2021 Spring

"Phase Equilibria *in* Materials"

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

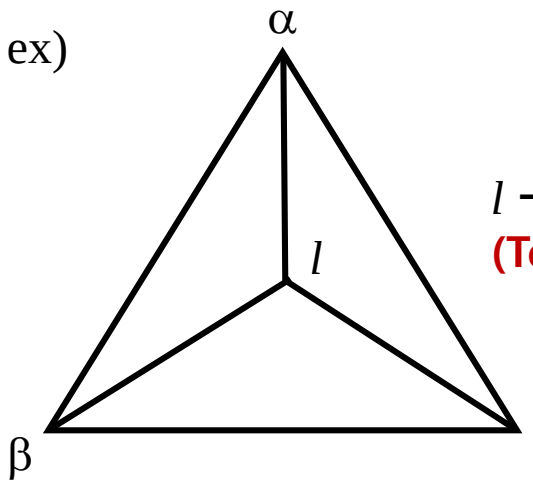
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

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)

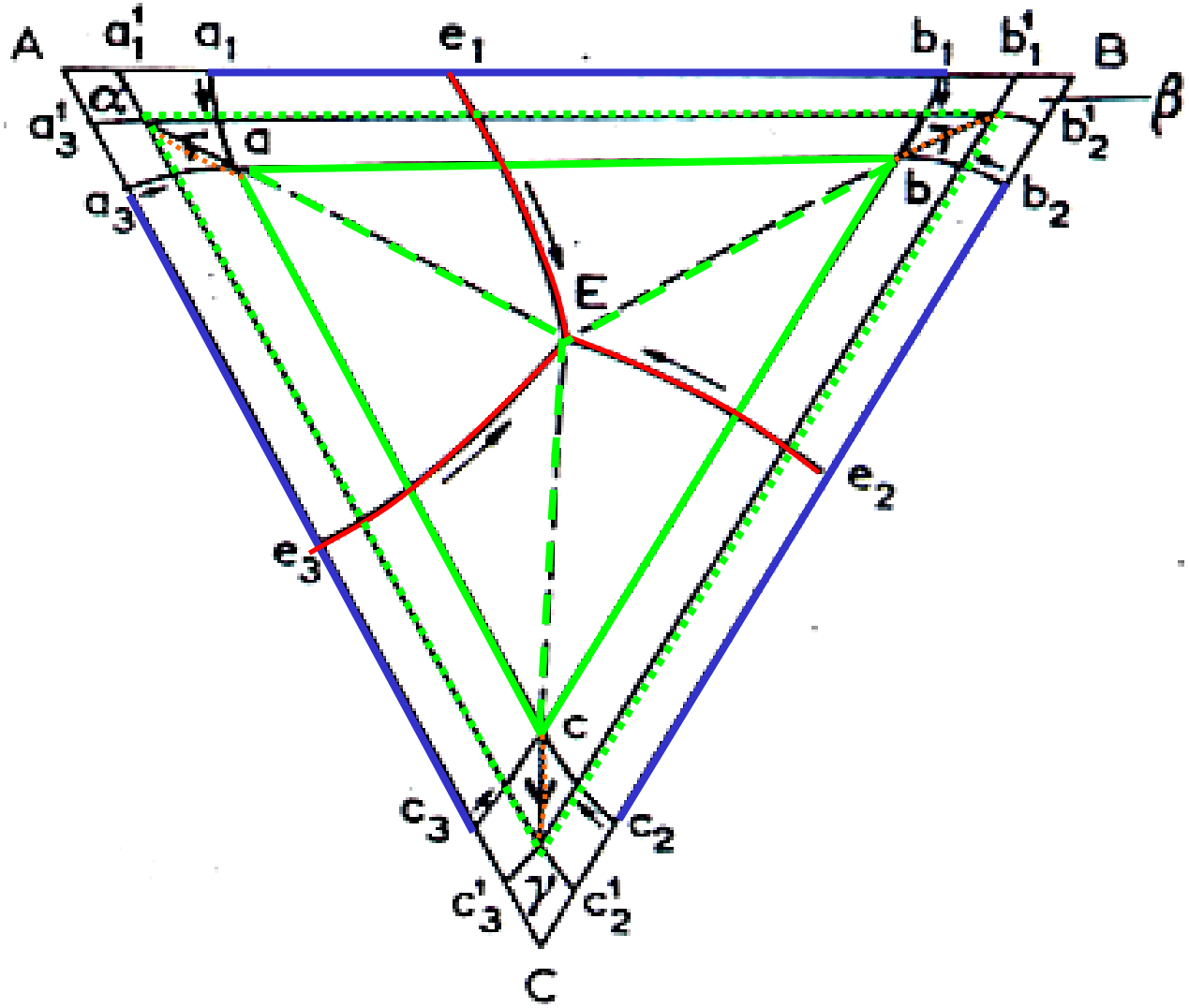


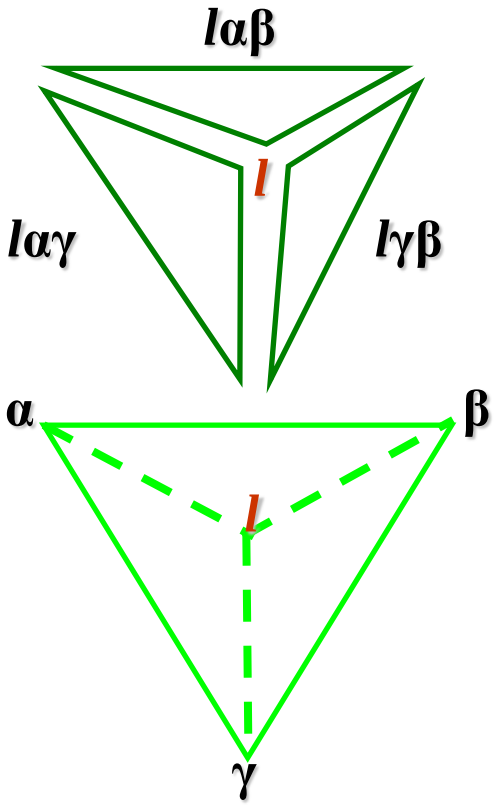
$l \rightarrow \alpha + \beta + \gamma$
(Ternary eutectic)

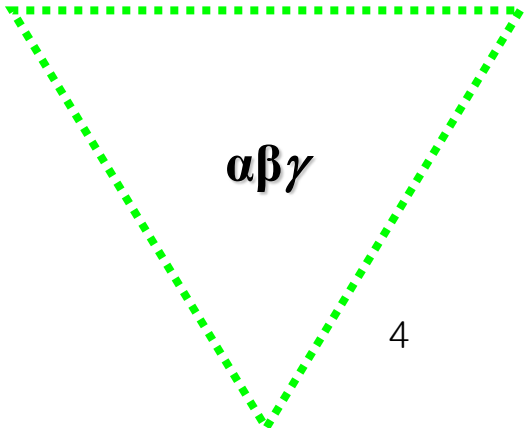
cf) $l + \alpha \rightarrow \beta + \gamma$: **ternary quasi-peritectic**
$l + \alpha + \beta \rightarrow \gamma$: **ternary peritectic**

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

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

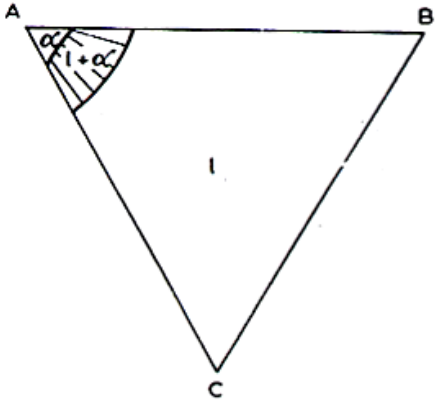




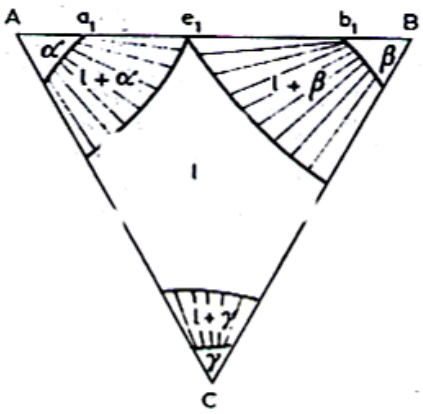


10.1. THE EUTECTIC EQUILIBRIUM (l = α + β + γ)

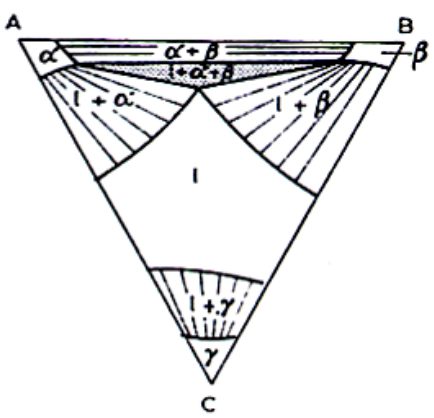
- **Isothermal section** ($T_A > T > T_B$)



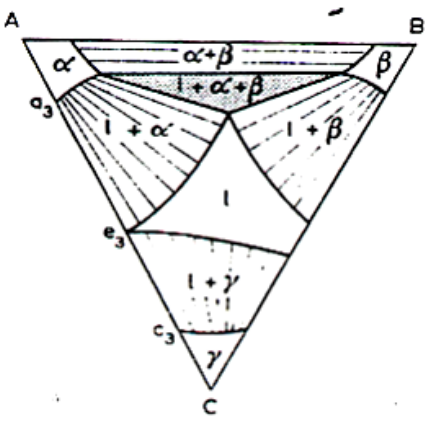
(a) $T_A > T > T_B$



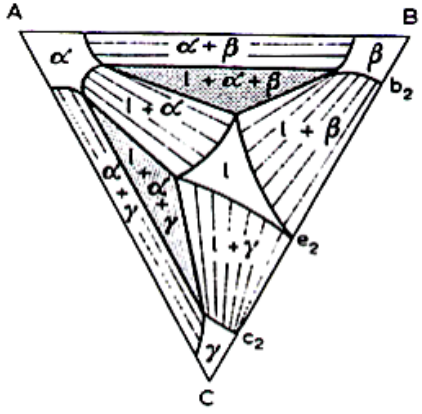
(b) $T = e_1$



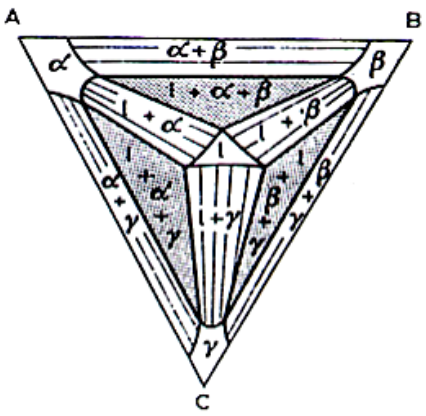
(c) $e_1 > T > e_3$



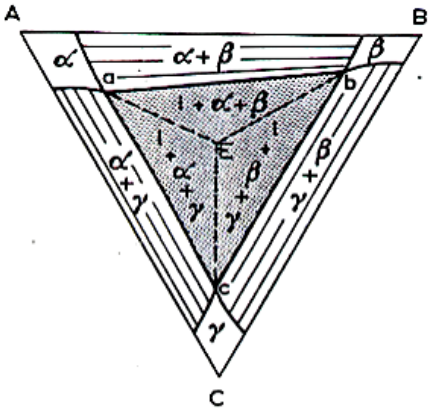
(d) $T = e_3$



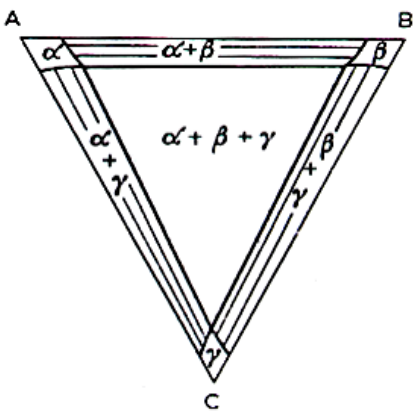
(e) $T = e_2$



(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**

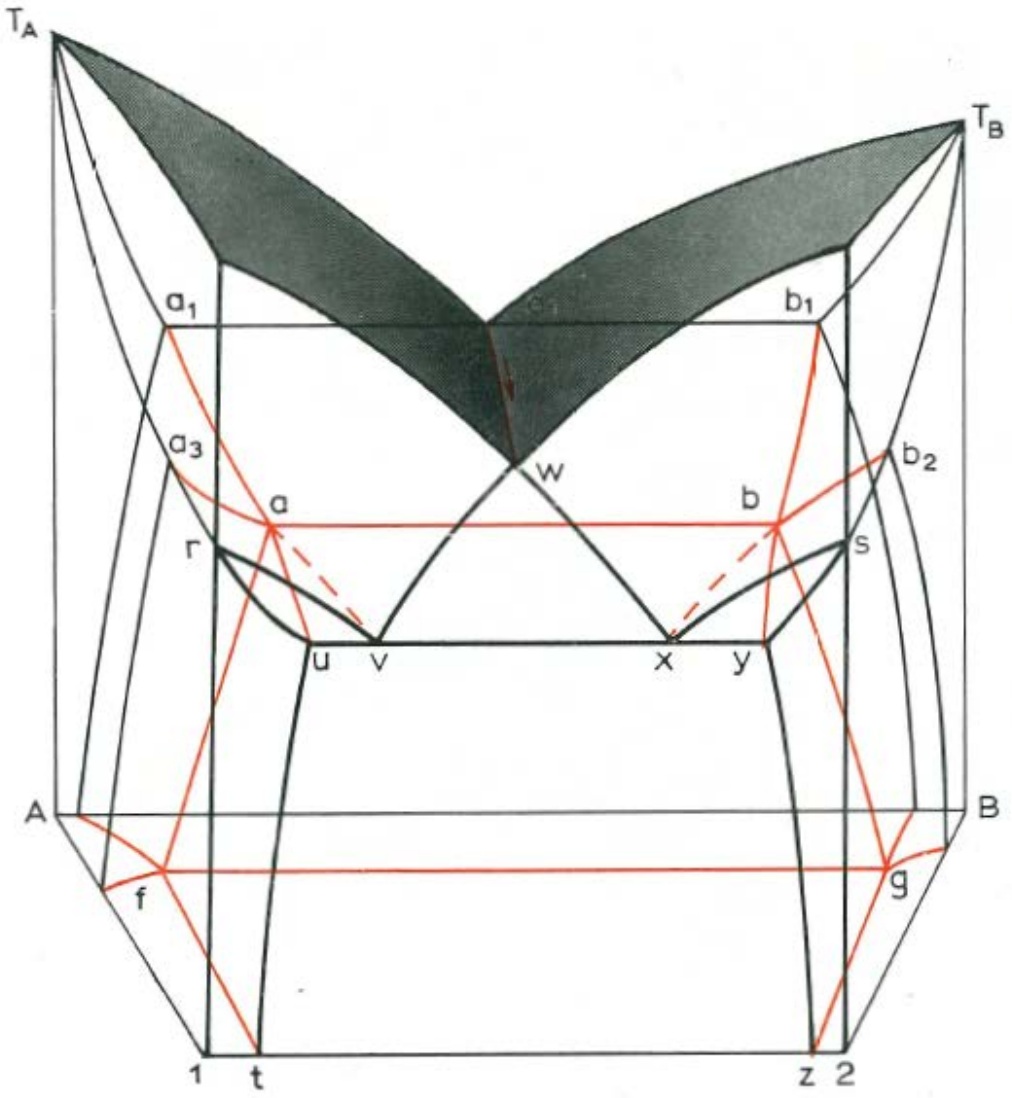
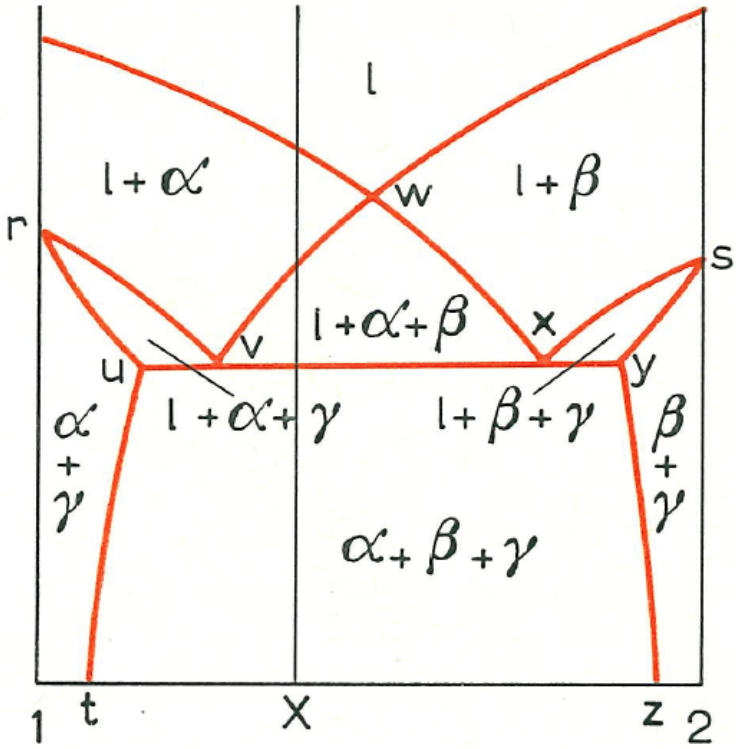


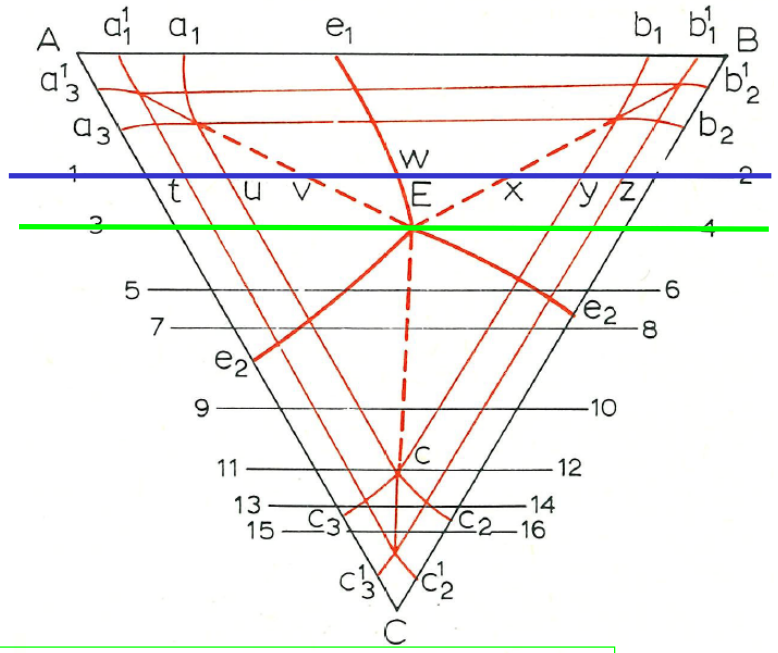
Fig. 179. Construction of vertical section 1–2.

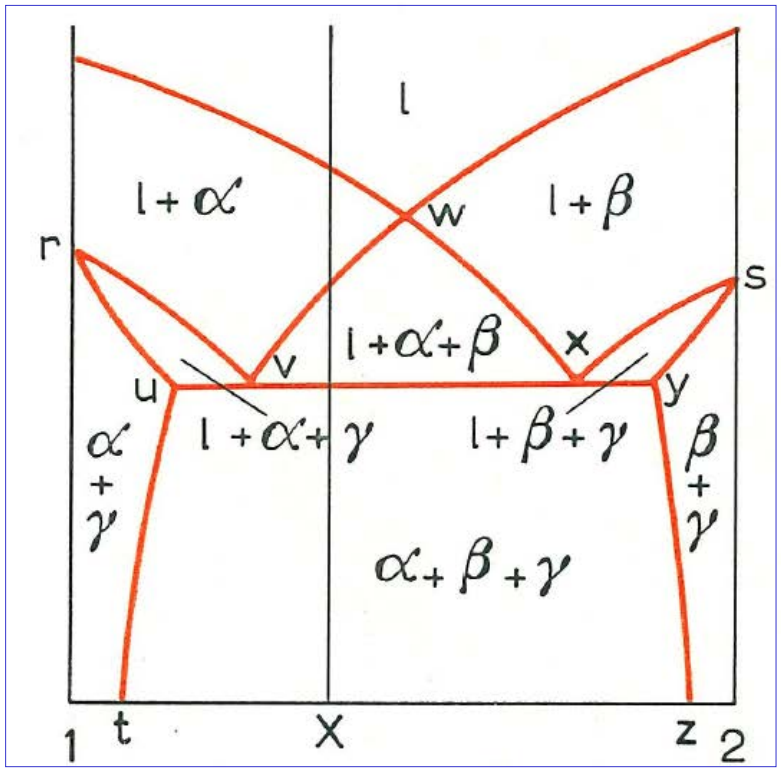


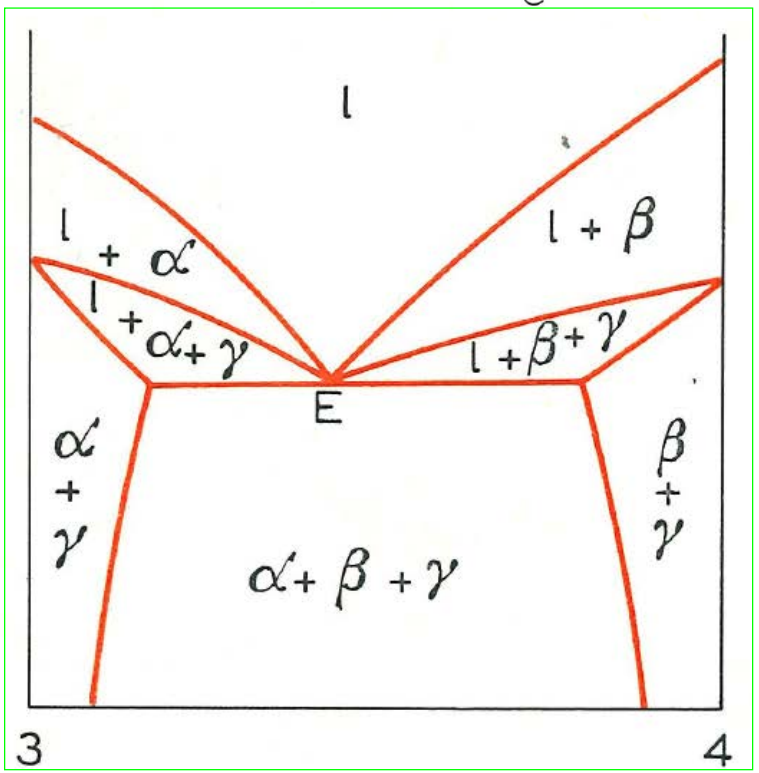
10.1. THE EUTECTIC EQUILIBRIUM

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

Vertical section **Location of vertical section**

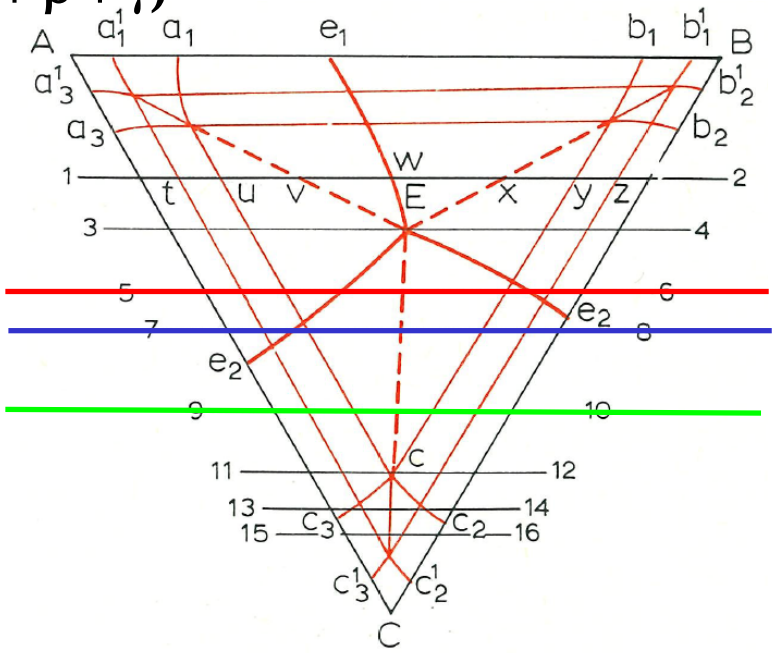


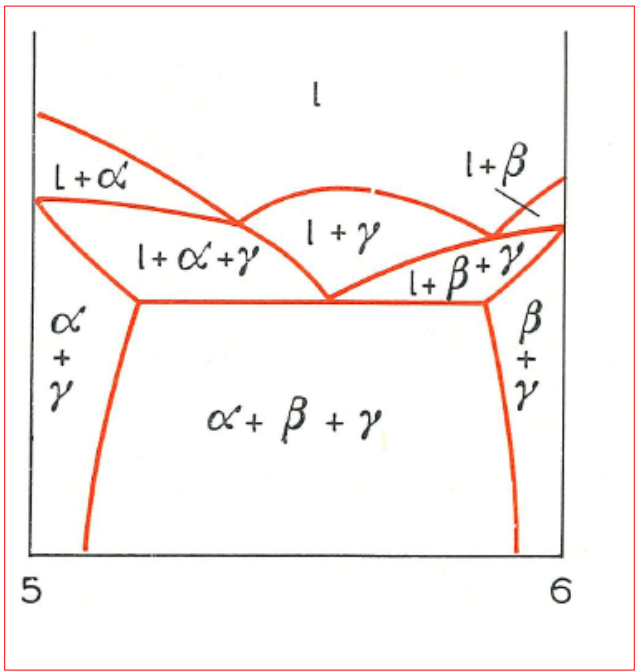


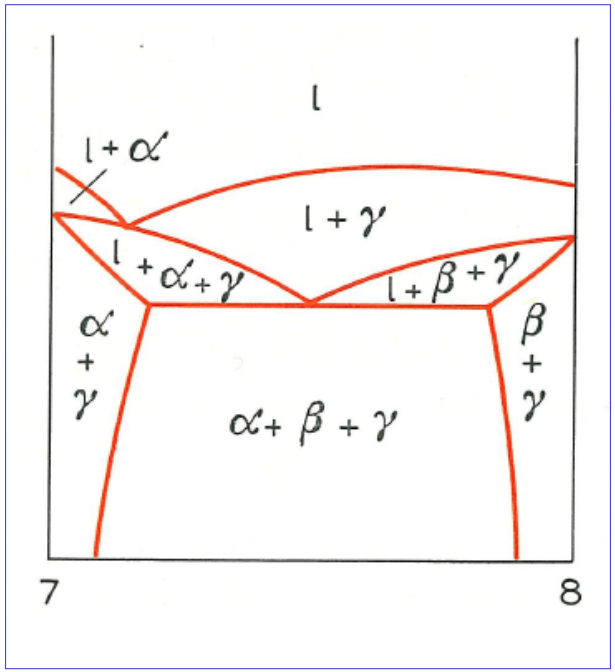


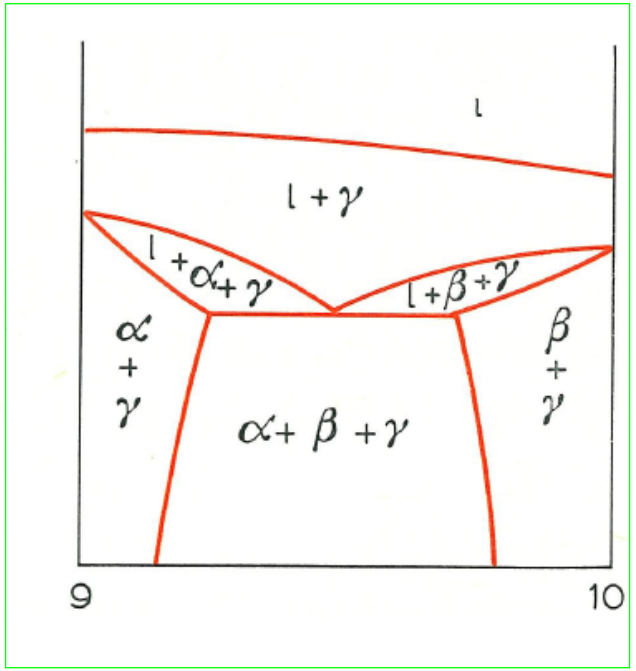
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**



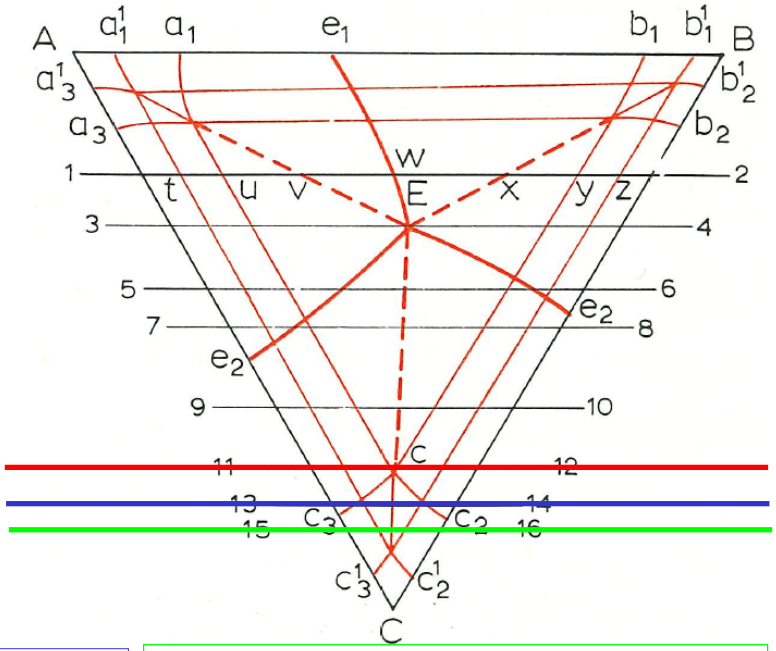


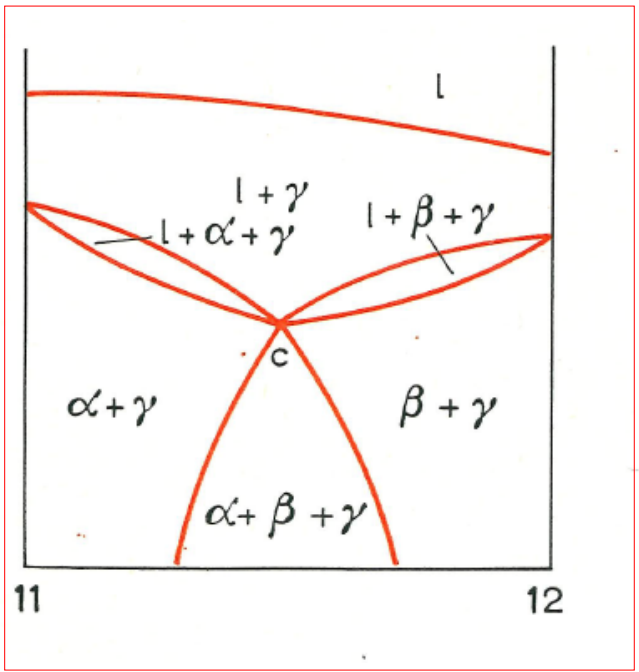


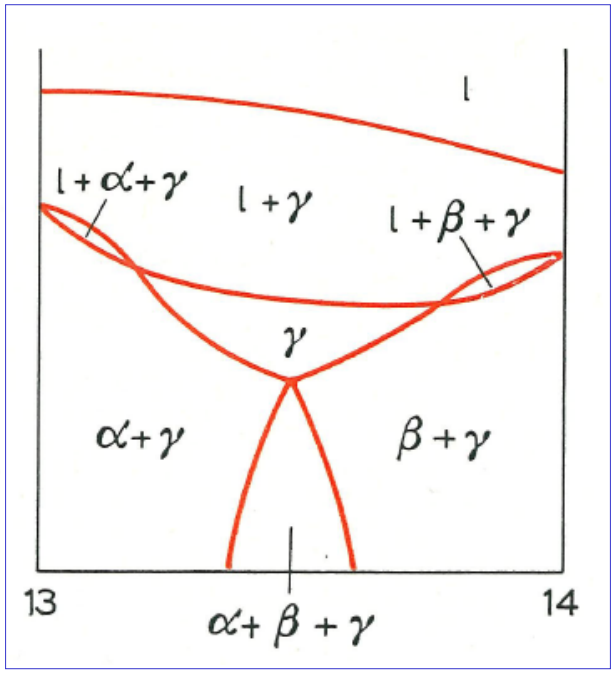


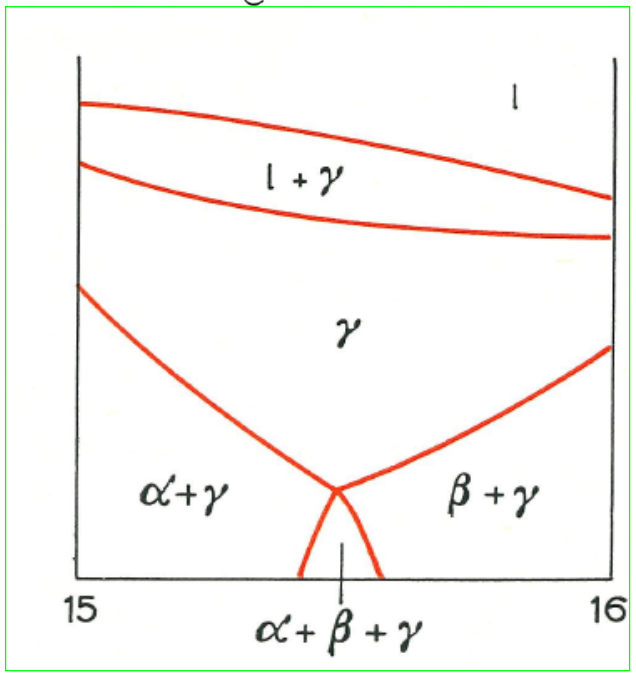
10.1. THE EUTECTIC EQUILIBRIUM ($l = \alpha + \beta + \gamma$)

Vertical section **Location of vertical section**

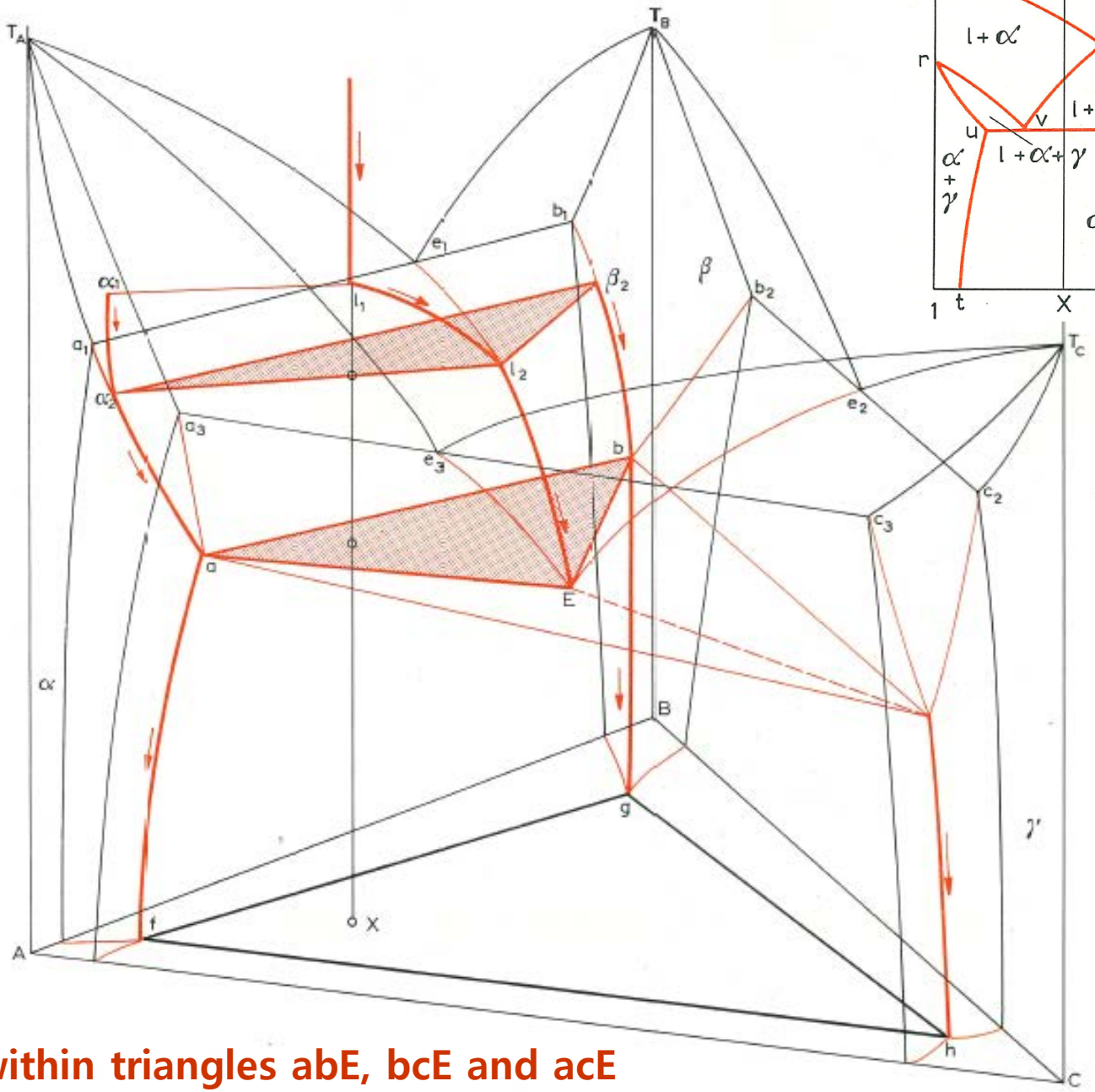


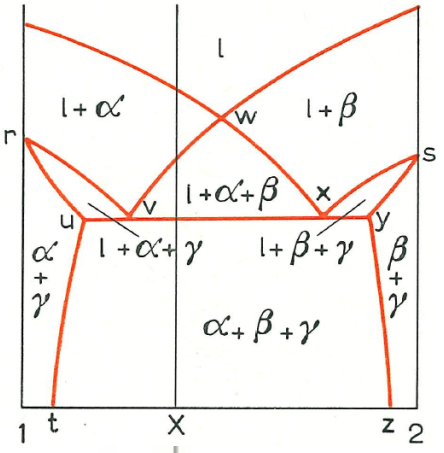






Transformation during cooling



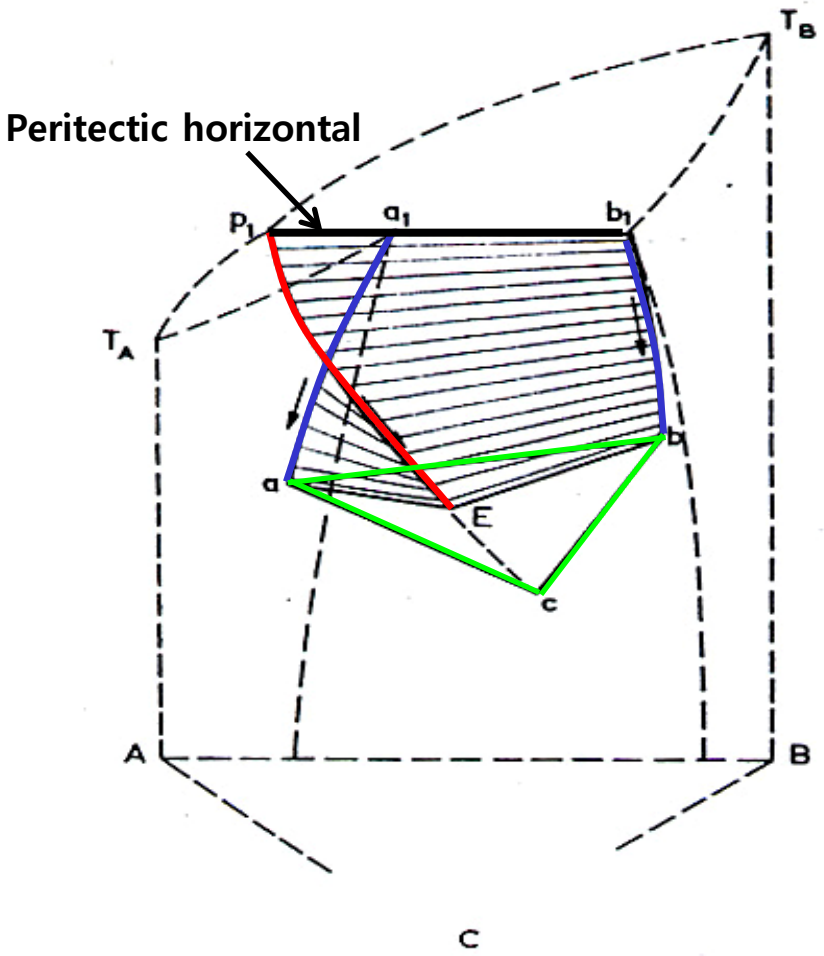


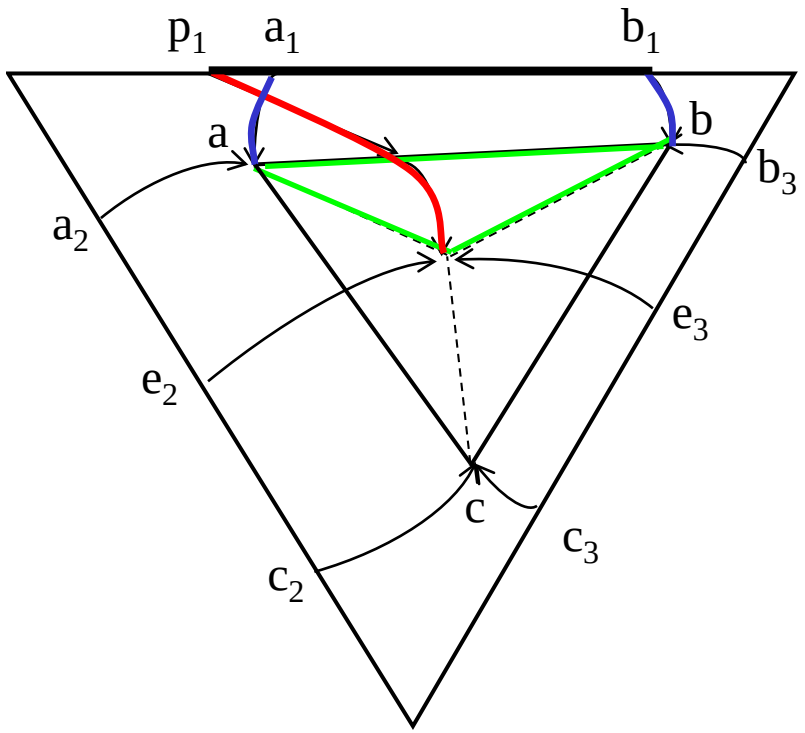
④ Alloys within triangles abE, bcE and acE

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



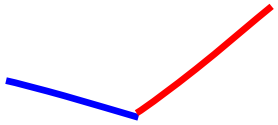


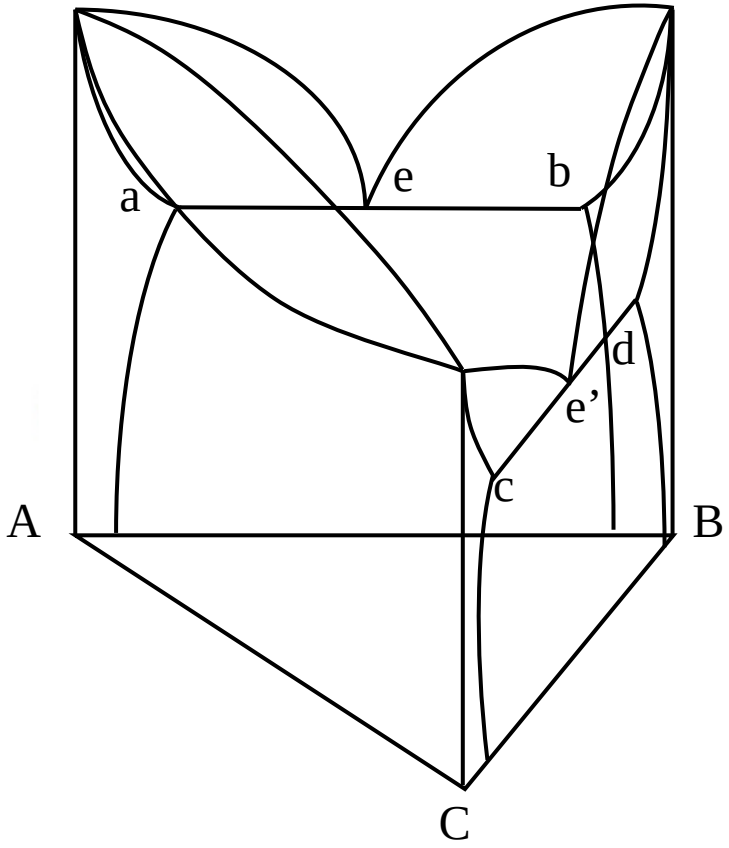
Monovariant liquidus line (P_1E) lies above monovariant solidus line (a_1a).

→ 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.



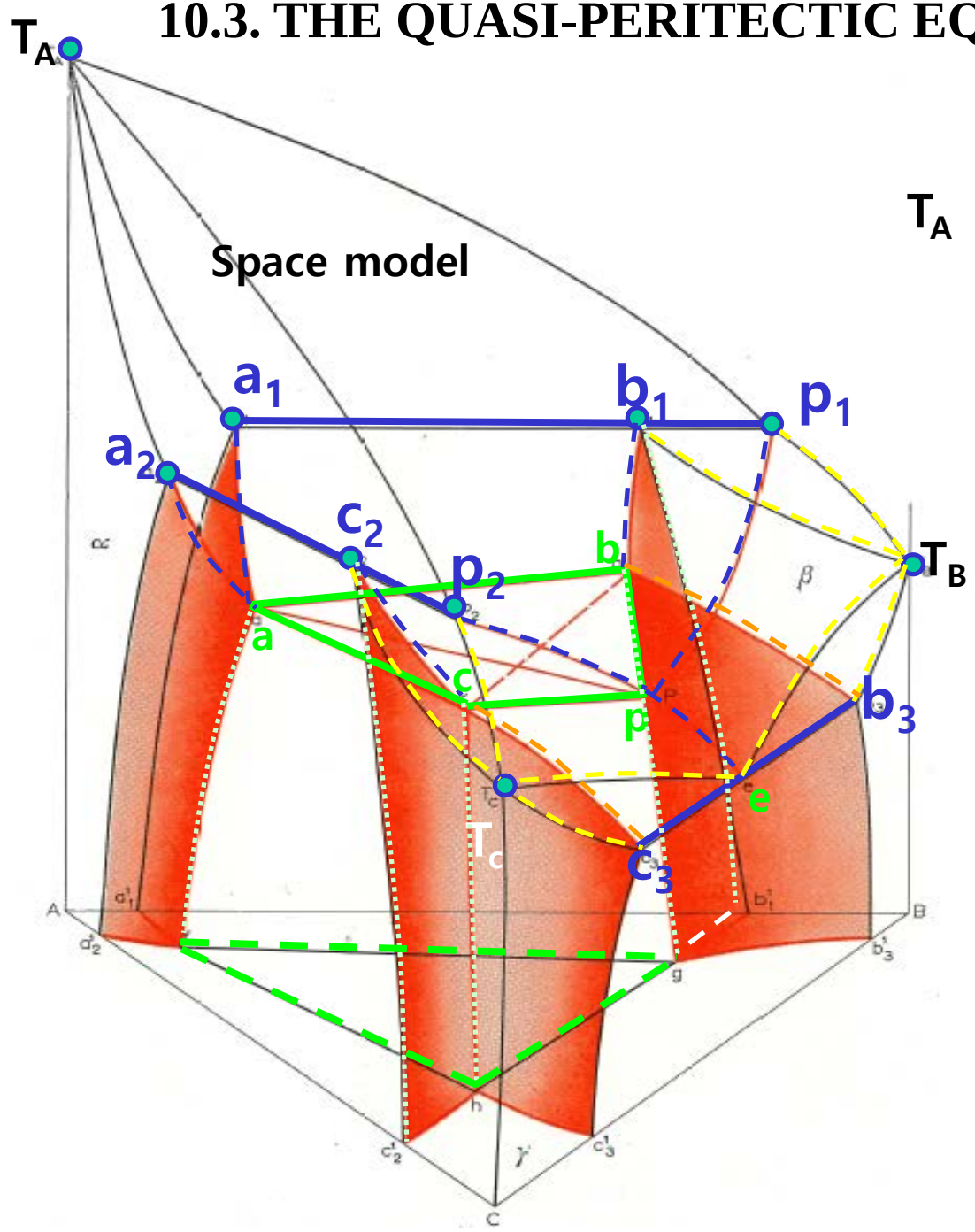


<one complete solid solution + two binary eutectic>

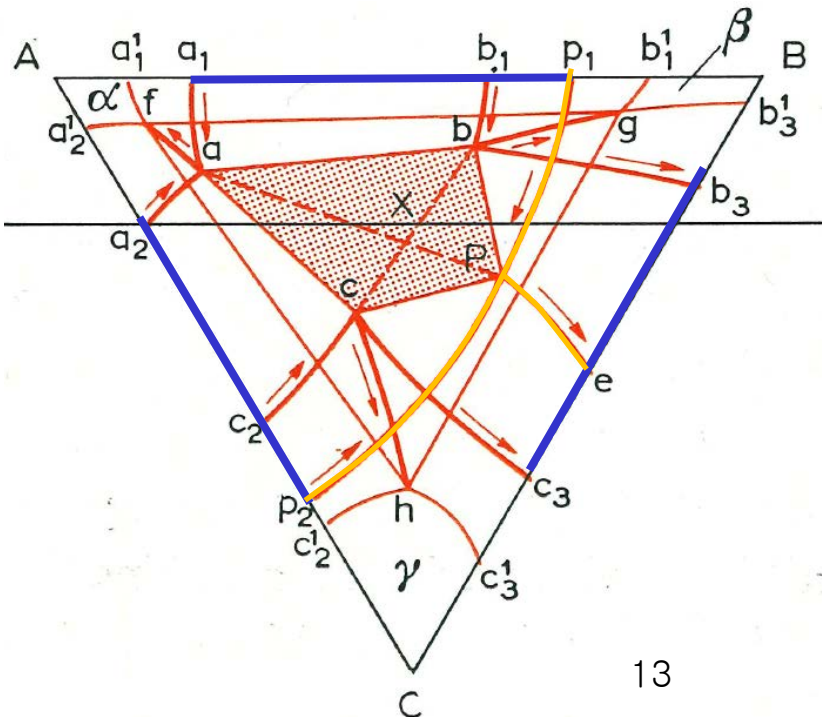
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

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

Space model

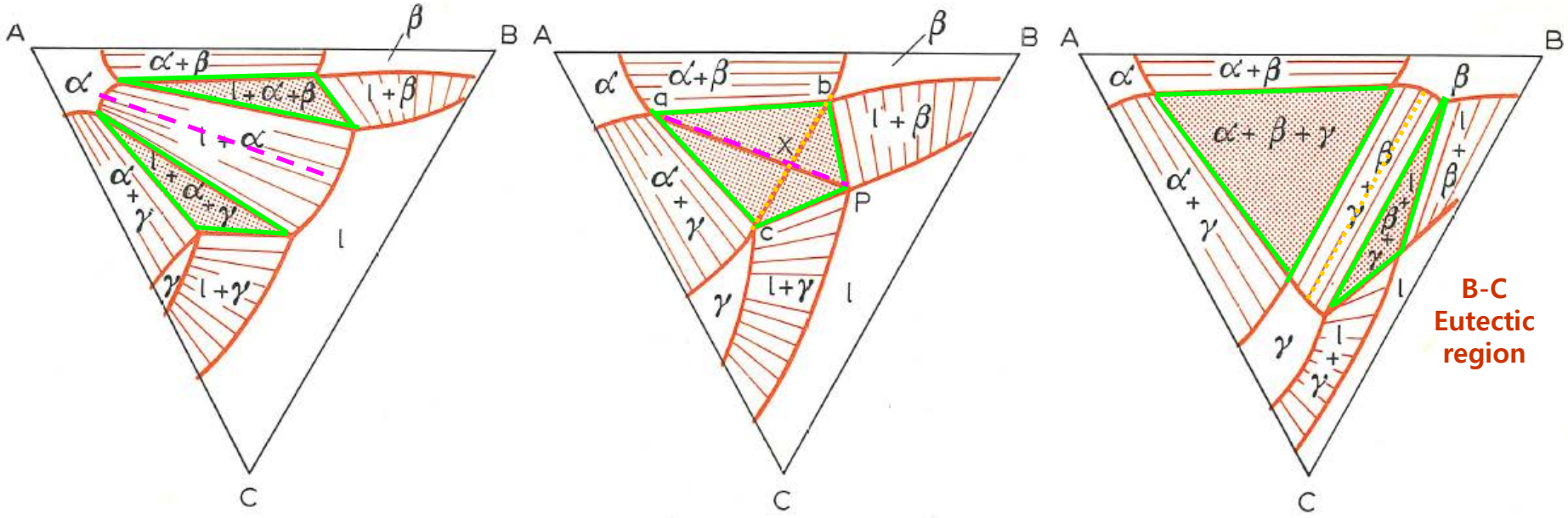


Projection



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

Isothermal section



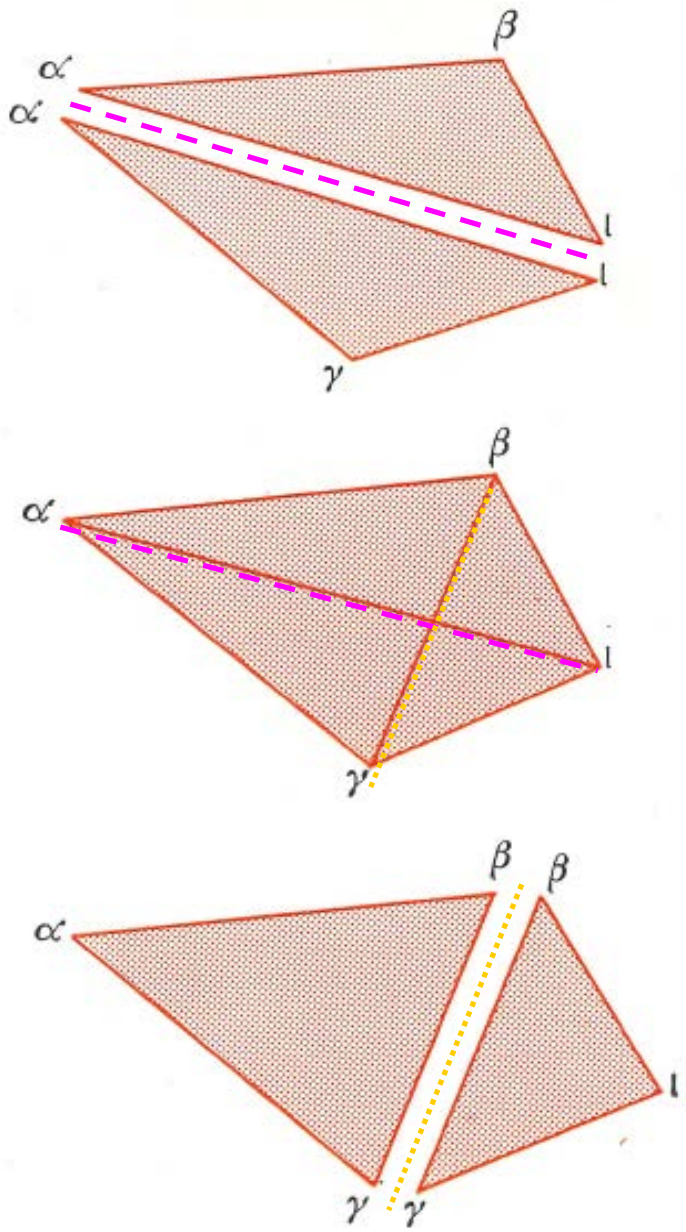
$T_B > T > P$ $\quad T = P \quad$ $P > T > T_C$

abP	peritectic	$l\alpha\beta$	equilibrium
acP	peritectic	$l\alpha\gamma$	equilibrium
bcP	eutectic	$l\beta\gamma$	equilibrium
abc		$\alpha\beta\gamma$	equilibrium

descending to the four-phase plane;

descending from the four-phase plane.

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

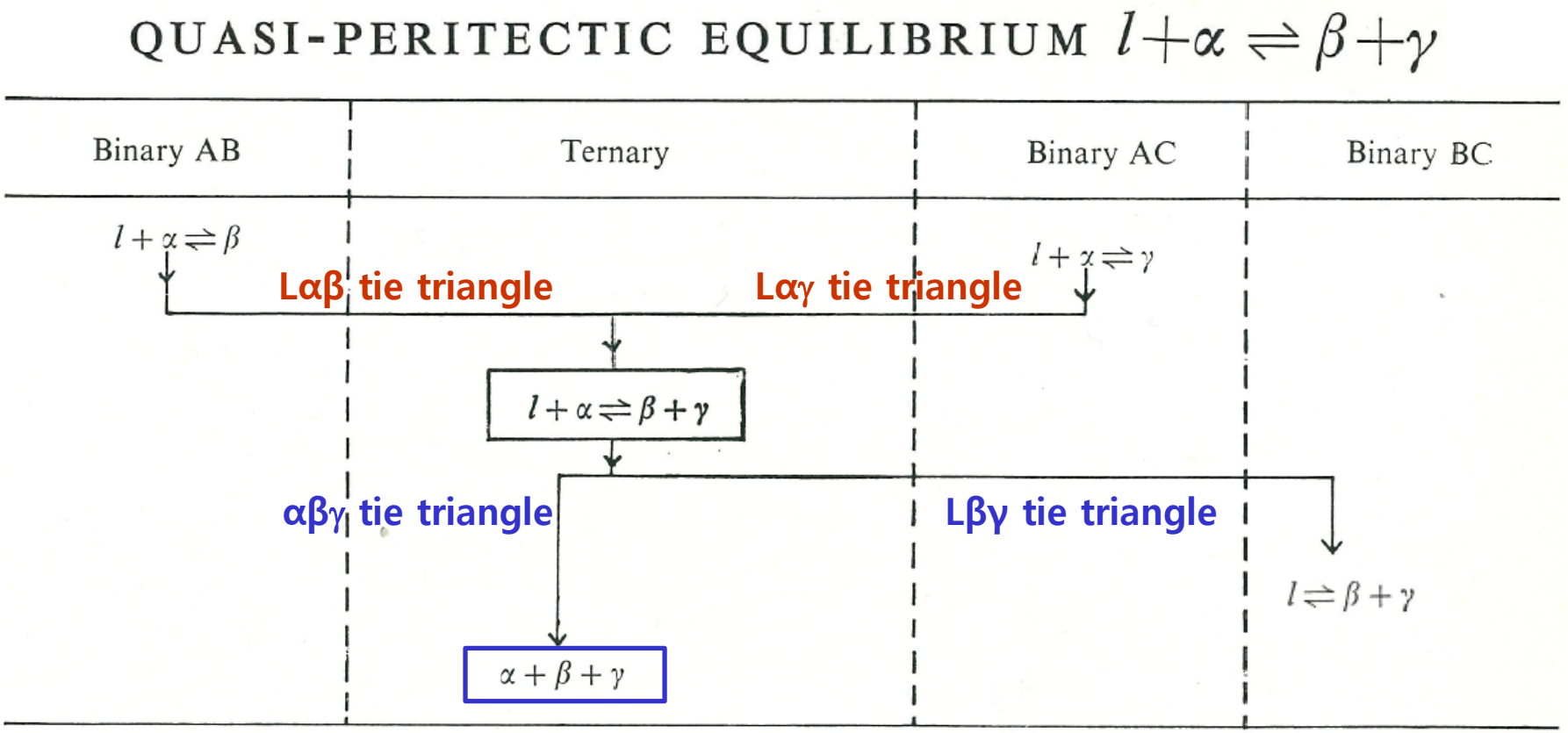
decreasing temperature

bcP eutectic lβγ equilibrium

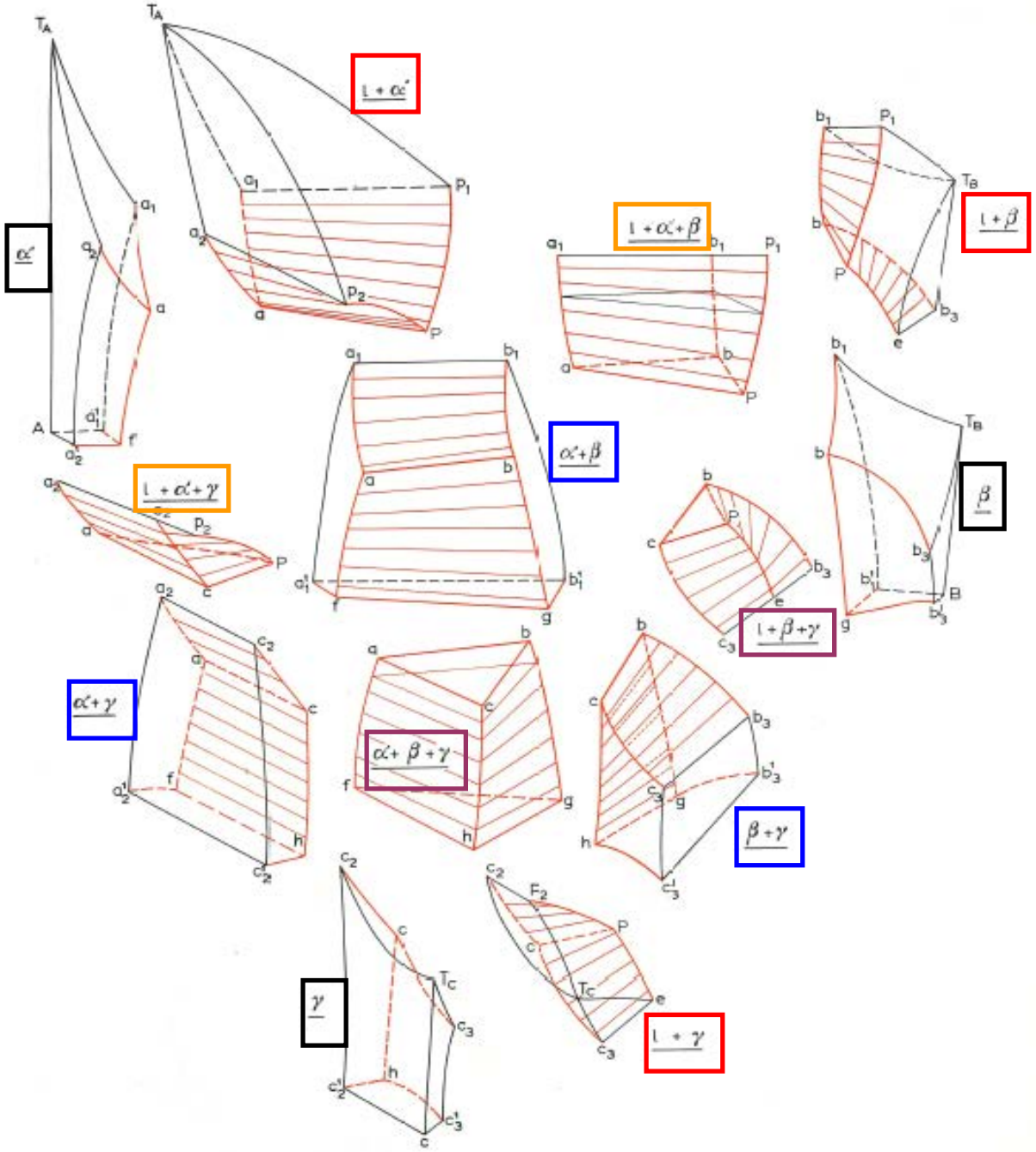
abc peritectic αβγ equilibrium

Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

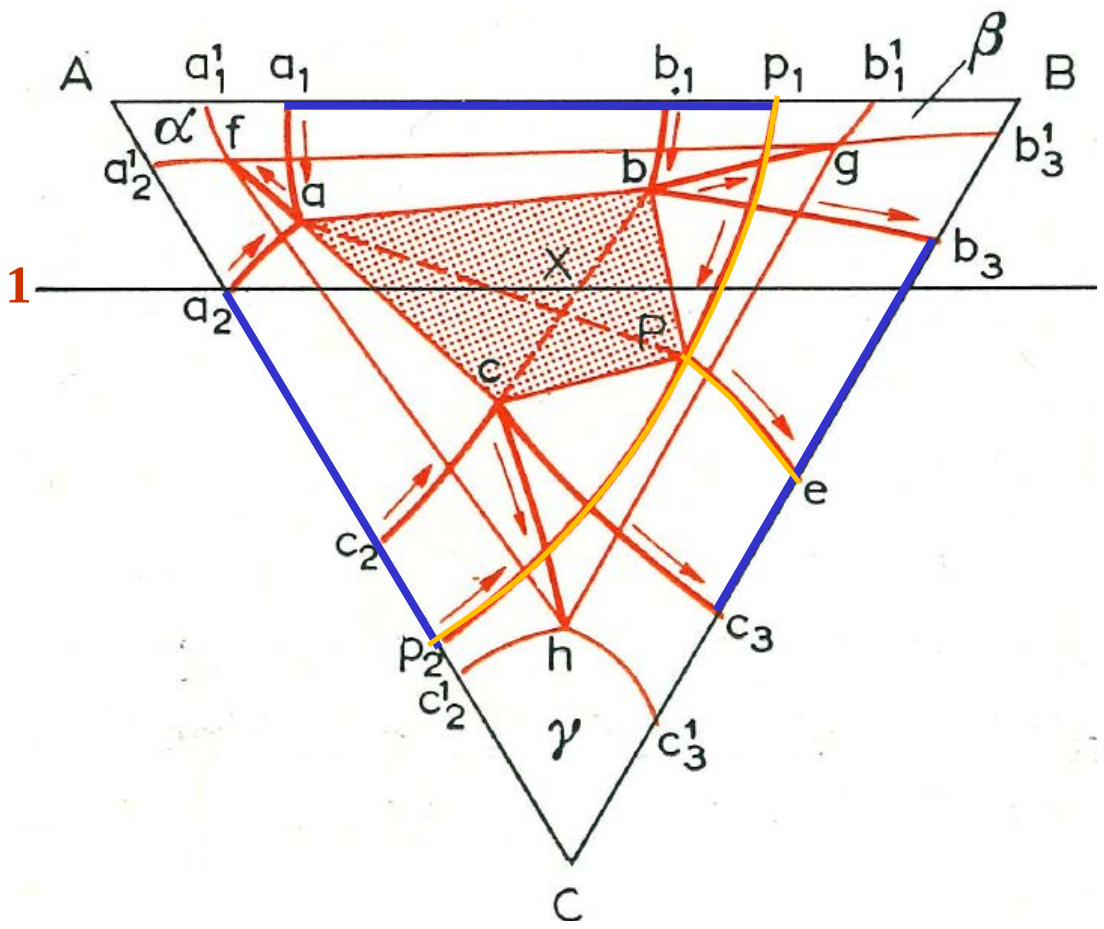


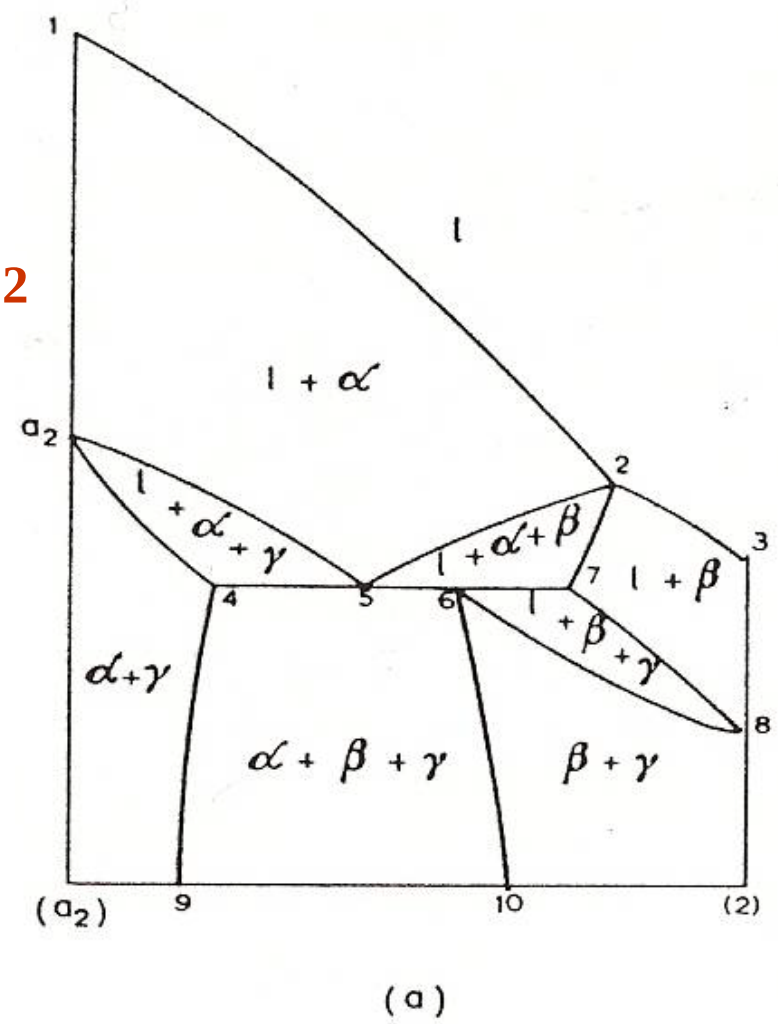
10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)



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

Vertical section

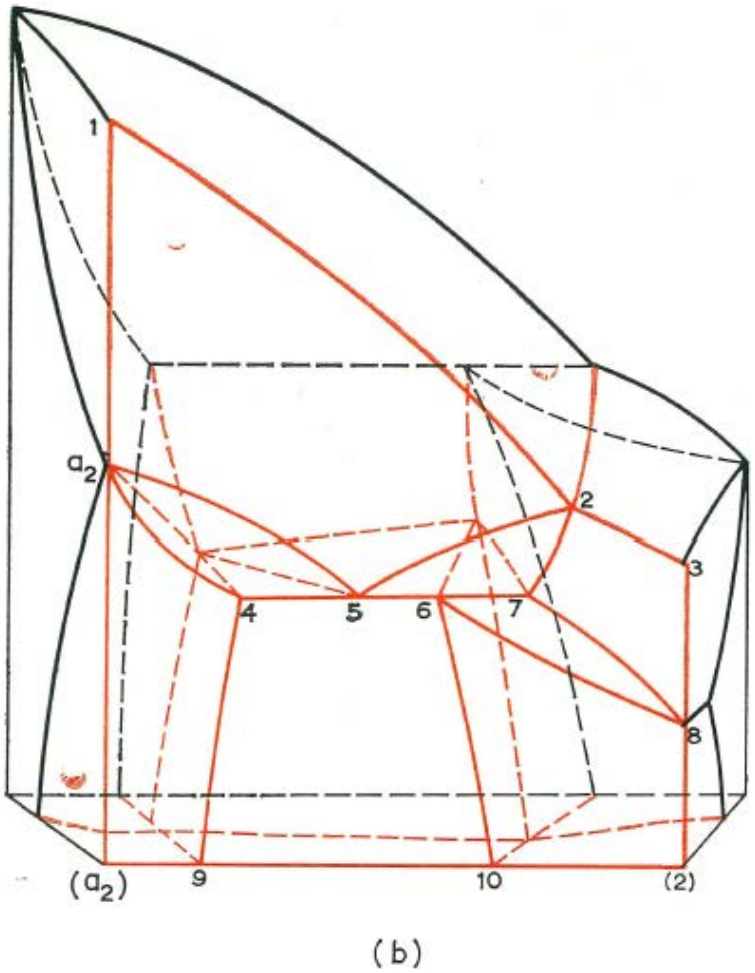




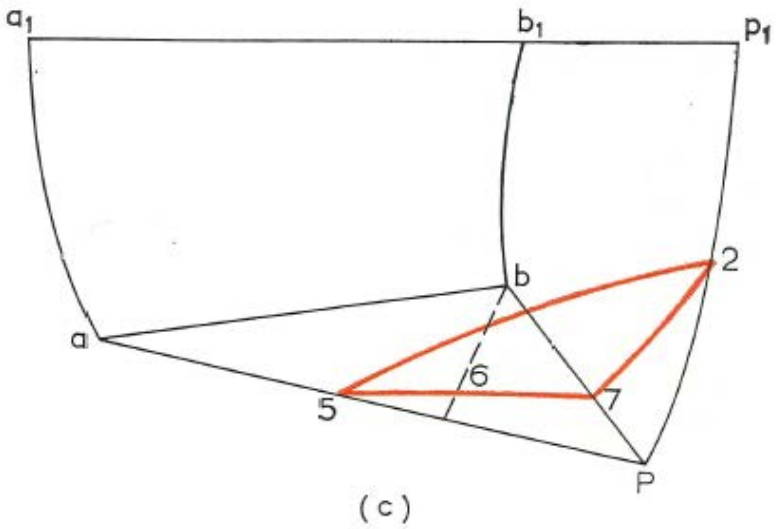
(a)

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

Vertical section



(b)



(c)

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 $AuSb_2$.

$P_1d_1b_1 \rightarrow dbp\ (\delta\beta L)$/ $b_3e_3c_3 \rightarrow bpc\ (\beta L\gamma)$

⇩

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

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

⇩

$Jkm\ (\alpha + \gamma + \delta)$

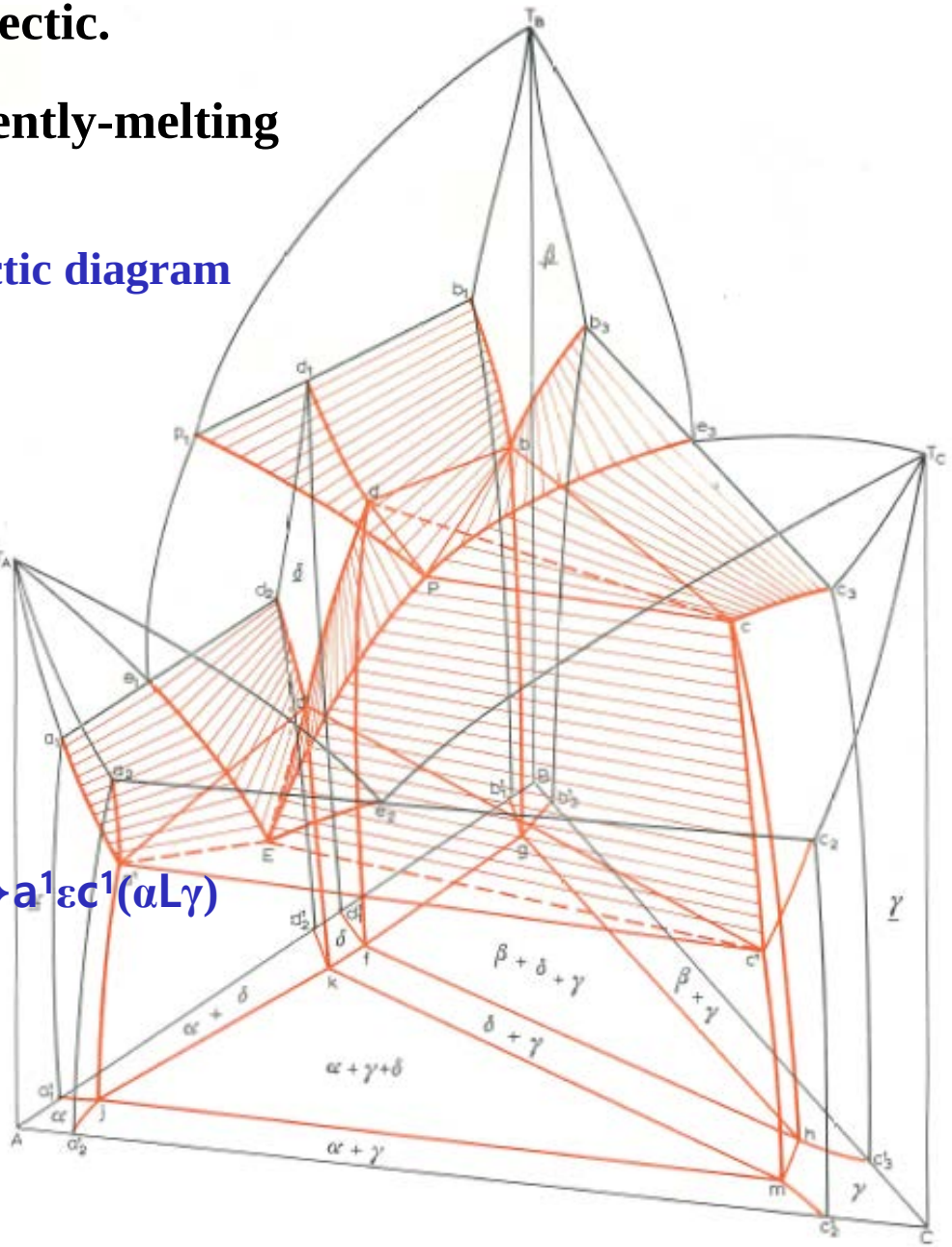
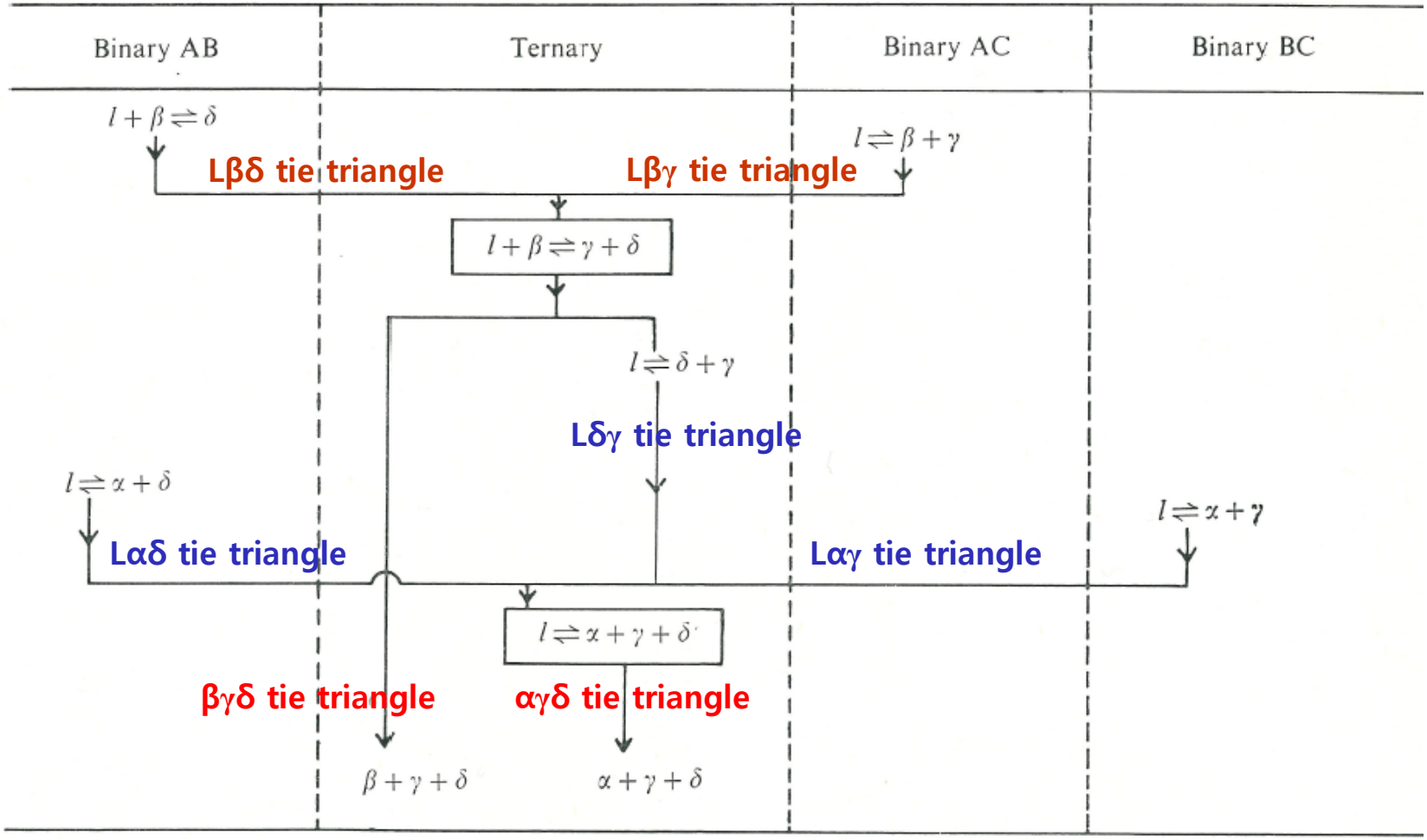


Fig. 189. Ternary system involving an incongruently-melting binary intermediate phase.

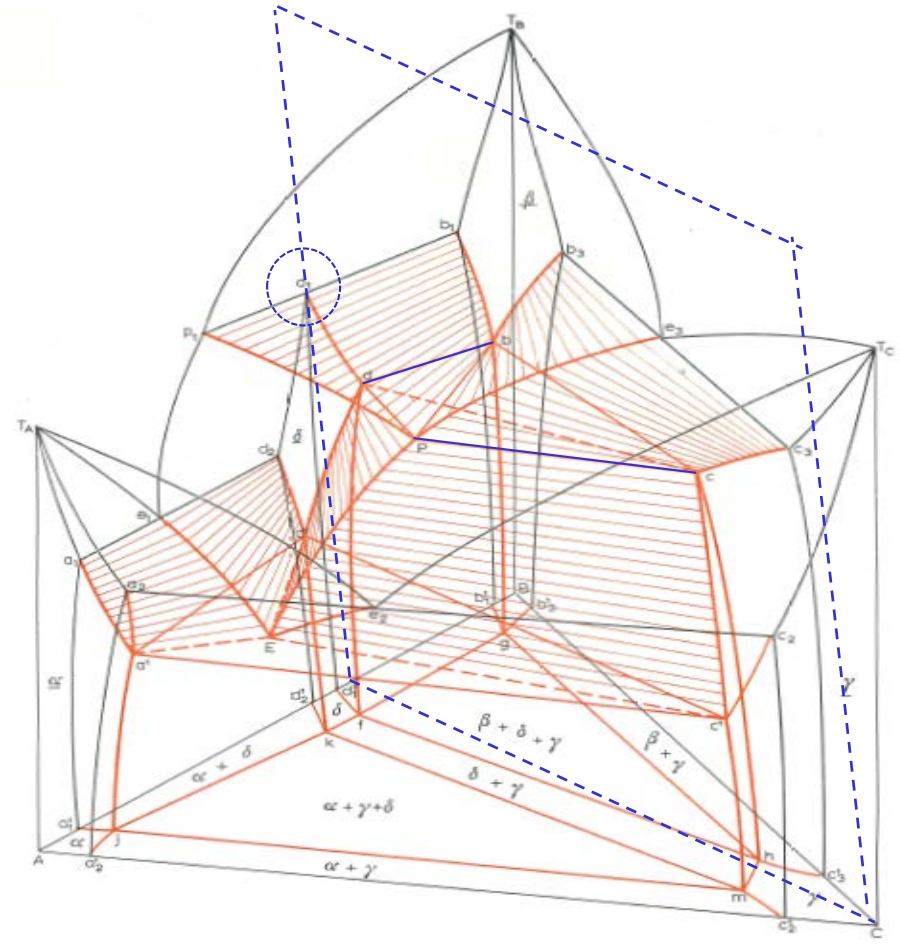
Tabular representation of ternary equilibria:

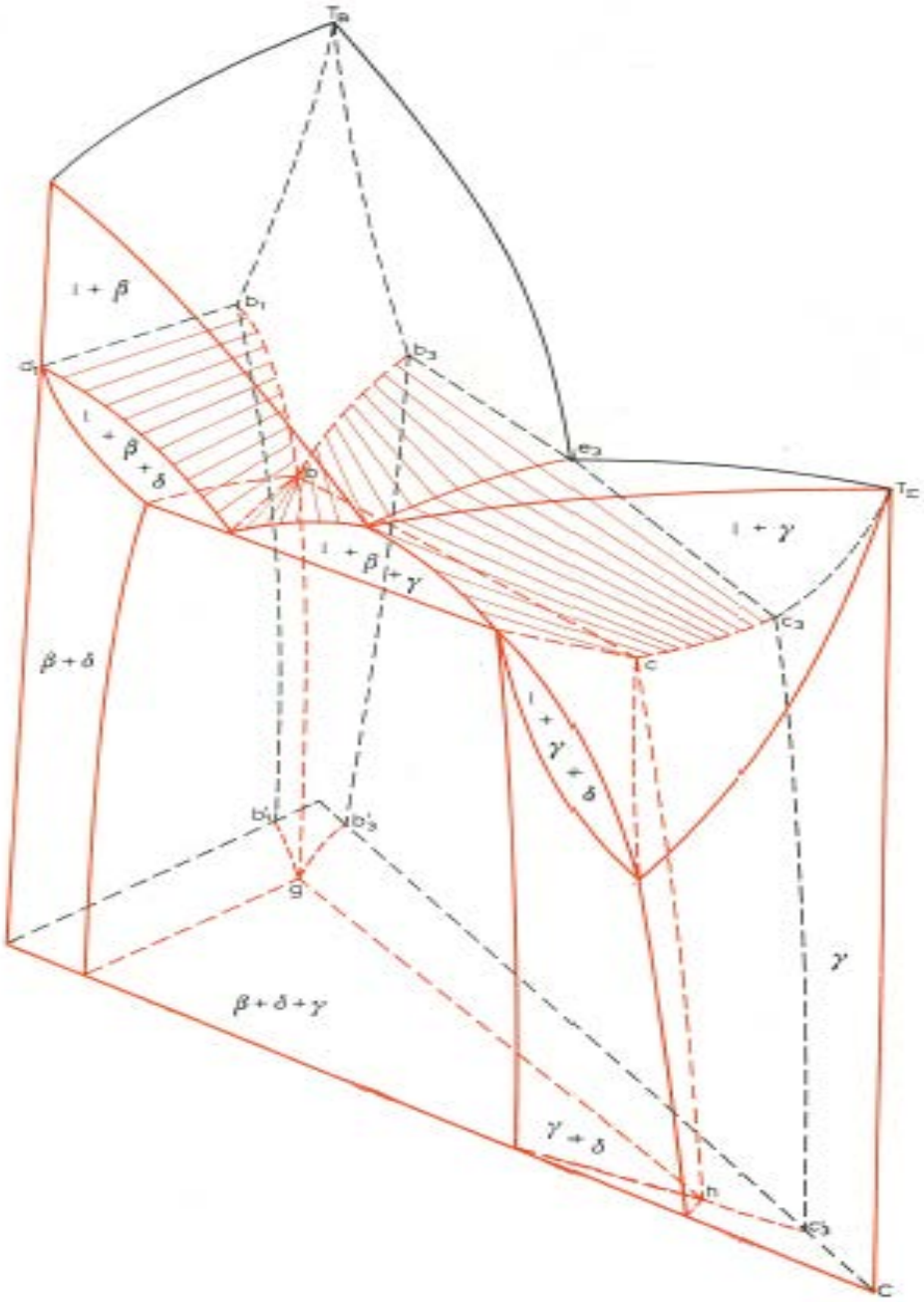
interlinks the binary and ternary reactions in tabular form

Quasi-peritectic diagram and ternary eutectic diagram



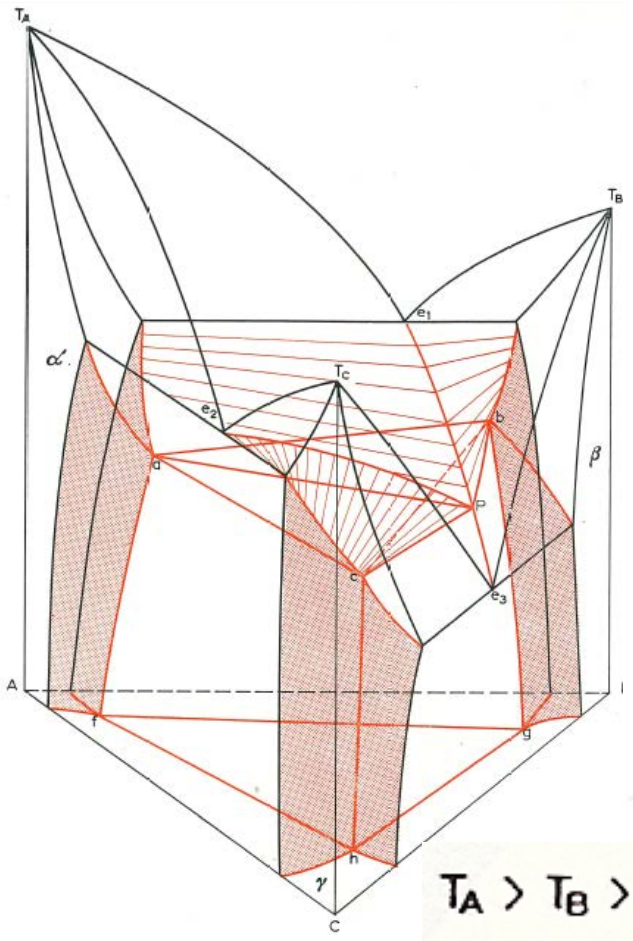
Vertical section which intersects point d1 on the AB binary, the tie lines db and Pc, and proceeds to the C corner

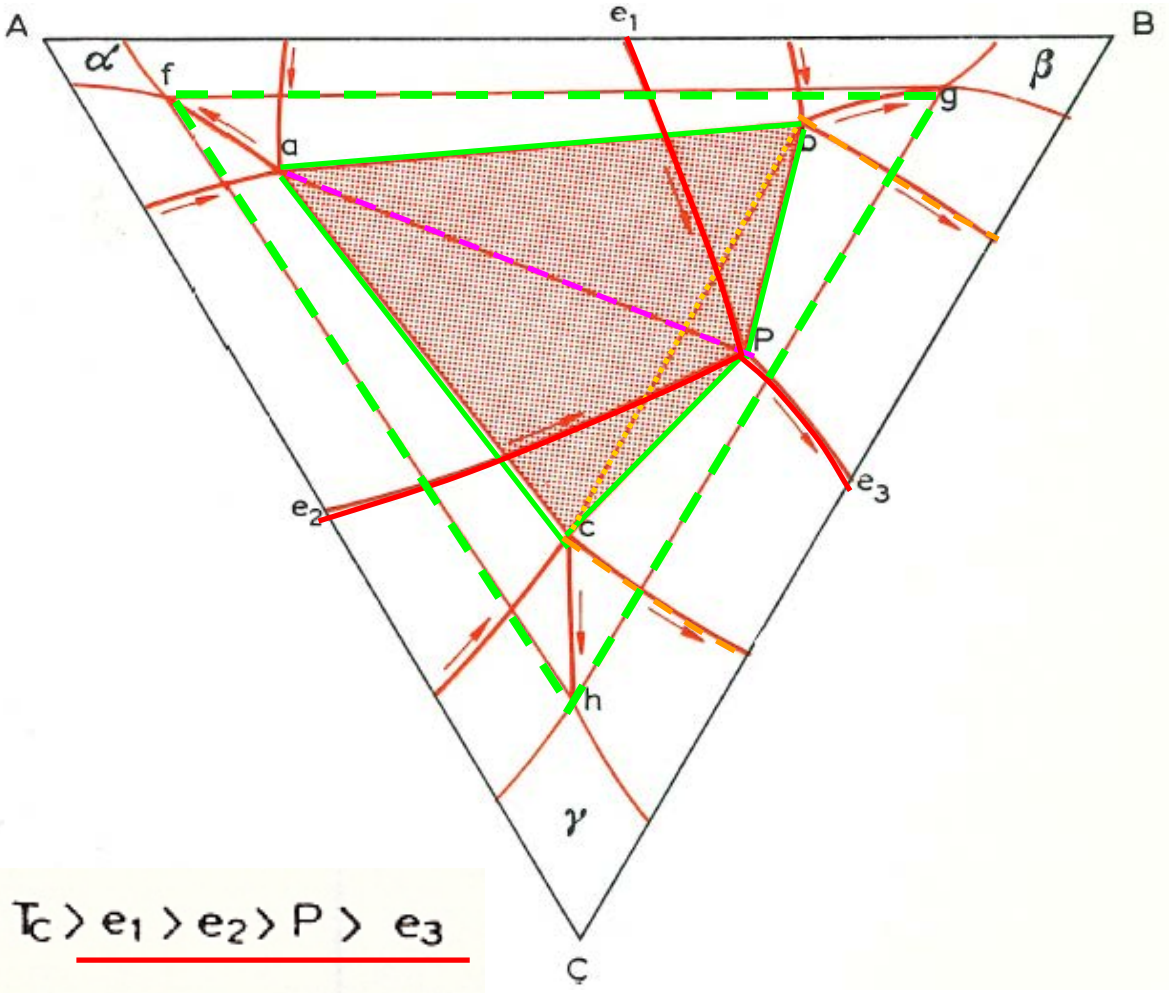




10.3. THE QUASI-PERITECTIC EQUILIBRIUM ($l + \alpha = \beta + \gamma$)

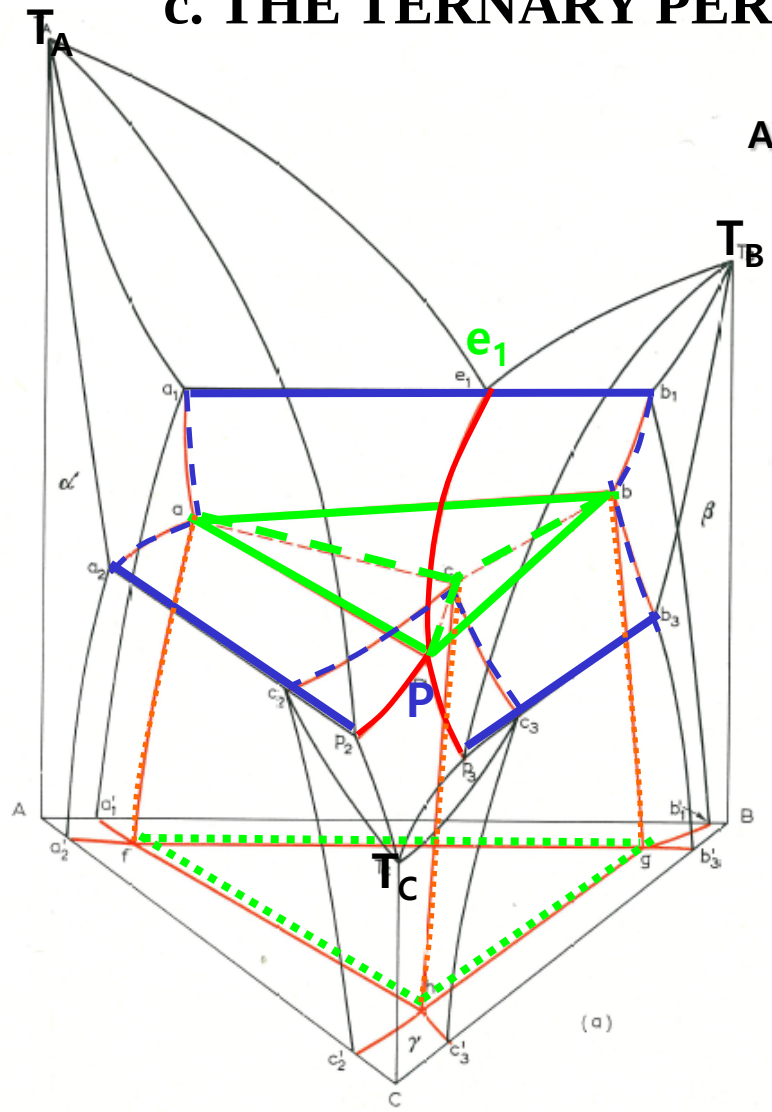
Fig. 191. The ternary quasi-peritectic system formed when all three binaries are eutectics. (a) Space model; (b) projection on the concentration triangle.

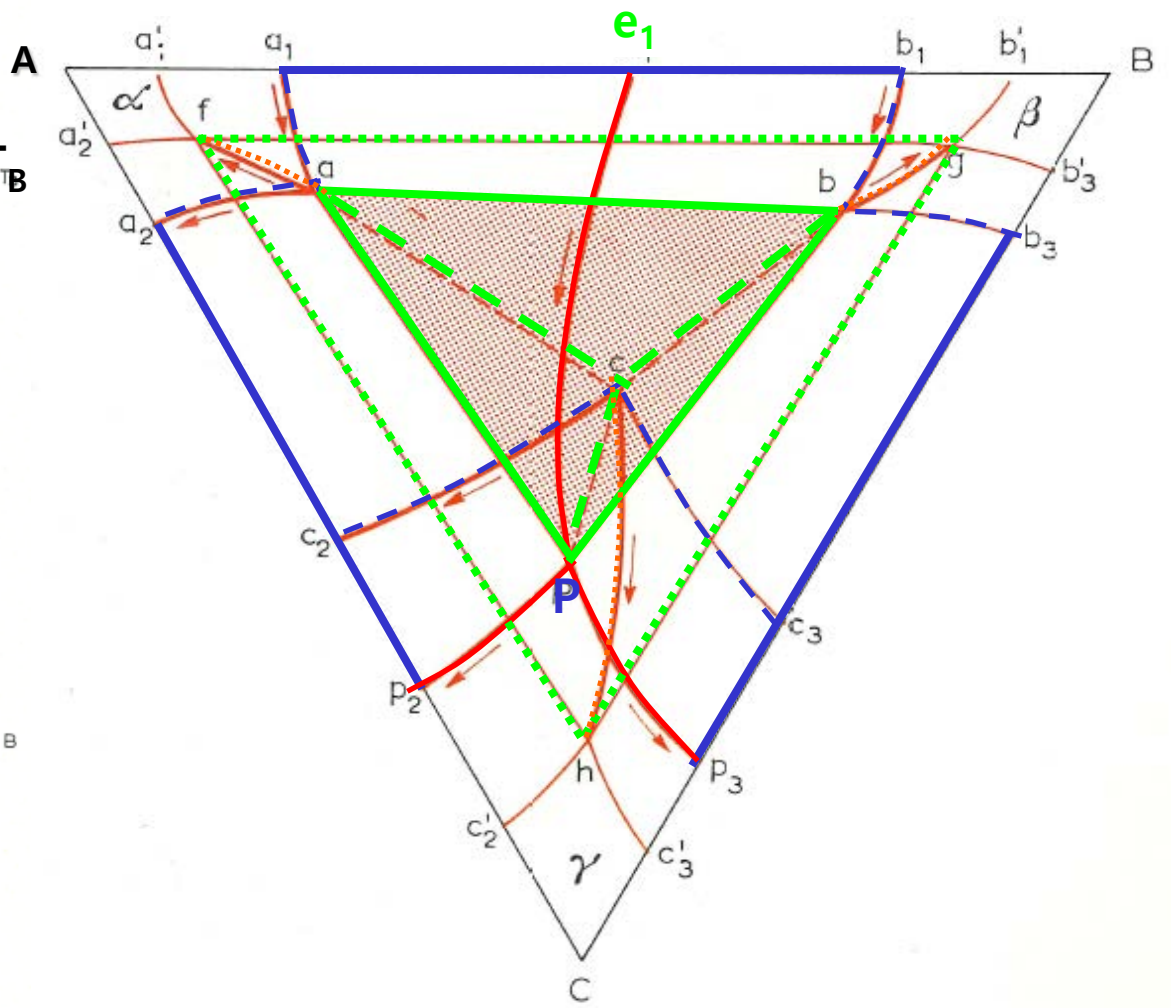




$T_A > T_B > T_C > e_1 > e_2 > P > e_3$

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



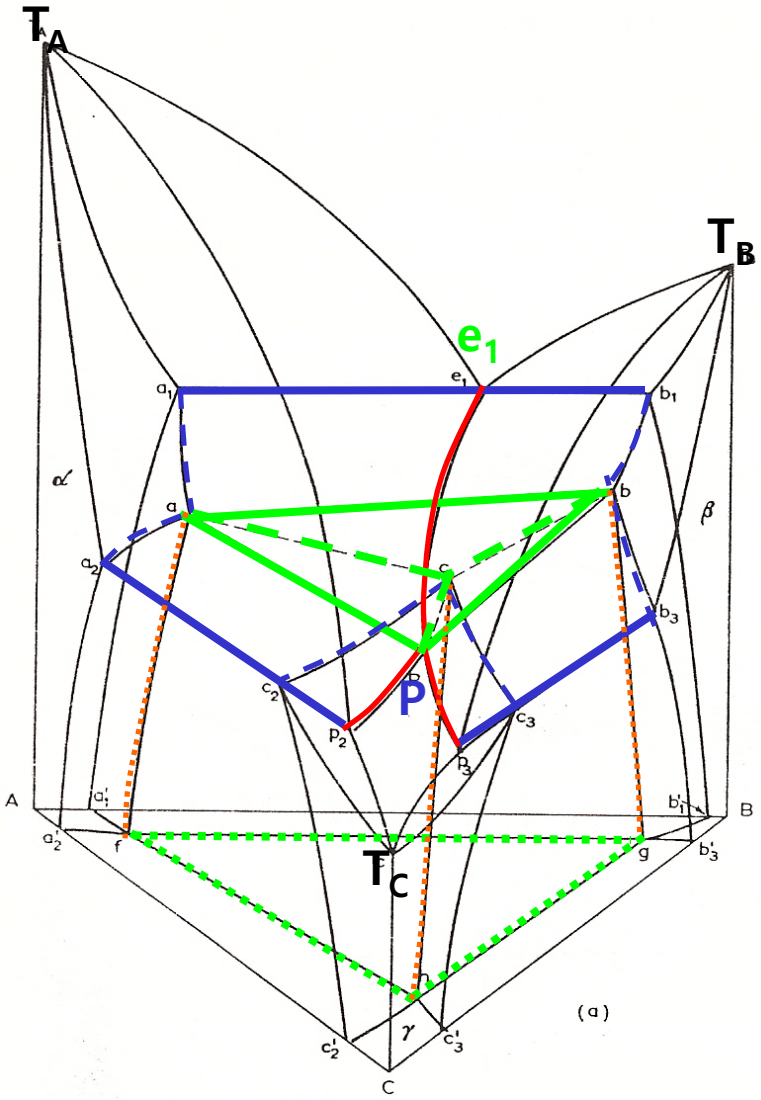


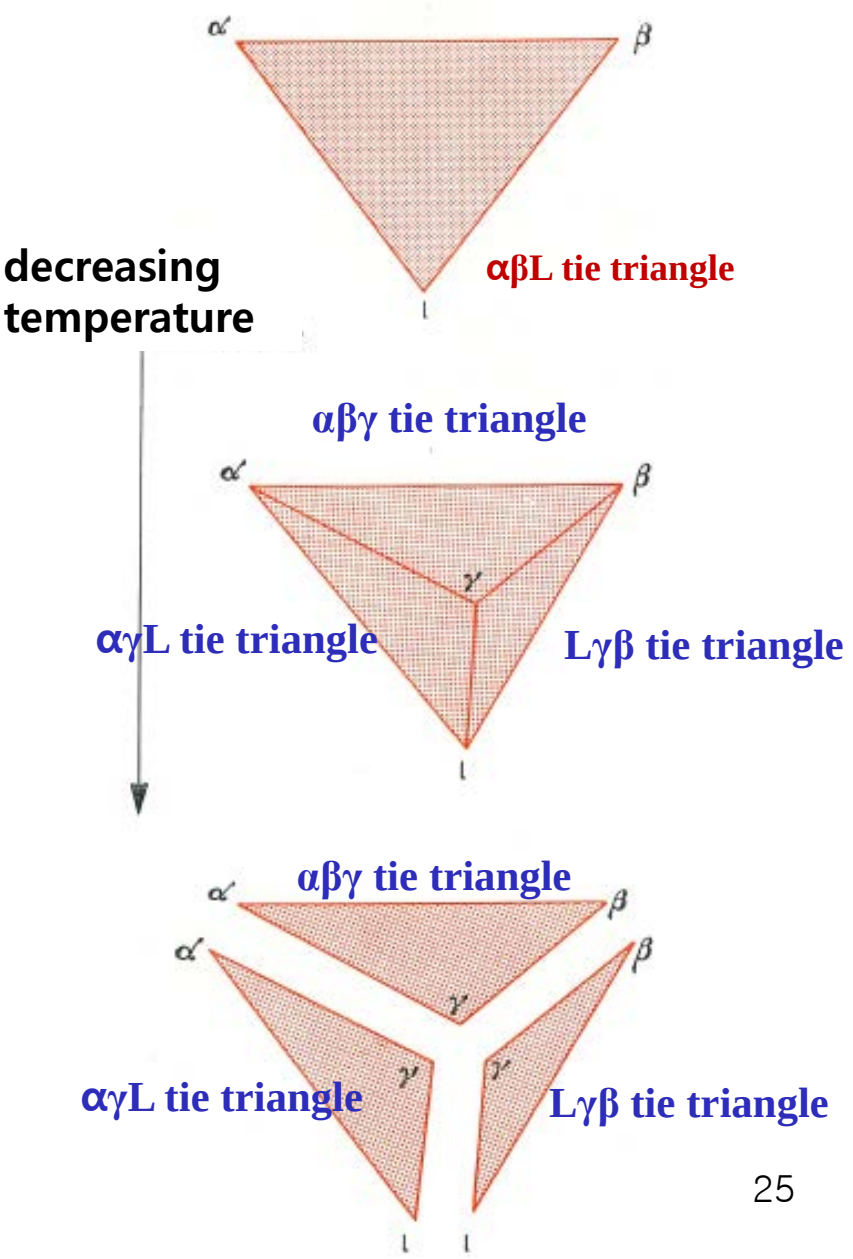
$\underline{a_1 e_1 b_1} \rightarrow abP\ (\alpha\beta L)$

$T_A > T_B > \underline{e_1} > P > P_2 > P_3 > T_C$

$aPc(\alpha\gamma L) \rightarrow \underline{a_2 c_2 P_2}$ / $Pcb(L\gamma\beta) \rightarrow \underline{P_3 c_3 b_3}$ / $abc(\alpha\beta\gamma) \rightarrow fgh\ (\alpha\beta\gamma)$

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

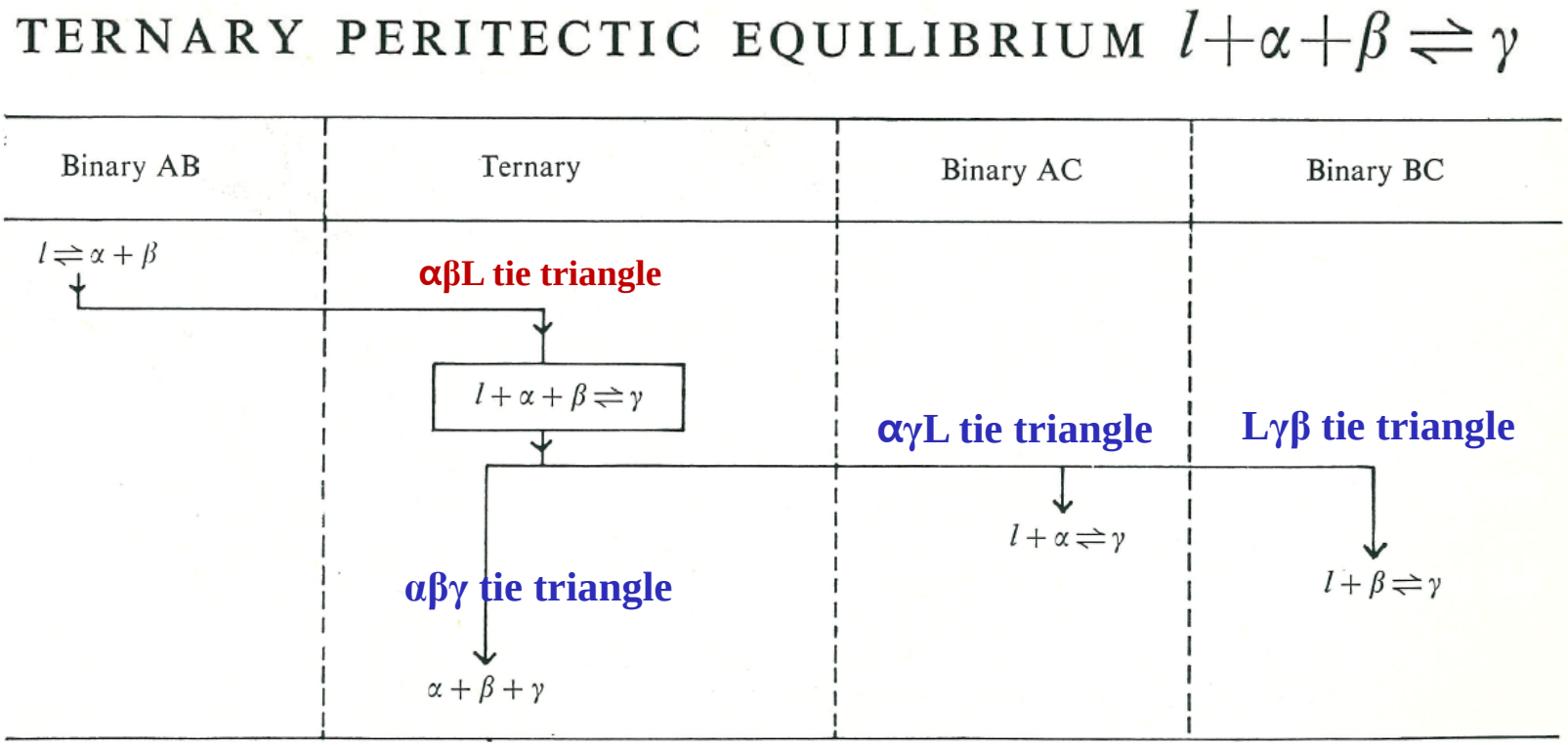




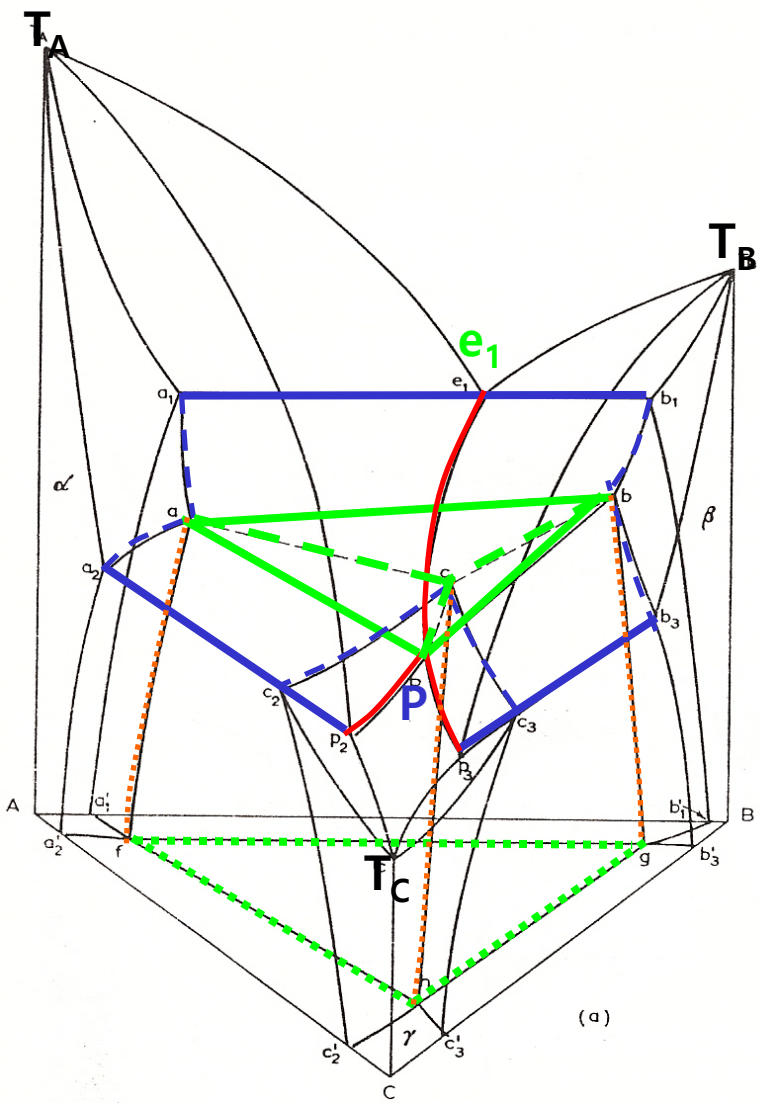
$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

Tabular representation of ternary equilibria:

interlinks the binary and ternary reactions in tabular form

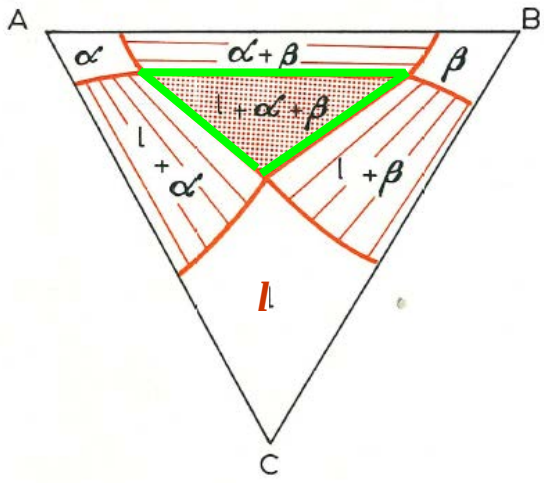


10.4. THE TERNARY PERIECTIC EQUILIBRIUM ($l + \alpha + \beta = \gamma$)

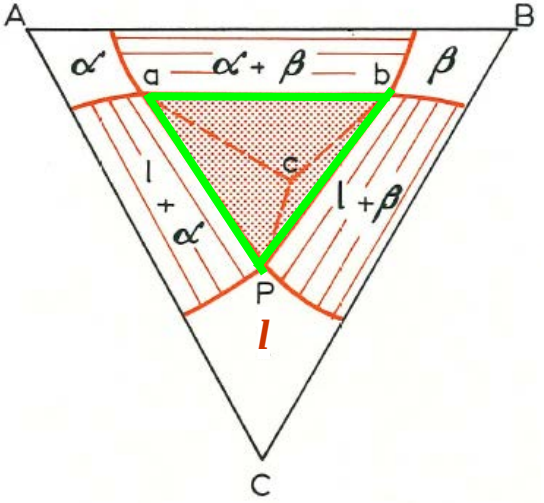


$T_A > T_B > e_1 > P > P_2 > P_3 > T_C$

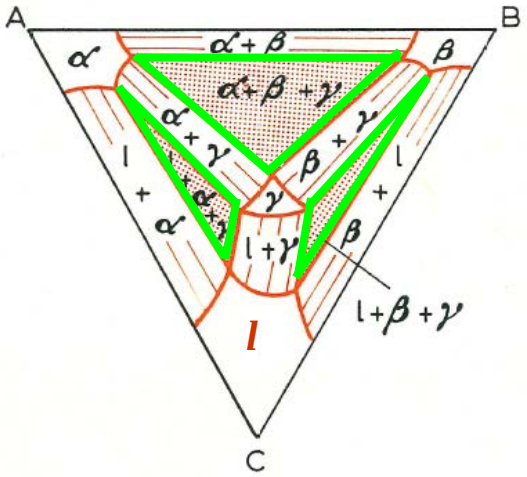
Isothermal section



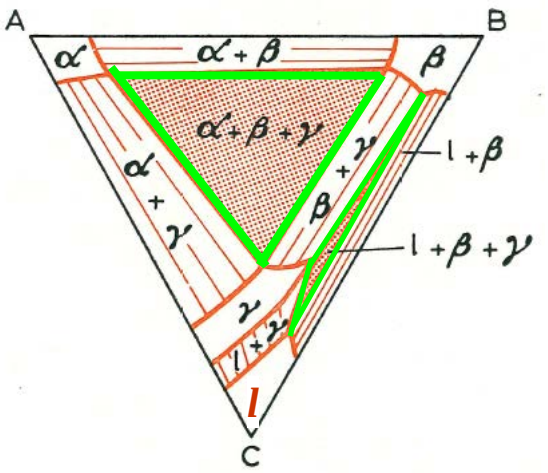
$e_1 > T > P$



$T = P$

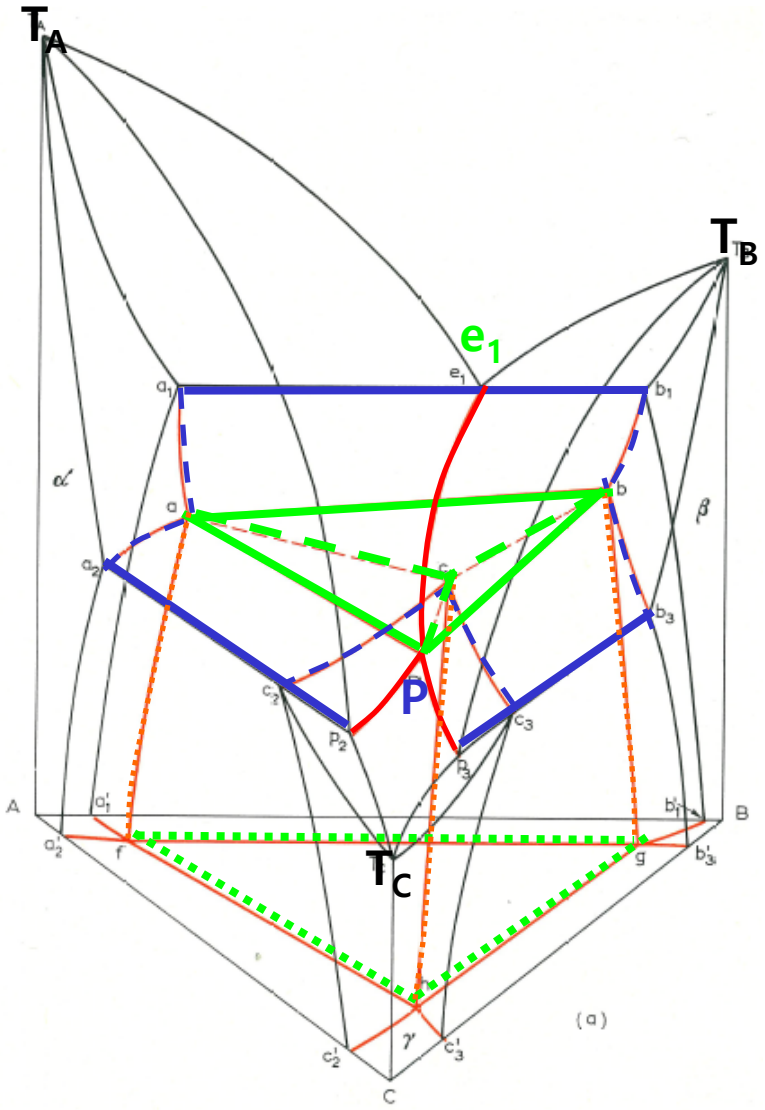


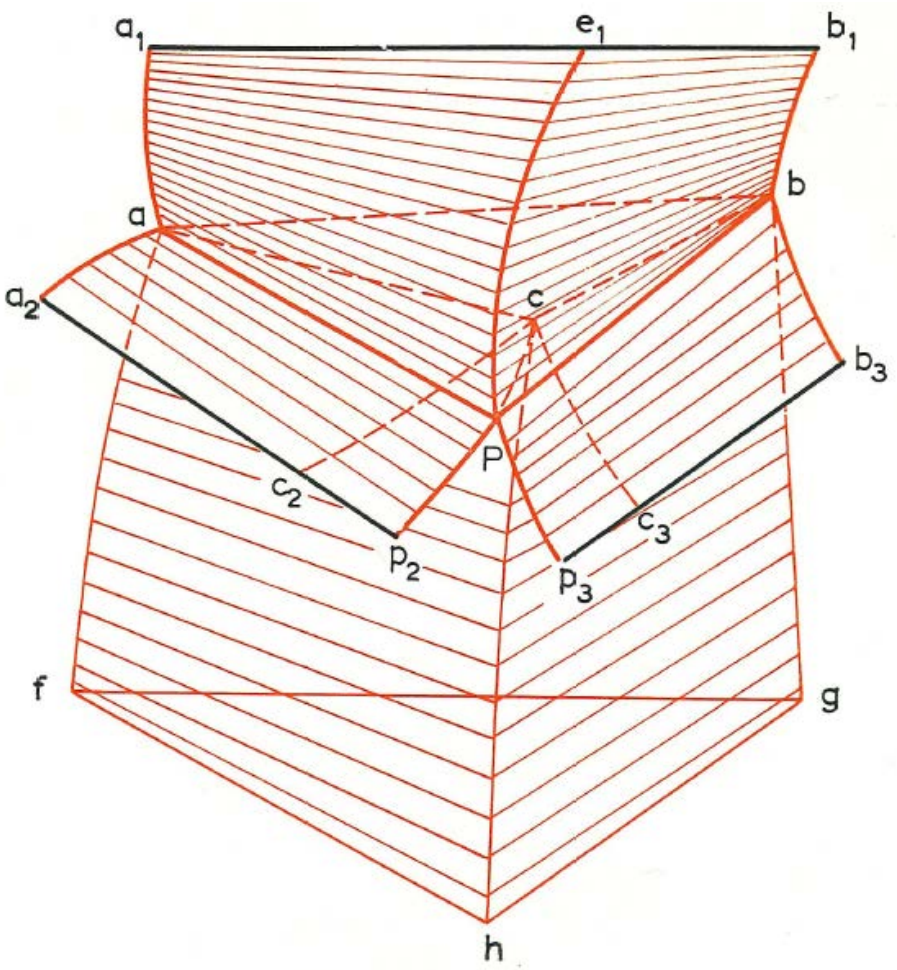
$P > T > P_2$



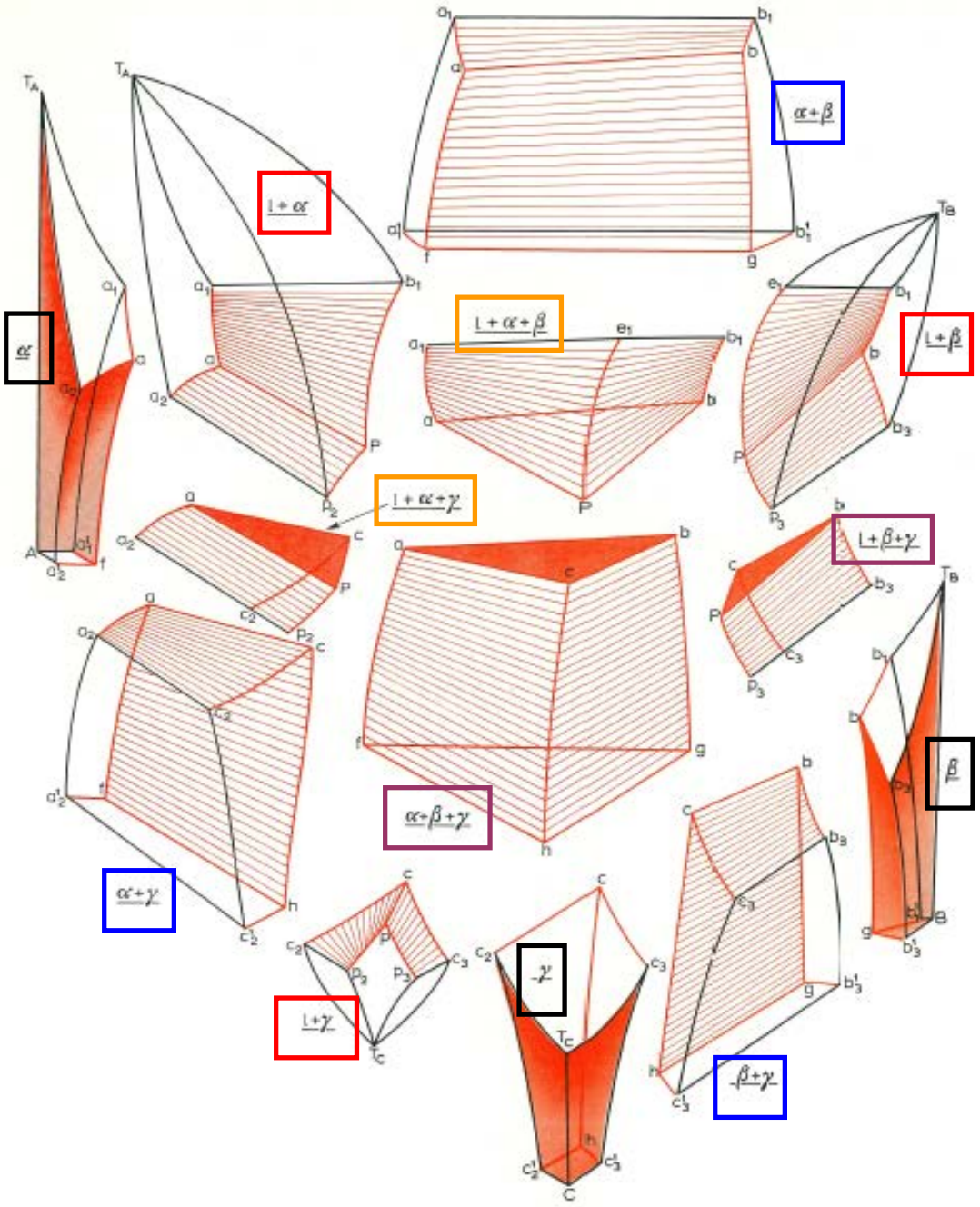
$P_2 > T > P_3$

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