2017 Fall

"Phase Equilibria *in* Materials"

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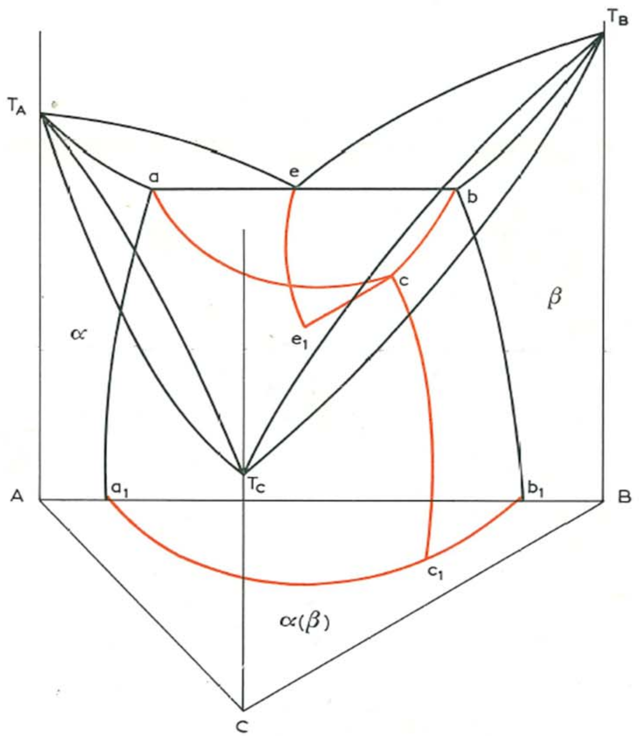
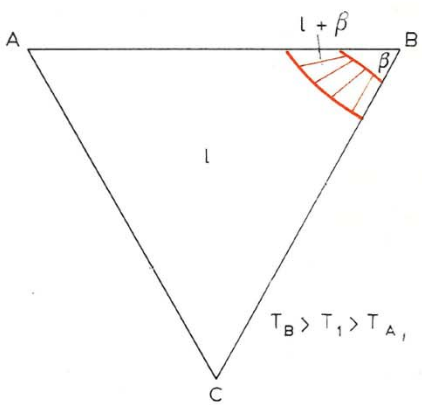
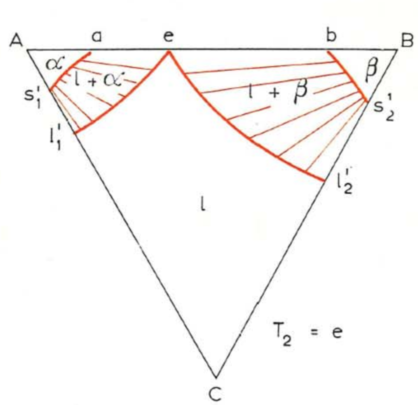
9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Isothermal section**

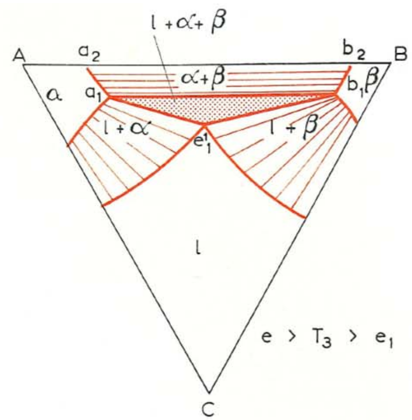




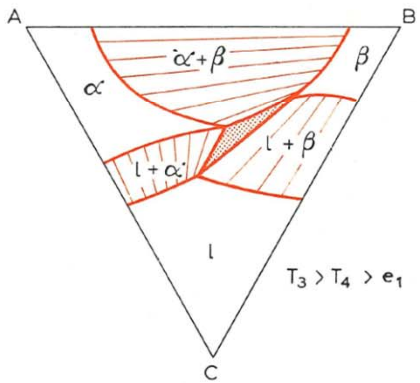
$T_B > T_1 > T_A$



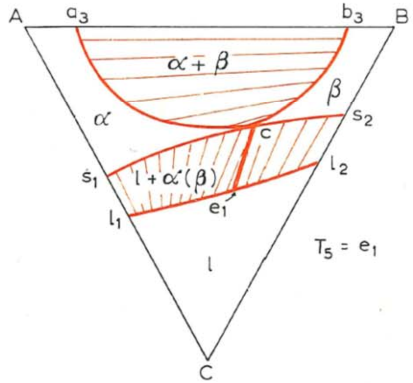
$T_2 = e$



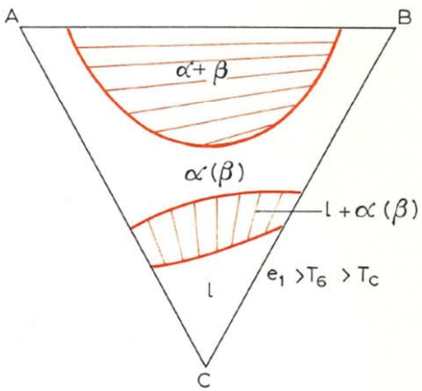
$e > T_3 > e_1$



$T_3 > T_4 > e_1$



$T_5 = e$

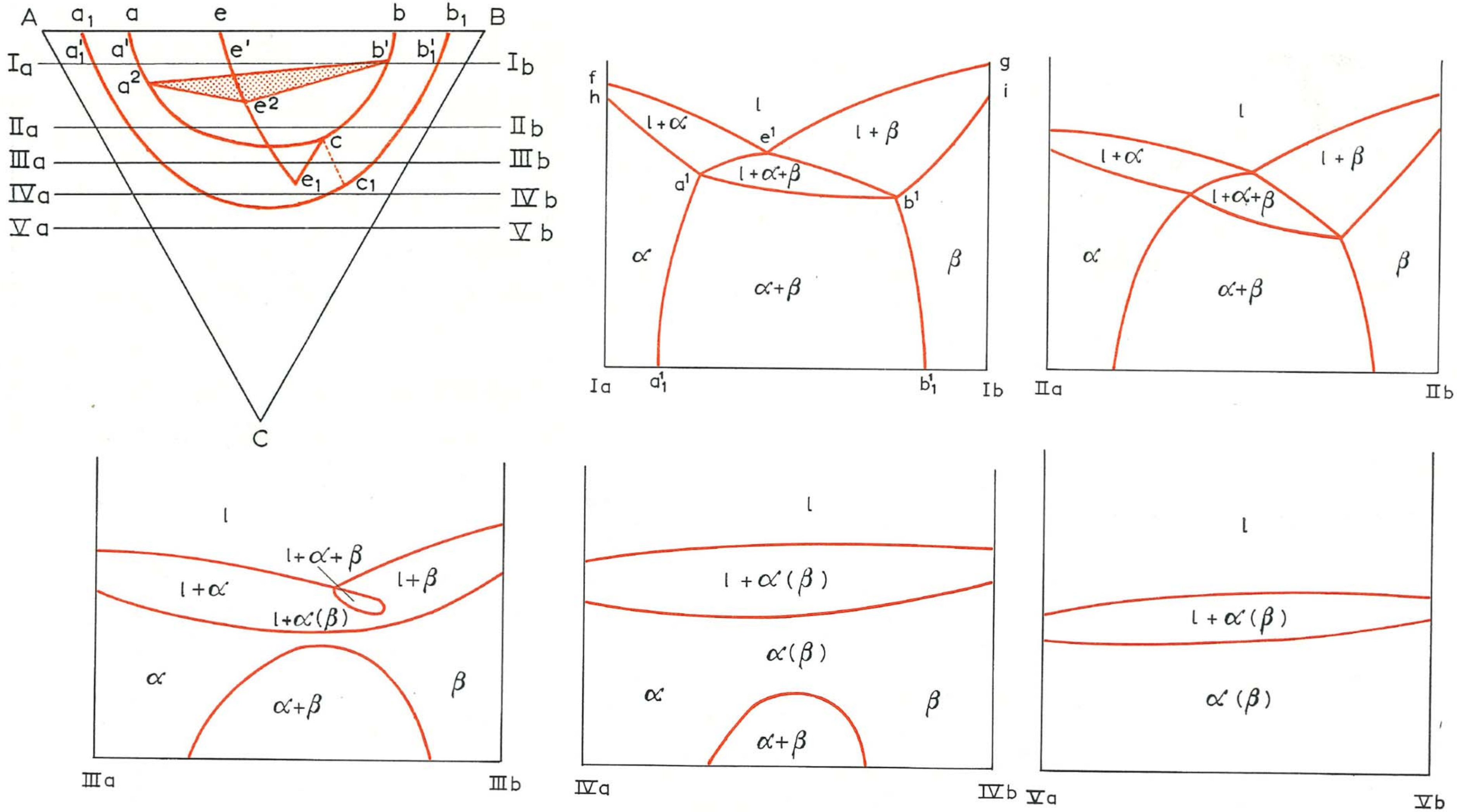


$e_1 > T_6 > T_c$

cf) Movie

9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Vertical section**



> Point 1: 4 on the α solidus surface

> Point 1- Point 2

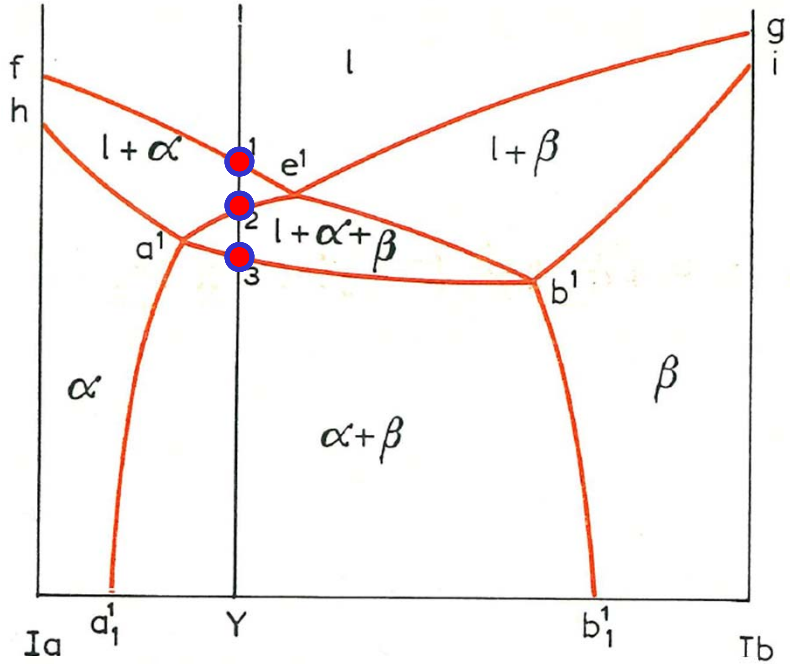
* 4→6 on the α solidus surface
* 1→5 on the α liquidus surface

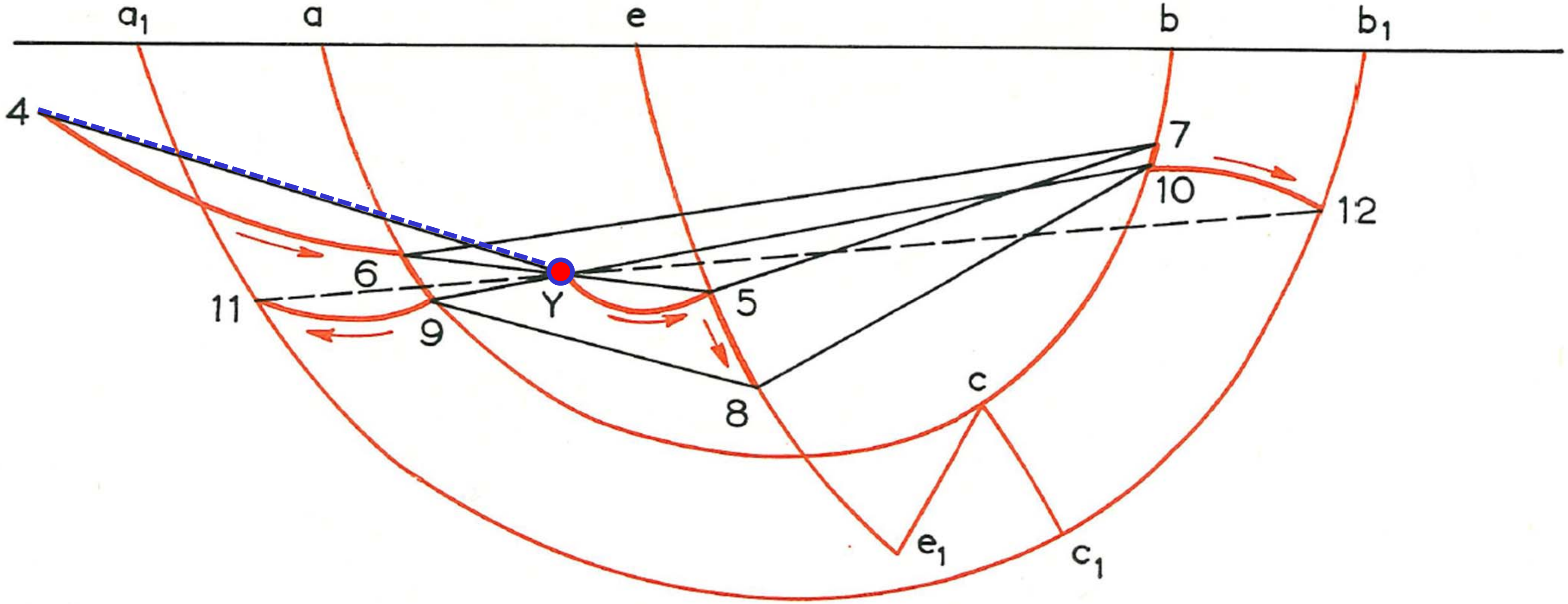
Three phase equilibrium l5, α6, β7

* 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

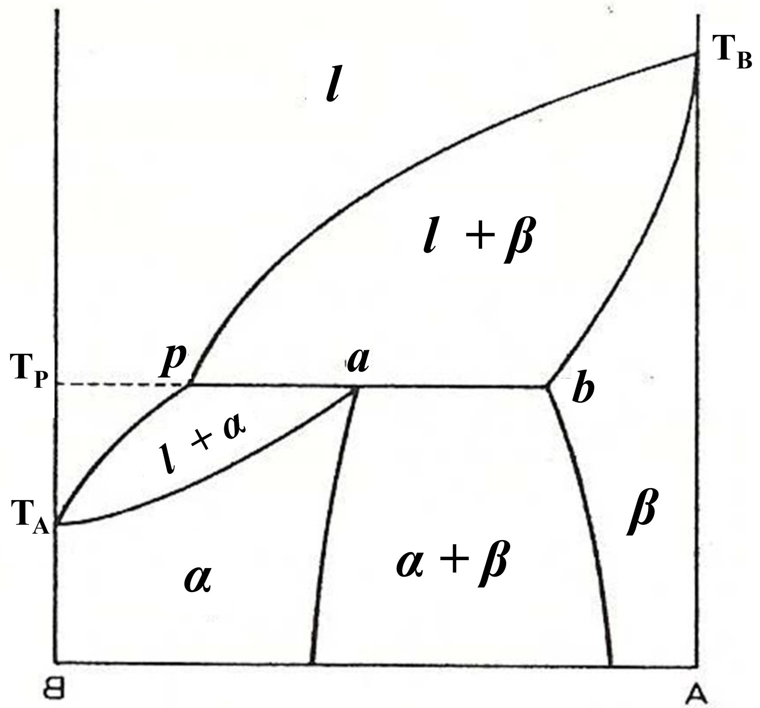


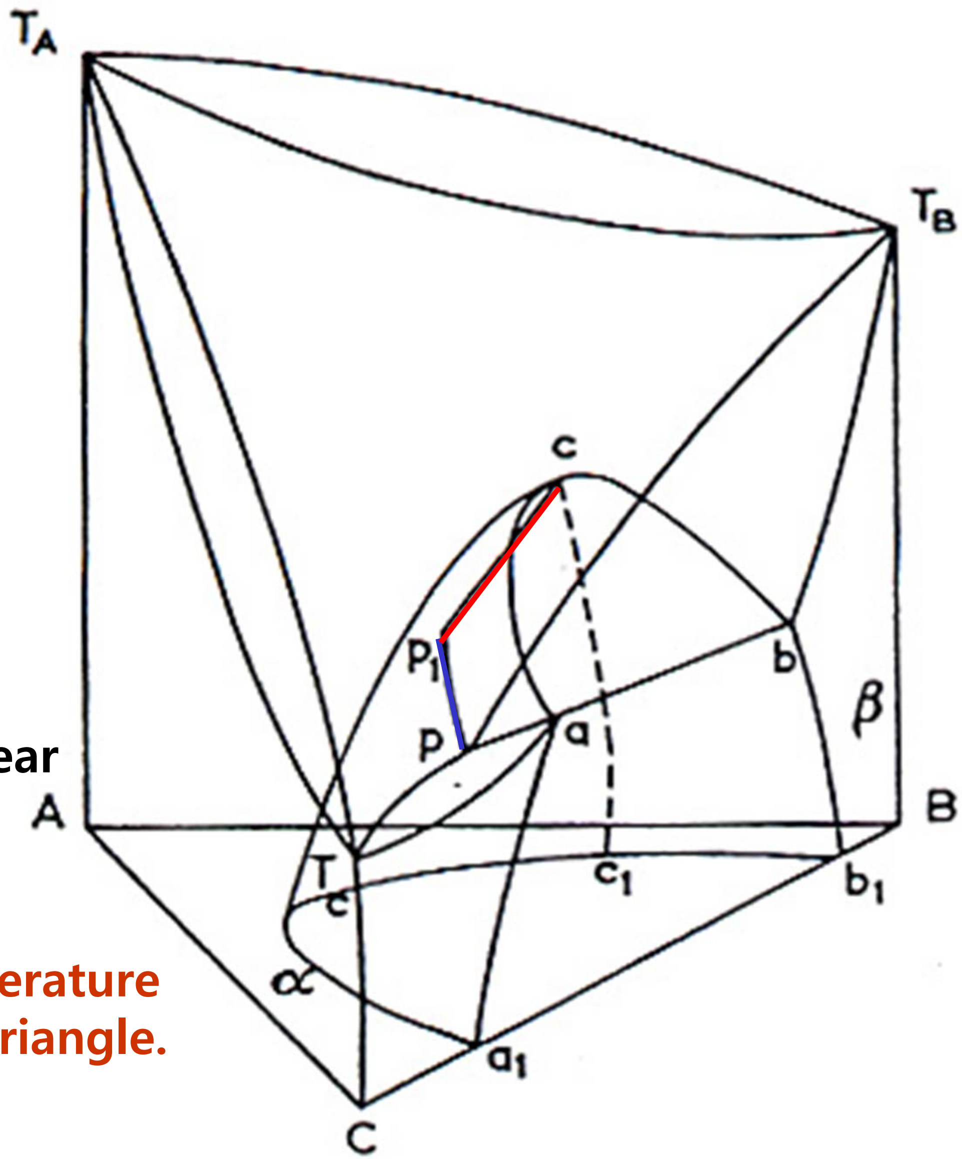


Projection of the solidification sequence for alloy Y on the concentration triangle

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- A peritectic solubility gap in one binary system





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

PP_1: monovariant curve for liquid

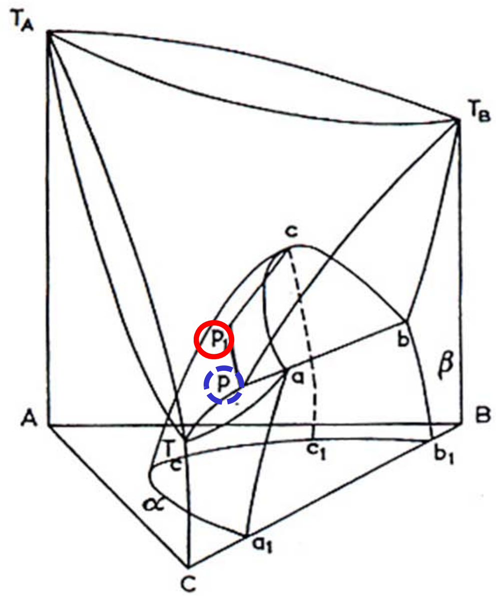
Points P_1 and c lie at the same temperature and the line P_1c is a degenerate tie triangle.

9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

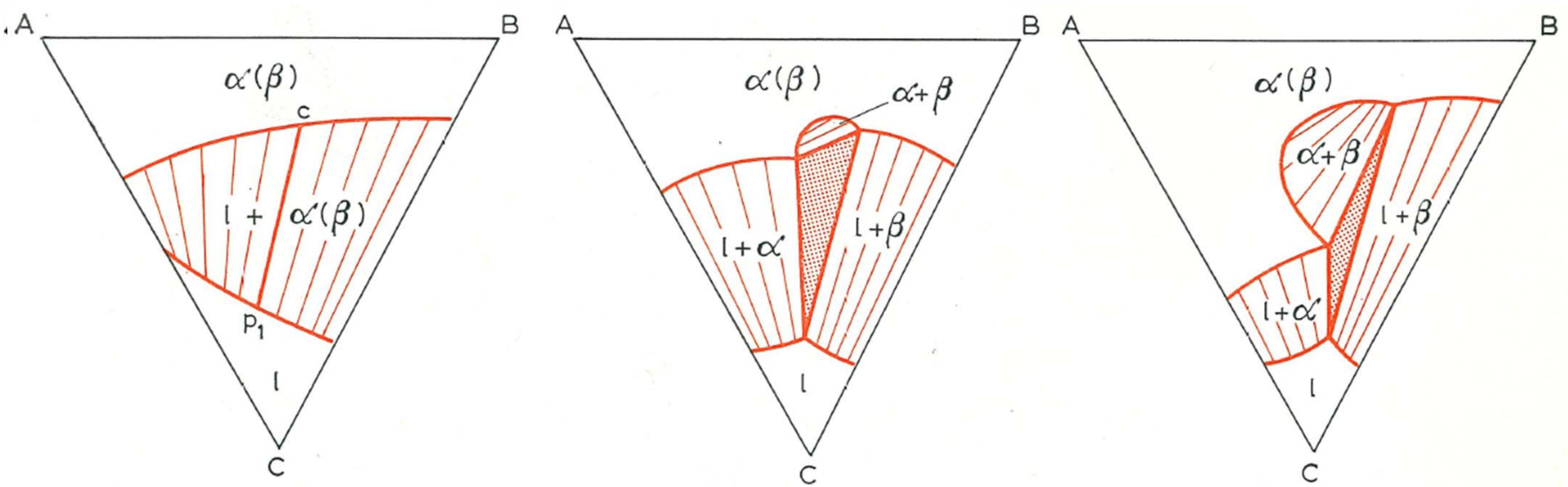
- A peritectic solubility gap in one binary system

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.



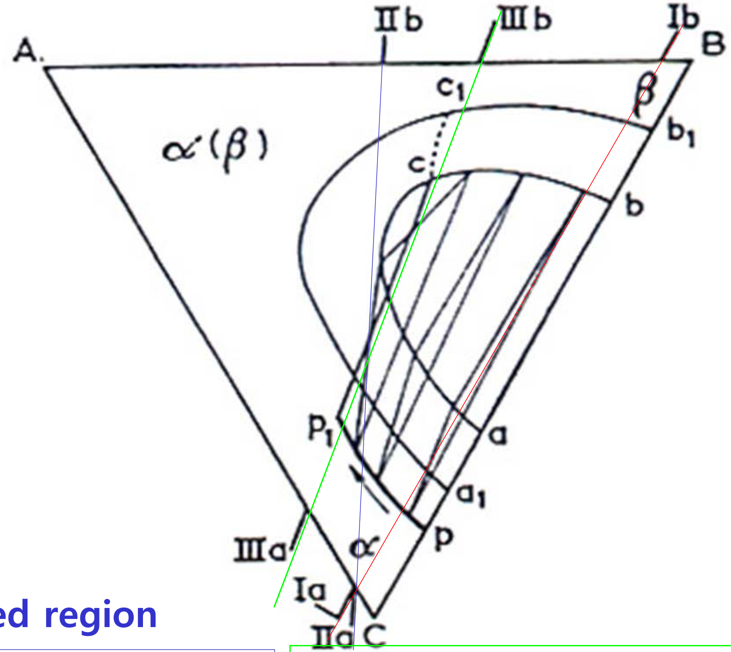
isothermal section



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

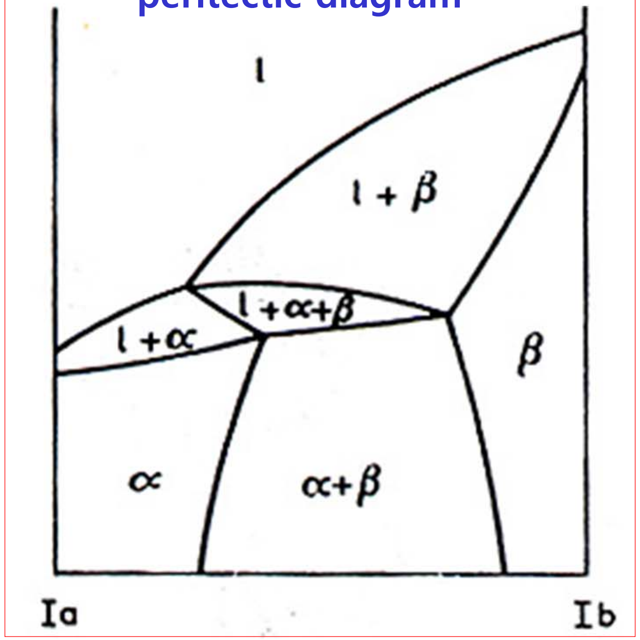
9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

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

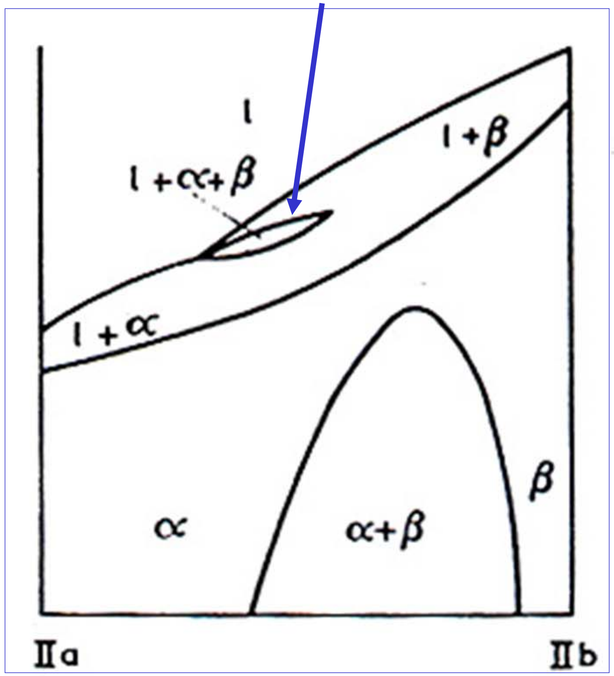


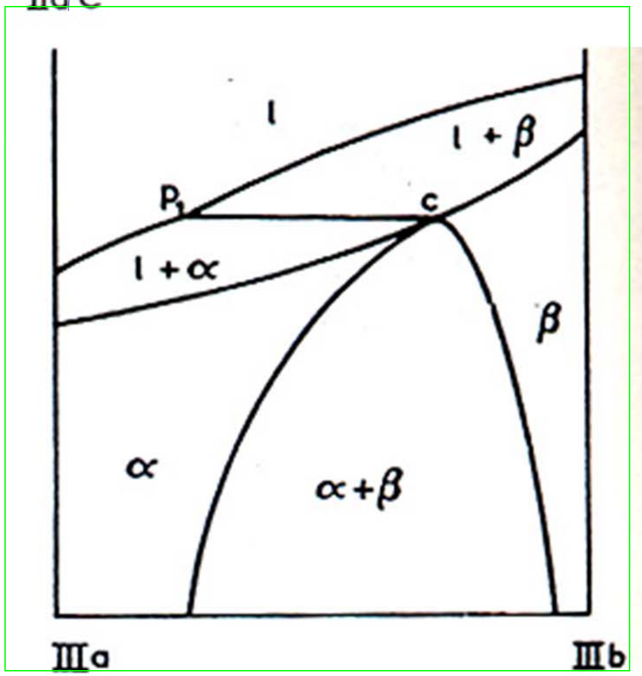
<vertical section>

Similar to the binary peritectic diagram



loop shaped region

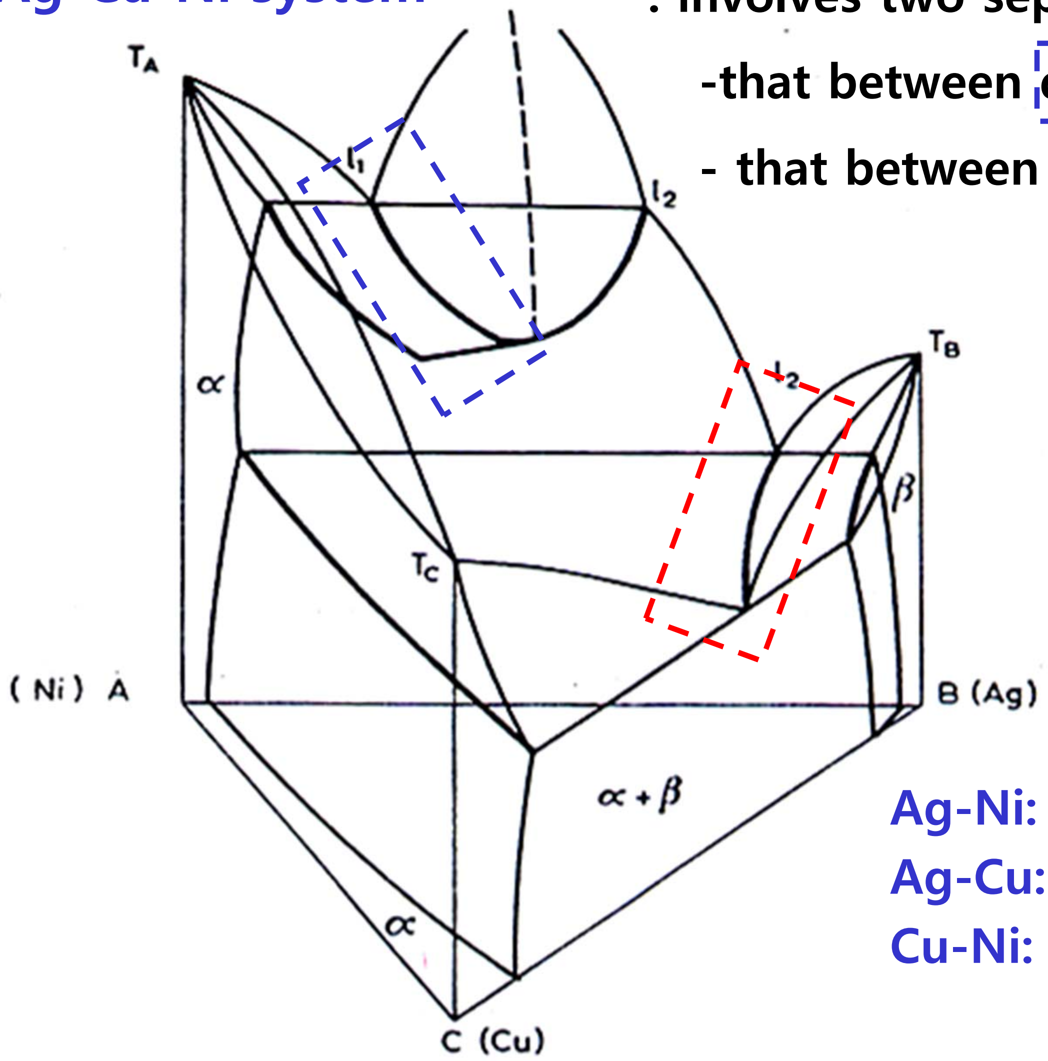




9.4. THREE-PHASE EQUILIBRIUM INVOLVING PERITECTIC REACTIONS

- **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 $\boxed{\alpha, l_1 \text{ and } l_2,}$ and

- that between $\boxed{\alpha, \beta \text{ and } l_2}$

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

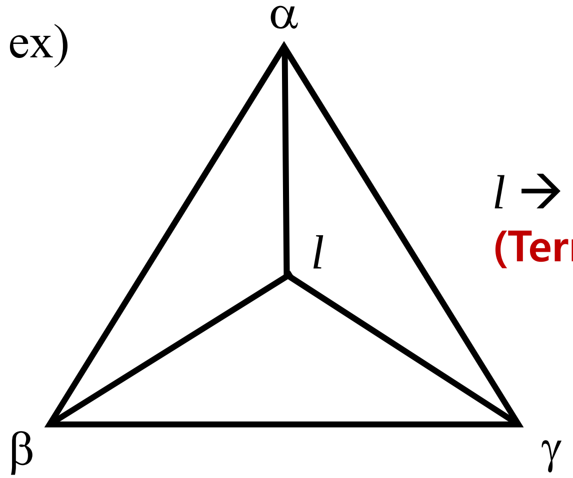
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

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

ex)

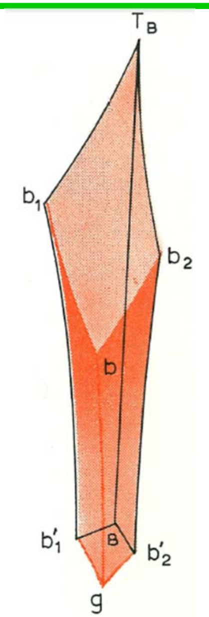


$l \rightarrow \alpha + \beta + \gamma$
(Ternary eutectic)

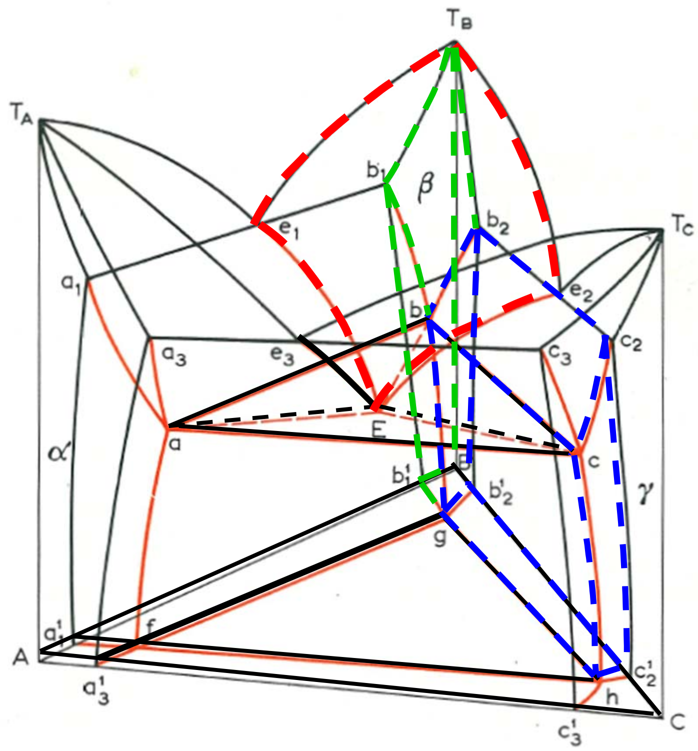
cf) $l + \alpha \rightarrow \beta + \gamma$: **ternary quasi-peritectic**
$l + \alpha + \beta \rightarrow \gamma$: **ternary peritectic**

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

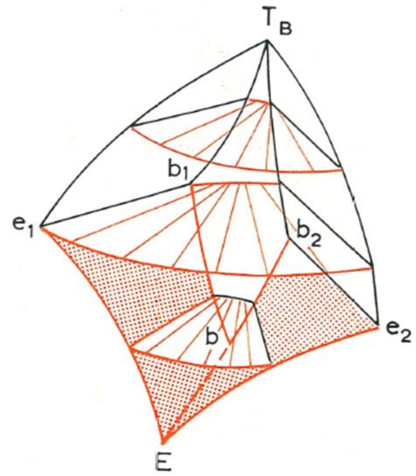
Ternary eutectic



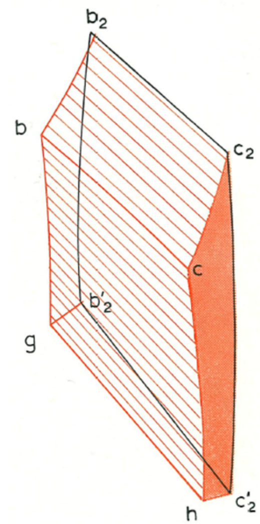
β phase region



(a)



(l + β) phase region

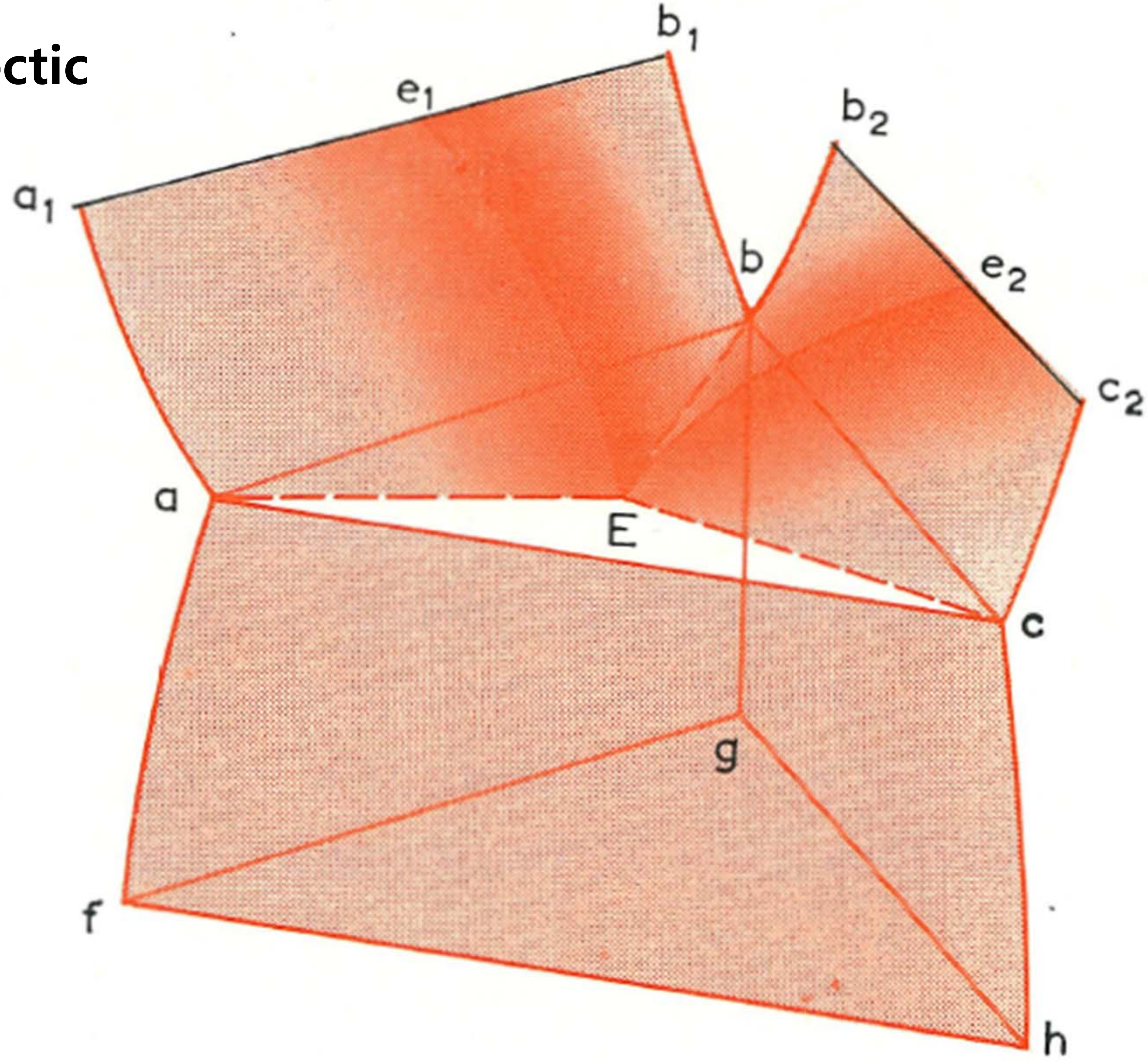


(β + γ) phase region

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

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

Ternary eutectic

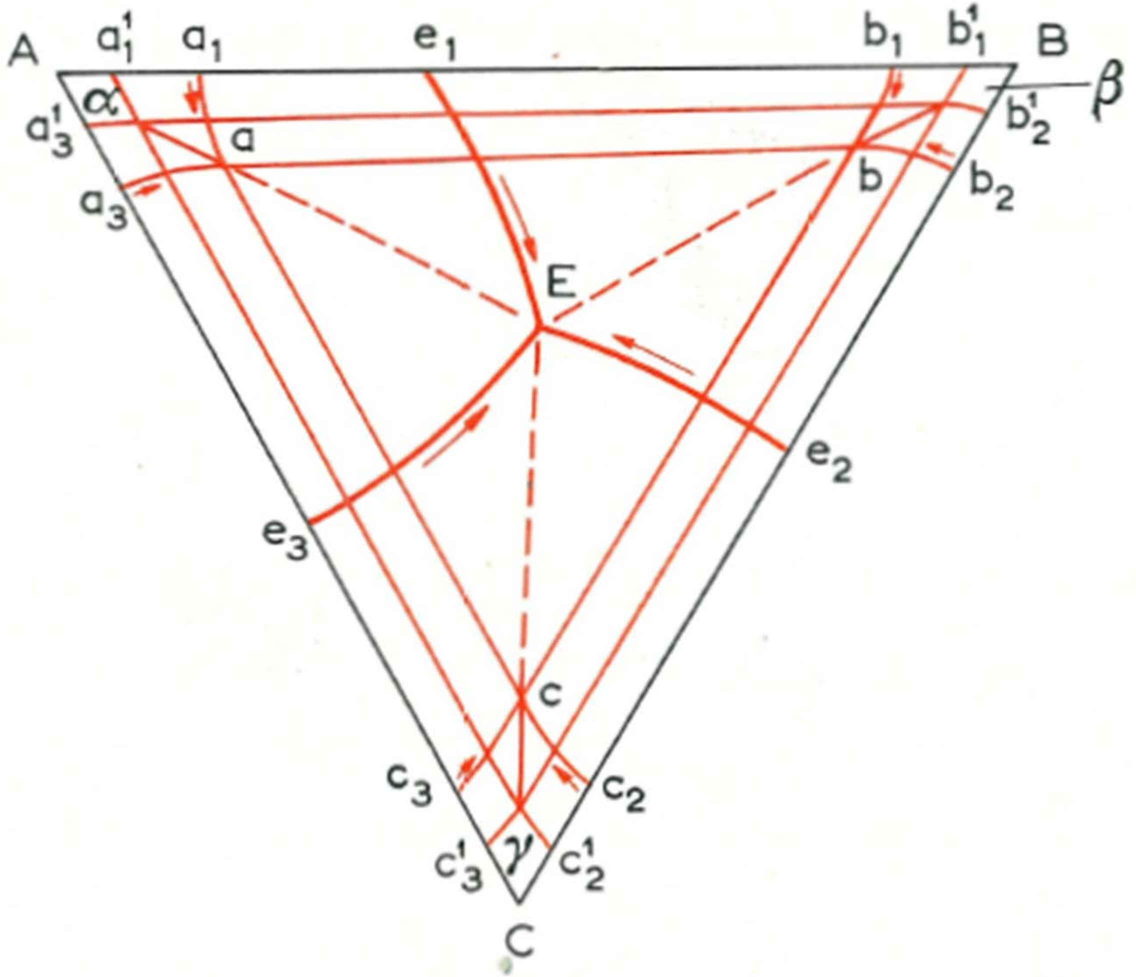


The eutectic four-phase plane as the junction of four tie triangles

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

Ternary eutectic

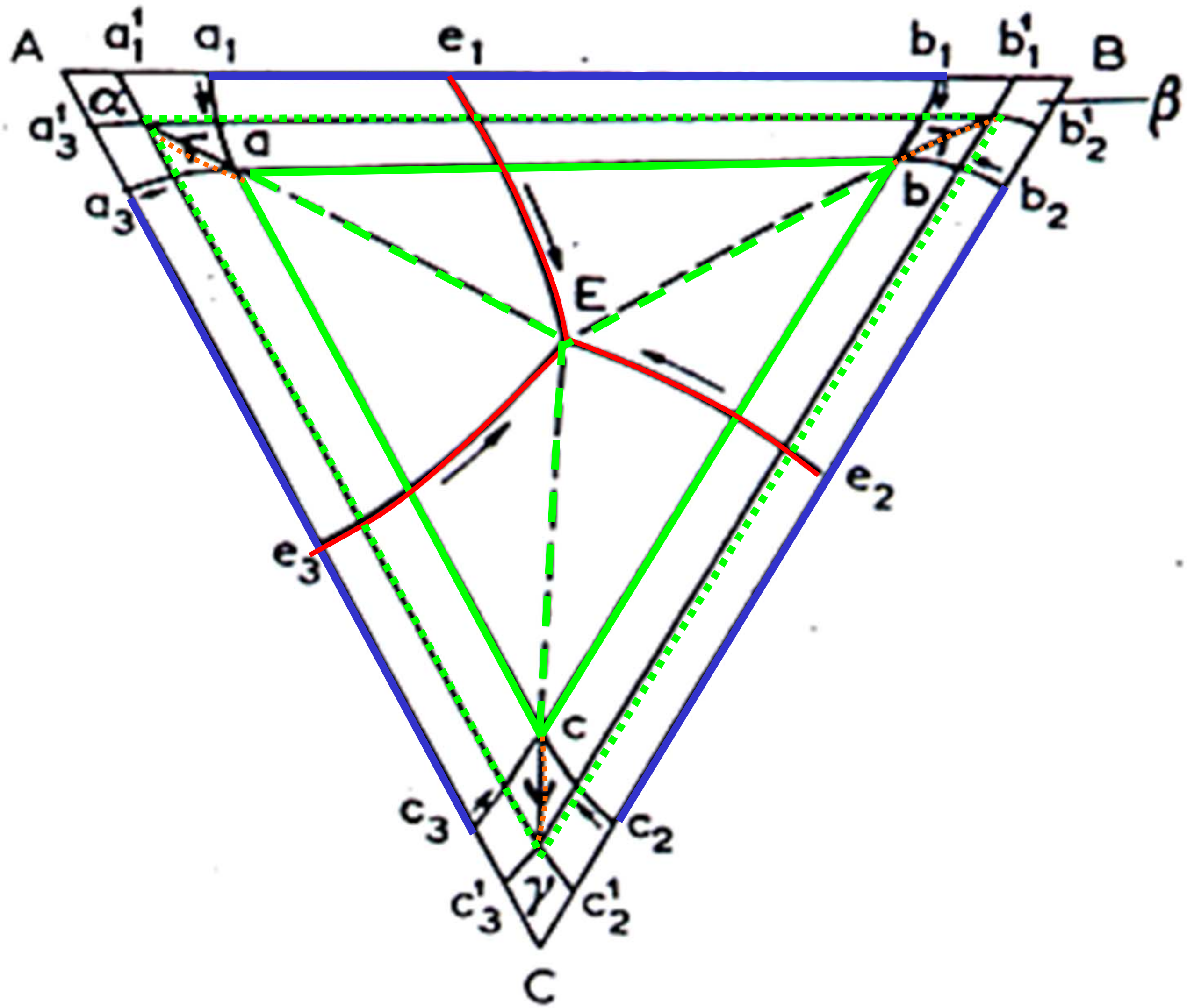
- **Projection : solid solubility limit surface**
  : monovariant liquidus curve

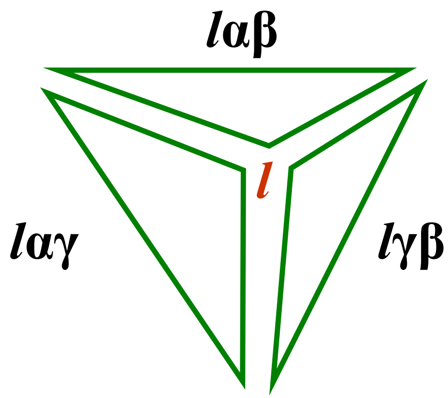


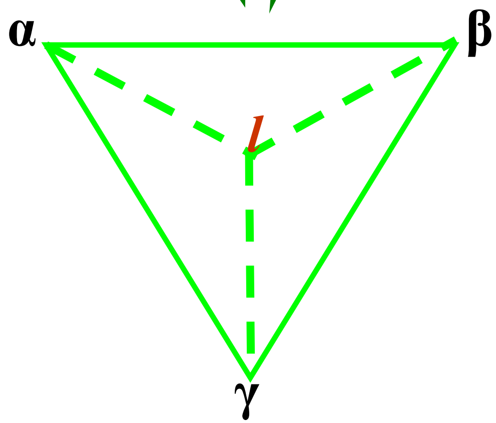
$T_A > T_B > T_C > e_1 > e_3 > e_2 > E$

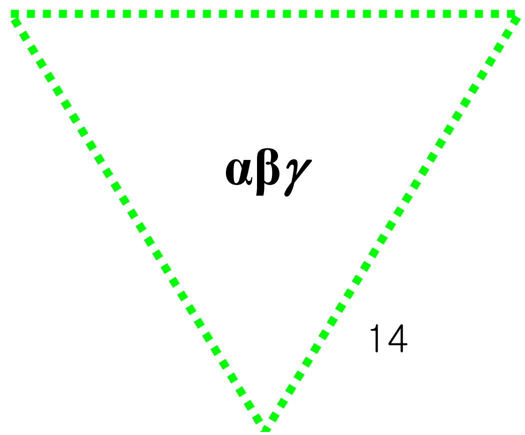
THE TERNARY EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

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



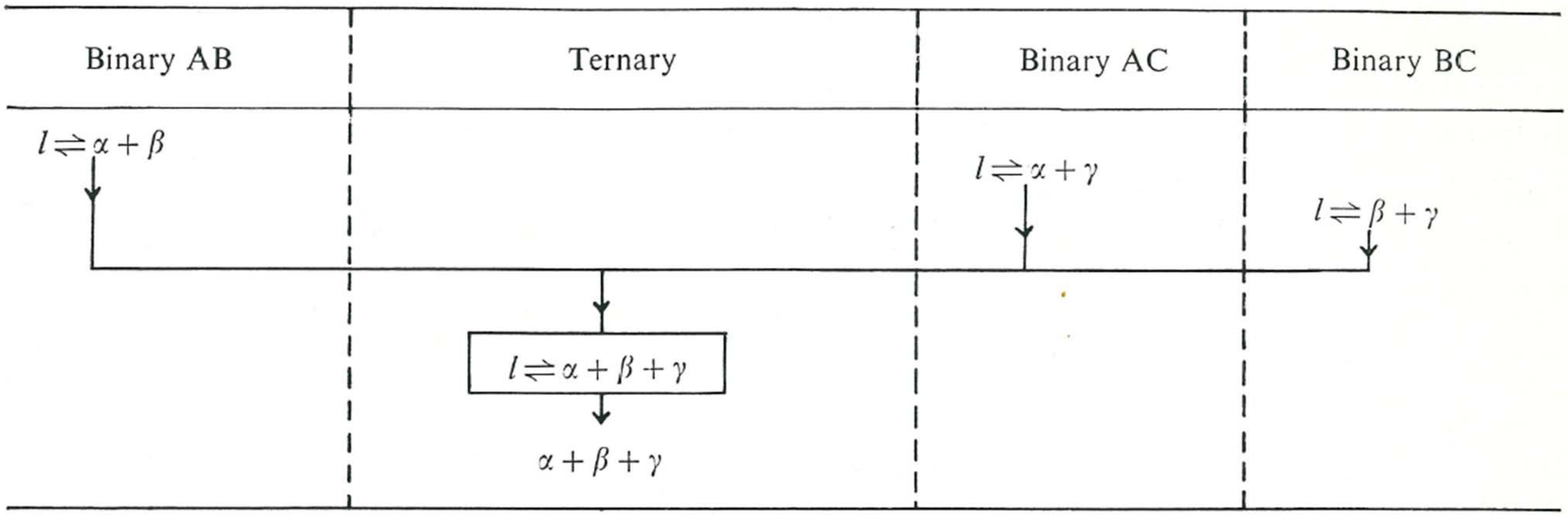




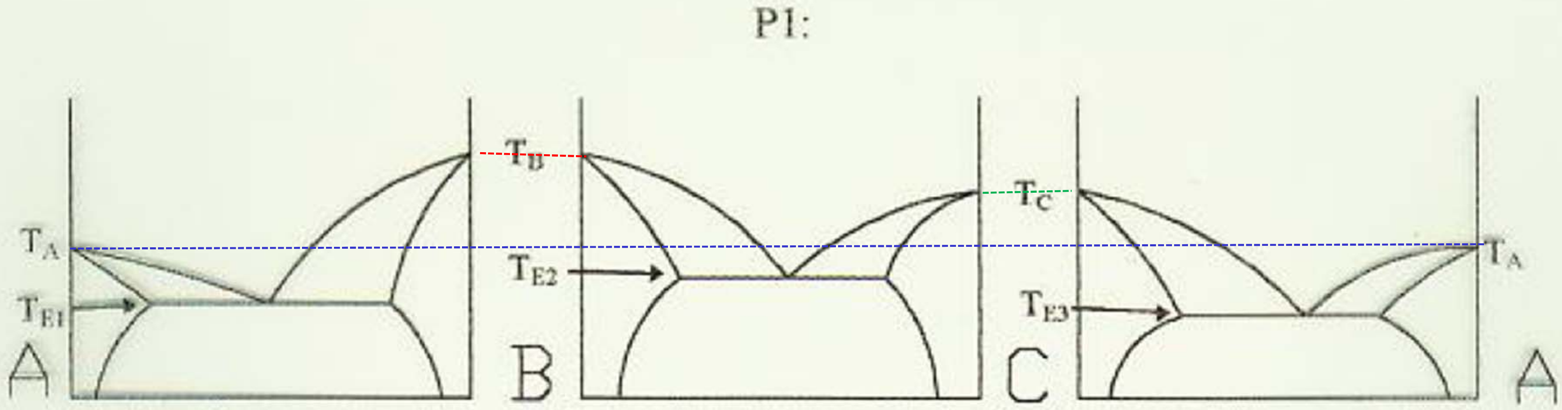


Tabular representation of ternary equilibria:
interlinks the binary and ternary reactions in tabular form

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



Ternary Eutectic System
(with Solid Solubility)



T_A: Melting Point Of Material A

T_B: Melting Point Of Material B

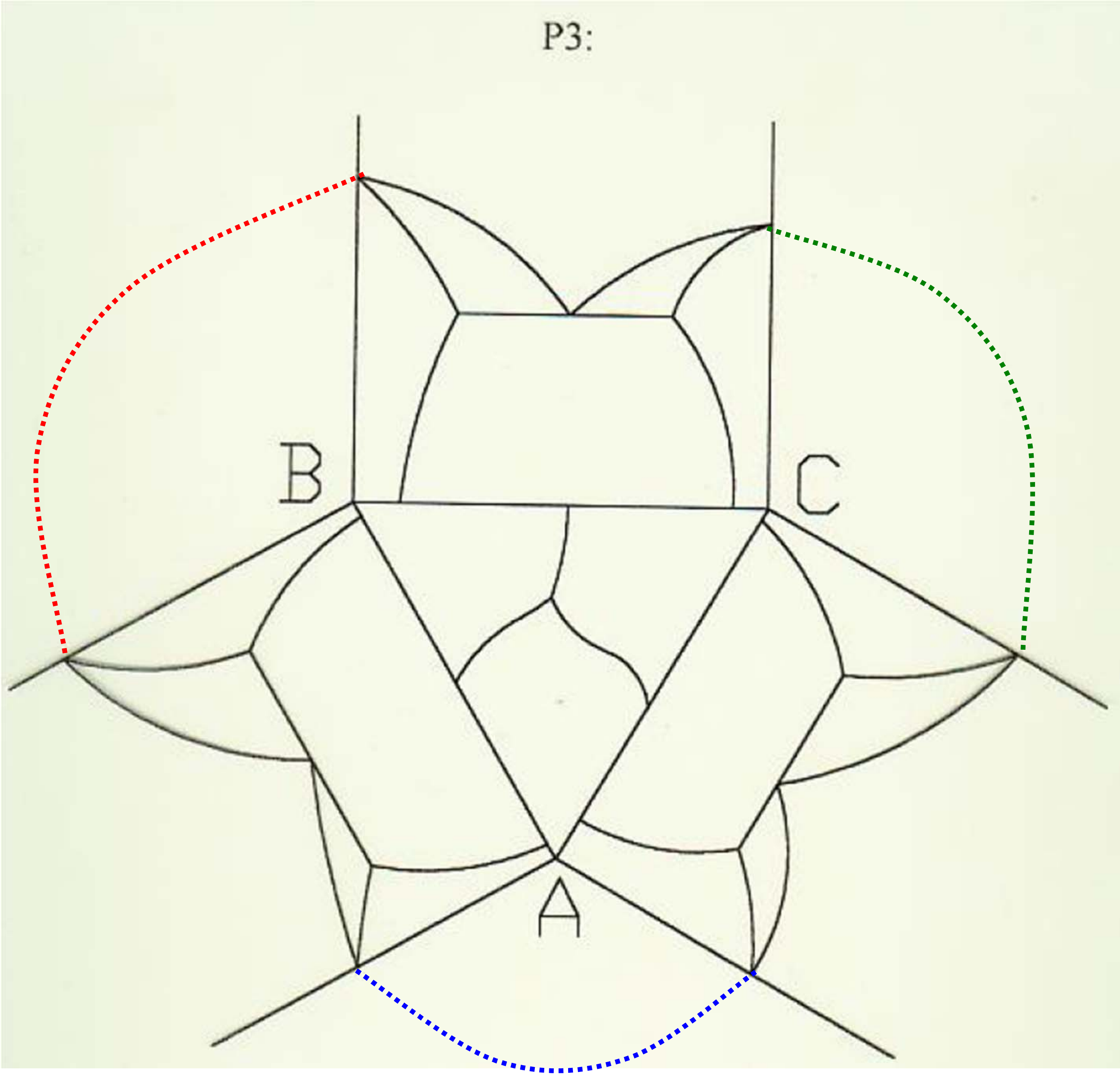
T_C: Melting Point Of Material C

T_{E1}: Eutectic Temperature Of A-B

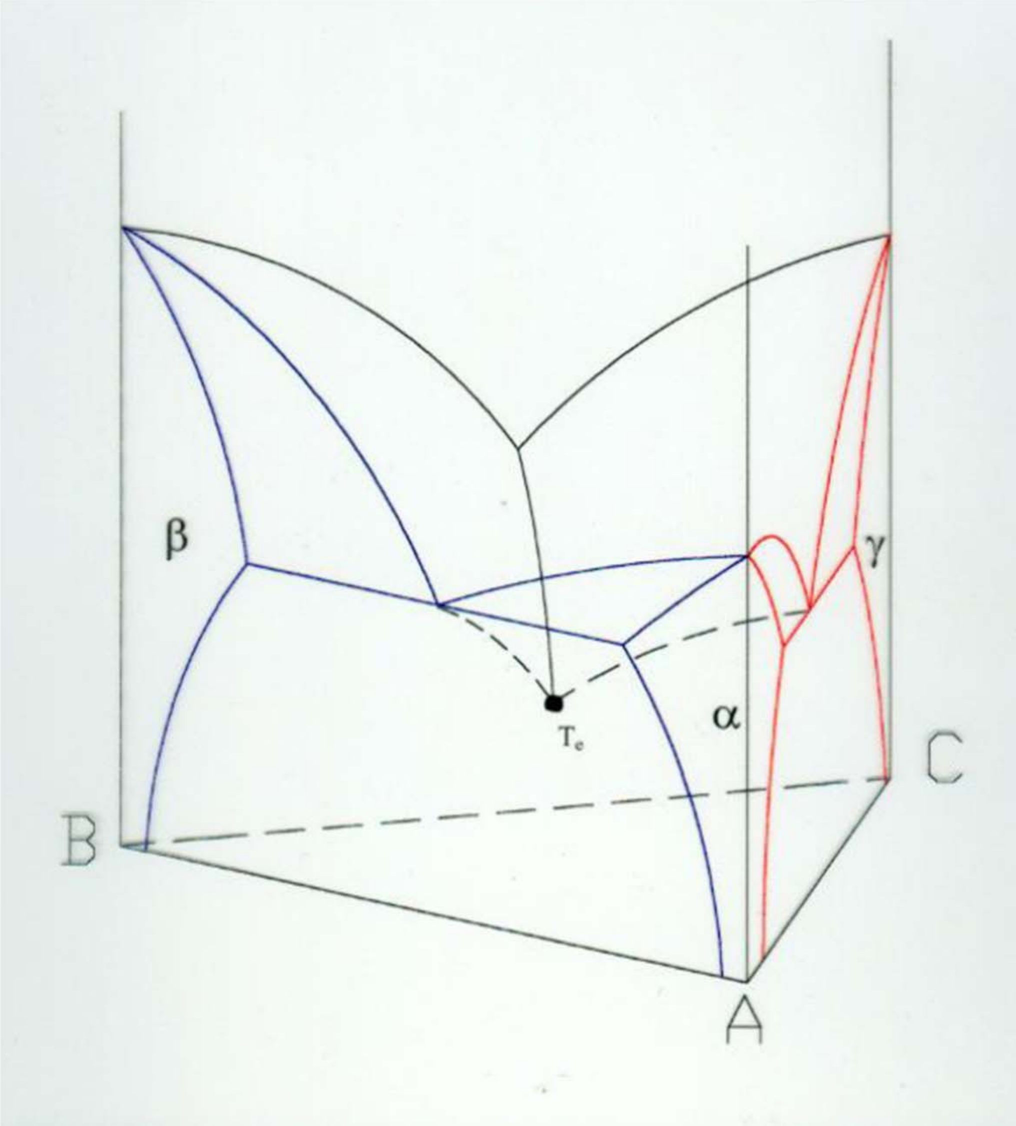
T_{E2}: Eutectic Temperature Of B-C

T_{E3}: Eutectic Temperature Of C-A

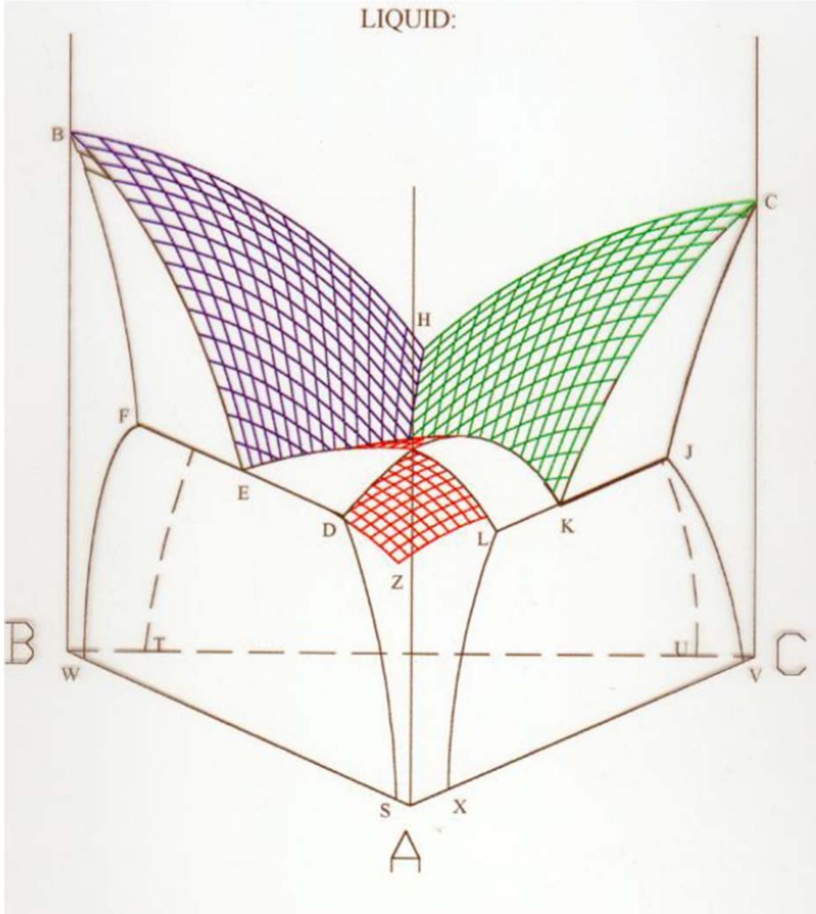
Ternary Eutectic System
(with Solid Solubility)



Ternary Eutectic System
(with Solid Solubility)

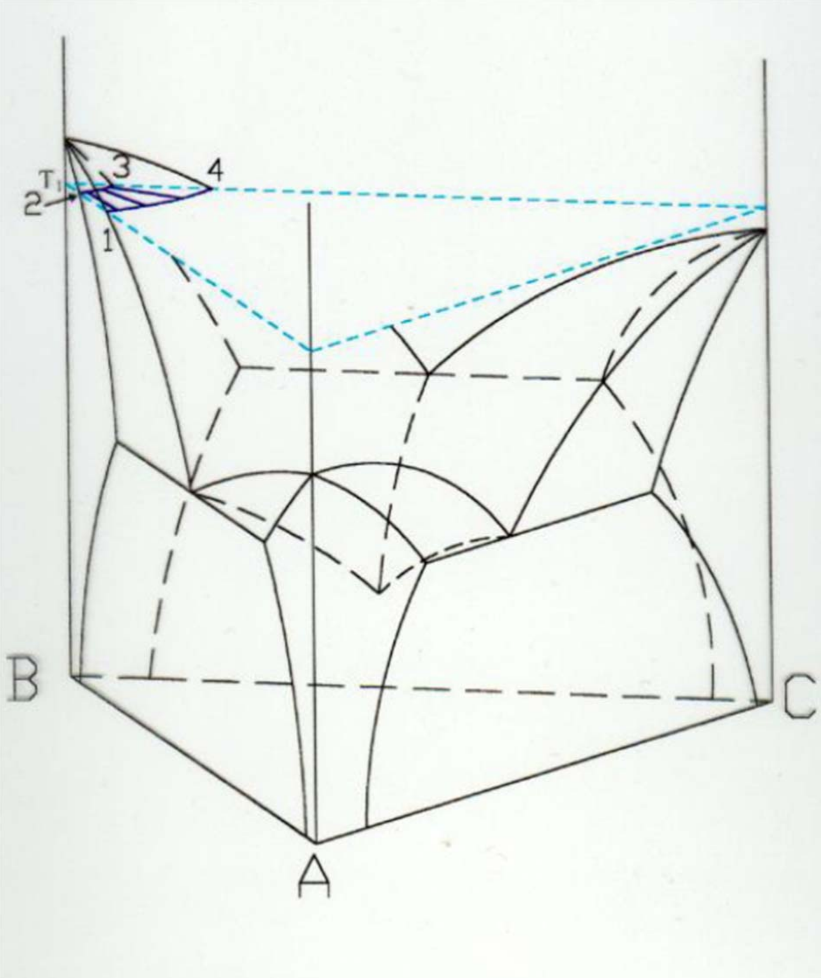


Main outline of Ternary Phase Diagram with Ternary Eutectic (T_e) and Solid Single Phase Regions Shown

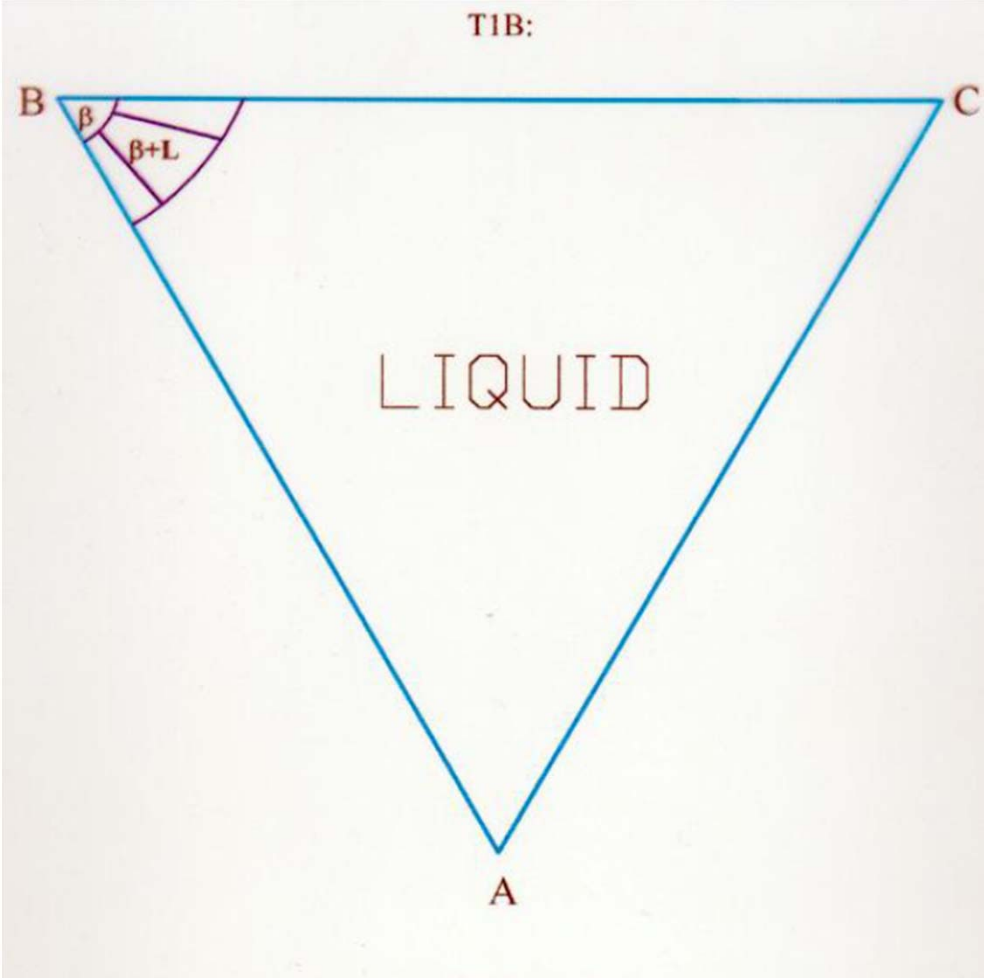


All Liquidus surfaces (α+L-Red, β+L-Purple, γ+L-Green)

Ternary Eutectic System
(with Solid Solubility)



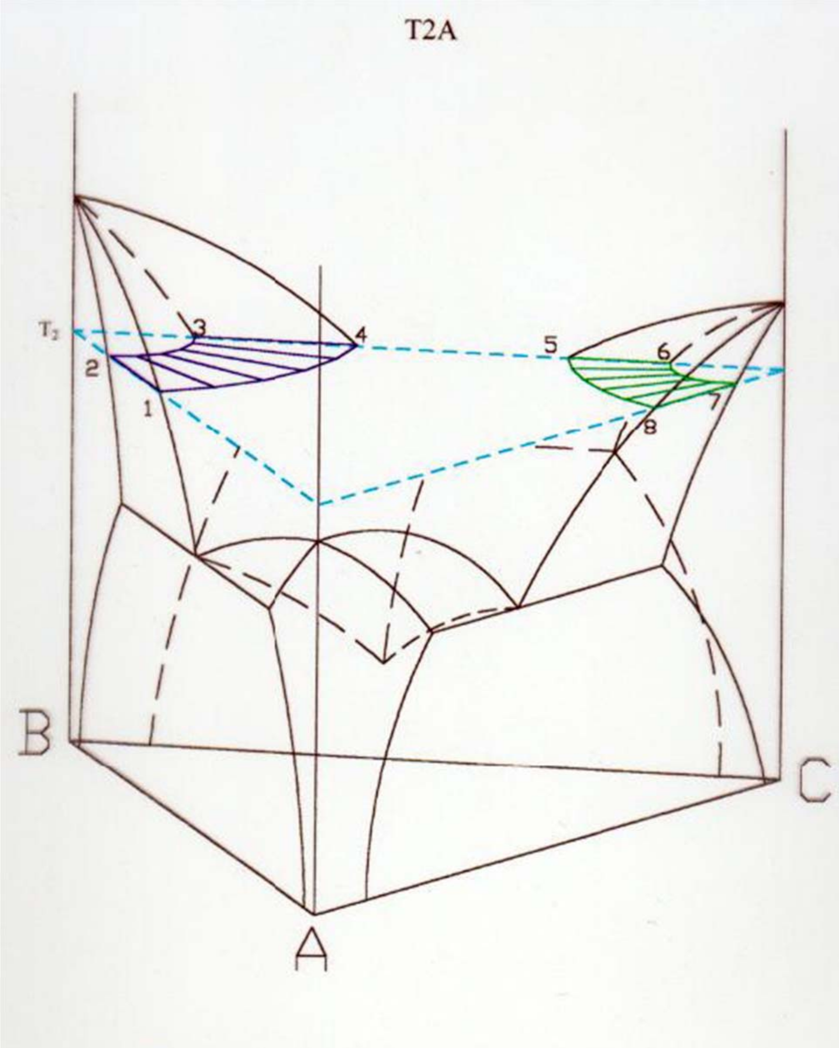
Temperature Slice At $T_1 < T_B$, But $> T_A$, T_C



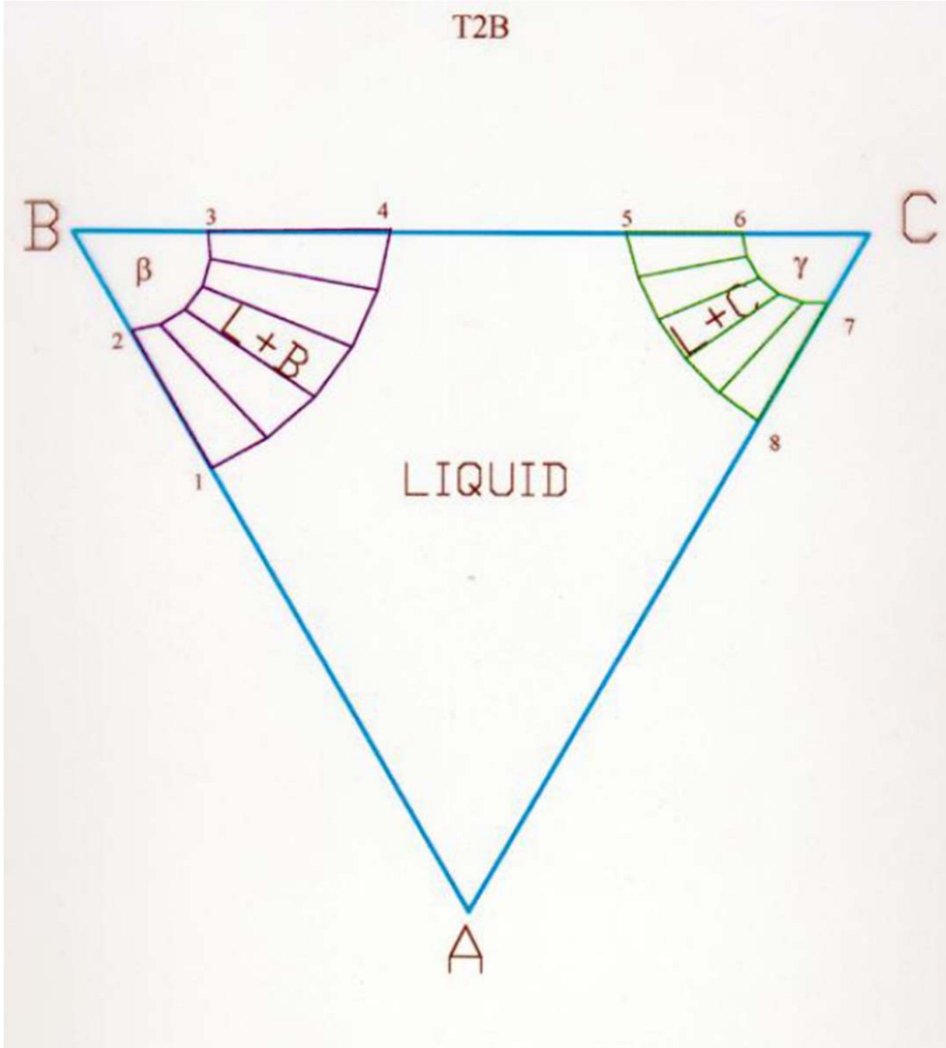
Isothermal Section At $T=T_1$

Ternary Eutectic System

(with Solid Solubility)



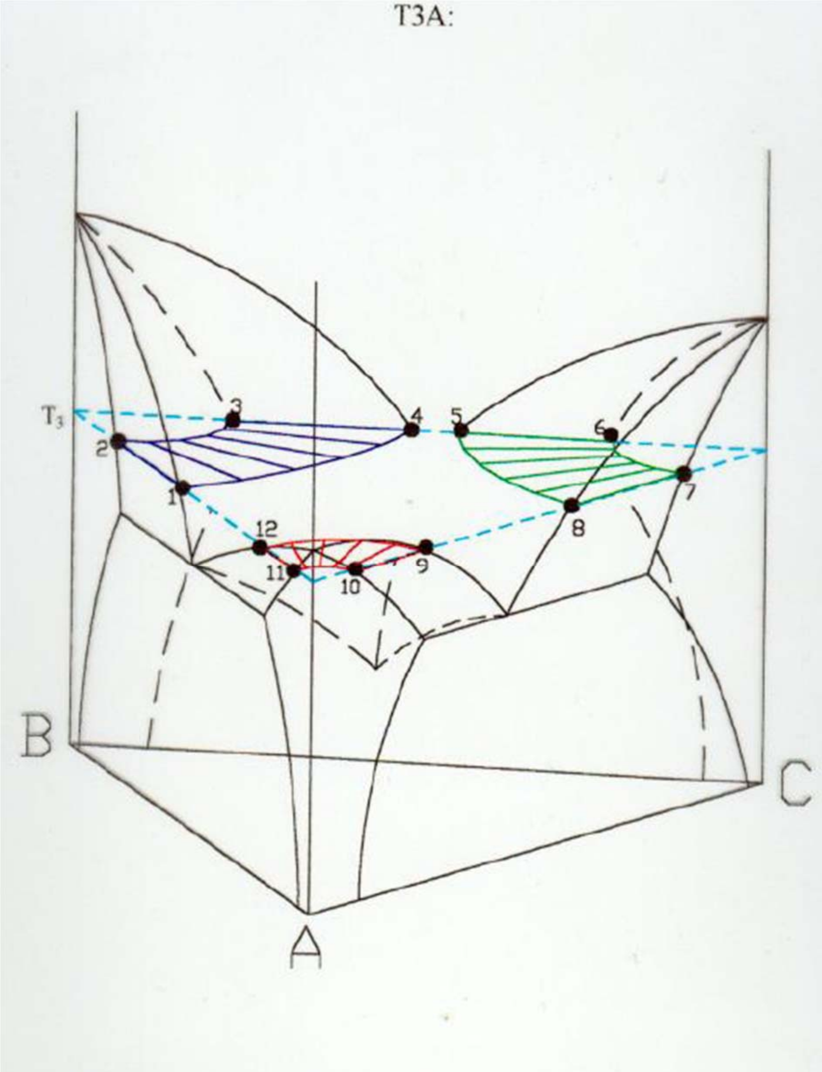
Temperature Slice At $T_2 > T_A$ But, $T_2 < T_B$, T_C



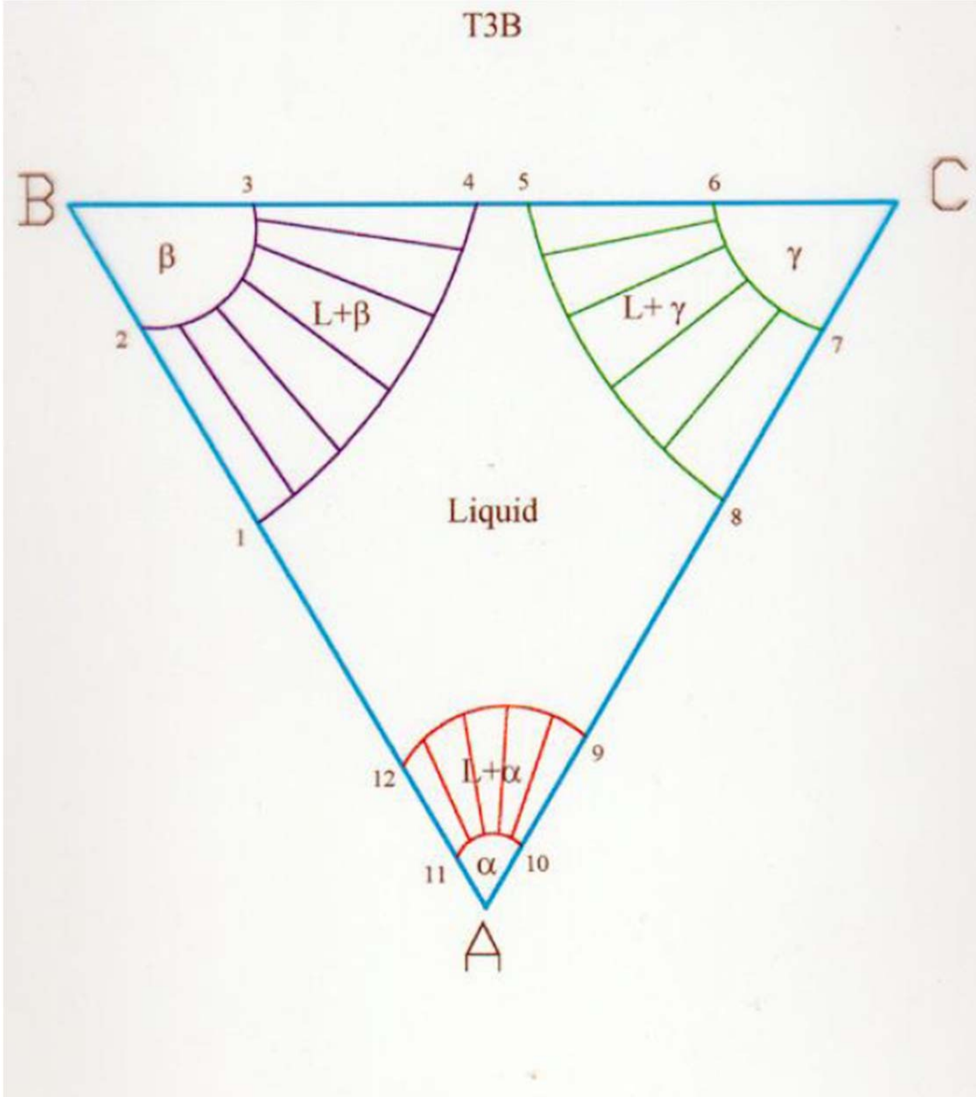
Isothermal Section At $T = T_2$

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}

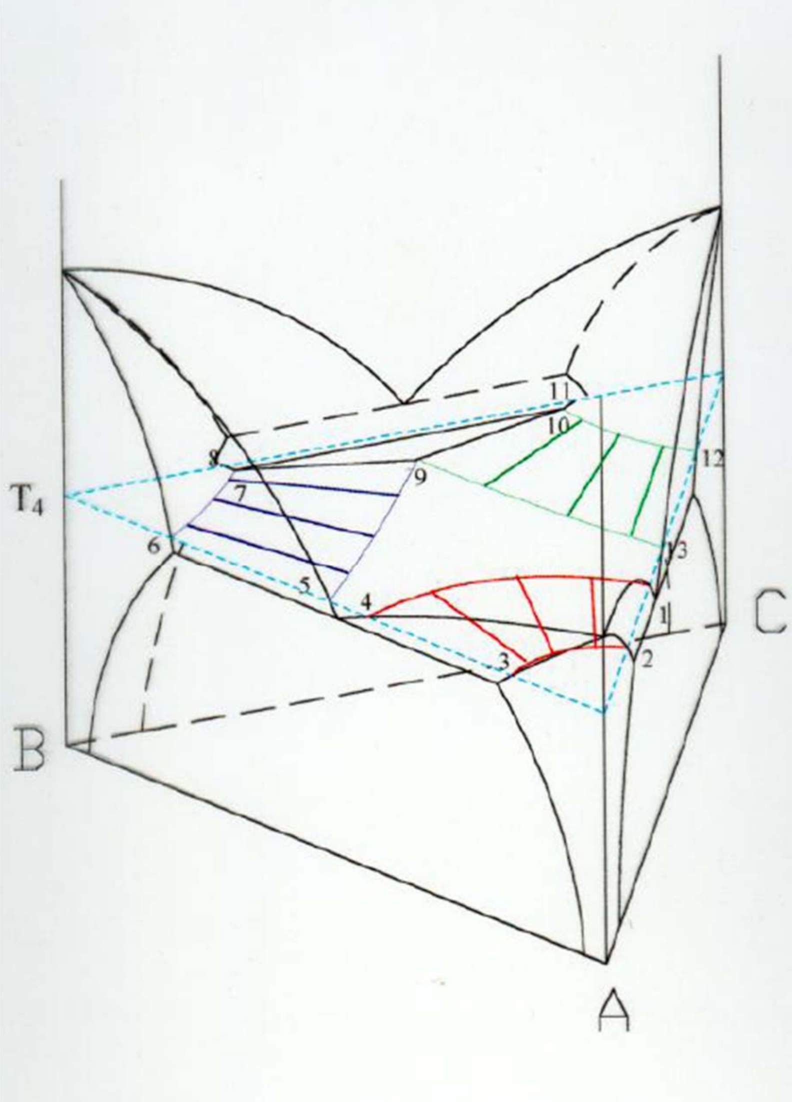


Isothermal Section At T= T_3

Ternary Eutectic System

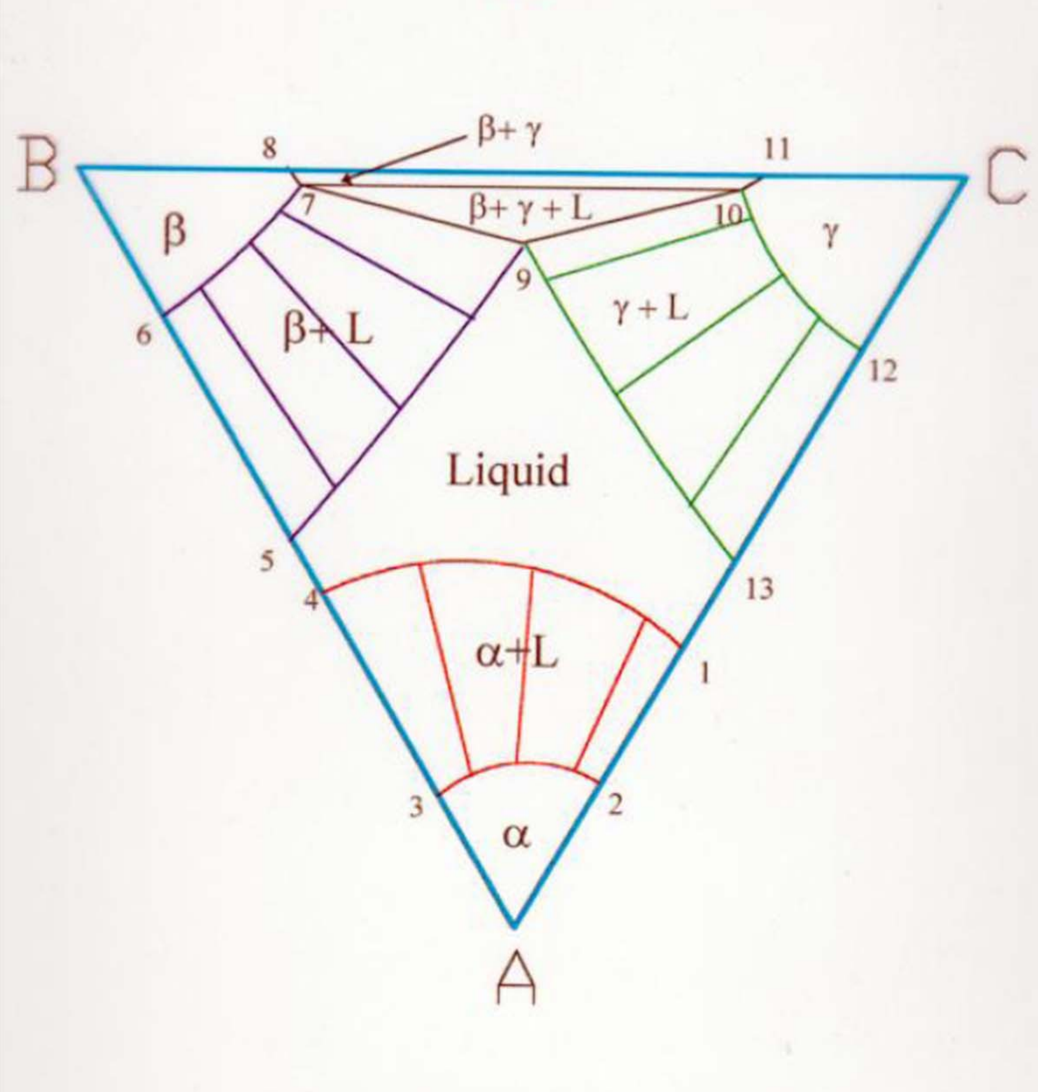
(with Solid Solubility)

T4A:



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

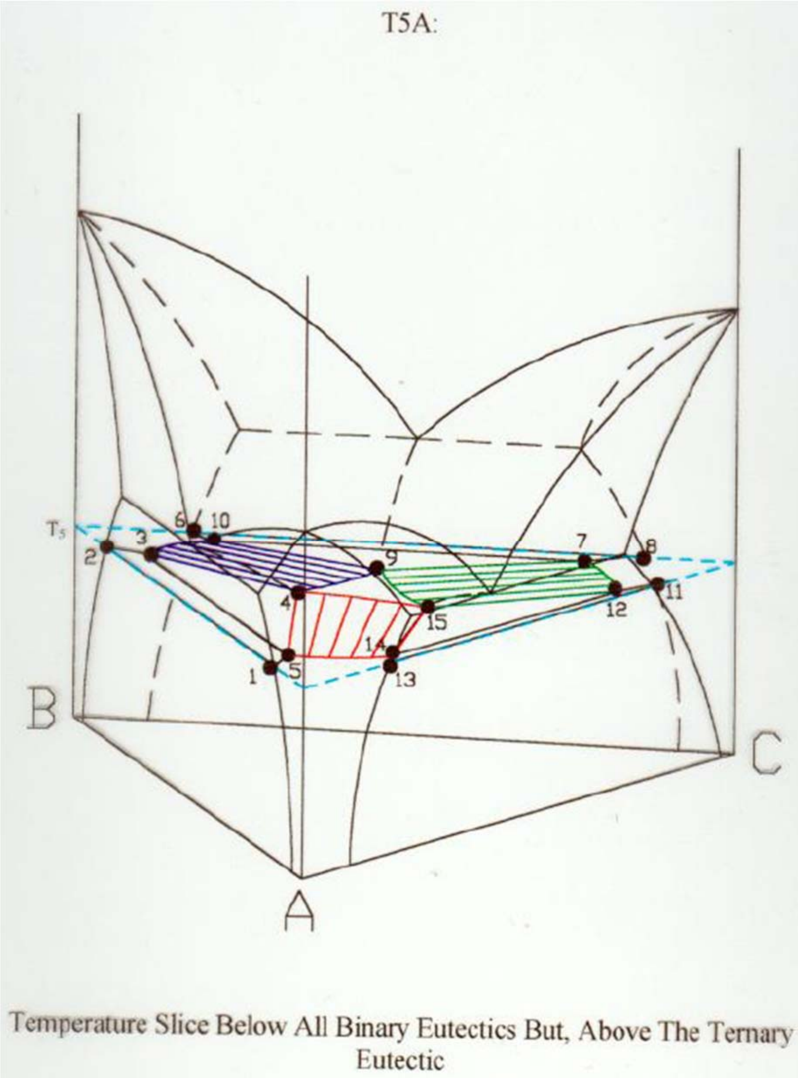
T4B:

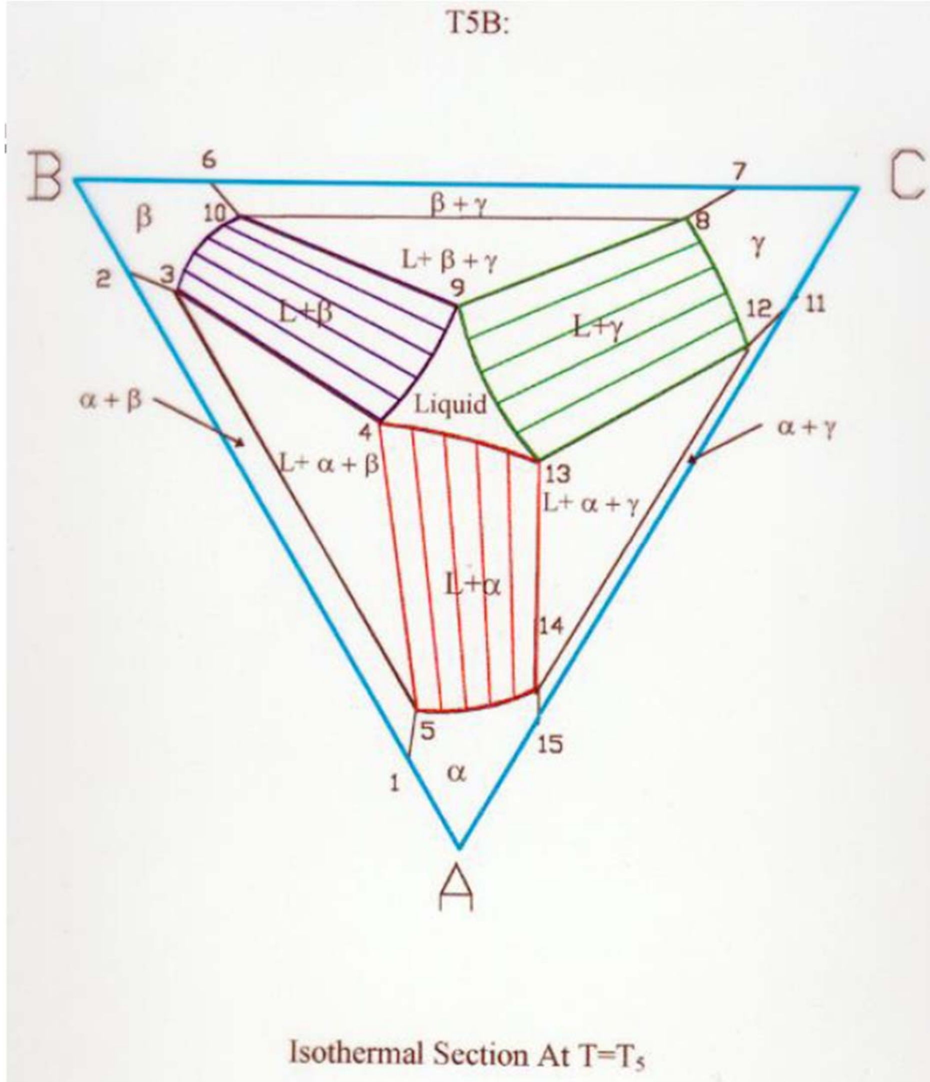


Isothermal Section At $T=T_4$

Ternary Eutectic System

(with Solid Solubility)

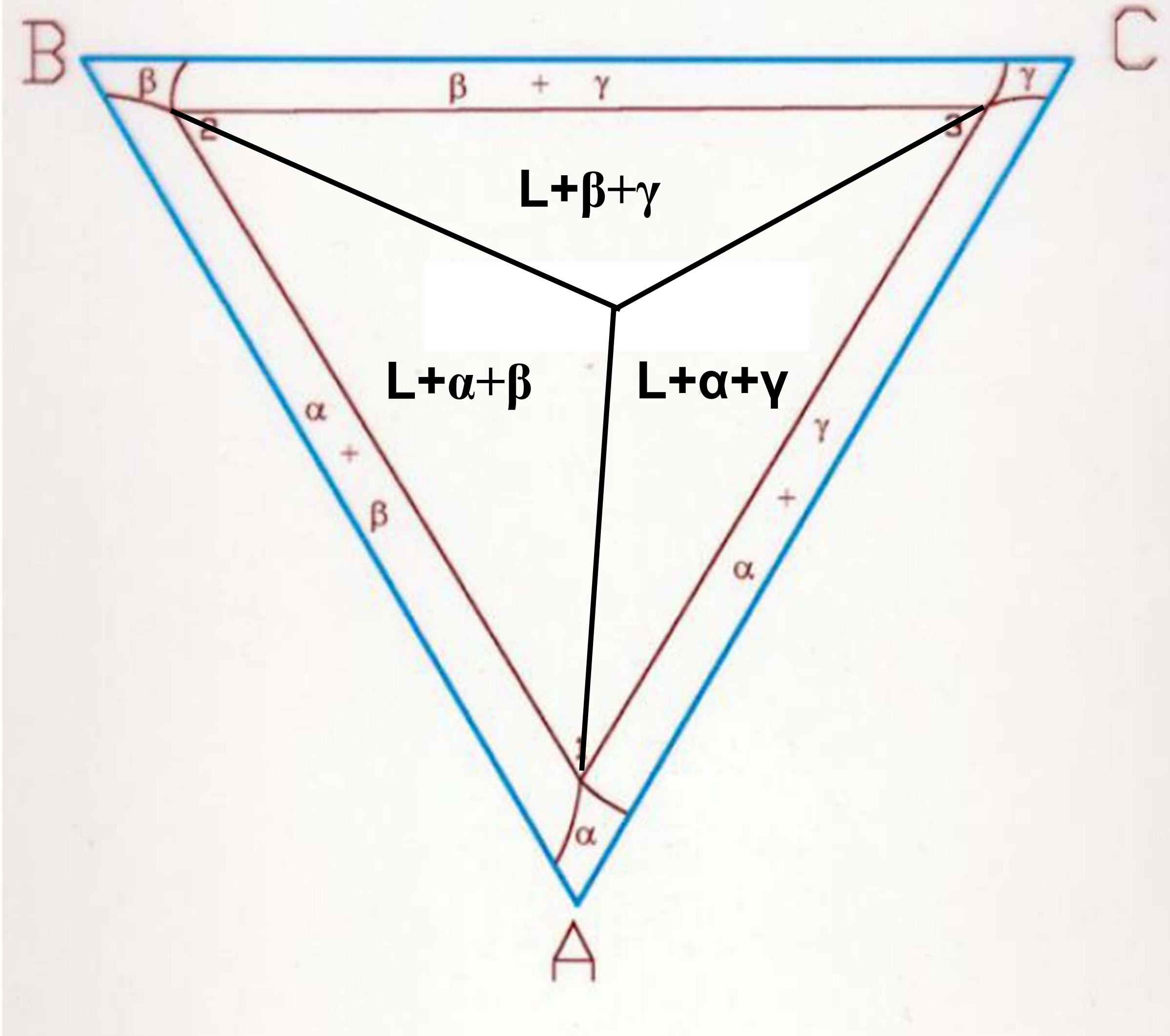




Ternary Eutectic System

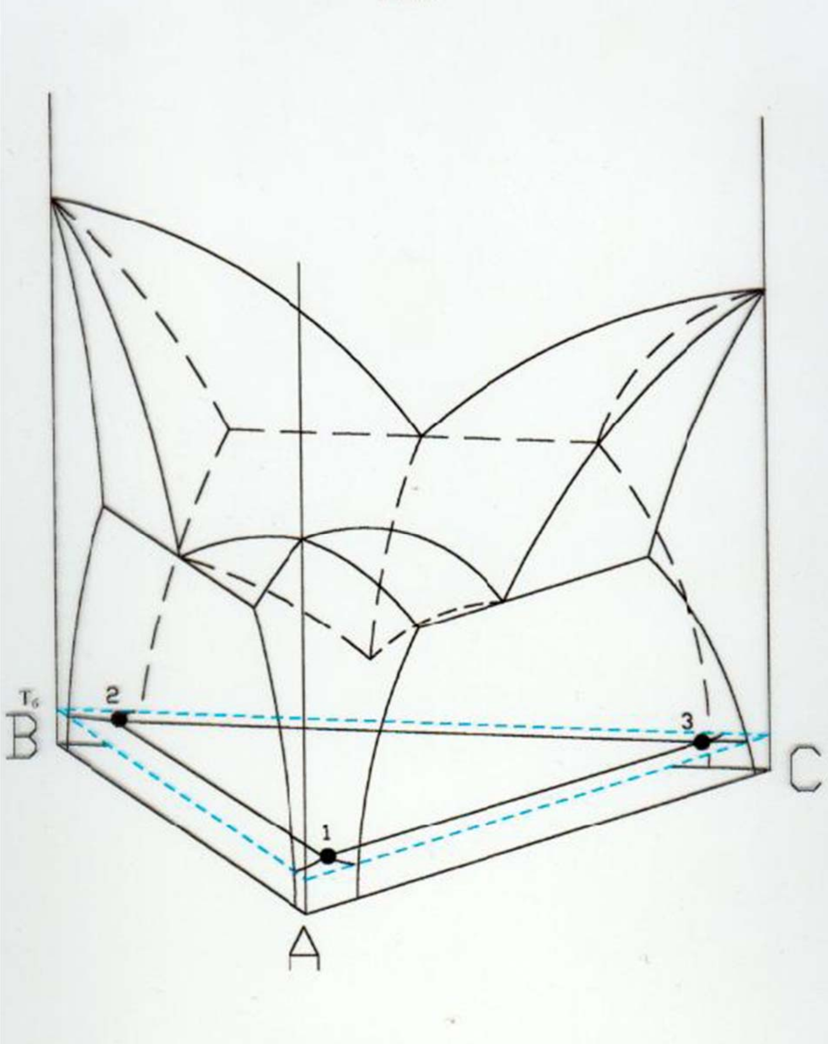
(with Solid Solubility)

T= ternary eutectic temp.

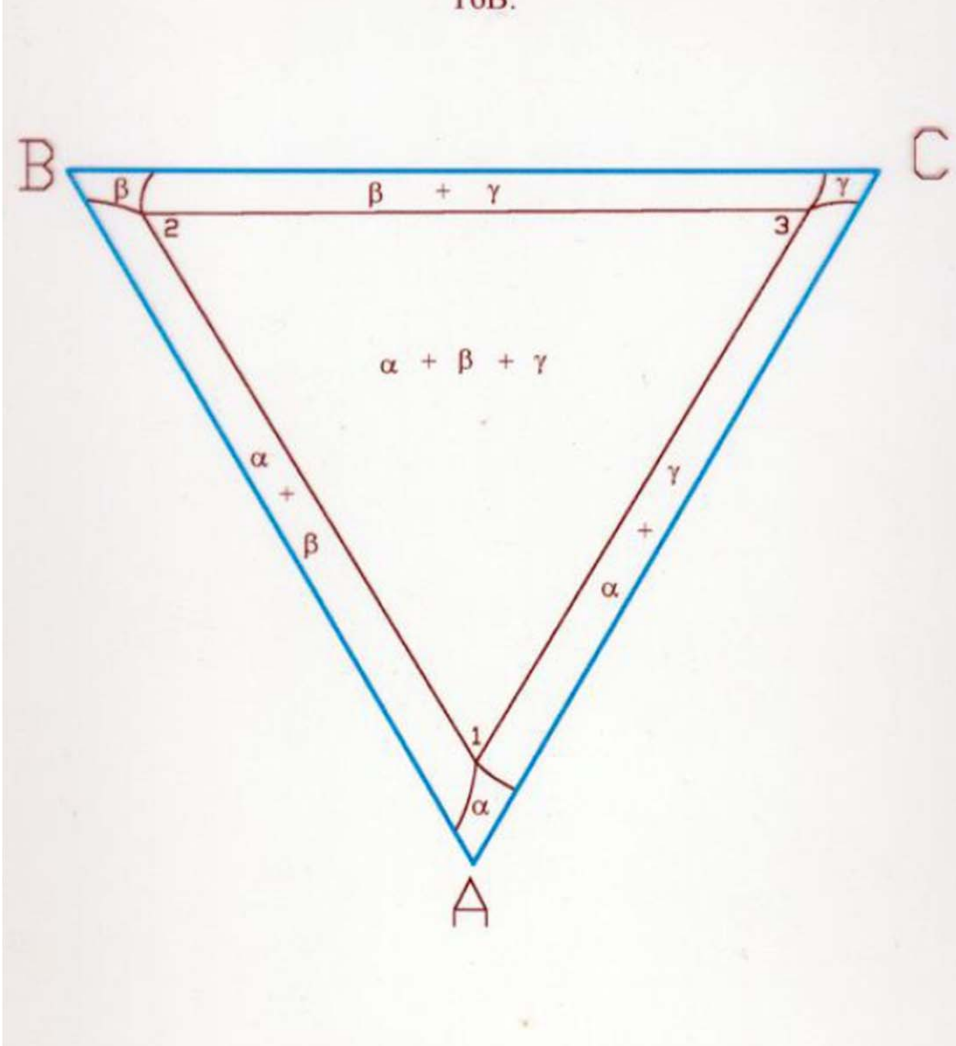


Ternary Eutectic System

(with Solid Solubility)



Temperature Slice at $T_6 < T_E$

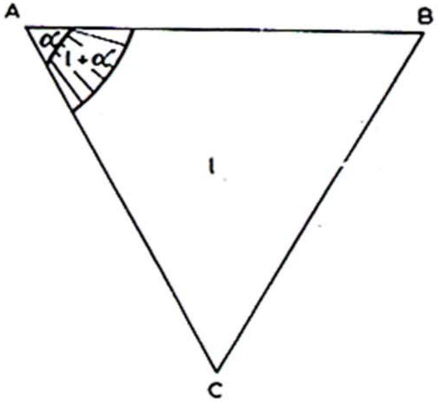


Isothermal Section At $T=T_6$

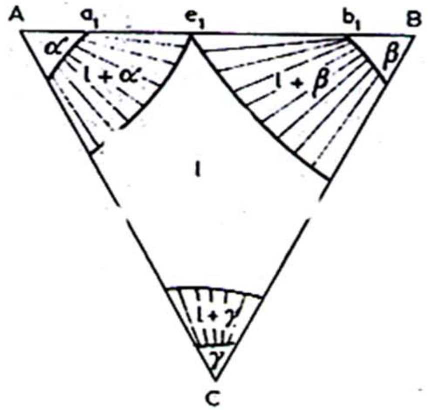
http://www.youtube.com/watch?v=yzhVomAdetM

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

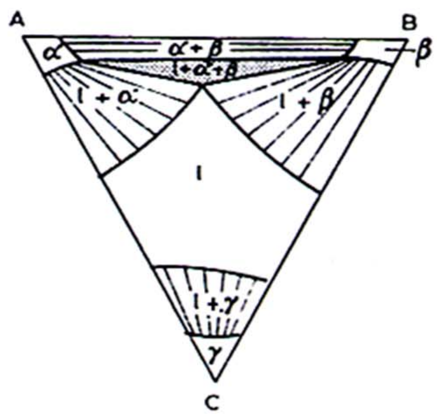
- **Isothermal section** ($T_A > T > T_B$)



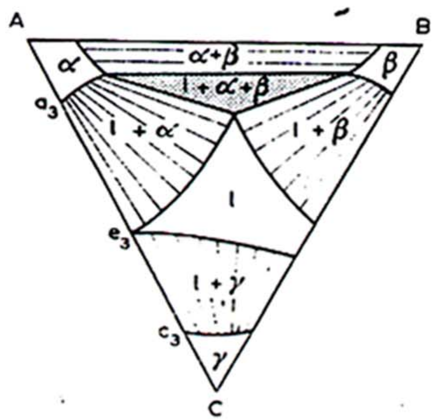
(a) $T_A > T > T_B$



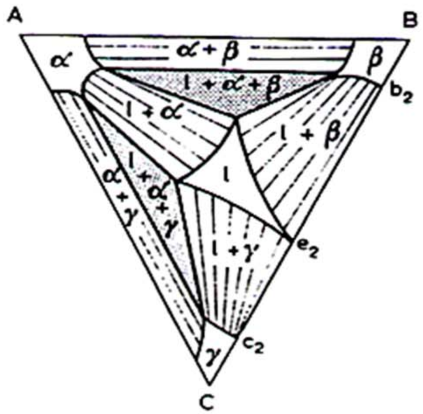
(b) $T = e_1$



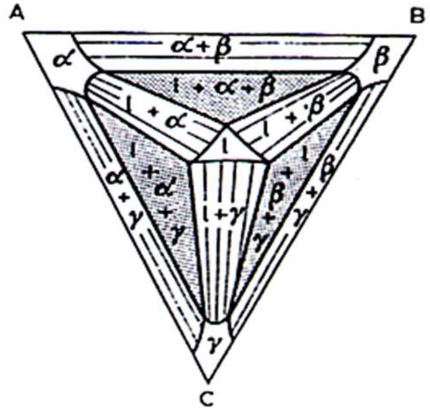
(c) $e_1 > T > e_3$



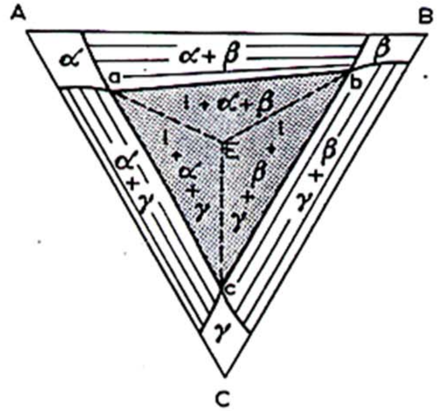
(d) $T = e_3$



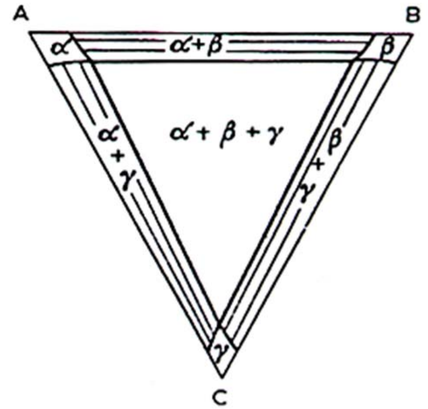
(e) $T = e_2$



(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**

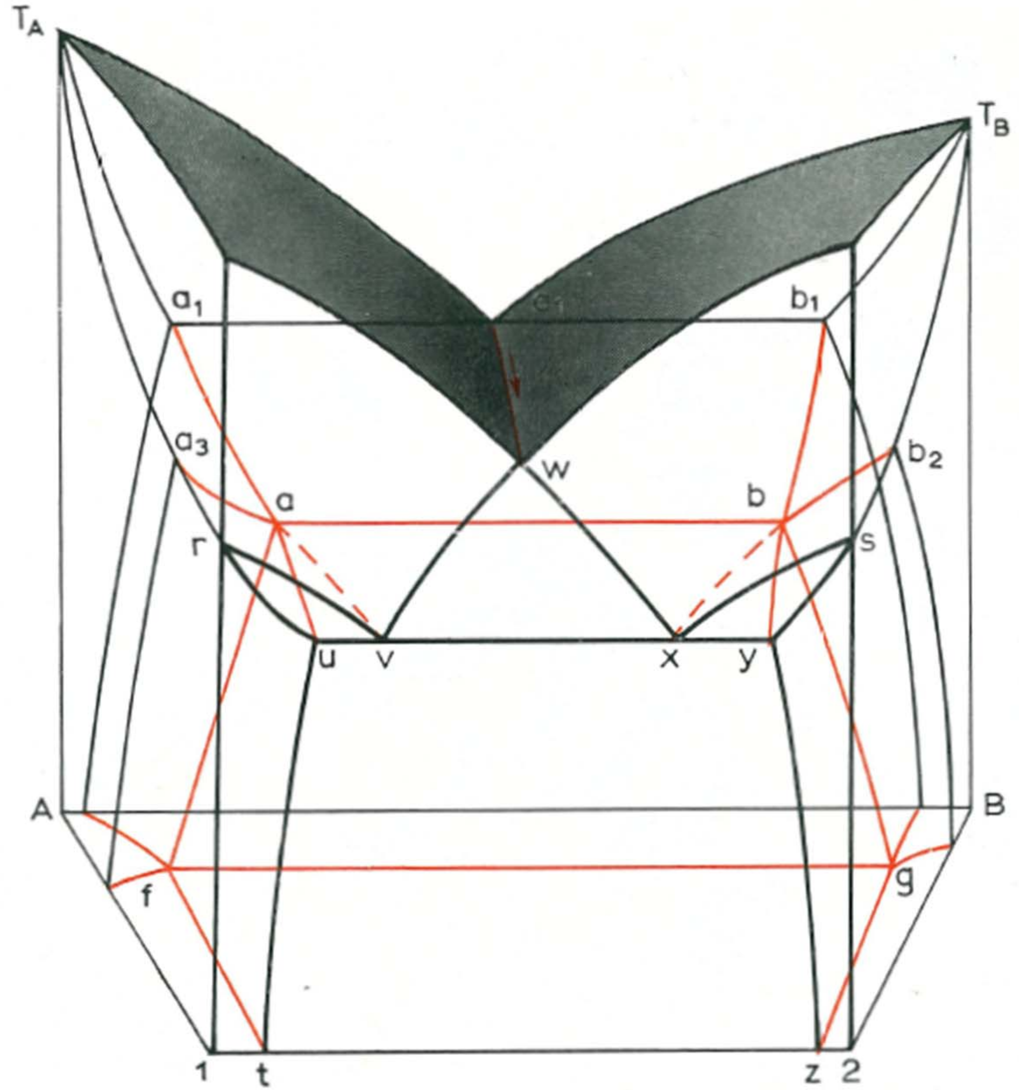
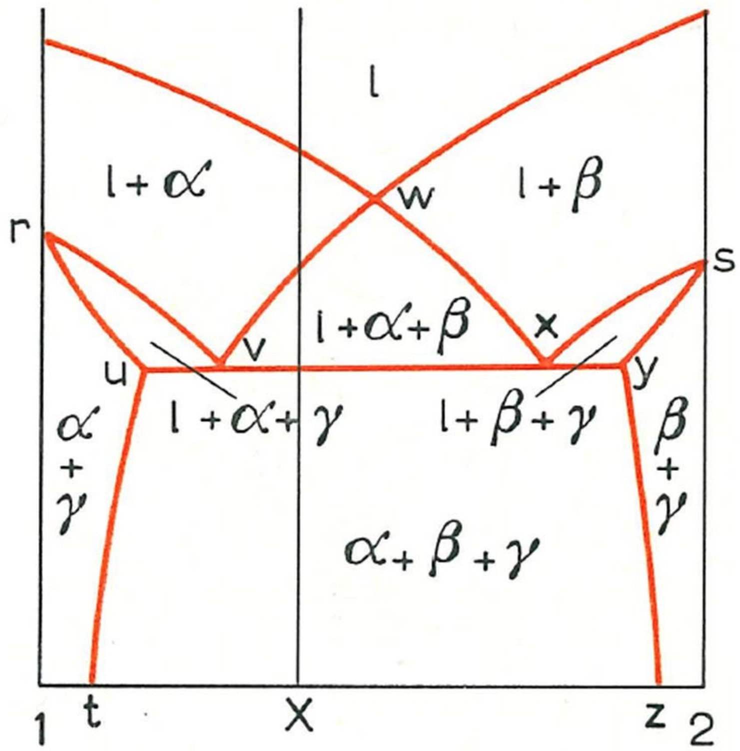
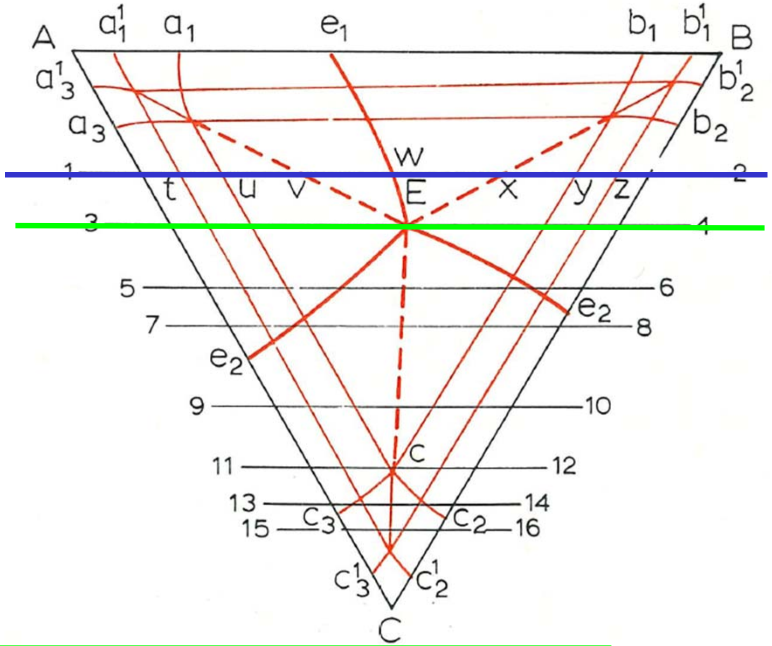


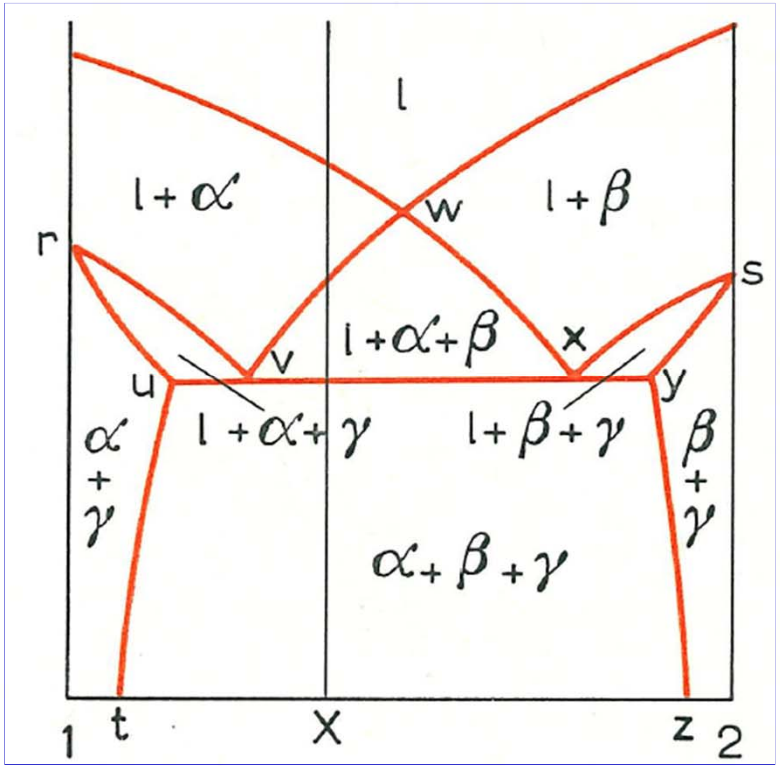
Fig. 179. Construction of vertical section 1–2.

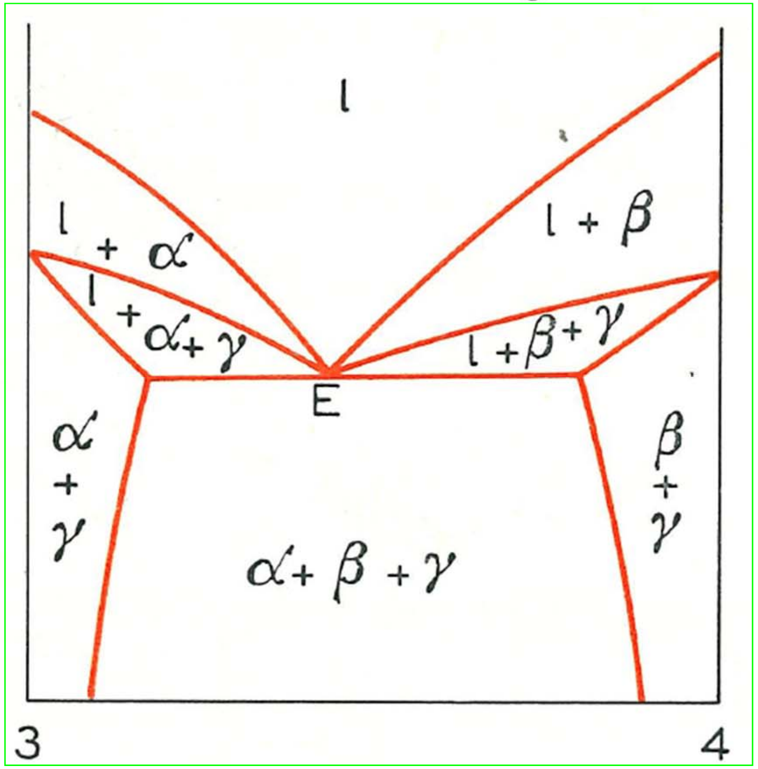


10.1. THE EUTECTIC EQUILIBRIUM
($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

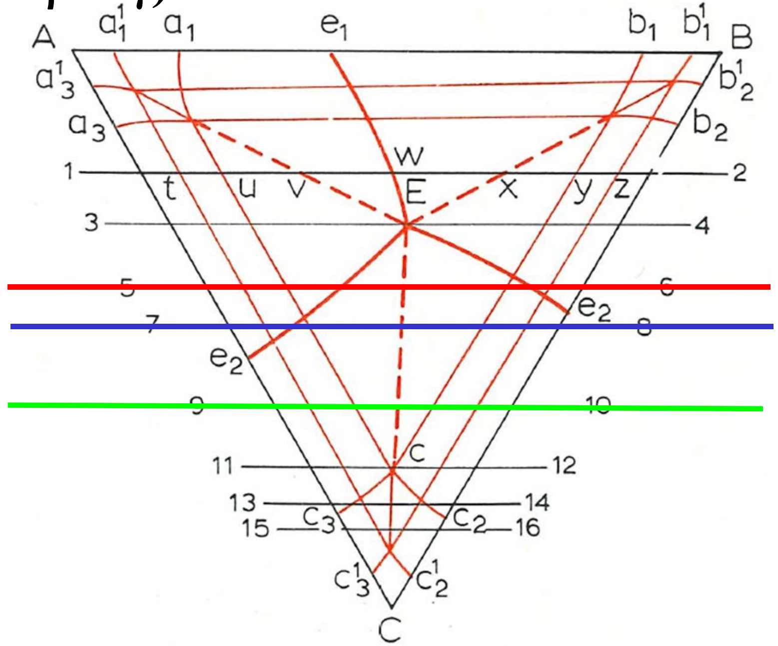


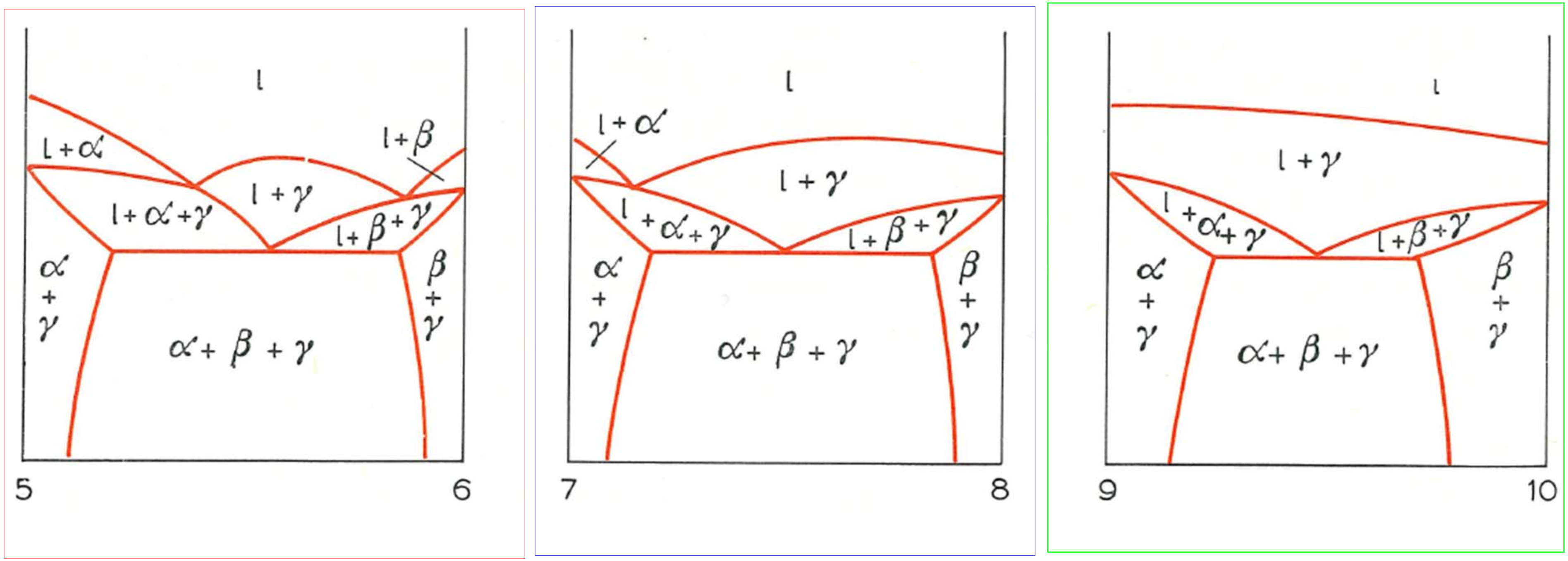




10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

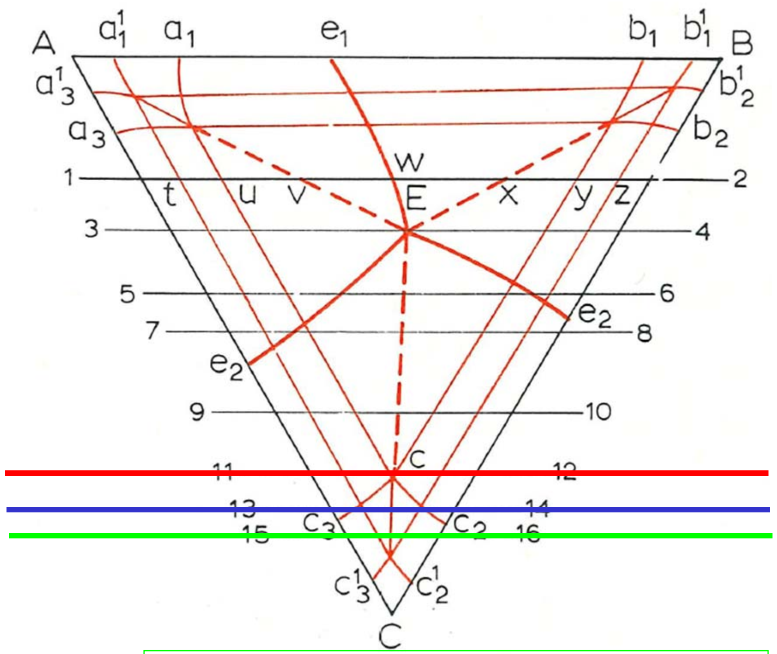
Vertical section **Location of vertical section**

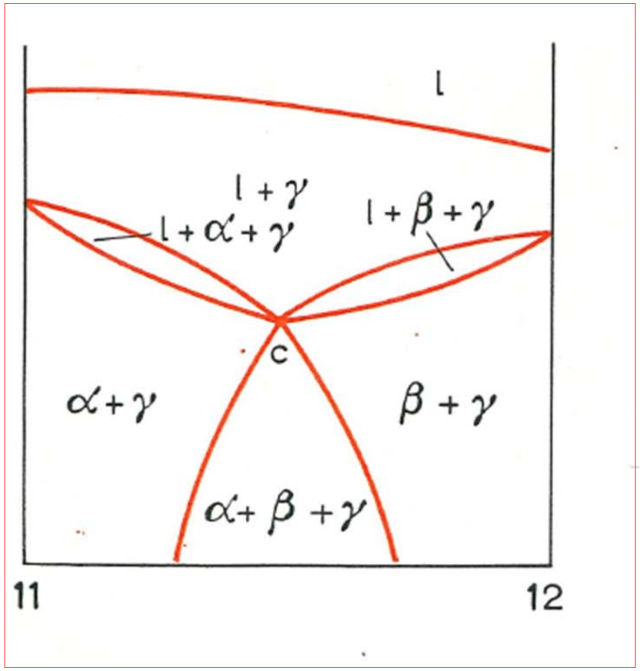


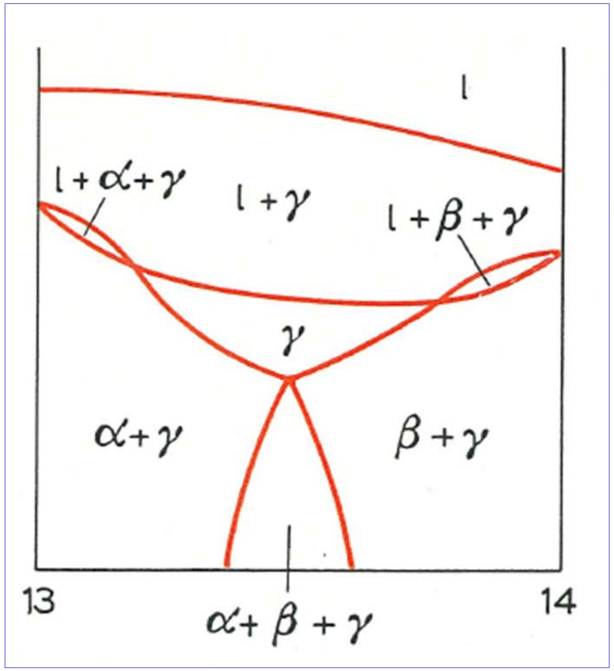


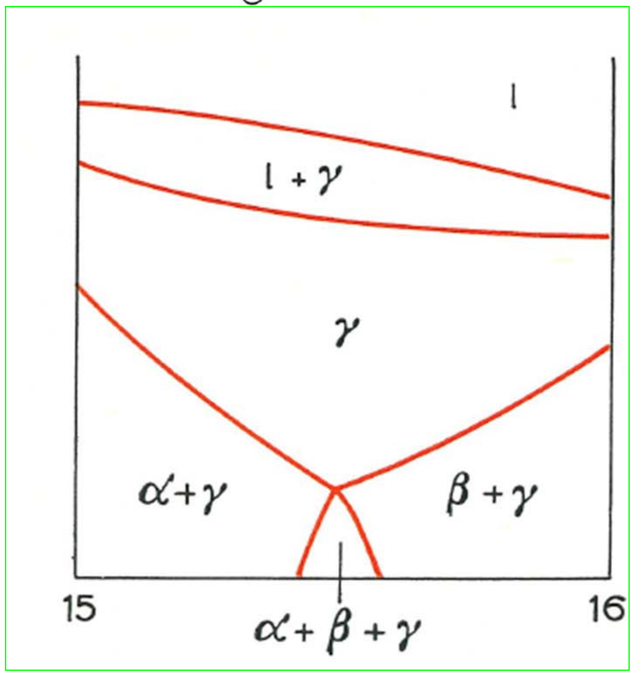
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

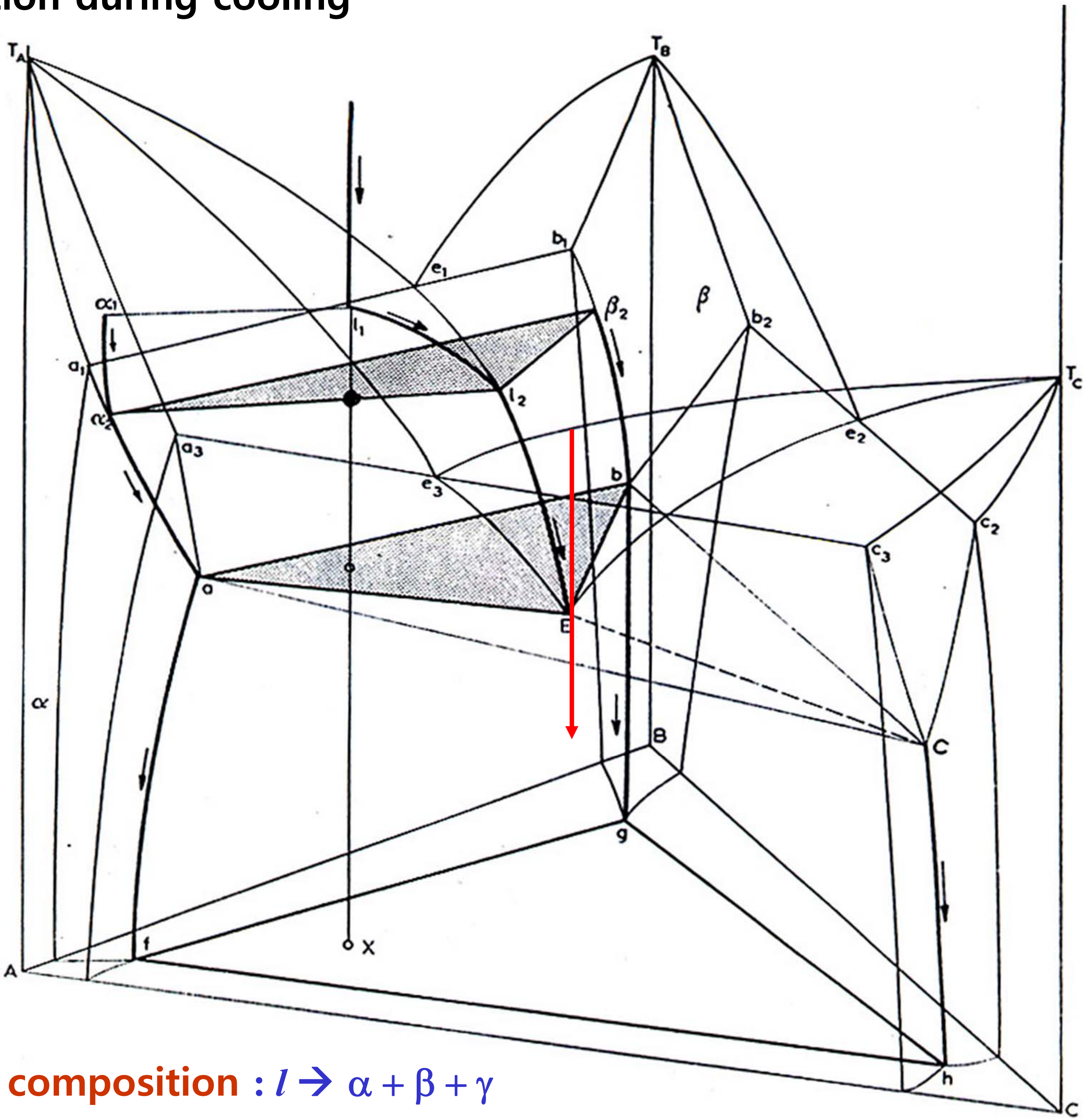






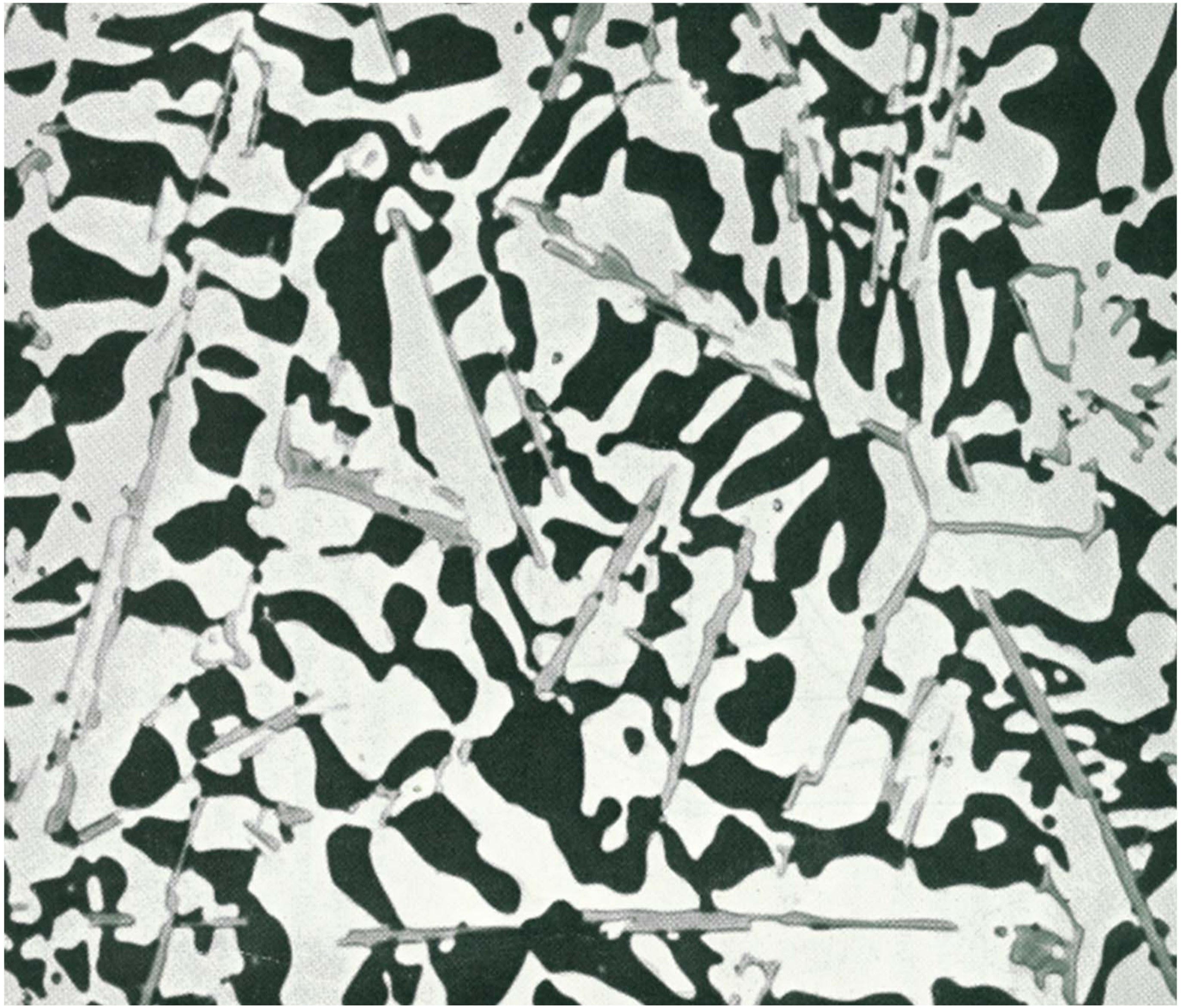


Transformation during cooling



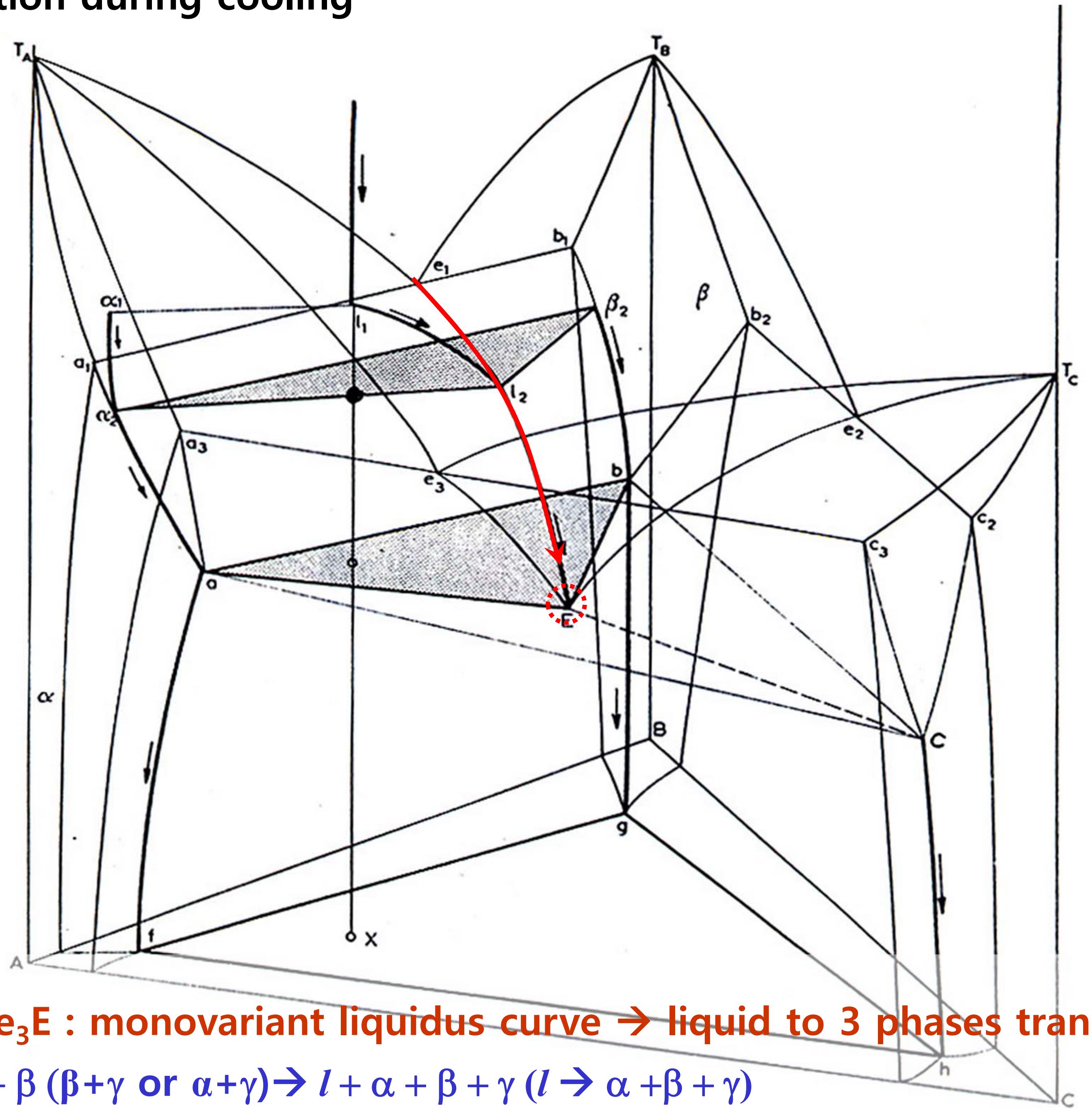
① **Eutectic composition :** $l \rightarrow \alpha + \beta + \gamma$

Ternary Eutectic microstructure



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

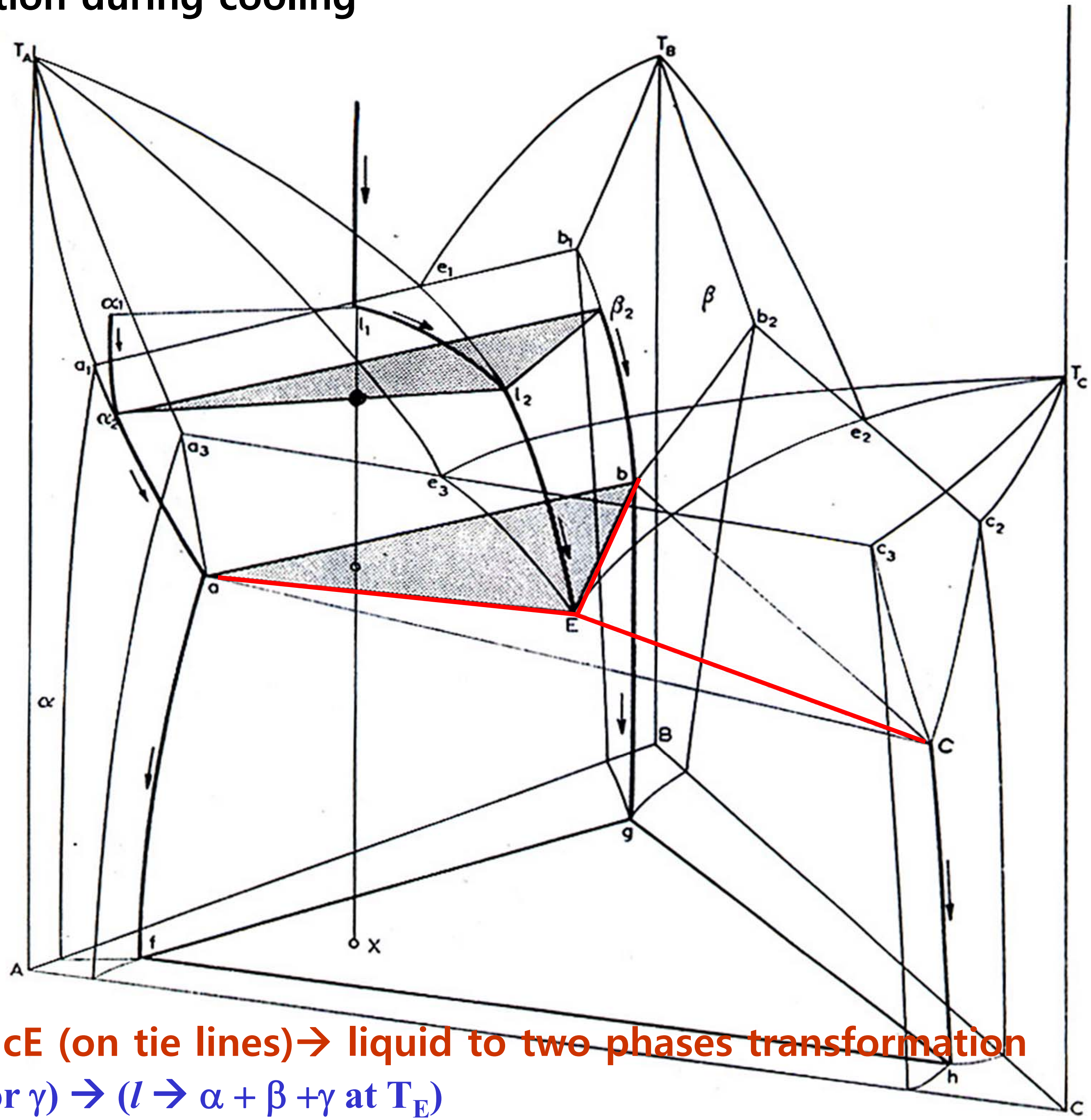
Transformation during cooling



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

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

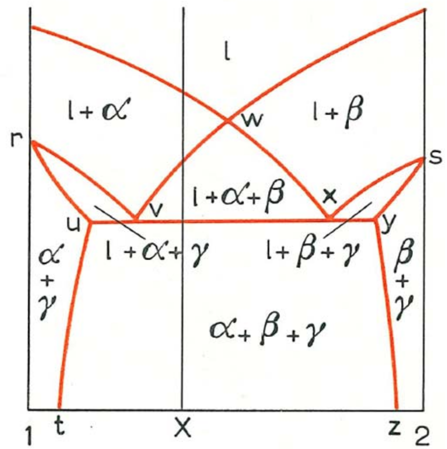
Transformation during cooling

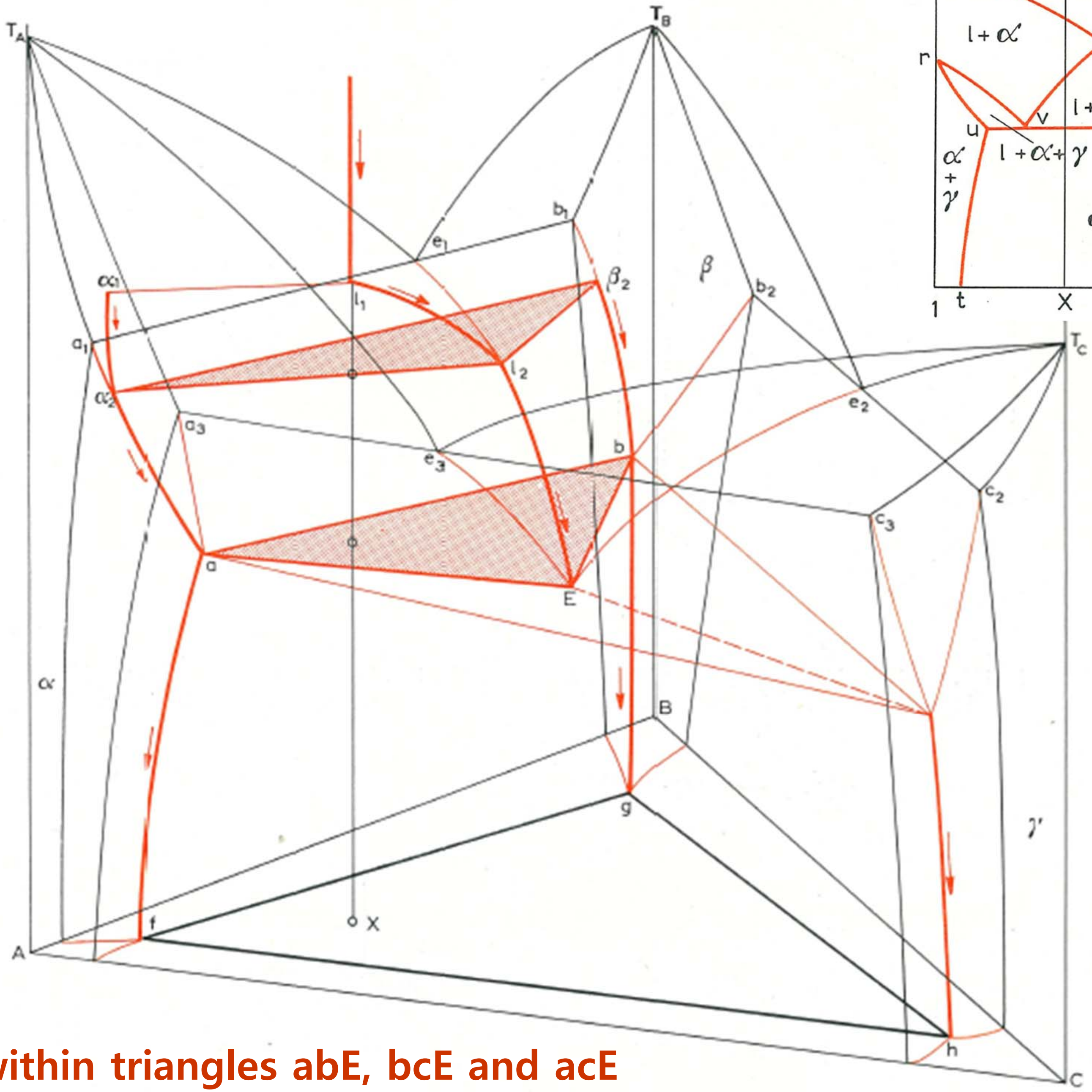


③ aE, bE, cE (on tie lines)→ liquid to two phases transformation

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

Transformation during cooling



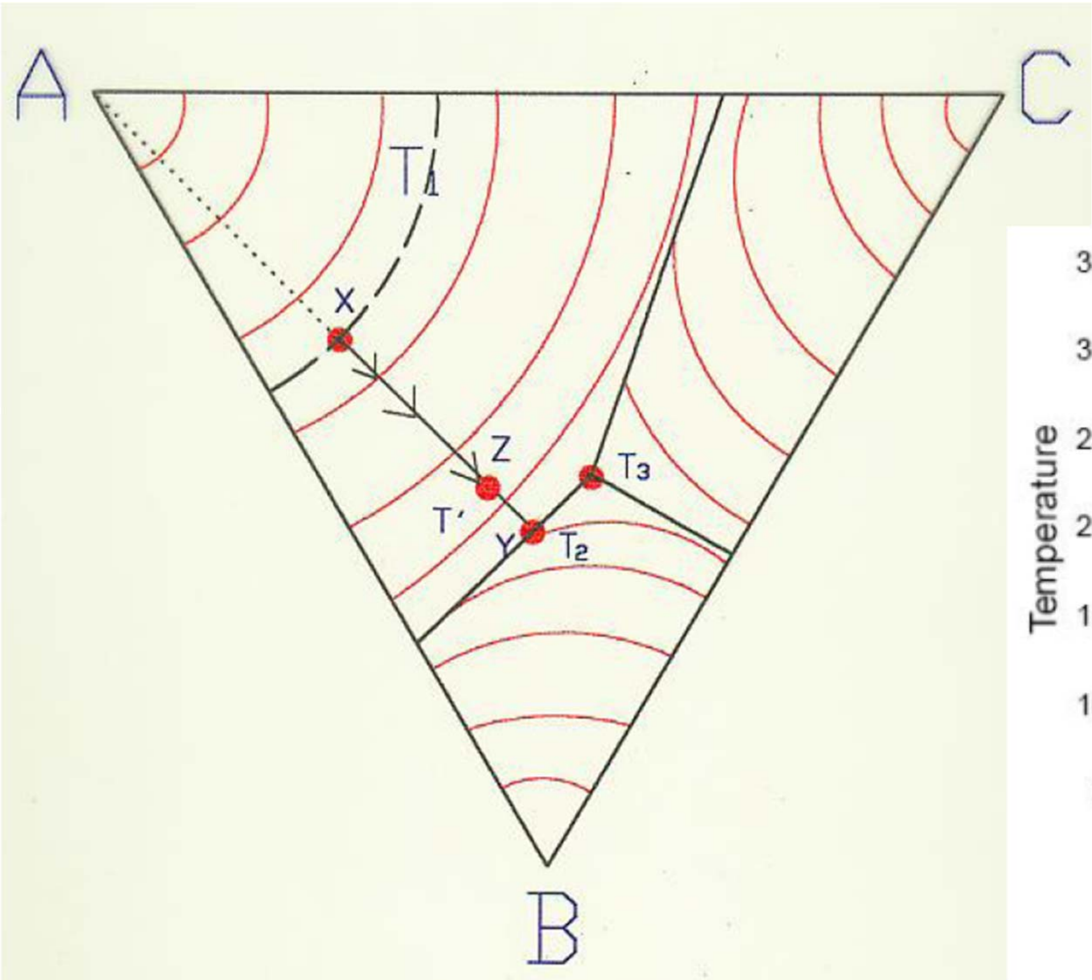


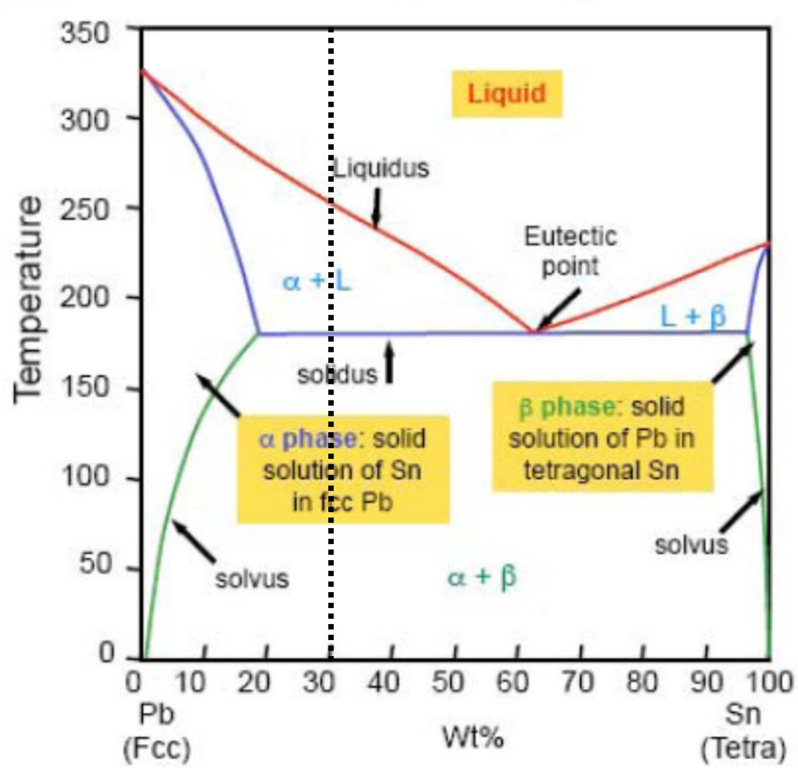
④ **Alloys within triangles abE, bcE and acE**

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

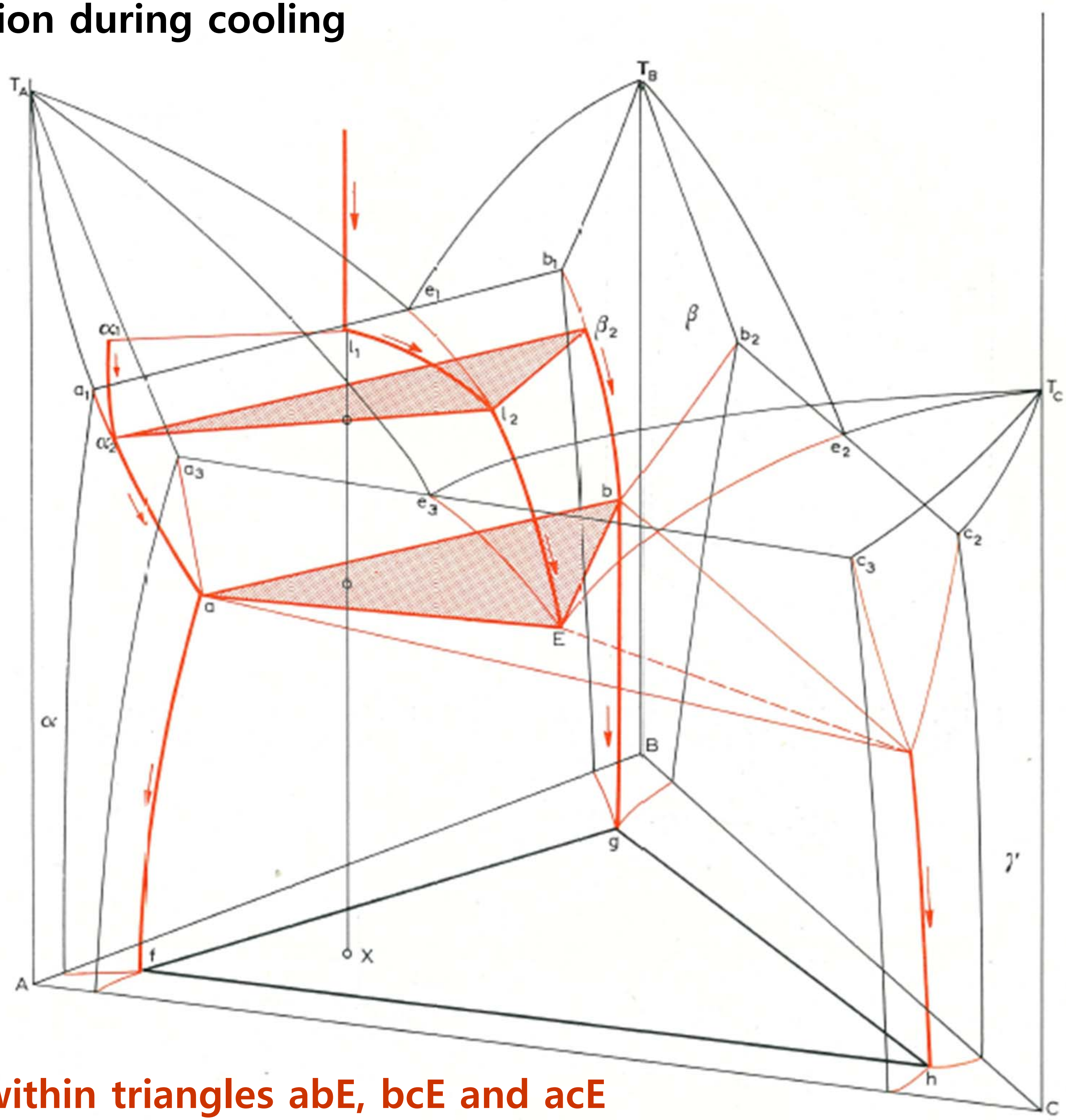
Ternary Eutectic System

Solidification Sequence





Transformation during cooling

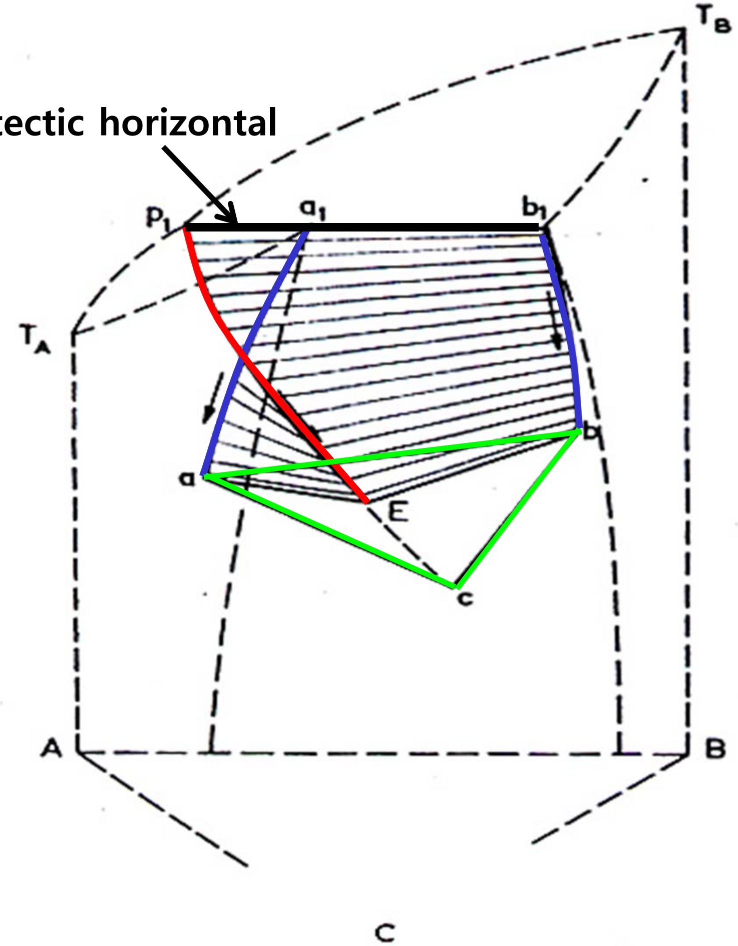


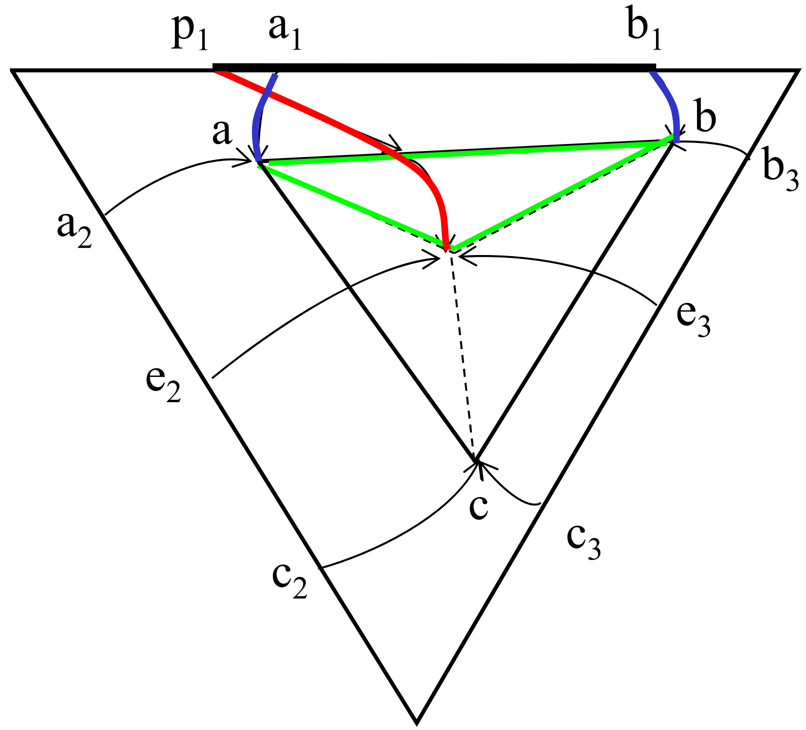
④ **Alloys within triangles abE, bcE and acE**

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

10.2. VARIANTS OF THE TERNARY EUTECTIC DIAGRAM

(a) Variant of the ternary eutectic system in which one binary is a peritectic





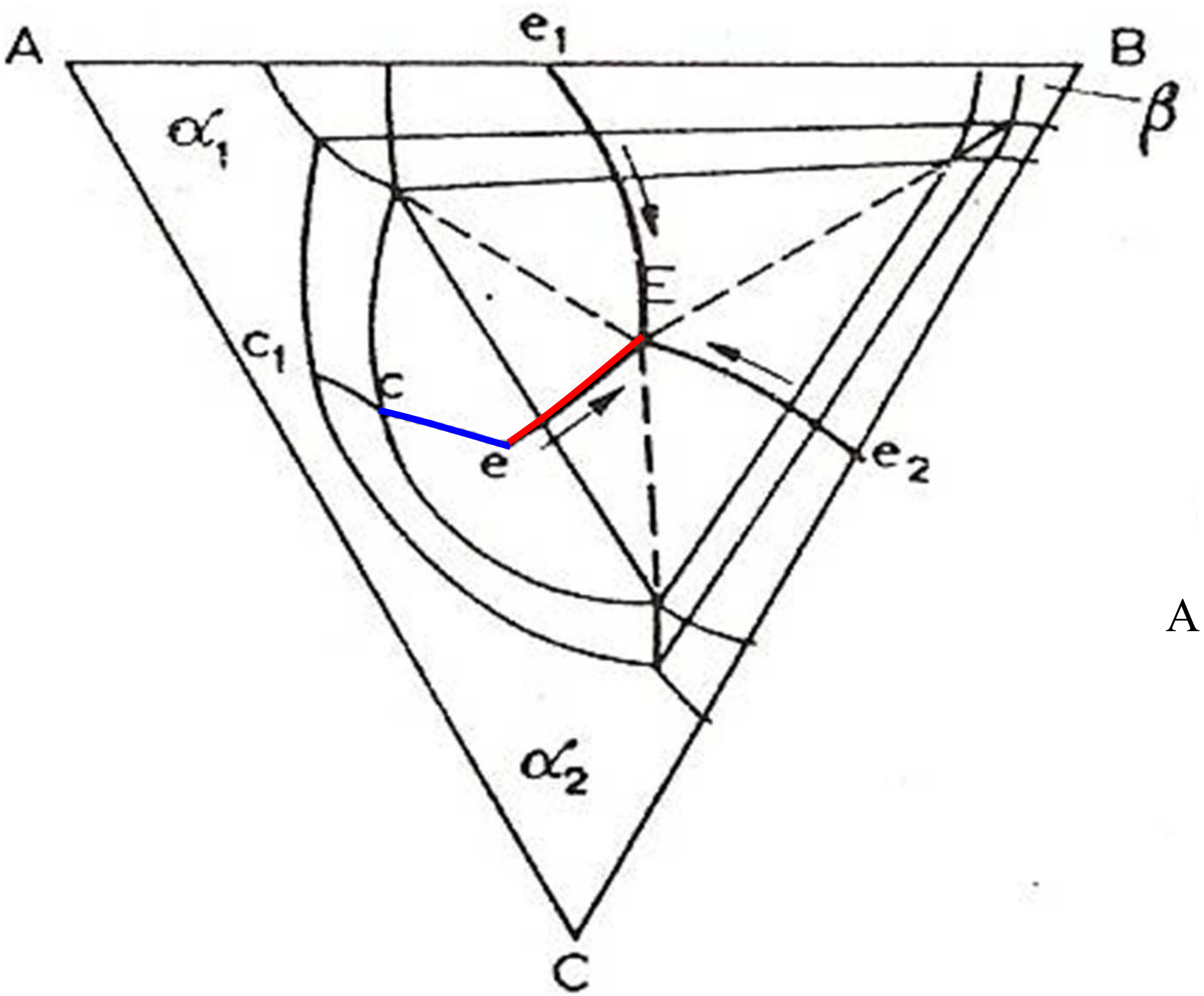
Monovariant liquidus line (P_1E) lies above monovariant solidus line (a_1a).

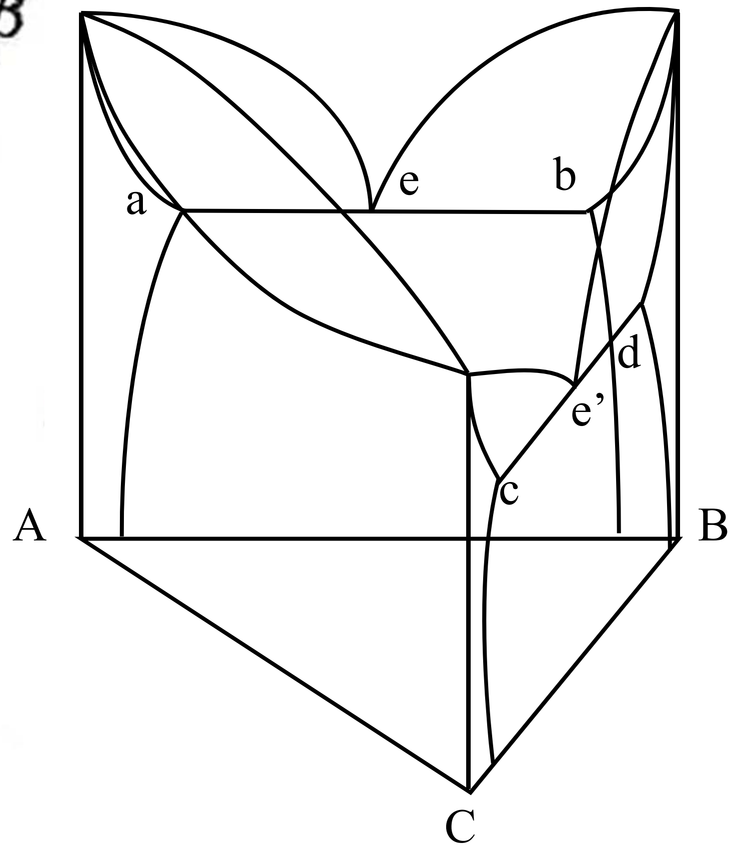
→ A ternary eutectic can be produced with one, two or three binary peritectic systems.

10.2. VARIANTS OF THE TERNARY EUTECTIC DIAGRAM

(b) Ternary eutectic system

in which two of the binary eutectics and one of ternary miscibility gap exist.



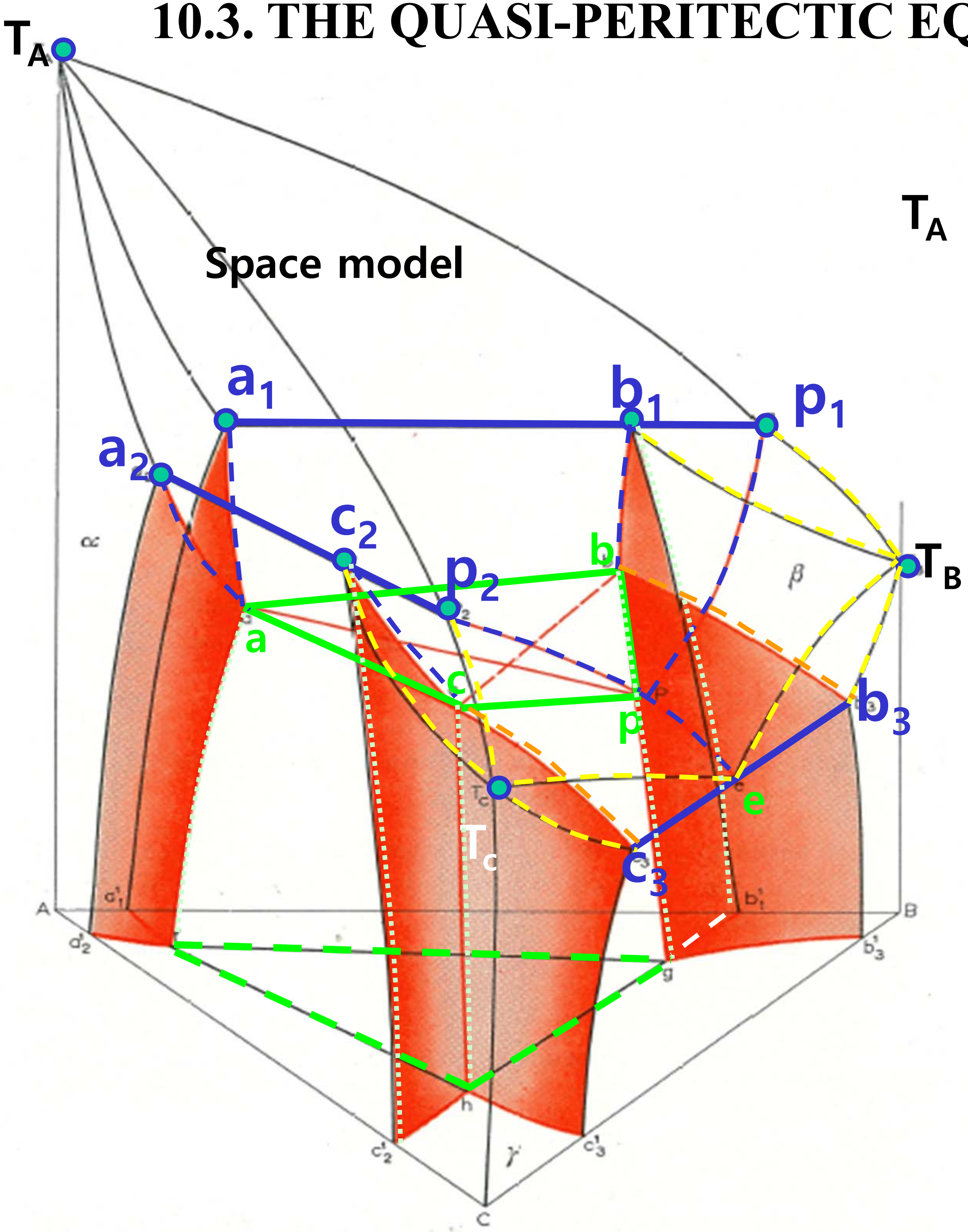


<one complete solid solution + two binary eutectic>

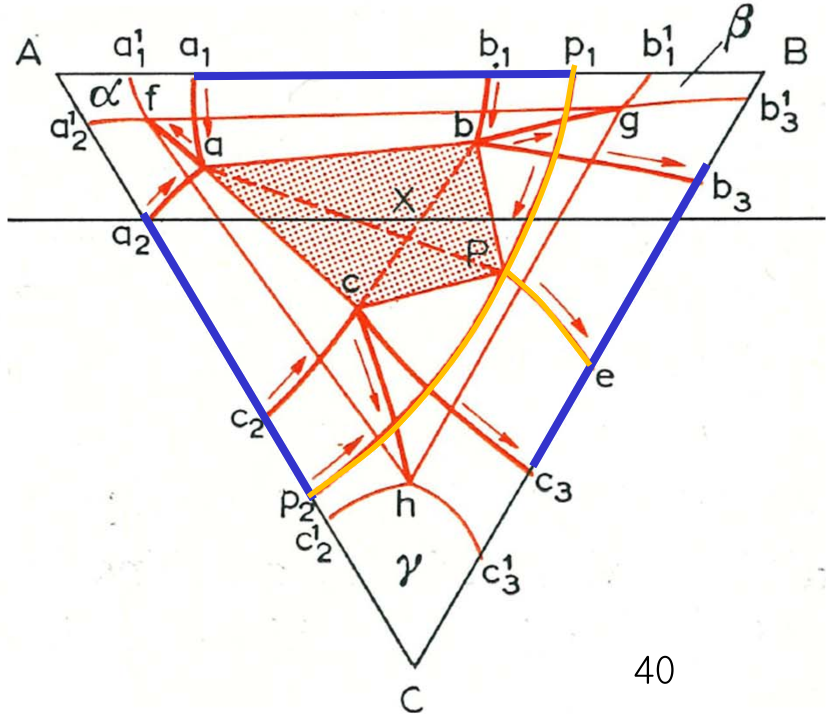
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

$T_A > P_1 > P_2 > T_B > P > T_C > e$

Space model

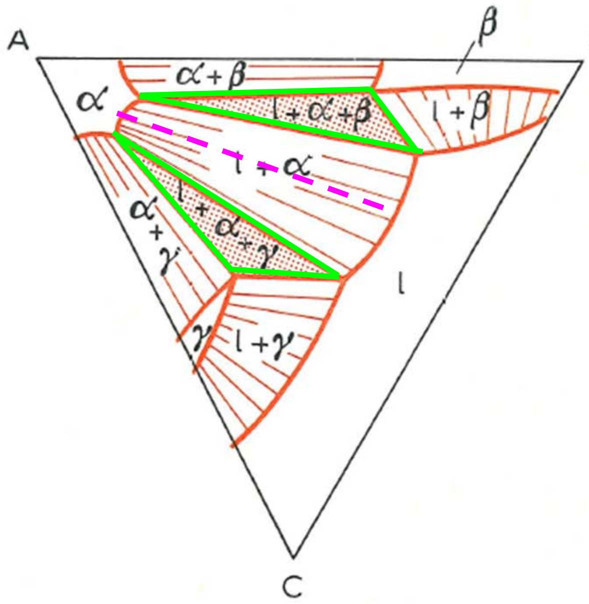


Projection

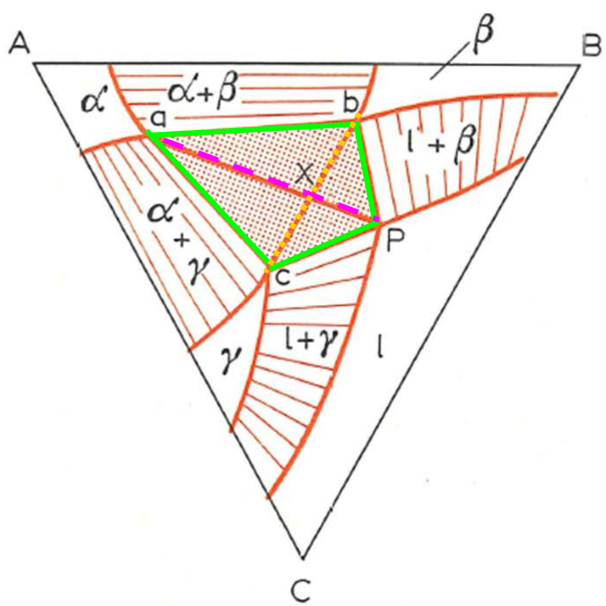


10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

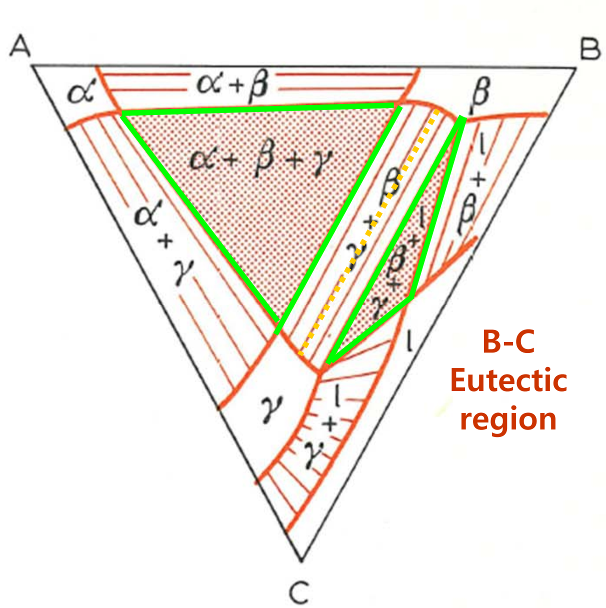
Isothermal section



$T_B > T > P$



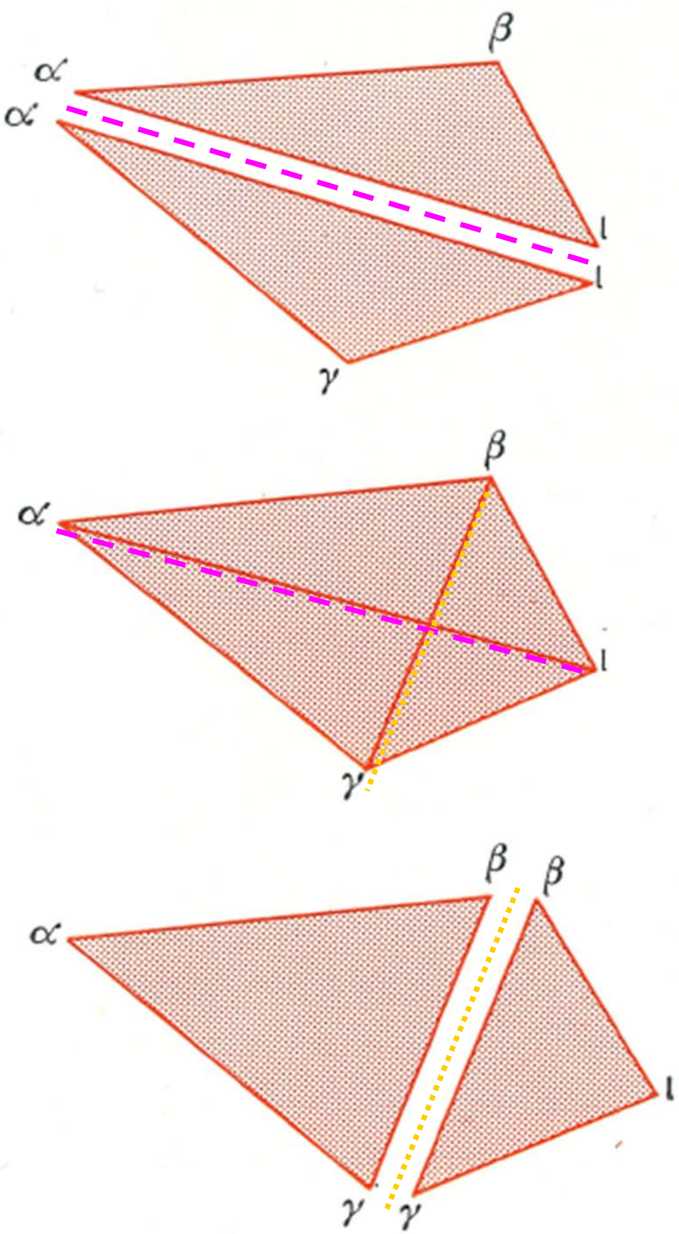
$T = P$



$P > T > T_C$

abP	peritectic $l\alpha\beta$ equilibrium	}	descending to the four-phase plane;
acP	peritectic $l\alpha\gamma$ equilibrium	}	
bcP	eutectic $l\beta\gamma$ equilibrium	}	descending from the four-phase plane.
abc	$\alpha\beta\gamma$ equilibrium	}	

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



Both three phase monovariant equilibria preceding the quasi-peritectic reaction are peritectic

abP peritectic lαβ equilibrium

acP peritectic lαγ equilibrium

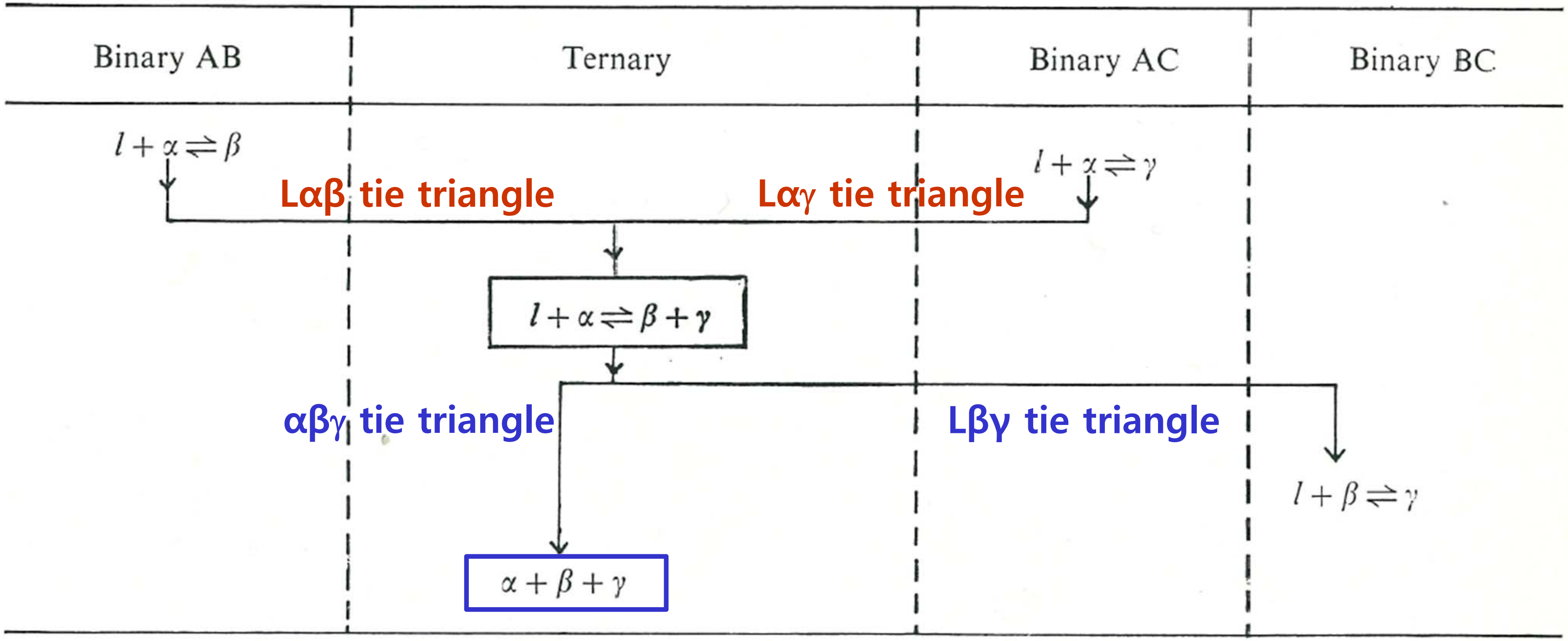
decreasing temperature

bcP eutectic lβγ equilibrium

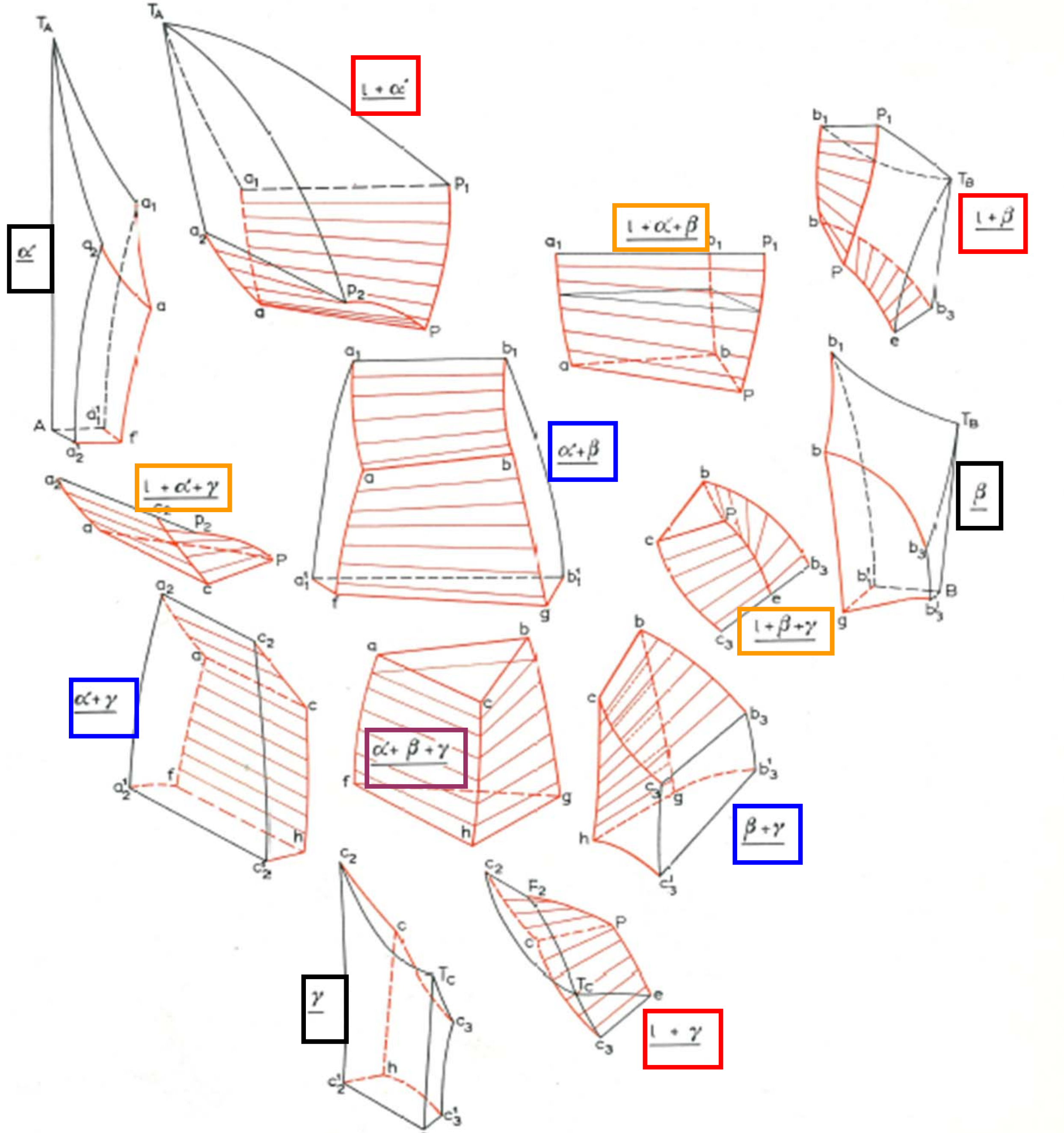
abc peritectic αβγ equilibrium

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

QUASI-PERITECTIC EQUILIBRIUM $l+\alpha \rightleftharpoons \beta+\gamma$

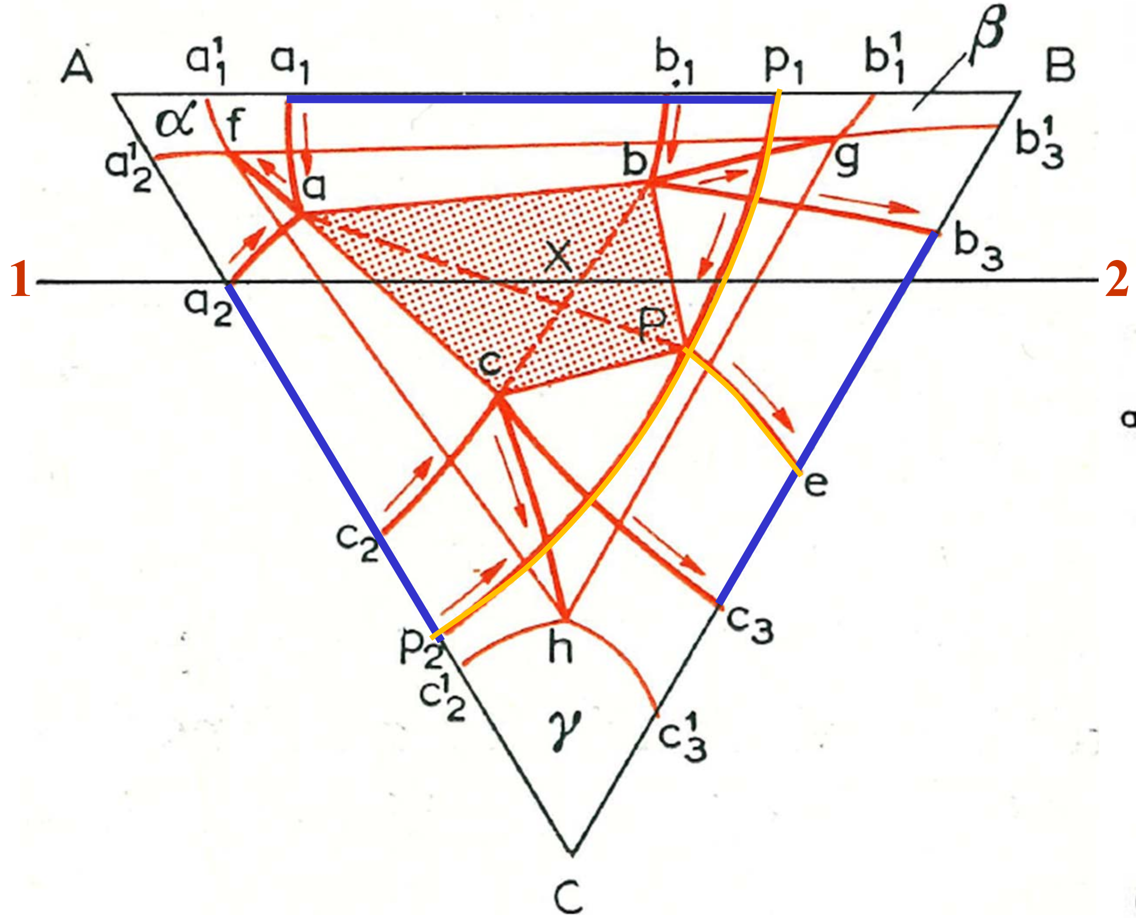


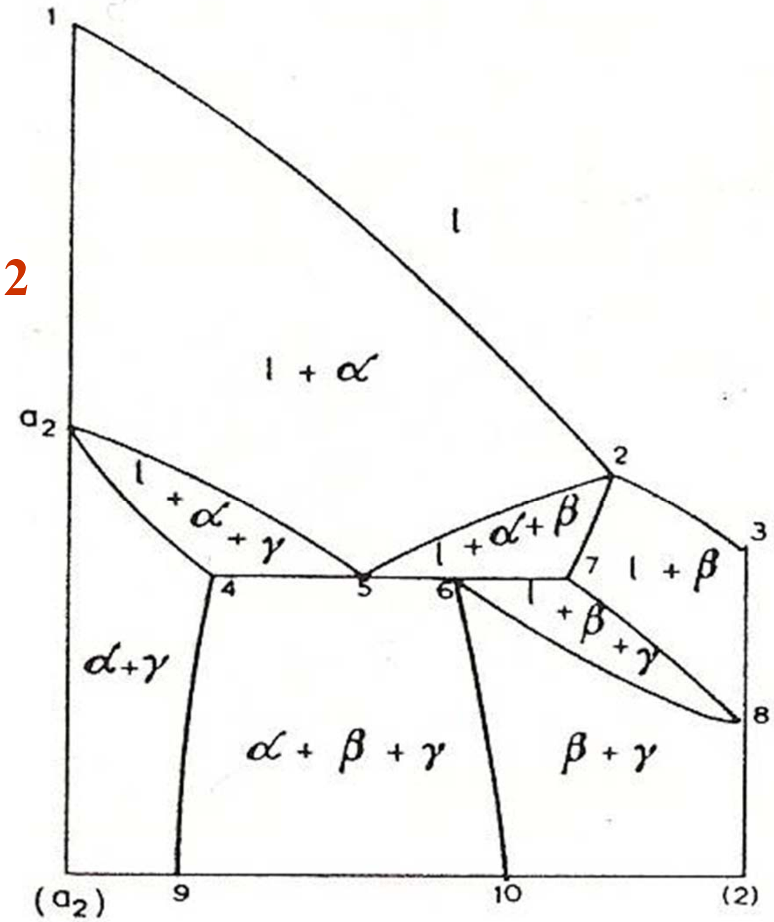
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)



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

Vertical section





(a)

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

Vertical section

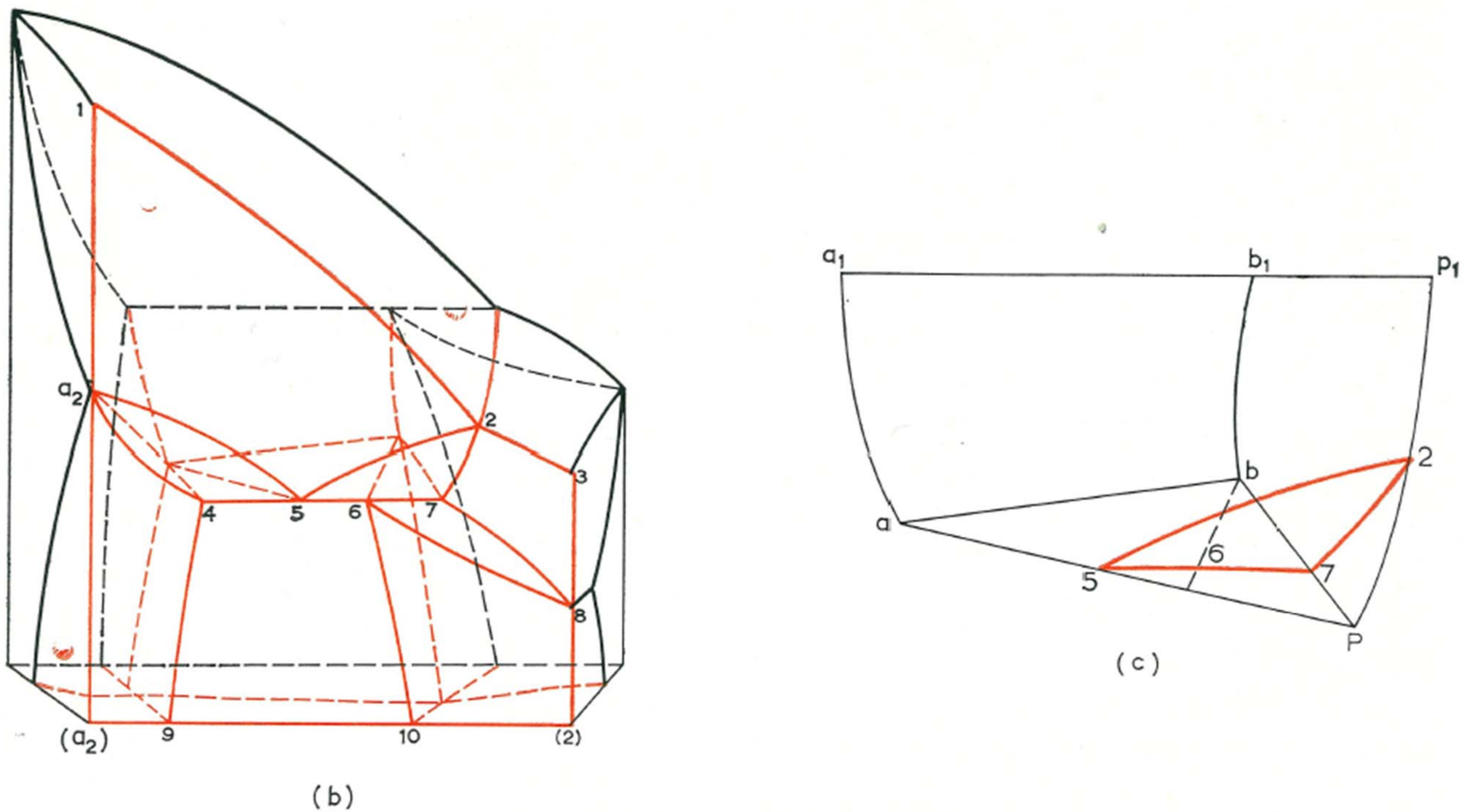


Fig. 188. A vertical section through the space model of Fig. 185a. (a) The vertical section a_2–2; (b) construction of the vertical section; (c) intersection of the vertical section with the $l+\alpha+\beta$ phase region.

10.3.2. one of the three phase monovariant equilibria preceding the quasi-peritectic reaction is eutectic and one peritectic.

*** Ternary system involving an incogruently-melting binary intermediate phase:**

Quasi-peritectic diagram and ternary eutectic diagram

e.g. **Au-Ge-Sb ternary** ***in which the δ phase is intermediate phase $AuSb_2$.***

$P_1d_1b_1 \rightarrow dbp$ $(\delta\beta L)$/ $b_3e_3C_3$ $\rightarrow bpc$ $(\beta L\gamma)$

⇓

$d^1\varepsilon c(\delta + \gamma + L)$ / $\boxed{gfn(\beta + \delta + \gamma)}$

$d^1\varepsilon c^1(\delta\gamma L)$ / $a_1e_1d_2 \rightarrow a^1\varepsilon d^1(\alpha\delta L)$/ $a_2e_2c_2 \rightarrow a^1\varepsilon c^1(\alpha L\gamma)$

⇓

$\boxed{Jkm\ (\alpha + \gamma + \delta)}$

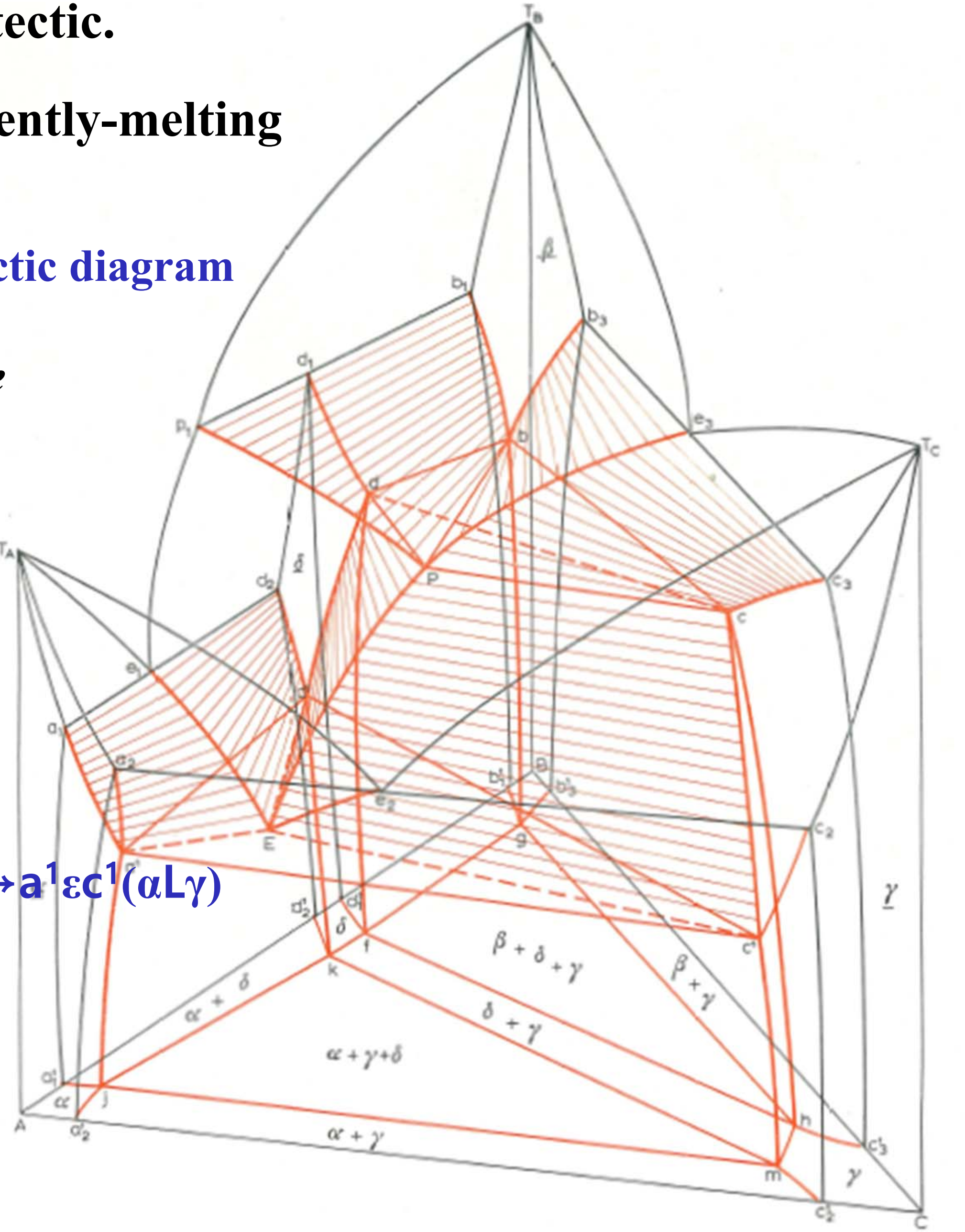
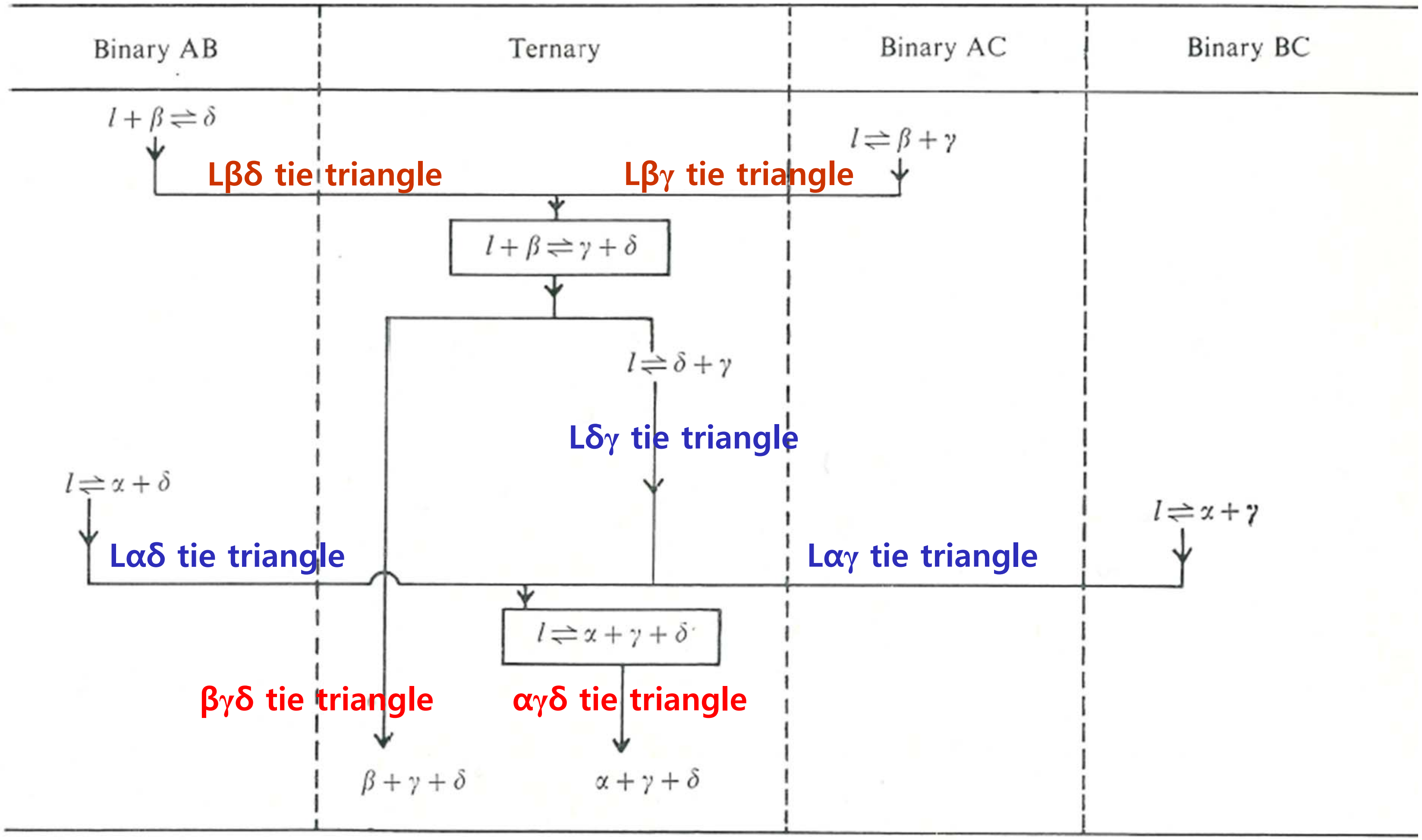


Fig. 189. Ternary system involving an incongruently-melting binary intermediate phase.

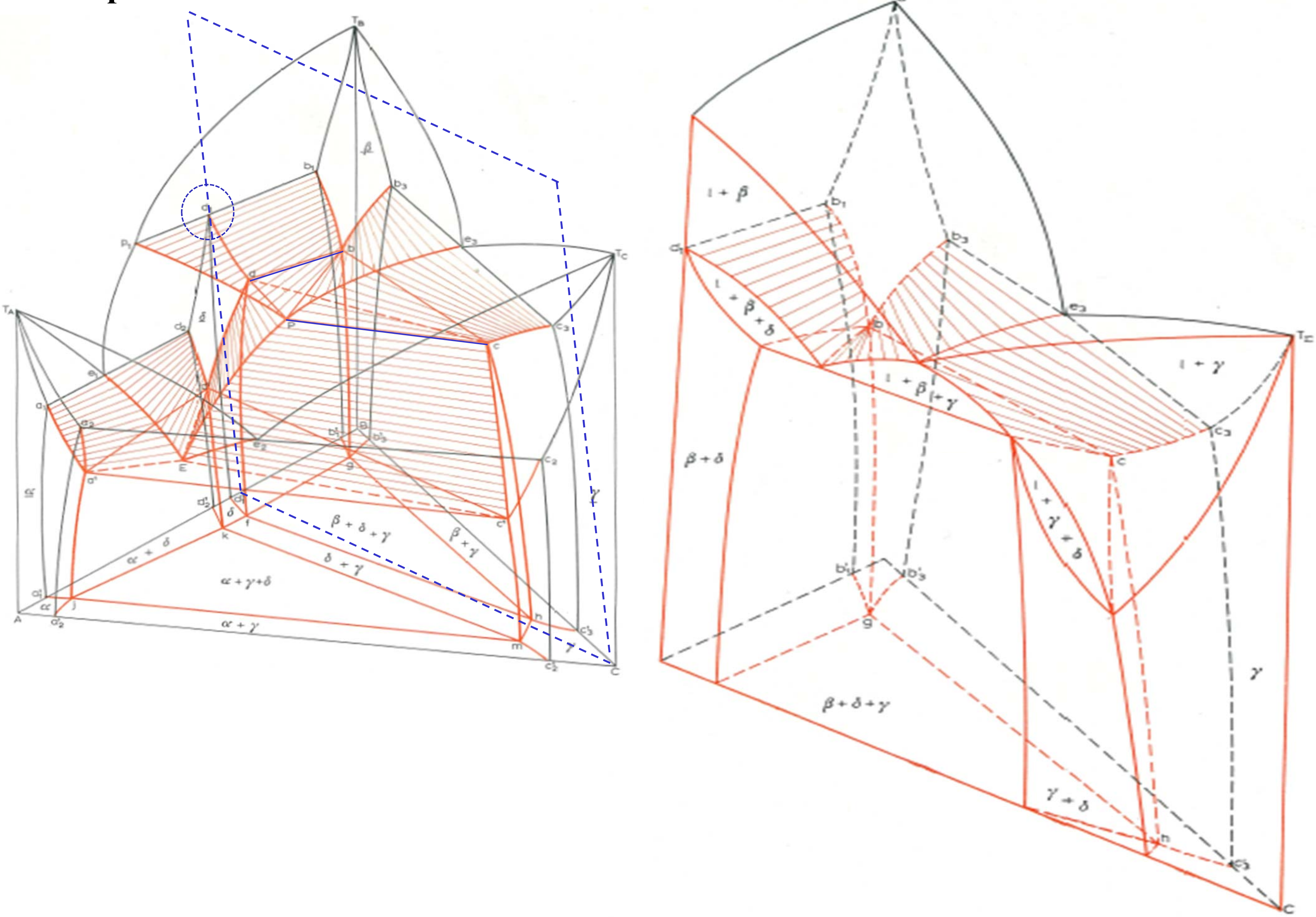
Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

Quasi-peritectic diagram and ternary eutectic diagram

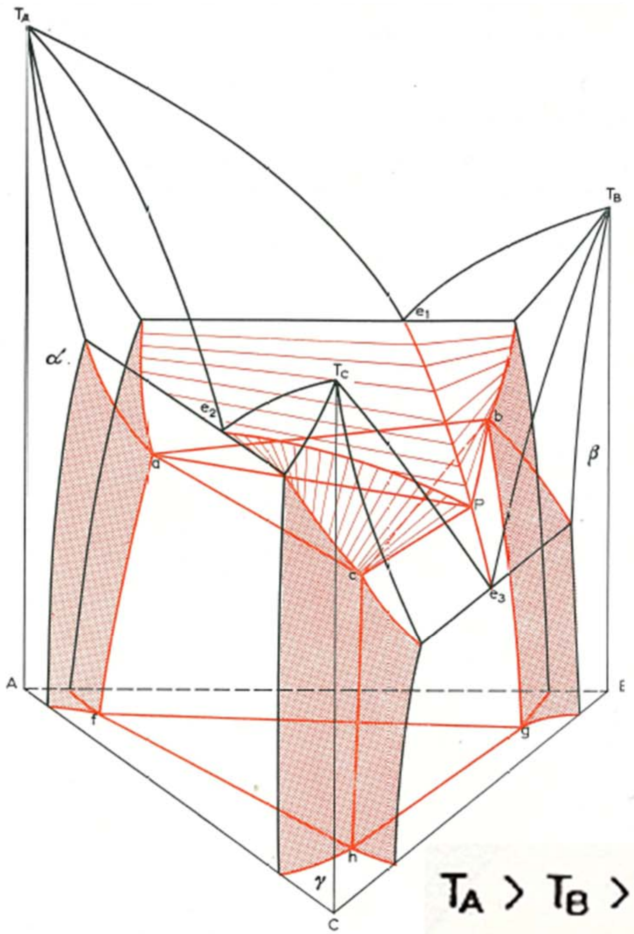


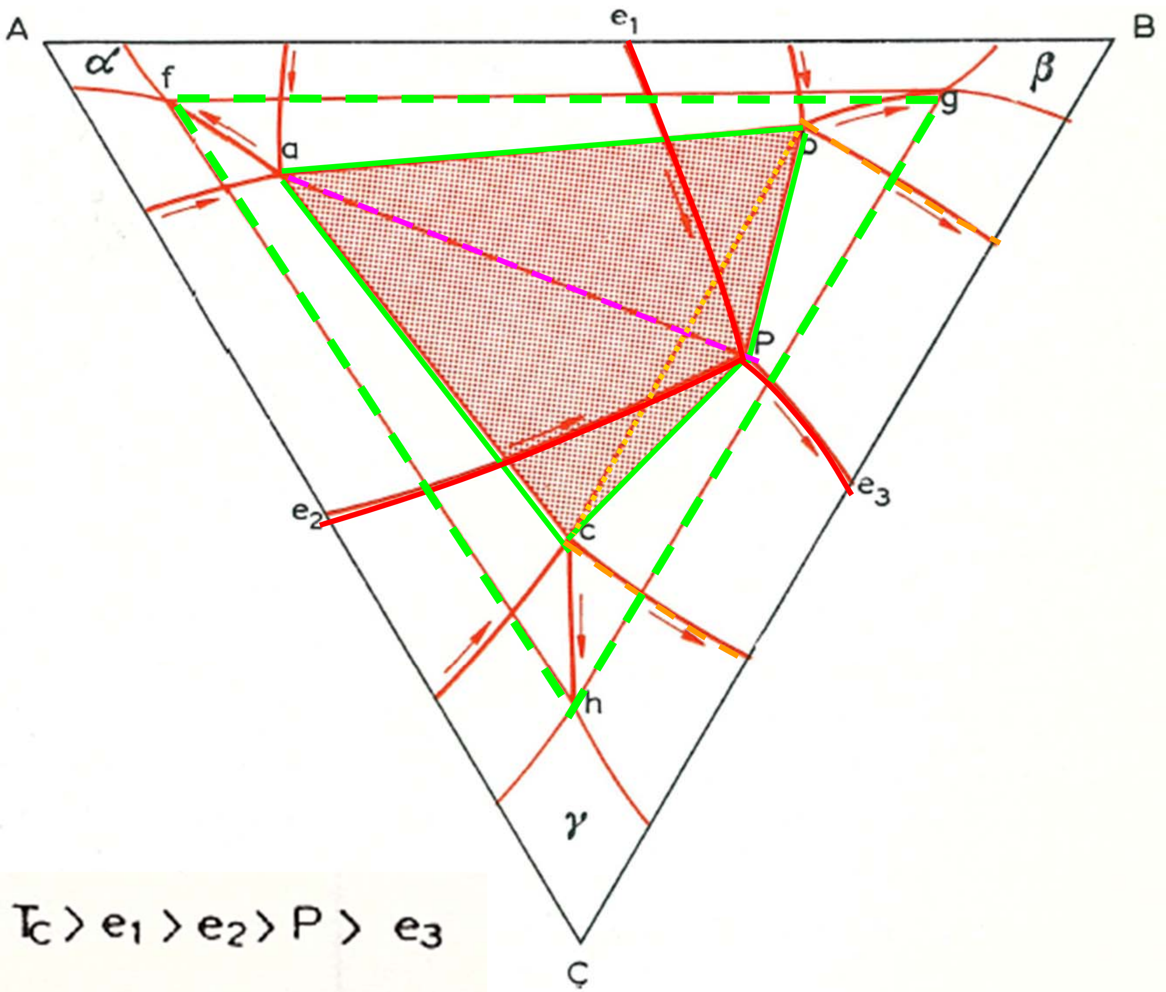
Vertical section which intersects point d1 on the AB binary, the tie lines db and Pc, and proceeds to the C corner



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

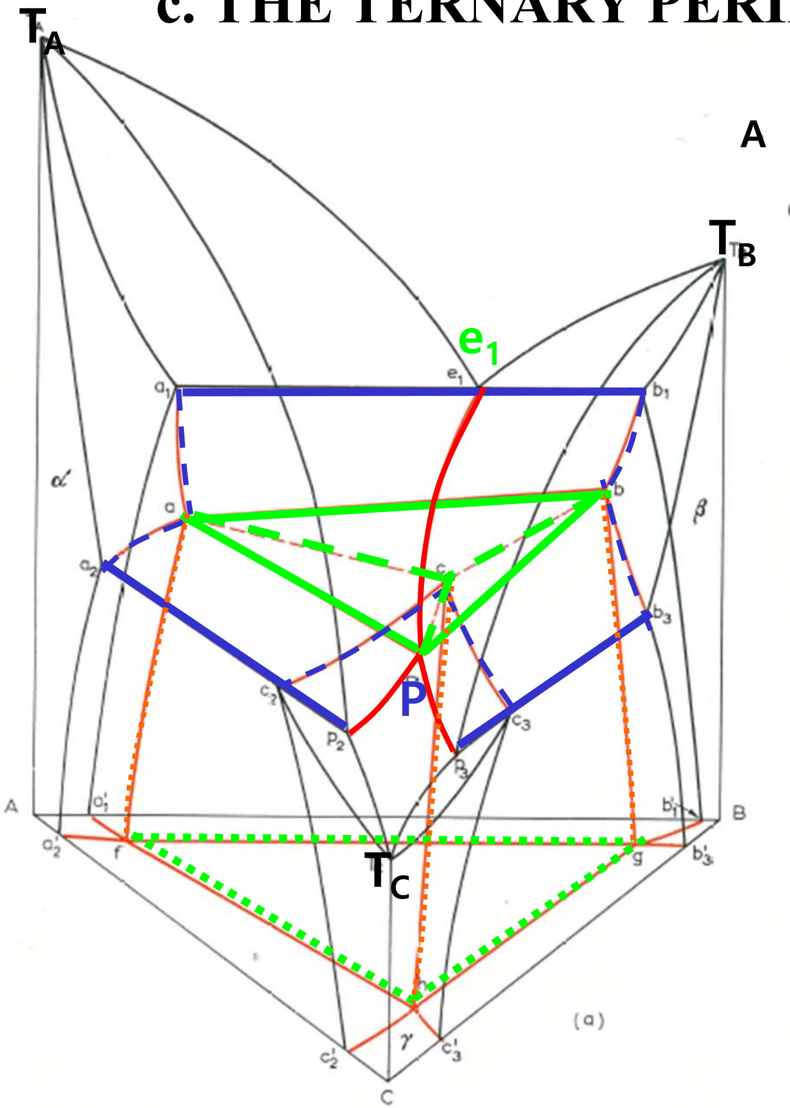
Fig. 191. The ternary quasi-peritectic system formed when all three binaries are eutectics. (a) Space model; (b) projection on the concentration triangle.

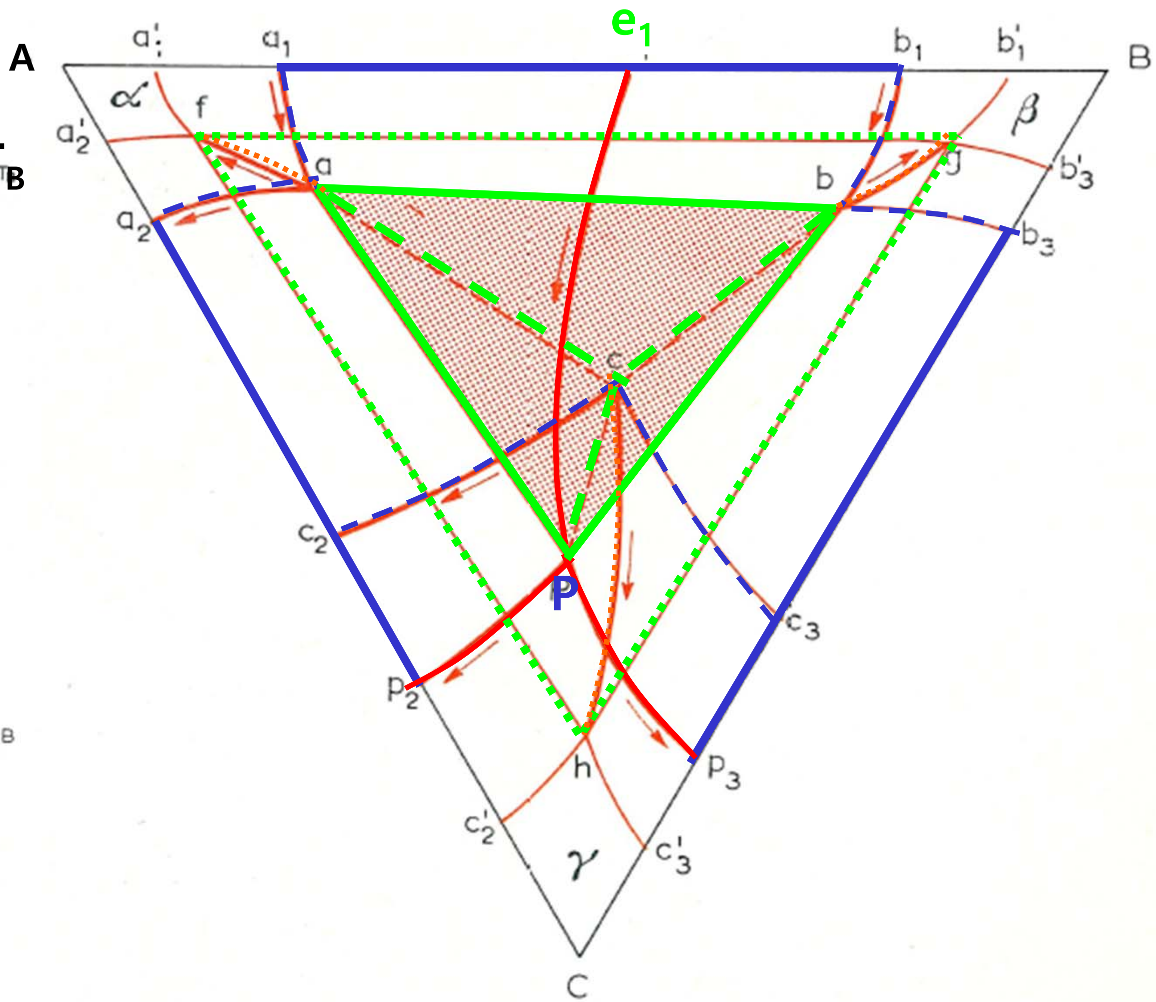




$T_A > T_B > T_C > e_1 > e_2 > P > e_3$

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





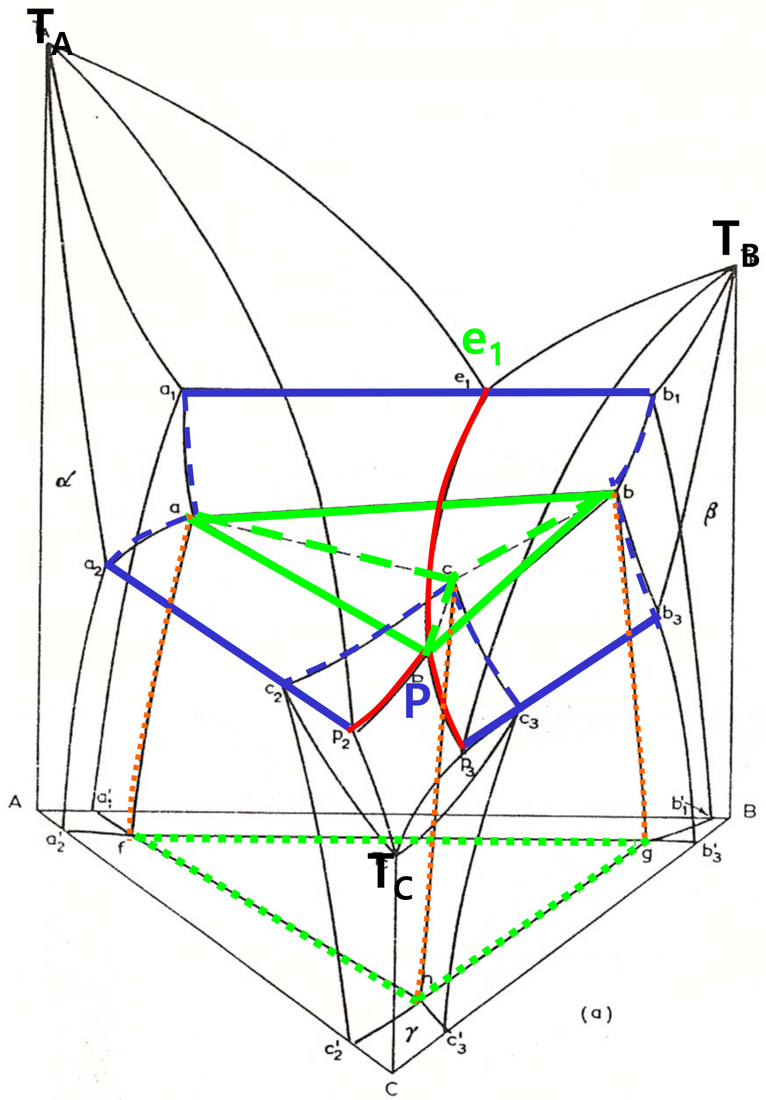
$\underline{a_1 e_1 b_1} \rightarrow$ **abP (αβL)**

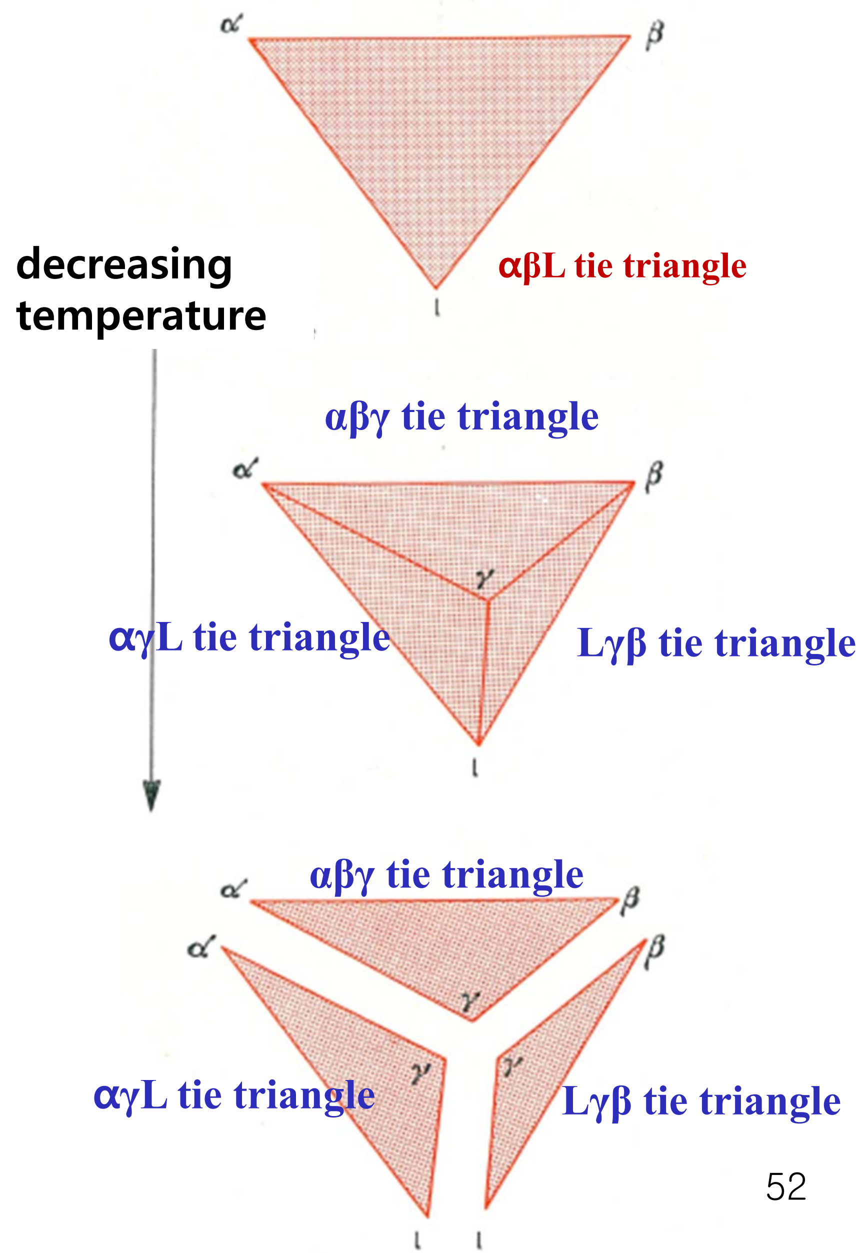
$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

⇓

aPc(αγL) → $\underline{a_2 c_2 P_2}$ / Pcb(Lγβ) → $\underline{P_3 c_3 b_3}$ / abc(αβγ) → **fgh (αβγ)**

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



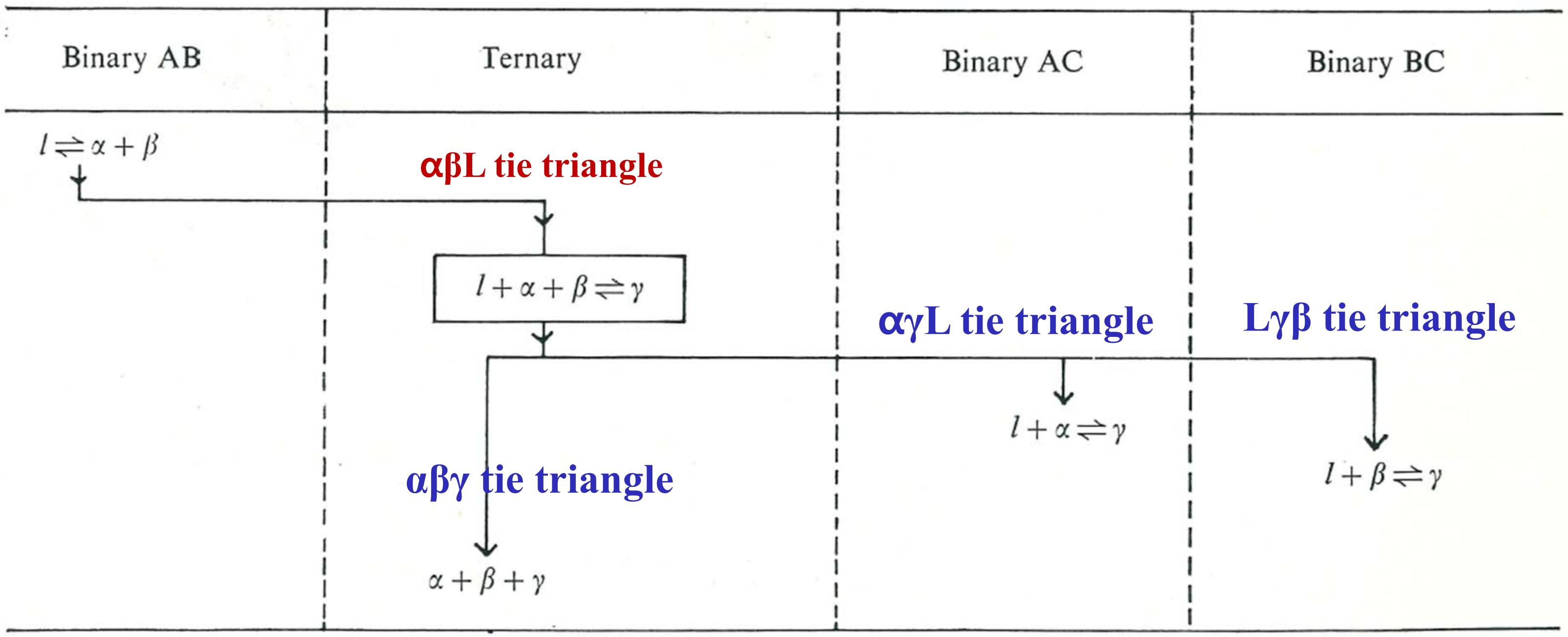


$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

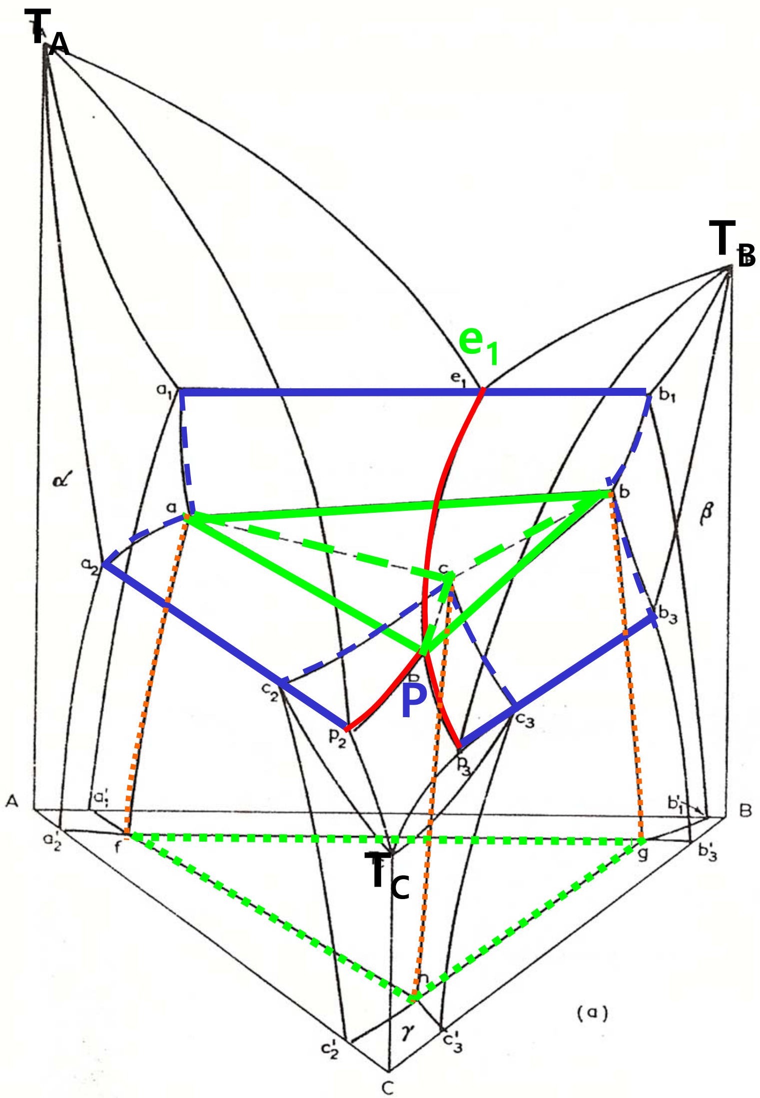
Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

TERNARY PERITECTIC EQUILIBRIUM $l+\alpha+\beta \rightleftharpoons \gamma$

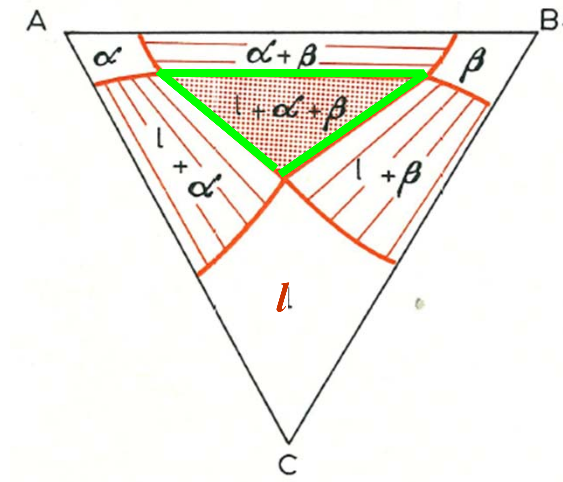


10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

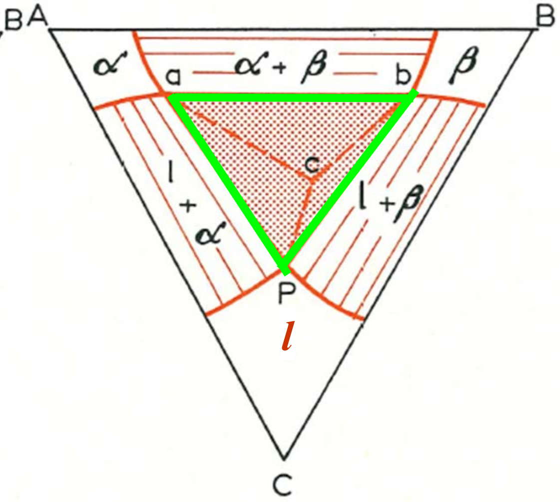


$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

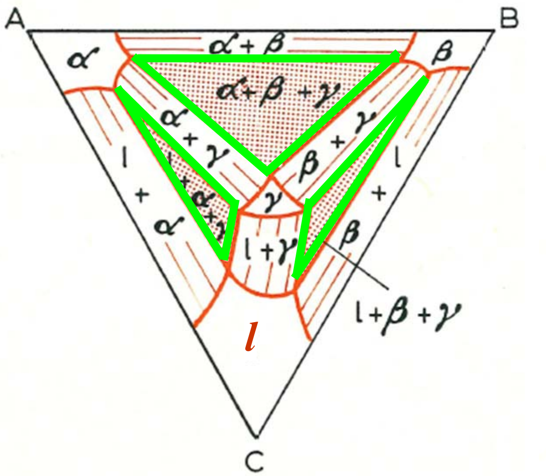
Isothermal section



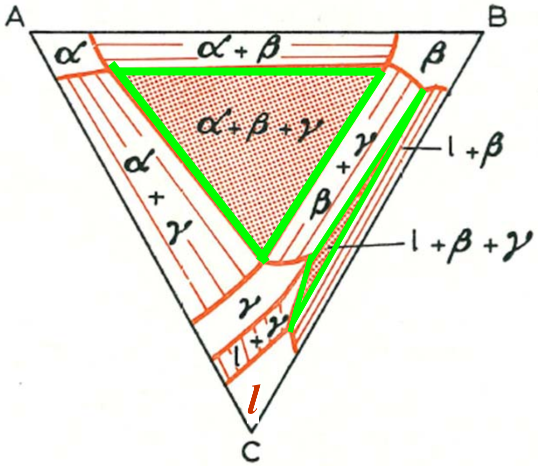
$e_1 > T > P$



$T = P$

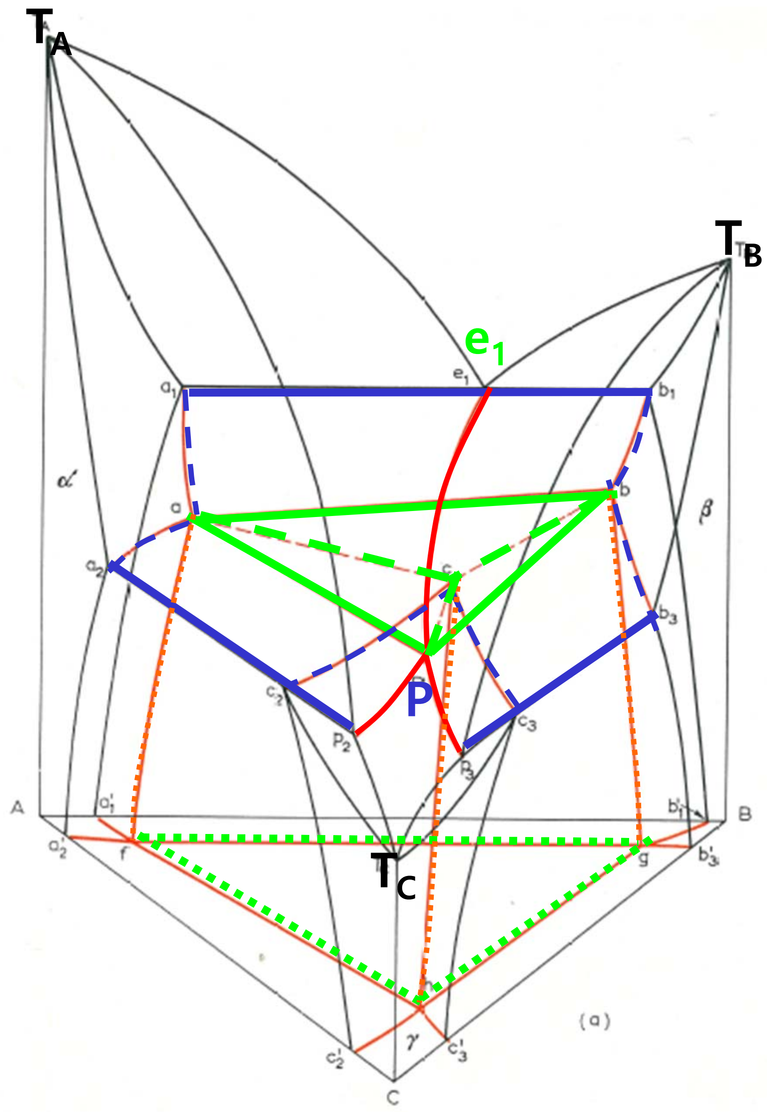


$P > T > P_2$

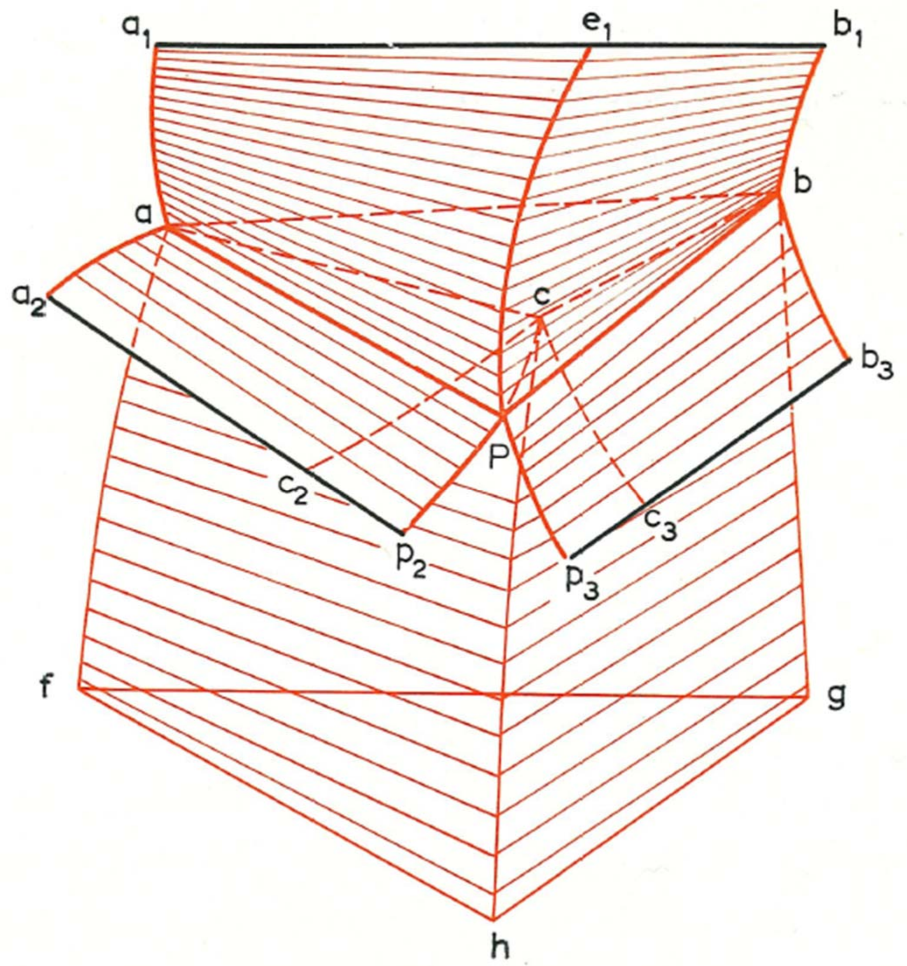


$P_2 > T > P_3$

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



$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$



The ternary peritectic four-phase plane as the junction of four tie triangles

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