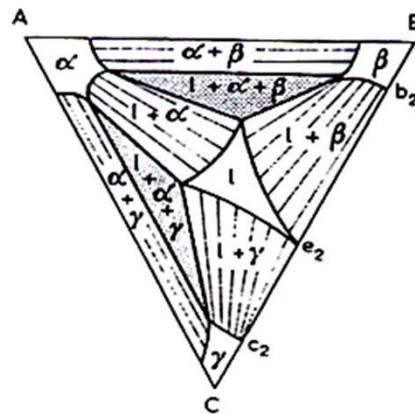
(b) $T = e_1$



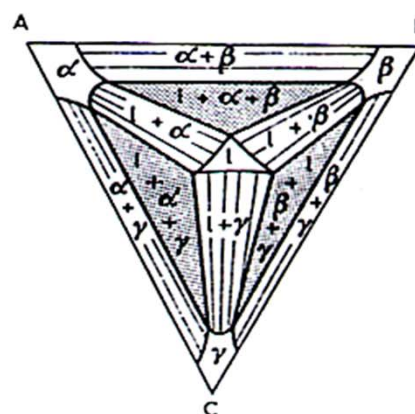
(c) $e_1 > T > e_3$



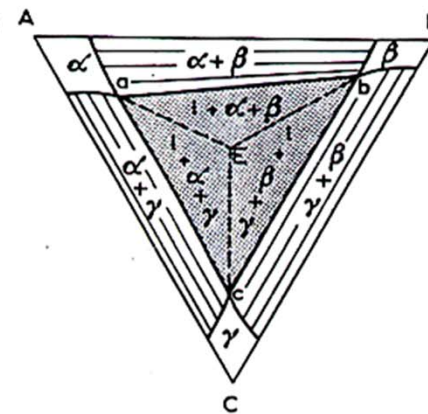
(d) $T = e_3$



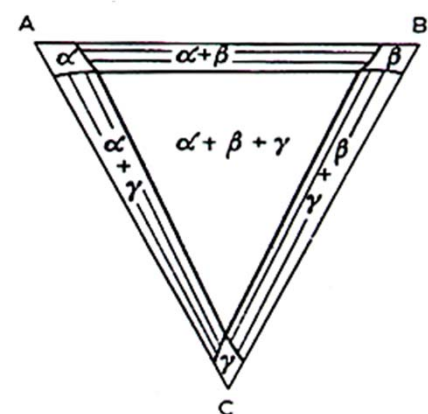
(e) $T = e_2$



(f) $e_2 > T > E$



(g) $T_A = E$



(h) $E = T$

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

Vertical section Location of vertical section

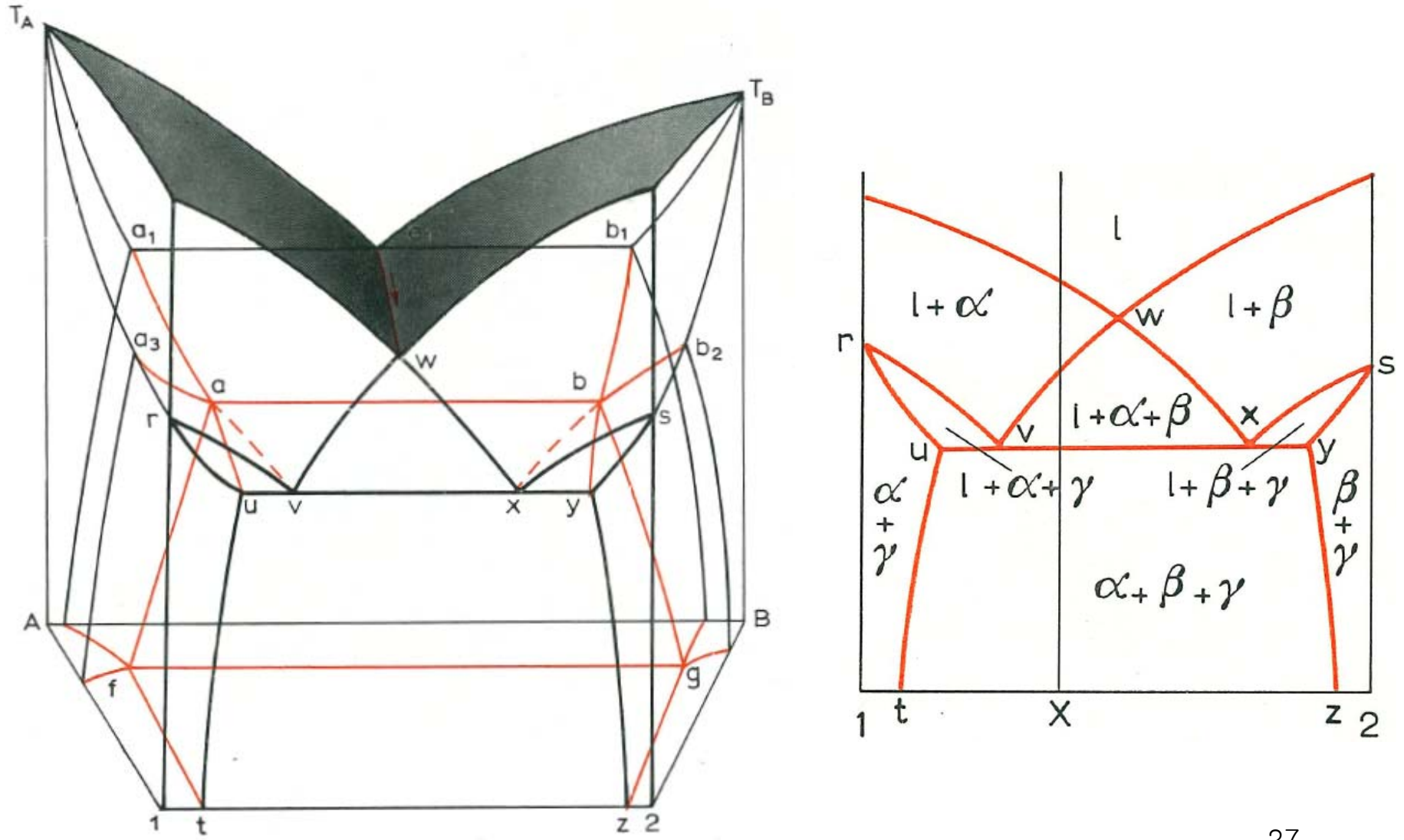


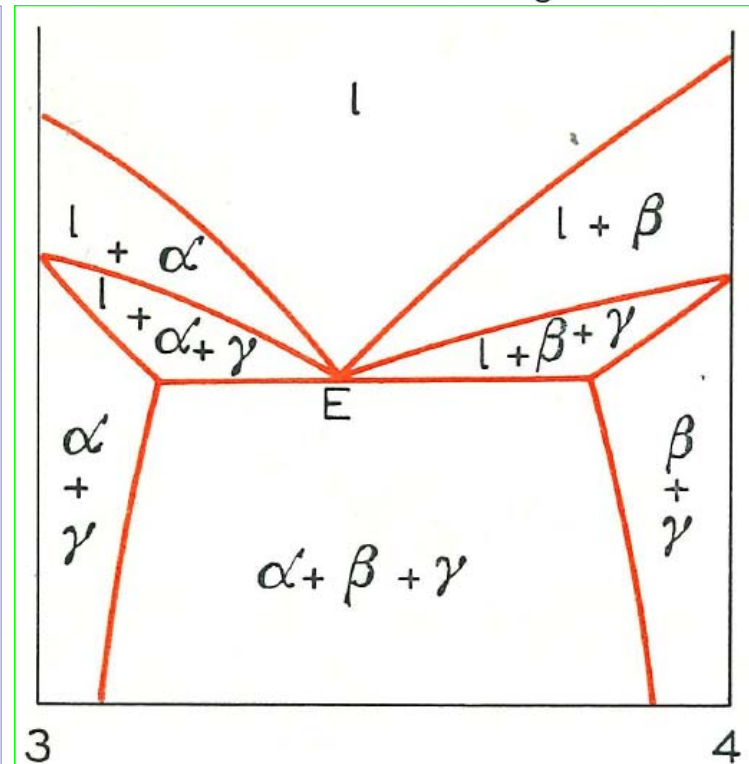
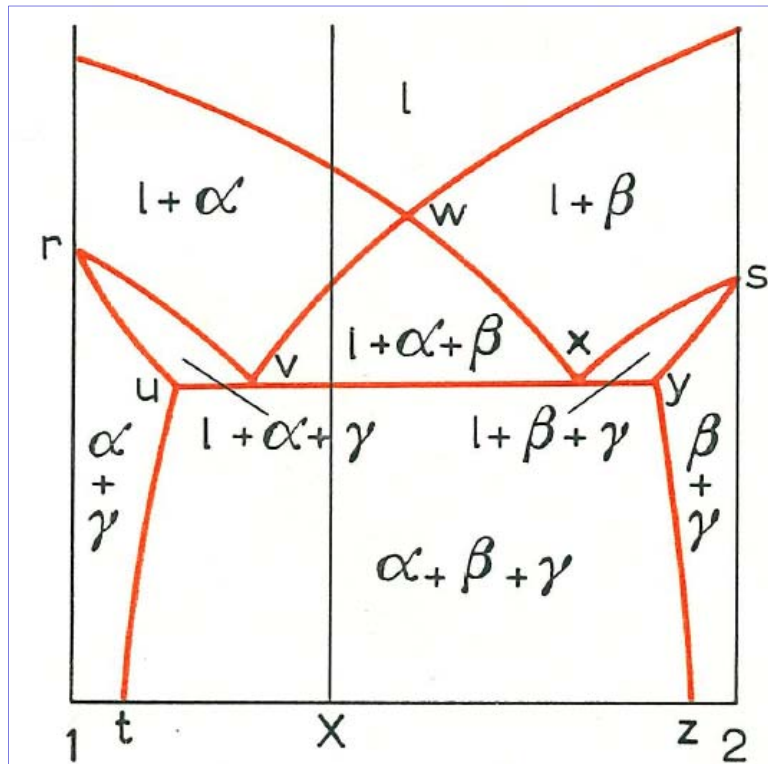
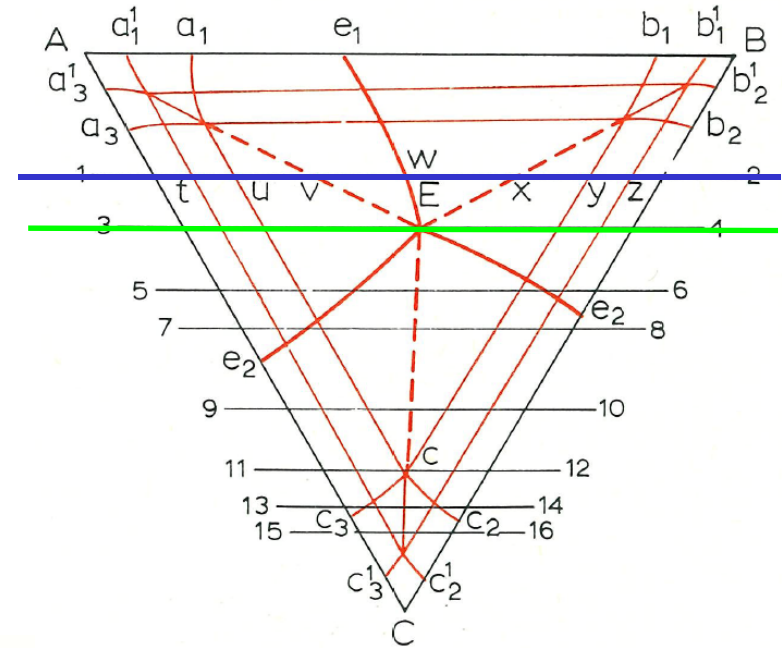
Fig. 179. Construction of vertical section 1-2.

10.1. THE EUTECTIC EQUILIBRIUM

$$(l = \alpha + \beta + \gamma)$$

Vertical section

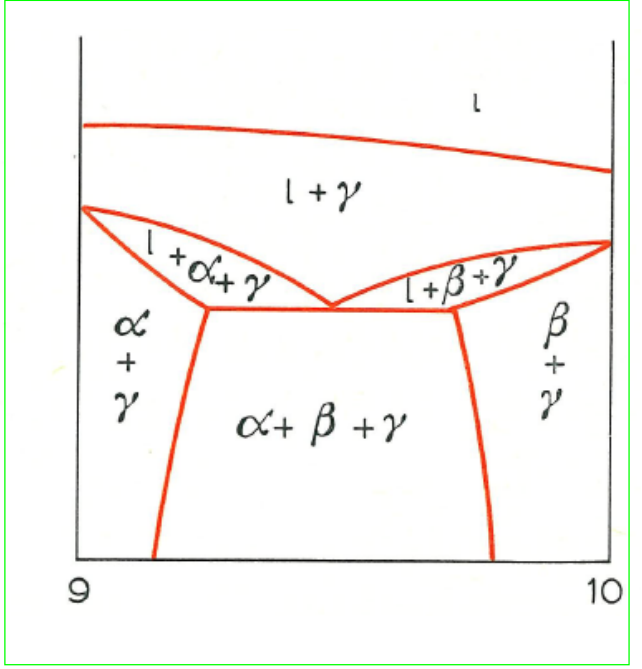
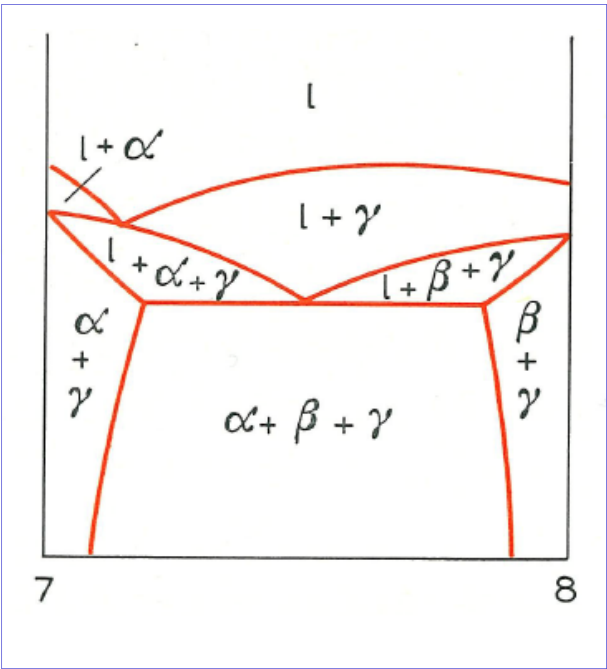
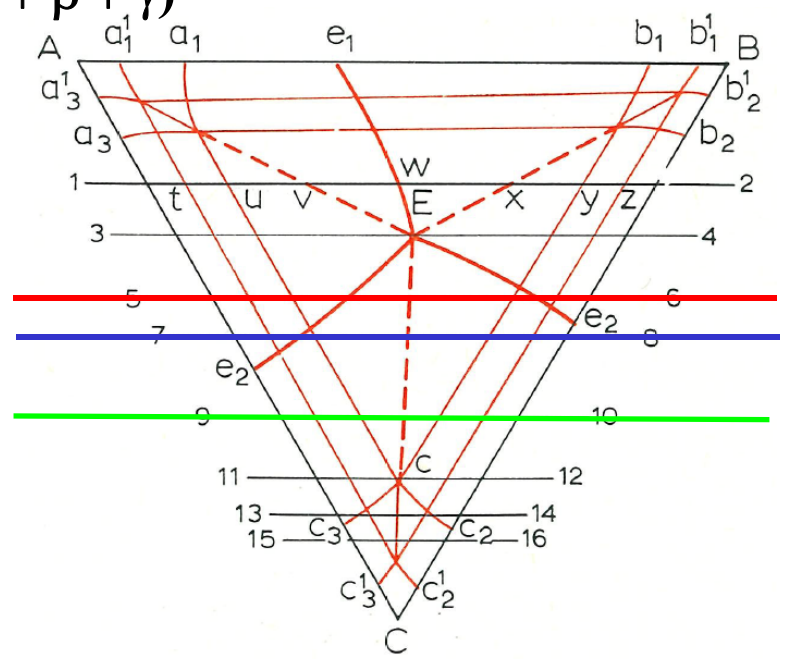
Location of vertical section



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

Vertical section

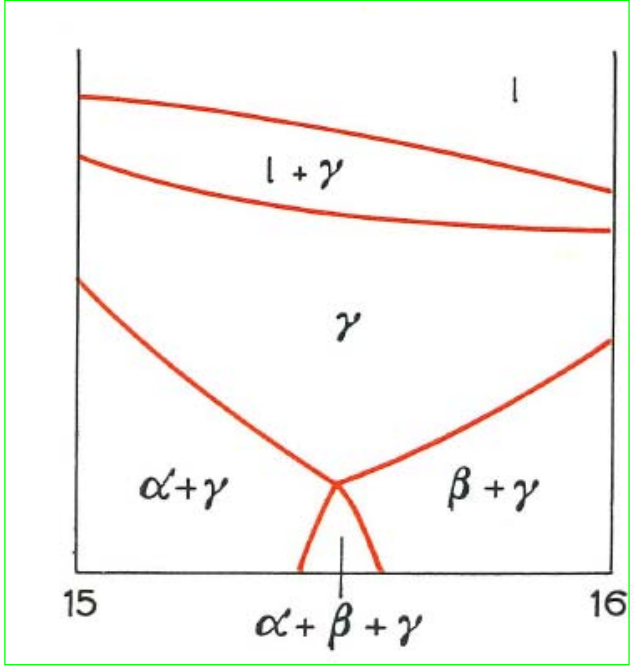
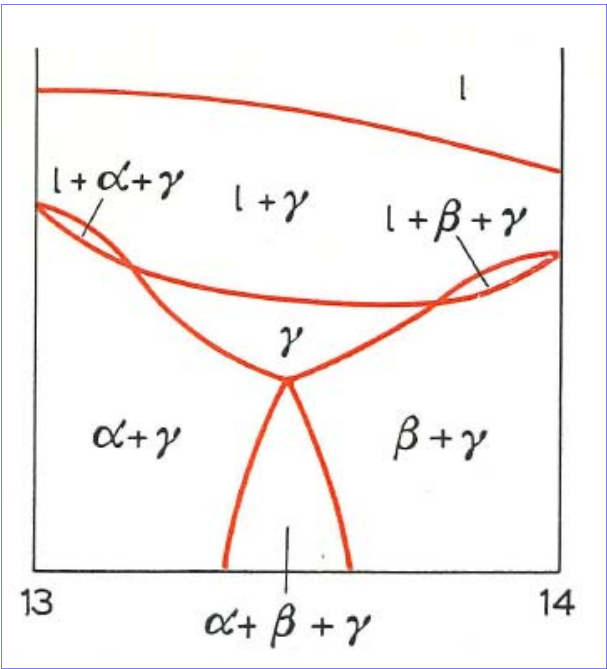
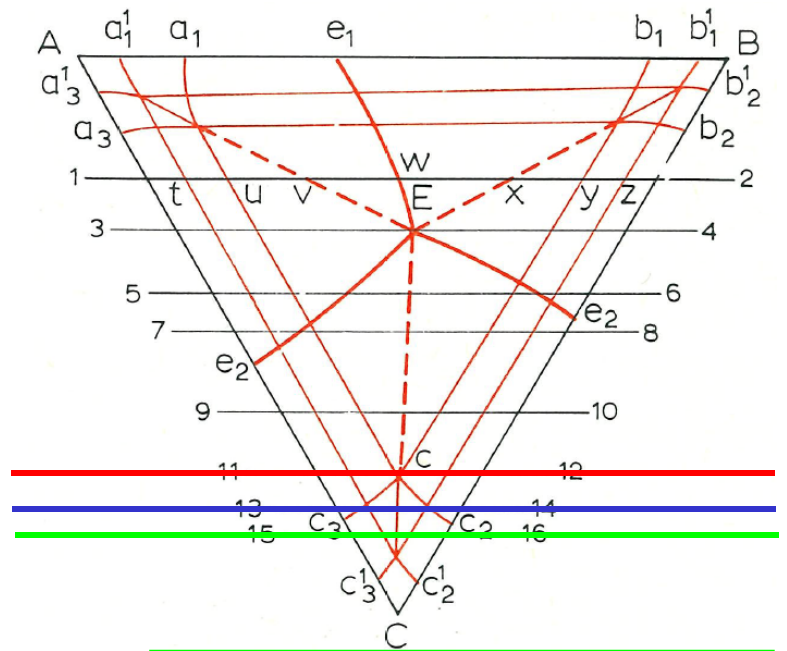
Location of vertical section



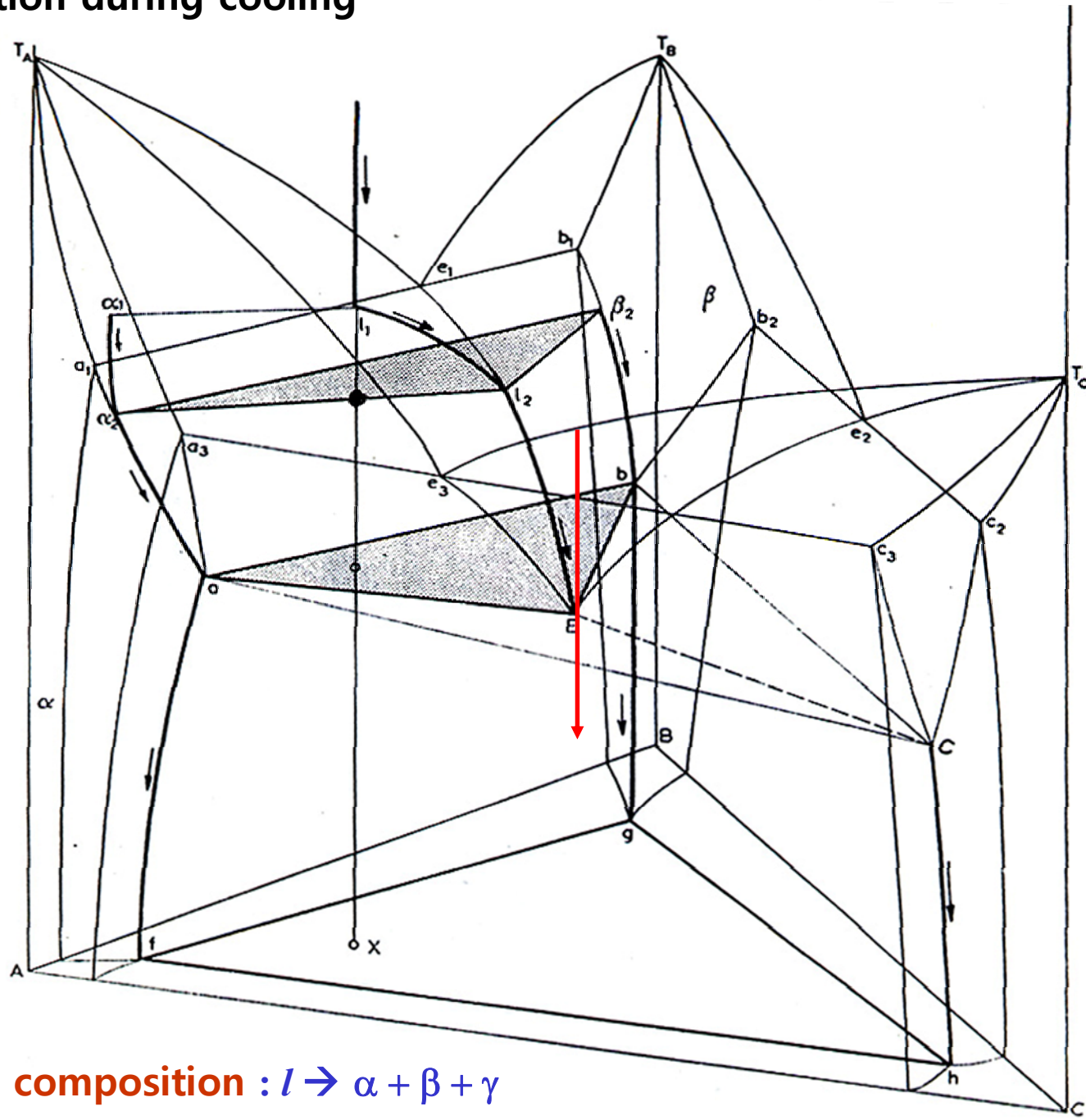
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section

Location of vertical section



Transformation during cooling



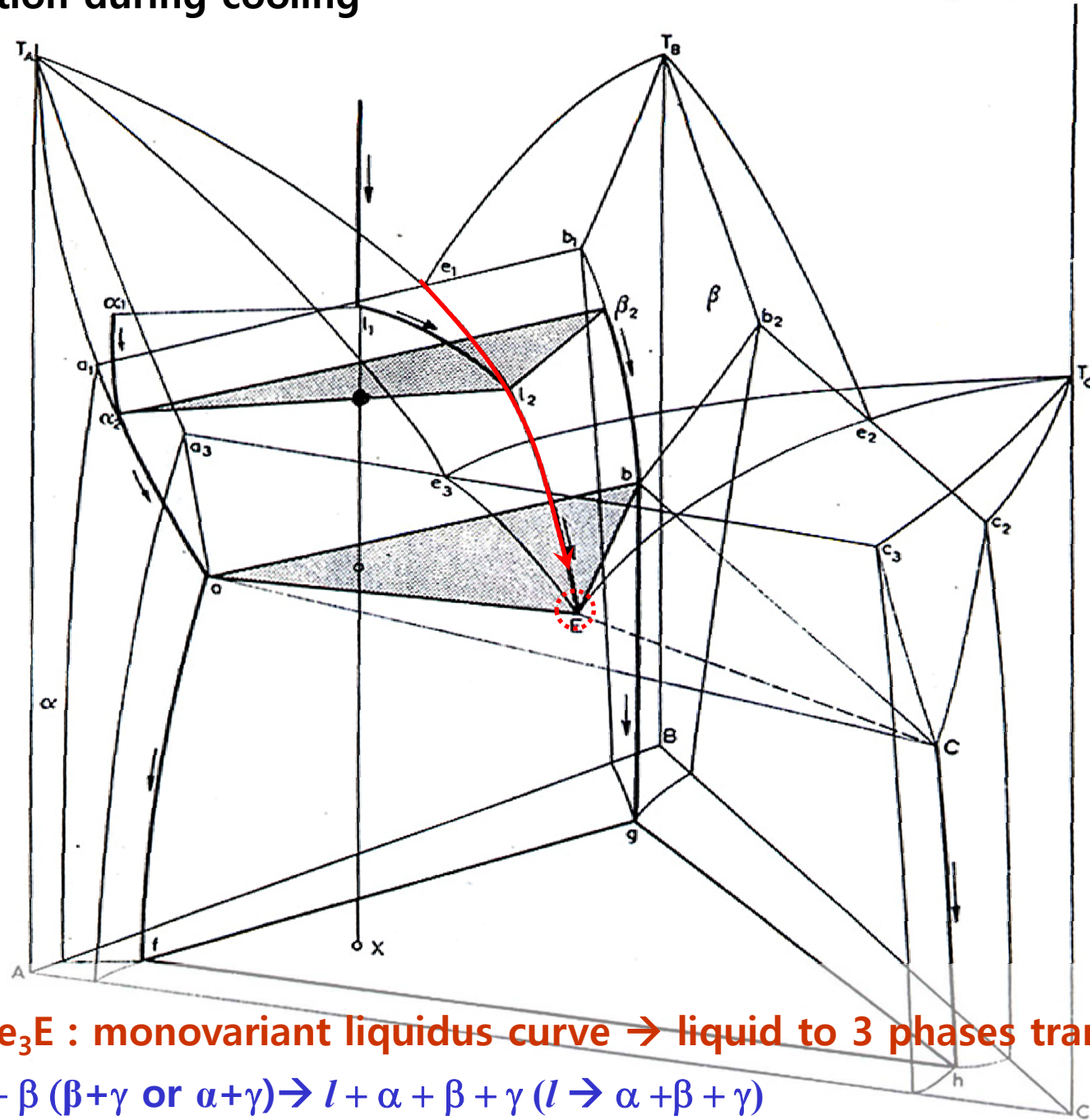
① Eutectic composition : $l \rightarrow \alpha + \beta + \gamma$

Ternary Eutectic microstructure



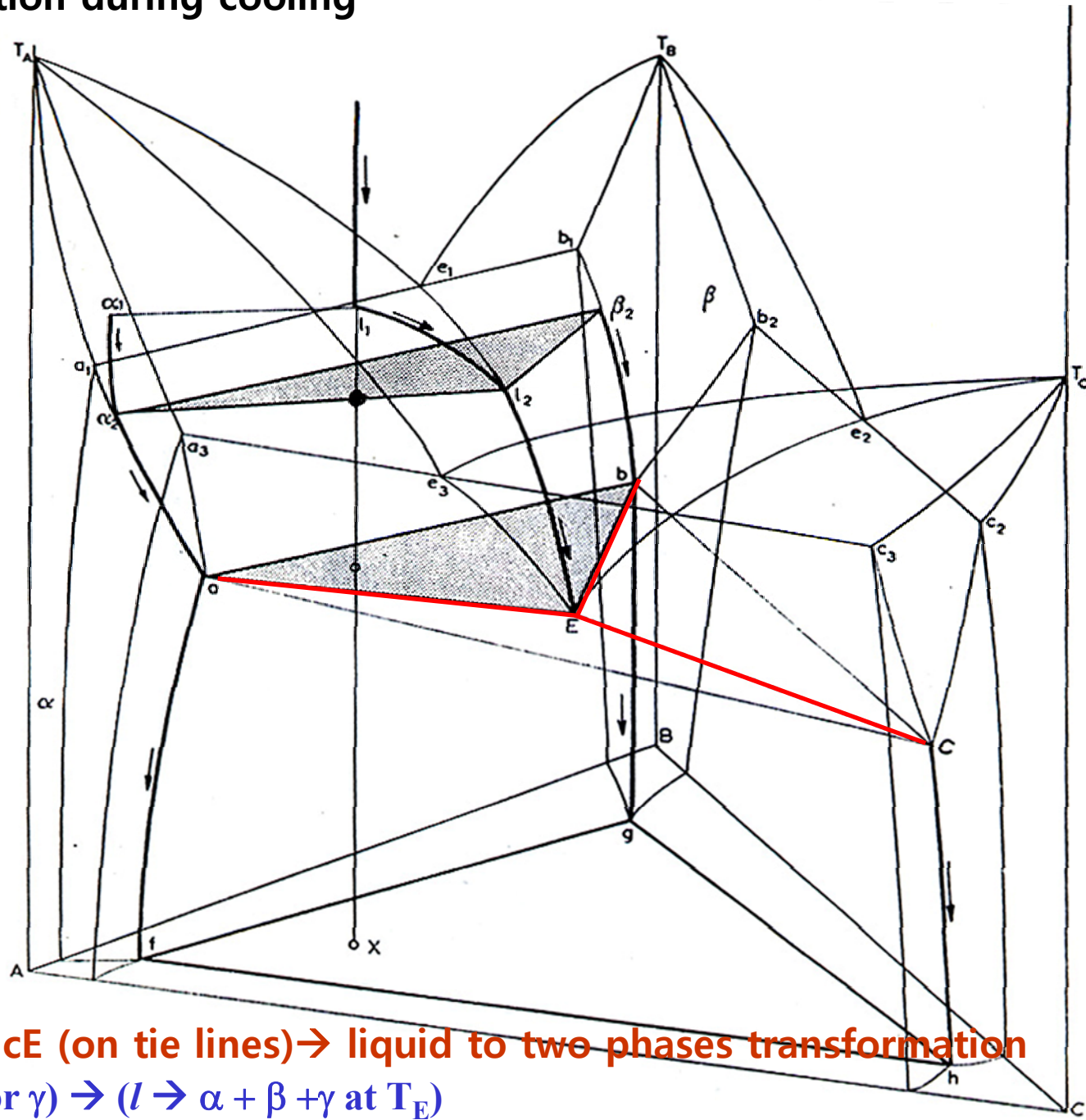
Microstructure of the ternary eutectic in the Al-Cu-Si system. α light, θ dark, Si grey, (x 900) 32

Transformation during cooling



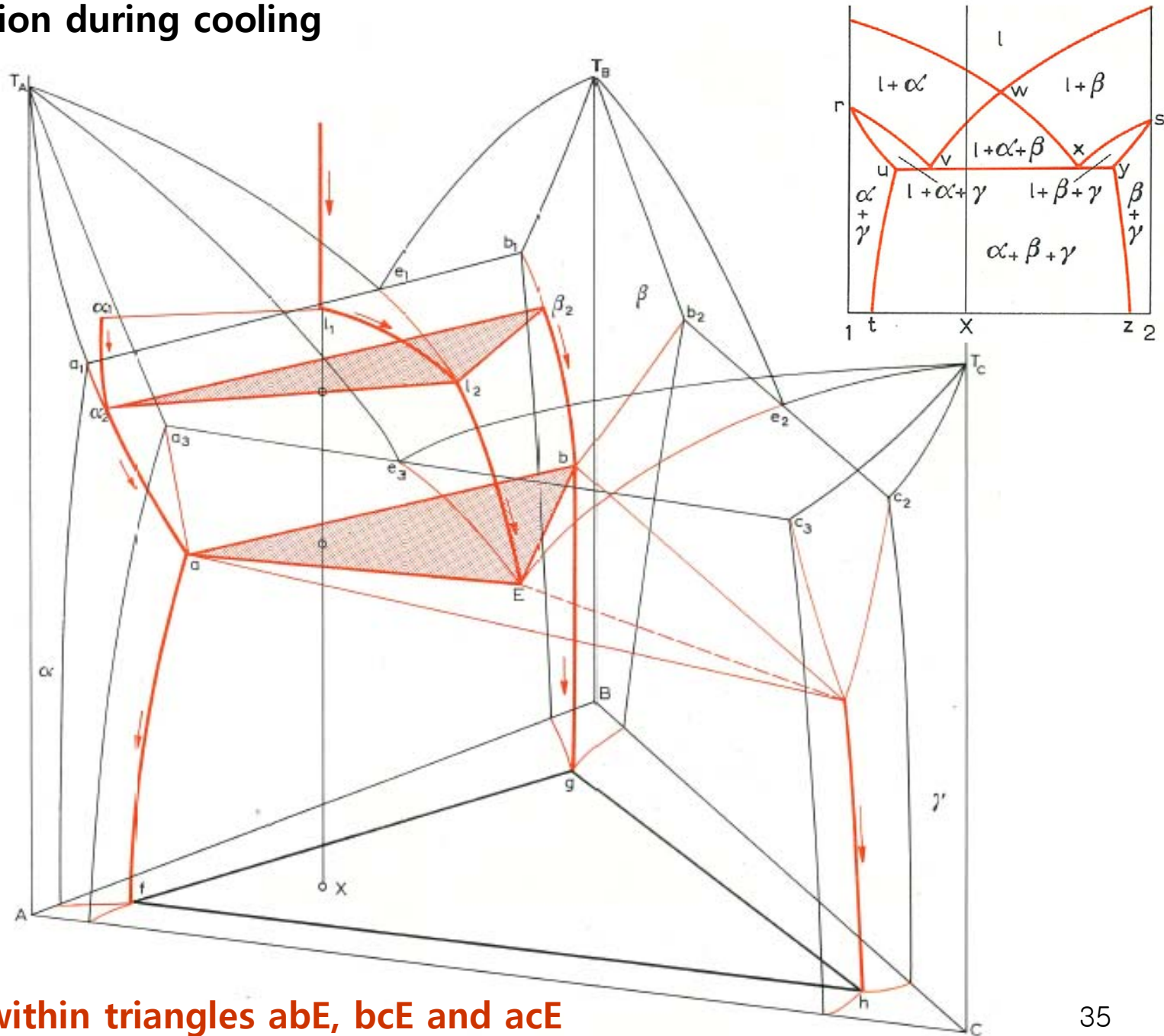
② e_1E, e_2E, e_3E : monovariant liquidus curve \rightarrow liquid to 3 phases transformation
 $: l \rightarrow l + \alpha + \beta$ ($\beta + \gamma$ or $\alpha + \gamma$) $\rightarrow l + \alpha + \beta + \gamma$ ($l \rightarrow \alpha + \beta + \gamma$)

Transformation during cooling



③ aE, bE, cE (on tie lines) → liquid to two phases transformation
 : $l + \alpha (\beta \text{ or } \gamma) \rightarrow (l \rightarrow \alpha + \beta + \gamma \text{ at } T_E)$

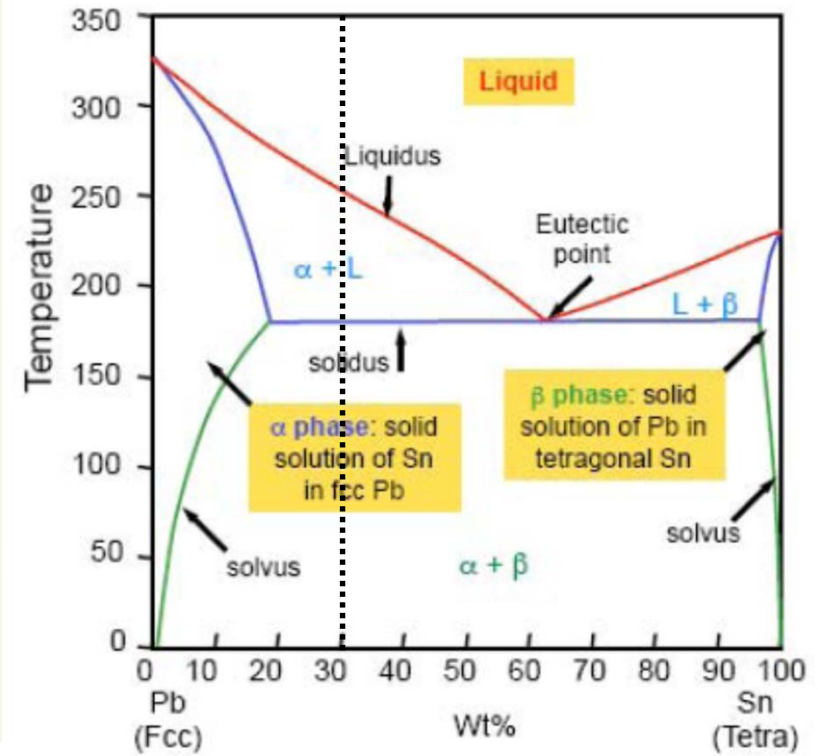
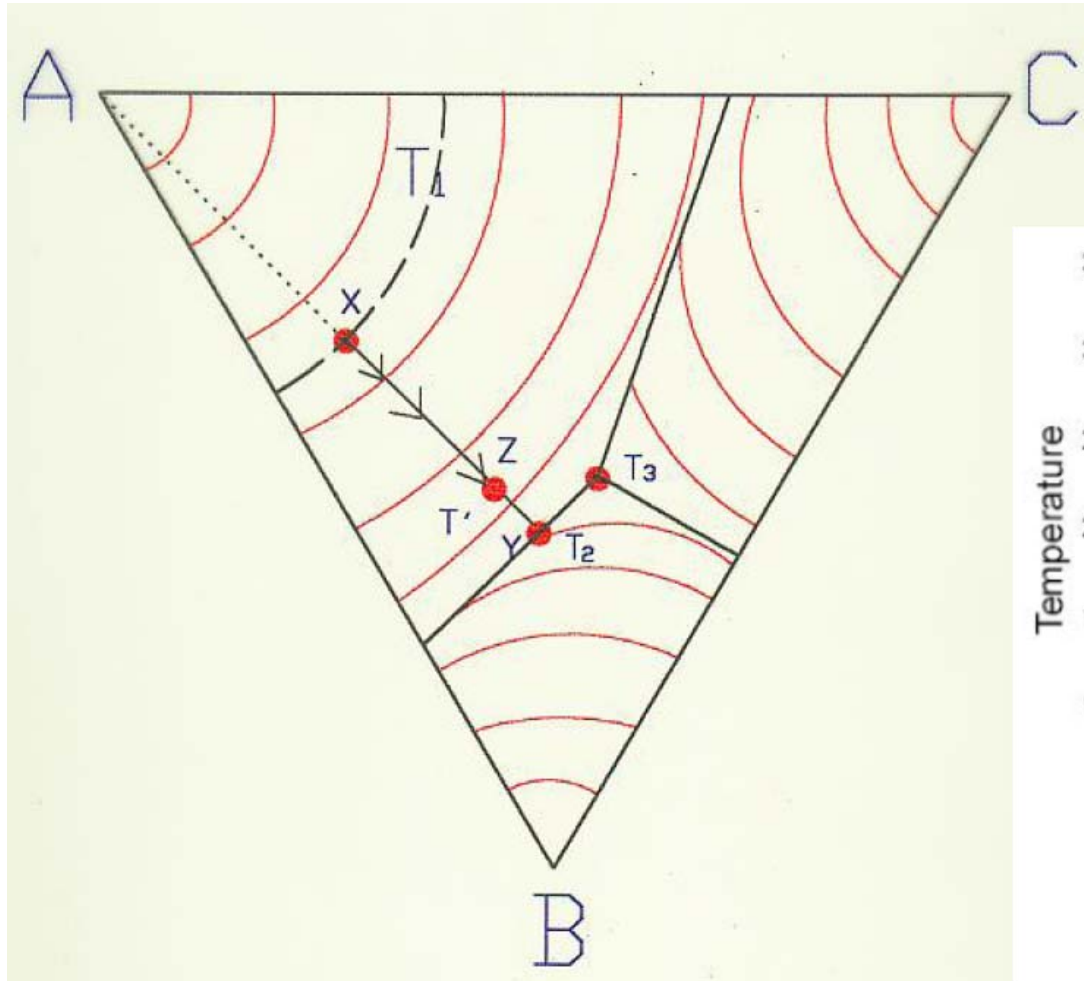
Transformation during cooling



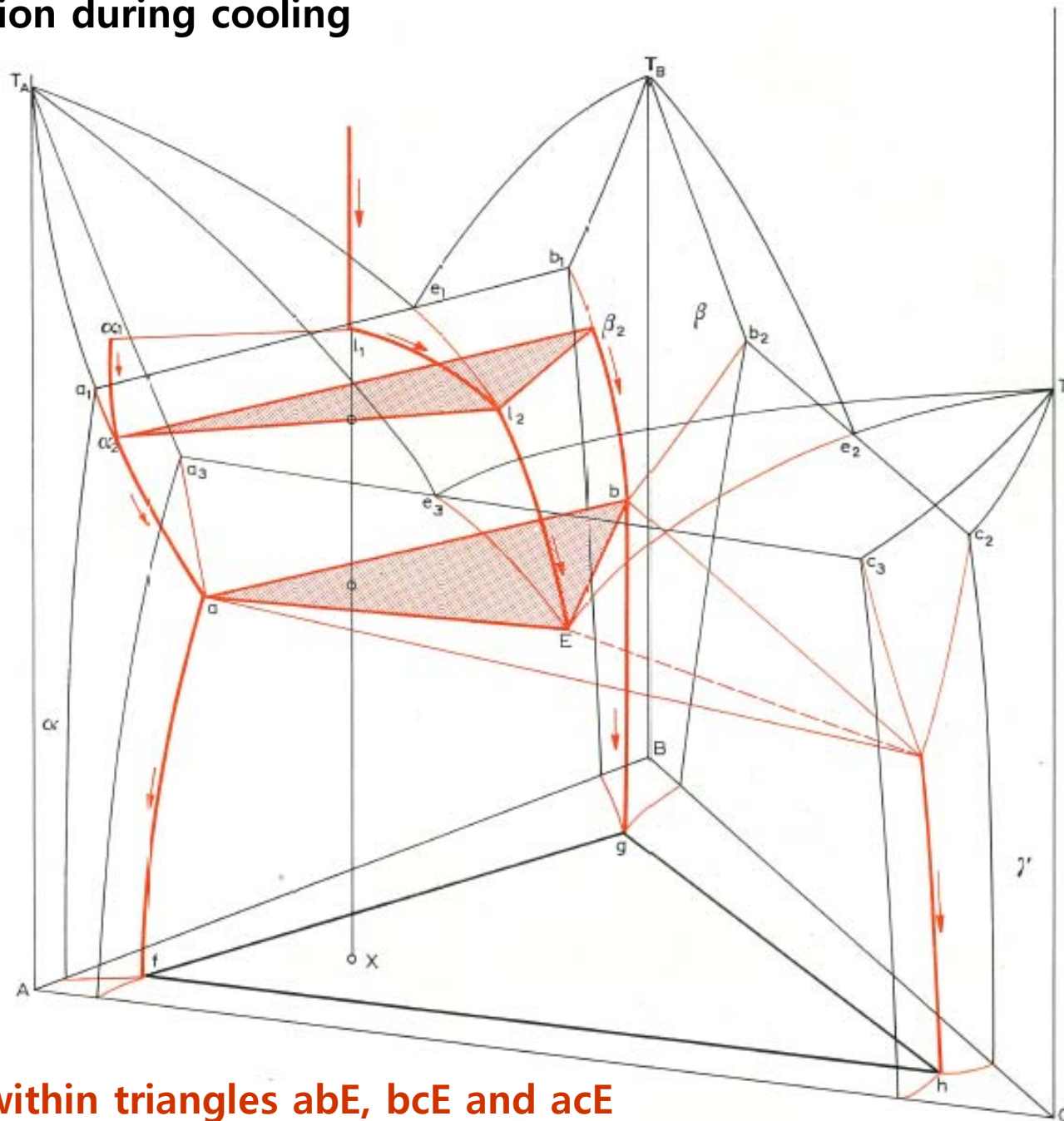
- ④ Alloys within triangles abE, bcE and acE
 ex) abE: $l + \alpha$ (or β) \rightarrow $l + \alpha + \beta \rightarrow (l \rightarrow \alpha + \beta + \gamma$ at T_E)

Ternary Eutectic System

Solidification Sequence



Transformation during cooling



- ④ Alloys within triangles abE , bcE and acE
 ex) abE : $l + \alpha$ (or β) \rightarrow $l + \alpha + \beta \rightarrow (l \rightarrow \alpha + \beta + \gamma$ at T_E)