2009 fall

Advanced Physical Metallurgy

"Phase Equilibria in Materials"

11. 19. 2009

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Contents for previous class

"Ternary Phase diagram"

G=f(comp., temp.)

→ Ternary system : A, B, C

→ $G=X_AG_A+X_BG_B+X_CG_C+aX_AX_B+bX_BX_C+cX_CX_A+RT(X_A\ln X_A+X_B\ln X_B+X_C\ln X_C)$

Gibbs phase rule : P=(C+2)-F **For isobaric systems : P=(C+1)-F**

For C=3,

① f=3, trivariant equil, p=1 (one phase equilibrium)

② f=2, bivariant equil, p=2 (two phase equilibrium) $l_1 \rightleftharpoons l_2,\ l \rightleftharpoons \alpha$, and $\alpha \rightleftharpoons \beta$.

③ f=1, monovaiant equil, p=3 (three phase equilibrium)

$$\alpha \rightleftharpoons \beta + \gamma, \quad \alpha \rightleftharpoons \beta + l, \quad \alpha \rightleftharpoons l_1 + l_2$$
$$l_1 \rightleftharpoons l_2 + l_3, \quad l_1 \rightleftharpoons \alpha + l_2, \quad l \rightleftharpoons \alpha + \beta$$
$$\alpha + \beta \rightleftharpoons \gamma, \quad \alpha + \beta \rightleftharpoons l, \quad l_1 + l_2 \rightleftharpoons l_3$$
$$l_1 + l_2 \rightleftharpoons \alpha, \quad l_1 + \alpha \rightleftharpoons l_2, \quad l + \alpha \rightleftharpoons \beta.$$

④ f=0, invariant equil, p=4 (four phase equilibrium)

$$\alpha \rightleftharpoons \beta + \gamma + \delta, \quad \alpha + \beta \rightleftharpoons \gamma + \delta, \quad \alpha + \beta + \gamma \rightleftharpoons \delta$$
$$l_1 \rightleftharpoons l_2 + l_3 + l_4, \quad l_1 + l_2 \rightleftharpoons l_3 + l_4, \quad l_1 + l_2 + l_3 \rightleftharpoons l_4$$
$$l \rightleftharpoons \alpha + \beta + \gamma, \quad l + \alpha \rightleftharpoons \beta + \gamma, \quad l + \alpha + \beta \rightleftharpoons \gamma$$
$$l_1 \rightleftharpoons l_2 + \alpha + \beta, \quad l_1 + l_2 \rightleftharpoons \alpha + \beta, \quad l_1 + l_2 + \alpha \rightleftharpoons \beta$$
$$l_1 \rightleftharpoons l_2 + l_3 + \alpha, \quad l_1 + l_2 \rightleftharpoons l_3 + \alpha, \quad l_1 + l_2 + l_3 \rightleftharpoons \alpha$$
$$\alpha \rightleftharpoons l_1 + l_2 + l_3, \quad \alpha + l_1 \rightleftharpoons l_2 + l_3, \quad \alpha + l_1 + l_2 \rightleftharpoons l_3$$
$$\alpha \rightleftharpoons \beta + l_1 + l_2, \quad \alpha + \beta \rightleftharpoons l_1 + l_2, \quad \alpha + \beta + l_1 \rightleftharpoons l_2$$
$$\alpha \rightleftharpoons \beta + \gamma + l, \quad \alpha + \beta \rightleftharpoons \gamma + l, \quad \alpha + \beta + \gamma \rightleftharpoons l$$
$$l_1 + \alpha \rightleftharpoons l_2 + \beta.$$

Contents for previous class

"Ternary Phase diagram"

" Two phase equilibrium (*f* = 2)"

1) <u>Two-phase equilibrium</u> between the liquid and a solid solution

2) Ternary <u>two-phase equilibrium</u> with a saddle point

3) <u>Two-phase equilibrium</u> between solid or liquid solutions: $\alpha_1 \rightleftarrows \alpha_2$ or $l_1 \rightleftarrows l_2$

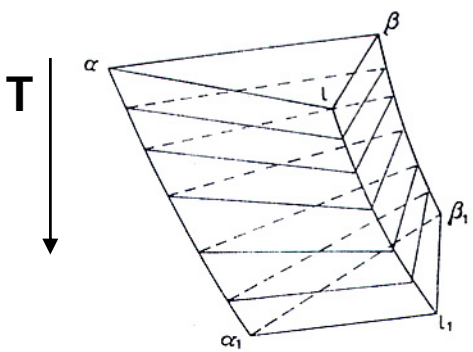
Miscibility gap

* Tie lines are not parallel to the binary tie line.

- Addition of C to a heterogeneous mixture of A & B in a ratio corresponding to the distribution of C

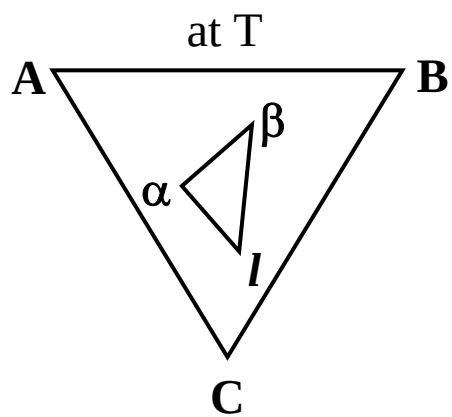
" Three phase equilibrium (*f* =1)"

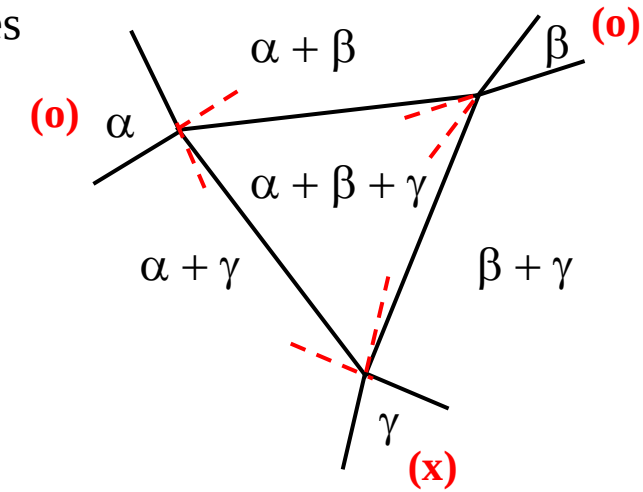
• Tie triangle



vertex of tie triangle

→ composition of three phases at T





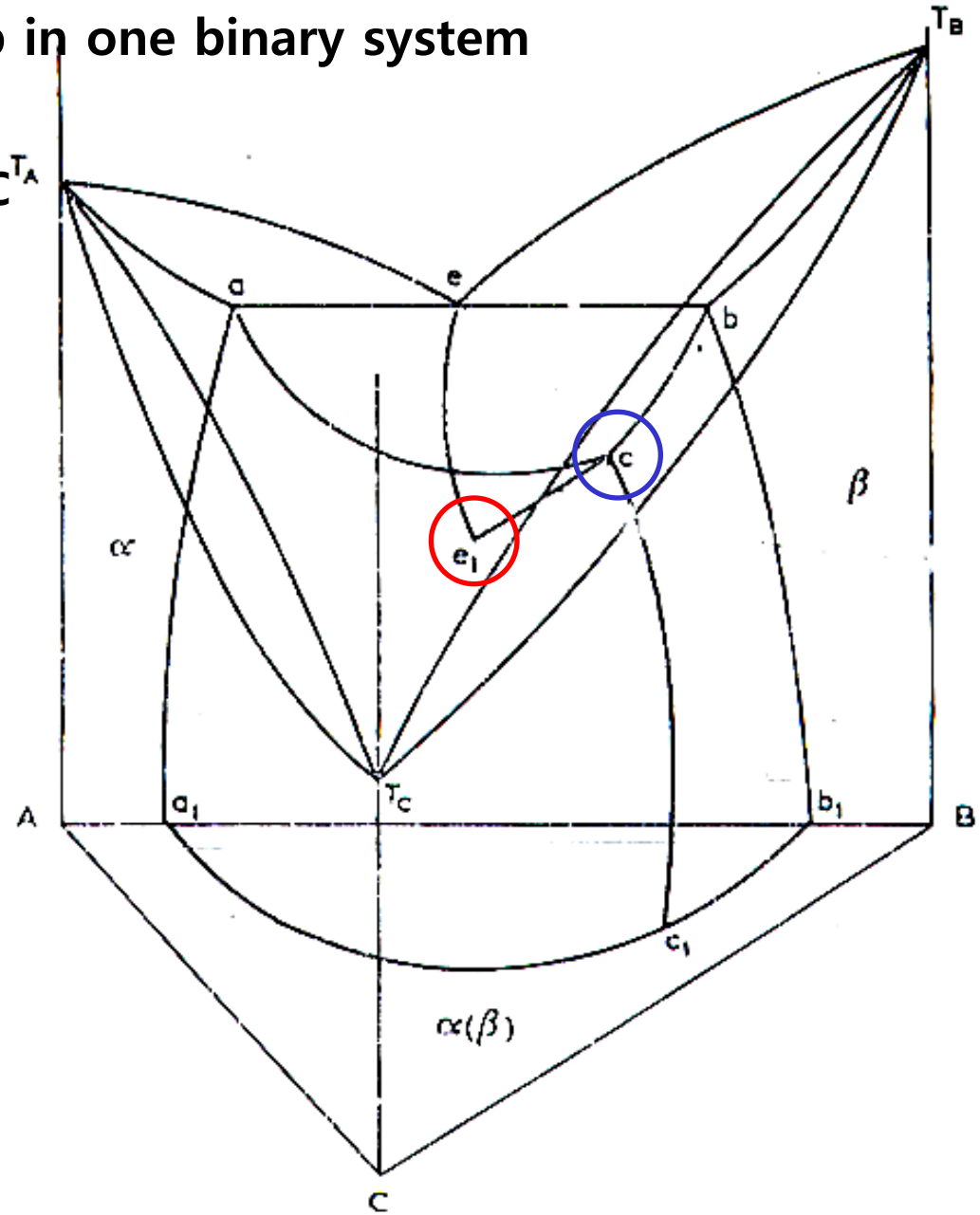
① Coalescence of miscibility gap and two phase region

② Coalescence of two two-phase region

9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

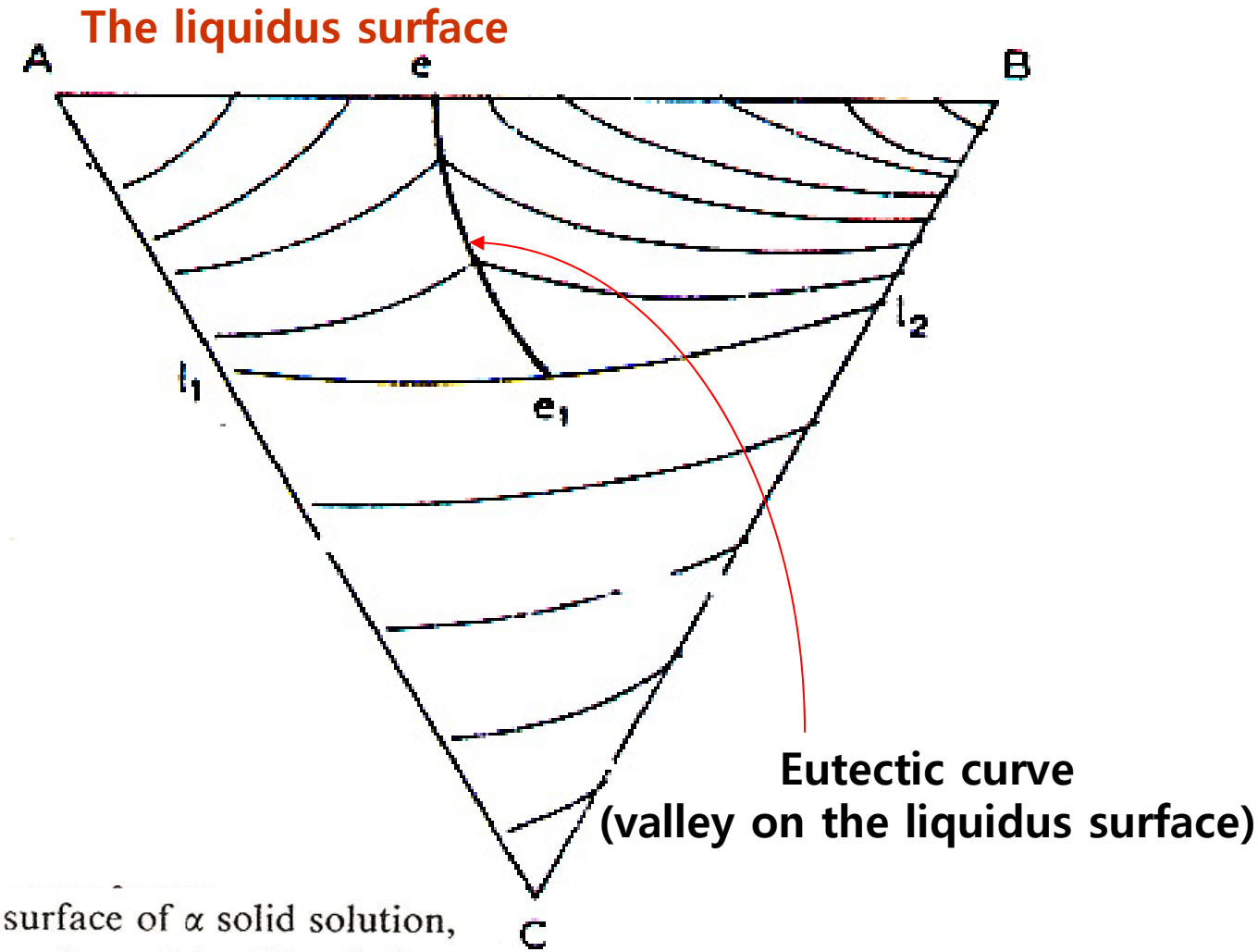
9.3.1. A eutectic solubility gap in one binary system

- One binary eutectic : AB
  Complete solid solution : BC, AC

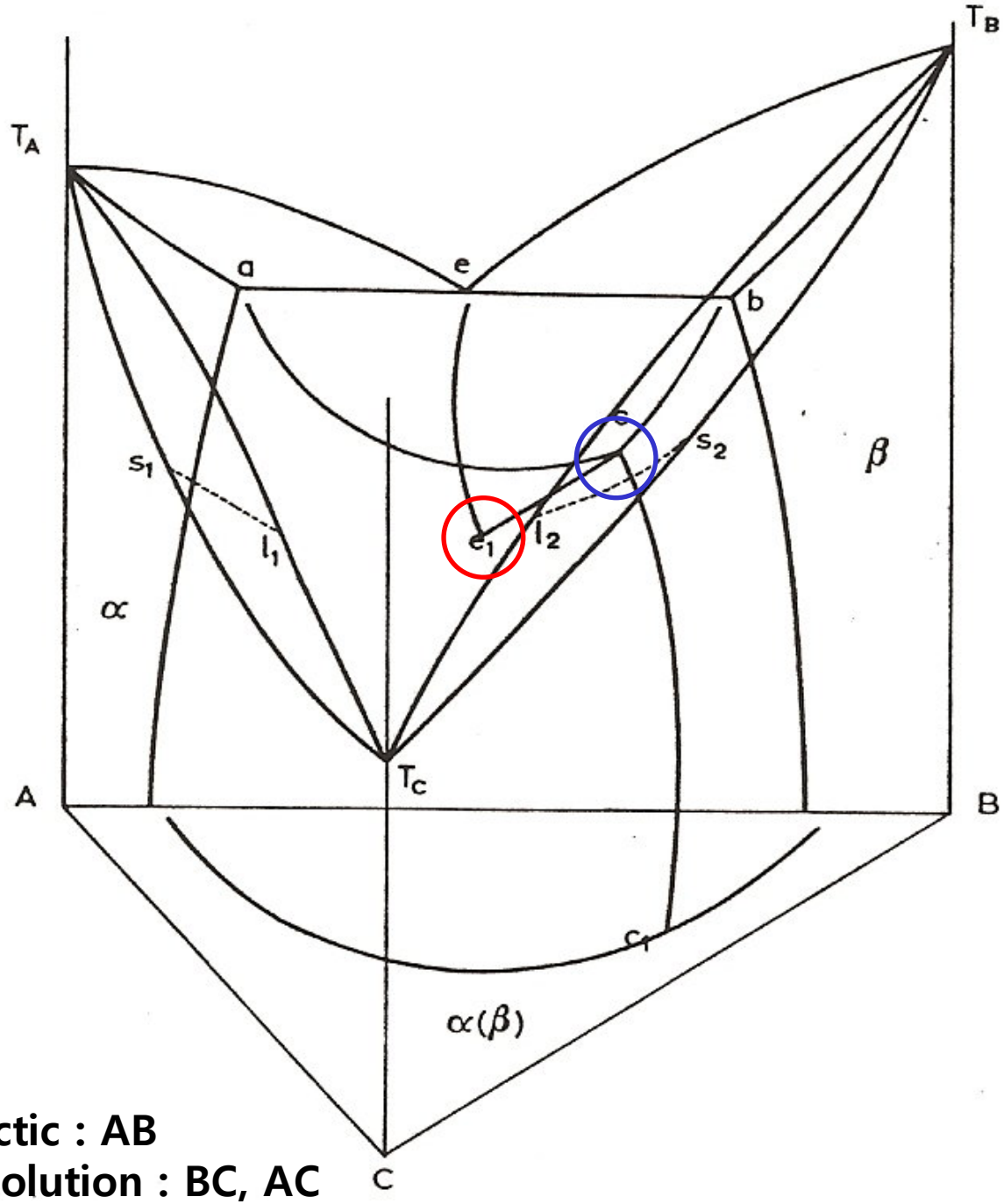


9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Projection**



$T_A e e_1 l_1 T_A$ – the liquidus surface of α solid solution,
$T_B e e_1 l_2 T_B$ – the liquidus surface of β solid solution,
$l_1 e_1 l_2 T_C l_1$ – the liquidus surface of $\alpha(\beta)$ solid solution. (a)

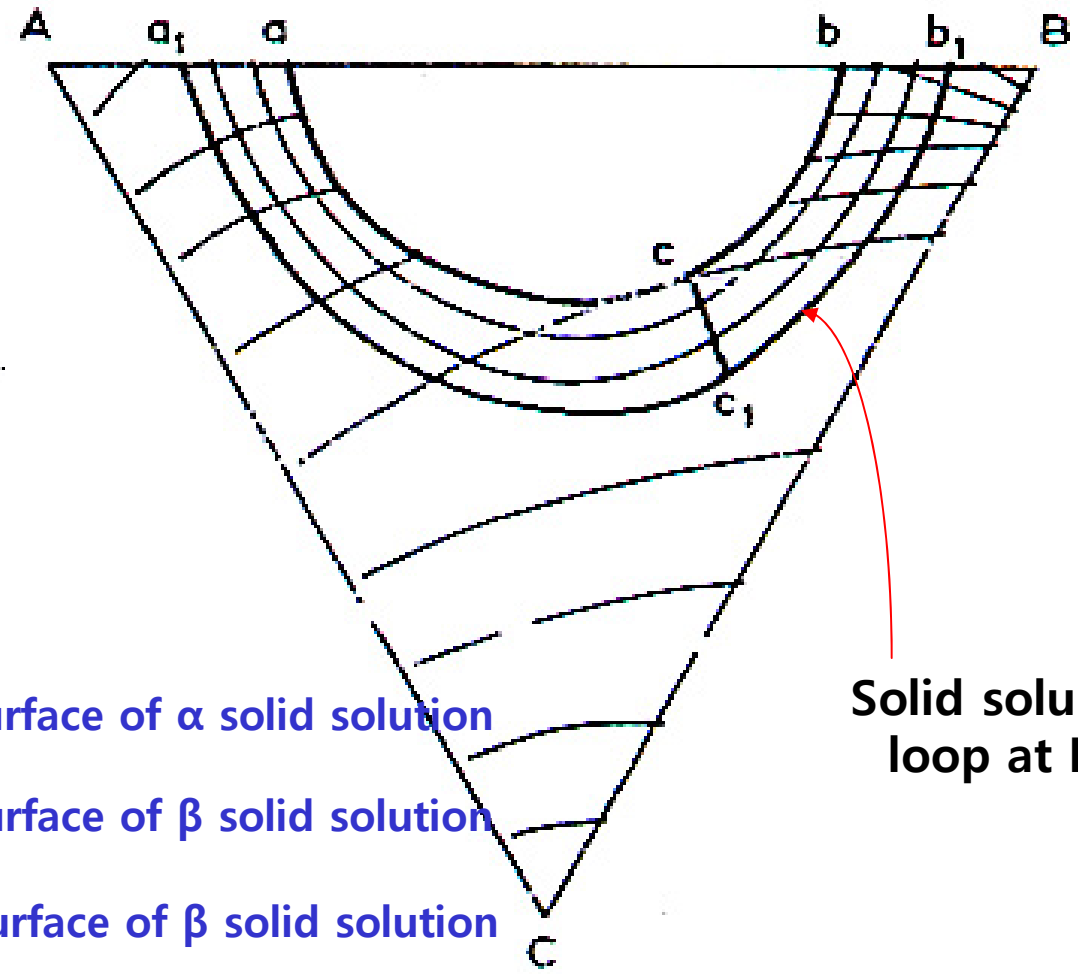


- **One binary eutectic : AB**
  Complete solid solution : BC, AC

9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

- **Projection**

The solidus surface and the solubility surface



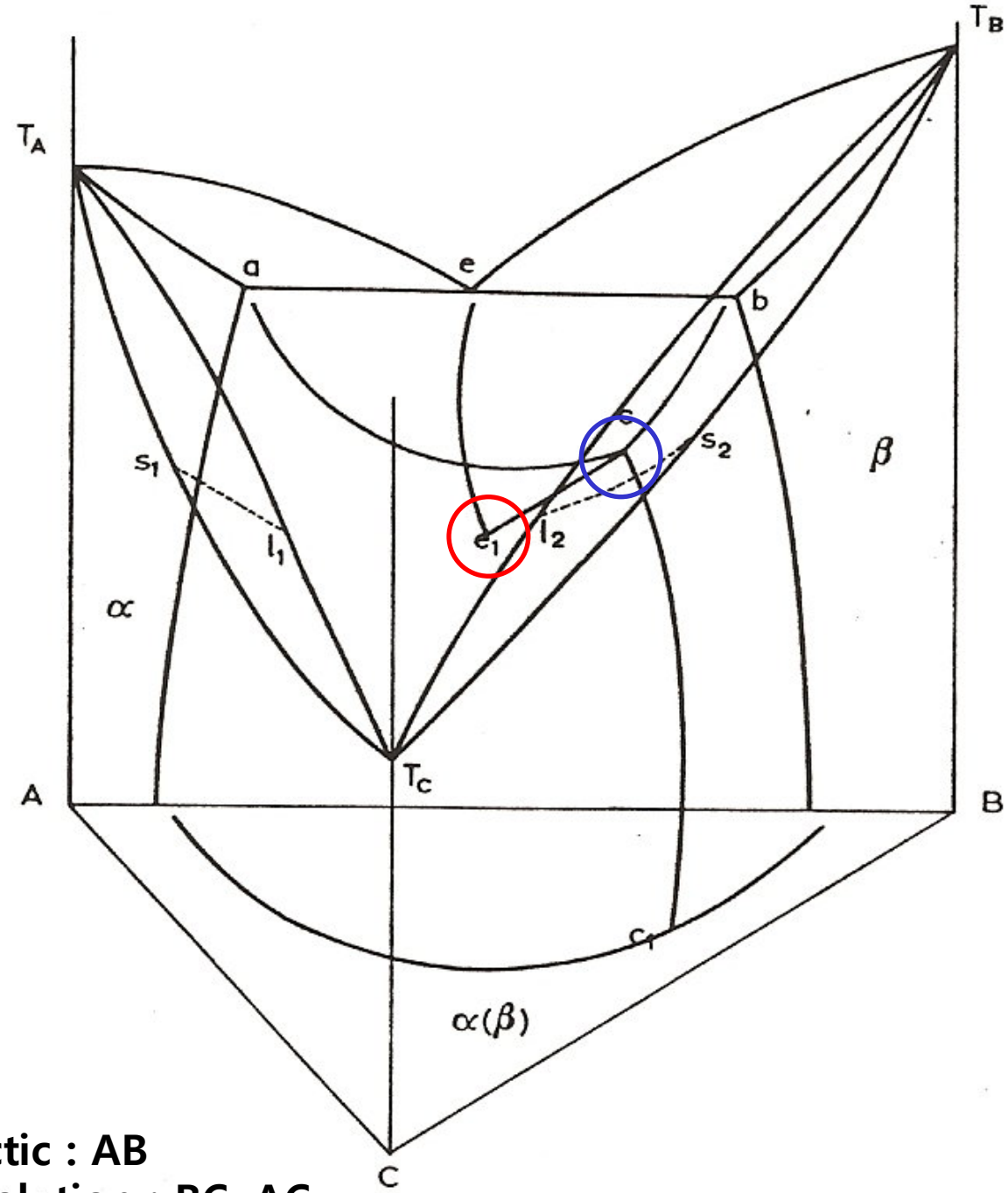
(b)

Solid solubility loop at R.T.

$T_A s_1 c a T_A$- the solidus surface of α solid solution

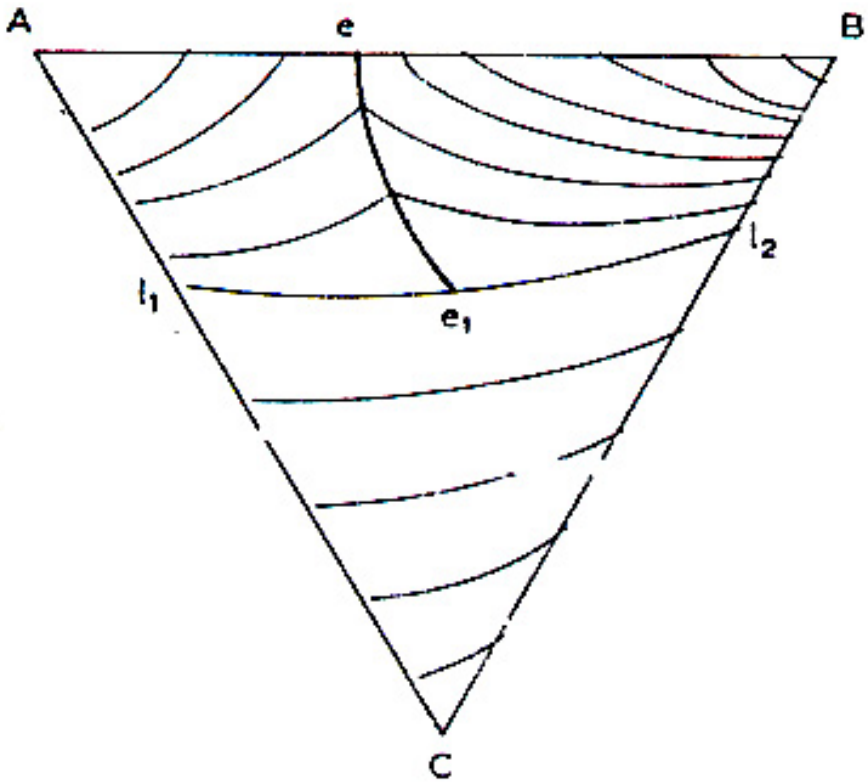
$T_B s_2 c b T_B$- the solidus surface of β solid solution

$T_c s_1 c s_2 T_c$- the solidus surface of β solid solution



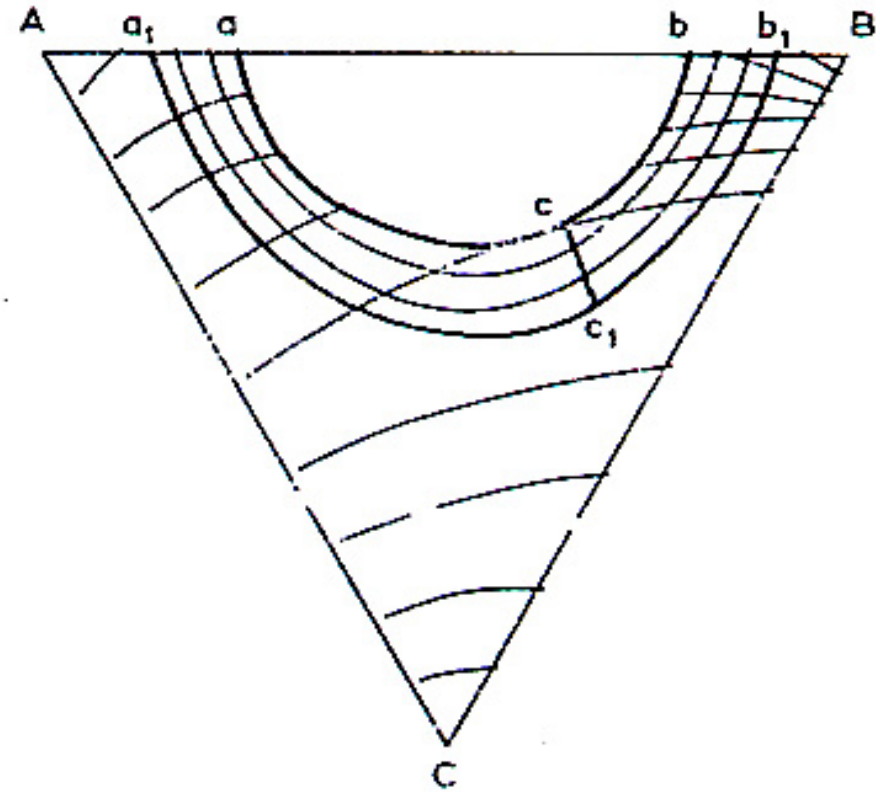
- **One binary eutectic : AB**
  Complete solid solution : BC, AC

The liquidus surface

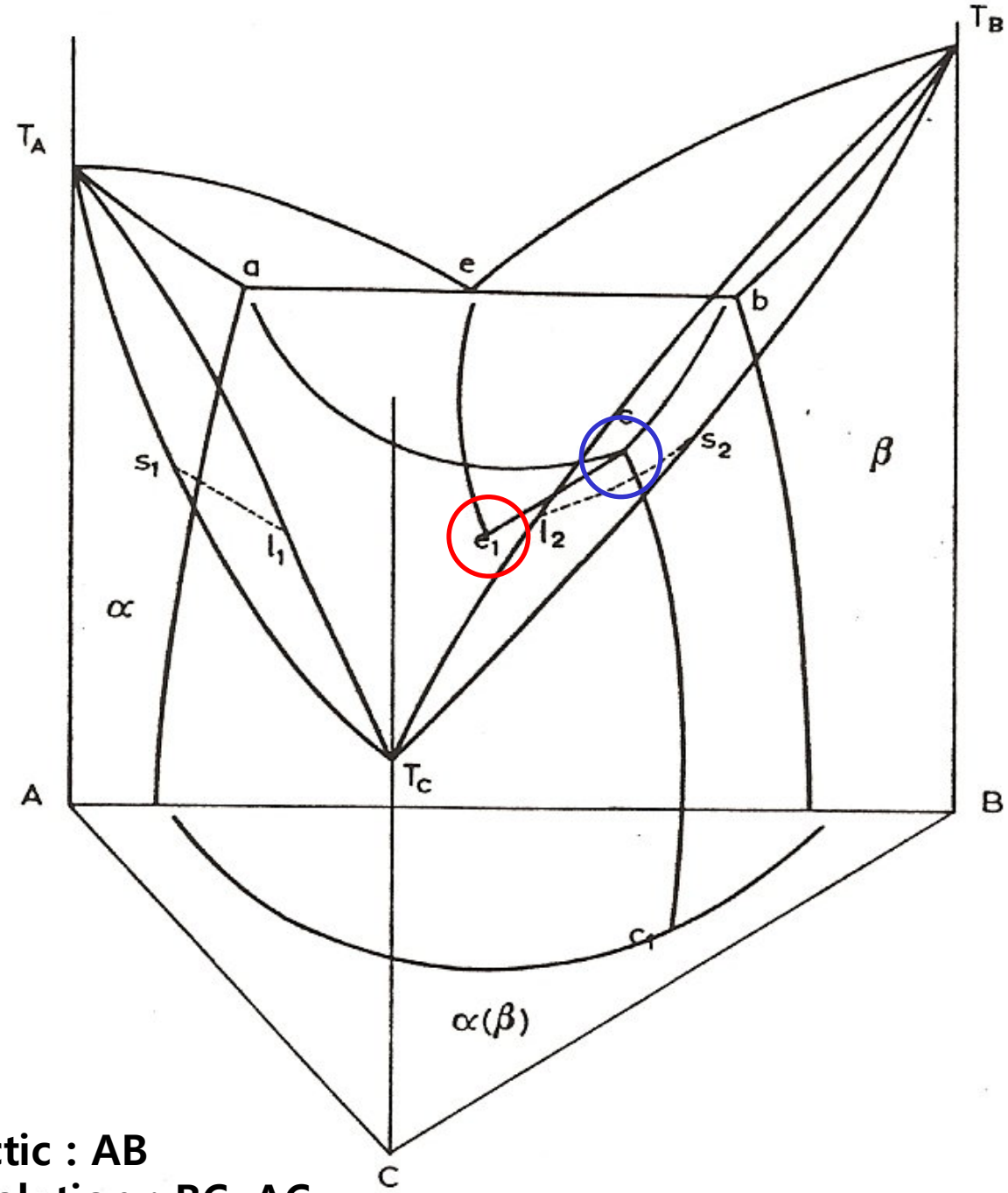


(a)

The solidus surface and the solubility surface

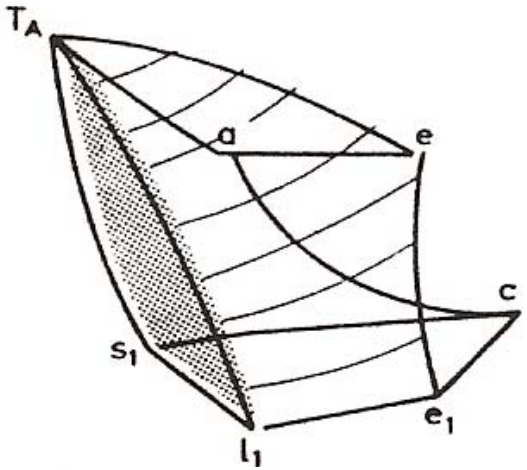


(b)

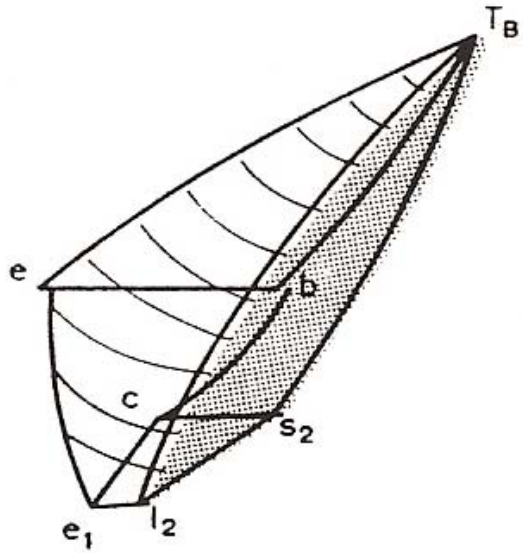


- **One binary eutectic : AB**
  Complete solid solution : BC, AC

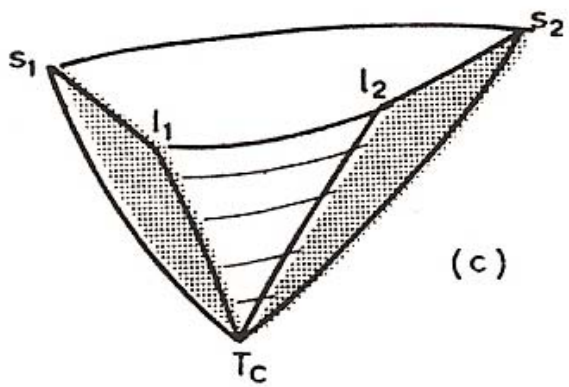
The two-phase regions



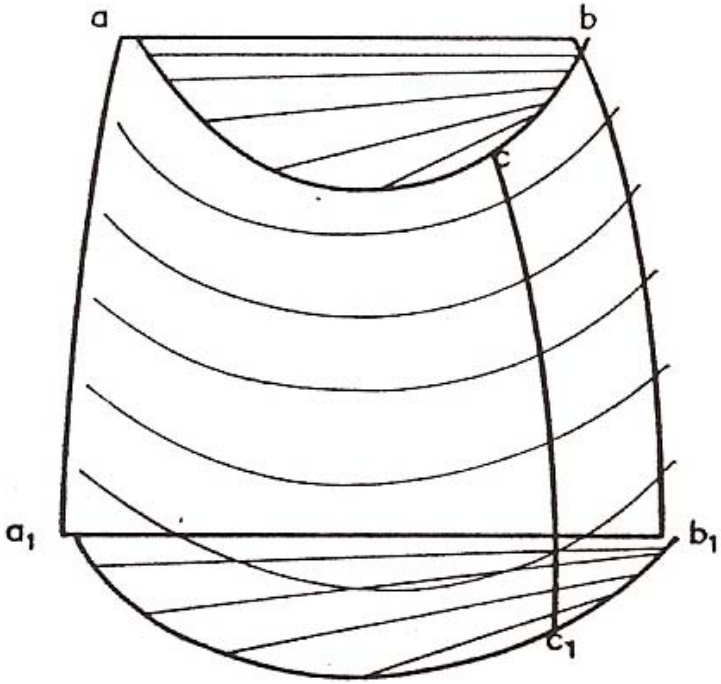
L+α phase region



L+β phase region



L+α(β) phase region

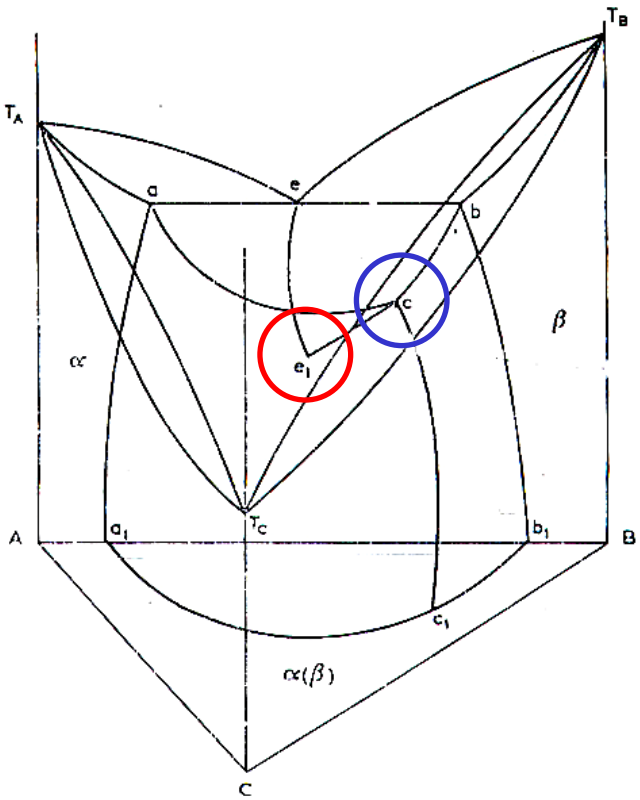


α+β phase region

9.3. THREE-PHASE EQUILIBRIUM INVOLVING EUTECTIC REACTIONS

9.3.1. A eutectic solubility gap in one binary system

- One binary eutectic : AB
  Complete solid solution : BC, AC



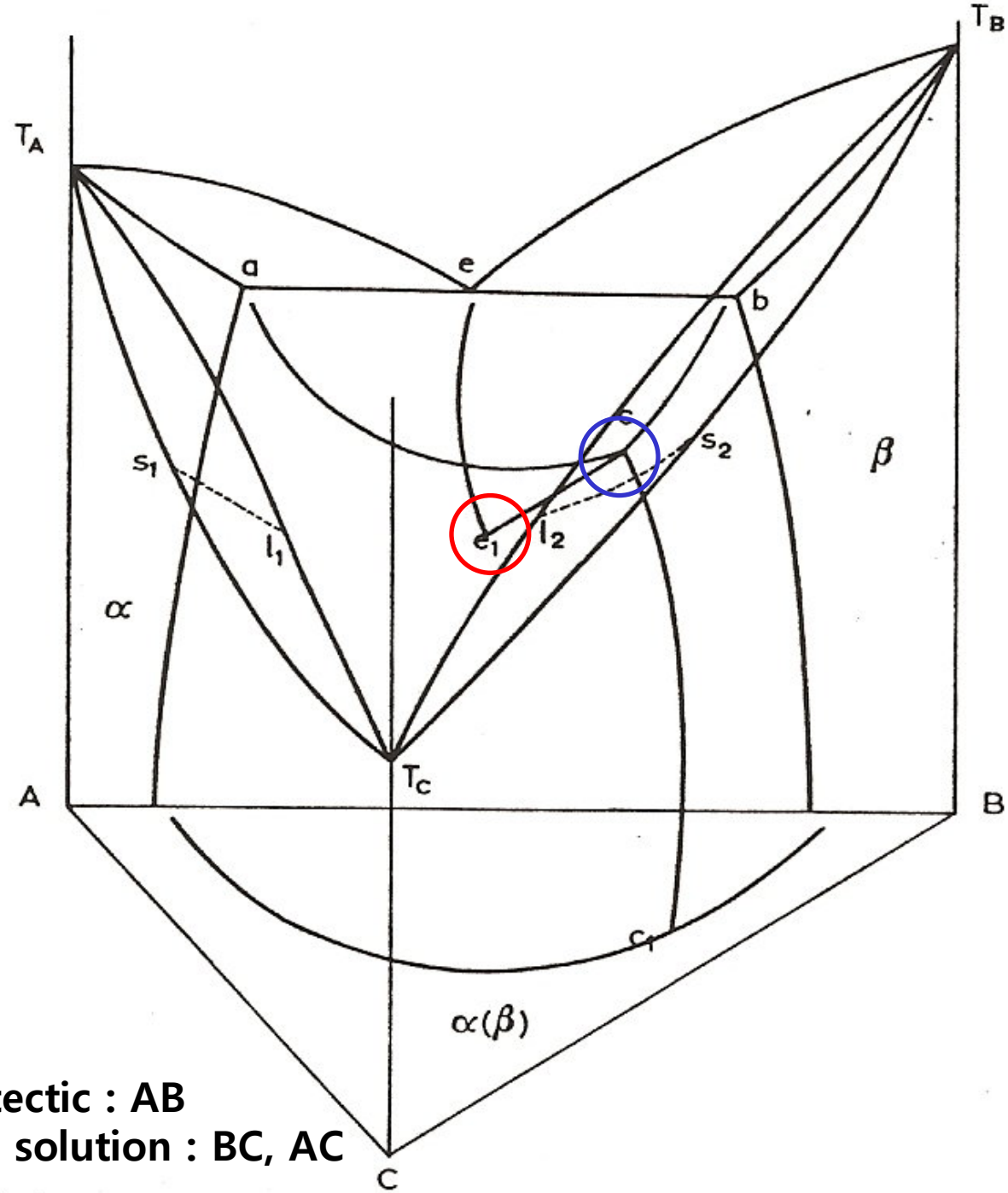
- Closed solid solubility loop
  → minimum critical point c
  : ternary α and β phases become indistinguishable.

- *l* → α + β in ternary composition range
  → three phase region

- Along ac : α composition
  along bc : β composition
  → *l* along ee_1
  → e_1 & *c* should be at same temperature

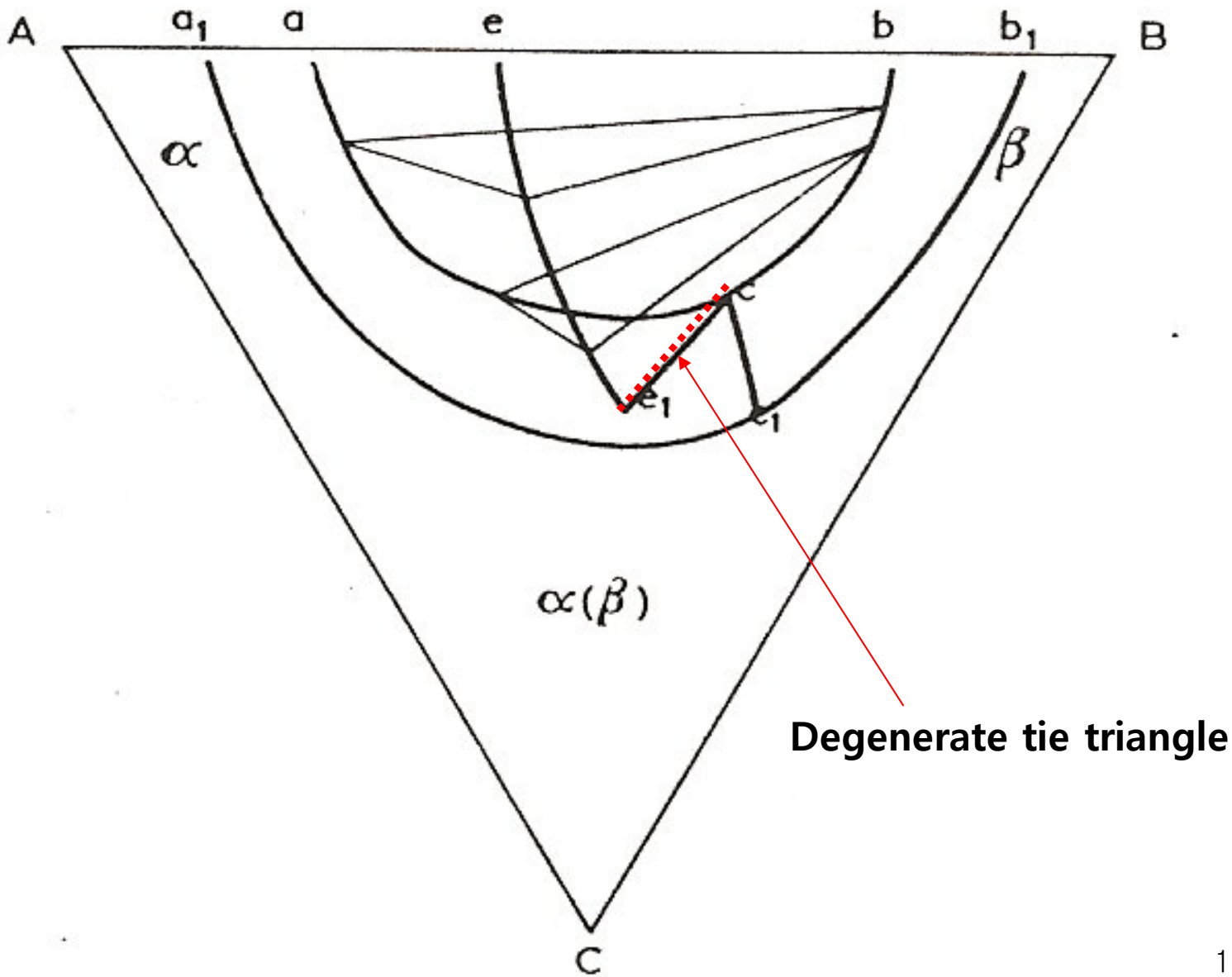
- Three phase region will start
  at binary eutectic temp.

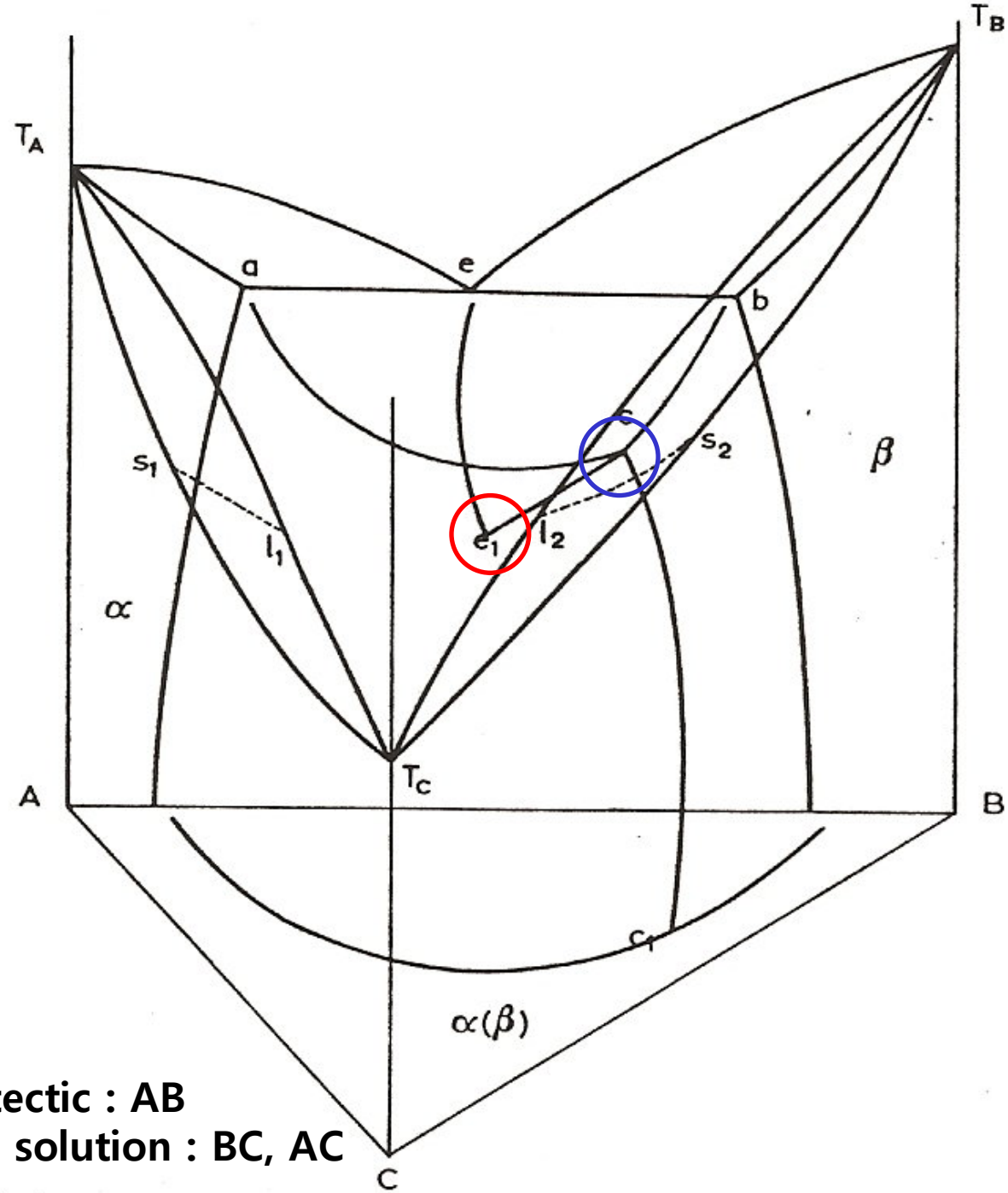
- Three phase region will end at e_1e temp.



- **One binary eutectic : AB**
  Complete solid solution : BC, AC

- **Projection**


A
a_1
a
e
b
b_1
B
α
β
c
e_1
c_1
$\alpha(\beta)$
C
Degenerate tie triangle



- **One binary eutectic : AB**
  Complete solid solution : BC, AC

The three-phase regions

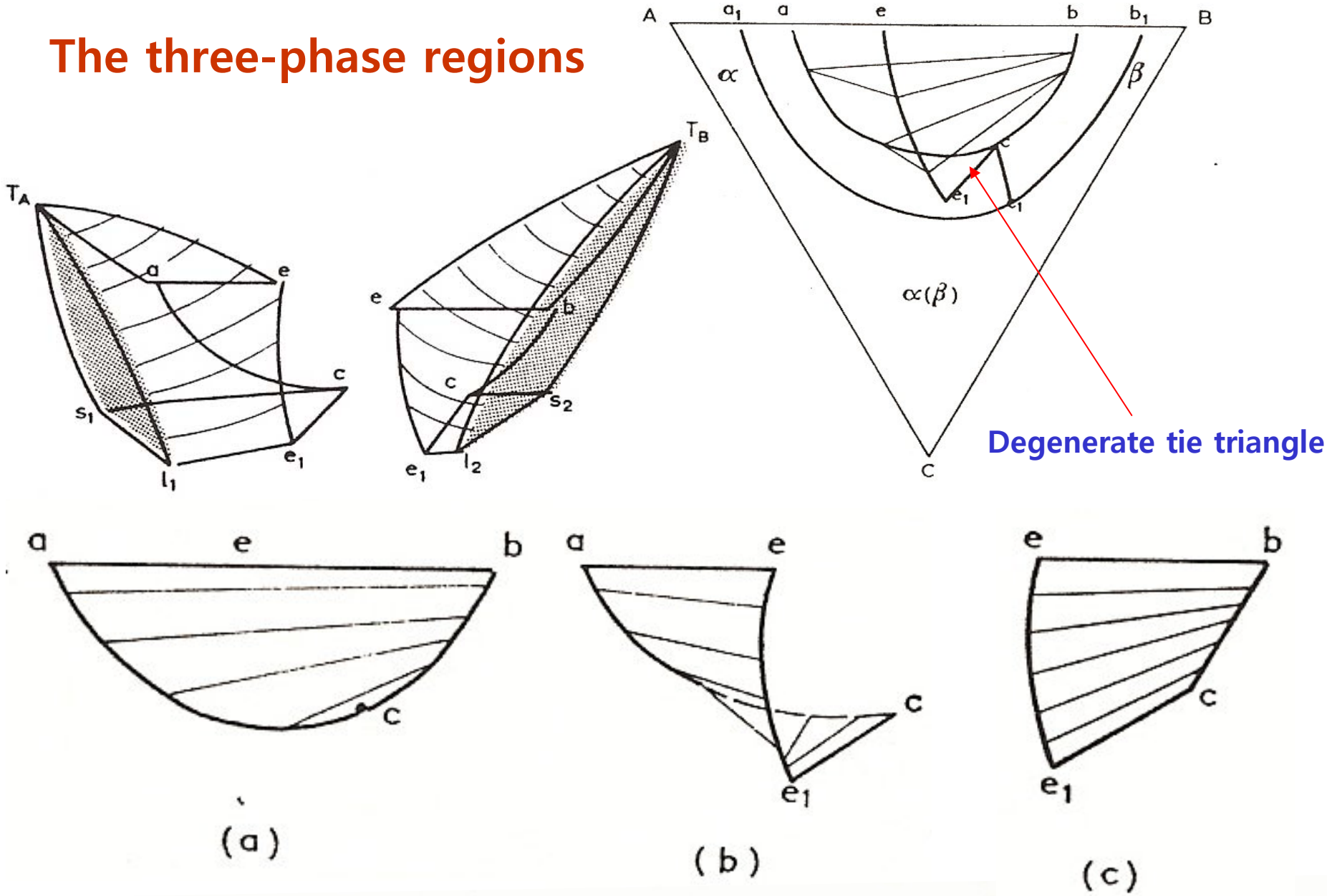
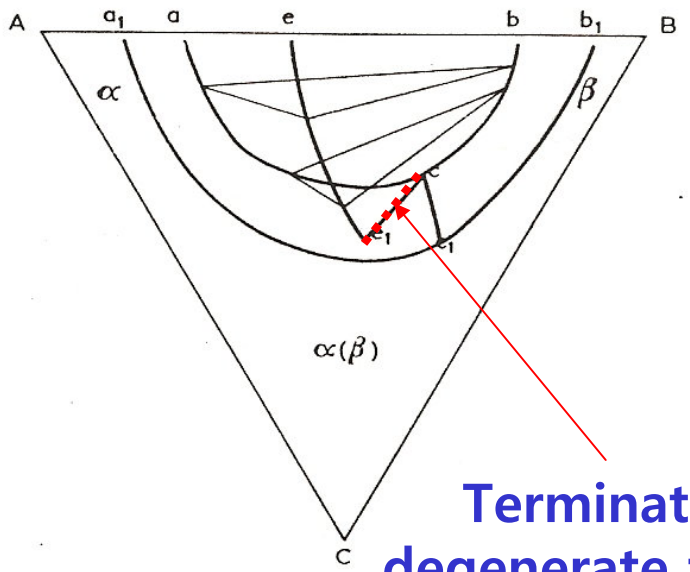
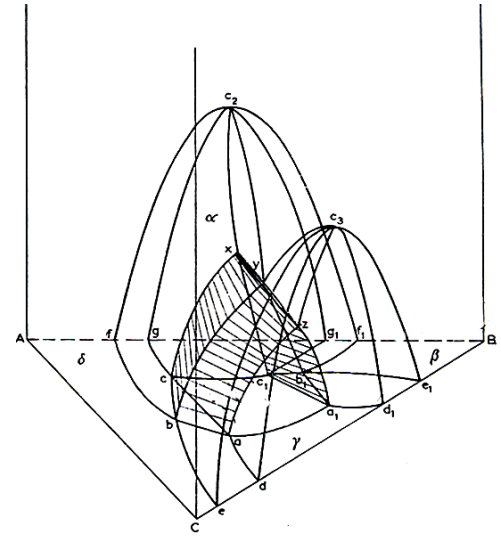


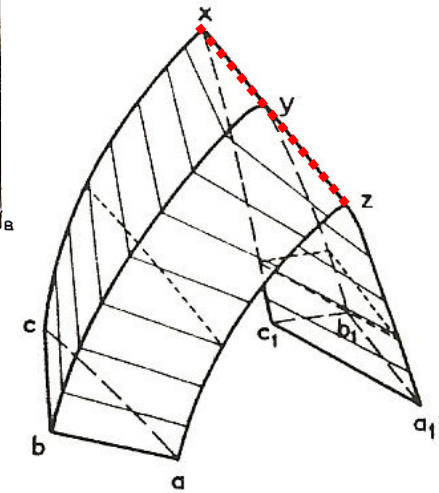
Fig. 147. The ruled surfaces bounding the three-phase ($l+\alpha+\beta$) region in Fig. 142. (a) The $\alpha\beta$ ruled surface; (b) the $l\alpha$ ruled surface; (c) the $l\beta$ ruled surface.

The ways in which three phase regions terminate in ternary systems:

(a)



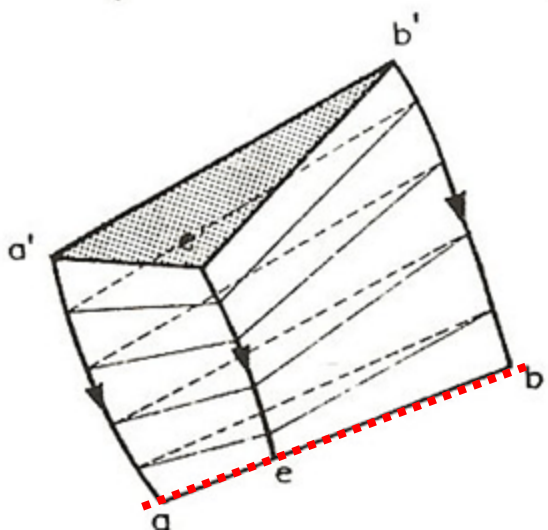


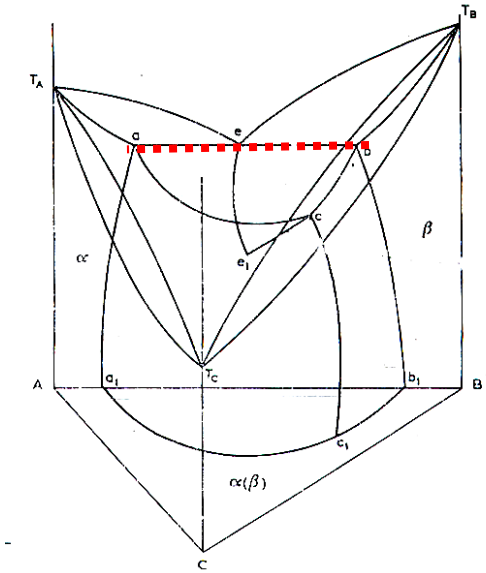


Termination at a degenerate tie triangle

→ **ternary system, 3 phases are in a straight line as three points.**

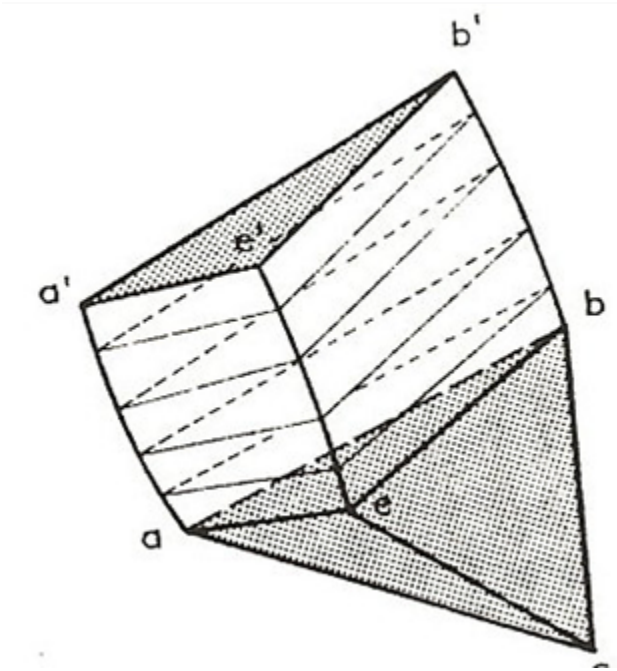
(b) **Termination at a reaction isotherm**



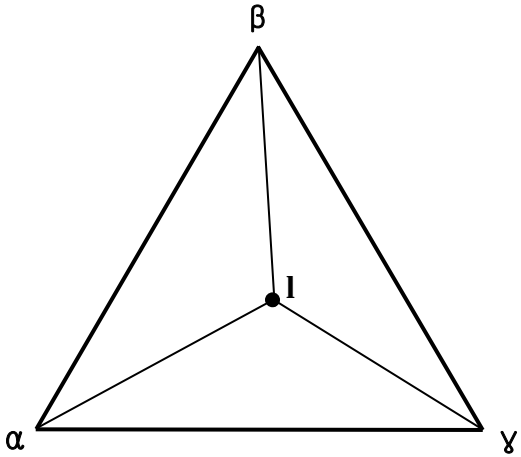


The ways in which three phase regions terminate in ternary systems:

(c) Termination at a four-phase plane

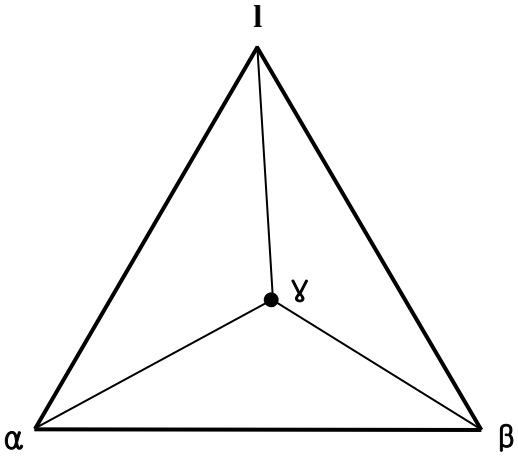


Ternary eutectic

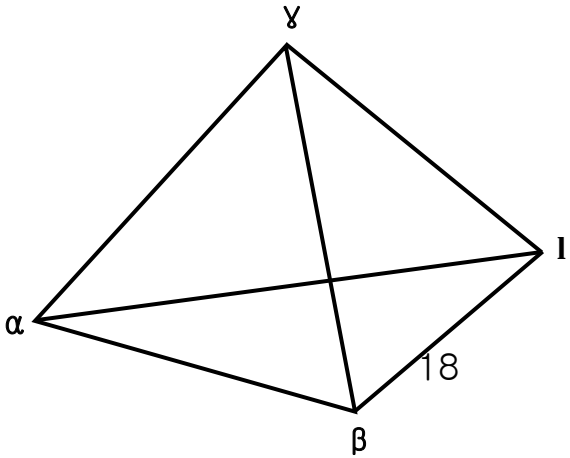


Ternary peritectic

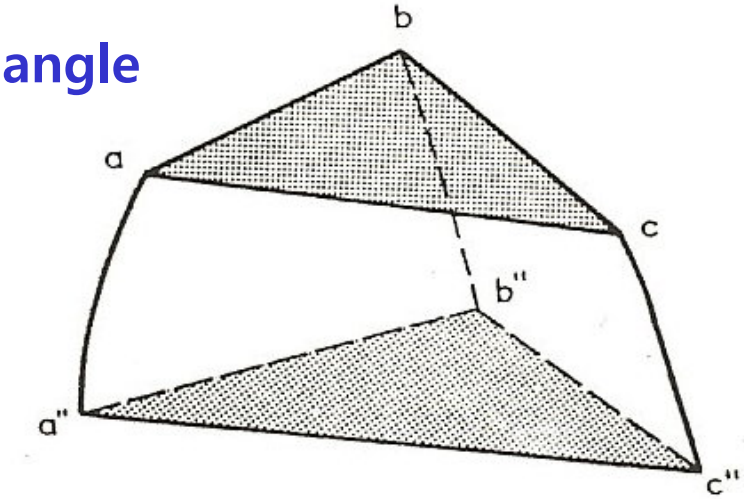
$L + \alpha + \beta \rightarrow \gamma$



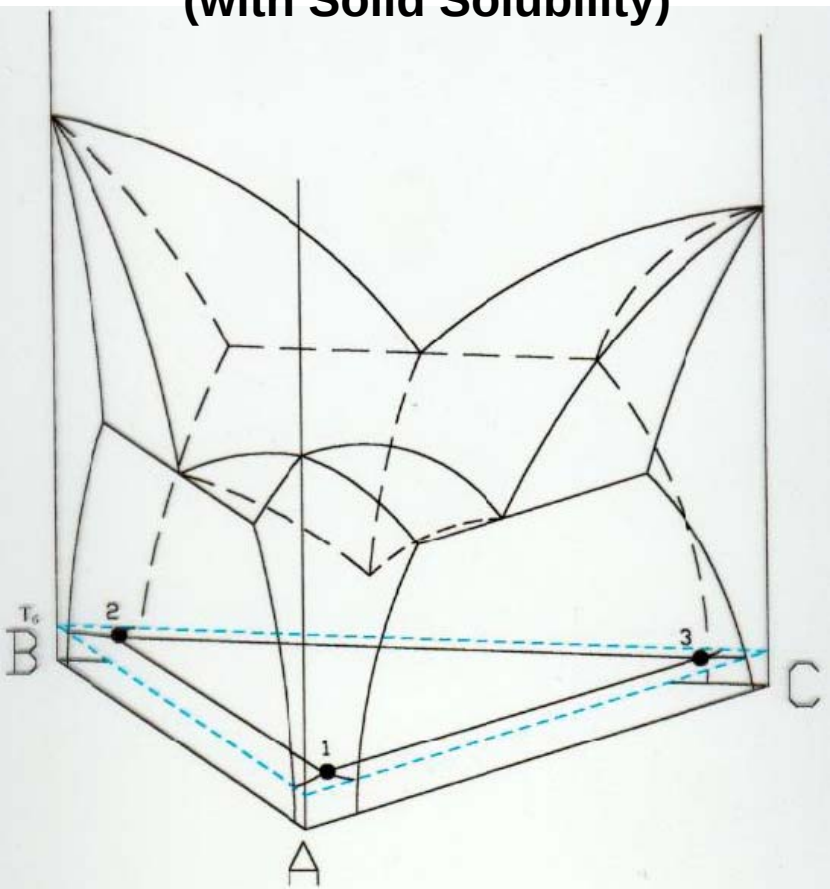
$L + \alpha \rightarrow \beta + \gamma$



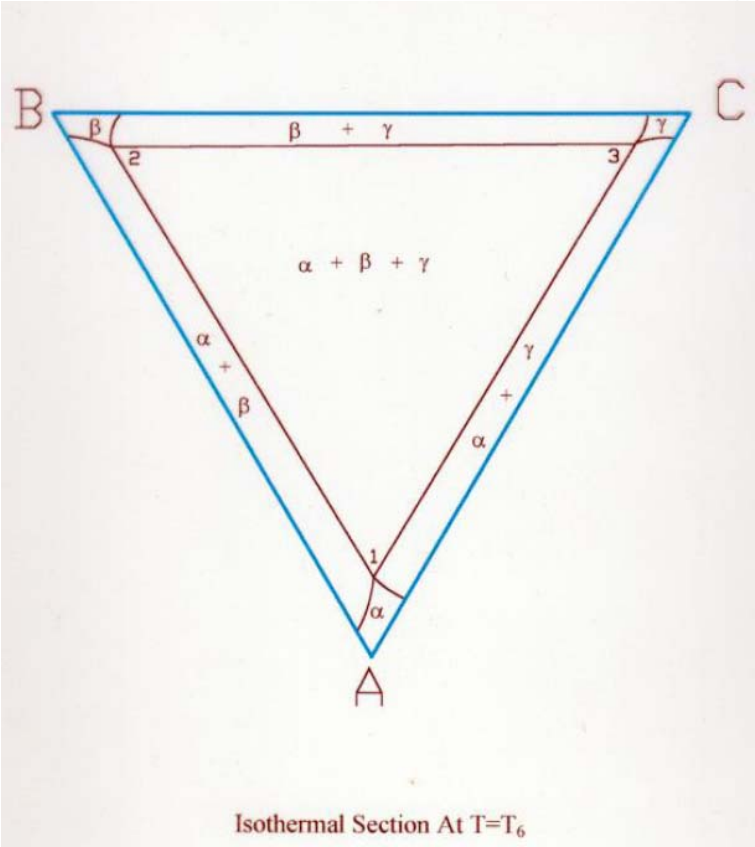
(d) Termination on the concentration triangle



Ternary Eutectic System
(with Solid Solubility)



Temperature Slice at $T_6 < T_E$



Isothermal Section At $T=T_6$