2021 Spring

"Phase Equilibria *in* Materials"

04.20.2021

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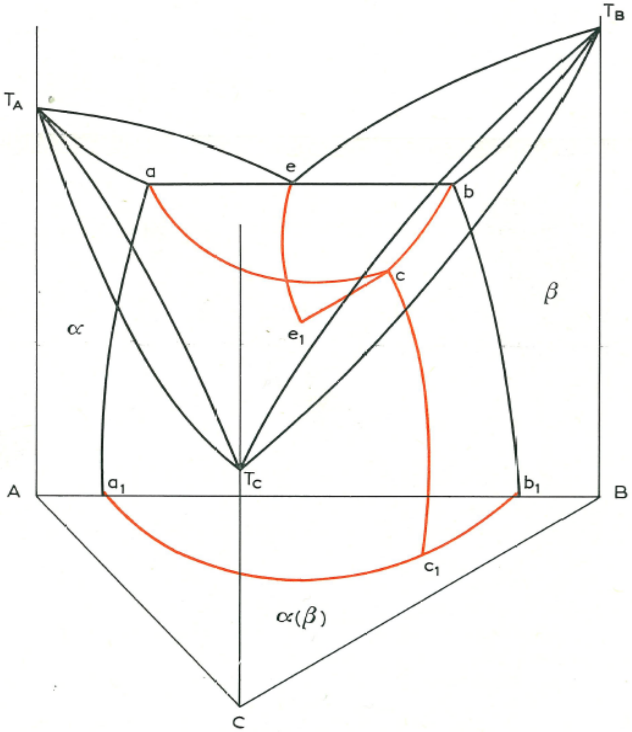
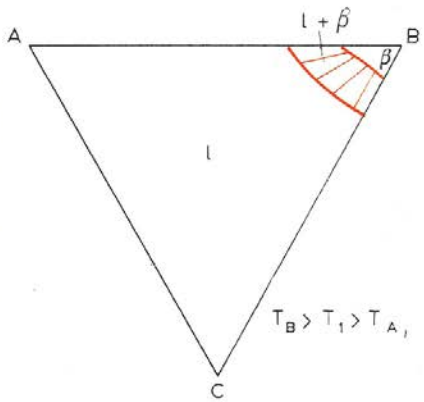
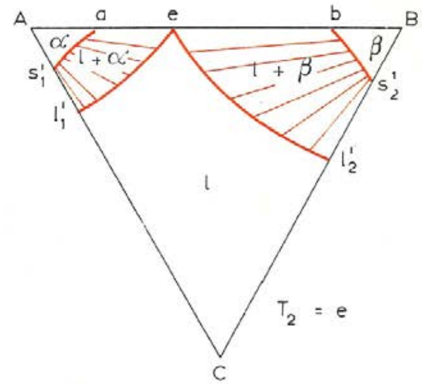
9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Isothermal section**

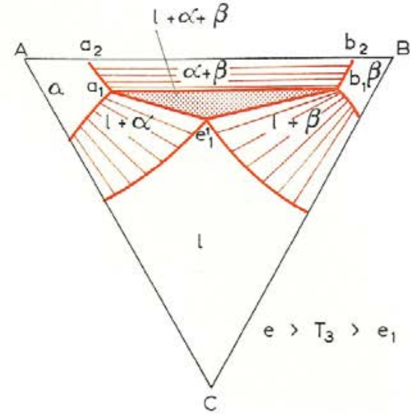




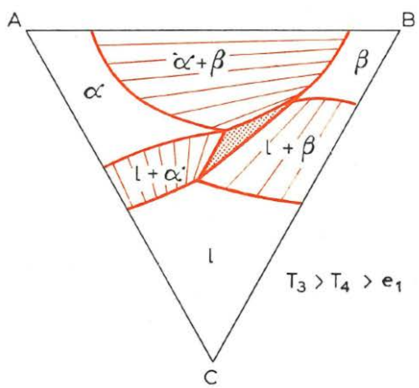
$T_B > T_1 > T_A$



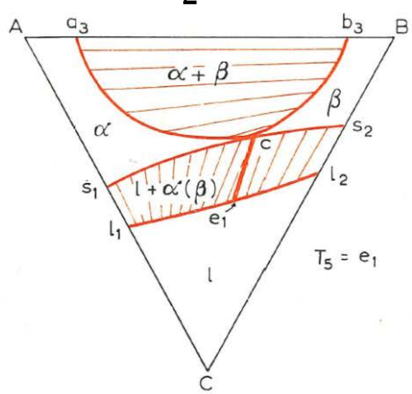
$T_2 = e$



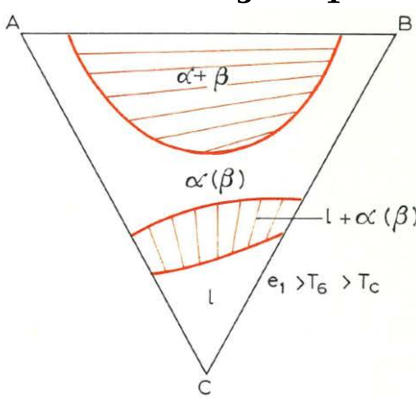
$e > T_3 > e_1$



$T_3 > T_4 > e_1$



$T_5 = e$

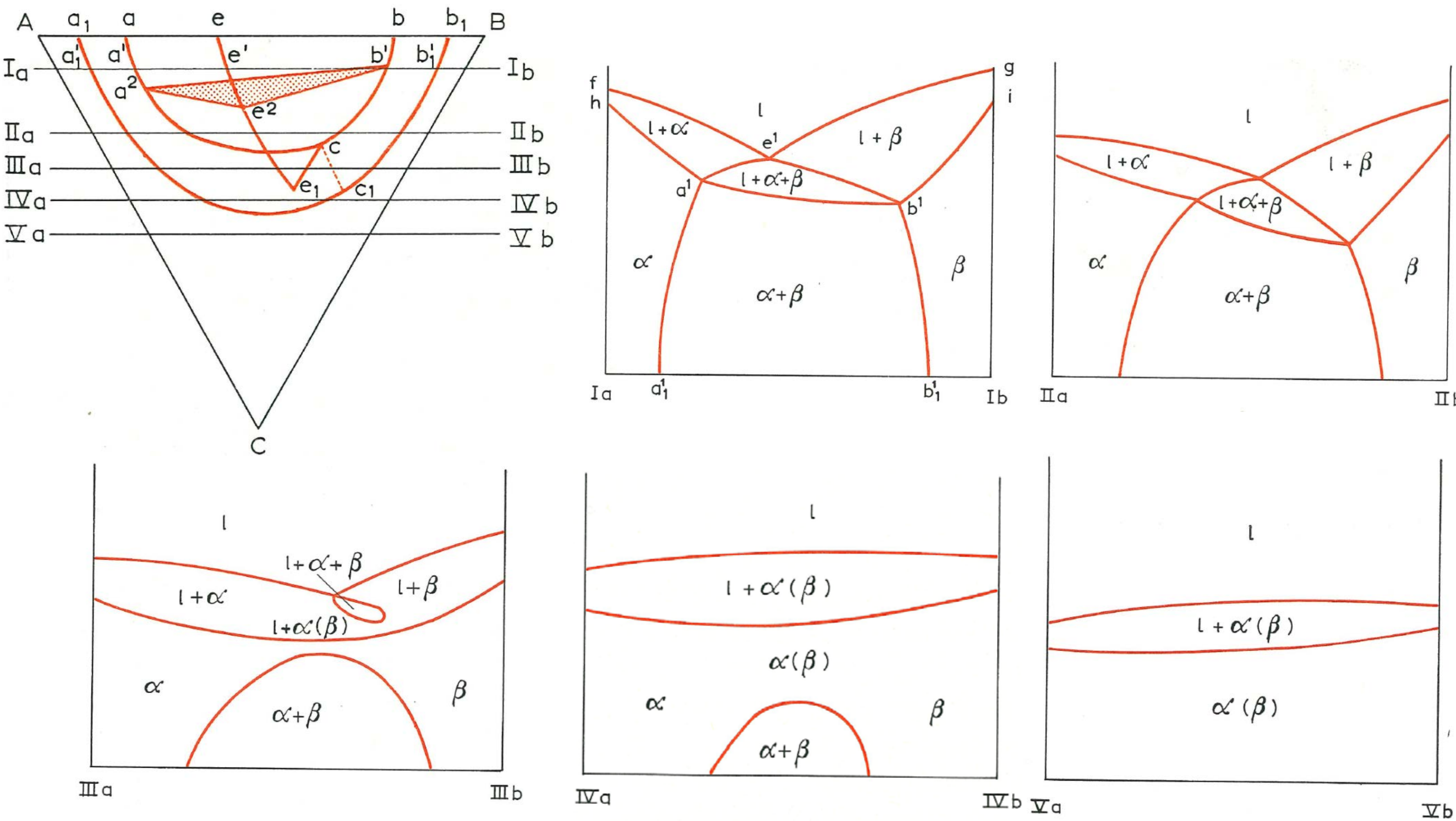


$e_1 > T_6 > T_c$

cf) Movie

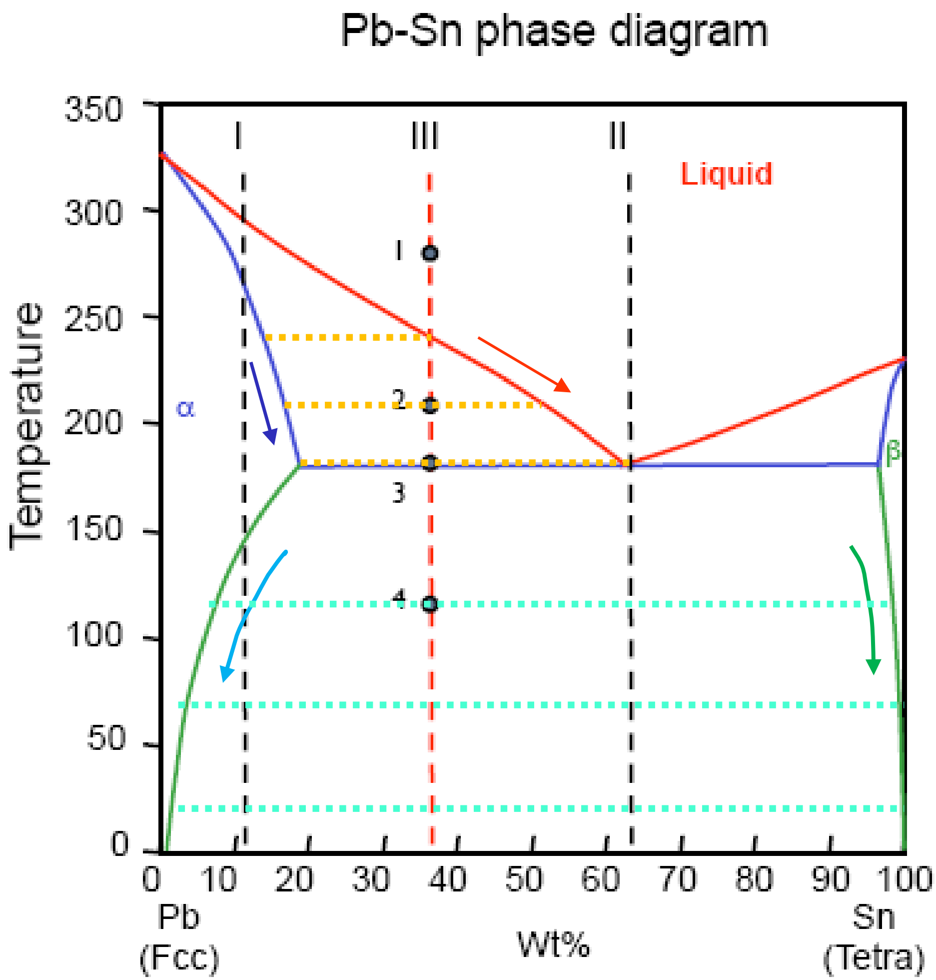
9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

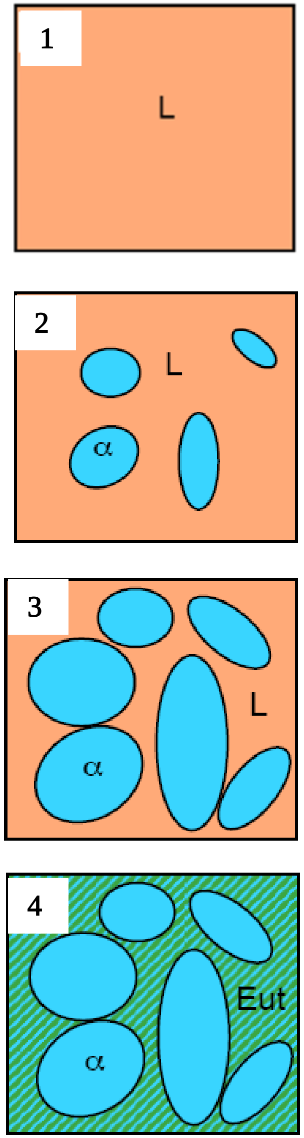
- **Vertical section**



1.5 Binary phase diagrams

Alloy III





> **Point 1: 4 on the α solidus surface**

> **Point 1- Point 2**

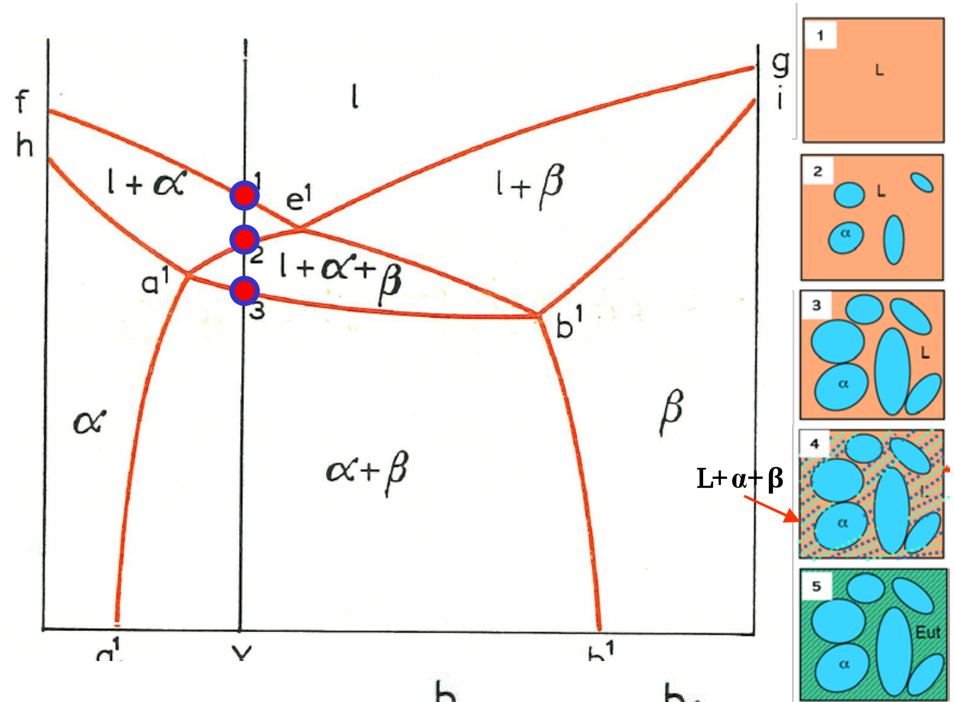
- **4→6 on the α solidus surface**
- **1→5 on the α liquidus surface**

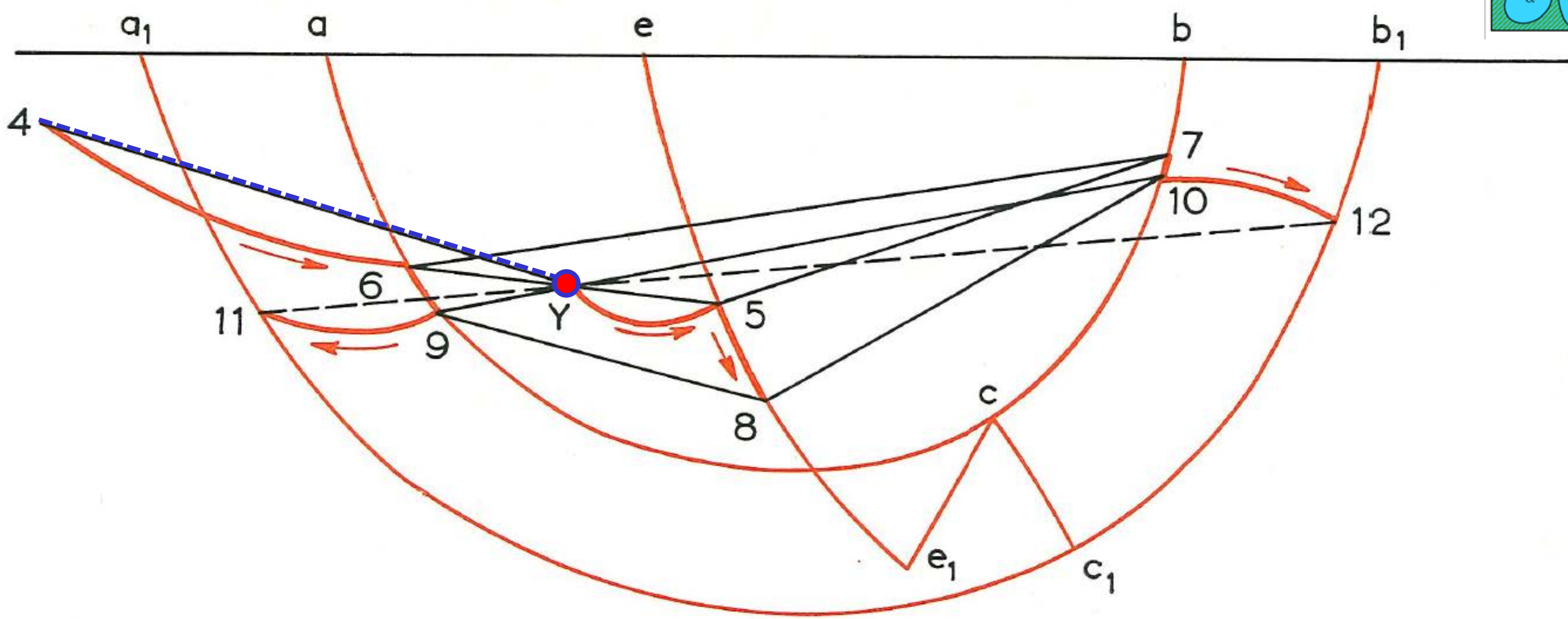
Three phase equilibrium l5, α6, β7

- **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**





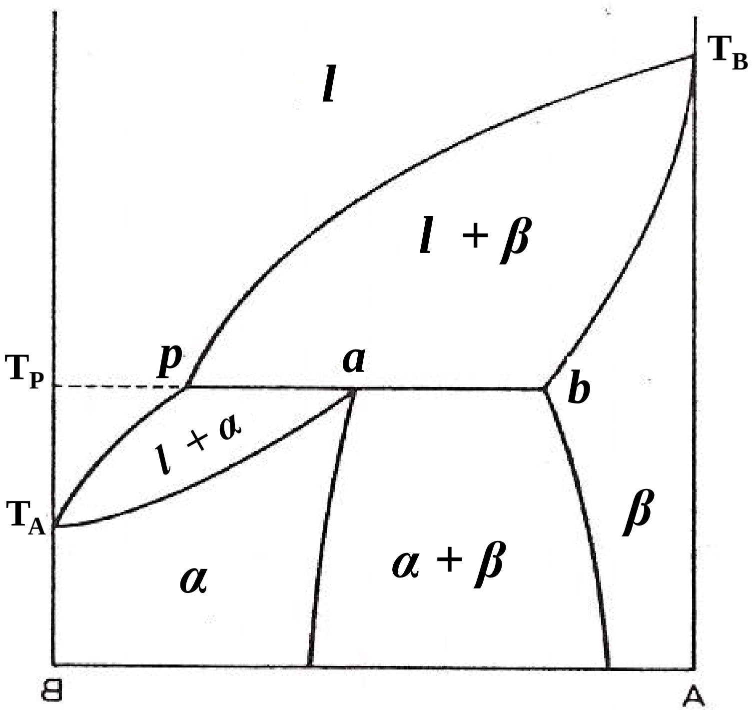
Projection of the solidification sequence for alloy Y on the concentration triangle

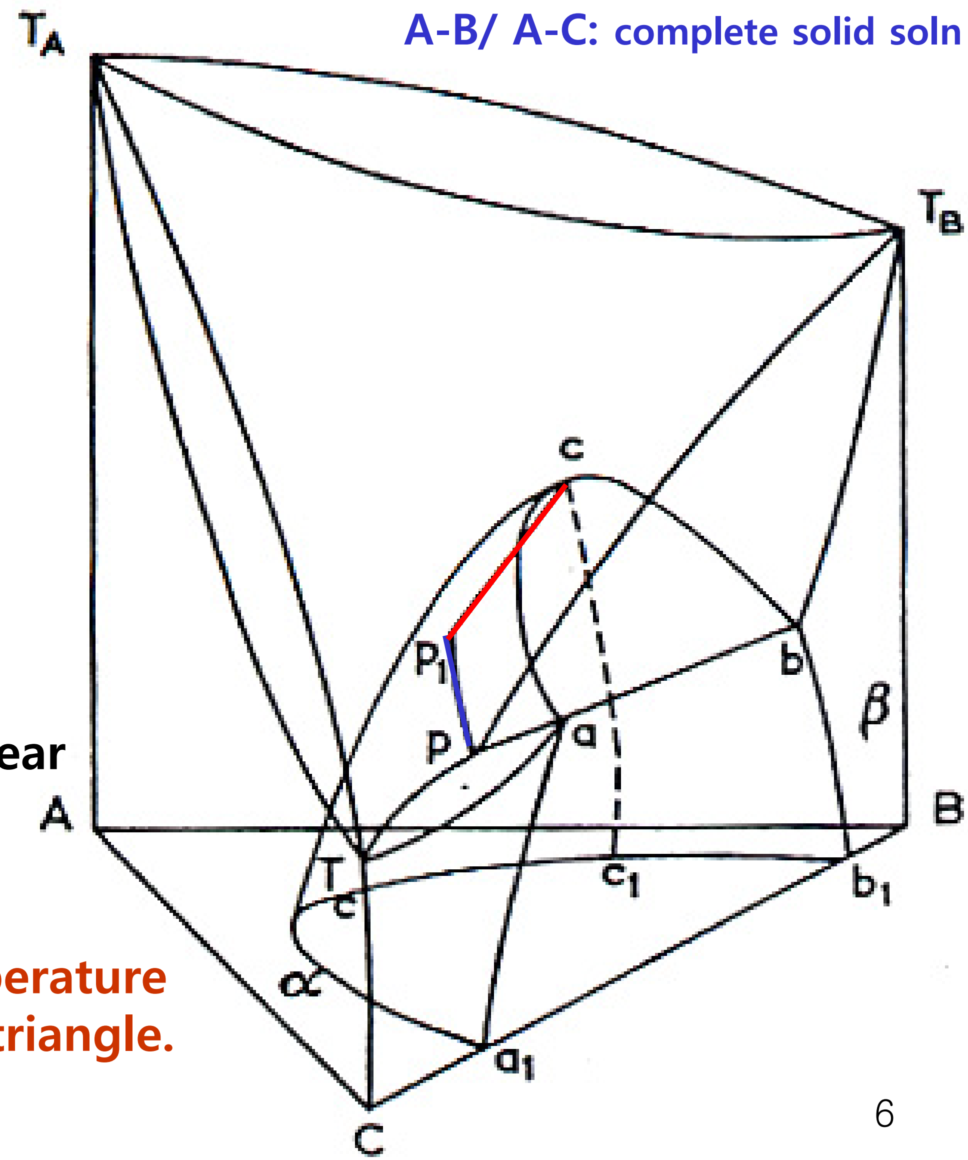
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A peritectic solubility gap in one binary system

B-C: peritectic

A-B/ A-C: complete solid soln





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

PP_1: monovariant curve for liquid

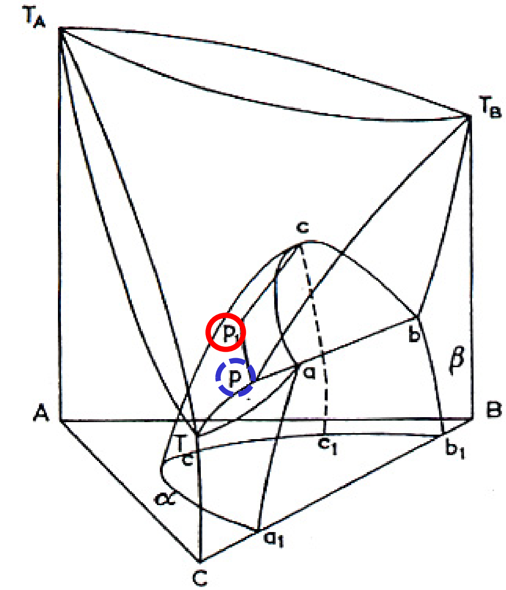
Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

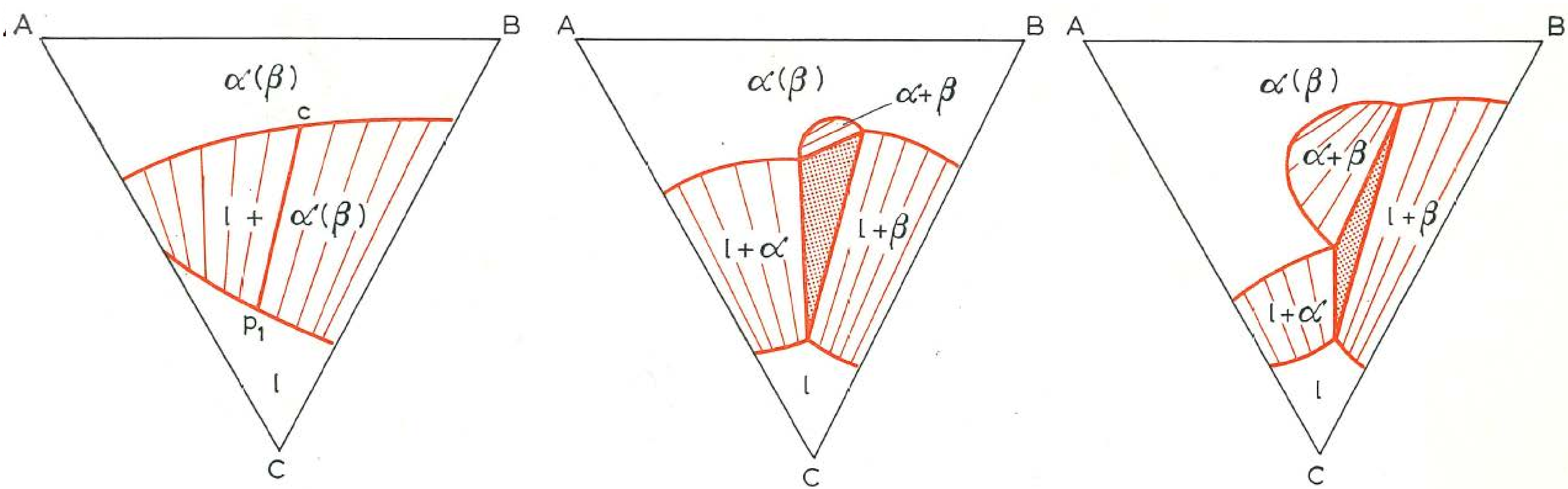
- **A peritectic solubility gap in one binary system**

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.



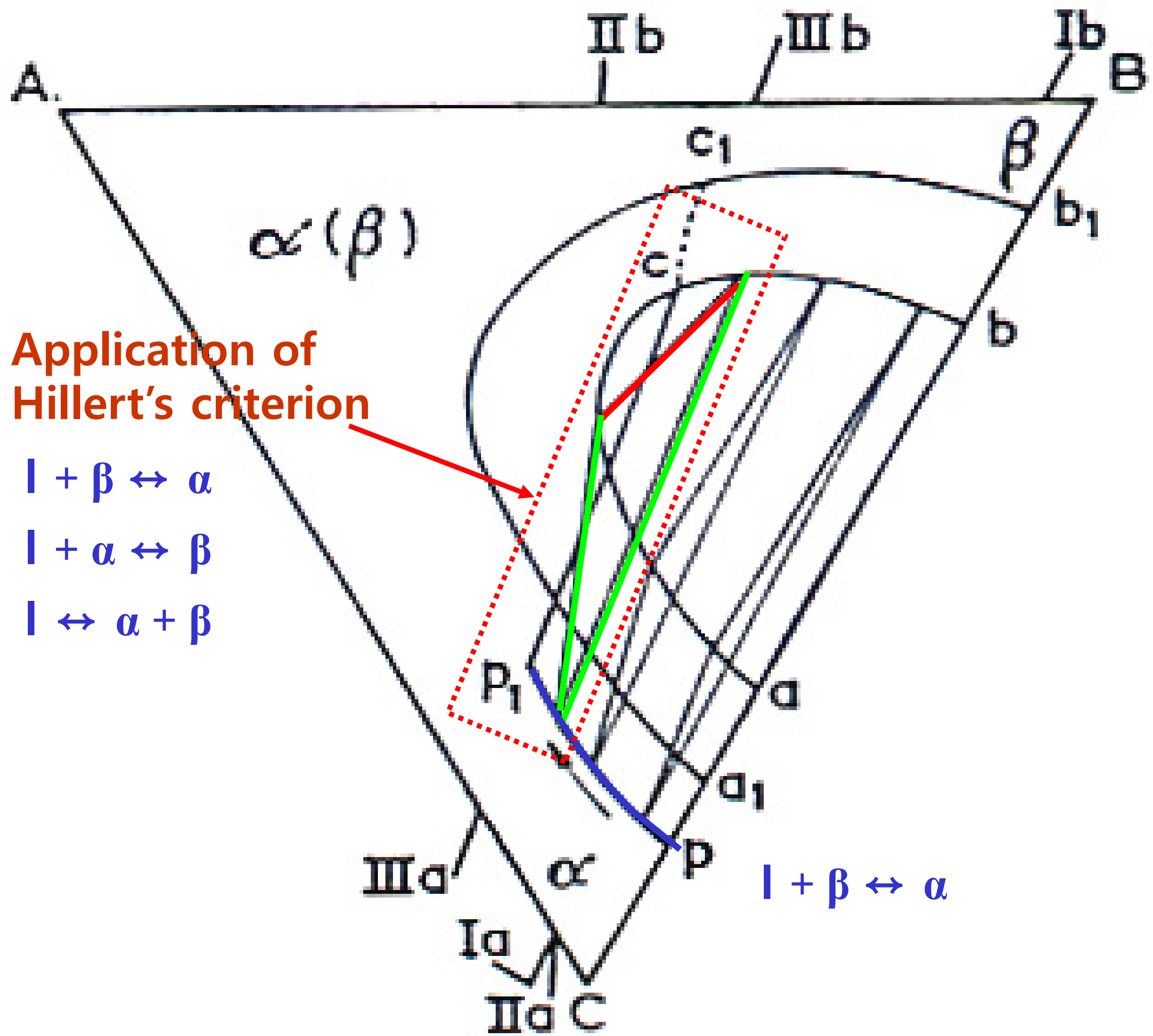
isothermal section



$T = P_1$ $\qquad$ $P_1 > T_1 > P$ $\qquad$ $T_1 > T_2 > P$

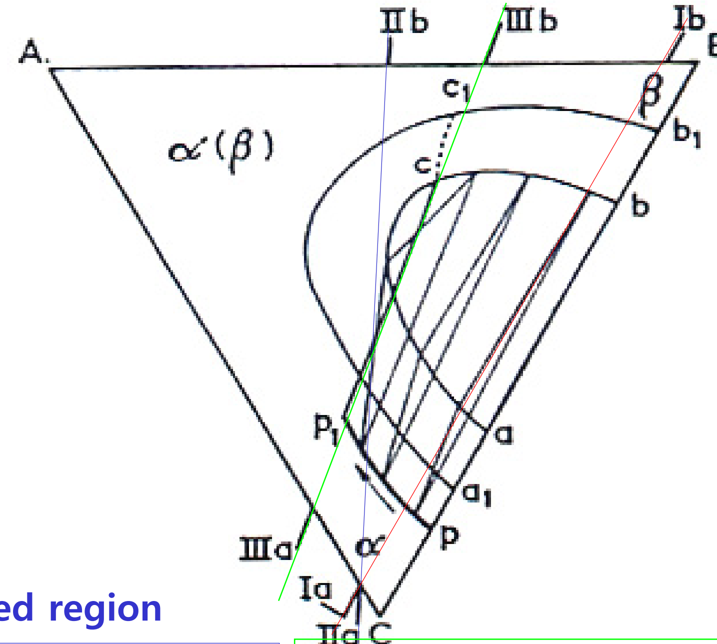
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A peritectic solubility gap in one binary system



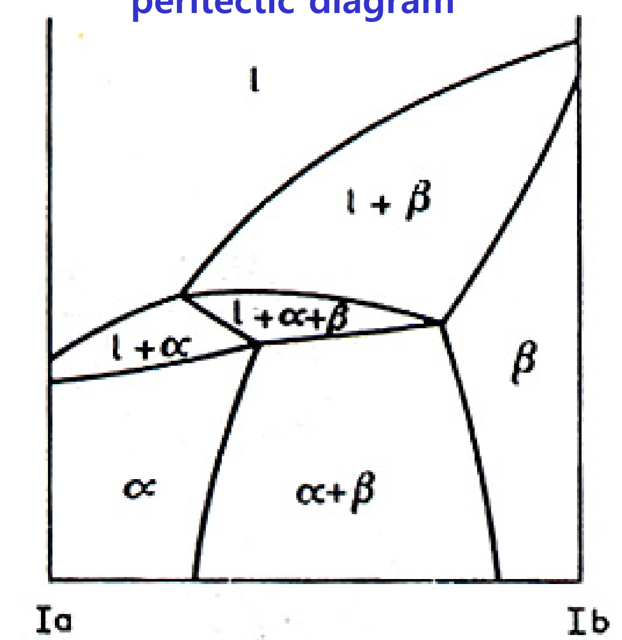
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- **A peritectic solubility gap in one binary system**

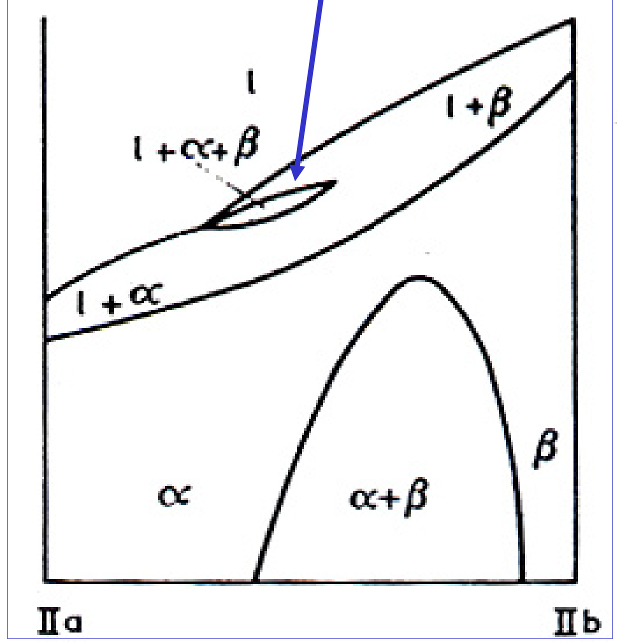


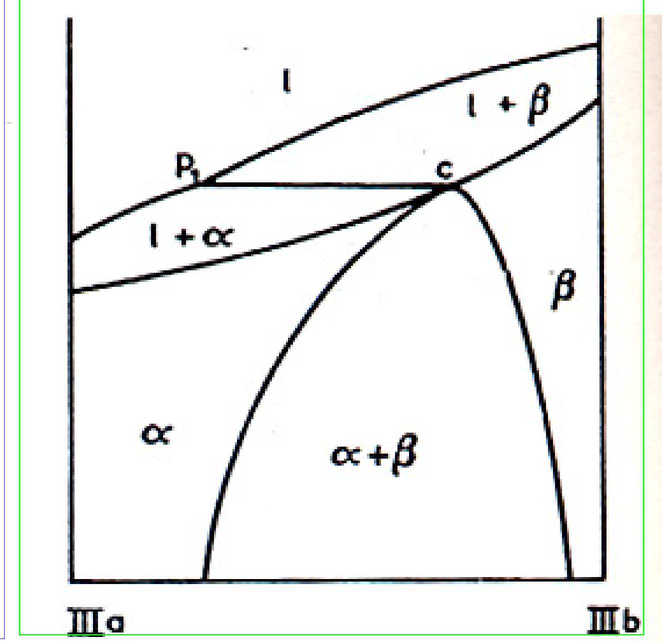
<vertical section>

Similar to the binary peritectic diagram



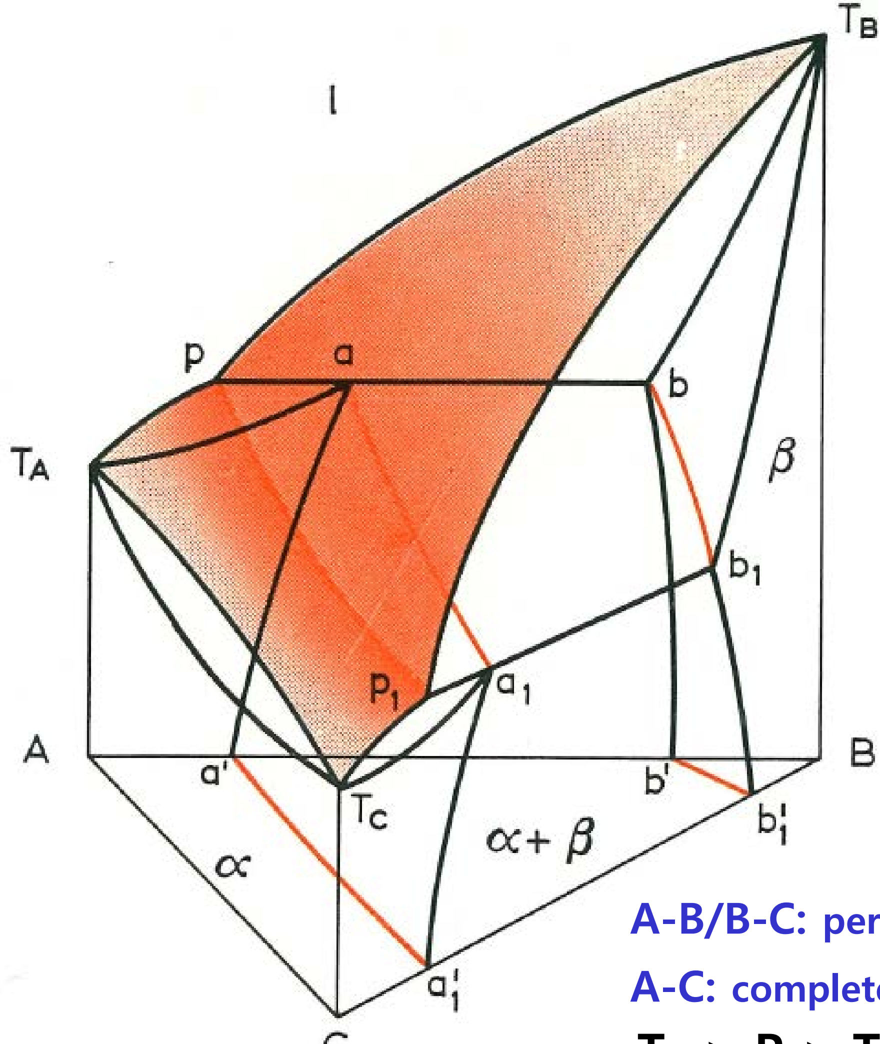
loop shaped region

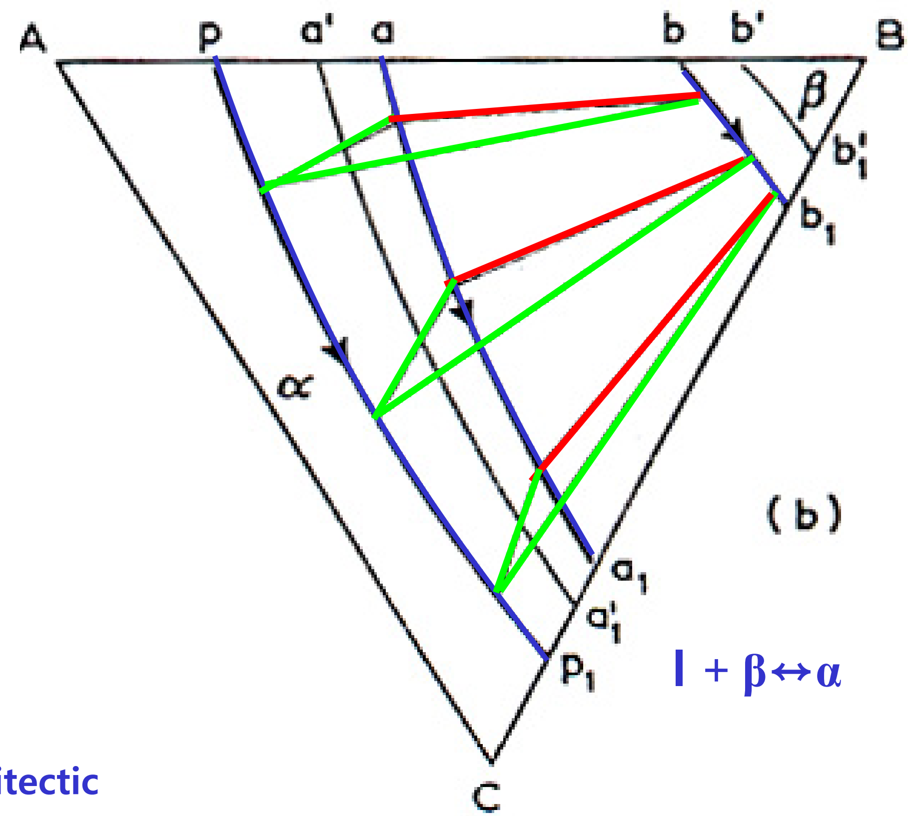




9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- **A peritectic solubility gap in two binary system**





A-B/B-C: peritectic

A-C: complete solid soln

$T_B > P > T_A > P_1 > T_C$

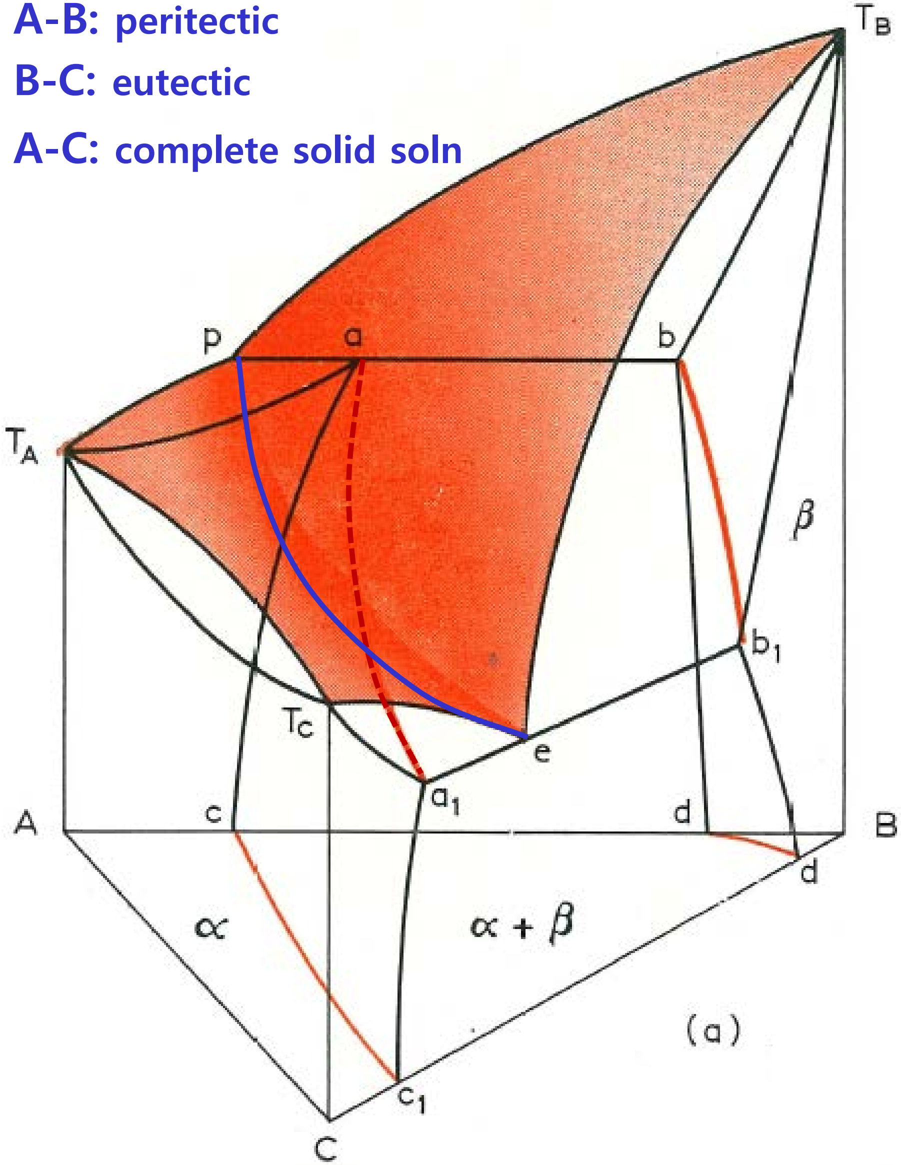
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

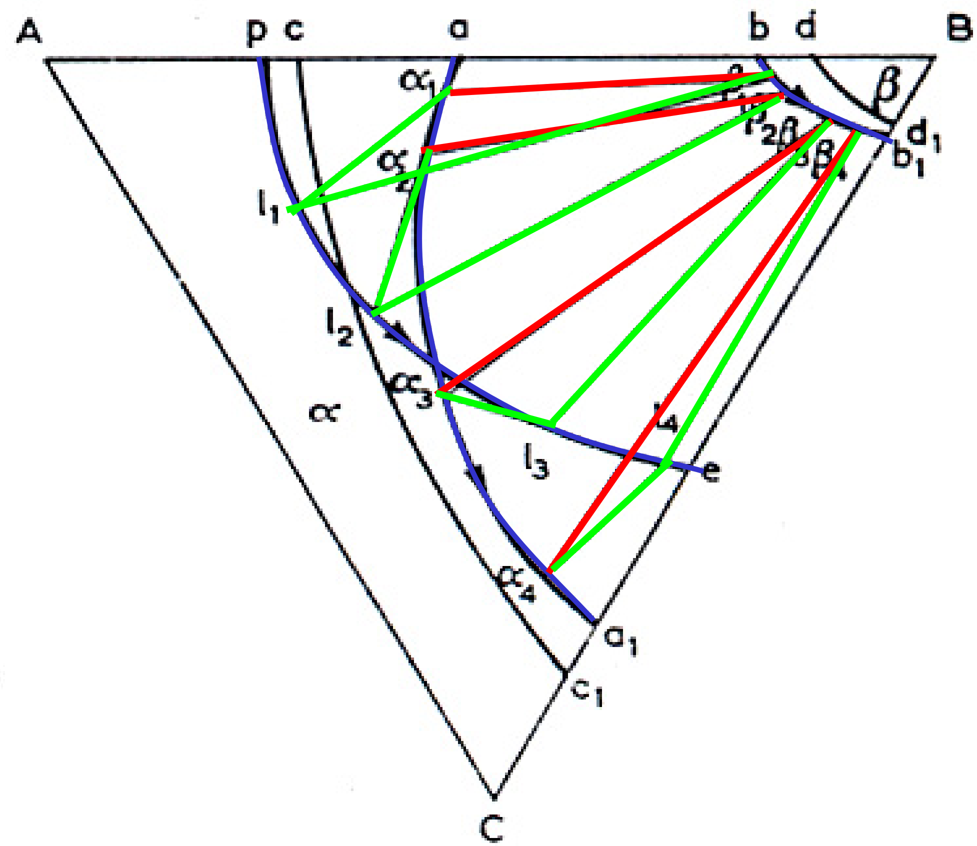
- **A transition from a binary eutectic to a binary peritectic reaction**

A-B: peritectic

B-C: eutectic

A-C: complete solid soln



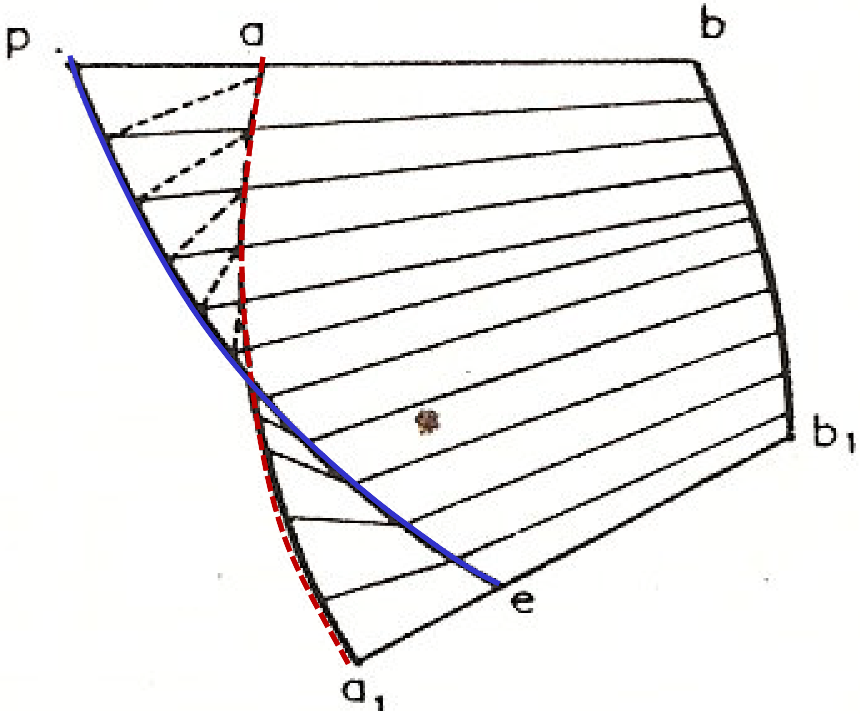


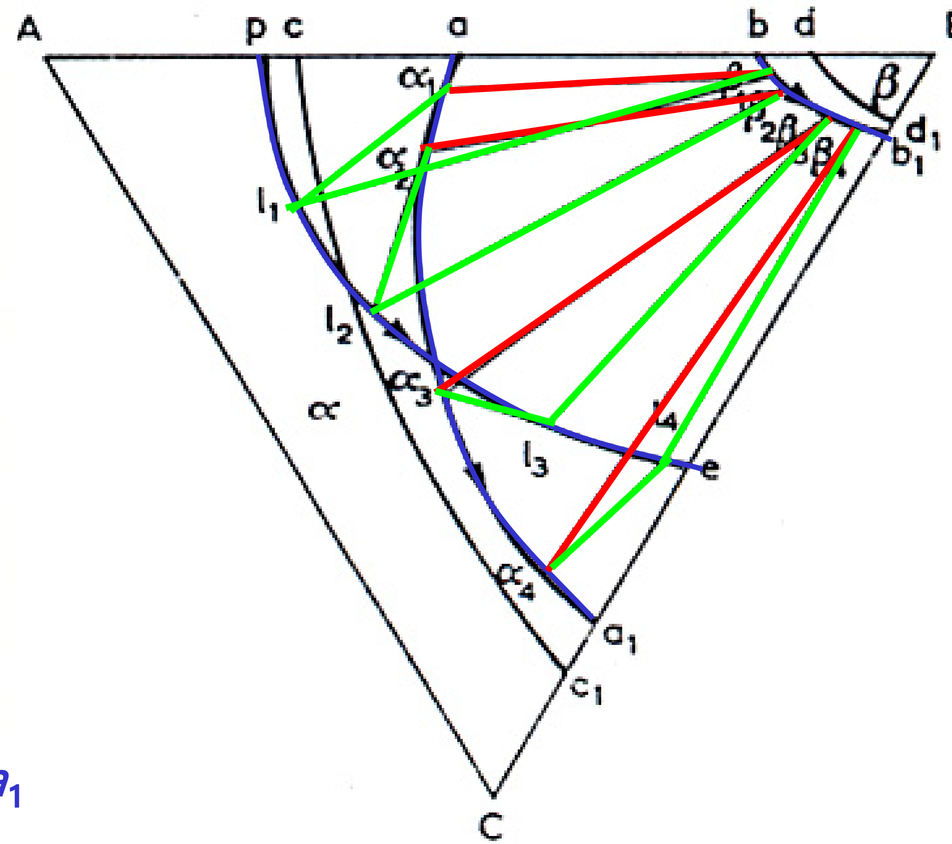
$T_B > P > T_A > T_c > e$

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A transition from a binary eutectic to a binary peritectic reaction

$T_B > P > T_A > T_c > e$





- curve *pe* always lies above curve aa_1
- Tie lines are drawn on the lβ and lα surfaces only.
- By Hillert to show that the transition form a peritectic to a eutectic reaction does not occur at a unique temperature.

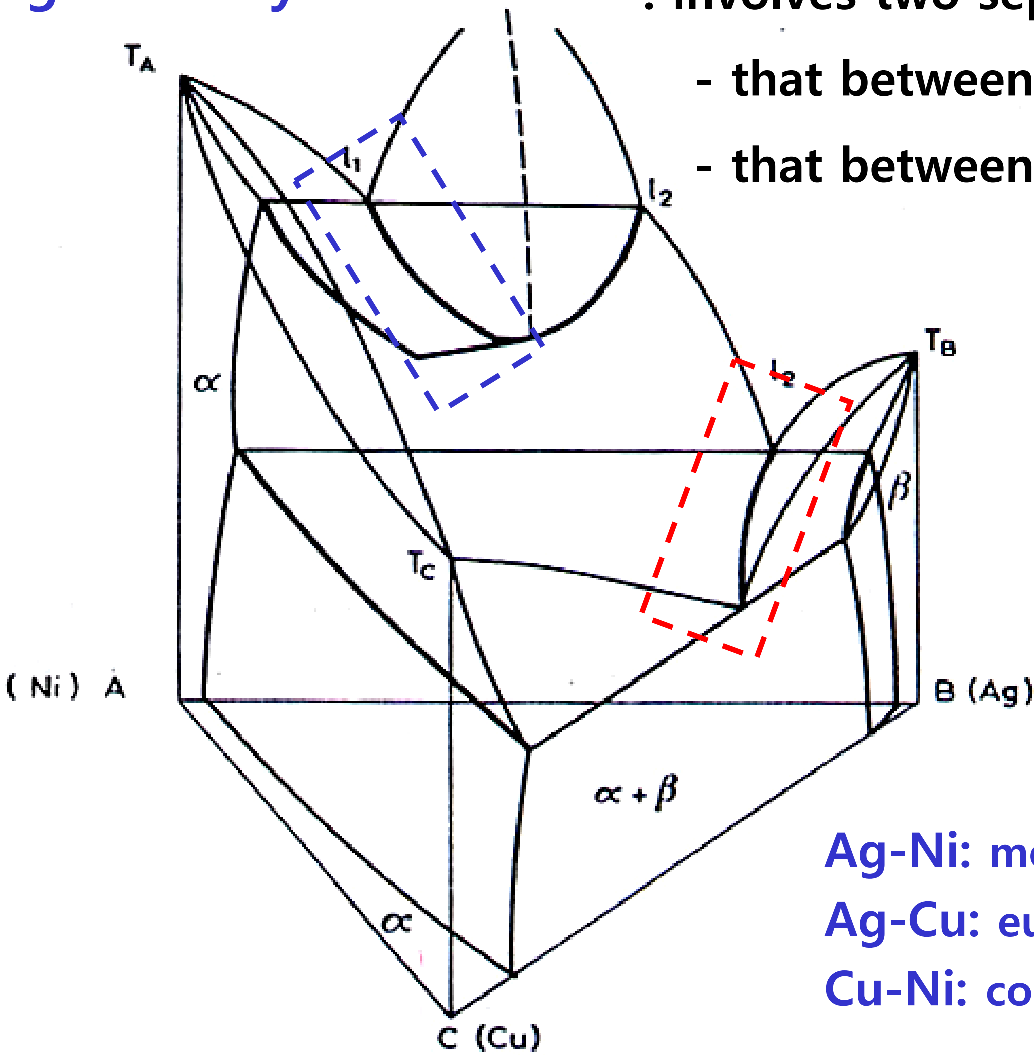
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

• 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: complete 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 ($l + \alpha + \beta = \gamma$)

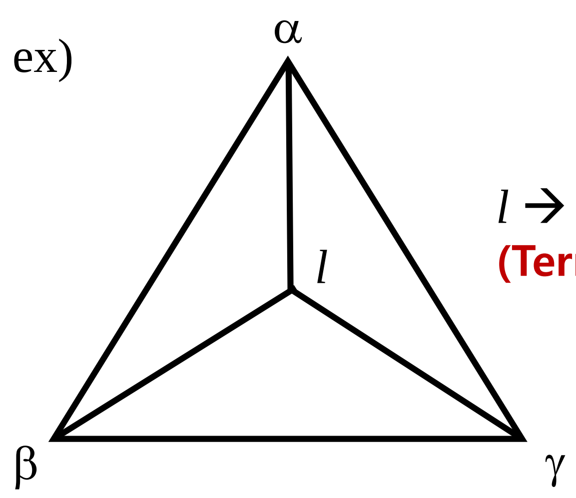
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

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.→ fixed
- **isothermal four phase regions**

ex)

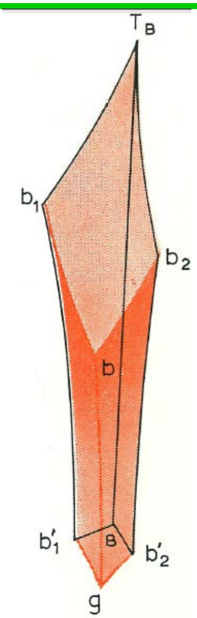


$l \rightarrow \alpha + \beta + \gamma$
(Ternary eutectic)

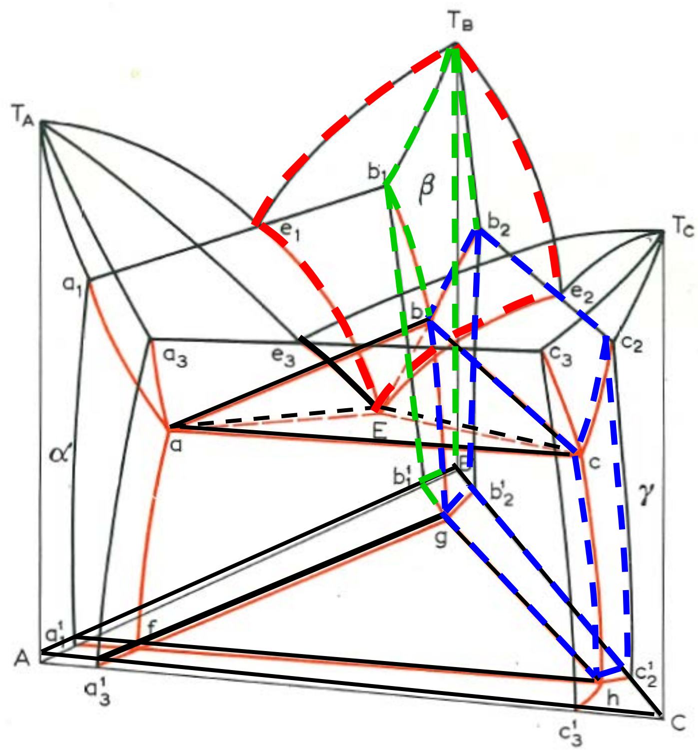
cf) $l + \alpha \rightarrow \beta + \gamma$: **ternary quasi-peritectic**
$l + \alpha + \beta \rightarrow \gamma$: **ternary peritectic**

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

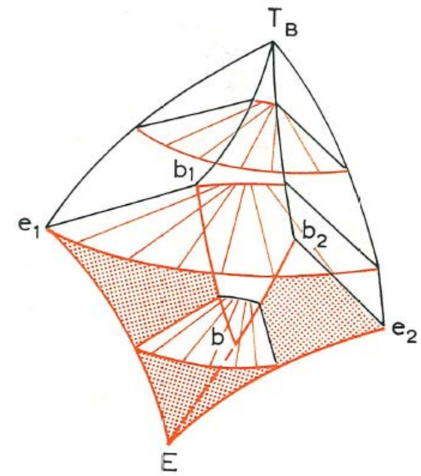
Ternary eutectic



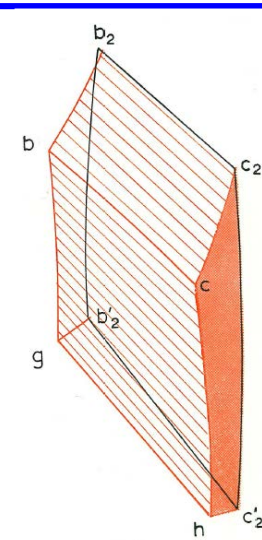
β phase region



(a)



($l + \beta$) phase region

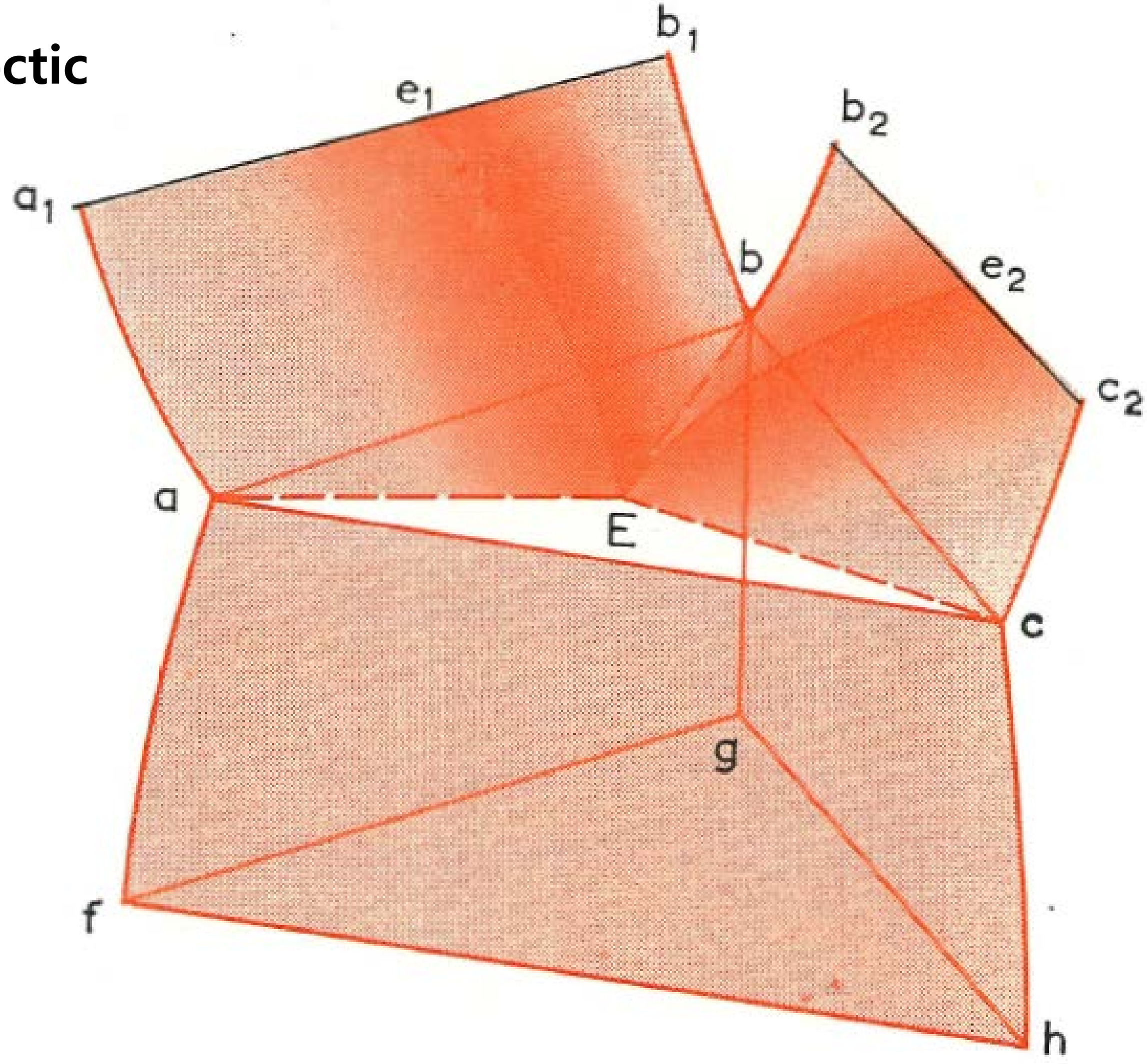


($\beta + \gamma$) phase region

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

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

Ternary eutectic

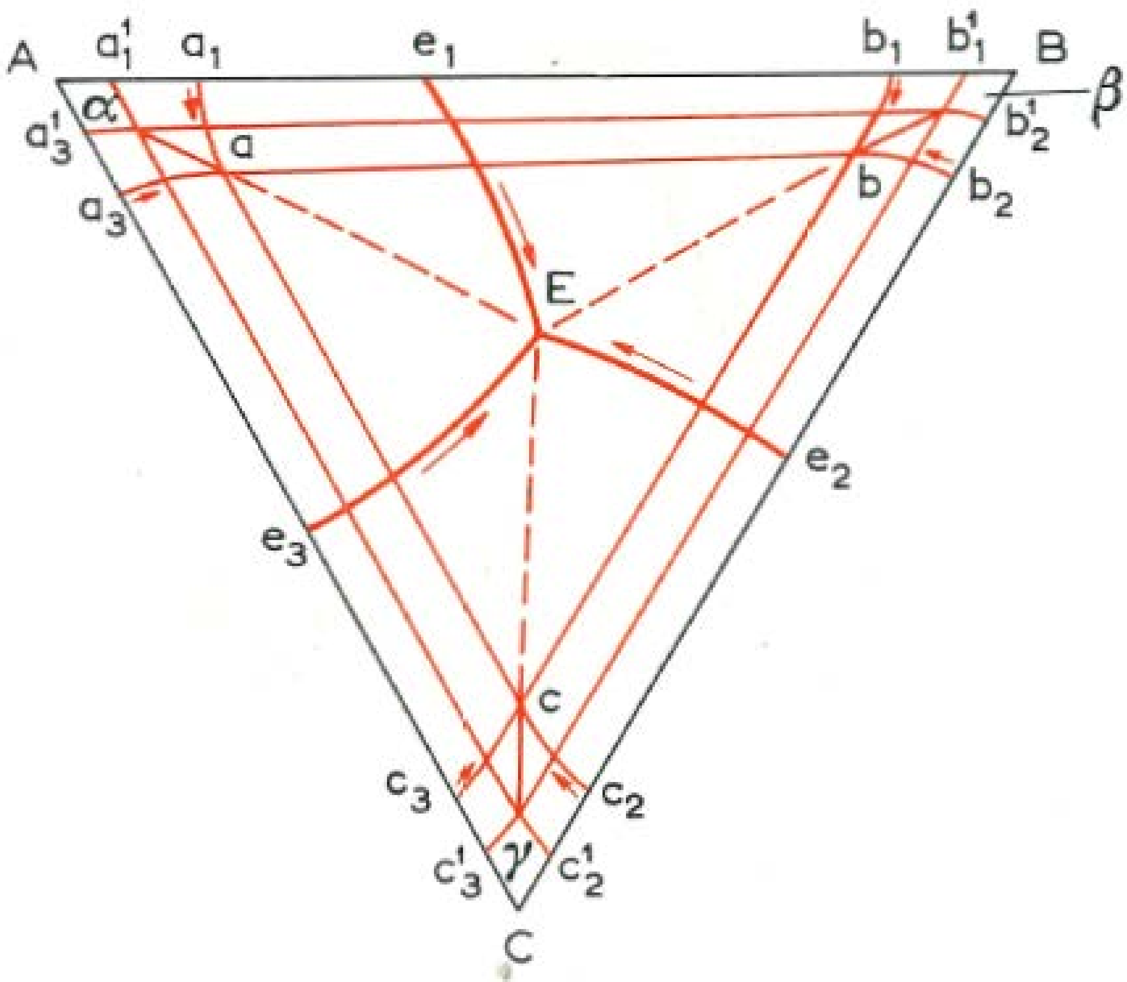


The eutectic four-phase plane as the junction of four tie triangles

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

Ternary eutectic • **Projection : solid solubility limit surface**

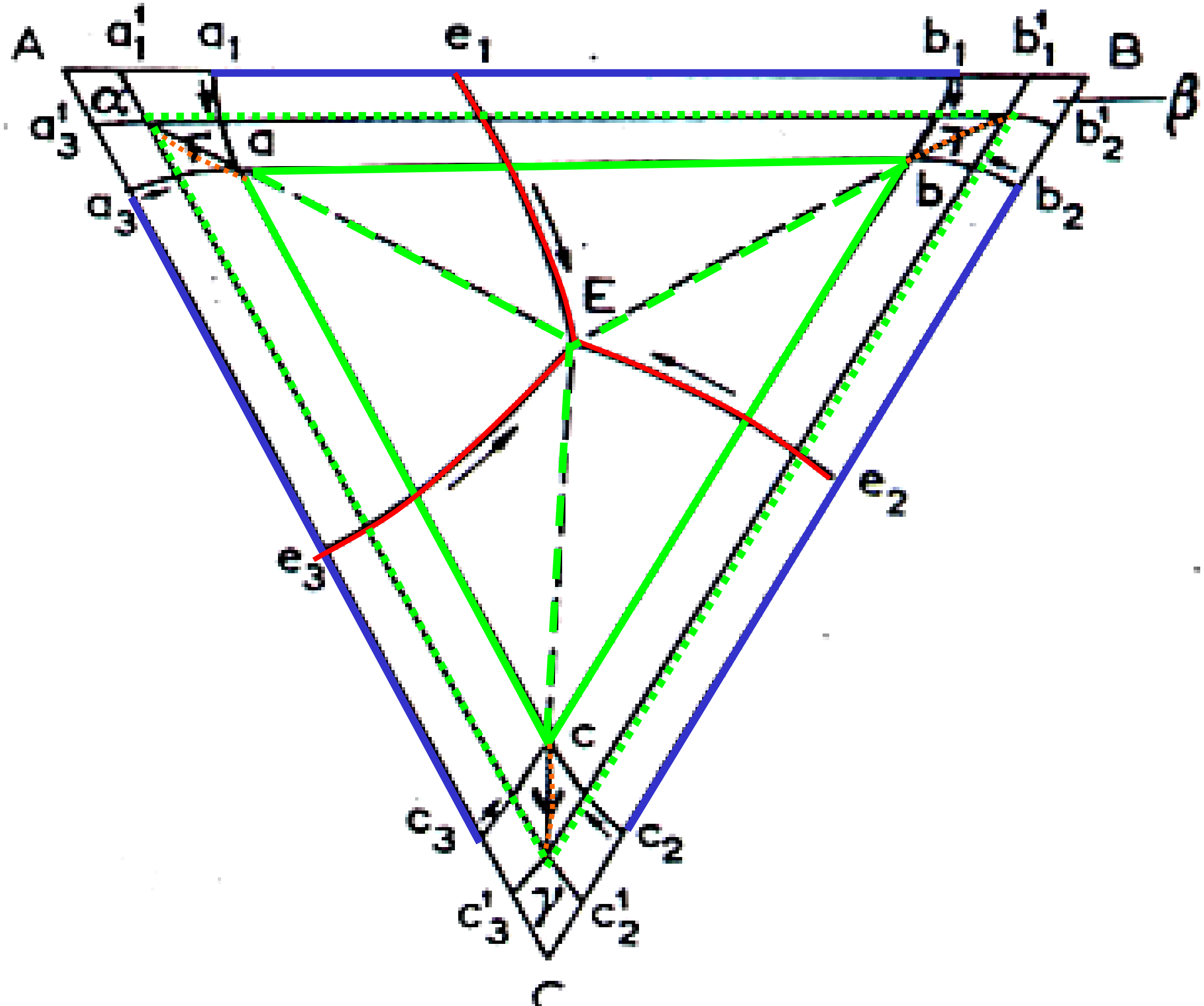
: monovariant liquidus curve

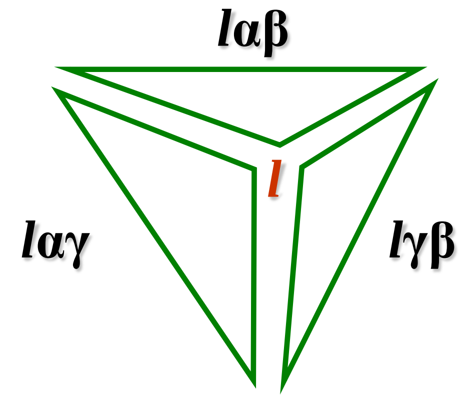


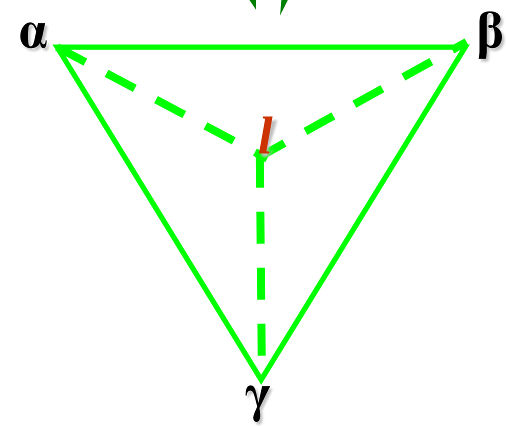
$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$

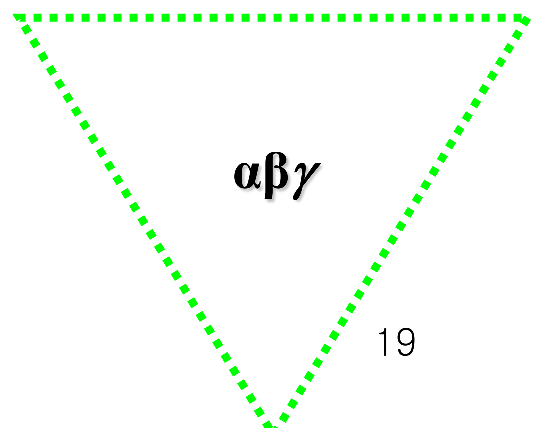
THE TERNARY EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

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





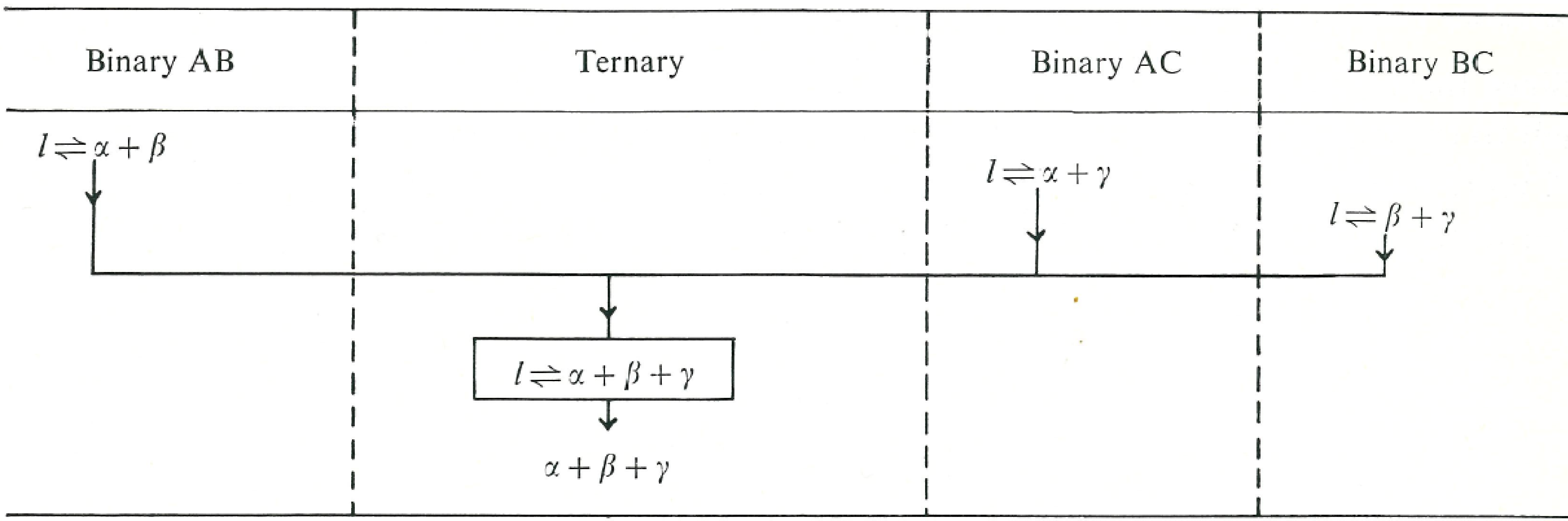




Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

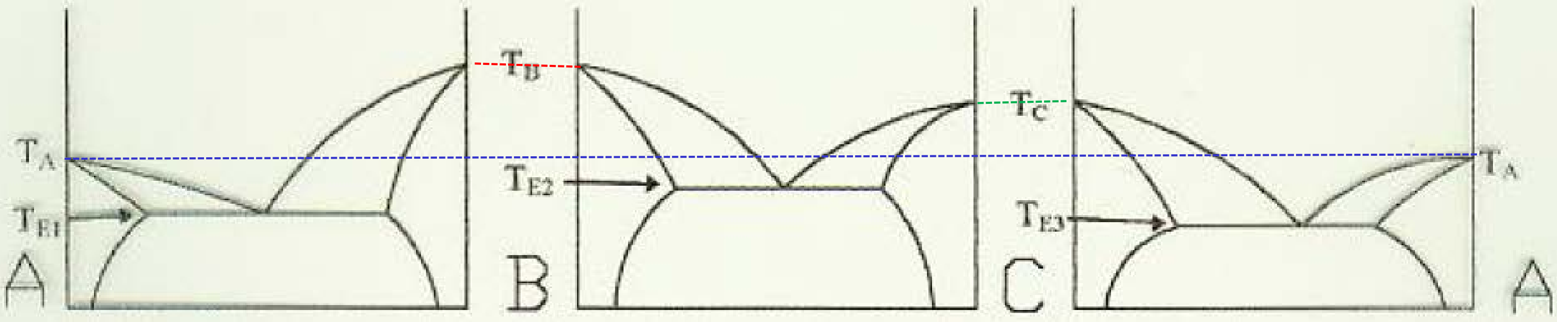
EUTECTIC EQUILIBRIUM $l \rightleftharpoons \alpha+\beta+\gamma$



Ternary Eutectic System

(with Solid Solubility)

P1:



T_A: Melting Point Of Material A

T_B: Melting Point Of Material B

T_C: Melting Point Of Material C

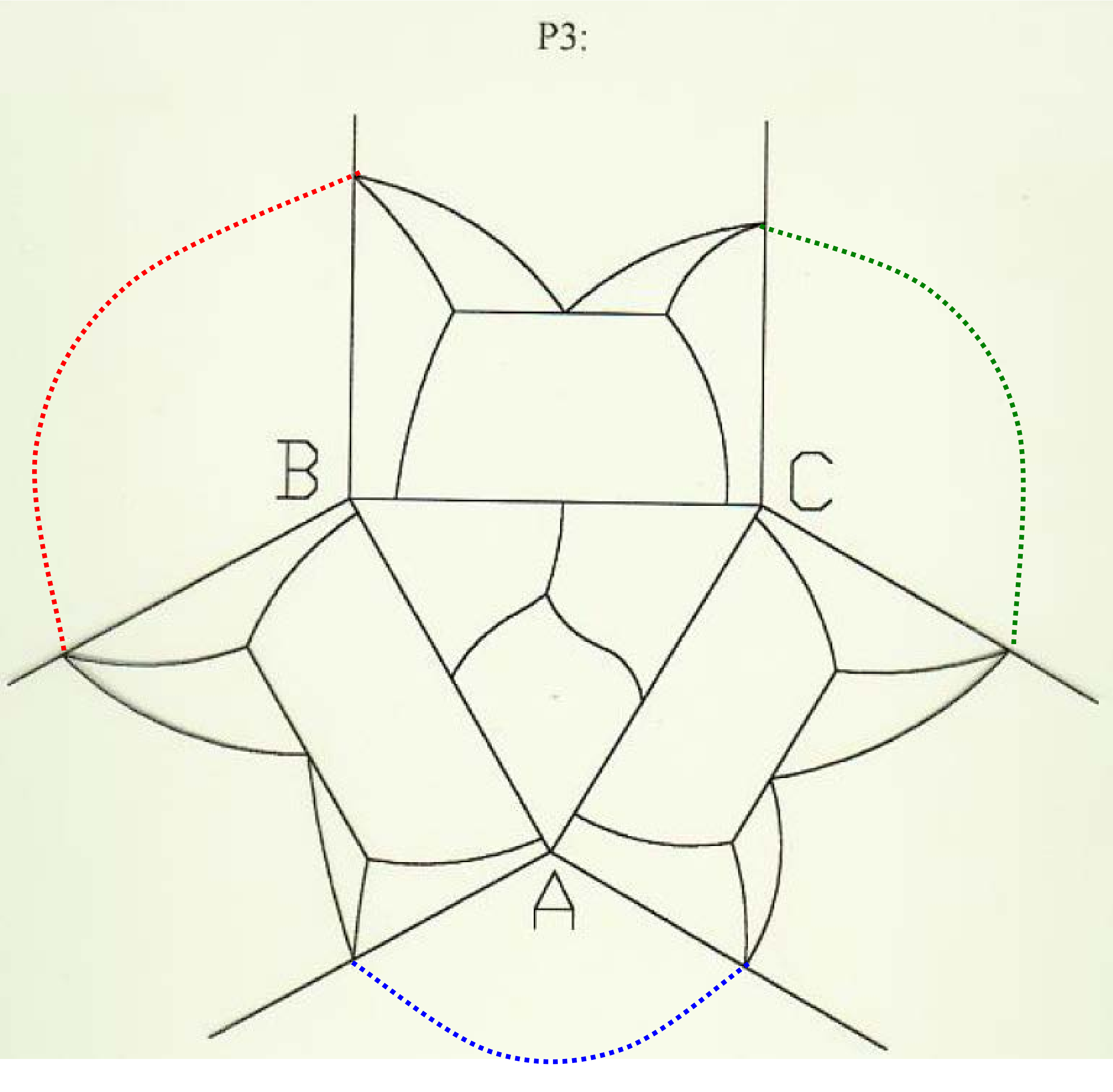
T_{E1}: Eutectic Temperature Of A-B

T_{E2}: Eutectic Temperature Of B-C

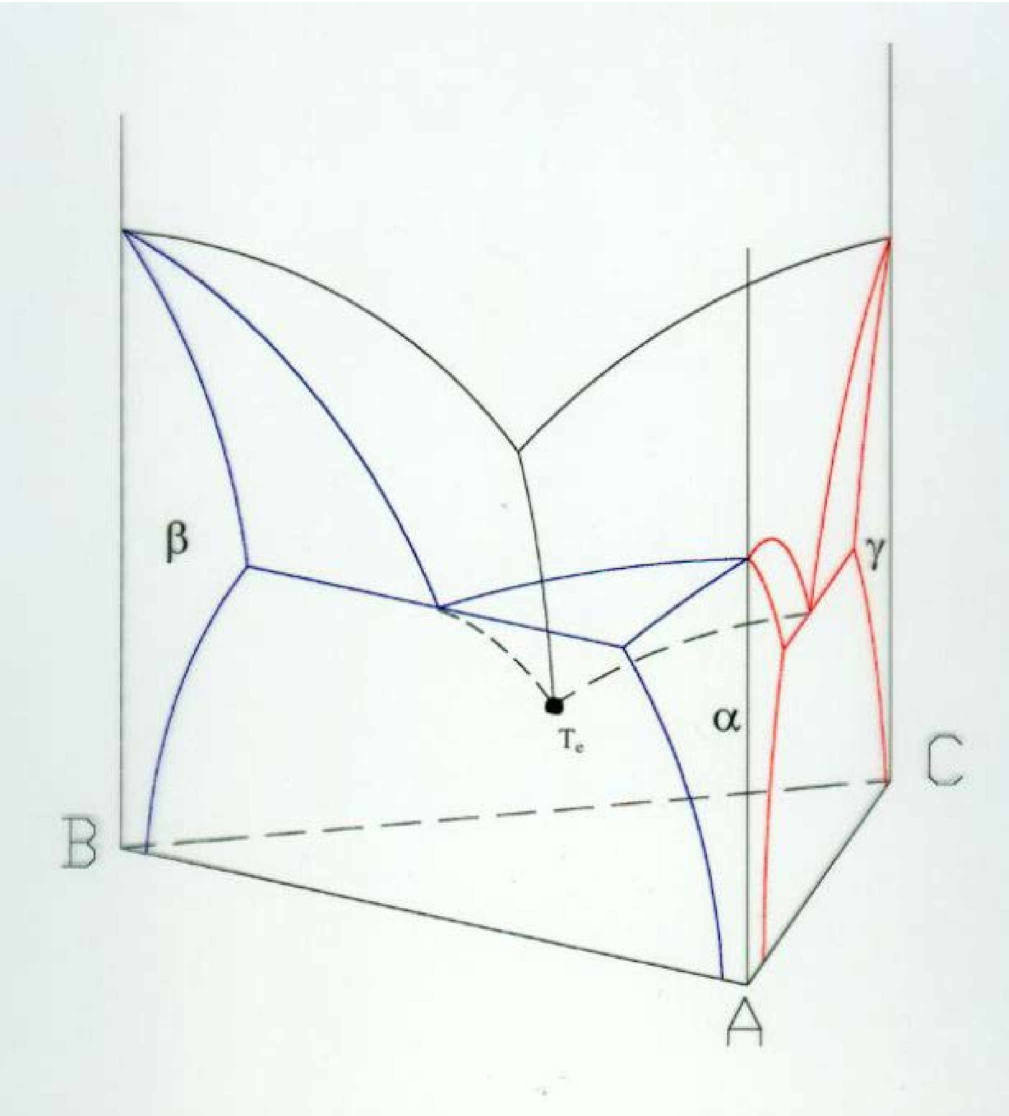
T_{E3}: Eutectic Temperature Of C-A

Ternary Eutectic System

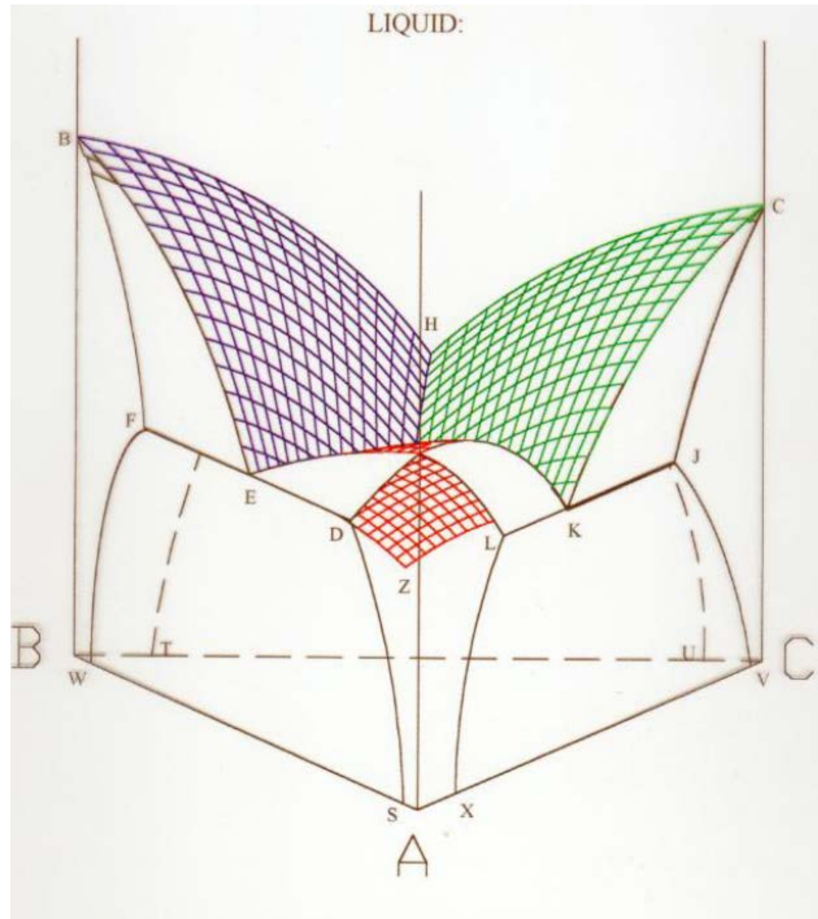
(with Solid Solubility)



Ternary Eutectic System
(with Solid Solubility)

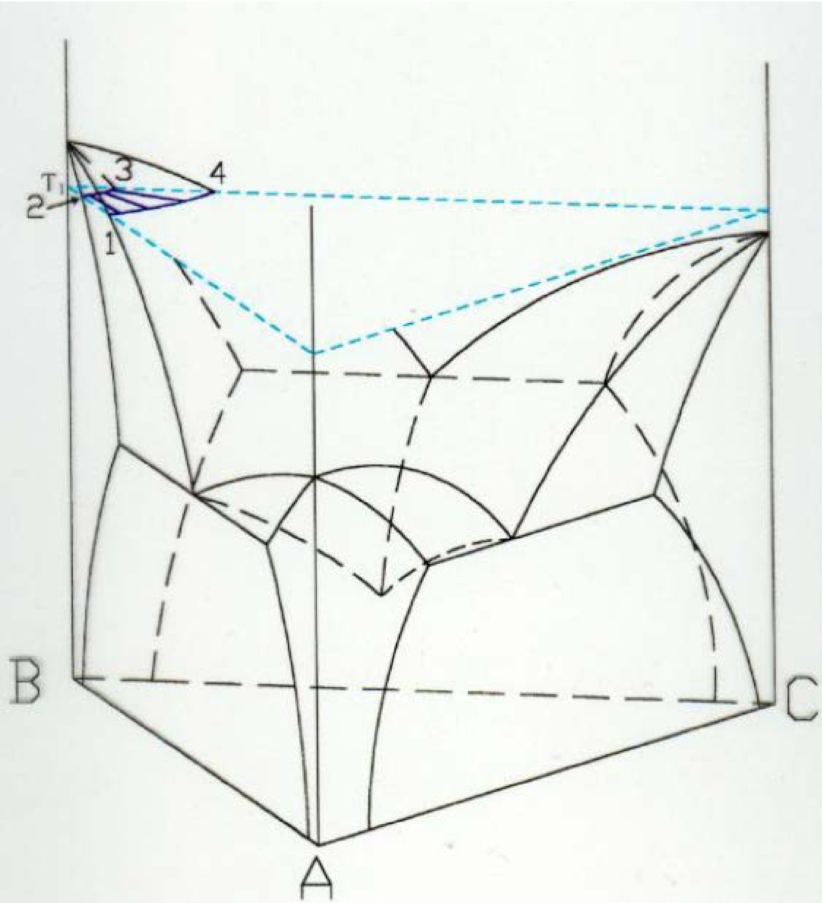


Main outline of Ternary Phase Diagram with Ternary Eutectic (T_e) and Solid Single Phase Regions Shown

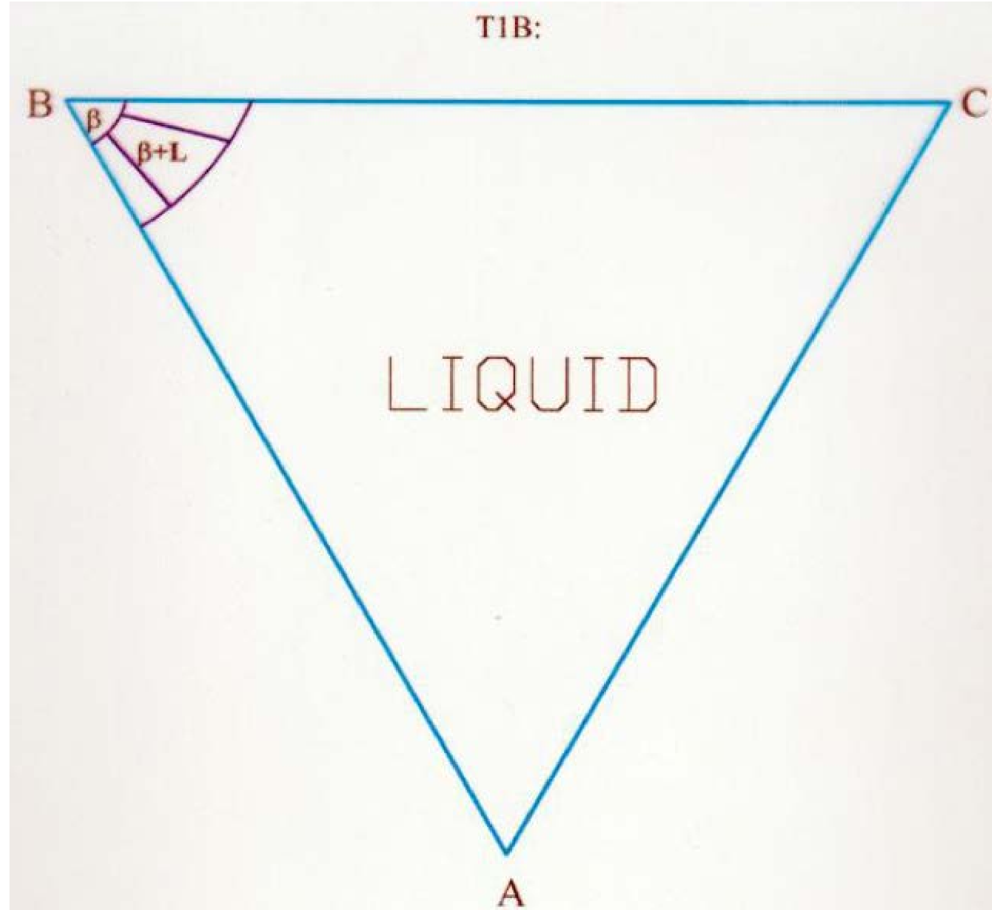


All Liquidus surfaces (α+L-Red, β+L-Purple, γ+L-Green)

Ternary Eutectic System
(with Solid Solubility)



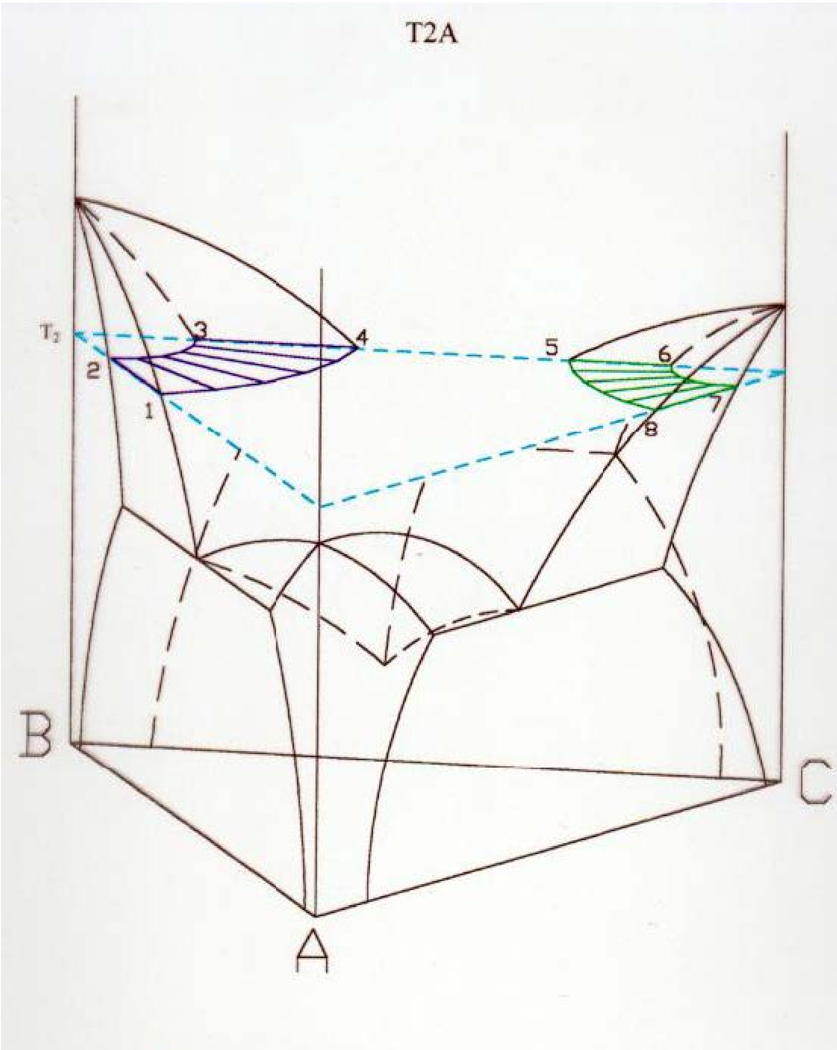
Temperature Slice At $T_1 < T_B$, But $> T_A$, T_C



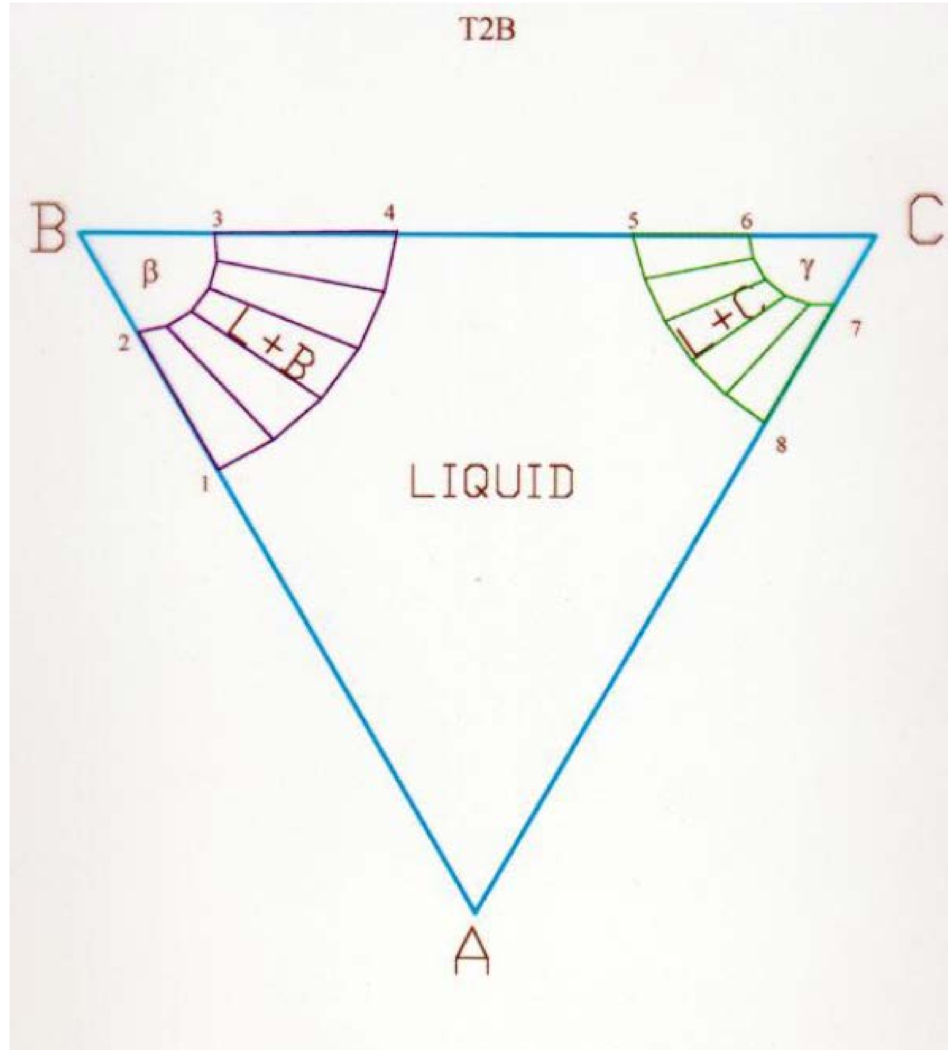
Isothermal Section At $T=T_1$

Ternary Eutectic System

(with Solid Solubility)

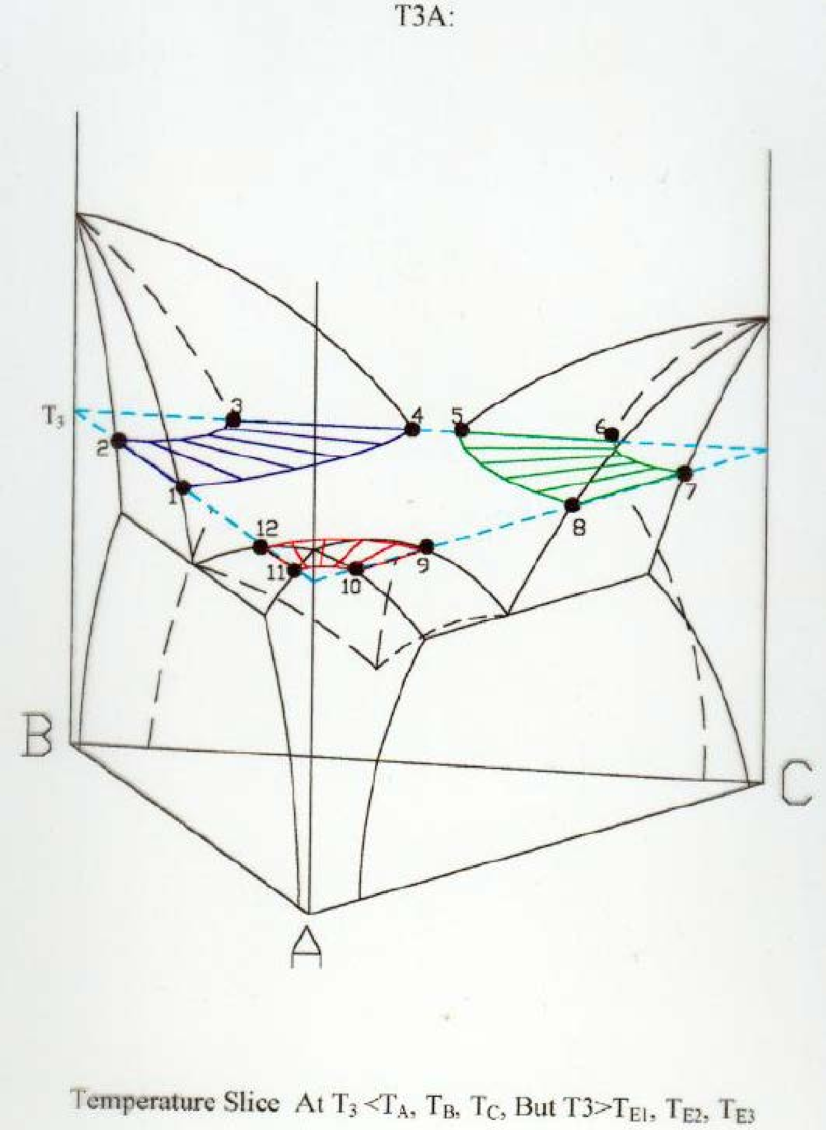


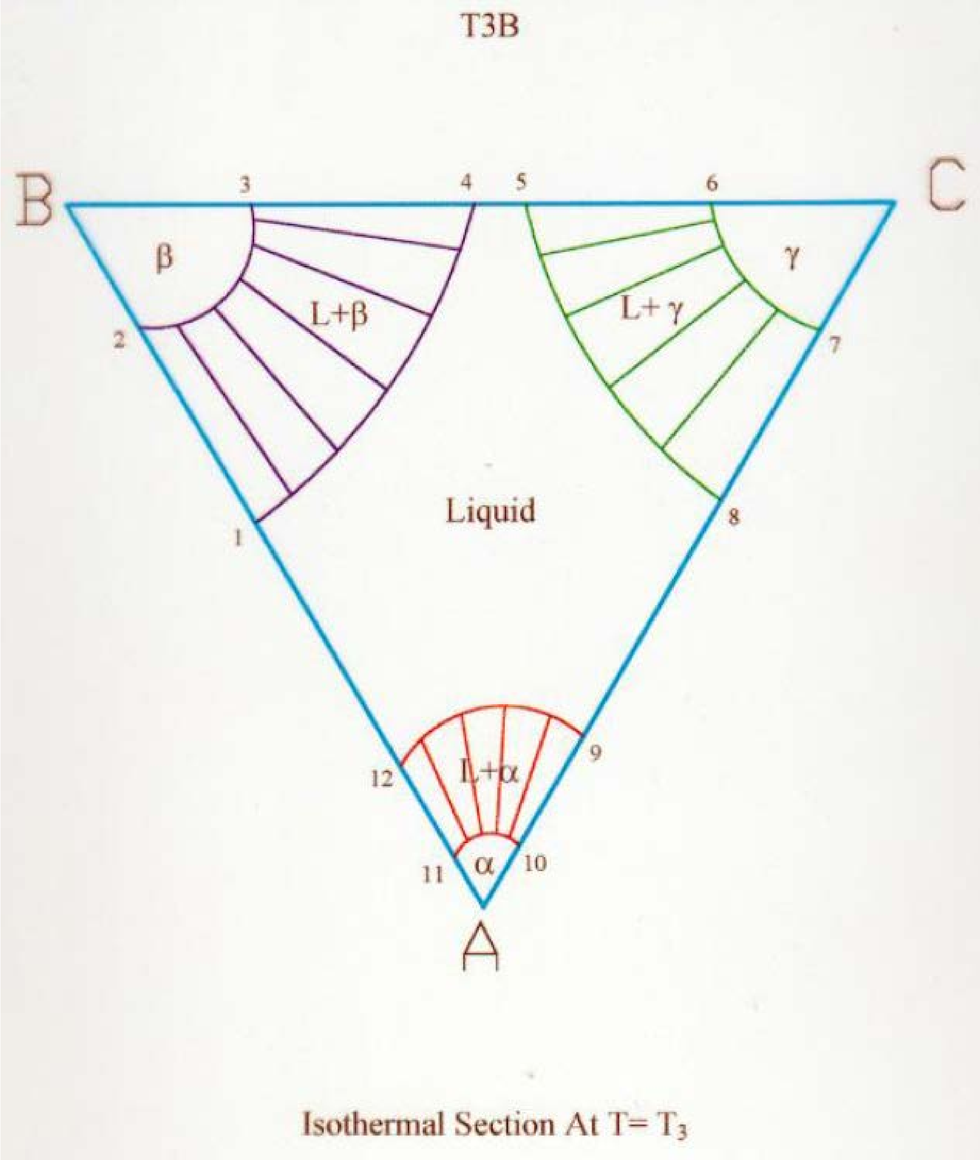
Temperature Slice At $T_2 > T_A$ But, $T_2 < T_B$, T_C



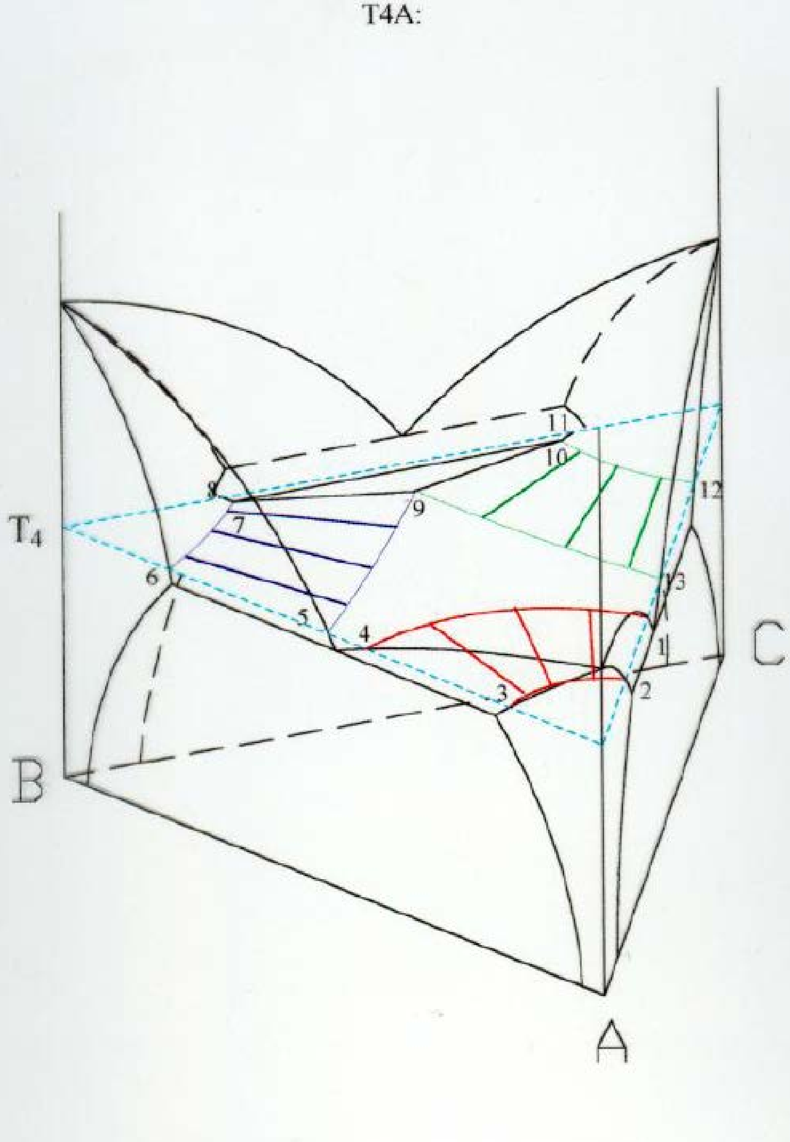
Isothermal Section At $T=T_2$

Ternary Eutectic System
(with Solid Solubility)

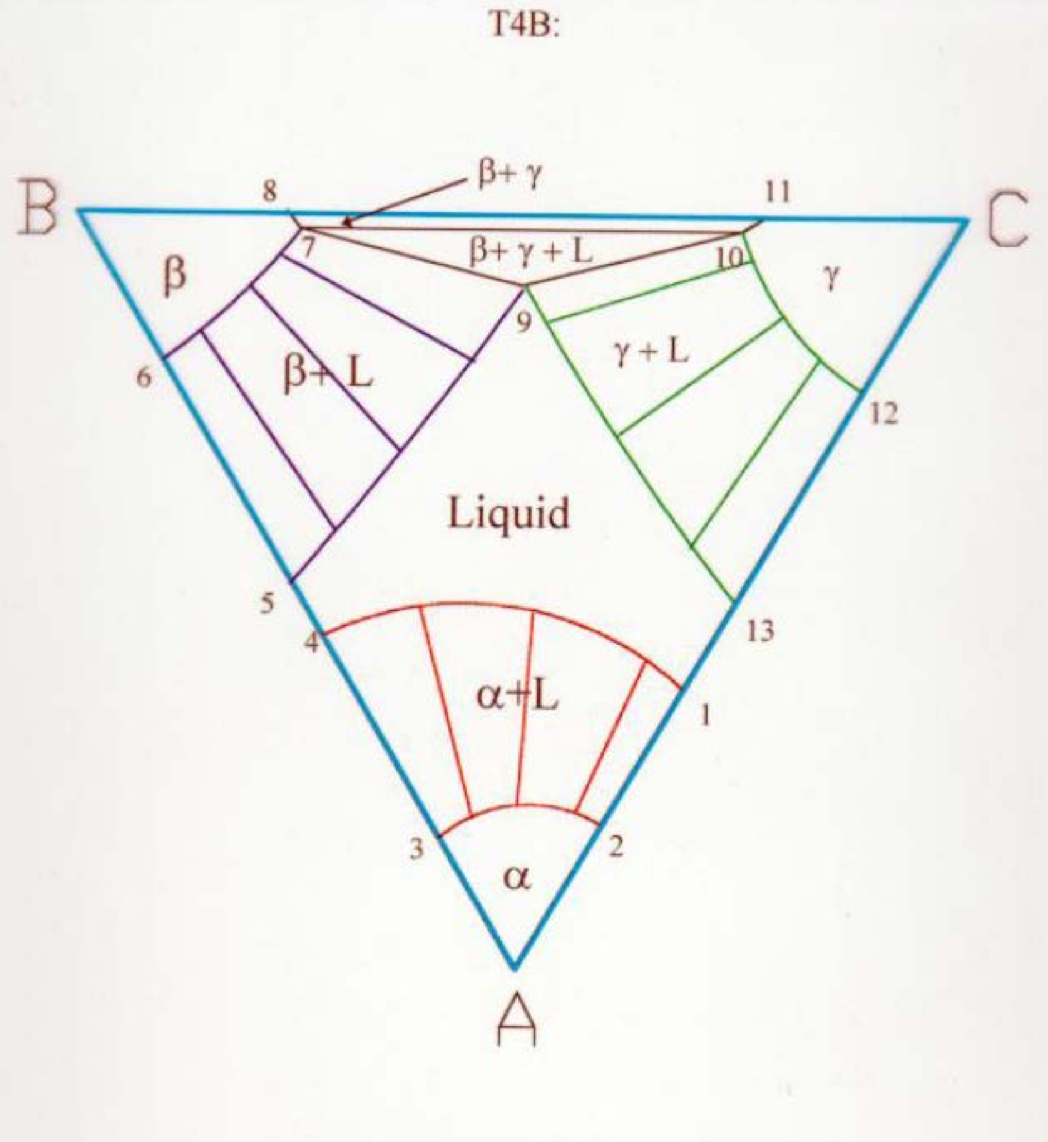




Ternary Eutectic System
(with Solid Solubility)

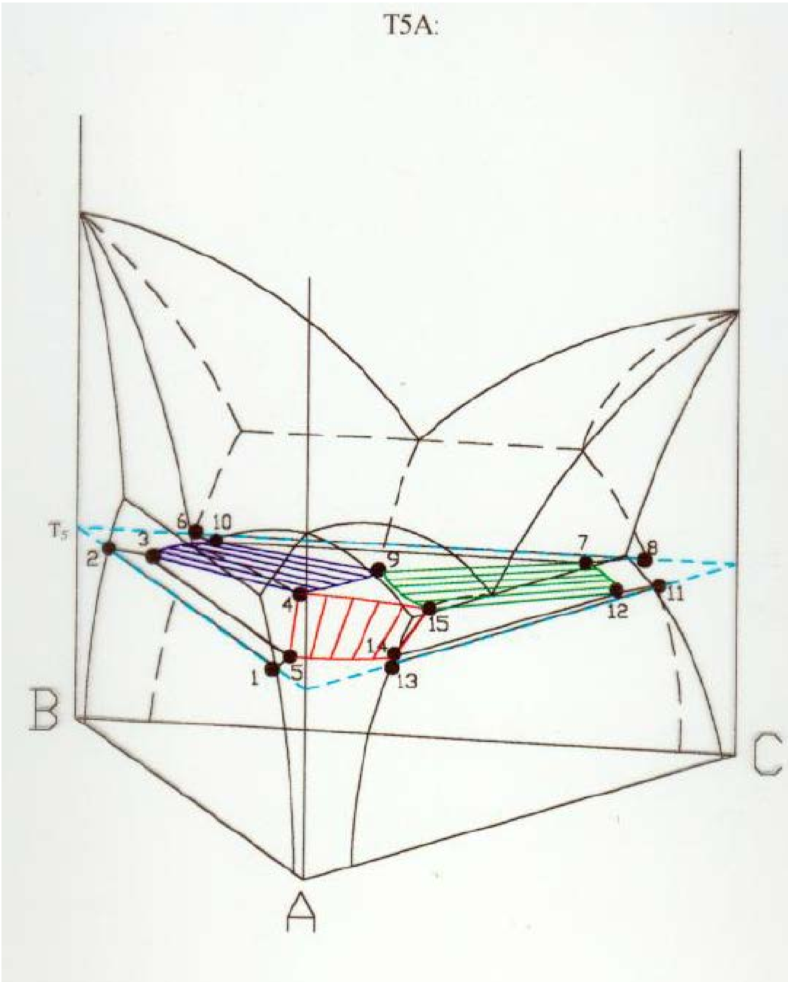


Temperature Slice At $T_4 < T_{E2}$ And $T_4 > T_{E1}, T_{E3}$

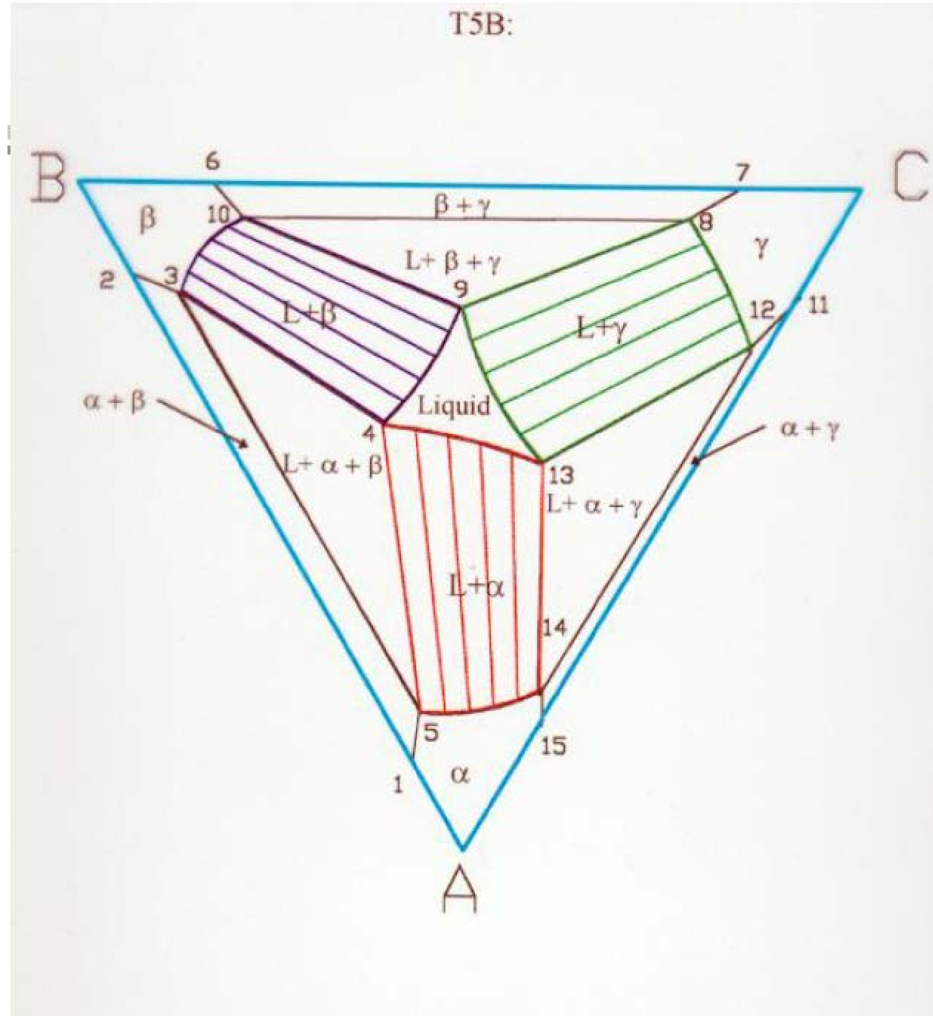


Isothermal Section At $T=T_4$

Ternary Eutectic System
(with Solid Solubility)



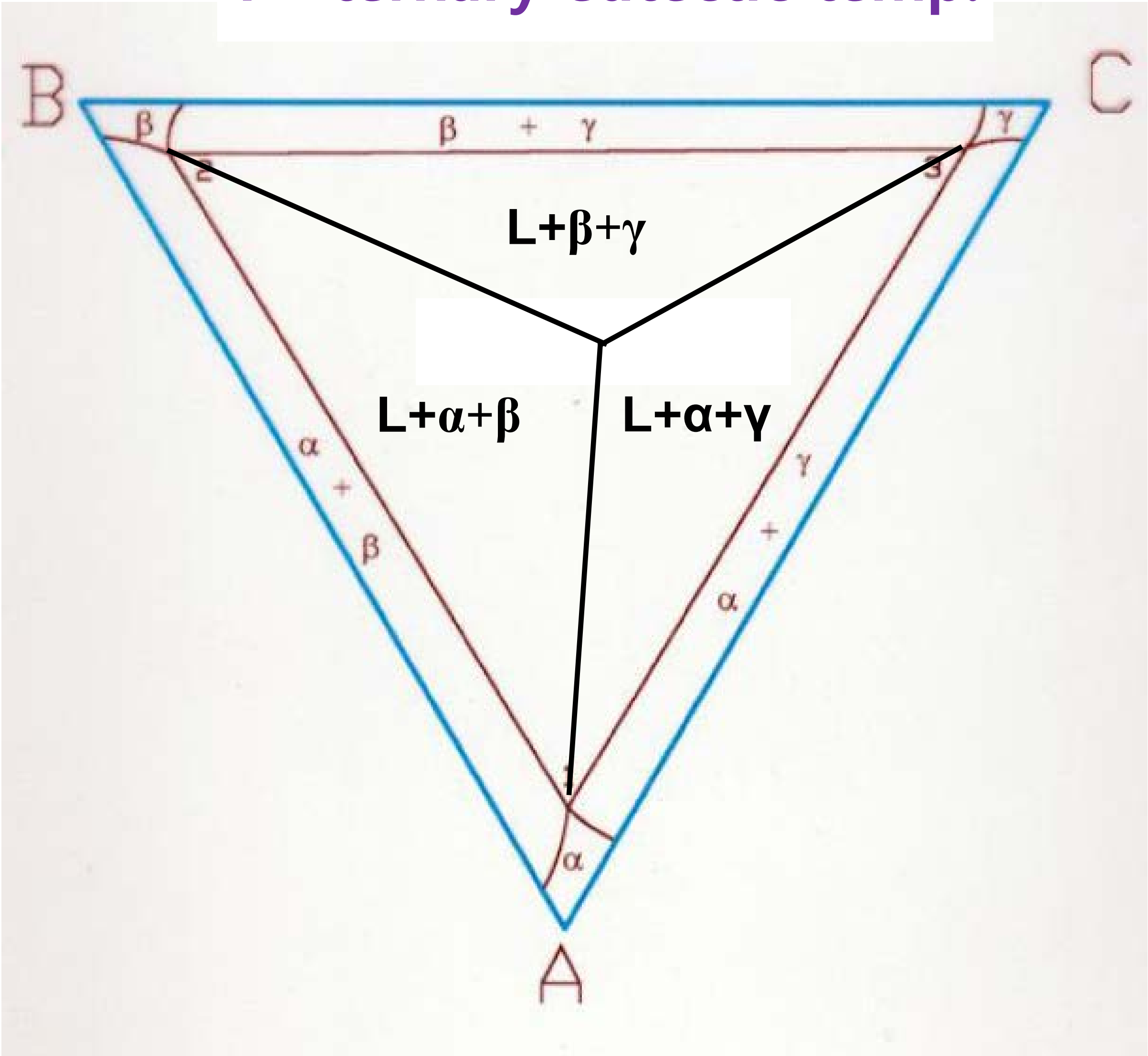
Temperature Slice Below All Binary Eutectics But, Above The Ternary Eutectic



Isothermal Section At T=T_5

Ternary Eutectic System
(with Solid Solubility)

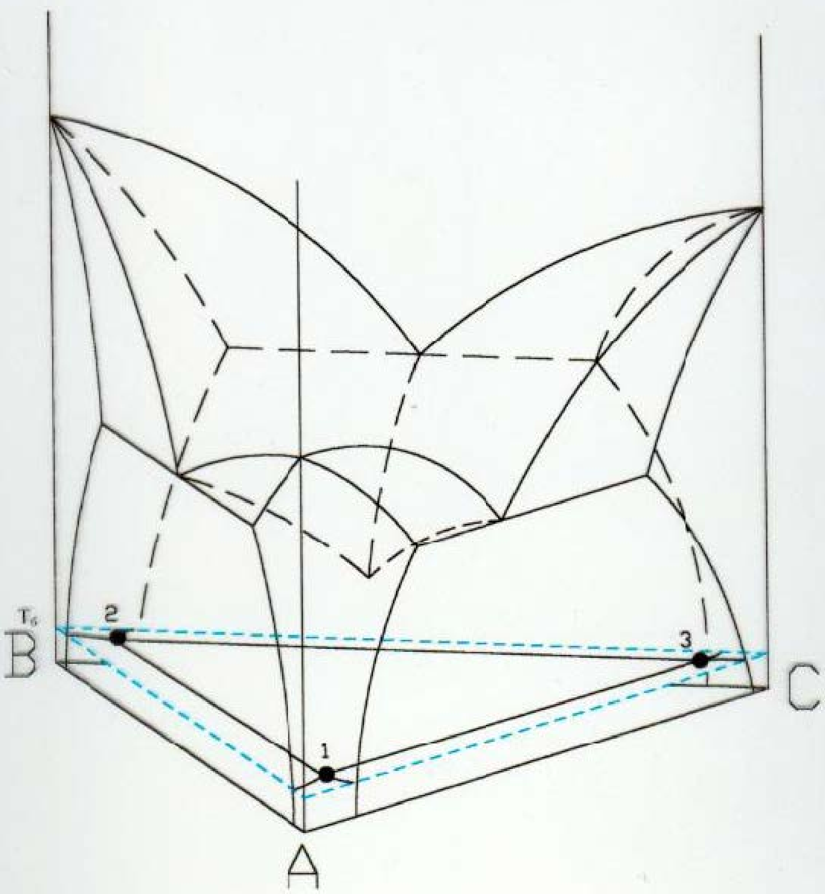
T= ternary eutectic temp.



Ternary Eutectic System

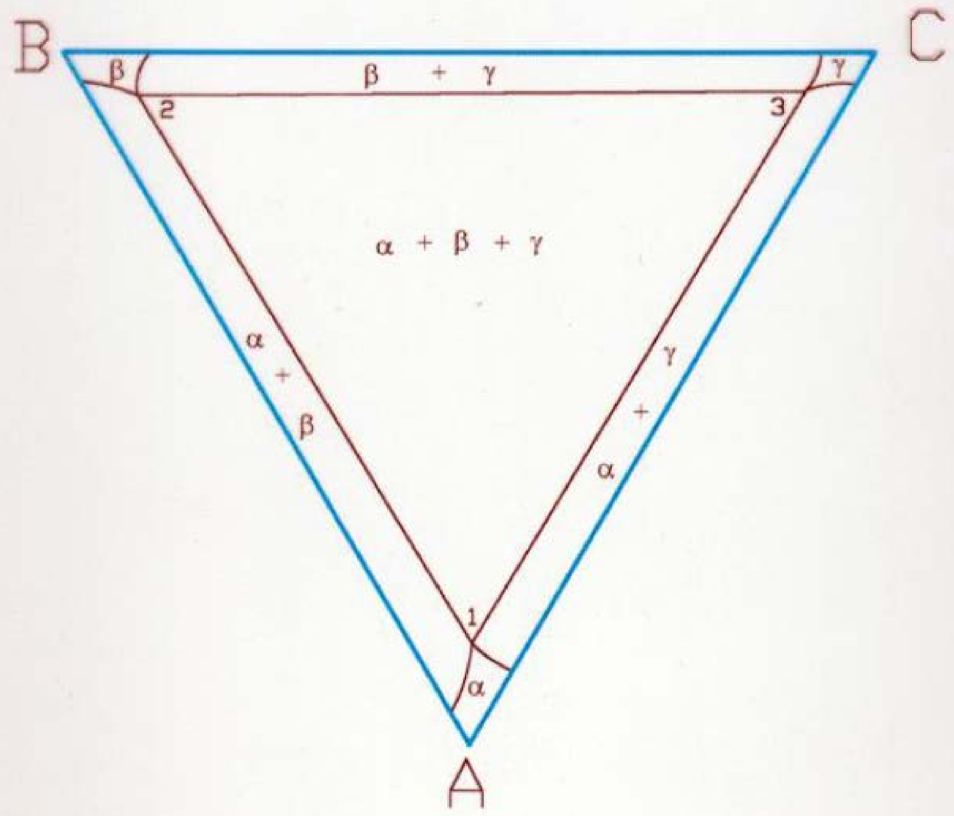
(with Solid Solubility)

T6A:



Temperature Slice at $T_6 < T_E$

T6B:

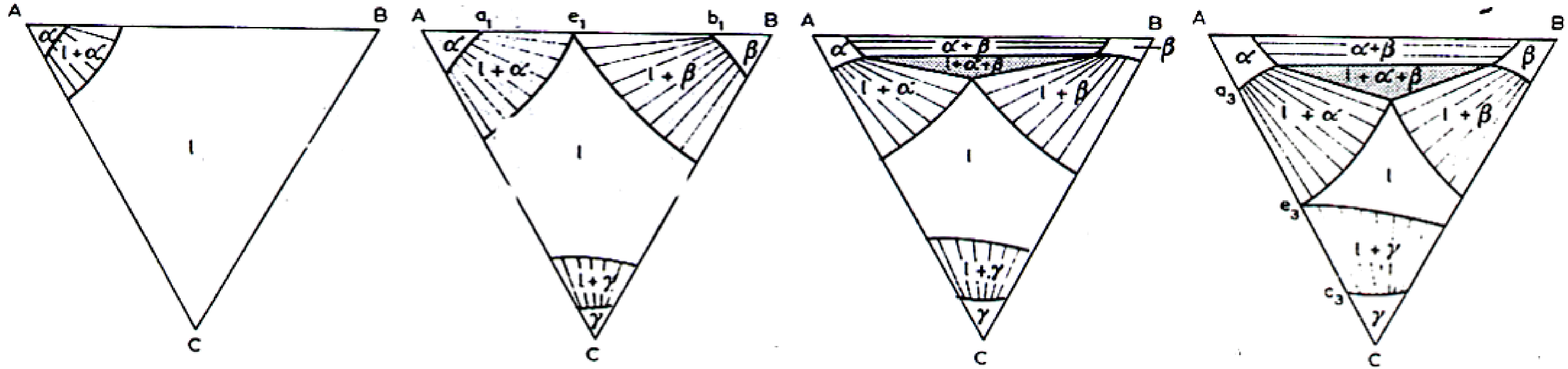


Isothermal Section At $T=T_6$

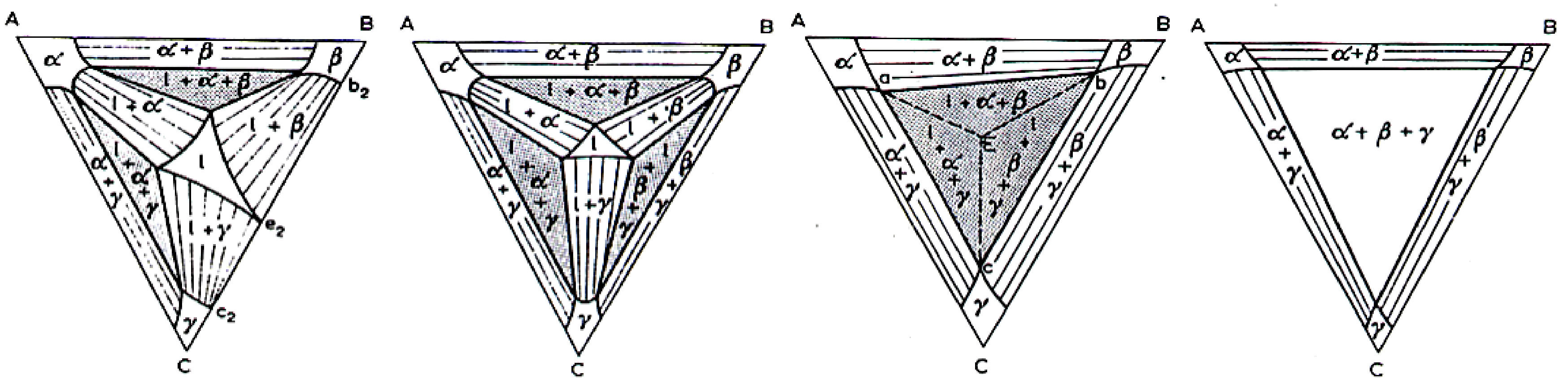
http://www.youtube.com/watch?v=yzhVomAdetM

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**

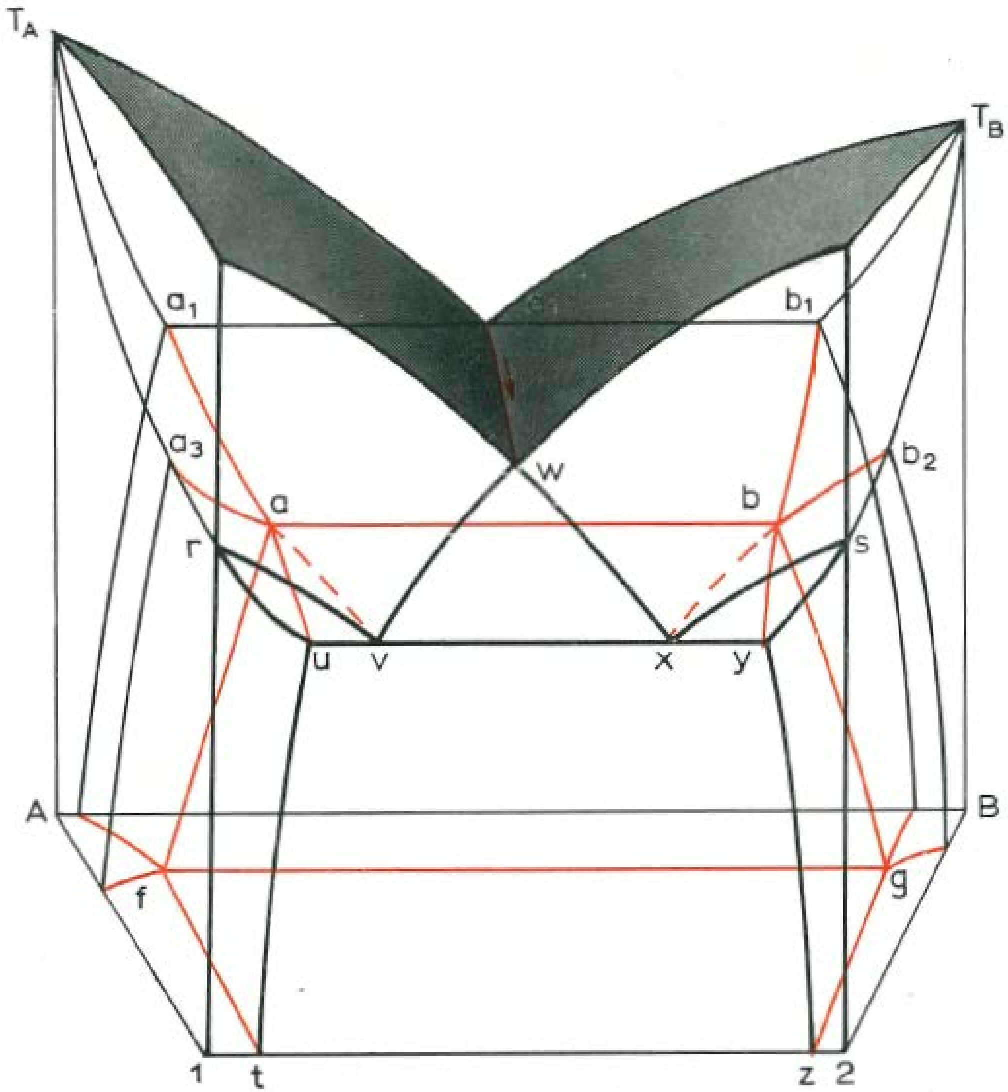
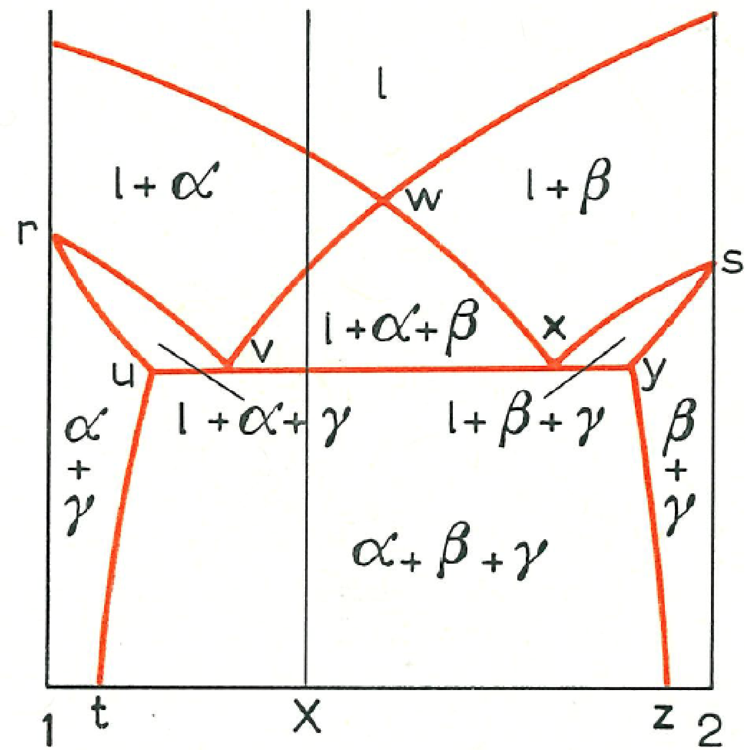
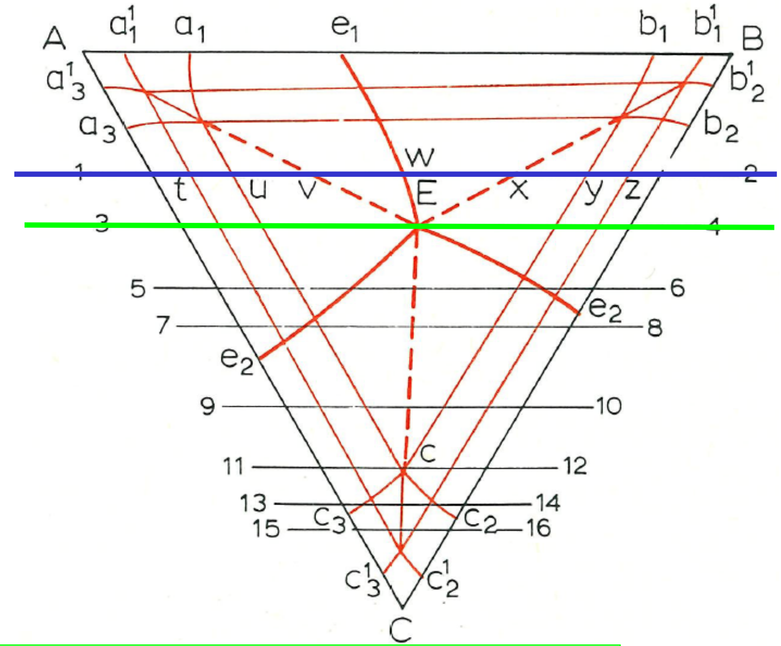


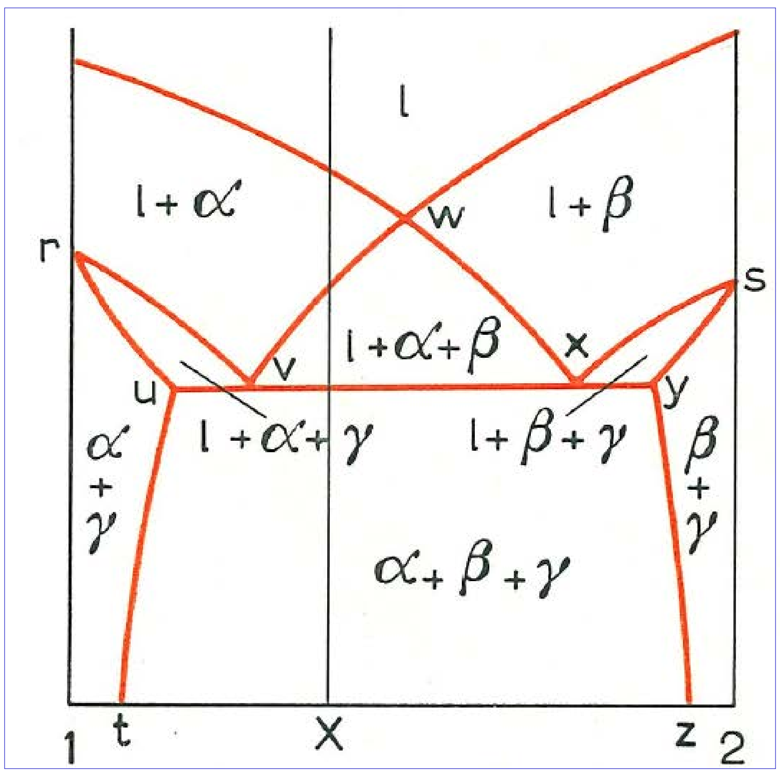
Fig. 179. Construction of vertical section 1–2.

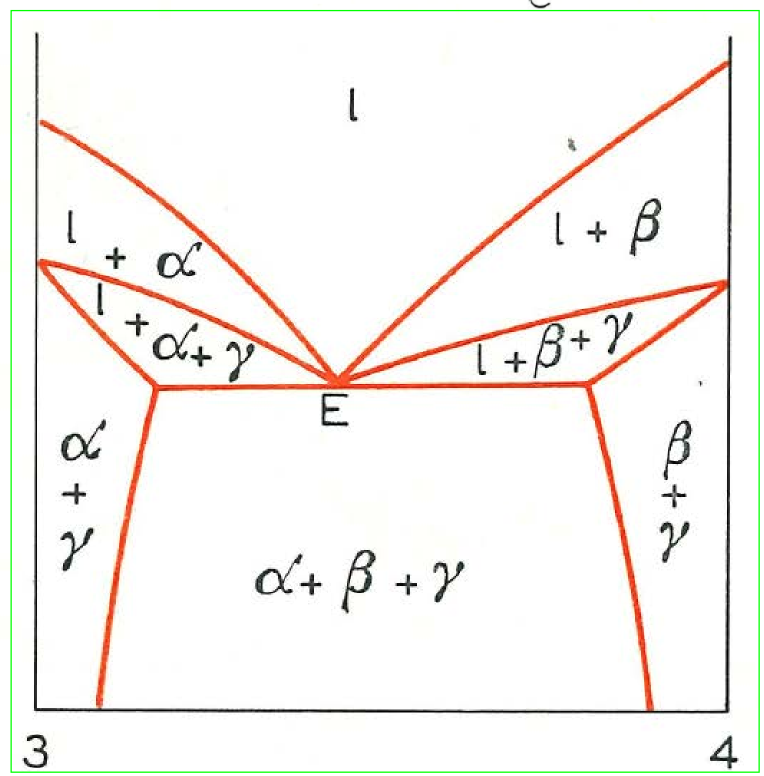


10.1. THE EUTECTIC EQUILIBRIUM
($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

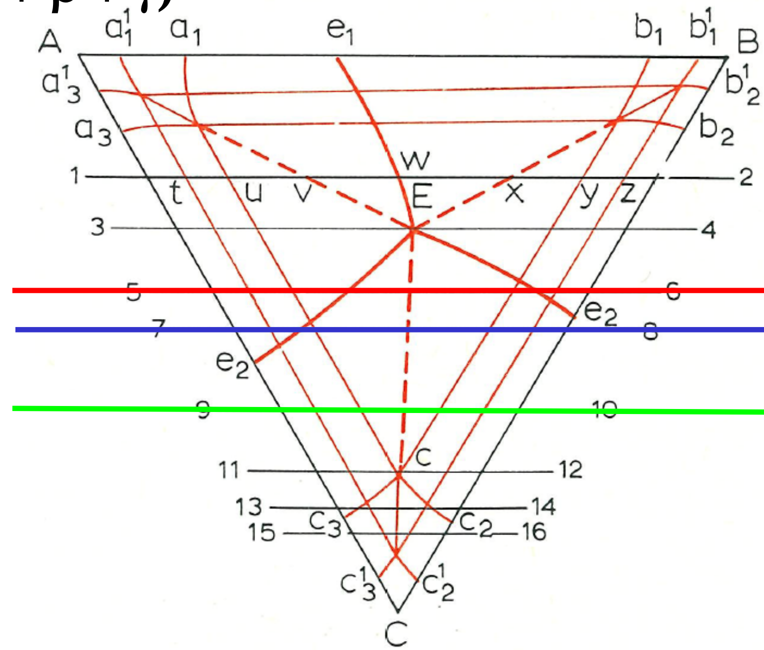


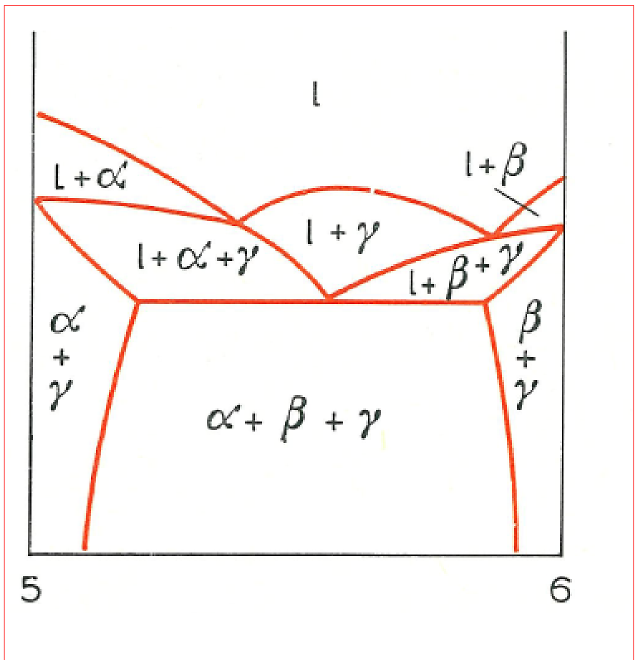


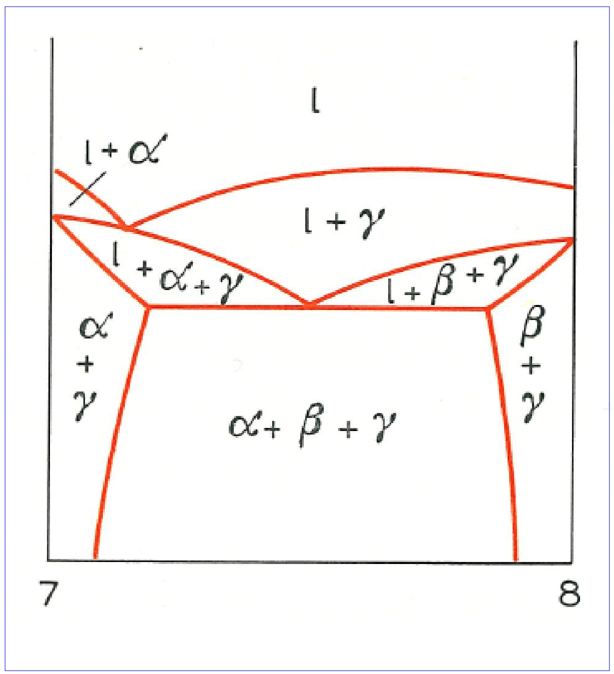


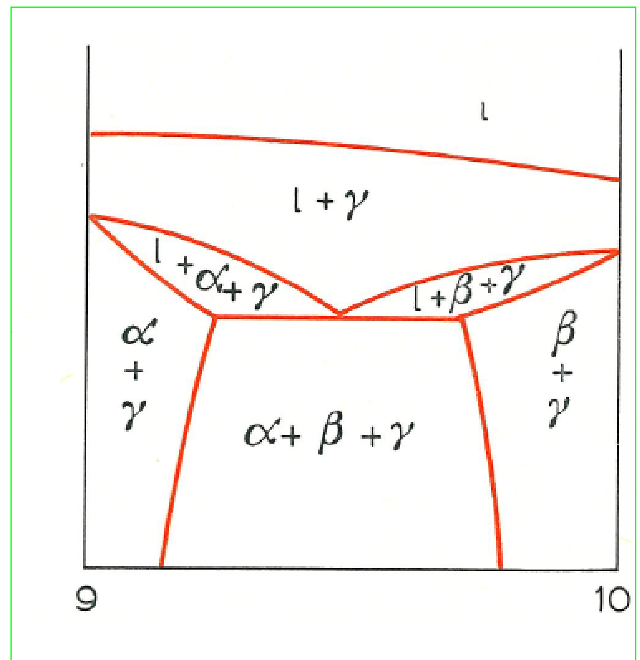
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**





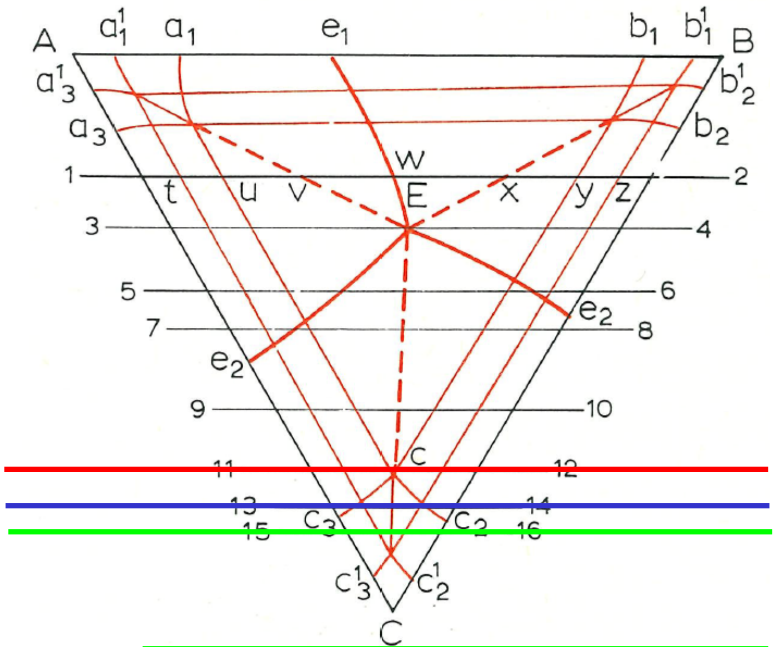


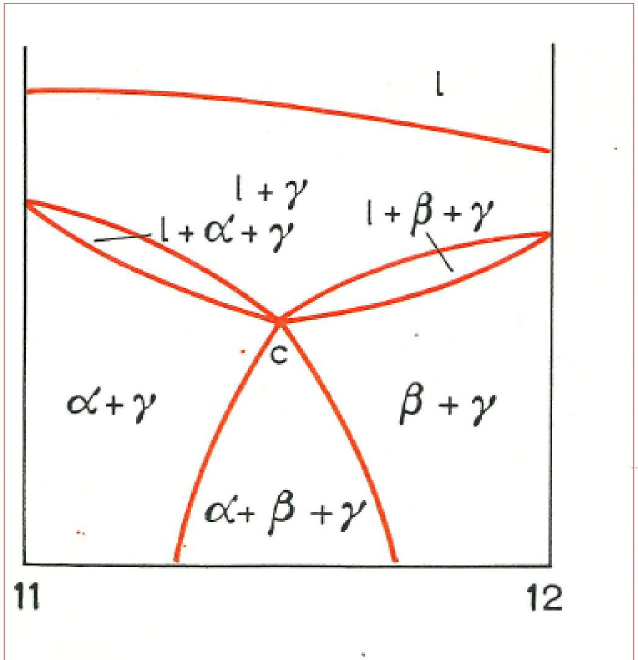


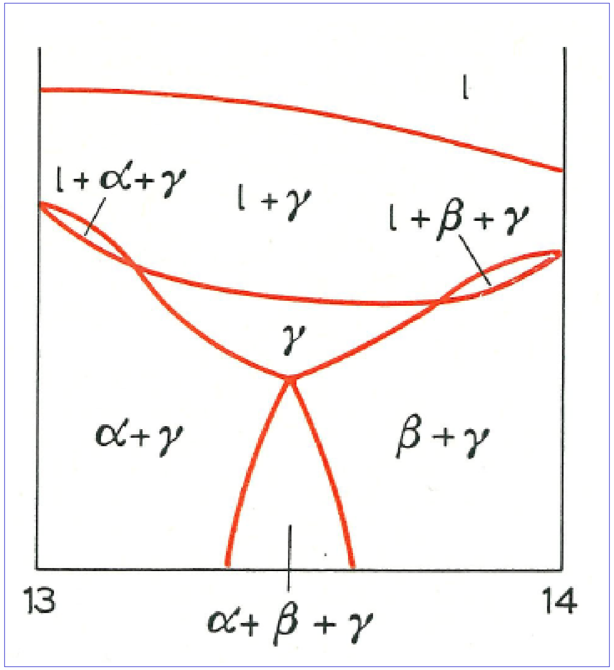
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

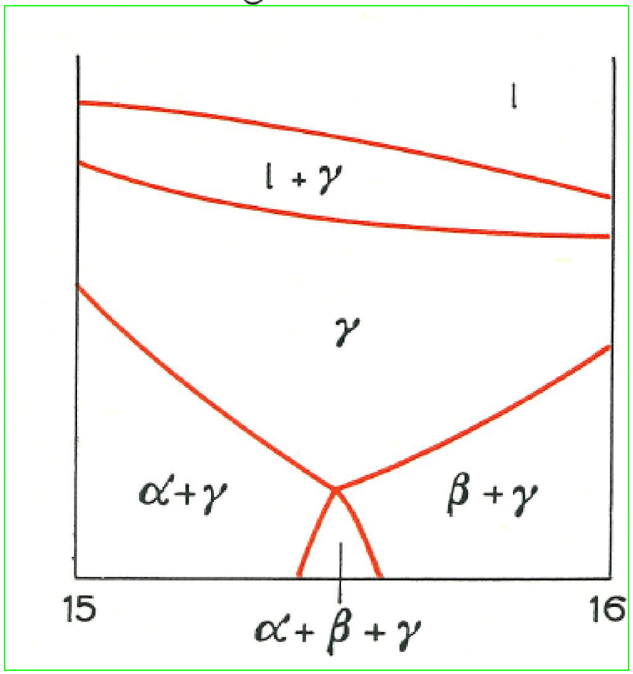
Vertical section

Location of vertical section

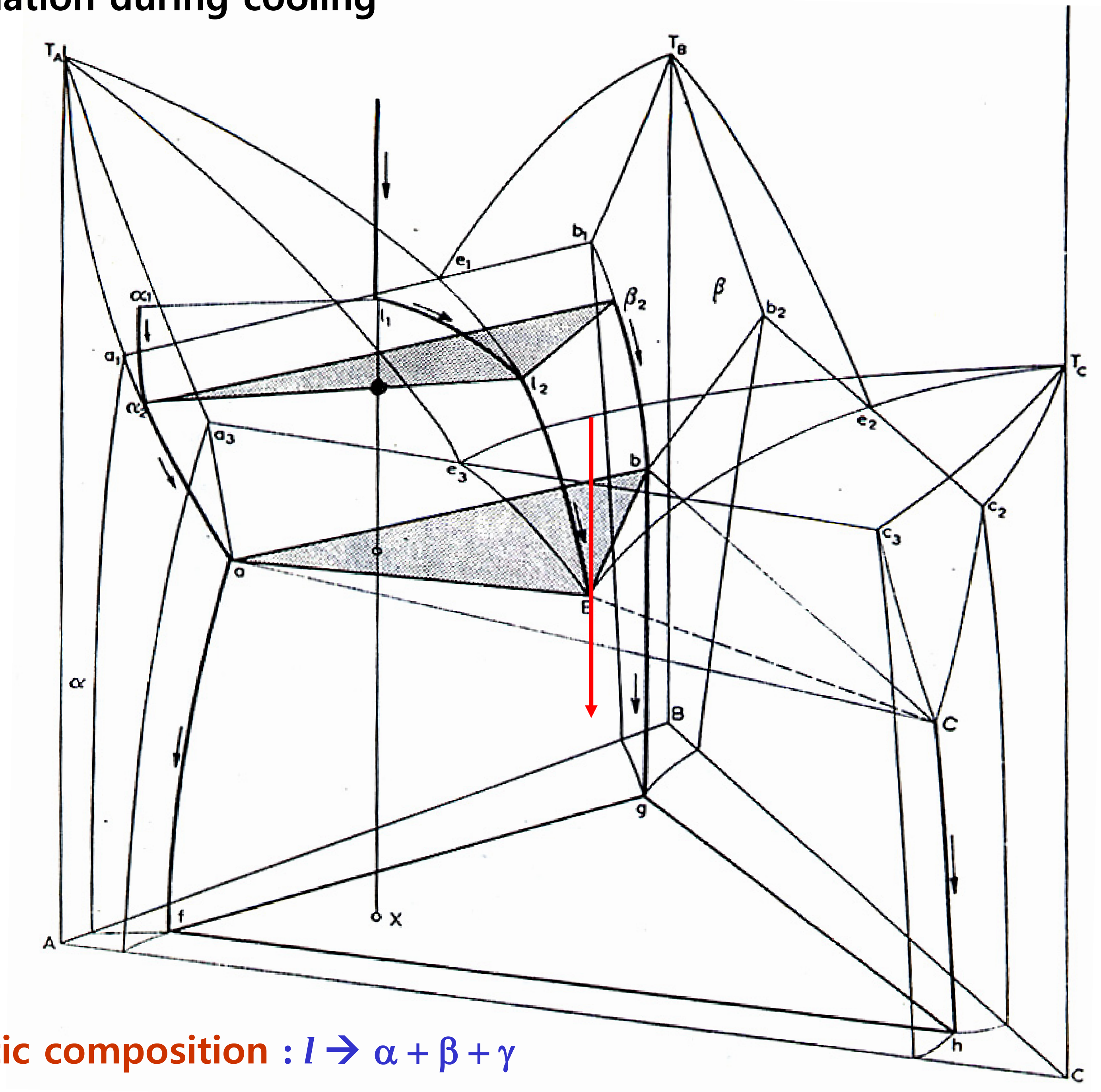








Transformation during cooling

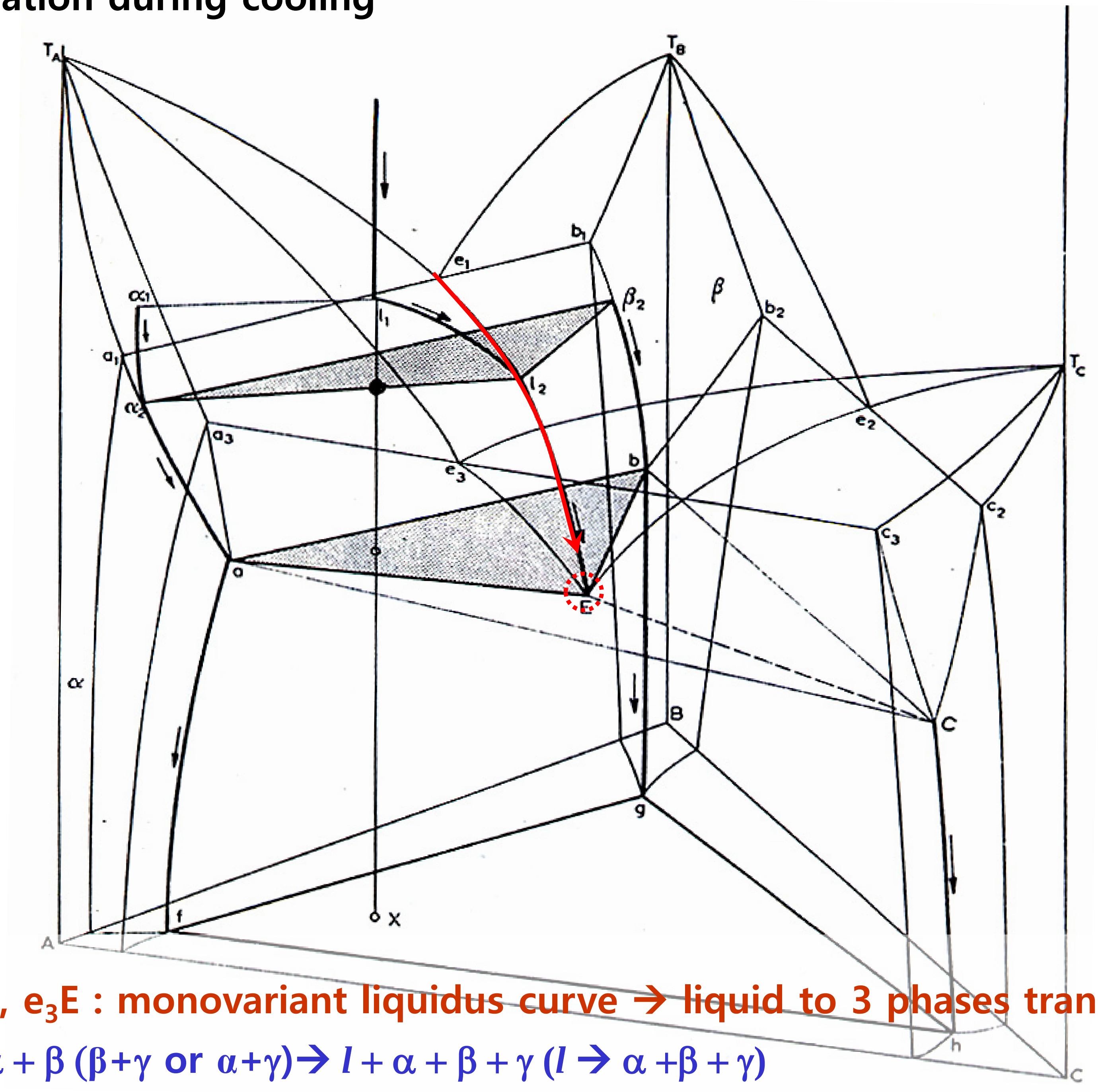


① **Eutectic composition :** $l \rightarrow \alpha + \beta + \gamma$

Ternary Eutectic microstructure

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

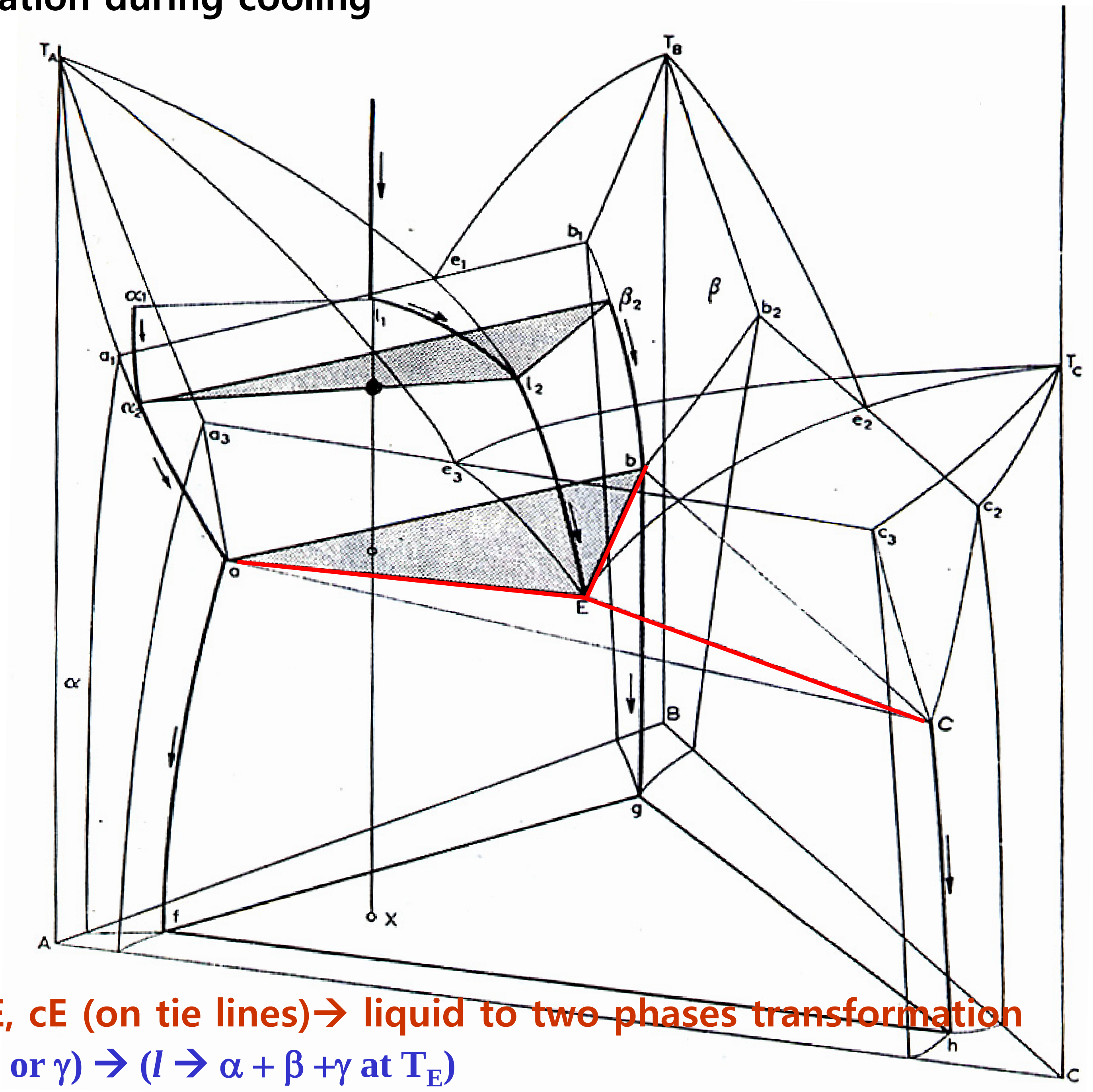
Transformation during cooling



② e_1E, e_2E, e_3E : monovariant liquidus curve → liquid to 3 phases transformation

: $l \rightarrow l + \alpha + \beta$ ($\beta+\gamma$ or $\alpha+\gamma$) $\rightarrow l + \alpha + \beta + \gamma$ ($l \rightarrow \alpha + \beta + \gamma$)

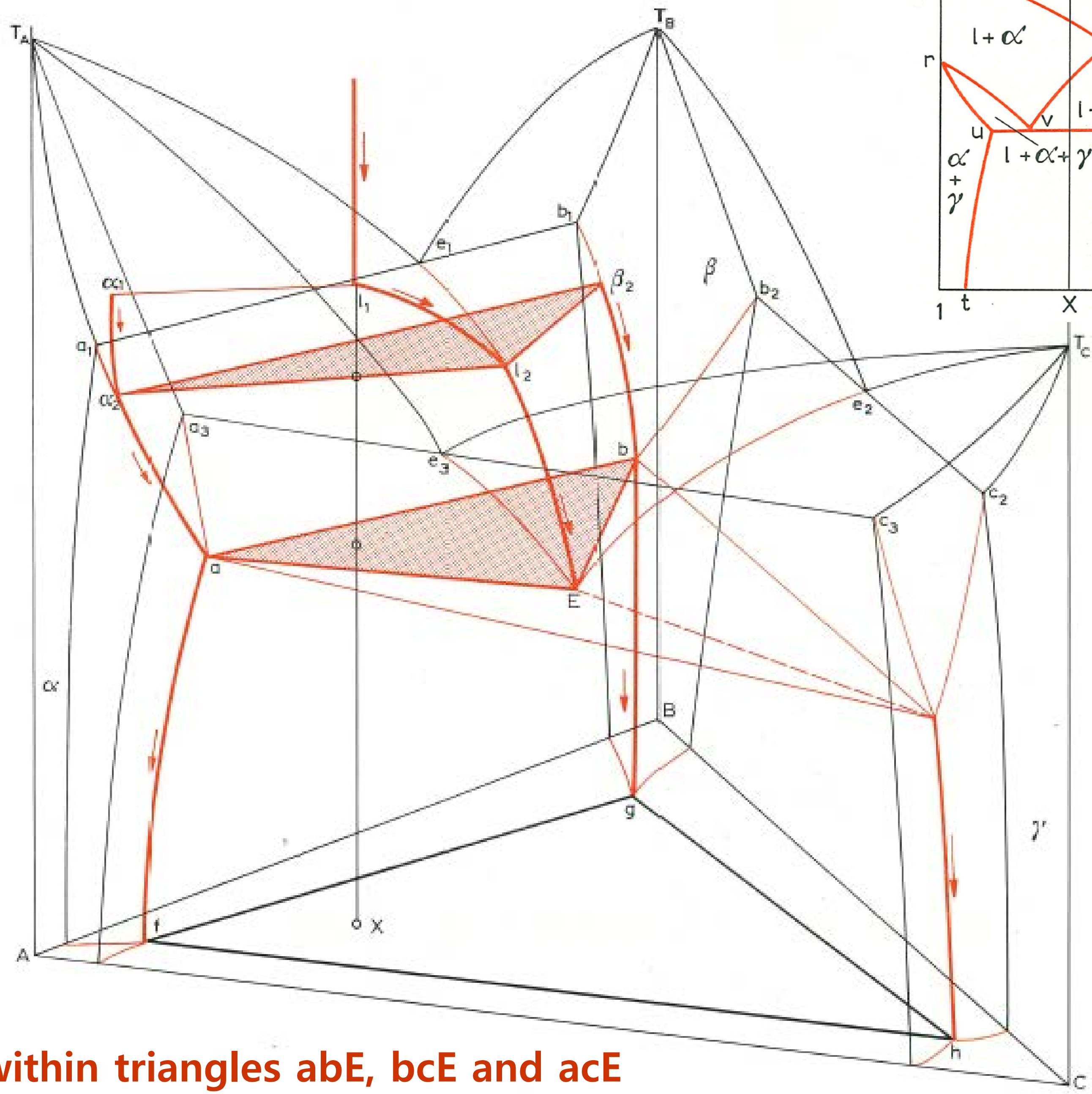
Transformation during cooling

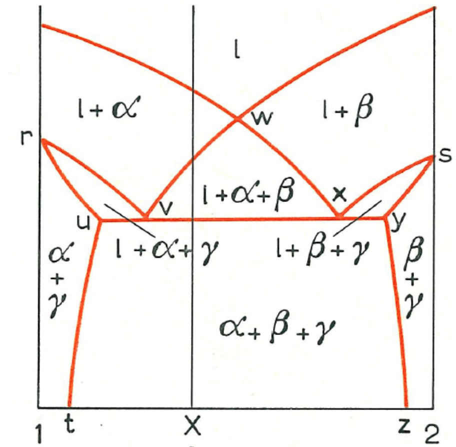


③ aE, bE, cE (on tie lines)→ liquid to two phases transformation

: $l + \alpha$ (β or γ) → ($l \rightarrow \alpha + \beta + \gamma$ at T_E)

Transformation during cooling



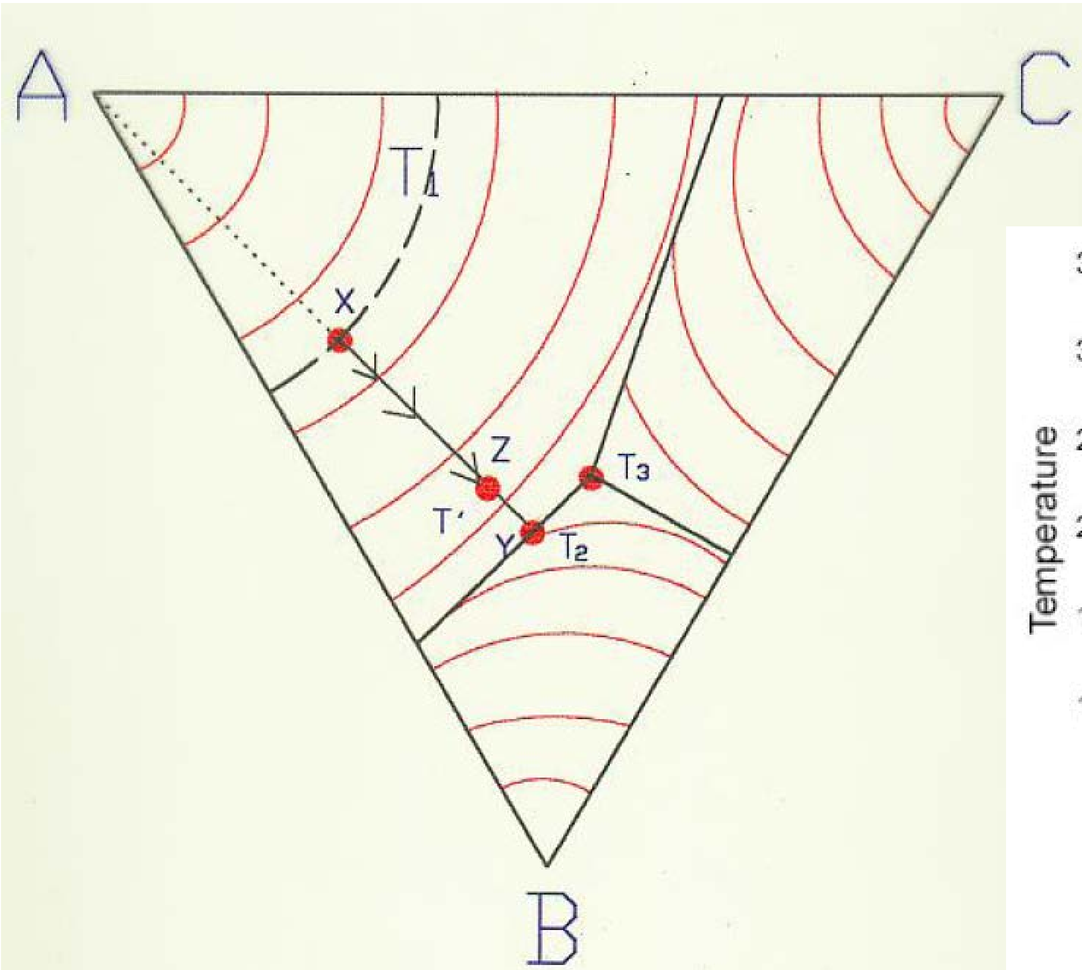


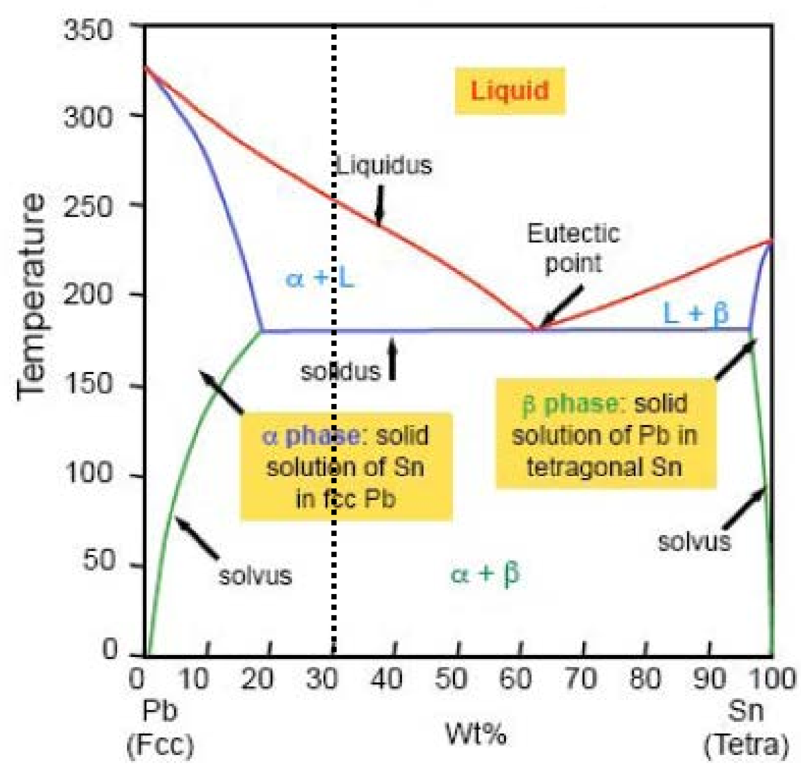
④ Alloys within triangles abE, bcE and acE

ex) abE: $l + \alpha$ (or β) $\rightarrow l + \alpha + \beta \rightarrow$ ($l \rightarrow \alpha + \beta + \gamma$ at T_E)

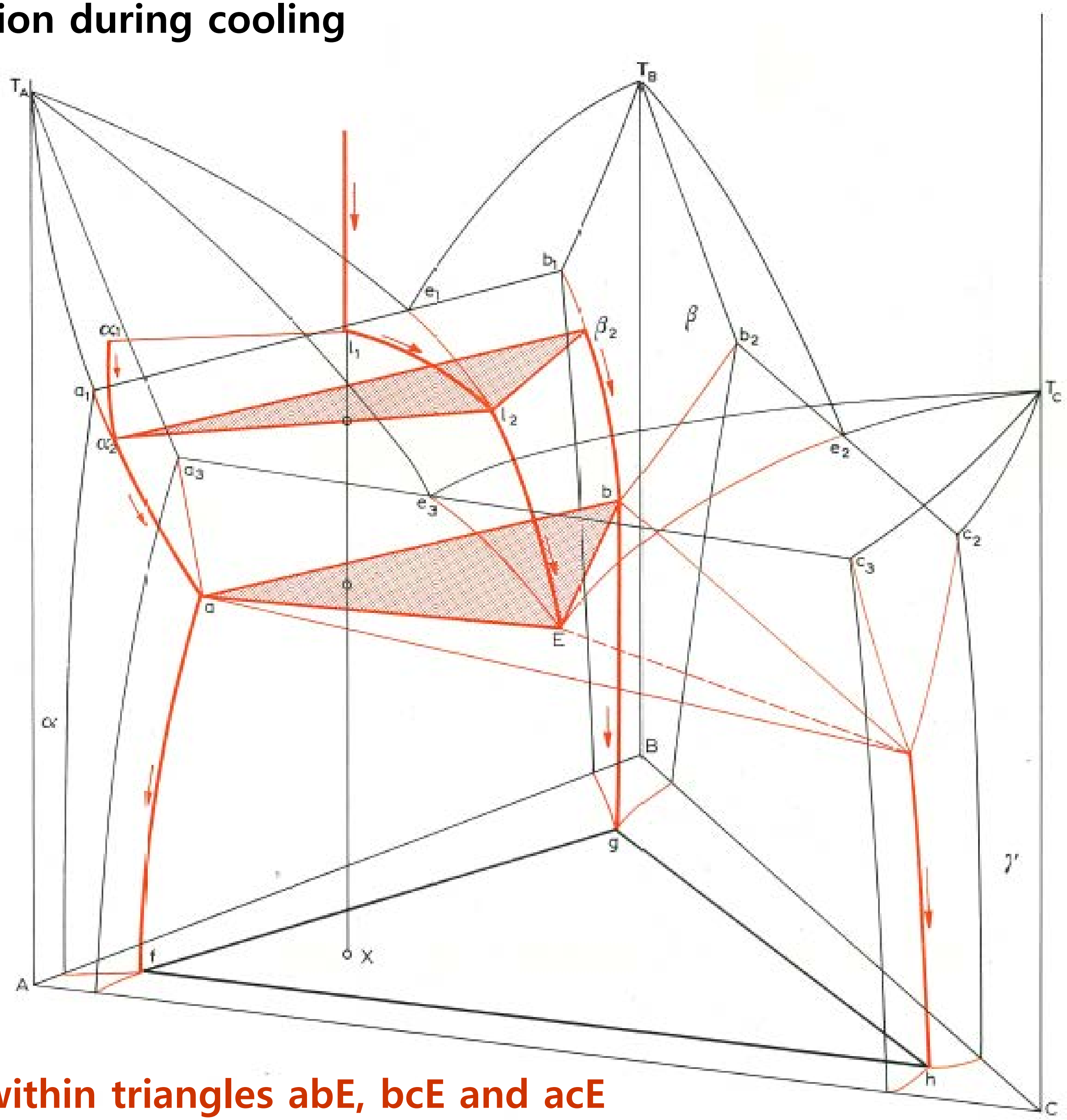
Ternary Eutectic System

Solidification Sequence





Transformation during cooling



④ Alloys within triangles abE, bcE and acE

ex) abE: $l + \alpha$ (or β) → $l + \alpha + \beta$ → ($l \rightarrow \alpha + \beta + \gamma$ at T_E)